‘Water we do about the river?’

An Integrated Approach to Understanding Water Quality in the Waikaka Stream, Southland, New Zealand

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Abstract

Water quality causes are a highly contested issue in New Zealand, with rivers and streams struggling with the effects of intensive pastoral agriculture. The Waikaka Stream in Southland is an example of a catchment that currently does not meet local water quality standards, due to 'very poor' water quality. Management of freshwater has changed significantly over time in New Zealand, but has typically been the responsibility of regional authorities, carried out with a reliance on technical and scientific information, often with a disregard for the socio-political dimensions of freshwater management. Consequently, in recent years communities in Southland have mobilised to form catchment management groups, offering an alternate bottom-up management regime. It is unknown how these community management groups fit into the wider environmental management structure in New Zealand, or how they can be best directed to contribute to the improvement of New Zealand waterways, including the Waikaka Stream. The aim of this study was to evaluate the water quality of the Waikaka Stream and analyse community responses to their perceived water quality problem. A socio-hydrology lens was employed to elucidate how the measured data compared to water quality perceptions. A mixed methodological approach used a 12-month data set with a monthly water sampling frequency, and semi-structured interviews with farmers in the Waikaka Catchment. Quantitative and qualitative results were integrated in the interpretation phase, to understand the disconnect between physical water quality parameters and community perceptions of the Waikaka Stream. The Waikaka Stream water quality was highly variable across the catchment, indicating that the current single monitoring site is not appropriate to be fully representative. Suspended sediment concentrations exceeded national guidelines across the entire catchment, with site averages ranging from 4.0 mg L^{-1} to 10.8 mg L^{-1}. *E. coli* thresholds were exceeded at six sites, ranging from 126 CFU/100ml to a maximum of 1414 CFU/100ml. Total nitrogen ranged from 0.3 ppm to 3.0 ppm, while total phosphorus measured between 11.9 ppb and 242.6 ppb. The water quality results showing exceedance of national guidelines, which contradicted farmer perspectives of 'good' water quality, highlighting the hidden risk of water quality. This discord creates issues for freshwater management, as it introduces distrust between farmers and the regulating regional government. The power dynamics between stakeholders can further complicate the collaborative management process and limit the implementation of improved management strategies. The formation of the Waikaka Stream Catchment Group indicates that farmers and local community members are seeking collaborative action to improve freshwater health. This study demonstrates that catchment groups deliver an opportunity for social learning, and a format by which local knowledge can be better included in management, to work towards the principles of Integrated Catchment Management (ICM). Catchment groups provide a link between individual farmers and regional government, therefore building trust for future collaborative management.

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The river moves from land to water to land, in and out of organisms, reminding us what native people have never forgotten: that you cannot separate the land from the water, or people from the land

- *Lynn Culbreath Noel –*

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1 Introduction

Freshwater has long been recognised as one of New Zealand's most plentiful and healthy resources. The value of freshwater transcends some of the largest commodity sectors in New Zealand including the economy, tourism, and export industries, as well as being a vital component of the country's "clean green" identity (Duncan, 2013a). Directly aligned with freshwater resources as profitable commodities, many New Zealand communities depend on good quality water for both lifestyle and livelihood, particularly through strongly embedded agricultural practices. For a significant portion of New Zealand's history, agriculture has been a cornerstone in its economic journey (Hunt et al., 2013). Because freshwater is central to the lives of so many New Zealanders for economic, social, and political reasons, water quality issues are highly contested by government, industry, and community stakeholders.

New Zealand's water quality history has been tumultuous, initially from point source pollution resultant from flax milling, sawmilling, and tanneries. However, most modern water quality issues arise from agriculture as non-point pollution, posing a challenge for environmental management (Smith et al., 2013). Economic restructuring in the 1980s resulted in fewer government subsidies for farmers, causing farm intensification assisted by technological advancements and increased fertiliser application to boost profits. The industry grew to survive without government support, but the attraction of a healthy economy and robust agriculture out-turn has neglected to address the unintended consequence of river water quality degradation. The nature of this non-point source pollution means that the origins of contaminants are difficult to identify. Therefore, regional authorities and local farmers are faced with water quality management challenges (Duncan, 2014). Poor water quality calls for clear and effective management strategies and plans. A multi-disciplinary approach is required, as all factors must be considered beyond the physical parameters of water quality, due to complex interactions between the social and biophysical environments (Fenemor et al., 2008). Current plans to maintain key water quality indicators at safe levels consist mostly of regulations enforced by regional governments. However, there is a rise of community groups taking ownership of their local freshwater on the catchment scale, as they recognise a need for local scale targeted management strategies. These groups are new in the sphere of management and as such have not yet defined clear goals. The way in which these community groups fit into the current environmental management structure in New Zealand is uncharacterised.

In New Zealand, poor water quality is often attributed to the impacts of farming and the agricultural industry. As such, farming intensification has been used to explain the observed decline in water quality. The changes in perception of farming have created a divide between farmers, and those who live in urban towns or cities in New Zealand. Traditionally agriculture bolstered the economy and provided employment for a large proportion of New Zealanders, and so it was fitting that farmers were considered 'national heroes' (Hunt et al., 2013). With the diversification of the New Zealand economy and water quality degradation due to the agricultural intensification, the general public's view of farmers has shifted to be more negative (Thomas et al., 2020). As the impacts of farming on water quality grew, so too did awareness of best farm management practice, which alongside negative urban perceptions has stimulated farmers to take ownership of their local area through community catchment groups.

1.1 Interdisciplinary approach to environmental management

Hydrological and social processes are tightly coupled in the current society we live in, as humans typically understand hydrological processes through interactions with human society (Vogel et al., 2015). Freshwater is used by people for all sorts of different vocations, including recreational activities, as well as being central to economic production. The land use of an area surrounding a water body is dictated by the people who live along its banks (Figure 1.1). Due to the interconnectedness of factors influencing water quality, it is essential to consider both physical and anthropogenic aspects, therefore taking a socio-hydrology approach to solve a water quality problem (Figure 1.1). All freshwater stakeholders must be considered in forming a management plan to account for the differing perspectives and values associated with a water body (Fenemor et al., 2011). The values that civilisations hold in association with water dictate how they interact with it, and derives the priorities for freshwater management (Stern and Dietz, 1994). Therefore, the focus of this study is to examine the connection between community experiences and perceptions of water quality, through a socio-hydrology lens, accounting for both biophysical and social processes in the water quality discourse. Such work is examined through the application of a case study catchment in Eastern Southland, New Zealand, and explores the regulation of water quality limits and themes of Integrated Catchment Management.

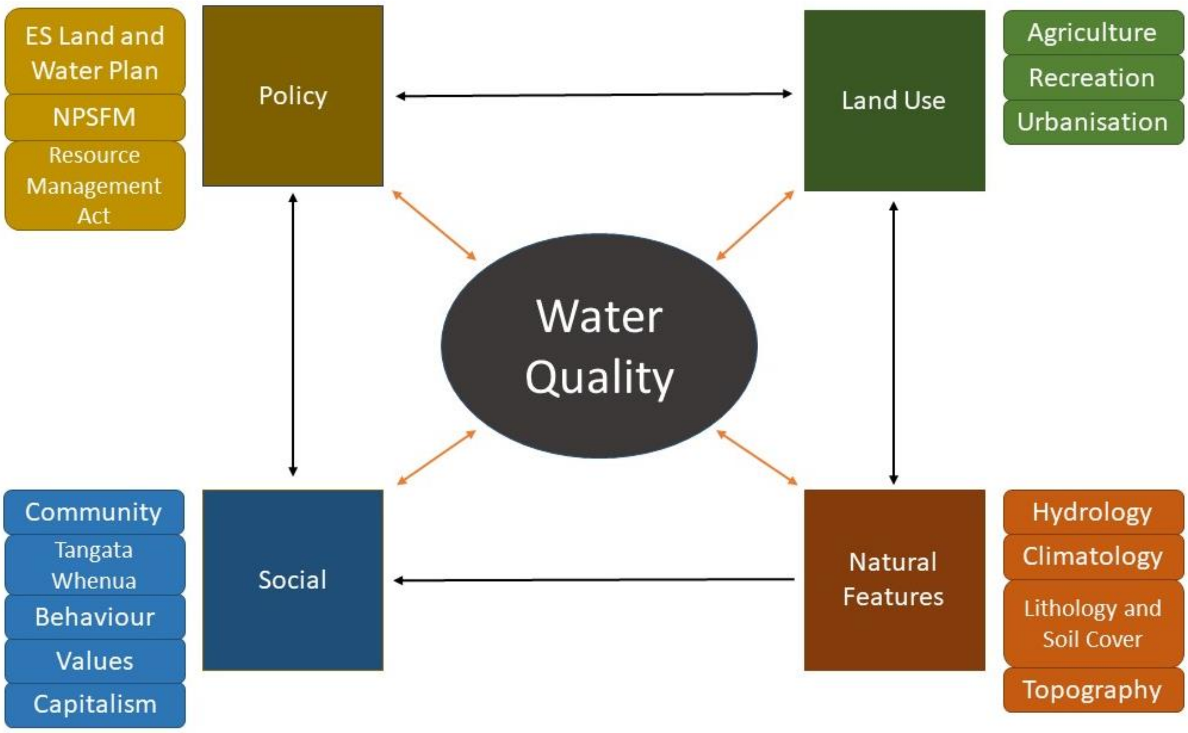

Figure 1.1: Conceptual diagram showing the interconnectedness of the factors that influence the water quality of a freshwater body. A multitude of factors influence the water quality of a freshwater body, and the water quality influences policy decisions, potential land use, the natural features of the catchment, and the social dynamics of the area. Links also exist between the four factors.

1.2 The Waikaka Catchment

Southland, New Zealand has a rich agricultural tradition and struggles with some of the poorest water quality in the country (Moreau and Hodson, 2015). Of the 11 sites monitored by regional authority Environment Southland as part of the long-term State of the Environment (SOE) monitoring network, three are rated as "very good", while the remaining are "poor" or "very poor" (Davies-Colley et al., 2011, Larkin, 2013). Most of Southland's waterways are lowland and relatively flat catchments, reflecting national trends of poor water quality in lowland rural streams (Monaghan et al., 2010). The Waikaka Stream in eastern Southland is one such water body characterised by poor water quality by the regulatory authority as 'poor' and with a land-use predominantly of pastoral agriculture (Figure 1.2). The local community are concerned about its current state, and how this may affect farming practice in the region if they are to meet regulatory water limits. The Waikaka Stream is monitored at one location in the catchment, and so it is impossible to know where environmental interventions can be most effective at mitigating adverse water quality impacts.

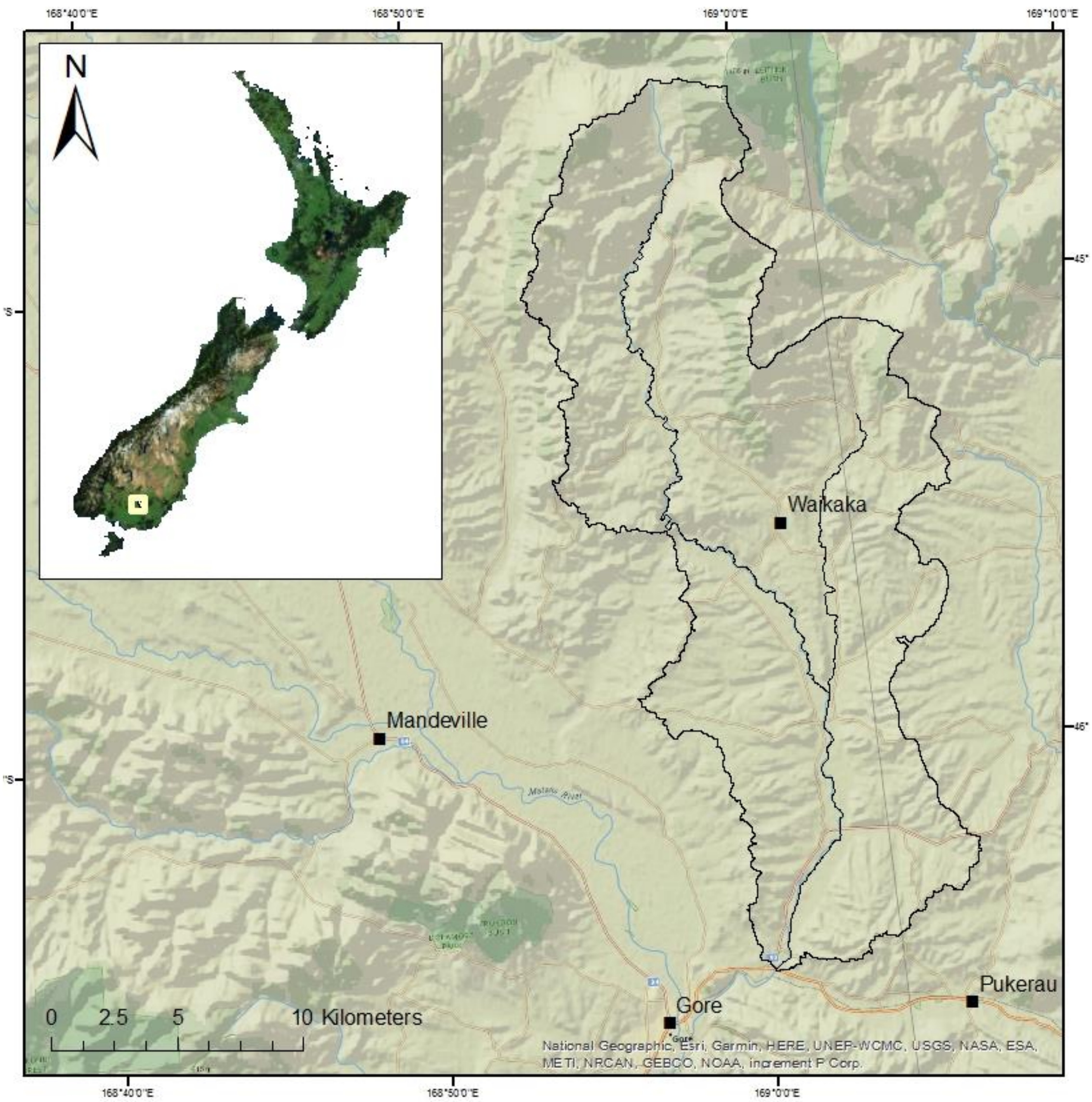

Figure 1.2: Map of the Waikaka Catchment in Eastern Southland, showing its location in New Zealand.

1.3 Research aim and thesis outline

The water quality and related environmental management debate is ever-growing in New Zealand and is complicated by the physical and social factors of every individual freshwater body. The Waikaka Stream Catchment offers a relevant and interesting agricultural case study in rural New Zealand: at the interface between emerging community awareness and lobbying, and the requirements to meet increasingly complex environmental management legislation. Through a multidisciplinary approach to understanding water quality, this thesis assesses the Waikaka Stream water quality and analyses the community response to the perceived water quality problem. The aim is to further develop the understanding of environmental management in New Zealand in the context of evolving water quality challenges and solutions, through the contribution of community management to the current management framework. To address the overarching aim, three objectives for the research are posed:

1. To investigate the spatial variability of the Waikaka Stream water quality through in-field sampling techniques
    - To evaluate the representativeness of Environment Southland's single monitoring site and understand spatial scale patterns in water quality
2. To explore community values and perceptions of water quality
    - To investigate how perceptions compare to scientific results, and how they affect freshwater management
3. To examine the role and function of community catchment groups in Southland, and their potential role as stakeholders in environmental management in New Zealand

To address these aims, the thesis describes the water quality issues related to agricultural catchments and provides an understanding of the benefits and drawbacks to current and hypothetical management approaches in Chapter 2. Chapter 3 provides a detailed study site description and outlines the methodology used in the study, including the qualitative and quantitative methods deployed for the research. The results of the research are presented in Chapter 4, establishing the water quality trends of the Waikaka Stream, as well as the community perceptions relating to water quality, and the potential of community management. Chapter 5 provides a discussion of the findings, examining how the Waikaka Catchment advances socio-hydrological understanding and contributes to the development of environmental management in New Zealand. Future recommendations are also outlined in Chapter 5 before the key findings are reviewed in Chapter 6.

2 Water Quality and Freshwater Management in New Zealand

Agriculture has imparted a significant muddy footprint on the water quality of New Zealand's lowland streams (Knight, 2016). Contemporary effects of agricultural intensification are responsible for an increase in nonpoint pollutants from farms (Davies-Colley et al., 2011, Smith et al., 2013). Establishing contaminant sources is difficult and complex because of New Zealand's economic reliance on agriculture, and the social capital associated with the farming community (Burton, 2004, Thomas et al., 2020). It is widely accepted that New Zealand has water quality issues, but the way in which local government deals with those issues is inefficient and highly contested by stakeholders with competing objectives, mandates, and responsibilities. All stakeholders value freshwater for different reasons, and to a varying degree create a complex debate around the best freshwater management method for New Zealand rural streams.

Freshwater management is monitored through quantification of physical water quality variables but can also be assessed by the perceptions of the public around its taste, smell, and sight, making it simultaneously a tangible and intangible resource to manage. Freshwater management often lacks adequate consideration of all factors relating to freshwater, and therefore fails to appropriately manage the resource. As such, there is a gap in freshwater management theory, as current work fails to link the physical origins of contaminant sources with community values and perceptions in a form that is useful for local management. This chapter will reflect on research underpinning human perceptions and values associated with freshwater in Section 2.1. Section 2.2 will go on to describe the current freshwater management system in New Zealand, before explaining the key sources and impacts of the major agricultural contaminants that water quality assessments in New Zealand are based on in Section 2.3. The shortfalls of the current environmental management structure will be discussed, before Integrated Catchment Management is outlined as the improved framework and approach to freshwater management in Section 2.4. Section 2.5 discusses community management as a way to improve water quality through a format that better utilises socio-hydrology as an approach. The key points are summarised in Section 2.6 leading to three research aims posited in response to the identified research gap.

2.1 Human values associated with freshwater

Water has always been central to humans and their civilisations (Back, 1981, Anderson et al., 2019). For centuries, people have built their settlements in and around freshwater, whether that be lakes, rivers, springs, or other waterways. As a result, issues around the development of those waterways for both food and energy production, are inextricably linked to the nature of society, and the complexity of ever-evolving culture (Back, 1981). The way in which a community uses and manages water is indicative of their values and way of life, as those values influence the way that people act, and the beliefs and attitudes they develop about the world around them (Ditton and Goodale, 1973, Anderson et al., 2019). An individual's values act as a filter for how they interpret information, and what they accept as true depending on whether it aligns with their values or not (Stern and Dietz, 1994). Individual views of water quality are therefore a function of complex relationships between attitudes, behaviour, and practices across space and time.

Environmentalism, or environmental values held by an individual can be understood by the reasons why people initially gain interest in the environment. The first is egoistic values, where people are prone to act on environmental issues when they are affected personally. Actions could be either for environmental protection and management or environmental degradation if the personal cost to the individual is high (Stern and Dietz, 1994). A second value type is altruistic values, which describe the sense of moral obligation an individual feels to act in favour of the environment when they believe adverse consequences of environmental issues are likely to affect others (Stern and Dietz, 1994). Biospheric values explain a third type, describing the notion of individuals prioritising the biosphere, and judging phenomena based on the costs or benefits to the biosphere, and the ecosystems within in (Stern and Dietz, 1994, Anderson et al., 2019). These values allow for an understanding of the complex motivations of people to act in favour of the environment, and therefore towards improved environmental management.

The experiences and world views of an individual will greatly influence the perspective they hold on water quality and freshwater issues. Many social factors influence the level of concern people have around water quality and the degree to which they care, or think issues are important to address. Factors such as socioeconomic status, gender, race/ethnicity, religion, age, and education level all shape a person's perception of water quality issues, which in turn leads to their behaviour and actions (Barnett et al., 2018). Humans have a strong connection with water as an essential resource to many facets of human life, and so form strong opinions about waterways based on what is most important to them. Equally strong opinions are formed on how freshwater should be managed to maximise usage without causing irreversible harm to the resources (Quinn and Halfacre, 2014, West et al., 2016, Anderson et al., 2019).

The level that people engage with water in their daily lives and through recreational activities impacts their level of concern, and perception of water quality issues. People who engage with water for recreational uses are likely to care about specific water quality characteristics such as clarity, and have concerns about impaired water quality (Barnett et al., 2018, Ditton and Goodale, 1973). However, this is limited to specific waterways that people care about and utilise, as they place social value on them for their recreational activities. Therefore, the level of concern from the public is not universal (Barnett et al., 2018). Because of the differing nature with which individuals interact with freshwater, water quality perceptions are never black and white and are certainly not consistent across the entirety of the public (Barnett et al., 2018).

The perceptions that people build around water, and water quality stem often not from scientific information, but sensory aspects of freshwater (Barnett et al., 2018). Humans base their judgement significantly on visual aspects of a waterway, such as visible algae, floating debris, and the riparian plants. The colour and clarity of the water also play a key role, even though poor colour and clarity do not always indicate the same level of physical water quality (West et al., 2016, Barnett et al., 2018). People also judge freshwater on its taste regardless of whether their perceived 'good' or 'bad' taste matches the water quality. Past bad experiences from freshwater can also influence people's perceptions, such as whether drinking water from somewhere inadvertently made an individual sick. An experience like that severely impacts someone's perception of that water, regardless of the physical water quality at any other point in time (Barnett et al., 2018).

Māori perceive freshwater and water bodies in very different ways to Pākehā, indicating that cultural values and traditions also influence water quality perceptions. Māori have custodial obligations in managing traditional tribal waters, influencing how they perceive waterways (Tipa, 2009, Anderson et al., 2019). Māori view people as Tangata Tikai (guardians) of natural resources, including freshwater, and have a very all-inclusive view of the environment, seeing everything as connected, including the Tangata Whenua (humans living on the land) (Tipa and Nelson, 2008). The concept of Ki Uta Ki Tai (from mountains to the sea) embodies that holistic view, where everything is connected and flows from one thing to the next (Tipa and Nelson, 2008). Therefore, freshwater is valued for more than just resource use in terms of survival and economic gain. The connectedness of all things means that distinctions are not made between animate and inanimate objects, and all are connected (Tipa, 2009). Water is central to the traditional way of life for Māori, and as such has retained cultural significance. Māori do not base their value of a stream or river on a dollar value, instead, by the traditions and history associated with the water body (Tipa, 2009). Ecosystem health and wellbeing are viewed as inseparable from humans and society, as freshwater is linked to livelihoods, a sense of place, and identity (Anderson et al., 2019). Māori have local knowledge that is not necessarily research-based, as modern management has been, but rather is land based practical knowledge, which has accumulated over generations. Their knowledge is dynamic and historical, meaning that the connection to land has been passed down through generations, and has changed and moved with those generations (Tipa and Nelson, 2008). Māori perspective is therefore central to the way that freshwater should be managed and considered in New Zealand, and differs from Euro-centric management approaches where resources were treated as separate entities. The values of Tangata Whenua are recognised as Te Mana o te Wai through the National Policy Statement for Freshwater Management (2017), and thus are part of the environmental management framework.

2.2 Freshwater management in New Zealand

2.2.1 Legislative setting

New Zealand's water quality has been managed by Regional Governments under the direction of Central Government since the 1940s (Bowden et al., 2004). The current governing document for resource management, including freshwater, is the 1991 Resource Management Act (RMA), which was enacted to promote the sustainable use of natural resources throughout New Zealand. The RMA is effects-based legislation emphasising the protection of the environment, rather than controlling land use and other activities. This results in a gap in management relating specifically to land use (Bowden et al., 2004). Under the RMA, Regional Councils are charged with ensuring that the guidelines and expectations are followed in practice (Memon et al., 2010, Weber et al., 2011). Alongside these plans, is the National Policy Statement for Freshwater Management (2017), which is the governing policy document for freshwater management specifically, set out by the Ministry for the Environment (MfE). The NPSFM guides regional councils on how to carry out their responsibilities outlined in the RMA. The document recognises Te Mana o te Wai as integral to freshwater management, acknowledging the integrated, and holistic wellbeing of a freshwater body. The policy aims to protect water quality and quantity, as well as encouraging sustainable management and resource use, and allowing communities to be able to protect their economic wellbeing (Environment;, 2014). Integrated management is embodied by ki uta ki tai, encouraging a holistic perspective to management in New Zealand (Tipa, 2009). The statement also affirms that iwi and hapu involvement in freshwater management is paramount. The NPSFM outlines a series of national values, which are listed below (Table 2.1). The NPSFM defines the overarching goals for New Zealand freshwater. By 2030, the aim is for 80% of rivers to be suitable for primary contact, and by 2040, the goal is that 90% of rivers in New Zealand will be suitable for primary contact (Environment;, 2014).

Table 2.1: The Compulsory National Values as outlined by the National Policy Statement for Freshwater Management.

Compulsory National Values	
Ecosystem Health	Protection of ecological processes
Human Health for Recreation	
Natural Form and Character	Biophysical, ecological, geological, geomorphological, and morphological aspects
Mahinga Kai	Ensure that kai is safe to harvest and eat
Fishing	
Irrigation, Cultivation and Food Production	
Animal Drinking Water	
Wai Tapu	Protection of the places where rituals and ceremonies are performed, or where there is special significance to iwi and hapu
Water Supply	
Commercial and Industrial Use	Protection of economic opportunities to people, business, and industries
Hydro-electric Power Generation	
Transport and Tauranga Waka	

Water quality monitoring is an essential part of NPSFM mandated Regional Council work, to assess change over time and observe water quality trends (Weber et al., 2011, Larkin, 2013). Monitoring is essential to improving and maintaining freshwater quality and ecosystem health, by allowing issues in healthy water bodies to be identified before they escalate and become bigger problems (Larkin, 2013, Davies-Colley et al., 2011). Streams identified as having water quality issues must be monitored to establish if efforts to improve water quality are working, or if more intervention is required. Mitigation strategies and future regulations are informed by monitoring and other scientific findings, and so monitoring is a key part of the management structure (Larkin, 2013). Monitoring river water quality also allows Regional Councils to provide information to the public, as is part of the role of the regional government (Larkin, 2013). In practice, monitoring includes Regional Councils collecting data for key water quality variables, including nutrients, bacterial contaminants, and clarity, across rivers, estuaries, and lakes, to ensure that freshwater quality is maintained or improved (NPSFM, 2017).

2.3 Agricultural impacts on freshwater

2.3.1 Freshwater contaminants

Key contaminants monitored in New Zealand are mostly linked to agricultural sources. Contaminants are substances that, at high concentrations, can have adverse effects on ecosystems in freshwater environments (Guercio, 2011). These have changed over time in New Zealand, mirroring the economic changes that have been predominantly responsible for water quality issues in New Zealand. Throughout the twentieth century, point sources were the main concern to freshwater. Industrial plants were unregulated and often discharged waste directly into freshwater systems (Dowd et al., 2008). A change in New Zealand legislation and policy, alongside evolving land use units has resulted in a shift from point sources as the biggest pollutant issue, to non-point sources. Non-point sources cannot be attributed directly to a single source, which are therefore harder to measure, track, and reduce. In the New Zealand context, non-point sources stem primarily from agricultural practice, which results in contaminant levels of suspended sediment, nutrients, and faecal coliforms (Dowd et al., 2008, Buck et al., 2004). These contaminant concentrations, often exacerbated by poorly managed land use changes, are then integrated into the hydrological cycle through hydrological transport pathways, showing the link between the landscape, freshwater systems, and human systems (Figure 2.1).

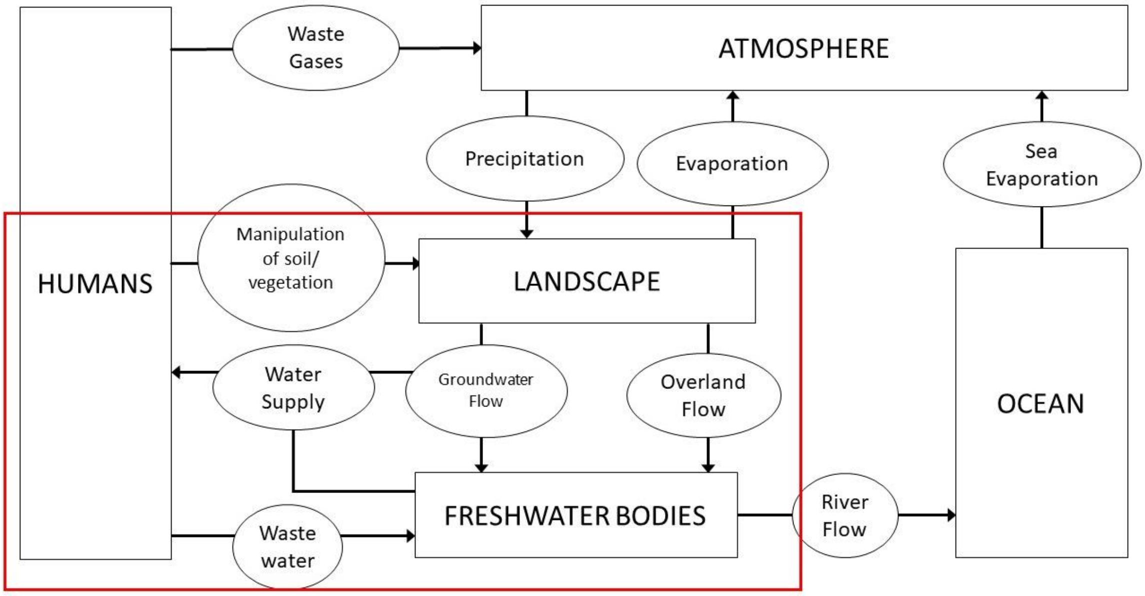

Figure 2.1: Conceptual framework of the transport of water contaminants into the water cycle system. The links between humans, landscape, and freshwater are highlighted in red to emphasise the connections explored through this thesis (adapted from (Falkenmark, 2011)).

Unlike point sources, non-point sources are harmful due to the cumulative impacts over a large temporal or spatial scale, as the initial concentrations are generally much smaller than a point source discharge. These cumulative impacts effects show the legacy of sheep and beef farming on the New Zealand landscape (Duncan, 2014). Non-point pollution poses a difficult management challenge, as the gradual nature of pollution, and the complexity of contaminant behaviour in the hydrological system proves incredibly difficult to mitigate. In New Zealand, for instance, agriculture is responsible for concerning levels of nutrients, *E. coli*, and sediment.

2.3.2 Nutrients in freshwater

Nitrogen and phosphorus are key nutrients used as water quality indicators in agricultural contamination discourse. A large cause of human alteration to both nutrient cycles globally has been the intensification of agricultural processes worldwide, particularly in crop and livestock production systems (Bouwman et al., 2012, Duncan, 2014). The concentration of nutrients dramatically increased throughout the twentieth century, as fertiliser and pesticides were used to increase production yields in search of greater economic returns (Bouwman et al., 2012, Monaghan et al., 2007). From 1900 to 1950, the global annual nitrogen soil surplus almost doubled, to 35,000 tonnes per year (t y^{-1}). From 1950 to 2000, this value increased to 138 t y^{-1}, reflecting the tripling of crop production, and the accompanied increase in fertiliser use (Bouwman et al., 2012). Dairy cow numbers in New Zealand increased significantly from 1975, reaching 5 million by 2005 (Figure 2.2). Cow numbers in Southern New Zealand increased from 25,000 to 291,000, between 1990 and 2003, thereby increasing the amount of animal manure as source material of nutrients (McDowell et al., 2004). The trends for nutrients in New Zealand correlate closely with the change in intensification of agriculture (Duncan, 2014). Nutrient trends show low gradients, indicating that they are retained for longer periods, particularly phosphorus which binds to sediment and circles slowly through the environment (McDowell and Wilcock, 2008). Nutrients are typically found to be higher in the lowland catchments of New Zealand, reflecting the greater agricultural land use in the lowland areas.

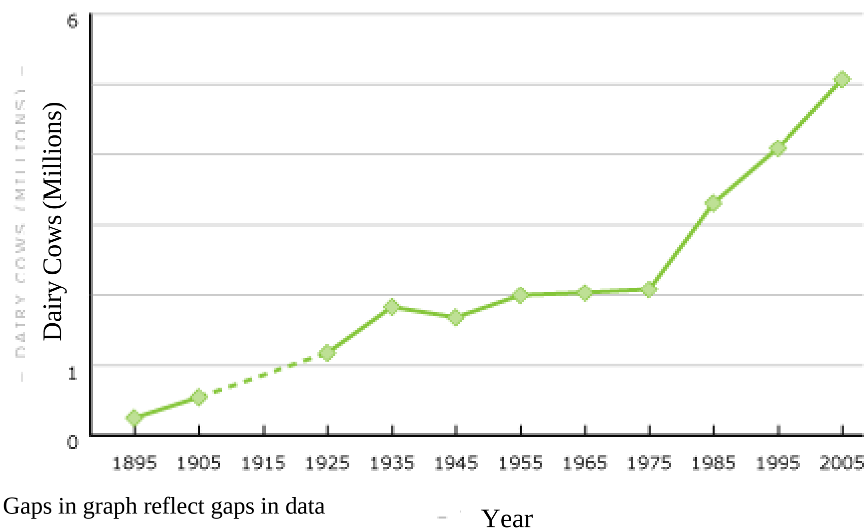

Figure 2.2: Graph of dairy cow numbers in New Zealand from 1895 to 2005 (Te Ara, 2020).

Excess nutrients in freshwater have many adverse impacts on the environment, and humans. Excess nitrogen and phosphorus contribute to eutrophication, in the form of algal blooms, that have been found in many nutrient-rich freshwater areas. Eutrophication interrupts the aquatic community and affects the entire ecosystem (Dowd et al, 2008). Eutrophication occurs instream where nutrient are the limited growth factor, and thus excess nutrient cause growth to accelerate. In streams where phosphorus is a limiting growth factor, excess phosphorus will cause eutrophication much faster, and at a higher rate, than a stream predominantly limited by nitrogen (McDowell et al, 2004). Excess nutrients not only affect the health of a river but affect humans and animal health by facilitating toxic algal blooms.

2.3.2.1 Nitrogen

Nitrogen is an essential element for plant and animal growth. Nitrogen has high solubility, and so easily enters the hydrological system without binding/fixing to soil particles. The inorganic dissolved forms of nitrogen available for biological uptake are of the most concern to water quality. Nitrogen can occur in three dissolved inorganic forms: Nitrate (NO_3^-), nitrogen dioxide (NO_2^-), and ammonium (NH_4^+). Leaching into groundwater is a key source of nitrogen that often results in excess nutrient concentrations in groundwater and waterbodies (Bouwman et al., 2012). Nitrogen concentrations have an overall declining trend in New Zealand, as a high proportion (55%) of locations monitored nationally showed increasing nitrogen concentrations, and pastoral land measures concentrations above expected natural levels (Figure 2.3) (2017). Southland is one area where nitrate trends are worsening. Nitrogen leaching has also been increasing over time, as agricultural soils show an increase in leaching of 29% between 1994 and 2013, indicating that New Zealand's water quality issues are characterised by agriculture. The impact of historical management practice through increased fertiliser use is still observed through this leaching into groundwater, which cycles in rivers and streams gradually over time (Buck et al., 2004). Where nitrogen rates are particularly high, and the water source is used for drinking water or recreational activities like swimming, it can have adverse effects on human health. Even modestly elevated nitrate levels have been recently linked to increased risks of gastric cancer in adults (Dowd et al., 2008).

2.3.2.2 Phosphorus

The pathways of dissolved phosphorus (orthophosphate PO_4^{3-} in water) are poorly understood, due to the complexity of the environmental interactions controlling phosphorus movement (McDowell et al., 2004). Unlike nitrogen, phosphorus does not have a gaseous form (Mellander et al., 2015). It is recognised that phosphorus in solution has low solubility and is preferentially bound to colloids in soil (McDowell et al., 2004). Phosphorus is linked to sediment transport through soil erosion and has a much slower cycle than nitrogen. Phosphorus is enriched in the topsoil layer, and therefore the entrainment of soil creates a concentrated source that can be transported by overland flow (Monaghan, 2014). Any phosphorus not taken up by plants accumulates in the soil and can be taken up by crops for many years after application (Bouwman et al., 2012). Phosphorus can be lost to both the lithosphere and the hydrosphere through decomposition, erosion, leaching, and sedimentation. The overall phosphorus trend in New Zealand is encouraging with a general decline in phosphorus concentrations, particularly in the South Island. Through State of the Environment monitoring, 42% of locations indicated improving trends over time (Environment;, 2014). These positive trends were observed in pastoral land use catchments, where 46% showed improving trends (2017).

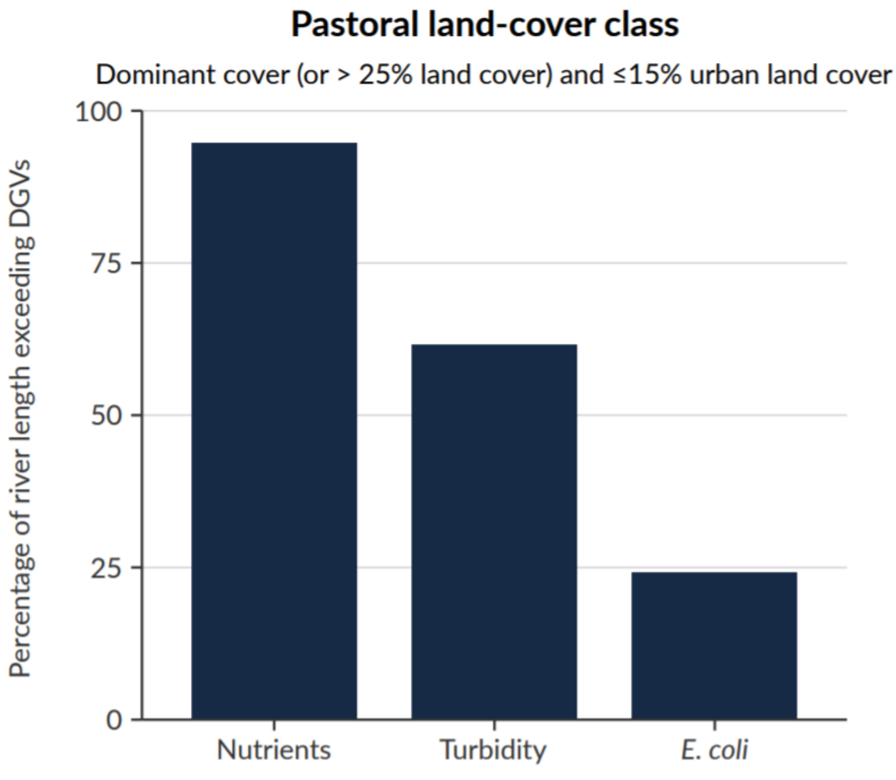

Figure 2.3: Percentage of river length in the pastoral land-cover class that exceeds expected concentrations for expected natural conditions for nutrients (nitrogen and phosphorus) E. coli, and turbidity (NZ, 2020).

2.3.3 *E. coli*

Escherichia Coli (*E. coli)* is a group of bacteria present in waterways where contamination with animal or human waste occurs. *E. coli* is an increasing concern to water quality in New Zealand, due to the large number of livestock farmed in New Zealand. The bacteria pose a health threat to humans and animals, especially if ingested (Nagels et al., 2002). New Zealanders engage in many recreational activities in and around freshwater rivers, such as fishing, swimming, and kayaking, therefore *E. coli* exhibits considerable risk to human health (Dymond et al., 2016). Cultural traditions, such as Māori food gathering, are also adversely affected by high *E. coli* levels, and further impacts Māori spiritual connection to rivers. *E. coli* is also of concern for the aquaculture industry. Much of the area where oysters, mussels, and other shellfish are farmed, is subject to the runoff from pastoral agriculture areas (Nagels et al., 2002). *E. coli* records in New Zealand showed 21% of the State of the Environment monitored sites were improving, however, 65% had indeterminate trends, meaning that insufficient data exists to understand *E. coli* trends across the entire country (2017).

E. coli is an indicator of how many other pathogens may be in freshwater due to the same key sources of agricultural contaminants, therefore providing a measurable variable with which to estimate whether a waterway is safe for swimming, drinking, or general contact. *E. coli* is therefore a cost-effective variable to measure for sampling logistics, and so is commonly used as a water quality monitoring indicator (Monaghan, 2014). (Dymond et al., 2016) identified three key sources of *E. coli* originating from livestock in waterways in New Zealand (Nagels et al., 2002, Moriarty and Gilpin, 2015). The first is excretion into the river system when livestock have direct access to a waterway. A second source comes from dairy effluent that is sprayed directly onto pasture. If the soil below has a high bypass flow and/or drainage is occurring from the soil, *E. coli* will move through cracks and pores in the soil to groundwater, or to drains that go directly to the river. The final source identified by (Dymond et al., 2016) is the occurrence of overland flow under intense rainfall, transporting *E. coli* from pasture often facilitated by sediment transport which, if attached to sediment causes faecal particles to remain in a river system longer (Monaghan et al., 2007, Moriarty and Gilpin, 2015, Davies-Colley et al., 2018). The deposition of *E. coli* directly into streams from animals is a much larger source of faecal bacteria than overland flow. Despite having an understanding of how *E. coli* can be transported through a landscape to a waterway, very little is understood about the difference that changing land use and environmental factors can have on *E. coli* concentrations, therefore making it difficult to understand *E. coli* transport specific to different catchments (Nagels et al., 2002).

2.3.4 Suspended sediment

High sediment concentrations have an adverse effect on river systems and ecosystems. Although naturally occurring, excessive sediment is associated with land disturbance and has a significant deleterious effect on the ecosystem if it remains in the catchment (Guercio, 2011). Suspended sediment causes a decline in light attenuation, reducing visibility and reducing aquatic species line of sight, as well as limiting available light for plants to carry out photosynthesis (Davies-Colley and Smith, 2001, Davies-Colley et al., 2014). Excess sediment can build up in beds and banks, altering flow patterns, and causing benthic smothering, where flora and fauna on the river bottom become suffocated by sediment (Davies-Colley and Smith, 2001). A reduction in visual clarity impacts the recreational value of a waterway, as people are less inclined to engage in recreational activities if river visibility is compromised. Lower clarity also reduces the cultural health of a waterway for Tangata Whenua (Tipa, 2009). Results from a New Zealand nationwide study showed that clarity was reduced in lowland rivers, and turbidity was higher, indicating higher suspended sediment concentrations in those areas (Davies-Colley et al., 2018). Over 50% of pastoral areas have turbidity above normal expected levels (Figure 2.3).

Agricultural environments are major and persistent sources of sediment. Steep land in these settings are erosion-prone, sediment is easily mobilised, and slopes often have high amounts of sediment, in some cases from historical deforestation (McDowell et al., 2013). The intensive grazing practices in pastoral agriculture result in a soil disturbance and therefore an increased erosion rate than non-pastoral land, increasing the amount of sediment in an aquatic system (Buck et al., 2004). Poor management of cropping lands and forestry, and eroding streambanks all contribute to sediment increases in freshwater systems (Guercio, 2011). Stock have a disruptive effect on land as they put pressure on soil, although sediment concentrations vary depending on the farm animal present. Cattle individually have a bigger impact on sediment than sheep, given that cattle weigh more (Trimble and Mendel, 1995). However, cattle use their tongues to eat about half the grass height while on pasture. Sheep use their teeth, and eat about 80% of the grass height, which leaves the ground more vulnerable to erosion than grass grazed by cattle would have (Julian et al., 2017). Agricultural sources of sediment result in particles of a clastic size range, that smother riverbeds and reduce visual clarity due to their fine nature, and high organic component, thus causing issues beyond the natural amount of sediment that would enter a waterway (Bright and Mager, 2016).

Sediment concentrations are often predicted through measuring the turbidity of freshwater, as it is more user friendly than measuring suspended sediment (Bright et al., 2018). Regulatory authorities have limited resources and time, and turbidity is used as a simple and cost-effective surrogate for sediment concentration. However, turbidity is only a measure of light scattered by sediment particles in water and does not always accurately reflect the actual suspended sediment concentration (Davies-Colley and Smith, 2001). Different turbidity measurement methods record different values according to sensitivity to particulate organic matter. The relationship between turbidity and total suspended material (TSM) is relatively poorly understood, particularly how turbidity responds to different forms of particulate material (Davies-Colley and Smith, 2001, Bright et al., 2018, Bright et al., 2020). New Zealand rivers show considerable variability in optical characteristics of suspended matter, such as the size and shape of particles, and the inorganic or organic nature, all of which impact turbidity results (Davies-Colley and Smith, 2001). As a result, relationships between turbidity, and TSM are very different, depending on the river. Despite the variability in measurements, turbidity thresholds are still implemented in regional plans as a sediment measurement over suspended sediment concentration, due to the ease with which turbidity can be measured. Clarity results are also used to understand sediment concentrations, as there is a relationship between total suspended material and river clarity (Davies-Colley et al., 2014). Clarity provides a link between measured water quality variables and human perceptions of water quality.

2.3.5 Contaminant source areas

Agricultural contaminants can be either source limited, or transport limited, and thus when an area has both an enriched source, and an effective hydrological transport mechanism, it is a high-risk source area (Figure 2.4). Source areas vary in their contribution of contaminants to freshwater based on morphometric factors, such as slope and infiltration capacity of the soil, and landscape management. A fast flow mechanism, combined with a high concentration of contaminants, results in a high potential for contaminant loss to a waterway (Monaghan, 2014, Betteridge et al., 2012). Underlying environmental influences interact with the external land use and management practices to establish the water flow pathways of an area, including soil type, topography, and land management (Duncan, 2014).

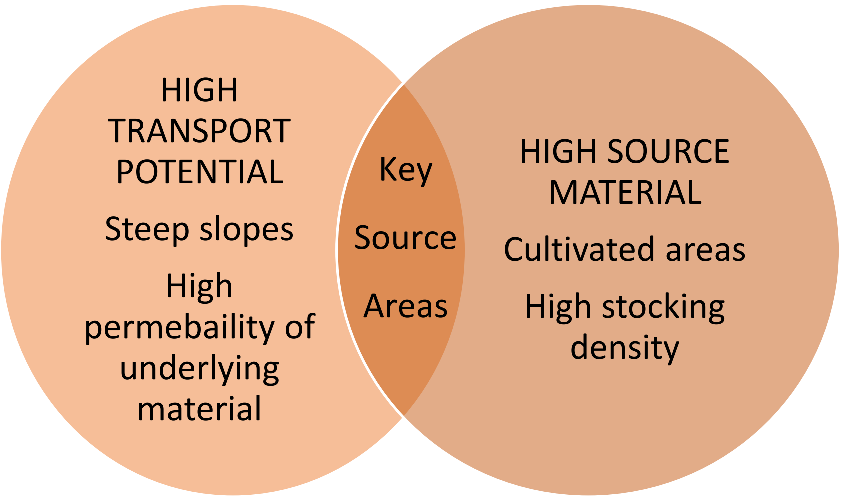

Figure 2.4: Venn diagram showing the two key components of source areas that put water quality at risk with examples of each.

Source areas vary over spatial and temporal scales, due to the complex environmental interactions of an area (Monaghan, 2014). In the context of pastoral land, source areas are often identified where animals spend more time and deposit more nutrients and microbes (Figure 2.4). Sheep wear out hillslope tracks while grazing and looking for shelter, leaving bare ground with an erosion risk, and mobilising sediment on slopes where it can be easily transported to a waterway (Julian et al., 2017). Such sediment may also be carrying *E. coli* or nutrients (especially phosphorus), and thus transports multiple contaminants to waterways. Areas prone to surface runoff, or overland flow are also key sources of contaminants. Overland flow occurs when there is a large rain event that exceeds the infiltration capacity of the soil, causing excess water flows across land, transporting nutrients, *E. coli* and sediment through quickflow (Figure 2.5) (Mellander et al., 2015). Surface runoff is exacerbated by soils with low infiltration rates, as they have poor drainage, which can often be a consequence of damage caused by animal treading (Monaghan, 2014). Steep land is often a key source due to the high contamination transport potential. Betteridge (2012) identified flat land where break feeding is used for either crops or pasture, as a key source, due to the high levels of *E. coli* and sediment entering the river system, from increased pressure on the land from stock. High livestock density areas are likely to be major sources of contaminants due to the increase of source material with the potential to flow to freshwater. Identifying sources of agricultural contaminants is essential to improving freshwater quality outcomes and adapting management to the scientific knowledge accordingly, despite the scientific focus often limiting the effectiveness of water quality management.

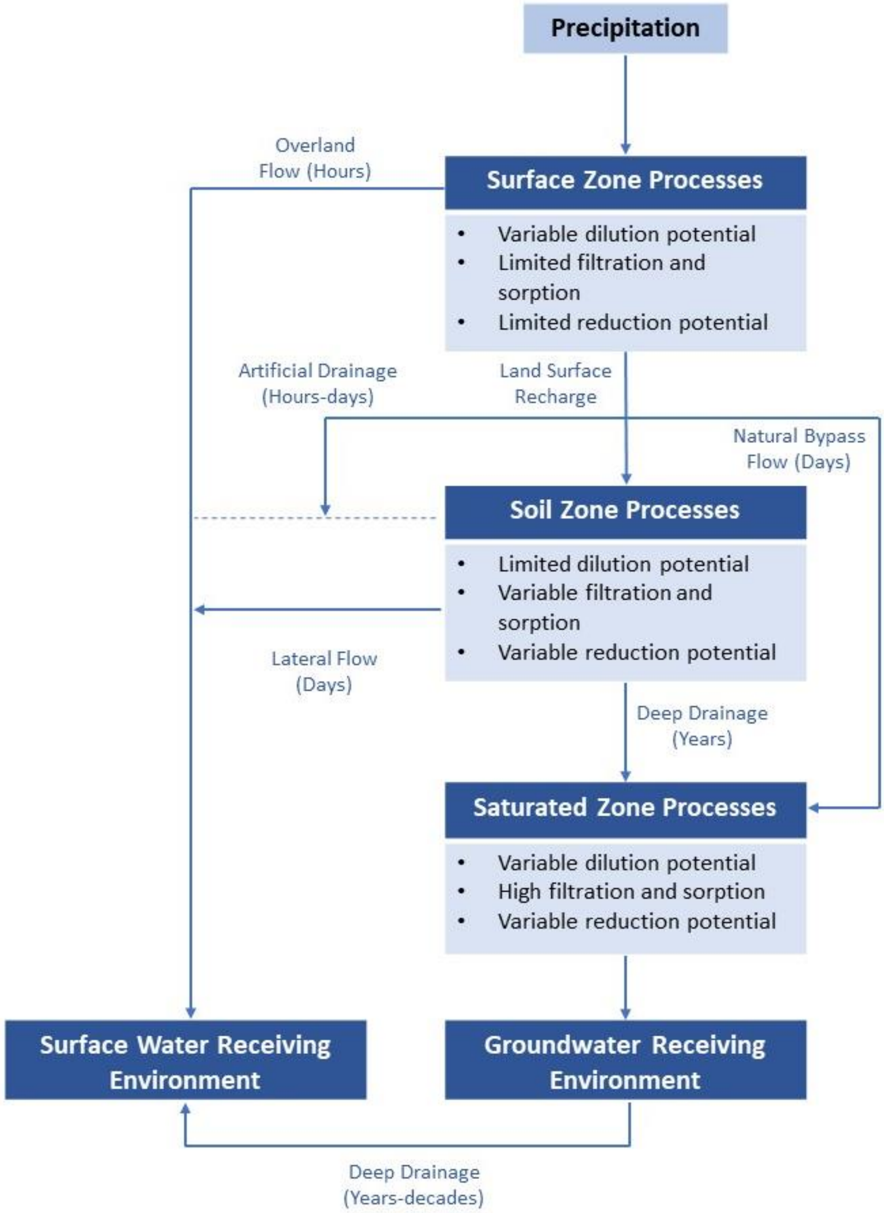

Figure 2.5: Conceptual model of the risk pathways to freshwater (adapted from Environment Southland).

2.4 Improving freshwater management in New Zealand

2.4.1 New Zealand freshwater management weaknesses

On-the-ground management often focuses on limit setting to address cumulative impacts and ensure that contaminant levels stay below recommended concentrations. Limit setting aims to focus on individual catchments, therefore encouraging collaborative management by focusing on the catchment as a whole ecosystem (Duncan, 2014). However, issues arise in the case of agriculture, whereby setting limits restricts farmer operations, causing major conflict and debate. Limit setting focuses on the end output, creating a major challenge for farmers who operate at the property scale, but are expected to meet catchment scale limits that are derived purely from scientific knowledge (Duncan, 2014). Governmental agencies in New Zealand have therefore gathered disdain from farmers who feel they are creating regulations that are very difficult to work within (Mitchell, 2020). There is a lack of faith in the government's ability to manage freshwater efficiently and successfully for the benefit of local communities and ecosystems (Weber et al., 2011). Therefore, there are constraints to the current management structure, and in Southland, for example, the public often does not agree with the documentation mandated by Environment Southland, as they do not believe limits are fair and reasonable (Duncan, 2013b, Mitchell, 2020). This discourse shows that there are considerable weaknesses and deficits in social capital and trust between stakeholders and local government.

Social and political aspects and links to freshwater are also often neglected, as they are poorly understood, and have traditionally been left out of the empirical scientific discussion of freshwater quality (Duncan, 2014). It is argued by both academics and regional authorities that in the development of policy relating to land use and freshwater management, greater recognition needs to be given to the social and political dimensions of freshwater, therefore transitioning away from a focus on numbers and predictive models (Swyngedouw, 2009, Memon et al., 2010, Duncan, 2013a, Vogel et al., 2015). Measurements from scientific inquiry are trusted as being the most reliable, and useful knowledge relied upon to provide more certain freshwater outcomes, which are seen to be fair, as well as being practical, reducing costs, and being time efficient (Duncan, 2014). Therefore, empirical science remains the basis for all policy in New Zealand, despite research showing that social and political aspects are overlooked and play a role in freshwater management (Swyngedouw, 2009, Duncan, 2014). A resultant gap in management emerges surrounding the inclusion of social and political factors in freshwater management, which has resulted in the formation of many community catchment groups in Southland (Anderson et al., 2019) If the NPSFM is meant to encapsulate all aspects of freshwater management, then why is it that so many catchment groups have emerged in the last five years? The aim of this research is to understand why the community catchment groups have formed, and what their role is in the future of management in Southland. The Integrated Catchment Management (ICM) framework is useful to understand the potential for catchment management groups in New Zealand, as it showcases a collaborative and integrated context of management, that appeals to many communities' aspirations for more representation in environmental management.

2.4.2 Integrated Catchment Management

"*Integrated catchment management is a process that recognises the catchment as the appropriate organising unit for understanding and managing ecosystem processes in a context that includes social, economic and political considerations, and guides communities towards an agreed vision of sustainable natural resource management in their catchment*." (Fenemor et al., 2011) Pg 314

Integrated Catchment Management (ICM) is a holistic style of management, recognising that an ecosystem is interconnected, and cannot be changed or improved without consideration of all aspects (Figure 2.6). A biophysical perspective is employed in ICM, recognising physical limits of a catchment, and accordingly placing a boundary around the management area. The traditional reliance on scientific research and solutions has not solved all water quality problems, and thus ICM endeavours to address the social, economic, and political settings to reach sustainable goals for catchments (Weber et al., 2011). It is generally accepted in New Zealand, that a holistic approach is needed to preserve natural capital (Fenemor et al., 2011). As such, ICM is recognised in the NPSFM, as the management style that should be utilised in New Zealand. Local Governments are expected to use ICM as their primary management approach, although the reality of environmental management on the ground is that implementation of good management principles is often limited with a lack of follow up, and they must still operate within the realms of the effects-based approach under the RMA, limiting success.

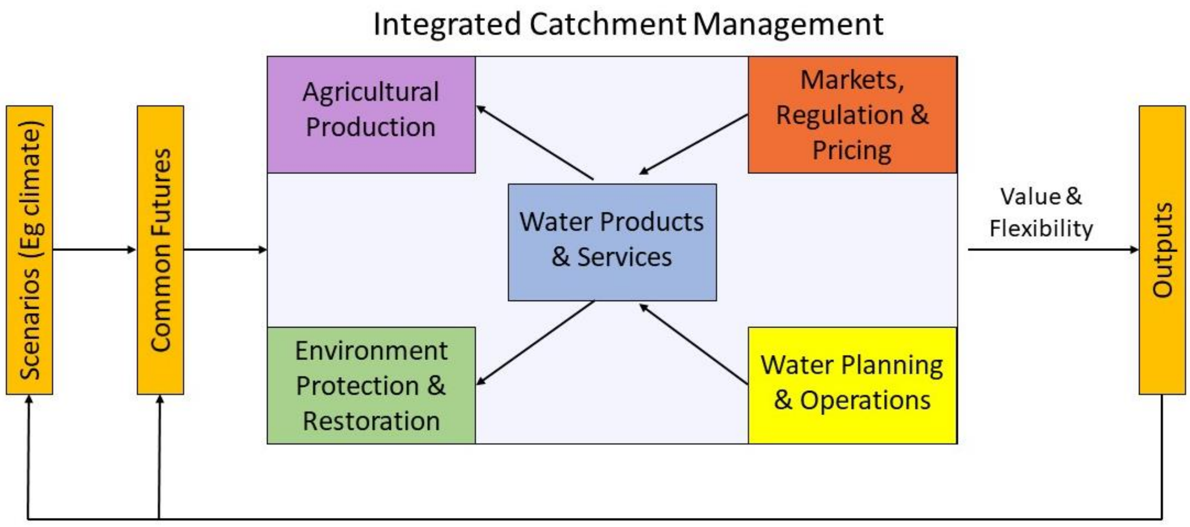

Figure 2.6: Integrated research framework for ICM, adapted from (Ayre and Nettle, 2015).

The transdisciplinary nature of ICM is both its greatest strength and biggest challenge. Euro-centric management approaches have been largely ineffective for remediating declining water quality as they analysed problems in a narrow thought process, where issues were compartmentalised and dealt with separately. Doing so created significant social barriers, and resulting in a lack of enforcement from authorities, and resistance from stakeholders (Falkenmark, 2011). The transdisciplinary framework of ICM has the potential to remove some of the traditional shortcomings of water management, by accommodating different schools of thought and knowledge, based on the understanding that local knowledge provided by communities and stakeholders is as important as the scientific and technical knowledge provided by experts (Figure 2.8) (Bowden et al., 2004, Fien and Skoien, 2010, Ayre and Nettle, 2015). The challenge of ICM is to incorporate stakeholder values alongside expert perspectives where those two views differ and conflict. Incorporating knowledge types is a key part of social learning that requires social capital, compromise, and constructive conflict, benefitting collaborative resource management. Failure to do so limits success, as the process is not worked through to conclusion as stakeholders lose commitment to the project (Schusler et al., 2003, Ayre and Nettle, 2015). Social learnings contribute to the success of collaborative management through a multitude of characteristics, including open communication, and creative thinking that allows stakeholders to connect through common values, and a knowledge exchange process (Fien and Skoien, 2010, Schusler et al., 2003). Building trust in this way encourages community resilience, which leads to ecosystem resilience and improved environmental outcomes (Figure 2.7).

Figure 2.7: Diagram showing how community resilience develops to build ecosystem resilience through integrated catchment management (Fenemor et al., 2011).

ICM aims to break the ‘paradigm lock’, that exists between scientific research and information, and practical change on the ground, which has been the biggest challenge for water management. Research suggests that the social capital formed by community management groups may act as a vehicle for the ICM to grow, with potential for ICM to be better streamlined and more accessible for public participation (Figure 2.8) (Fenemor et al., 2011, Thomas and Bond, 2016). A lack of good stakeholder engagement limits the success of ICM, so bridging that gap is essential for future improvements (Fien and Skoien, 2010, Fenemor et al., 2008). At present, the documented use of ICM by New Zealand regional authorities shows a limited and ad hoc application, highlighting a further limitation of the current freshwater management system (Memon et al., 2010). The use of ICM in New Zealand is poorly regulated, and therefore limited ICM is documented. There are several case studies across the South Island where ICM approaches have been used to varying degrees of success (Table 2.2).

Table 2.2: New Zealand examples of Integrated Catchment Management principles and their general outcomes.

New Zealand ICM Examples	**Outcomes**
Hurunui Catchment (Thomas et al., 2020)	Community collaboration was undermined by Environment Canterbury, and thus the community ideas and plans were stifled in favour of the economy
Motueka Catchment (Fenemor et al., 2008)	Government-funded research worked to build a collaborative partnership towards sustainable resource management and involving stakeholders in the governance process The ICM process built both ecosystem and community resilience to ensure effective management is longstanding
Orari Catchment (Anderson et al., 2019)	Māori developed innovative approaches to freshwater co-management and provided a strong sense of cultural values which assisted in identifying flow thresholds The role of people in environmental management was considered in a new way to traditional euro-centric views
Taieri Catchment (Memon et al., 2010)	Community trust and collaboration was formed among regional council, community, and local university through a Ph.D. research project, that developed an integrated education resource

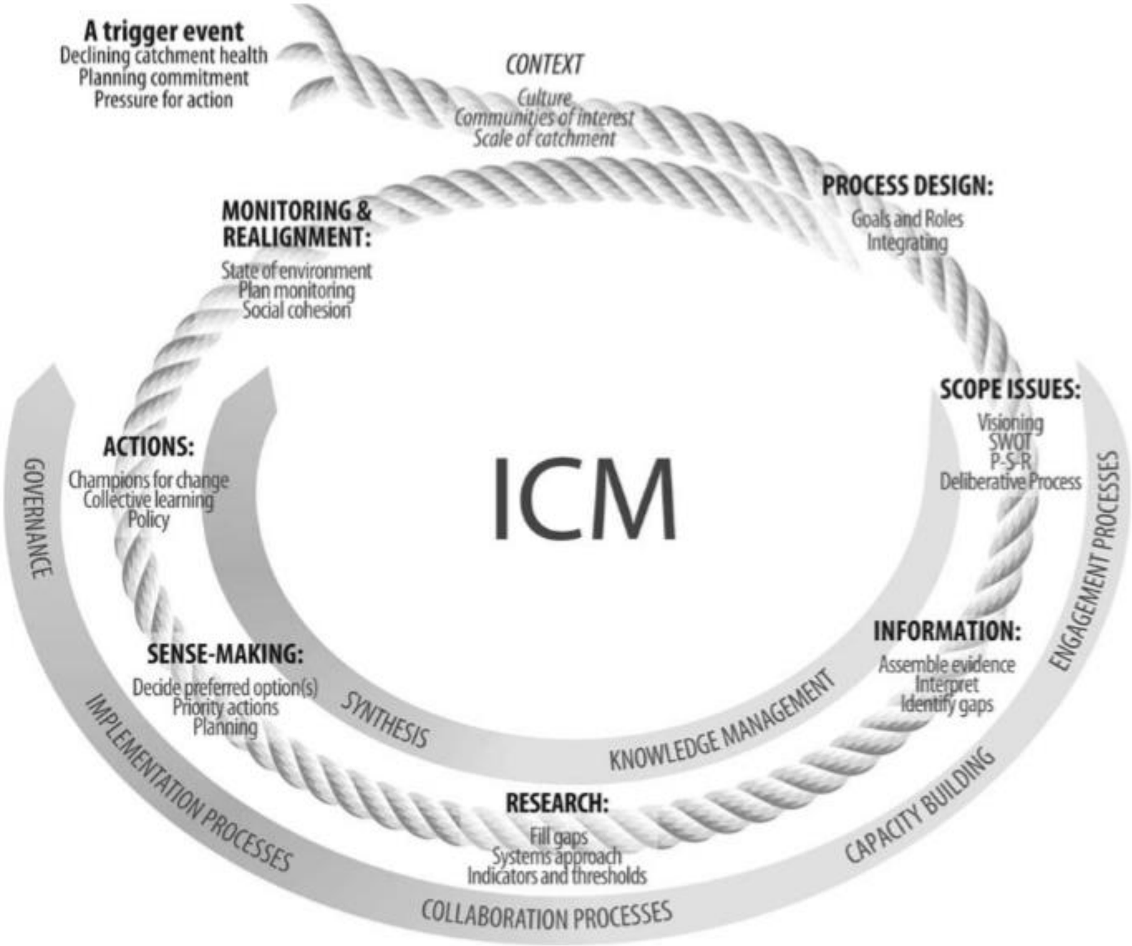

Figure 2.8: Diagram showing the process of integrated catchment management (Fenemor et al., 2011).

2.5 Community management

Community catchment management is an increasingly popular management strategy, both in New Zealand and around the world (Cook et al., 2013). Community catchment management usually manifests in the formation of voluntary catchment groups within a small area made up of those who live in the region (Oliver, 2001). The groups carry out a range of activities from education, to research and monitoring programmes traditionally operated by local government, as well as on the ground rehabilitation (Oliver, 2001). The community aspect gives catchment groups an effective platform to launch education and awareness programmes and initiatives, as well as a formal structure to lobby local government (Fien and Skoien, 2010). Catchment groups aim to embody and implement Integrated Catchment Management principles, seeking effective environmental management and improved environmental outcomes. Environmental management goals include utilising public participation, and collaboration between different stakeholders, and shifting responsibility from solely technical experts to catchment users (Fien and Skoien, 2010). The nature of catchment groups is that they are a decentralised form of management, changing the traditional sense of planning and decision making (Cook et al., 2012). Decentralisation leading to flexibility is a key characteristic and strength of voluntary resource management groups (Prager, 2015). Management groups have the potential to act as the on-ground implementation scheme that local government and other regulatory authorities often lack. Bottom-up management approaches have become more common in the last decade, and the formation of catchment groups embodies this shift from top-down management approaches (Cook et al., 2013). This shift away from top-down, centralised approaches to management, has yet to prove how it will make a difference to the environment long term (Thomas and Bond, 2016).

New Zealand’s management history includes community and other non-governmental organisations. The first community groups were formed around the time of the River Boards Act of 1884. These groups had limited funds and an inability to implement any useful plans on the local scale, causing their effectiveness to be constrained (Knight, 2016). Catchment boards formed from 1943, and had a major focus on flood protection, as floods were a major issue relating to the co-existence of humans and the environment. These catchment boards were the first management groups in New Zealand that focused on water issues at the catchment scale. By 1948, most of New Zealand was covered by catchment boards who were working to keep water away from people and reduce the impact of flooding. The Water and Soil Conservation Act of 1967 deemed that all regions should have catchment boards, and they should take a whole catchment approach to management (Knight, 2016). This shows the early acknowledgement of the benefit of integrated style catchment management, recognizing the interconnectedness of freshwater with different spheres of the human environment. However, the economy was prioritised even when pollution was severe, as New Zealand was slow to respond to emerging pollution problems in both the 19^{th} and 20^{th} centuries. In 1972, responsibility for rivers and streams was put to regional catchment boards, who monitored water quality more closely than any regional council at the time (Knight, 2016). When the 1991 Resource Management Act was enacted, power and responsibility were transferred back to regional authorities, and catchment boards disbanded, as they were perceived to have become inefficient and served no purpose at that point (Knight, 2016). These shifts between catchment scale to regional governance are cyclical and reflect shifting political agendas in environmental management.

"Such bodies (speaking to voluntary management groups) can form a basis for wider participation, because their formation is a spontaneous response to a perceived problem in the water environment" - *(Cook et al., 2012) Pg 49*

As of 2020, in Southland there are 21 community catchment groups that have established in the last decade, and most of them within the last 5 years (Figure 2.9). These catchment groups work with local regional authorities, and the New Zealand Landcare Trust, aiming to improve environmental outcomes, as well as educate and include farmers and landowners in the management process. The direction of catchment groups in New Zealand is uncertain, and each group operates differently, with different goals. Therefore, the contribution of local catchment groups to freshwater management is largely uncharacterised. Southland has seen the rise of near 20 groups in a very short period, indicating a change in thinking circumstance leading to such a mobilisation, though the intention and motivation of such groups is unknown. Other regions in New Zealand, namely Canterbury have similarly seen the formation of community groups, although their progress has varied, and in some instances been stifled by regional government overreach (Thomas and Bond, 2016). Most other regions have fewer catchment groups than Southland but have developed due to a more distinct problem, and therefore have a clearer purpose and goals than many small catchment groups in Southland (Memon et al., 2010).

Figure 2.9: Southland map showing the first 17 catchment group boundaries (Land Care Trust, 2018).

Catchment groups often form in response to a perceived problem in the environment, specifically freshwater, indicating that local people care about their environment enough to create a formal structure from which to address the issue (Fien and Skoien, 2010, Cook et al., 2012). A gap in research exists around these community groups, as there is lack of a full understanding of why such groups form, how they operate, and their contribution to environmental management. The local community are stakeholders of their natural resources, and therefore have an investment in their surroundings, and want to be involved in the management process.

Groups have a good opportunity to act without the barriers that face local authorities when managing freshwater (Oliver, 2001). Because groups are community-led, the backlash that regional governments often face because of their regulatory requirements, does not exist (Cook et al., 2012). Community groups keep dignity by promoting self-sufficiency, instead of a regulatory authority that is often perceived as the rule enforcer. Local authorities sometimes struggle to engage meaningfully with the public, due to their regulatory role in communities. By comparison, catchment groups have the capacity to build off existing connections, where the community relationships can be used to benefit resource management and the environment, by increasing public engagement (Oliver, 2001). If trust exists between all stakeholders with an interest in the catchment, social capital can be built, upon which, collaborative management can be employed (Fien and Skoien, 2010). Social capital is central to a catchment group's success, as the networks and trust that forms between community members, is the basis for progress in resource management (Oliver, 2001). Having an engaged community built on trust encourages cooperation and increases the likelihood that implemented initiatives and schemes will be effective, improving natural resource management, and therefore water quality. Government agencies typically have a technocratic focus, which is often criticised for not considering and being responsive to the social dynamics of a catchment (Cook et al., 2012, Duncan, 2013b). Community catchment groups, however, offer a way to account for the social dynamics and needs of an area, through a format that accounts for the values associated with a freshwater body.

2.6 Summary

New Zealand finds many challenges in redressing its environmental management of freshwater. Tenets of ICM and embedding Te mana o te Wai perspectives are central to the best practices laid out by the NPSFM. Yet despite these overarching goals to embrace ICM practices into freshwater management, a flurry of community-based action has emerged in the agricultural communities in Aotearoa, New Zealand. The collective response of communities has been to develop local catchment groups to engage more directly with local government and highlights the deficit of current 'top-down' approaches to freshwater in New Zealand. The physical causes of, and solutions to, water quality issues stemming from agricultural production are region-specific, and therefore local understanding is essential to the overall management picture, to reduce the environmental impact of intensive agriculture(Buck et al., 2004, Bouwman et al., 2012, Zonderland-Thomassen et al., 2014). As described in Chapter 1, this thesis will address the links between physical water quality, and the water quality perceptions of the local community, alongside assessing the potential for community management. In the following chapter, the study site will be outlined in detail before the quantitative and qualitative approaches of this study are described.

3 Study Site and Methods

Water quality research is an interdisciplinary field, as it is increasingly acknowledged that solving water quality problems cannot be done solely on the merits of physical science. Biophysical processes that explain the nature of water quality are intrinsically linked to social processes, and therefore researching the two together offers a holistic perspective to the water quality debate (Vogel et al., 2015). The methods of this thesis incorporate both quantitative and qualitative techniques. Quantitative data can be analysed statistically to identify patterns in natural phenomena. In the context of this research, trends can be identified in the water quality variables, while assessing their relationships with each other. Using quantitative data allows for a greater spatial and temporal water understanding of the site, accounting for seasonal variation in the Waikaka Stream.

Water quality is also a human perception, and therefore the social setting needs to be assessed through qualitative methods (Anderson et al., 2019). These results inform or explain the quantitative data and allow for an insight of people's perspectives of a specific water quality issue while gaining an understanding of their ideas based on their personal circumstances and world views. Practical local knowledge existed before the development of modern science, and so is an important part of water management that has been overlooked in favour of empirical science (Vogel et al., 2015). Traditional knowledge includes that of Māori, including their worldview of interconnected social and physical systems, and the importance of protecting freshwater well-being (Tipa, 2009). This thesis therefore uses a combination of quantitative and qualitative results to address the aims established in previous chapters. Chapter 3 describes the practical approach to this study, providing detail on both the quantitative and qualitative processes carried out to gain a full water quality perspective of the Waikaka Stream. The chapter also outlines the specific study site context.

3.1 Research strategy

To understand the water quality trajectory for the Waikaka Stream, qualitative and quantitative methods were employed through a mixed methodology, allowing the scientific findings to be informed by social science. The mixed methodology allowed the researcher to approach the project from different angles, which offered a more holistic insight and added a deeper understanding to the overall research (Henn, 2005). Using both qualitative and quantitative data ensured that social and political aspects of freshwater management in the Waikaka Stream were included and not overlooked, as they often are in the case of natural resource management. The sum of qualitative and quantitative research is lesser than the combination of both parts together holistically (DeLyser and Sui, 2013). For this research, integration between qualitative and quantitative data occurred in the interpretation and discussion phase, and the data were analysed separately (Figure 3.1).

The approach taken by this research was to use a socio-hydrology lens, whereby the physical environment is linked to the interactions of people with freshwater systems. Socio-hydrology is based on the science of water and people, and analyses coupled human-water systems, to understand the complexities associated with the water cycle and the way that humans are an integral part of the water cycle (Swyngedouw, 2009, Sivakumar, 2012, Sivapalan et al., 2012, Anderson et al., 2019). Over the past few decades, there has been a greater focus on the interactions between hydrology, and human systems, as hydrologic systems are being altered by human activity, more so then they have been in the past (Ratna Reddy and Syme, 2014, Vogel et al., 2015, Xu et al., 2018). In the context of water quality, land use change driven by socioeconomic and political factors is a major driver of adverse environmental harm, and therefore responses must consider these factors (Ratna Reddy and Syme, 2014). The collaboration between natural and social systems research builds stronger resilience for both systems to negative environmental changes, such as intensive cultivation resulting in sediment runoff, or excessive fertiliser use which deposited high concentrations of nutrients into waterways (Xu et al., 2018, Anderson et al., 2019). Therefore, a mixed-methodological approach allowed research aims outlined in Chapter 1 to be addressed (Figure 3.1). The results are complementary to one another, as the qualitative results will enhance the otherwise strictly quantitative data (Bryman, 2006). The mixed methodology bridges the gap between technical scientific knowledge, and the local and community knowledge associated with the local environment (Fraser et al., 2006).

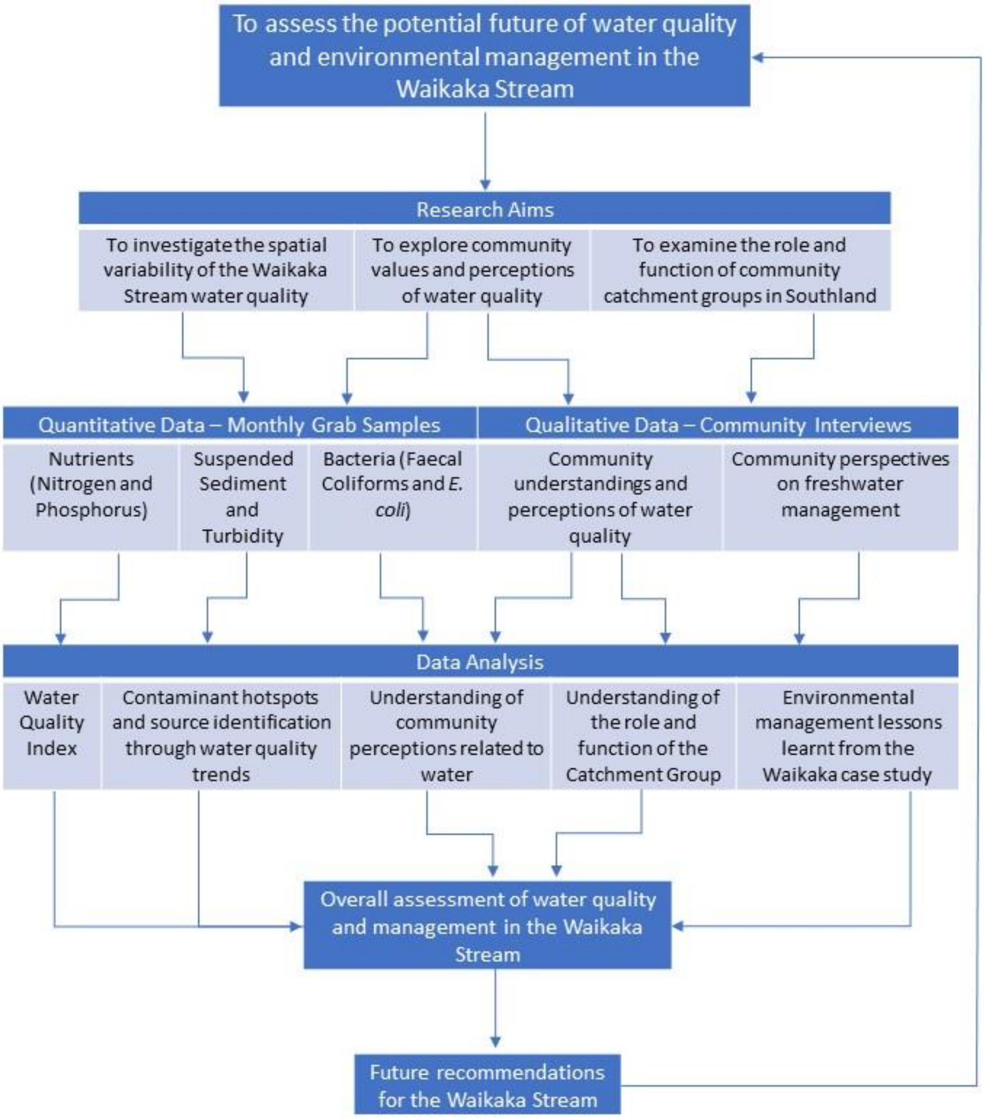

Figure 3.1: Research strategy schematic showing the combination of qualitative and quantitative methods to inform the interpretation phase of the study.

3.2 Study site

The Waikaka Stream is located in Eastern Southland, and is a tributary to the Mataura River, with the confluence located northeast of Gore (Figure 1.2). The catchment is 328 km^2, covering predominantly low-lying land of gentle topography. The Waikaka has a stream order of 5 and shows two main tributaries, that combine below the Waikaka township Maitland (Figure 3.2). A large aquifer underlies 70% of the catchment, predominantly in the lower sections of the stream (Figure 3.2). The dominant land use in the catchment is pastoral agriculture, principally sheep, beef, and dairy farms. The catchment is characterised as a lowland stream heavily impacted by agricultural land use and therefore is an interesting case study showing the impacts of pastoral agriculture on water quality. The upper reaches are more natural, with larger areas of tussock grasslands, and are less stock intensive as a result.

3.2.1 Climate

The Waikaka Stream is located inland, and so experiences a temperate climate, compared to those streams and rivers in closer proximity to the coast (Macara, 2013). The inland areas of Southland where the Waikaka Stream is located often receive mean annual temperatures of around 9-10 ^oC, which is colder than coastal areas in the same region. Coastal areas receive a higher mean annual temperature of around 11 ^oC (Macara, 2013). The lack of influence of the sea is observed in the more extreme temperatures inland (Macara, 2013). Eastern Southland is the driest area in Southland, due to the Western Ranges blocking the rain from southwest fronts . Rainfall is unevenly distributed throughout the catchment, as the mean annual rainfall is high in the headwaters of the catchment, around 1220 mm $year^{-1}$, compared to a lower mean annual rainfall in the lower reaches, around 775 mm $year^{-1}$ (Figure 3.2). Eastern Southland experiences frequent flooding while being relatively unaffected by snow due to elevation and temperature controls. The weather in Southland, and Eastern Southland specifically, is driven mostly by westerly winds.

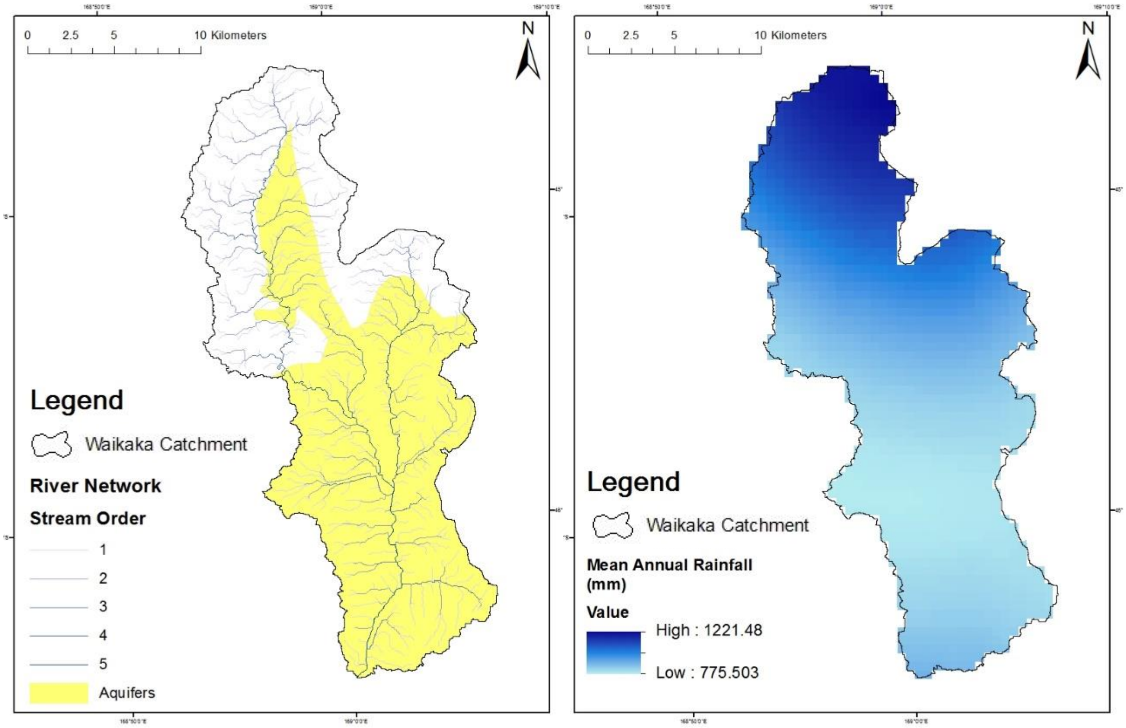

Figure 3.2: The stream network and underlying aquifer of the Waikaka Catchment (left), and the mean annual rainfall (mm) of the catchment (right).

3.2.2 Geology and soils

The main lithology (Figure 3.3) of the Waikaka Catchment is Caples Group Metasediments from the Triassic (200–250 MA), which is comprised of sandstone, siltstone, mudstone, and volcanic conglomerate with occasional limestone units (Turnbull and Allibone, 2003). The Caples Group lithology is mostly undifferentiated, that is, it consists of massive or thick-bedded grey sandstone with occasional black mudstone interbeds (Turnbull and Allibone, 2003). Along the river valley is a sequence of sandstone and siltstones of the East Southland group from the Oligocene to Miocene (5–28 MA). These East Southland group basement lithologies are derived from marine and estuarine deposits, with non-marine derived lignite deposits (Turnbull and Allibone, 2003). The lowland portion of the catchment is dominated by Quaternary alluvium and marks the boundary of the underlying aquifer.

The Waikaka Stream Catchment has a mix of pallic, brown, and recent soil orders while having smaller sections of gley and podzol soils (Figure 3.3). Pallic soils, those characterised by slow permeability and a limited depth for rooting plants, cover the largest area in the Waikaka Catchment (Hewitt, 2013). Pallic soils follow a seasonal trend, where they are dry in the summer, and wet in the winter. The soil has a high potential for dispersion, which makes it susceptible to erosion. Brown soils cover the topmost section of the Waikaka Catchment. These soils are not susceptible to waterlogging and have relatively stable topsoils (Hewitt, 2013). Brown soils are common on slopes, hence being located at the top of the catchment. Recent soils and gley soils are found mainly around the river channel (Figure 3.3). Recent soils are generally no older than 2000 years, and as such are weakly developed (Hewitt, 2013). The soils are generally deep rooting and contain a high plant available water capacity. Gley soils indicate the areas in New Zealand that used to be wetlands but have now been drained for productive agricultural land. Gley soil is prone to waterlogging in winter and spring, as it has high groundwater tables, and a high bulk density (Hewitt, 2013). The last main soil type found in the Waikaka Catchment are podzol soils, which are strongly acidic, contributing to its low fertility (Hewitt, 2013). Podzol soil usually occurs in areas of high rainfall and are usually associated with forest trees and organic material.

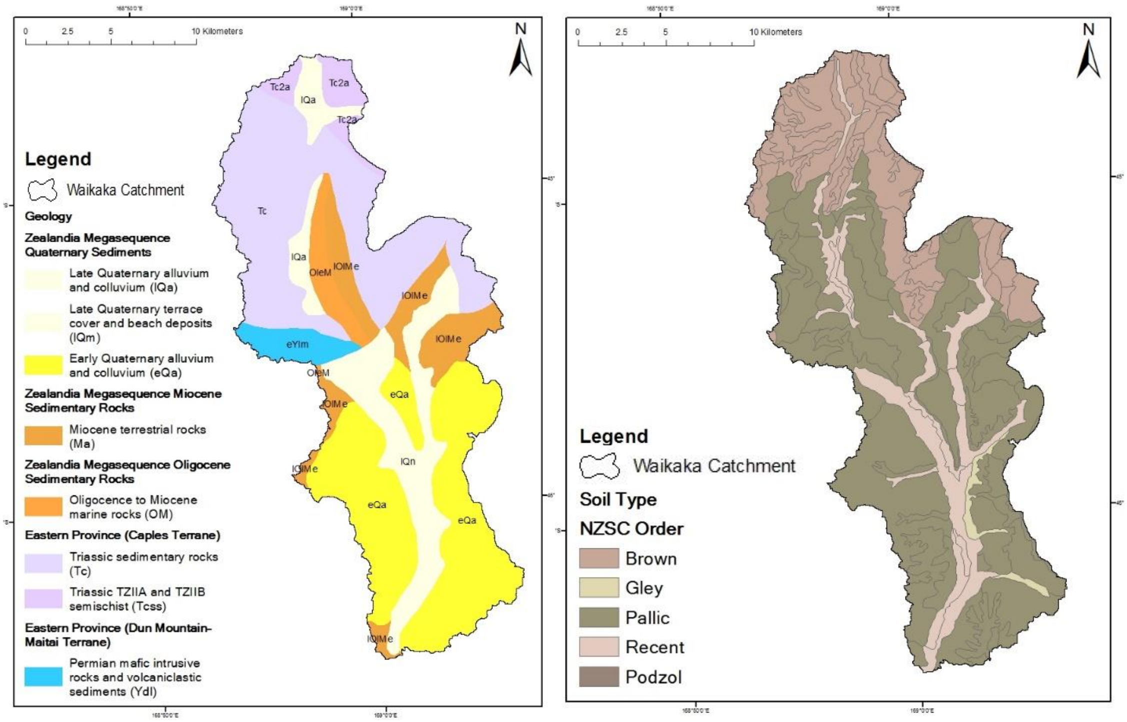

Figure 3.3: The geology (left) and soil layers (right) of the Waikaka Stream.

3.2.3 Physiographic zones

The regional council (Environment Southland) classified the Southland region into nine physiographic zones. These zones are designed to understand how contaminants move through the landscape and are based on several factors that control contaminant movement. Climate, topography, geology, and soil type are the primary factors that influence physiographic zone classification (Snelder et al., 2016). The main physiographic zones in the Waikaka Catchment are Bedrock/Hill Country, Gleyed, Lignite Marine Terraces, and Oxidising (Figure 3.5). There are small sections of Alpine and Riverine physiographic zones. Each zone has different properties and, therefore, different controls on water movement (Table 3.1, Figure 3.4). As soil and geology are key classifying factors of physiographic zones, the spatial physiographic patterns of the Waikaka Catchment closely follow those of the intrinsic properties (Figure 3.3).

Table 3.1: The main properties of the six physiographic zones found in the Waikaka Catchment (Snelder et al., 2016).

Physiographic Zone	**Soil and Geology**	**Topography and Climate**	**Hydrological Connectivity and Pathways**	**Transport Mechanisms (**Figure 3.4**)**
Bedrock/Hill Country	Bedrock and glacial till (rock debris and sediment) Native forest, tussock, or plantation forestry land cover Soil overlies bedrock	Rolling to steep land Up to 800m above sea level	Minimal groundwater High rainfall Dense network of branching streams	Flow through wet soils Overland flow following rainfall
Gleyed	Poorly drained, fine textured soils prone to waterlogging Distinctive rust or grey coloured spots	Low lying areas Found in historic wetland areas	High water table during winter Shallow aquifers interconnected with streams and drains	Extensive artificial drainage after high rainfall Overland flow (runoff) during heavy rainfall
Lignite Marine Terraces	Organic rich sediment at/near the land surface Lignite and coal sediments High organic content geology Slowly permeable soils, prone to waterlogging	Low elevation Flat land Coastal terraces	Minimal connection to main river systems No dilution by pristine zones Some water drains to underlying aquifers Extensive network of small streams	Extensive artificial drainage Overland flow in poorly drained and sloping areas Overland flow risk in summer due to a lack of recharge from groundwater
Oxidising	Aerated soils with plenty of oxygen Slowly permeable soils may experience waterlogging	Low elevation Flat to gently undulating land Terraces along major river system margins Inland basins, some lowland areas	High density of small streams, can rapidly rise during heavy rainfall Alluvial deposits as extensive groundwater resources Flat, free draining soils, water seeping to aquifers	Artificial drainage where soils experience waterlogging Sloping areas often experiencing overland flow Leaching into soils
Riverine	Soil water drains quickly through shallow, stony soils to underlying shallow aquifers Little risk of waterlogging	Flat to undulating land, alluvial terraces adjacent to main rivers Steeper slopes in headwater areas	River fed by alpine regions, including snow melt Shallow aquifers highly connected to the main rivers Recharge from alpine rivers	Deep drainage through stony soils Leaching to groundwater
Alpine	Soils are very thin or non-existent Mostly bedrock	Land above 800masl Steep sloping land High elevation resulting in high precipitation (snow or rainfall)	High rainfall Water flows across the land surface in a dense network of streams, discharging to Southland’s main rivers Snow melt in spring	Overland flow (runoff)

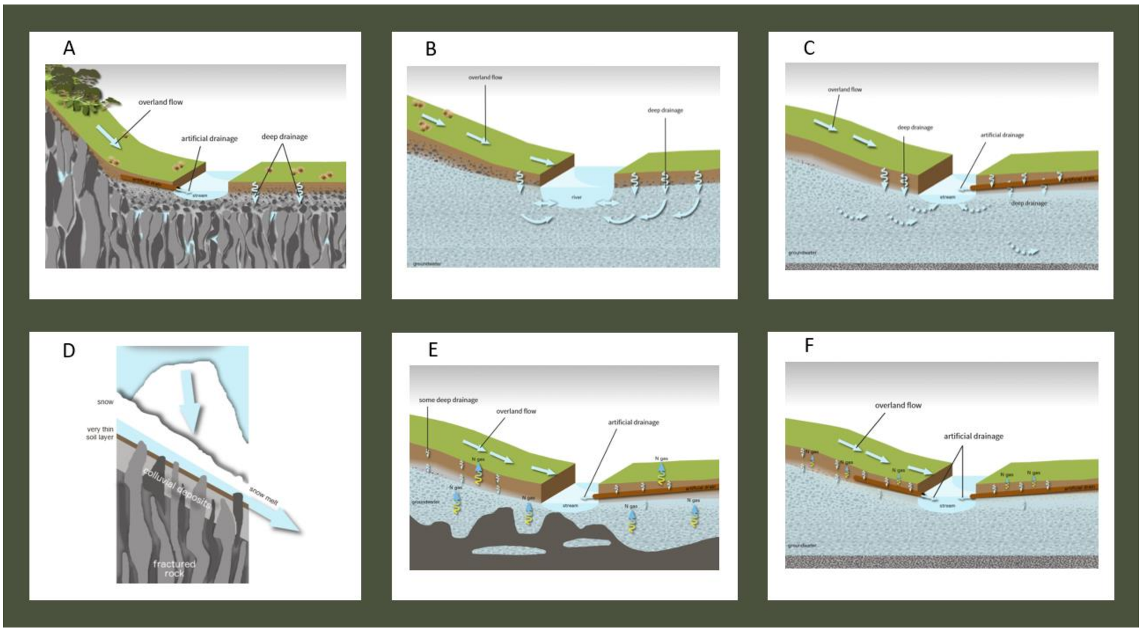

Figure 3.4: Tthe main pathways by which contaminants can travel through the six physiographic zones found in the Waikaka Catchment. Includes the Bedrock/Hill Country zone (A), the Riverine zone (B), the Oxidising zone (C), the Alpine zone (D), the Lignite/Marine Terrace zone (E), and the Gleyed zone (F) (Snelder et al., 2016).

3.2.4 Land use

Agricultural land use dominates the Waikaka Catchment and is comprised primarily of sheep and beef farming, with a small number of dairy farms (Figure 3.5). The catchment has around 150 farms, or land parcels. Dairying mostly occurs in the lower reaches of the catchment, where there is flat pastoral land. The intensity of farming varies across the catchment, owing in part to the varying topography of the farmland. In the headwaters, farming tends to be less intensive in comparison to lower regions of the catchment, and therefore is the least modified by humans. The upper region also has areas defined by the land cover database (LCDB) as low producing grassland, which is a mixture of exotic and indigenous grassland pastoral grazing (Figure 3.5). Soil fertility is low in the headwaters, resulting in extensive grazing styles, as the conditions do not allow for intensive grazing. These areas generally see more sheep than cattle, as they require less from the land. Farm management practice varies between farmers in the catchment, partly based on the natural characteristics of the land, and partly based on farmer management style. Most farmers in the catchment rely heavily on cultivation for winter feed, placing a large strain on soil in the area. The catchment has a small area in the lower half that is short-rotation cropland, where the land is regularly cultivated for crop production (Figure 3.5). Urban and forest land uses only cover 9% of the catchment, in comparison to the farmland expanse, which covers more than 80% of the catchment. Most of this is high producing exotic grassland, which consists of high soil fertility resulting in intensive grazing management. The Waikaka township is the largest urban area in the catchment located in the very centre of the catchment (Figure 3.5). The top section of the catchment is the only major area that includes areas of exotic forest land and tussock grassland.

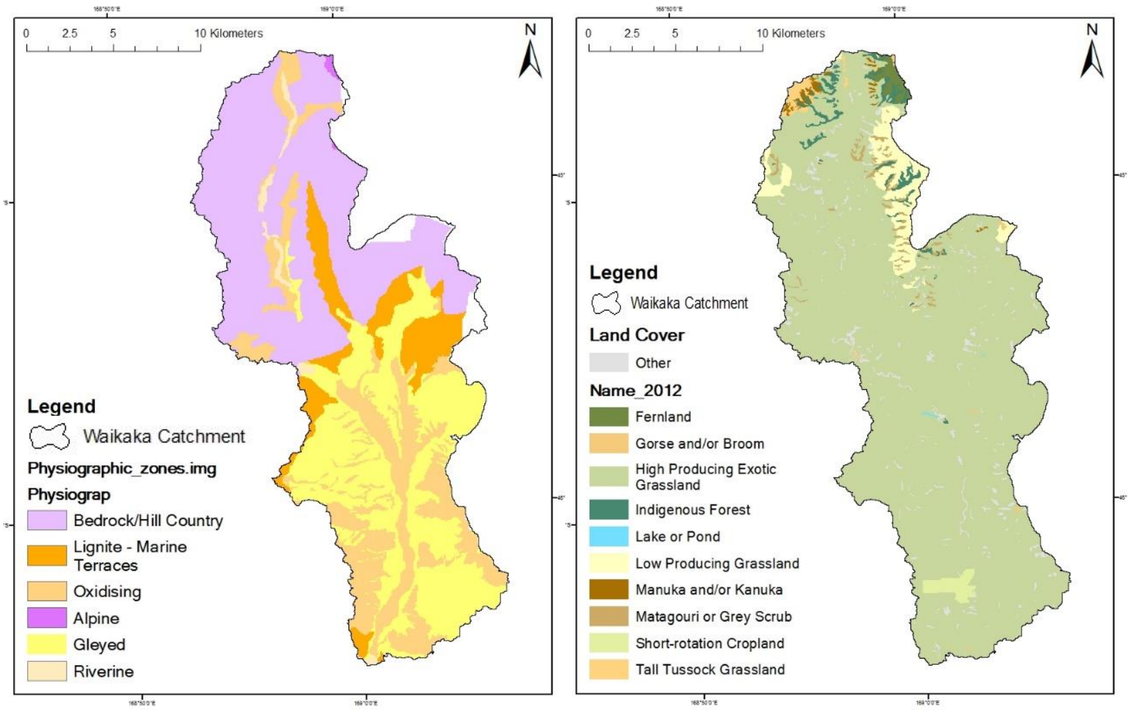

Figure 3.5: The physiographic zones (left) and land uses (right) of the Waikaka Stream.

3.3 Sampling strategy

The dynamic and complex nature of hydrological processes confound understanding of river behaviour and provide challenges for best sample practice to achieve representative results. Understanding river processes underpins the resultant contaminants and their transport pathways through a catchment (Rode and Suhr, 2007). Water quality in hydrological systems is variable in both space and time due to complex river processes, and thus a spatially dispersed sampling strategy has been employed, by deriving sampling locations based on several factors. To capture the water quality variability along the

Waikaka Stream, a systematic sampling approach identified 16 sampling sites based on key criteria outlined in Table 3.2.

Table 3.2: Key criteria used to locate the 16 sampling sites along the Waikaka Stream.

Criteria	Description
Practicality	Sites had to be accessible and be safe to sample frequently.
Stream Order	Sites had to be from a mix of stream orders and contain an even number of tributaries and main stem sampling sites.
Spatial Distribution	Sites on the main stem needed to be spread evenly down the Waikaka Stream.
Underlying Environmental Characteristics	Sites were required to evenly distributed through different physiographic zones to account for intrinsic environmental variation.
Land Use	Sites needed to be distributed throughout the catchment to ensure that all major land uses in the catchment were being captured.

The criteria were established for practicality, and representation of water quality variability in the Waikaka Stream Catchment. 16 sites were selected, as they covered the different dynamics that need to be captured for representative sampling, according to the above criteria (Table 3.2). The distribution of the sampling sites ranged from site 1, upstream in the headwaters of the Waikaka Stream, to site 16, just above the confluence of the Waikaka and the Mataura river (Figure 3.6). The main Waikaka tributaries were captured in the sampling strategy: the main tributary had eight sampling sites, the Waikaka East (colloquially known as the Little Waikaka) had three sampling sites, while smaller tributaries were sampled at a minimum of one site (Table 3.3, Figure 3.7). All physiographic zones identified by Environment Southland are sampled at a minimum of one site (Table 3.3).

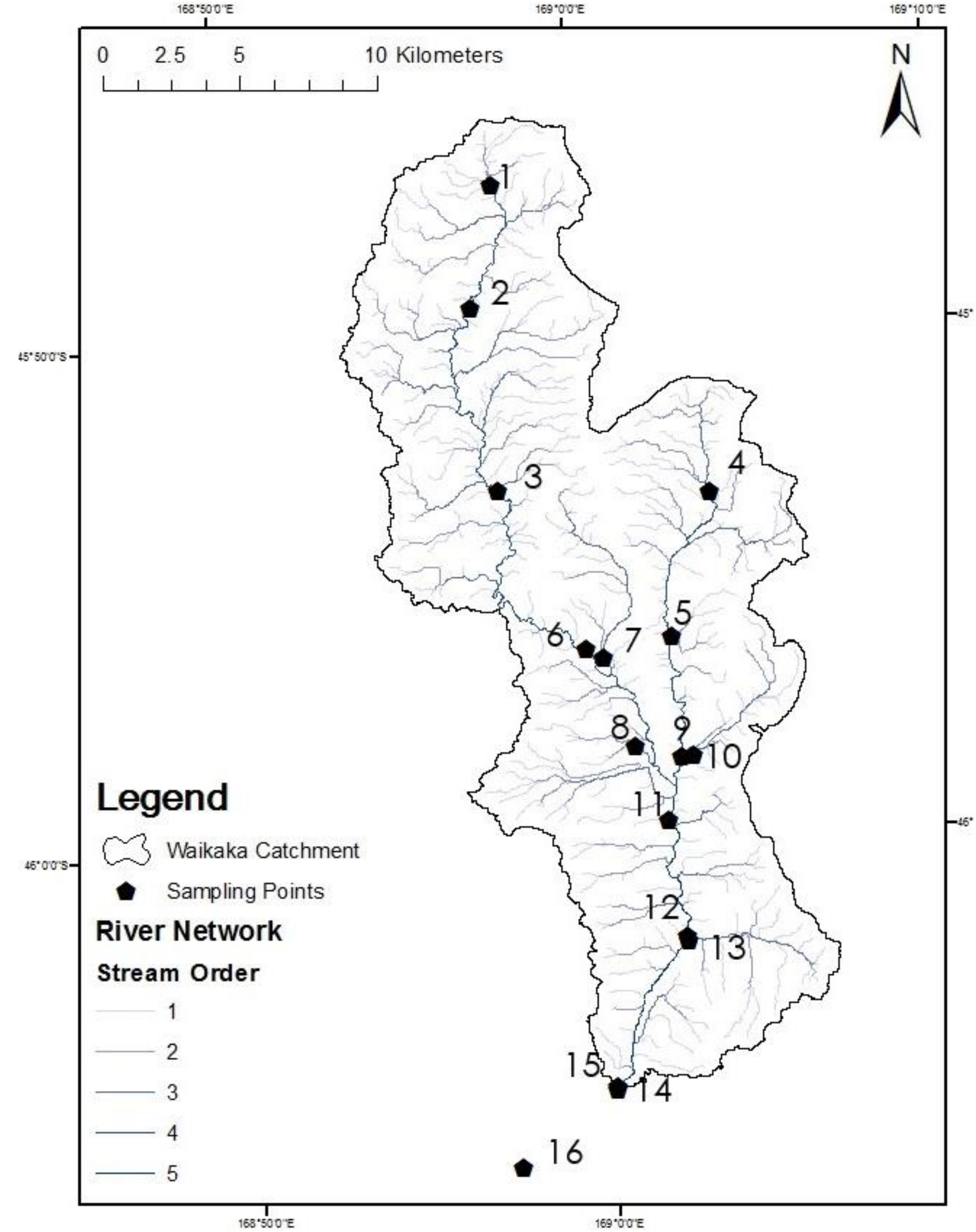

Figure 3.6: Sampling sites across the Waikaka Catchment, including the Waikaka East and other tributaries.

Table 3.3: Sampling site descriptions, including distances from the confluence, physiographic zones, underlying geology, and surrounding land uses.

Site	Distance (km) from Confluence	Physiographic Zone	Geology	Site Description	Surrounding Land Use
Key	Main Stem Site		Tributary		
1	59.6	Riverine – fed by bedrock/hill country	IQa – Late Quaternary alluvium and colluvium	Sandstone bedrock Sandy gravel bed Grassy bank	Hill country farms Tussock grassland Wild deer grazing
2	52.2	Riverine – fed by bedrock/hill country	Tc – Triassic sedimentary rocks	Tussock upstream Flow through gravel path Slow flowing	Hill country farms Sheep stations
3	40.5	Riverine – fed by bedrock/hill country	IQa - Late Quaternary alluvium and colluvium	Rocky bed Fast flowing Grassy banks, slips in places	Dairy grazing Sheep farms Beef cattle
4	33.7	Gleyed – fed by bedrock/hill country and lignite-marine terraces	IQn – Late Quaternary terrace cover and beach deposits	Steep bank vegetation Rock and sand bed Slow flowing	Dairy grazing Sheep farms
5	26.9	Oxidising – fed by gleyed and lignite-marine terraces	IQn - Late Quaternary terrace cover and beach deposits	Gravel bed Branches overhanging stream Grass banks	Sheep farms Beef cattle
6	27	Oxidising – fed by gleyed	IQn - Late Quaternary terrace cover and beach deposits	Weedy bed Earthworks Slow flowing	Residential area Waikaka township Sheep farms Cultivation
7	27.7	Oxidising – fed by gleyed	IQn - Late Quaternary terrace cover and beach deposits	Fast flowing Gravel bar on true right Rocky bed	Sheep farms, cultivation
8	22.1	Gleyed – fed by glyed (small parts oxidising)	IQn - Late Quaternary terrace cover and beach deposits	Very slow flowing Greenery right down to stream Narrow stream	Sheep farms Beef cattle
9	21.1	Oxidising – fed by gleyed	IQn - Late Quaternary terrace cover and beach deposits	Sediment and rocky riverbed Grass vegetation Ephemeral stream in winter Red tinged rocks	Sheep farms Cultivation
10	21.5	Oxidising – fed by gleyed	IQn - Late Quaternary terrace cover and beach deposits	Stoney bed, farm gate across the flow path Slow flowing	Sheep farms Dairy grazing
11	18.4	Oxidising – fed by gleyed	IQn - Late Quaternary terrace cover and beach deposits	Fast flowing Overhanging tree branches Rocky riverbed	Truck yards Sheep farms Dairy grazing

Site	Distance (km) from Confluence	Physiographic Zone	Geology	Site Description	Surrounding Land Use
12	13	Oxidising – fed by gleyed	IQn - Late Quaternary terrace cover and beach deposits	Sttep bank on one side Gravel bed on other side Fast flowing	Dairy farming Dairy grazing Sheep farms
13	12.9	Oxidising – fed by gleyed	IQn - Late Quaternary terrace cover and beach deposits	Narrow and fast flowing Large rocks dictating flow path Overhanging tree branches	Dairy farming Dairy grazing Sheep farms
14	6.2	Gleyed – fed by lignite-marine terraces and gleyed and oxidising	IOIMe - Oligocene to Miocene marine rocks Eastern Province (Caples Terrane)	Grass riparian banks with willow Fast flowing into confluence eddy	Sheep farming Dairy and beef grazing Dairy factory
15	6.2	Gleyed– fed by lignite-marine terraces and gleyed and oxidising	IOIMe - Oligocene to Miocene marine rocks Eastern Province (Caples Terrane)	Grass riparian banks Coarse gravel bed Bank covered in grass and reeds	Sheep farming Dairy and beef grazing Dairy factory
16	0.4	Riverine – fed by all types bar bedrock	IQn - Late Quaternary terrace cover and beach deposits	Grassy area Wide with large gravel bed Lots of organic matter in river	Sheep farming Urban centre

Figure 3.7: Photographs of each sampling site in the Waikaka Catchment, showing the character of each section of the stream.

Monthly sampling trips were conducted over a 12-month period between October 2018 and September 2019, under baseflow conditions. At each site, time-stamped samples were taken for the analyses of *E.coli*, total coliforms, suspended material, nitrate (NO_3), ammoniacal nitrogen (NH_4), total nitrogen (TN), orthophosphate (PO_4^{3-}), and total phosphorous (TP). Samples used for measuring total suspended sediment and turbidity were collected in 1 L HDPE containers. Thirty ml containers pre-washed in 5% HCl were used for collecting samples analysed for nitrogen and phosphorus. Sterile 100 mL LDPE containers were used to collect *E. coli*, and total coliforms. Bacterial samples were processed within 48 hours of collection51. Field and equipment blanks were taken on all trips and used for quality control. All samples were collected following standard protocols and transported directly to the School of Geography at the University of Otago, where they were frozen until analysed.

3.4 Laboratory methods

3.4.1 Turbidity and suspended particulates

Turbidity was measured using the EPA 180.1 method, on the Hach 2100P turbidimeter which reports in units of NTU and using ISO 7027 method, on the Hach 2100Q turbidimeter which reports in units of FNU, to account for the difference in methods (Bright et al., 2018). Total suspended material (TSM) and suspended sediment concentration (SSC) were determined by filtering a known volume of water through pre-treated[1] 47 mm glass fibre filter with a 0.7 µm pore size. The water samples collected in the 1 L container were weighed and filtered through the glass fibre filters. Filters were placed in an oven at 105°C for 12 hours and then weighed. The process was repeated twice to obtain three dry filter paper weights to give total suspended material (TSM) concentration. To determine particulate organic matter (POM) concentration from each sample, the filters were subsequently placed in a muffle furnace at 500°C for 1 hour to remove organic material. The samples are then weighed and the final weight, as a loss on ignition, was determined to the POM concentration. Subtracting POM from the TSM weight determined the (inorganic) suspended sediment concentration (SSC).

3.4.2 Nitrogen and phosphorus concentrations

Flow injection analysis (FIA) was used to determine the nitrogen and phosphorus concentrations in water samples, measuring: total nitrogen (TN), total phosphorus (TP), nitrate-nitrogen (NO_3^-), ammonical-nitrogen (NH_4^+), and phosphate-phosphorus (PO_4^{3-}).

[1] Filter papers were placed in a muffle furnace at 500°C for one hour to remove any trace organic material from processing. Filters were then soaked in distilled, deionised, water for a minimum one hour to allow maximum swelling and loose fibres to detach, before oven-drying prior to use at 105°C for 12 hours.

A chromium reduction column was used to reduce nitrate, NO_3^- to nitrite (NO_2^-). The resulting chemical reaction creates a purple azo dye, which is measured using a light wavelength of 540 nm. Ammonium was also measured photometrically through FIA using a sodium hydroxide reagent and indicator solution. Reacting water and sodium hydroxide produces ammonia gas, which reacts with the indicator stock solution, resulting in a blue colour that can then be measured photometrically at a wavelength of 590 nm. To determine the orthophosphate concentration, the water samples were reacted with ammonium molybdate, which was then reduced to form phosphomolybdenum blue. The resultant blue solution was measured at a wavelength of 720 nm to establish the orthophosphate concentration. These samples were carried out with 10 mL of filtered water from each sample in glass test tubes that were washed in deionised water (DDW) and oven-dried to minimise contamination.

Total nitrogen and phosphorus were measured using an unfiltered 10 mL sub-sample in a two-stage digestion process. The first digest solution contained 2.5 mL of boric acid, sodium hydroxide, and peroxodisulphate and digested in an autoclave for 90 minutes. Samples were cooled, and then a second digest solution of 0.5 mL of 10 molal sulfuric acid was added to the samples, that were digested in an autoclave for a further 90 minutes. Upon cooling the samples were then analysed on a Lachet Instruments FIA system, using standard methods with an operational range of 0.08 ppb to 1000 ppb.

3.4.3 Escherichia coli (E. coli)

E. coli and total coliforms were determined using the most probable number (MPN) Colilert method. Within 24 hours of collection, the water samples were treated with the colilert reagent and mixed until the reagent is dissolved. The samples were placed in Quanti-trays and placed in an incubator at 35ºC for 18 hours. After incubation, the number of wells in each Quanti-tray were counted, where a positive total coliform was indicated by a colormetric response (yellow), and *E. coli* was indicated by an infrared fluorescence response.

Table 3.4: The operational ranges, accuracy, and precision of the FIA methods for NO_3^-, NH_4^+, PO_4^{3-}, TN and TP, the colilert method for E. coli, the loss on ignition method for POM and SSC, and the turbidimeter method for turbidity. Sources: (Heiri et al., 2001) (Bright et al., 2018).

Contaminant	Operating Range	Accuracy	Precision
NO_3^- (mg L^{-1})	0.0003 – 0.1	± 0.002	0.001
NH_4^+ (mg L^{-1})	0.01 – 4	± 0.02	0.009
PO_4^{3+} (mg L^{-1})	0.004 – 10	± 0.001	0.003
TN (mg L^{-1})	0.007 – 5	± 0.02	0.004
TP (mg L^{-1})	0.004 – 1	± 0.005	0.003
E. coli (CFU/100ml)	1 – 2419	± 27	9
SSC (mg L^{-1})	0.3 – 200	± 0.01	0.22
POM (mg L^{-1})	0.3 – 200	± 0.01	0.22
Turbidity (NTU)	0 – 1000	± 0.2	0.1

3.5 Interview protocol

The sampling technique used to interview participants was snowball sampling. Snowball sampling works by engaging with a gatekeeper or informant who acts as a connection, or gatekeeper to the rest of the informants, in the case of this research, the Waikaka Stream community (Henn, 2005). The technique allows the researcher to find others who fit the sampling requirements, to save time and energy, and ensure the informants meet the criteria (Kitchen and Tate, 2000). Snowball sampling was chosen because the research focuses on a specific catchment and community. The sampling technique allowed the researcher to gain access to the Waikaka community, in this case, using the Waikaka Stream Catchment Group co-chairman as the key link to the community. The chairman is embedded and lives in the community, and so has links to other members of the community for the researcher to tap into, along with contact details for the catchment group members,

To understand the thoughts, feelings, and opinions of the Waikaka Stream community, a systematic sampling approach was utilised alongside snowball sampling. This allowed the researcher to find participants who were varied in farming type, location in the catchment, age, and engagement with the community catchment group, while the availability of participants was also a practical consideration (Table 3.5). Multiple participants in the same household have been grouped as a singular participant, as their opinions aligned with each other, and their farming styles were shared.

Table 3.5: Farmer participant information, all names are pseudonyms, and ages are grouped to protect participant identity. Farms under 800 acres are classed as small, between 800 and 1200 acres classed as medium, and over 1200 acres classed as large.

Name	**Age Bracket**	**Farm type**	**Farm size**	**Length of time on farm**
Participant 1	40-44	Sheep and beef, dairy grazing	Medium	14 years (family farm)
Participant 2 (2 individuals)	55-59	Sheep	Large	Entire life
Participant 3	55-59	Dairy, beef	Medium	11 years
Participant 4	40-44	Sheep and beef, dairy and hoggart grazing	Small	4 years (family farm)
Participant 5 (2 individuals)	50-59	Sheep and beef	Large	27 years
Participant 6	55-59	Dairy	Small	26 years
Participant 7	35-39	Sheep and beef	Large	10 years (family farm)
Participant 8 (2 individuals)	55-64	Sheep and beef	Medium	21 years
Participant 9	55-59	Sheep and beef	Small	37 years (family farm)
Participant 10	65-69	Sheep, some cattle	Large	Entire life

The catchment group provided both key contacts, and a sampling frame to allow the researcher to approach participants who represent the community dynamics, according to the above criteria. Ten participants were contacted, who represent different community demographics and views. Seven of those are sheep and beef farmers, and three are dairy farmers, which is representative of the proportion of farm types in the catchment (Table 3.5). Participants also varied in age, so that perspective of young farmers could be compared to those who have been farming for a longer period, accounting for the fact that some had grown up in the catchment and others had moved into the catchment at a later stage (Table 3.5). The participants are spaced around the catchment, from the headwaters to the confluence with the Mataura River. Some farmers who had not engaged with the catchment group were interviewed to understand the barriers to community management and community engagement. Eight of ten participants interviewed had some form of involvement, allowing for an informed conversation around community catchment management. The location of farms in the catchment has not been included to maintain anonymity of participants.

Interviews were conducted with key community members, with questions aimed at understanding the water quality perceptions of the community. Understanding the community perceptions included the changes they notice in water quality, as those who observe it most closely, are most engaged with the stream. Interviews were also targeted at understanding the motivation of community members to join the Waikaka Stream Catchment Group, the local Water Management Board, newly formed in 2018. The aim of structuring the qualitative data collection in this way was to develop engagement between the community and the research. Engaging in a project such as this allows farmers to work to achieve outcomes that are both sustainable, and equitable (DeLyser and Sui, 2013). The research is designed to inform them, and then allow them to formulate their own way forward, so the entire management process is participatory, and managed by the community. Interviews were all conducted at the farms of participants and ranged from 30 to 60 minutes each. All interviews were audio-recorded with permission from participants. The semi-structured interview guide is in Appendix D.

3.5.1 Ethical practice

Category B ethics was obtained for this research from the University of Otago Human Ethics Committee (Non-Health), before contacting individuals and conducting interviews. The category B ethics form is in Appendix A. A major part of ethics considers a person's identity, and the research is conducted to maintain confidentiality and anonymity for all participants. Transparency is also vital to the research, to ensure there is no deception, or lack of clarity around the understanding of participating in this research (Henn, 2005). All participants signed consent forms once they had been provided with the project information to obtain informed consent. The participant information sheet and consent form are in Appendices B and C.

Māori consultation was undertaken to ensure permission to work in the Waikaka Stream Catchment. Māori consultation is an important ethical consideration, as it acknowledges the heritage of New Zealand, and obtains permission from the local runanga, which is in keeping with the culture of New Zealand, and the acknowledgement of Māori connection to, and of ownership of the land.

3.5.2 Positionality

Positionality allows the researcher to reflect on their personal position and views of research being conducted. An awareness of personal perspective is essential to acknowledge any inherent bias that might be present and passed on unintentionally to others (Milner, 2007). This project required a reflective assessment of positionality because a pre-existing relationship exists between the researcher and the members of the Waikaka community. The positionality of this research operated on two levels within the Waikaka community; the researcher spent their childhood interacting with individuals and groups in the Waikaka and surrounding communities, which creates a desire to maintain and achieve good outcomes for the catchment and community. Secondary to that personal catchment connection is the researcher's upbringing on a sheep and beef farm. That upbringing drives their own goals of working with the community to become more sustainable, maintaining the care already shown for the environment, developing the ethos of sustainable farming, and removing the negative stigma associated with agriculture. Being embedded in the community offers a rare opportunity to conduct research where a level of trust has already been established and provides an opportunity for the community to be involved in the research. It also offers an avenue for people who otherwise would not put themselves forward to be involved in research to comfortably do so, and thus creating a deeper community outreach level for the research scope. To ensure that the researcher did not bias the research, the purpose of the research was made clear to participants, and they were informed that the researcher would not share their opinion on any comments in subsequent interviews. Doing so ensured that the data collected from participants is true of the individual's opinions without being influenced by the researcher's own opinions. When processing the results from interviews, neutrality must be maintained to gain an accurate picture of the social setting around the Waikaka Catchment, and the opinions of the local community. To achieve this, interview data were processed using aliases for each participant to ensure as best as possible that the data was treated independently of the researcher's own knowledge of participants and their views and opinions that came through interviews.

3.6 Data analysis

3.6.1 Quantitative analysis

All water quality data was analysed using the medians due to the non-parametric nature of the data (Rode and Suhr, 2007). Spatial trends were the focus of statistical analysis, while temporal data was used to account for seasonal variation and assume true annual medians across each site. Basic statistics were calculated for each water quality variable, and the variables focused on were particulate organic matter (POM), suspended sediment concentration (SSC), total suspended material (TSM), total coliforms, *E. coli,* total nitrogen (TN), nitrate–nitrogen (NO_3), ammoniacal nitrogen (NH_4^+), total phosphorus (TP), dissolved reactive phosphorus (DRP), and turbidity. Kendall's correlations were conducted between all variables due to the nonparametric nature of the data using ICM SPSS Statistics 25.0. Mann-Kendall trend analysis was carried out on Environment Southland data to establish trends in water quality over the past 25 years, using macro code within Minitab v. 16.

A water quality index was calculated following the CCME Water Quality Index User's Manual from the Canadian Water Quality Guidelines for the Protection of Aquatic Life (Saffran et al., 2001). The overall index was calculated to give a score for the Waikaka Stream as a whole, while indices were also calculated for each individual site for comparison purposes. Each site is classed according to its overall score (Table 3.6).

Table 3.6: Water Quality Index values and categories (Saffran et al., 2001).

Water Quality Categories	**WQI Value**
Excellent	95-100
Good	80-94
Fair	65-79
Marginal	45-64
Poor	0-44

Both hierarchical cluster analysis (HCA) and principle component analysis (PCA) were conducted for this study. Nine variables were used for HCA to categorise sampling sites into four major clusters based on water quality variables (SSC, TSM, Turbidity (NTU), TN, TP, NO_3, NH_4^+, DRP, and *E. coli*). The same variables were used in PCA, along with the HCA clusters, to identify the key characteristics of each cluster in terms of their water quality profile. Discriminate analysis was also conducted on the same variables to assess if there were any underlying factors, such as geology, soil type, or physiographic zone that could explain the variation in water quality indicators across the Waikaka Stream. No significant clusters were found from discriminate analysis and have been excluded from further consideration in the thesis.

Several variables (TSM, SSC, POM, turbidity – NTU, and FNU) that describe sediment and optical properties of water were measured at each site. To simplify the results, turbidity as measured in NTU was used as the surrogate indicator of sediment concentration. Turbidity measured in NTU was more sensitive to the presence of organic material than FNU and deemed a better sediment proxy for the Waikaka Stream which consists of high POM concentrations (Bright et al., 2018). In the context of the Waikaka Stream, TSM and SSC directly correlate to turbidity although the correlation is noisy (See Appendix F). The results will therefore focus on turbidity as the indicator of land use disturbance, while TSM and SSC have been included in wider analysis and their trends discussed.

3.6.2 Qualitative analysis

Interviews with key informants were transcribed from audio recordings. Information was sorted into key topics, or themes, according to separate research aims, whether existing or emerging based on interview content. The major discussion points and obvious themes that emerged from interviews were water quality perceptions, farm management, environmental management and the catchment groups, and wider farmer attitudes (Table 3.7). Within these broad themes exist sub-themes, or codes to further break down the information to sizeable and logical sections. For example, the management and catchment group section has been broken down into broader management of the stream, catchment group formation and motivations, catchment group usefulness, challenges for catchment groups, and future directions for community groups such as the Waikaka Stream Catchment Group.

Table 3.7: Key codes that were used to sort qualitative information, with a breakdown of the sub-themes that fitted within each code.

Broad Topic Codes	**Subtopics**
Water quality perceptions	Identified water quality issues
	Perceptions from sensory aspects
	Change over time
Farm management practices	Good practices
	Bad practices
	Longevity of practices
	Contaminant source areas
	Philosophy of management
Change in the region	Physical changes and management changes
	Shift in farmer thinking
Water management	Issues with current governance and management
	Community management
	Relationship with regional government (Environment Southland)
Waikaka Catchment Group	Motivation for formation
	Usefulness
	Future directions
	Challenges
Farmer attitude and mindset	Interest in, and attitude to water quality
	Effort from farmers
	Local knowledge
	Generational differences
Farmer negativity	Negativity felt from urban populations and media
	Farming type clashes (sheep and dairy)
Wider application	Future of the Waikaka Stream
	Comparison to other regions

3.7 Summary

The approach of this study was to use a socio-hydrology lens to gain an understanding of freshwater of the Waikaka Stream, using both quantitative and qualitative data. Water sampling techniques were used to provide insight into the spatial variation of water quality, while participant interviews were completed to expand water quality results and understand the local community perceptions associated with the Waikaka Stream. Interviews also provided knowledge of the newly catchment group, gauging perspectives from a diverse range of farmers to understand the perspectives of different demographics within the catchment. The following chapter presents the quantitative and qualitative results that address the research aims outlined in Chapter 1.

4 Results

The quantitative and qualitative findings of this study are described in this chapter, using a socio-hydrology lens based on one year of monthly water sampling, and 10 semi-structured interviews with farmers in the catchment. The chapter will first describe the overall trends of the Waikaka Stream water quality in Section 4.1. This section displays the overall water quality index results, as well as cluster analysis used to identify sites of poor water quality, and the potential causes of increased concentrations of contaminants. Community water quality perceptions are outlined in Section 4.2, alongside farmer knowledge relating to farm management practice and identified agricultural contaminant sources in Section 4.3. Section 4.4 presents the results of farmer interviews of the formation of a community catchment group in the Waikaka Stream, including the key motivations for involvement in such a group, and future challenges and direction for the group. The final section (4.5) refers to the shift in farmer thinking over time, a clear theme that appeared through farmer interviews. These results are summarised at the conclusion of the chapter to lead into discussion points in Chapter 5.

4.1 Waikaka Stream water quality trends

The water quality data exhibited non-parametric distributions, which is typical of hydrological data. The stream also demonstrated notable spatial variation in key water quality indicators, suggesting the catchment does not see uniform concentrations of contaminants at all sites. Total coliforms and *Escherichia coli (E. coli)* showed high variation, with large confidence intervals, standard deviations, and interquartile ranges (Table 4.1). Nutrients showed less variation, with much lower extreme values (maximums), and lower interquartile ranges. The high maximum concentrations recorded suggest that the stream has the capacity to yield concentrations much higher than the measured medians, likely under high flow conditions. The variation observed of key water quality variables indicates that the overall median values for the Waikaka Stream does not be fully represent the catchment's spatial diversity, suggesting that median values are useful as indicators, but less beneficial for investigating localised water quality issues.

Table 4.1: Descriptive statistics for each variable (overall across the catchment using 192 observations, not per site). Variables displayed are particulate organic matter (POM), suspended sediment concentration (SSC), total suspended material (TSM), turbidity in units of NTU, total coliforms (TC), E. coli. total nitrogen (TN), nitrate (NO_3), ammonia (NH_4^+), total phosphorus (TP) and dissolved reactive phosphorus (DRP). Medians and means that exceed regulatory thresholds are bolded.

Variable	POM	SSC	TSM	Turbidity	TC	E. coli	TN	NO_3	NH_4^+	TP	DRP
Units		(mg $^{-1}$)		(NTU)	(CFU/100ml)		ppm			ppb	
Mean	2.9	**7.3**	10.3	4.0	1195	**560**	0.96	0.62	**37**	**62**	**21**
Median	2.8	**6.1**	9.1	3.6	921	**291**	0.90	0.57	**36**	**51**	18
Min	0.4	0.1	0.8	0.9	120	30	0.31	0.01	0	12	5
Max	9.7	32.4	42.1	12.8	2420	2420	2.98	2.31	200	243	121
Interquartile Range	1.6	5.3	5.2	1.8	1972	531	0.67	0.67	28	37	13
Standard Deviation	1.4	5.2	6.0	1.6	842	652	0.50	0.50	28	38	14
Confidence Interval	(2.6, 3.0)	(5.4, 6.8)	(8.3, 9.9)	(3.4, 3.8)	(764, 1078)	(170, 412)	(0.83, 0.97)	(0.50, 0.64)	(32, 40)	(46, 56)	(16, 20)

The sites further from the confluence of the Waikaka Stream and the Mataura River (those closer to the stream headwaters) showed a larger range in sediment indicators and bacteria measurements than the lower sites in the catchment (Table 4.2, Figure 4.1). The site 59.6 km from the confluence showed the highest total coliforms and *E. coli* levels at 2419.6 CFU/100 mL and 980.4 CFU/100 mL respectively. The headwaters also measure the highest TSM concentration, at 10.8 mg L^{-1}, indicating that the headwaters observe hotspots of contaminants that the lower reaches do not. Main stem sites lower in the catchment show gradual increasing trends in nutrients (Table 4.2). The levels of nutrients are more standard across the entire catchment and show gradual increasing trends downstream throughout the catchment.

Table 4.2:Median values for key variable at each site in the catchment. Variables displayed are suspended sediment concentration (SSC), total suspended material (TSM), total coliforms (TC), E. coli, total nitrogen (TN), nitrate (NO_3), total phosphorus (TP), dissolved reactive phosphorus (DRP) and turbidity in units of FNU. Sites located on the main stem of the Waikaka Stream are indicated by grey highlight. Other sites are located on various tributaries. Variables that exceed the regulatory thresholds are bolded.

Site Number	**Distance (km) from Confluence**	**SSC**	**TSM**	**TC**	***E. coli***	**TN**	**NO_3**	**TP**	**DRP**	**Turbidity**
		(mg L^{-1})		**(CFU/100ml)**		**(ppm)**		**ppb**		**(NTU)**
1	59.6	**10.8**	12.9	2420	**980**	0.65	0.37	35	17	2.5
2	52.2	**6.5**	10.2	921	225	0.51	0.34	31	13	3.6
3	40.5	**6.4**	8.5	1414	**488**	0.69	0.46	31	11	3.6
4	33.7	**10.7**	13.9	2420	**1414**	**1.02**	0.77	**50**	18	5.4
5	26.9	**6.0**	9.0	980	194	**1.03**	0.69	**57**	**21**	3.7
6	27.0	**5.7**	8.4	1046	179	**1.10**	0.59	**72**	18	3.8
7	27.7	**5.2**	8.4	866	166	0.65	0.52	33	12	3.6
8	22.1	**7.8**	10.3	1046	**308**	**1.16**	0.65	**76**	**30**	3.9
9	21.1	**5.2**	8.3	687	179	0.91	0.56	**58**	**22**	3.6
10	21.5	**7.0**	10.6	687	126	**1.01**	0.41	**108**	**31**	3.7
11	18.4	**4.6**	7.4	727	210	0.79	0.47	44	13	3.3
12	13.0	**5.8**	8.3	675	176	0.97	0.65	46	16	3.1
13	12.9	**4.0**	7.9	1733	**333**	**1.16**	0.54	**94**	**28**	3.5
14	6.2	**7.8**	11.4	1046	**361**	**1.23**	0.84	**69**	**24**	**5.3**
15	6.2	**5.2**	7.3	687	248	0.96	0.65	**58**	18	3.2
16	0.4	**6.6**	9.4	461	172	**1.03**	0.65	**56**	19	3.7
Environment Southland Monitoring Site[2]		**6.6**	-	461	172	**1.0**	0.7	**56**	19	3.7
Regulatory Thresholds[3]		2.5	-	-	260 (alert level)	1	1	50	21	5

[2] Environment Southland records measure water quality variables through event flow, and so have been adjusted to reflect the measurements taken at base flow (See Appendix H for unadjusted water quality measurements).

[3] Note that current regulatory thresholds are difficult to derive due to changing guidance documents and ongoing consultation. The thresholds here are derived from the NPSFM NOF Band A for nitrate, and thresholds used in MfE reporting of ANZ Guidelines (2018) but are subject to ongoing regulation changes.

The Environment Southland (ES) monitoring site is located proximal to the final site in this study, at 0.4 km above the confluence of the Waikaka Stream and the Mataura River. The highest concentrations of each water quality indicator were observed at different locations in the catchment, indicating that the key water quality variables are influenced by different factors within the Waikaka Catchment. The highest recorded total suspended material measurement of 12.93 mg L^{-1} was in the headwaters. Total coliforms and *E. coli* levels were both high in the stream headwaters, equivalent to 2420 CFU/100ml[4] and 980 CFU/100ml respectively (Table 4.2). Fifty percent of the measurements were above the alert level limit specified by the NPSFM management, and these results were located predominantly at the top end of the catchment (Table 4.2). Total nitrogen concentrations peaked at 1.23 ppm 6.2 km above the confluence, while nitrate peaked at 0.84 ppm at the same site (Table 4.2). The highest total phosphorus concentration was 108.1 ppb, recorded 21.5 km upstream of the confluence, while the highest DRP measurement of 31.06 ppm was recorded at the same site (Table 4.2). The highest turbidity measurement of 5.44 NTU was measured mid-way down the catchment at 33.7km from the confluence. The difference between the turbidity results of this study and the Environment Southland findings are likely a function of different precision between turbidity measurement instruments (Davies-Colley and Smith, 2001).

[4] The colilert method, without dilution saturates at 2420 CFU/100ml so values are right centred (ie. cut off) beyond this point. Any value of 2420 is a minimum and concentration of total coliforms could be considerably greater.

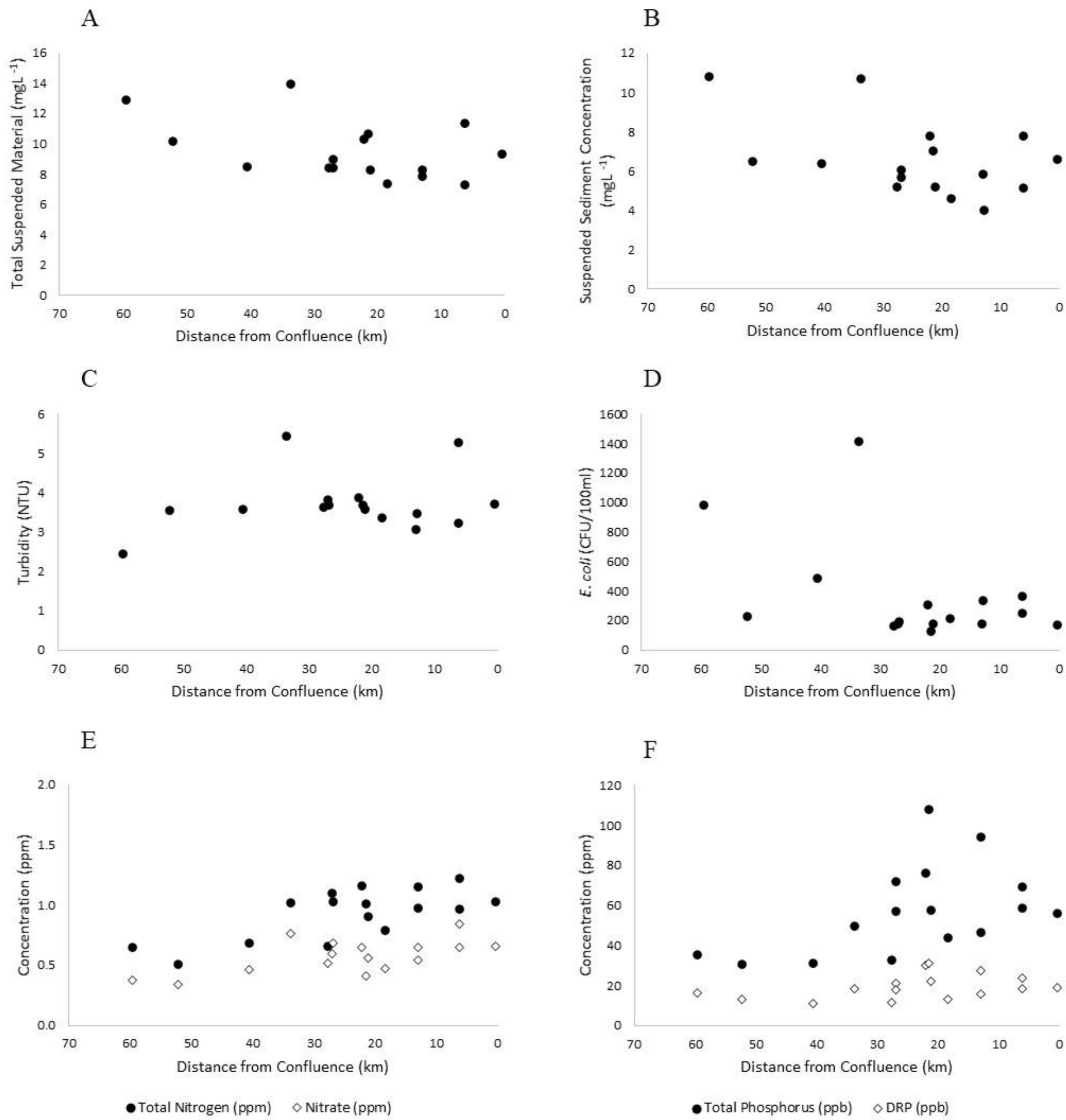

Figure 4.1: Shows the distance spread of the concentrations of measured water quality variables A) total suspended material B) suspended sediment concentration C) turbidity D) E. coli E) total nitrogen and nitrate F) total phosphorus and dissolved reactive phosphorus.

The water quality trends differed based on the variable due to different sources and transport pathways. Sediment indicators (TSM, SSC, and turbidity) observed higher values in the headwaters of the catchment, apart from turbidity with its lowest measured point in the headwaters (Figure 4.1, Figure 4.2). POM explains on average, 30% of TSM in the Waikaka Catchment, contributing to high turbidity measurements. The *E.coli* and total coliforms trends are more sporadic in the stream, but do decrease downstream, like the sediment variables (Figure 4.1, Figure 4.2). *E. coli* showed much higher levels in the headwaters of the Waikaka Stream, and the Little Waikaka (Waikaka East) (Figure 4.2). Nitrogen and nitrate trends showed an increase further down the catchment. Phosphorus variables showed the same increasing trend across the catchment, where concentrations were higher in the lower reaches of the stream, closer to its confluence (Figure 4.1, Figure 4.2).

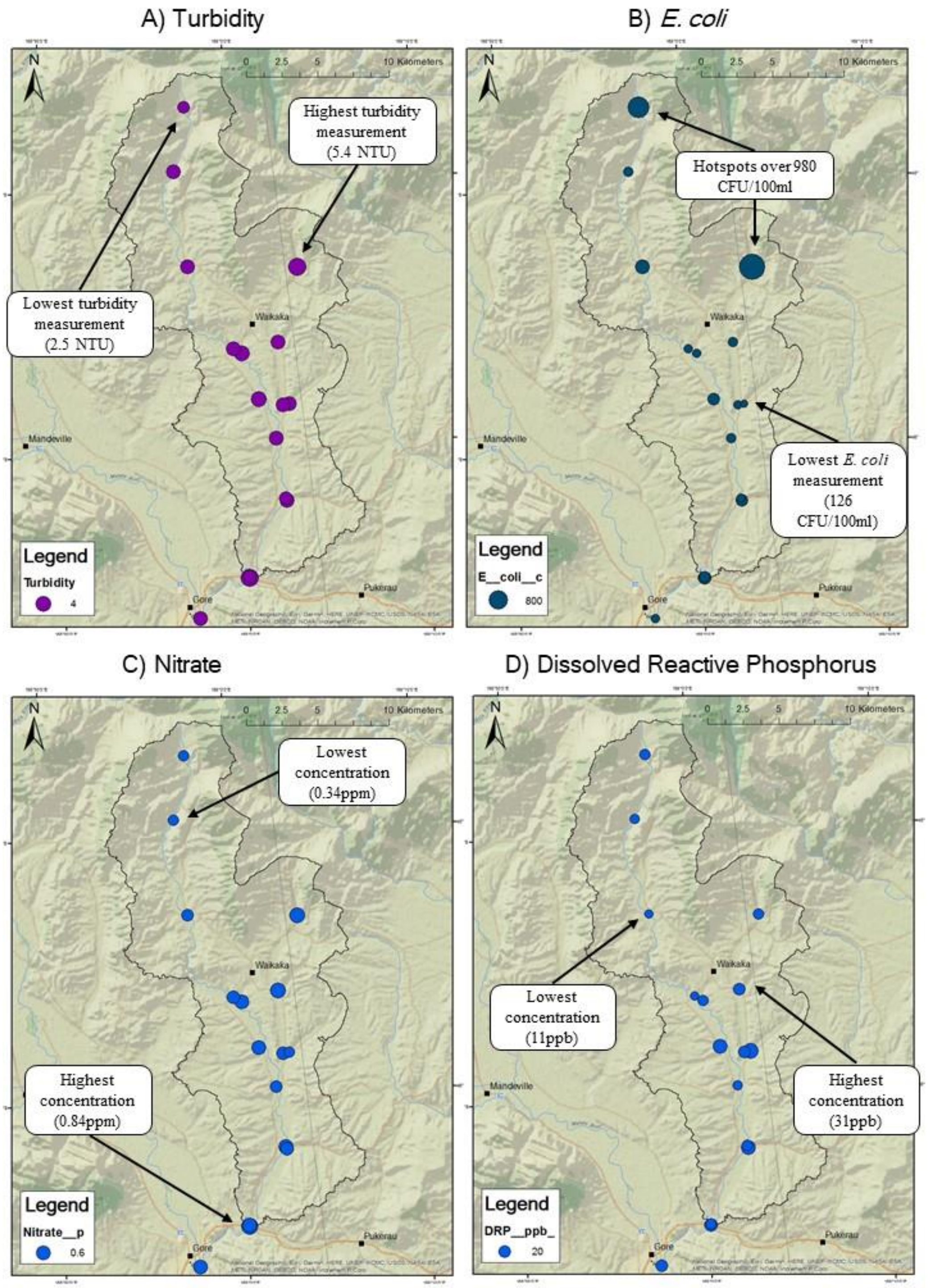

Figure 4.2:Maps showing the Waikaka Stream and key water quality variables on a spatial scale within the catchment. Variables shown are A) turbidity B) E. coli C) nitrate and D) dissolved reactive phosphorus. Dot sizes are proportional to concentration of variables, and the highest and lowest measurements are annotated.

The Waikaka Stream has been monitored by Environment Southland since 1995, with more variables being added between then and present-day recording, including a macroinvertebrate community index. The long-term trends have been calculated using a Mann-Kendall trend analysis, to establish the overall trend for water quality variables in the Waikaka Stream. Three variables showed no significant trend over the duration of their recording (Table 4.3). One of these was suspended sediment concentration, which has the shortest record of four years. Turbidity matches this record of no trend, indicating no significant increase or decrease over the 20 years of turbidity records (Table 4.3). Faecal coliforms overall were found to be decreasing over the 20 years, while *E. coli* was observed to have no significant trend over that time, indicating that *E. coli* levels in the Waikaka Stream are improving, or stable. Total nitrogen and nitrate were increasing, so even though ammonia is decreasing over time, nitrogen trends are still poor for the stream. Total phosphorus showed an increasing temporal trend, however dissolved reactive phosphorus is the concerning part of phosphorus to freshwater, and the DRP trend was decreasing. This indicates that the phosphorus levels are improving in the Waikaka Stream.

Table 4.3: Waikaka Stream long term water quality trends, using Environment Southland data dating back to 1995. Trends were determined using Mann-Kendall trend analysis with a significance level of 0.05. A decreasing trend indicates an improvement in water quality, and an increasing trend indicates deteriorating water quality.

Water Quality Variable	**Years of Record**	**Trend**
Suspended sediment concentration	4 years (From 2015)	No trend
Turbidity	20 years (From 1999)	No trend
Faecal coliforms	20 years (From 1999)	Decreasing trend
E. coli	20 years (From 1999)	No trend
Total nitrogen	21 years (From 1998)	Increasing trend
Nitrate	13 years (From 2006)	Increasing trend
Ammonia	24 years (From 1995)	Decreasing trend
Total phosphorus	21 years (From 1998)	Increasing trend
Dissolved reactive phosphorus	24 years (From 1995)	Decreasing trend

4.1.1Water Quality Index

A water quality index (WQI) was calculated based on eight measured variables that have threshold limits used in a WQI calculation: suspended sediment concentration (SSC); *E. coli*; total nitrogen; nitrate; ammonia; total phosphorus; dissolved reactive phosphorus; and turbidity. The WQI offers a summary of the overall water quality at an individual location, with 0 as the poorest and 100 as the best quality. The Waikaka Catchment had a WQI of 26.6, characterising the stream as having poor water quality (Table 4.4). The WQI was also applied to each sampling site to build a spatial picture of water quality in the stream. The overall WQI trend, although very shallow, is decreasing, where the upper catchment has a higher water quality index than lower down (Figure 4.3). However, all sites except site 2 are ranked as 'poor', as the WQI is below 44 (Table 4.4). The highest WQI of 45.4 is observed at site 2 placing it in the 'marginal' water quality class, and the lowest WQI of 19.1 was calculated at site 14, giving a range in WQI of 26 (Table 4.4).

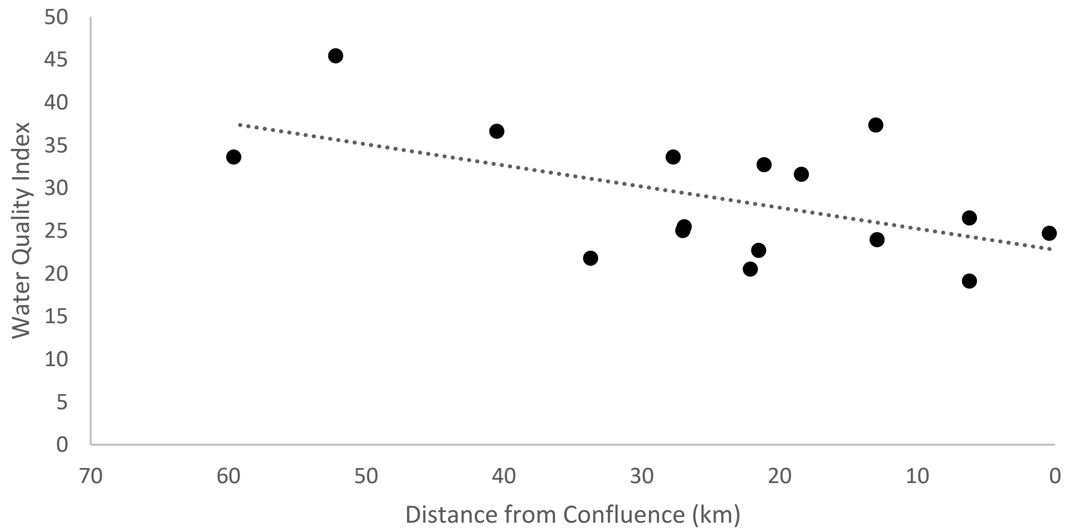

Figure 4.3: Scatterplot of the Water Quality Index throughout the Waikaka Stream.

Table 4.4: Water Quality Indices for each site, sorted according to the nature of sites, whether they are on the main stem of the Waikaka Stream, or tributaries. All sites are 'poor' apart from site 2, as their WQI is below 44.

Main Stem Sites		**Tributary Sites**	
Site & Distance from Confluence (km)	WQI	Site & Distance from Confluence (km)	WQI
1 (59.6)	33.6	4 (33.7)	21.8
2 (52.2)	45.4	5 (26.9)	25.4
3 (40.5)	40.5	6 (27.0)	25.9
7 (27.7)	33.6	8 (22.1)	20.5
11 (18.4)	31.6	9 (21.1)	32.7
12 (13.0)	37.3	10 (21.5)	22.7
15 (6.2)	26.5	13 (12.9)	23.9
16 (0.4)	24.7	14 (6.2)	19.1

The calculated WQI observed a changing profile over time. The stream in winter months had a lower WQI than in spring and summer, except for December with a low WQI of 23.9 (Figure 4.4). The lowest WQI is in May with a measurement of 15.5. All months are determined to be in the 'poor' range of water quality. April saw the highest overall water quality, with a WQI of 56.6, making it the only month with 'marginal' water quality rather than poor (Figure 4.4). These trends are consistent with management practice, as the most intensive period for farming is in winter, with winter grazing and cultivation practices. The low value in December is an anomaly within the data, which could be due to the weather, where it was abnormally wet compared to a normal year. Therefore, although there is variation across a temporal scale, the stream still proves to be consistently in the poor category of water quality based on the current guidelines and variables measured.

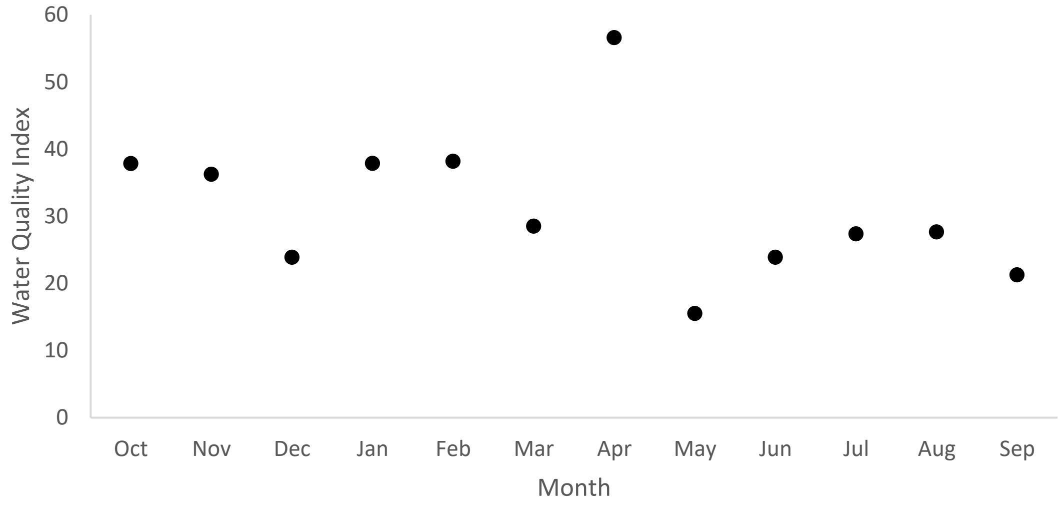

Figure 4.4:The Water Quality Index in the Waikaka Stream over a year period, from October of 2018, to September of 2019.

4.1.2 Evaluation of co-migrants and landscape influences on water quality indicators

Weak positive correlations were determined between multiple water quality variables across the catchment. Total nitrogen concentrations were correlated with *E. coli* levels, with a coefficient of 0.164 (Table 4.5). *E. coli* and turbidity are also linked through a Kendall's correlation coefficient of 0.197 (Table 4.5). A Kendall's correlation coefficient of 0.103 determined a correlation between dissolved reactive phosphorus, and suspended sediment concentration. The weak correlations indicate that the variables' behaviour depends on multiple other variables outside those with significant correlations identified. The positive correlations indicate that as one variable increases, so too does the other (See Appendix F).

Table 4.5: Correlation results from significant correlations between water quality variables.

Correlation Variables	**Kendall's Correlation Coefficient**	**Significance (P value)**	**Number of Samples**
TN and *E. coli*	0.164	0.01	117
DRP and TSM	0.103	0.35	192
E. coli and Turbidity (FNU)	0.197	0.00	117

Four different clusters were identified through hierarchical cluster analysis, based on the water quality indicators measured at each site (Figure 4.5). Sites 1 and 4 are a cluster most dissimilar from the others, as they have the greatest distance link at 25. The next cluster comprised sites 3 and 13, at a distance link of 5. The other two clusters are larger and more similar. Cluster 3 consists of sites 2, 5, 6, 7, 8, and 14, while cluster 4 consists of sites 9, 10, 11, 12, 15, and 16. These clusters are not explained by any one of the underlying physical characteristics (geology, soil type, physiographic zone) of the land at each site (See Appendix G).

Cluster 1 has high concentrations of suspended material, as well as the high concentrations of total coliforms and *E. coli* compared to other clusters (Table 4.6). Cluster 2 and 3 show mid-range concentrations of *E. coli* and total coliforms, where cluster 4 shows very low concentrations. Cluster 2 is characterised by very low turbidity and suspended material (Table 4.6). Cluster 2 also shows low nitrate concentrations compared to the other three clusters. Cluster 3 and 4 are very similar, but cluster 3 shows higher concentrations of total phosphorus, and dissolved reactive phosphorus, while cluster 4 shows higher concentrations of nitrate (Table 4.6). The characteristics of the clusters link to instream properties, which underlying properties contribute to, alongside the land use in the catchment (Table 4.6).

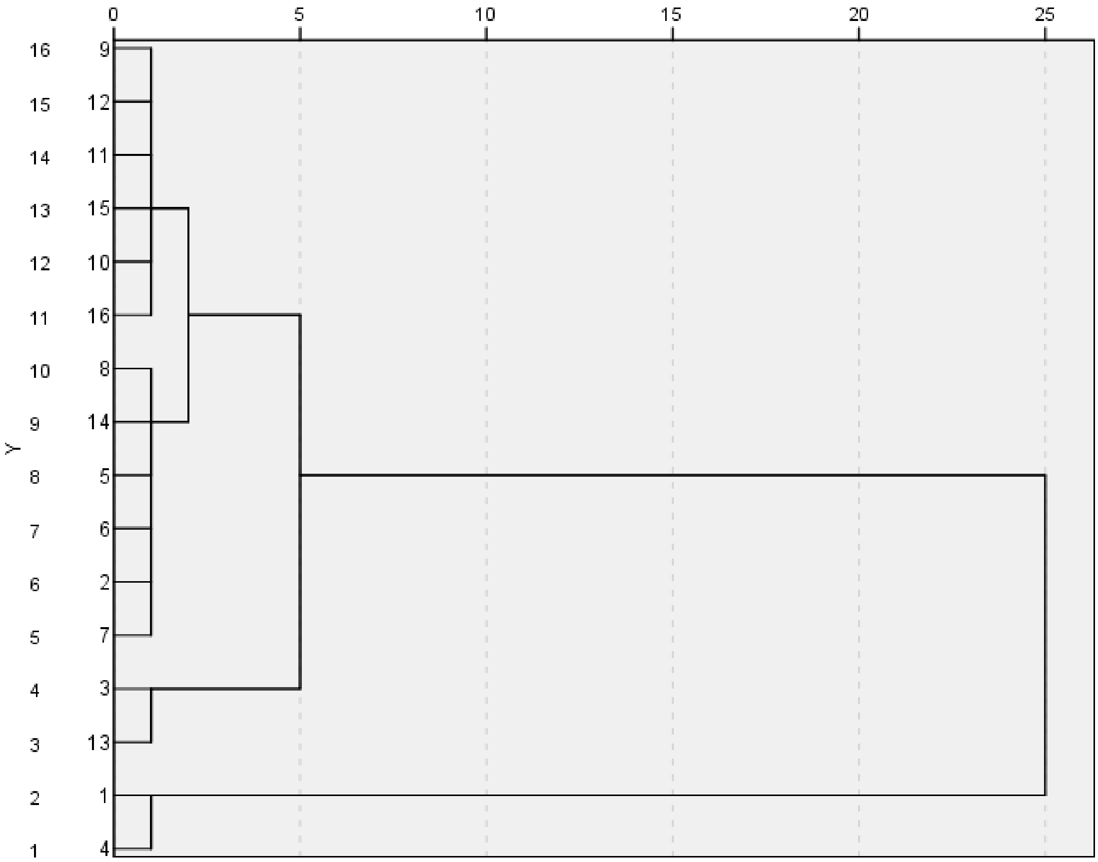

Figure 4.5: Dendrogram output of hierarchical cluster analysis, showing the distance linkages between sites using Ward's method.

Table 4.6: Characteristics of the four clusters identified by hierarchical cluster analysis, alongside interpretation of the cluster overall.

Cluster	Characterisation	Interpretation
1 (Site 1 and 4)	High TSM High TC and *E. coli* Low ammonia Low TP	Sites are in the headwaters of the Waikaka Stream, and the Waikaka East Hotspots of sediment, but low nutrient concentrations
2 (Site 3 and 13)	Low TSM Very low turbidity Mid-range TC and *E. coli* Low nitrate	Main stem sites Higher volumes of water than other sites All variables are low indicating a dilution effect
3 (Sites 2, 5, 6, 7, 8 and 14)	Relatively low turbidity Mid to low TC and *E. coli* Some high nitrates Higher TP and DRP	Sites are predominantly in the midlands of the catchment Separated from Cluster 4 by high phosphorus concentrations
4 (Sites 9, 10, 11, 12, 15, 16)	Relatively low turbidity Low TC and *E. coli* High nitrates Some high TP and DRP	Sites are predominantly in the lowlands of the catchment Separated from Cluster 3 by high nitrogen concentrations

Principal component analysis identified two components. All nutrients have been grouped into one component, including total nitrogen, total phosphorus, dissolved reactive phosphorus, ammonia and nitrate, suggesting they are similar (Figure 4.6). The downstream trend of these variables is also similar, showing a gradual increase downstream, and indicating that their sources and behaviours are similar, thus resulting in the same cumulative trend (Figure 4.6). The other strong showing component consists of total suspended material, *E. coli,* total coliforms, suspended sediment concentration, turbidity, and particulate organic matter (Figure 4.6). These variables also show similar trends to each other, as they show higher concentrations as hotspots in the upper reaches of the catchment, while the lower reaches have lower concentrations, indicating possible transport or source links between *E. coli* and sediment (Figure 4.6).

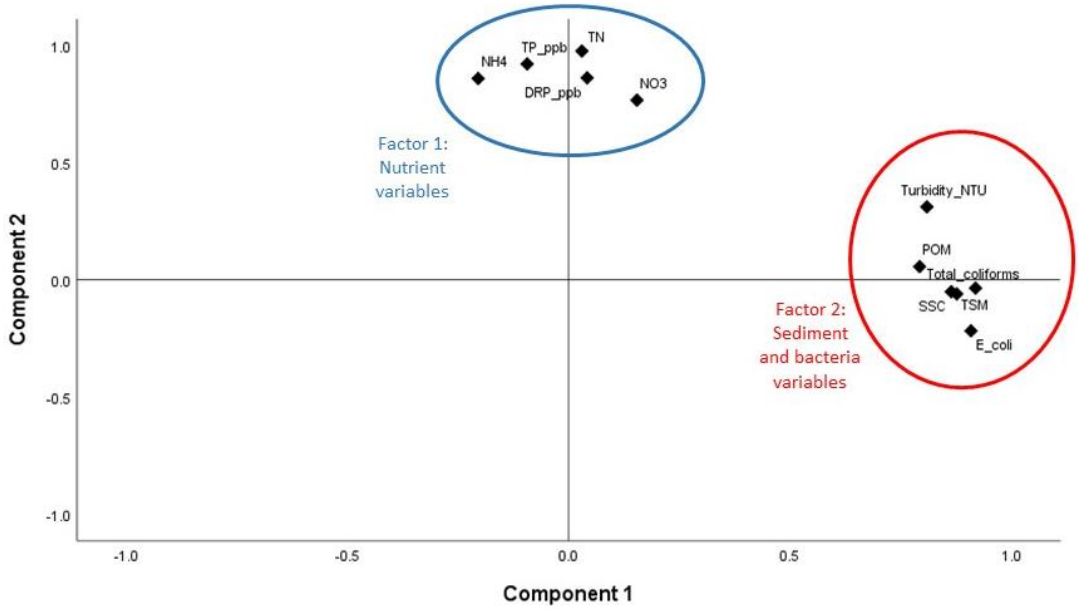

Figure 4.6: Component plot in rotated space, identifying the key components of each cluster (result of PCA)

4.1.3 Summary of quantitative results

The Waikaka Catchment exhibits some clear water quality challenges, and shows significant variability longitudinally, resulting in different hot spots for the key water quality variables measured, namely *E. coli* and sediment concentrations. Nutrient variables follow the same trend decreasing downstream, while *E. coli* and sediment variables are also related to each other and show an overall increasing trend downstream. The Water Quality Index indicates that the water quality is in a poor state overall. The following section describes the qualitative results outlining the farming community perceptions of water quality and management in the catchment. Local knowledge findings revealed in key informant interviews will also be summarized, alongside the motivations of the Waikaka Stream Catchment Group.

4.2 Water quality perception results

Key informants provided their perspective on the local water quality of the Waikaka Stream. Their observations are based on intrinsic characteristics, including the smell and view of the river, as well as the surrounding bank area. Eight of ten informants described the water quality as “quite good”, identifying that it was not perfect, but was “not too bad”. The water clarity was observed to be “very good”. Aquatic life was noticed by most participants, who said fish numbers were high, and the stream was full of bugs, and other life (Table 4.7). The macroinvertebrate index for the Waikaka Catchment deems the stream to be ‘fair’, supporting the stream health observations of farmers in the community (StatsNZ, 2020). Participants noted that the river does not smell unpleasant at any point, and the weeds in most sections are negligible (Table 4.7). The lack of side effects that occur from poor water quality gave the locals the impression that the Waikaka Stream water quality was good. This perception is different from the Environment Southland results according to current freshwater variable thresholds (Table 4.2). Issues that were identified by participants include sediment and gravel build up in certain areas, slime on the rocks, mainly in low flows, and potential high nutrient levels. Several participants also identified and acknowledged that there may be both nutrient and *E. coli* issues, particularly nitrogen and *E. coli.* Most participants said they noticed no significant changes in the Waikaka Stream over time, despite measured changes in water quality over time. The river was said to have naturally fluctuated with climatic changes, but no changes were outlined to be long term. Participants identified that seasonal changes were observed yearly because of natural processes (Table 4.7). Most participants stated that the stream was part of their daily surroundings, and as such they did not take much notice of it day to day. Participants have increased their awareness of the stream state in more recent years than they had previously. Participant 7 stated that their children play in the stream, hunting for wildlife and swimming in the deeper sections, and so they regularly encounter, and notice the state of the water.

Table 4.7: Participants direct observations of the streams, with supporting quotes.

Observation	Quote
Consistent seasonal changes	"Well yeah it does change, but it's no different to what it used to be when I was a kid… I think it's more the climatic conditions, more than anything if the river gets low. When people start going on about the quality of the river (saying it) is not that good, they must be checking it after a major rainfall, like the water gets dirty, no different to what it used to be" - Participant 8
Aquatic life in the stream	"You know there's a lot of trout in it" - Participant 3 "There's plenty of things for the kids to go and find when they wanna go looking in the creeks and stuff" - Participant 7
Clear water	"The river that runs through there majority of the time is clear" - Participant 3
Would swim in the water	"If the creeks were big enough, I wouldn't hesitate to go for a swim" - Participant 7 "When it gets low, like we swim in it and that kids are always in it during the summer and that sort of thing" - Participant 4 "I tend to think there's more fish in the Waikaka Stream, cause like I see them all the time, like I farm alongside the stream and take a strong interest in it, so there's more fish in the stream than there have been" - Participant 6
No smell	"It never gets stagnant or that, doesn't smell or anything like that" - Participant 4
Would drink the water	"I would drink it yeah" - Participant 10 "I reckon it's (water quality) excellent… I drink out of the creeks" - Participant 5

4.3 Farmer knowledge

4.3.1 Changes over time

All farmer participants had noticed physical changes in their time farming in the catchment. All cited the transition to more intensive farming, and large shift from sheep to dairy farming as a key driver of land use change in the past 10 to 15 years. The Waikaka Catchment has seen a lower increase in dairy compared to other areas in Southland. In all types of farming stocking rates have increased, as has wintering in the catchment, as outlined by Participant 6 “There’s definitely been more wintering in the catchment, and that would affect either my river or my creek”. More recently, farming in the area has become slightly less intensive as technology and genetic breeding has developed. These developments allow for a lower stocking rate as productivity can be enhanced by technology, rather than by increased stock numbers. Many participants said that although changes have been observed, the change in their own farming style was minimal, and their properties were operating much the same as they had been their entire farming careers.

4.3.2 Farm management practices

Participants identified that the water quality is a direct result of land management. Between all participants, there was an extensive list of practices identified, both good and detrimental for water quality. The most discussed practice was cultivation, followed by winter grazing practices. Many participants thought that improving cultivation and winter grazing would make the most difference to the local water quality, along with measures such as buffer strips and sediment traps. Many different practices were discussed, and all participants identified things that could be done better to improve water quality, many of which were outlined in their farm environment plans, which 9 out of 10 participants had (Figure 4.7).

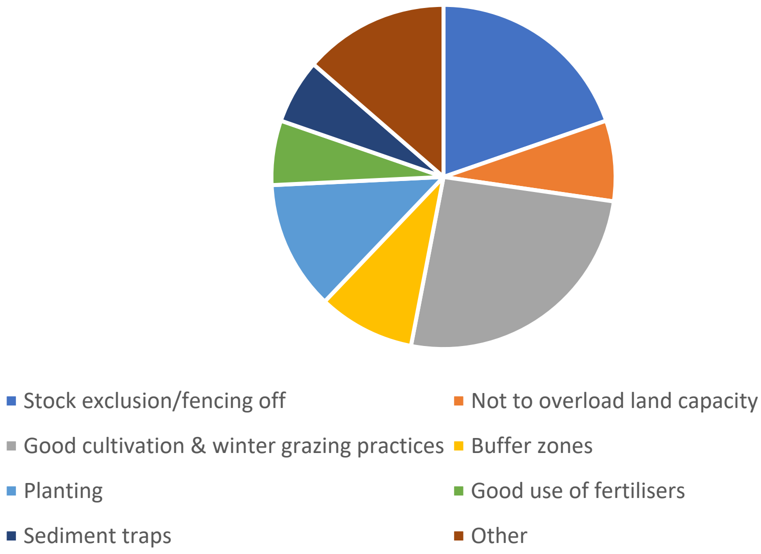

Figure 4.7: Good management practices identified by participants.

The expanse of good management practices identified shows that farmer participants are aware of what good farm management is. All participants had steps to implement many practices on their own properties, following the guidelines of regional authority Environment Southland, and industry groups such as Beef and Lamb NZ. Many farmers had further plans and future measures to reduce the impact on water quality from their farming practice. These practices have been implemented gradually, and the water quality of the Waikaka Stream has changed gradually, if at all, rather than showing dramatic improvement. The gradual nature of agricultural pollutants means that trends are gradual and slow changing (see Appendix I).

Participants identified some practices as being implemented by farmers very recently. These included the introduction of buffer zones around waterways, resulting in movement of fences and winter grazing structures. All wet areas are now fenced off by farmers, where they used to be left mostly open to stock. Cultivation practices were identified as seeing the most change to traditional cultivation techniques in recent years. For example, groundwork was always done starting at the bottom of a paddock and of a slope, where now that is reversed, and work begins at the top and works down.

4.3.3 Contaminant source areas

Participants were able to identify a range of source areas, both in general and specific to their own property (Figure 4.8). Steep areas and slopes were the most common discussed contaminant source areas, as most properties had rolling or steeper terrain, so most contained some slopes, if not steeper hills. The identification of contaminant source areas shows that farmers are aware of their problem areas, and of the transport pathways for contaminants in water.

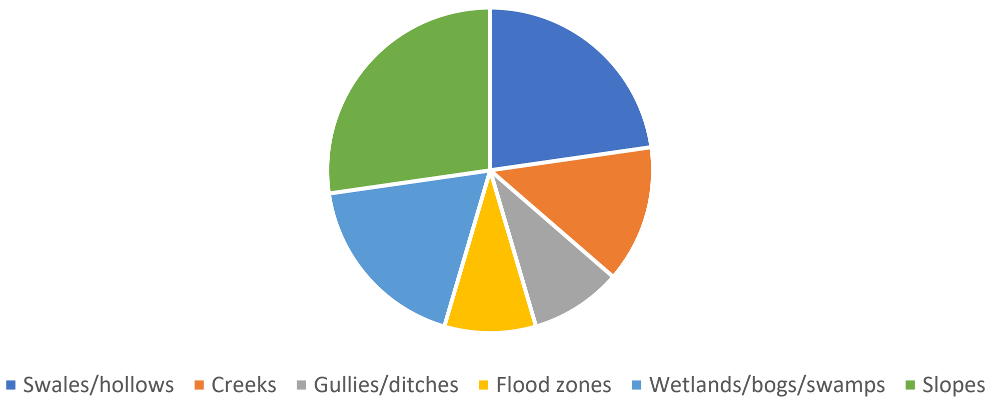

Figure 4.8: Contaminant source areas identified by participants.

4.4 Catchment group formation

The Waikaka Stream Catchment Group was officially formed in the winter of 2018, when co-chairs were appointed by the farming community. Since then the group has been evolving and developing, to building a working committee, and hosting workshops and speakers in the local district. Participants had varying levels of engagement with the group thus far, from being a co-chair of the group, to having only vaguely heard of the group. The following section will present the qualitative results relating to the catchment group.

4.4.1 Catchment group motivations

The motivation of farmers and other community members to be involved in the Waikaka Stream Catchment Group varies between individuals, based on factors such as their age, length of time in the area, and occupation. Most participants have a variety of reasons that stirred them to be involved, or as to why they think other people have decided to get involved (Figure 4.9). The most common response regarded the community aspect of the catchment group, citing the responsibility and accountability that people feel which has in turn resulted in some collective action (Table 4.8). Participants also cited other catchment groups as a trigger to forming their own group, which is linked into preserving an image of farmers caring about their local area and water quality. Other groups in the region have formed, often due to a specific water quality problem, which has shown their keen interest in improving water quality in their local area. Participants stated that having a local initiative formed for productive change encouraged them to be involved, due to the familiarity of the area and the community. The group gave them an easy avenue to action their desire to take accountability for their river. Because the group is local, farmers feel a collective sense of responsibility to take action to improve their water quality, and to assess the true quality of their river. Some participants are driven by the perception of a water quality problem based on Environment Southland records, and media reporting.

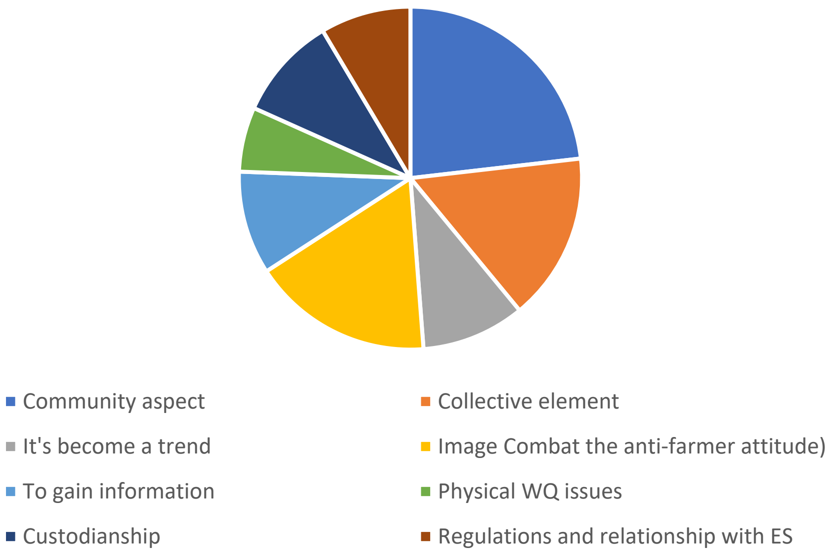

Figure 4.9: Participants opinions of why people have mobilised to form a catchment group in the Waikaka Stream.

Table 4.8: Key reasons that farmer participants identified, for wanting to form, and be involved with the Waikaka Stream Catchment Group. Direct quotes relating to each key motivation are also displayed.

Motivation	Quote
Community involvement	"Yeah nah this has gotta be every little community has gotta have a crack at this and I think they will" - Participant 4
Collective benefit	"I think we collectively need to, take ownership of our waterway… we've all gotta put our hands up" - Participant 7
Following the catchment group trend	"You know most people know about the Pomahaka Group, that, it's like oh well, it's sort of becoming the thing to be part of" - Participant 1
Farmer image	"Just being able to show that, you know, you are looking after the river, you have improved it" - Participant 1 "Well part of it is the PR, to be seen to be doing something, and to have a plan you know" - Participant 3
Gain information and knowledge	"I think it's also to get more information about, you know, what the actual current status of the river you know" - Participant 1 "I mean if there is weak spots in the river where they can you know, actually identify "well yes, somethings happening around this area" you know, and can sort of figure out what it is" - Participant 2 "we can get information on our farming practices" - Participant 5
Water quality issues	"I was interested in making sure that water quality, is improved in Southland, and this is one way of doing it" - Participant 9
Custodianship of the land	"I s'pose the older you get the more… you know once you get grandkids and all those things you start thinking about what's gonna happen" - Participant 3 "I wanna get things tidied up here, like I mean the place has been in the family for, I don't know 100 and something odd years, well since 1886, so it's something I definitely wanna tidy up" - Participant 4
Incoming regional regulations	"Possibly regulations that come upon us that we've got no control over" - Participant 5

4.4.2 Challenges

Participants identified a range of challenges and barriers to the success of the catchment group. The most common challenge identified was the struggle with getting buy-in from all farmers and the public within the catchment, as only 40% have showed interest (Figure 4.10). The group was formed by local farmers, but not every individual in the catchment has chosen to be involved. Another significant challenge for the catchment group in the future identified by participants is the attitude, both of the group members, and by other neighbours in regard to improving water quality (Table 4.9, Figure 4.10). Some farmers explained that people were not sure why they should bother putting effort in if not every farmer was doing the same, and therefore becoming discouraged by the lack of engagement and regard from neighbours. Some participants, particularly the younger farmers, cited the generational gap as a possible cause of a lack of buy in, explaining that for different reasons, both younger and older farmers may choose not to engage in the water quality action of the catchment group. Some older farmers find it hard to adjust the way they have been farming their entire lives, and so the shift in thinking has been very difficult for them, and a barrier to progress. Participant 4 identified that younger farmers are often in more debt and so may be less inclined to spend money on environmental improvement, as they have more financial pressure on them (Table 4.9). However, participant 4 also described that younger farmers find it easier to consider environmental effects as they have lived their lives in a world where water quality and farm management have been common discussion, unlike older generational farmers.

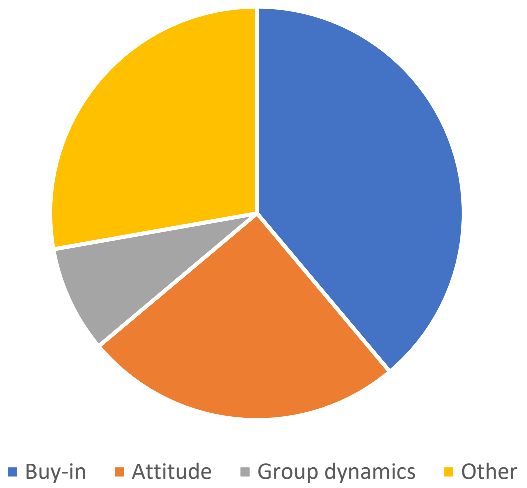

Figure 4.10: The key challenges for the catchment group as identified by farmer participants.

Table 4.9: Key challenges identified by participants, alongside direct quotes relating to each challenge.

Challenge	Quote
Farmer buy-in	"We've got quite a big buy in issue whereby there's always gonna be people who are not into it" - Participant 4 "There's definitely the buy-in issues" - Participant 1
Farmer attitude	"It's not those that are willing, it's those that are ignorant and unwilling, that is your problem, because you're dealing with self-employed, individual people" - Participant 6 "The idea of 'well why do I need to do this to improve the water quality, where, right next door, they're gonna be doing something that's making a mess of it'" - Participant 1
Incoming blanket regulations	"Regulations that come upon us that we've got no control over" - Participant 8
Identifying causes of water quality problems	"Identifying the reasons why *E.coli* levels are so high" - Participant 5
Working with group dynamics	"Making decisions with a big group, but also getting everybody in the group… you gotta have as many people on it as you can, but it does make decision making harder, if everybody gets their say" - Participant 7
Coming up with new ideas	"Farmers only know what they know, it's not like we're geniuses and got lots of time to go and think up new ideas" - Participant 6
Generational differences	"it's just a generation thing I mean they (Mum and Dad) spent half their live getting this place turned around, getting water out of paddocks so they could farm it, and now… we're just trying to direct it and fence it off sort of thing, it's against the grain that they were, what they were taught and worked for really" - Participant 4

4.4.3 Waikaka Stream catchment group future directions

The future of the Waikaka Stream Catchment Group is unknown and highly changeable. Participants described what they think the group will look like, and how it will operate in the future. They also identified objectives they would like the group to achieve, or aspects that they think need to be included for the group to be more effective in community resource management. Many participants felt that the group needed to grow and improve its structure by forming a committee rather just having chairperson (Figure 4.11). They said that one of the key purposes of the group was be a central support system and provide relevant information for the catchment members, to further social learning of the community. Therefore, differing ideas exist for the trajectory that the group should take in the future to be most effective, based on the participants' experiences and personal wants for the catchment group.

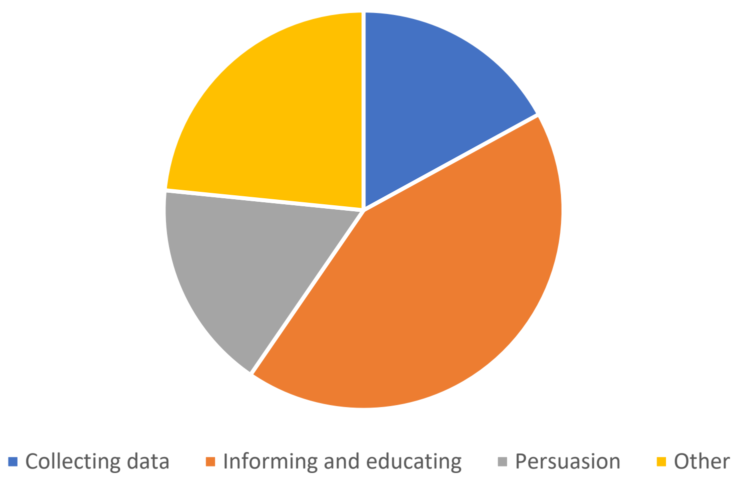

Figure 4.11: Future directions for the catchment group as described by the 10 participants.

4.5 Wider shift in thinking

All participants identified that there had been a shift in farmer thinking regarding environmental issues and water quality in relation to farm practices. The change was identified to be mostly gradual, as the topics were spread through word of mouth, and slowly became greater talking points, and points for consideration over the years. The dairy boom was identified as a larger trigger, due to the issues that came from much higher numbers of cattle in Southland, and around the country. The increased recognition of issues resulted in more strict requirements and regulations for dairy farmers, that eventually translated to all farming types (Table 4.10). Media sources, such as newspapers and radio stations, have also contributed to the heightened awareness of farmers to environmental issues, namely water quality in this context. The increasing number of regulations, both nationally and regionally has also increased dialogue and consideration of water quality issues related to farm management in a more formal way than previous. As time goes on, and younger farmers come through to owning or running their own properties, the different ways of thinking come through naturally, as they have been exposed longer to discussions around environmental concerns, where older farmers have to make a more dramatic shift in their thinking, having done things differently for a longer time (Table 4.10).

Table 4.10: The causes of a shift in farmer thinking around environmental issues, alongside direct quotes relating to each cause.

Cause	Quote
Increased awareness	"with the amount of discussion about it, I think there's a heightened awareness, yeah" - Participant 10 "There was a lot more, you know, awareness put out there you know whether it was through media or…" - Participant 2
Generational shift	"Here are some principles that previously wouldn't have been, you know, a generation ago, you wouldn't have really bothered considering" - Participant 1 "I think in the next generation when those guys that are 10 and 15 now start farming, there's gonna be, gonna be huge yeah, definitely" - Participant 4
Dairy expansion	"It started happening after the dairy farmers were here, because the dairy farmers had to… sheep farmers have had to follow suit" - Participant 9 "Certainly, when the dairy ah, brought issues, that 100 times blew out the issue we were not thinking about" - Participant 6
Impending regulations	"Here's the old story, you can ask people kindly and they'll do things, and other people won't" - Participant 10 "When ES started with their rules… that's when I started looking too, because they told me I couldn't do all these things" - Participant 7
Negative public perceptions	"When we got told we were doing it all wrong" - Participant 7

4.6 Summary of key results

The Water Quality Index indicates that the Waikaka Stream water quality is in a poor state, which is different from the overall perspective of the local farmers in the catchment. Therefore, a disparity exists between the farmer perspective of water quality, and water quality ratings according to current legislative thresholds. Best management practices were identified by all participants, indicating their understanding of the impact agriculture can have on land, and therefore the flow on effects to nearby waterways. Key source areas were also identified, and steep slopes were noted as the source areas that are of greatest concern to the catchment.

Key informant interviews revealed the key motivations behind the formation of the Waikaka Stream Catchment Group. The factors included a desire to take responsibility and act as respectful custodians of their local area representing a wider shift in farmer thinking over the past decade. Farmers now consider environmental aspects in their day to day management far more than historically. This change is fuelled by negative attention on the agricultural industry, as well as raised awareness and consideration of water quality and other environmental issues. The catchment group faces many challenges in the future and are still trying to find their place in the existing environmental management framework. The community-led initiative offers an insight into farmer thinking, allowing them to make positive change through collective action, which is a key reason the group has formed.

5 Discussion

Water quality in the Waikaka Stream is complex, ever-changing, and highly variable, and therefore requires an integrated approach to resolve water quality problems. Results from this study show that the Waikaka Catchment generally contains poor water quality, despite the community perceptions of water quality being positive. This chapter will use these results to address the key aims of the study. First, observed water quality trends in the Waikaka Stream will be examined, identifying hot spots of poor water quality and cumulative impacts within the catchment (Section 5.1). These levels will be compared to other regions in New Zealand to understand how the Waikaka Stream water quality problem compares to regional and national freshwater guidelines. Section 5.1 will also discuss community perceptions of freshwater quality in relation to the physical water quality results. Section 5.2 elaborates on the community management group motivations, potential, and shortfalls of such a group in the Waikaka Stream, including how catchment groups embody principles of Integrated Catchment Management. The first two sections identify six key challenges to environmental management in New Zealand revealed through the Waikaka Stream case study. Section 5.3 elaborates on catchment groups in the broader environmental management context, the contribution they provide to socio-hydrology, and further discusses the key challenges identified in the first two sections. The section explores shifts in farmer thinking over time, and barriers to good management implementation. Section 5.3 also discusses how catchment groups fit into the current authority structure, and the potential for such groups to encourage a socio-hydrological approach to environmental regulations. Chapter 5 concludes by discussing recommendations to the community regarding the Waikaka Stream, the future research possibilities following this study, and the limitations of this research in Section 5.4.

5.1 Waikaka Stream water quality

The Waikaka Catchment water quality is dependent on intrinsic and extrinsic environmental and human factors. The results of cluster analysis showed that no intrinsic characteristics of the catchment including geology, soil type, and physiographic zone collectively explained the spatial distribution of degraded water quality observations. In the Waikaka Stream, the largest human impact is agricultural practice, which has resulted in extensive intensification through increased stock numbers, contributing to the deterioration of freshwater systems. The high concentrations of water quality indicators, whether 'hot spots' or cumulative downstream trends are therefore most likely explained by the impacts of land use and environmental practices of surrounding areas, such as fertiliser application and winter cultivation. The findings of this study suggest that land use exerts a greater influence on water quality in the Waikaka Stream than the underlying physiographic units of the catchment. Principally the study has shown that nutrient variables (total nitrogen, total phosphorus, nitrate, and dissolved reactive phosphorus) increased downstream, while sediment and *E. coli* water quality variables decreased with the highest measurements observed in the catchment headwaters. Therefore, the Waikaka Catchment exhibits different source areas for these variables and warrant different sub-catchment management intentions to ameliorate the current water quality.

Participants acknowledged some key areas were contributing to the poor water quality of the Waikaka Stream. Such observations support previous studies that recognise that farmers have a good understanding of the interactions between soil and water, and contaminant transport (Duncan, 2013b). For example, farmers in the Waikaka were aware of the areas that caused the most trouble for water quality, based on transport capacity. Participant 1 noted "any sort of swale, and, well the creeks are obvious, but yes it's those swales to pick up, that's where waters gonna run down there when it's raining", where swales refer to sunken areas that often harbour water, and turn into an extended stream network if sufficient ground saturation occurs (Figure 5.1). Such networks are often considered to be ephemeral, that is, a stream that only flows when excess water is available, and the soil becomes saturated, drying out again when the precipitation levels and soil moisture lower. These streams often reoccur in a natural hollow and are common transport pathways for contaminants (Ortega et al., 2014). In the case of the Waikaka Stream, steep slopes were identified by most participants as being a key source area, predominantly in the hill country at the top of the catchment (Figure 5.1). The steep areas offer rapid transport pathways for mobilising particulate and particle-bound contaminants (*E. coli*, and phosphorus) as rills and gullies open, particularly under high precipitation, therefore potentially explaining high concentrations of sediment and *E. coli* in the upper reaches of the Waikaka Catchment (Quinn and Stroud, 2002). Such slopes are more prone to failure due to the higher incident angle that reduces pore water pressure. Material is more likely to move as the critical shear stress required for mobilisation of particles is lower. The lower reaches are gently sloped so that steep slopes are distal to the stream network, therefore within the lower catchment and erosional loss from steep areas are less influential. Topography is an important influence on water quality in the Waikaka Catchment, which is most acutely observed in the upper catchment. Therefore, understanding specific on-farm source areas is essential to forming practical, targeted, and scale appropriate management plans (Gove et al., 2001).

Figure 5.1: Photographs show different potential source areas in the Waikaka Catchment. Left - The formation of an ephemeral stream, creating a direct transport pathway to the stream. Middle – The lower reaches of the stream are prone to flooding, although they contain flood banks on some sides, some have only flood plains. Right – Steep slopes have high transport potential and so are often source areas in agricultural land.

5.1.1 Spatial water quality trends

5.1.1.1 Cumulative impacts

Both nitrogen and phosphorus increased downstream, indicating a cumulative effect of nutrients in the Waikaka Stream. Nitrogen and phosphorus trends are often similar owing to the same source material, despite having different transport properties (McDowell and Wilcock, 2008). The associated trends of both nutrients could indicate that the transport pathways for phosphorus, generally more limited than nitrogen, may be the dominant pathways for all nutrient contaminants in the Waikaka Stream. Legacy impacts of land management exist as nitrogen leaches from prior fertiliser applications (Duncan, 2014). The Waikaka Catchment lies above a large aquifer that is not used for irrigation, and therefore intensive nitrate fertiliser applications from the 1970s may still be leaching into the stream, adding to the cumulative trends observed. Nitrogen mainly comes from fertilisers and animal excreta, with dairy cows excreting the highest amount due to the size of the animal. However, beef cattle, sheep, and deer also add nitrogen to land and contribute to the nutrient profile of the Waikaka Stream (Scarsbrook and Melland, 2015). Nutrients in freshwater are supply limited, and the supply must be restricted or attenuated to reduce concentrations that cause adverse effects in rivers and streams.

The catchment has a gradual increase in nitrogen, with the highest nitrate (0.84 ppm) and total nitrogen (1.23 ppm) levels observed 6.2 km above the confluence, indicating that most areas along the stream contribute nitrogen. The gradual increase in nitrogen and phosphorus concentrations indicates that transport is consistent and slow. The major transport pathways are therefore likely underpinned by throughflow and groundwater leaching under normal conditions (Mellander et al., 2015). The release of nutrients can be minimised by improved on-farm management, such as better pasture management and lower stocking rates (Quinn and Stroud, 2002). However, even if individual farming units meet nutrient regulations, accumulation occurs across the entire catchment, potentially resulting in nutrient levels exceeding regulatory thresholds, as current freshwater management does not account for cumulative effects of sequential developments along a waterbody. Hence, a key challenge emerges for future development of environmental management of the Waikaka Stream, in terms of managing the cumulative impact across the catchment (see Section 5.3.4 for further discussion).

5.1.1.2 Contaminant hotspots

E. coli and sediment variables show higher concentrations in the headwaters of the Waikaka Stream than in lower reaches. Many sites in the catchment have measurements exceeding regulatory limits, indicating *E. coli* and sediment are part of the water quality problem. These variables are transport limited, and therefore are likely to have built up in the catchment over time (Guercio, 2011). The sediment flux is most strongly associated with intrinsic catchment characteristics, including lithology, rainfall, and landcover morphology combined with extrinsic climatic controls, rather than land use (Quinn and Stroud, 2002, Hicks et al., 2011). The headwaters of the Waikaka Catchment are rolling hills that have retained native tussock grasslands. Occurring on steeper slopes and marginal grazing lands, the tussock grasslands recorded hotspots of higher suspended sediment and *E. coli* concentrations. Tussock grasslands provide greater protection from erosion than exotic pastures. Therefore, higher sediment yields in the rolling hills of the upper catchment are likely a function of grazing on higher slopes, and greater vulnerability to erosion, rather than tussock grassland cover. In this way, the decrease in sediment downstream is due to distance from sediment sources, as well as sediment attenuation through the river network as material accumulates in the gentle lower slope reaches. Land use does not appear to be a significant influence, since land use in the headwaters is mostly grazing pastoralism (Julian et al., 2017).

Unsealed roads are another sediment source in the Waikaka Catchment (Figure 5.2). Gravel roads, although not a direct cause of agriculture, are often found in farming areas due to the low-density housing (Quinn and Stroud, 2002). Over time shoals of gravel form on the outer edges of gravel roads that can be washed into waterways near fords and bridges. Although most of the metalling material is a coarse pebble, attrition from vehicles results in plumes of fine dust being disturbed from vehicular passage, that is easily washed away from road surfaces during significant storm events. In the Waikaka Stream’s rural setting, unsealed roads are common, particularly in the headwaters, and contribute high levels of sediment to the stream during storm events (Figure 5.2).

Similarly, bed and bank erosion is a significant source of sediment in the catchment observed at many sites along the stream, creating sediment hotspots when bank collapses occur (Figure 5.3) (Bright et al., 2018). The continuation of bank erosion overall is likely lesser than the topographic control in the Waikaka headwaters, given the decreasing trend of sediment downstream. The erosion of these riverbanks and the loosening of soil through cultivation also contributes to the faecal bacteria profile of the stream, offering a transport mechanism for *E. coli* to enter a waterway, resulting in *E. coli* hotspots (Nagels et al., 2002).

Figure 5.2: Photographs show an unsealed road at the top of the Waikaka Catchment during rainfall. The sediment can be seen running off the side of the road, and directly entering the stream, causing a plume of dirt in the water.

Bacteria (*E. coli)* predominantly comes from animal waste in agricultural settings, which can be irregular (McDowell and Wilcock, 2008). Free grazing animals in pastoral farming, particularly dairy cows are a major recognised source of *E. coli* worldwide (Dymond et al., 2016). Animals with direct access to waterways are likely to increase *E. coli* levels as nothing stops them directly contaminating the water (Figure 5.3). However, the Waikaka Stream does not contain significant herds of dairy cows, and most dairy farms are further down the catchment, failing to explain the high levels of the *E. coli* in the upper catchments. A potential explanation for high levels of *E. coli* at the top of the catchment is that the hill country of the Waikaka Stream is home to wild deer and ducks. Participant 5 stated that "populations of wild deer are skyrocketing… these hills are now full with deer, we counted 150 deer on a crop paddock one night, so we're now in the situation where we're gonna fence our paddocks off from the hill to keep the deer off our crops, but you know what I'm saying is those wild deer are wallowing in our waterways all the time". These animals are uncontrolled, not domesticated, or maintained by farmers, apart from pest control and recreational hunting. While cattle are acknowledged as key sources in agricultural settings, deer have also been found to be a major source of sediment, and *E. coli* due to their nature of wallowing in water (McDowell, 2007). If these wallows are hydrologically linked to waterways, the resultant stirring of sediment and direct source of urine and faeces causes both sediment and *E. coli* to enter waterways in concentrations generally above the regulatory guidelines (McDowell, 2007). All current management strategies for deer wallowing are limited only to farmed animals, where access can be restricted and managed. Wild deer in the headwaters go largely unmanaged, apart from deer hunting. There are no management strategies for duck populations either, apart from recreational hunting through the winter. Wild populations present a second challenge for effective environmental management of the Waikaka Stream, highlighting difficulty over establishing whether communities, or councils should be responsible (see Section 5.3.3 for further discussion).

Figure 5.3: Photograph of Site 9 (left) showing a bank collapse on the true right side of the stream, and Site 3 (right) showing direct animal faeces in the waterway because of unfenced stock near the stream.

5.1.2 Comparison to Environment Southland monitoring

The water quality results demonstrated that the resolution of Environment Southland data is too low to capture variation and nuances in the Waikaka Stream. The Environment Southland monitoring point is useful to understand the overall flux of contaminants from the stream, and for its contaminant concentration delivery to the Mataura River. Environment Southland only have resources for a single monitoring point on the Waikaka Stream. Therefore, management strategies must be reasonable to work within the realms of practicalities (Mitchell, 2020). However, the lack of higher resolution sampling means that the effect of one farm improving their practice may be not detected. Conversely, if one property contributes high levels of contaminants there is little mechanism to be able to detect the material origins of non-point source pollutants. The scale of monitoring does not match the scale at which the land is being managed, which is by the individual farm. This leads to the third significant management challenge, as farmers cannot observe the effects of their individual actions, and are instead collectively held accountable (See Section 5.3.3 for further discussion). Best management for the Waikaka Stream may require a compromise where blanket regulations can be used to work towards an overall positive change in the stream, rather than a smaller scale farm targeted approach (Mitchell, 2020). Using a bottom line for contaminants could be more effective if farmers improve their management practices on the same scale, working at the catchment level with their neighbours, rather than the smaller individual level.

5.1.3 Comparison to regulatory thresholds

The Water Quality Index (WQI) was a tool used to gauge the water quality of catchment or site, considering the aggregated effect of multiple water quality variables (Saffran et al., 2001, Nagels et al., 2001, Madalina and Gabriela, 2014, Tyagi et al., 2013). Using the WQI, the Waikaka Stream water quality was consistently rated as 'poor'. Of note was that tributary sites had a lower WQI than the main stem sites which can be explained in part by the different characteristics of sites, and the contaminant sources and flow pathways associated with each. The tributary sites are being fed by a far smaller area than the main stem sites, and so main stem sites with a higher flow probably dilute pollutants far more than small tributaries. The key sources of contaminants may also be closer to small tributaries, indicating the impacts of scale on localised water quality (Gove et al., 2001). Hotspots of contaminants are, therefore, more likely to be measured in smaller tributaries (Figure 5.4).

Figure 5.4: Left - Photograph of a main stem site (Site 11), showing a very wide channel and relatively high flow capacity. Right - Photograph of a site on the Little Waikaka (Site 4 – tributary) showing the small nature of the stream in comparison to main stem sites.

Sediment levels in the Waikaka Stream (measured in the form of SSC and TSM) are higher than the NPSFM freshwater threshold value of 2.5 mg L^{-1} (equivalent to 5 NTU in turbidity). No site has a median below that value, indicating that there are prevalent and persistent sediment sources and transport pathways within the Waikaka Catchment. The catchment has a high proportion of particulate organic matter within the total suspended material, which similarly indicates land displacement (Bright and Mager, 2016, Bright et al., 2020). In the Waikaka Stream, the turbidity measurements do not always match the SSC and TSM concentrations due to the presence of organic matter, and may not be a suitable surrogate for determining sediment disturbance in the catchment uniformly (Bright et al., 2018).

Regulatory thresholds for water quality in New Zealand are set out in the NPSFM through the National Objectives Framework (NOF). These NOF's set nationally recognised maximum thresholds that regional councils must observe in setting their water quality regulations. The NOF framework identifies four bands of thresholds depending on the pristine, or degrees of degradation in a river system. The limitation of the NOF is that these 'bottom lines' for water quality were added to the NPSFM in 2014, with specified limits for periphyton, nitrate (for toxicity), ammonia (for toxicity), dissolved oxygen, and *E. coli*. These NOFs, however, do not specify limits for dissolved phosphorus, total nitrogen, total phosphate, or ammonium, which had been previously defined by the Australian and New Zealand Environmental Conservation Council (2000) with thresholds for protecting ecosystems. The current environmental reporting statistics used for State of the Environment reporting by Stats NZ for the Ministry of the Environment has, at least informally, adopted a new set of standards by which to measure the effect of nutrient contamination in rivers. These guidelines, derived from Australian New Zealand Guidelines for Marine and Freshwater (ANZG, 2018) as reported on the Australian Government website are draft default guideline values that are still being negotiated through the stakeholder process, despite being used as thresholds by the NZ Government. The draft default guidelines (DGVs) being used for nitrate are linked to the River Environment Classification (REC) model, so that different land units have different threshold values.

According to the ANZG (2018) thresholds, most variables measured in the Waikaka Stream exceeded the recommended guidelines (Table 5.1). Only clarity showed to meet the thresholds, while the macroinvertebrate community index returns a ‘fair’ rating, indicating why farmers perceive the water quality to be of ‘good’ quality. SSC recorded the highest number of exceeded values, as 90% of the measurements exceeded the 2.5 mg L^{-1} threshold. *E. coli* exceeded 260 CFU/100ml 50% of the time, while 55% of total phosphorus measurements exceeded the threshold value of 55 ppb. These results show that the Waikaka is measuring water quality concentrations higher than recommended thresholds. However, the difficulty surrounding the ANZG (2018) thresholds is the lack of transparency around what the thresholds mean and how they are derived for the different land units. The water quality thresholds for the Waikaka are, in effect, set by Environment Southland, but finding which guidelines are to be reached through the ever-moving discourse over setting regulatory thresholds at the national level, and consequent iterations of regional water plans over the past two decades, has had the effect of making regulations look like a set of arbitrary rules, that change with political whim.

Table 5.1: Waikaka Stream measures of water quality compared to the ANZG (2018) guidelines. No water quality measures meet the guidelines except clarity (StatsNZ, 2020).

Water quality measure	**Median value recorded for the Waikaka Stream**	**Comparison to ANZG (2018) guidelines**
Turbidity (NTU)	6.55	Does not meet
Clarity (m)	0.9	Meets
E. coli (CFU/100ml)	315	N/A
Macroinvertebrate community index (index rating)	Fair	N/A
Total nitrogen (gm^{-3})	1.33	Does not meet
Nitrate-nitrogen (gm^{-3})	0.745	Does not meet
Ammonical nitrogen (gm^{-3})	0.042	Does not meet
Total phosphorus (gm^{-3})	0.054	Does not meet
Dissolved reactive phosphorus (gm^{-3})	0.024	Does not meet

For example, some DGVs are linked to toxicity levels for humans (e.g. *E. coli* for recreation), while others are derived from levels which protect high proportions of instream organisms and life (e.g. visual clarity or turbidity). This study recognises that the Waikaka Stream has water quality issues and meets the general criteria of being degraded, however, the extent to which this exceeds regulatory thresholds for humans and/or ecosystems is not clear. For communities and non-technical experts, it is exceedingly difficult to navigate the tomes of political documents that govern local water rules. There is a lack of transparency surrounding freshwater guidelines in New Zealand, which makes effective environmental management very difficult to achieve. Regional limits change often as regional councils update their plans frequently, and limits are often not agreed upon by stakeholders, which delays the process, leaving farmers wondering what they should be aiming for and adhering to.

5.1.4 Community water quality perceptions

Community perceptions of water quality in the Waikaka Stream do not align with the measurable water quality parameters. Research participants viewed the water quality as overall quite good. Most acknowledged that the water was not free of all water quality issues, but overall, they believed it to be of ‘good’ quality – something that lies in stark contrast to the WQI metric, which rated the water as generally ‘poor’. Most participants would happily swim in the water, as they did not consider it as having any adverse effects on their health, however according to the water quality thresholds many variables do not meet the recommended levels. Therefore, a disparity between perceived quality and quantified quality exists, a trend that was observed by interviews with farmers from Canterbury when asked the same question (Duncan, 2013b). The disparity between observed and measured water quality shows that although humans can perceive the health of a waterway, there are some water quality indicators that cannot be assessed in this way. Where physical effects of poor water quality, such as eutrophication or nuisance growth are absent, it is impossible for humans to assess whether nutrients and *E. coli* are an issue in a waterway. Perceptions are derived from sensory elements, such as sight and smell (Barnett et al., 2018). Therefore, the lack of sensory clues leads the local community to perceive the water quality to be good, when there are unseen issues with freshwater (West et al., 2016). People also often perceive a stream that can provide all their recreational activities as fine and healthy, so because all normal activities are not impacted, adverse effects do not register with the community (Barnett et al., 2018). In the case of the Waikaka Stream, the locals can engage with it recreationally in the way they would like to, and as such perceive the waterway to be healthy and of a good standard. Here lies a fourth challenge, since concentrations of nitrogen and phosphorus set by regulatory authorities are based on either toxicity to humans or ecosystems, or relative to lower thresholds that may reduce harm to sensitive or vulnerable species (see Section 5.3.4 for further discussion). Therefore, the regulatory measure does not align with the measures that communities use to judge their local freshwater.

Despite the dissonance between perception and scientific quantification, the Waikaka community showed good understanding of biotic factors in healthy waterways. In the Waikaka Stream, participants had outlined how the stream had improved over time, as it is ‘clearer’, indicating a low turbidity reading, and looks ‘healthier’ now than it had in previous years, despite the long term trends showing no change in turbidity in the last 20 years. The environmental legacy of poor practice may have changed individual perceptions of what ‘good’ water quality looks like, as the ‘good’ perception of water quality is relative to the person. Participant 7 outlined that “When I was a kid there weren’t crayfish and stuff, but in the last few years there’s been trout and stuff coming back into the creeks,” indicating that, even if current water quality is below regulatory guidelines, it is better than it used to be, as culturally valued indicators of ecosystems are present. The macroinvertebrate index for the Waikaka Catchment deems the stream to be ‘fair’, indicating that the macroinvertebrate community have a reasonable ability to survive change, and therefore proving the usefulness of a tool that represents biotic factors, rather than purely chemical indicators of water quality (StatsNZ, 2020). Water quality trend analysis on Environment Southland data indicated that faecal coliforms, ammonia, and dissolved reactive phosphorus showed improving trends in the Waikaka Stream, explaining the observed improvement in ecosystem health. Habitat assessments have become popular as an assessment tool, particularly for community use, acknowledging that laboratory tests and water samples are not the only determinant of a healthy stream, and are not always practical options for monitoring and management (Mitchell, 2020).

Community perceptions of ‘good’ water are also derived from their understanding of good farm management, indicating to individuals that because land practice and water quality are linked, good management practices have resulted in good water quality (West et al., 2016). Management practices were stated to have changed to be more environmentally friendly over time, as awareness of environmental impacts grew through NGOs, regional government, and informal knowledge being passed on by the community. These observations show that farmers who live and work in the land around the stream have gained knowledge about the land-water connection, as well as how their farming behaviour impacts the ecosystem. Therefore, they expected water quality changes to mirror their practice. Improvements were observed through Environment Southland monitoring in ammonia, DRP, and faecal coliforms. A large proportion of good management centres around how fertilisation, cultivation, and winter grazing is carried out, as this is an area with high potential for creating the movement of pollutants to waterways (Buck et al., 2004). Many farmers discussed the new preventative measures that they considered a good idea. These included buffer zones and future planting to act as contaminant filters, as well as day to day management of stock and land to further reduce the adverse impact of agriculture on freshwater. Enacting these processes gave many individuals the impression that water quality in the catchment was of high quality. Improvements have been observed in the local water quality in faecal coliforms, ammonia, and dissolved reactive phosphorus over the 24 years of Environment Southland records. The high concentrations of nutrients in fertiliser applied in the late twentieth century, however, can be stored in aquifers, such as the one in the Waikaka Catchment, and therefore could take a long time flush out (McDowell and Wilcock, 2008). These effects show that agricultural intensification has a long-lasting impact on land and freshwater systems (Buck et al., 2004). The pollutant lag time complicates response management, as it is difficult to track progress against any changes in management practice, as well as confusing community perceptions. Future management should seek to quantify leaching and groundwater discharge of nitrate in the Waikaka Catchment, to better determine and address the nutrient sources in the Waikaka Stream.

Participants acknowledged that there are potential issues with the stream around variables such as nitrogen and *E. coli*, even though they perceive the water to be of good quality, showing that the community has some understanding of the hidden nature of water quality problems. Community members showed awareness of existing freshwater issues, illustrating that information distributed by regional authorities and private agricultural companies has permeated through to the farming community, and an understanding of the flow-on effects of management practices is present (Leveque and Burns, 2017). Human behaviour is directly influenced by human perceptions, and thus realistic perceptions of the local community would help to better address freshwater problems in the Waikaka Stream (Raymond et al., 2010, West et al., 2016). The practical implications of mismatched perceived and actual water quality are significant for future environmental management of the stream. The dissonance causes the observed upset and distrust that often occurs between community members, particularly farmers, and regional authorities, which must be rebuilt for effective collaboration and successful management (Weber et al., 2011). A major challenge for environmental management is how to get landowners to better understand the hidden risk in water quality so that they can work towards better management plans, and farm best practice (See Section 5.3.4 for further discussion). Breaching the difference between perceptions and measurements of water quality would facilitate a better relationship between farmers and authorities, to enable positive change (Fien and Skoien, 2010). The disparity in water quality measurements and perceptions has contributed to the formation of the Waikaka Stream Catchment Group, one of many evolving community groups in Southland, as frustration has led to community action.

5.2 The rise of community catchment groups and their function in New Zealand environmental management

5.2.1 Motivations

Southland freshwater management in the last five years has been strongly characterised by the emergence of local community catchment groups, including the Waikaka Stream Catchment Group in 2018. The formation of such a group in an area where the community perceives water quality to be good, begs the question of why a catchment group is needed in the Waikaka Stream? The motivation of local farmers and other stakeholders varies based on their perceptions and experiences, and understanding these can help to understand the perceived democratic deficit, where groups have formed as a shortcoming of the democratic body in the area (Cook et al., 2012). The community aspect of a catchment group is at the heart of the group's inception, tying in the notion of strength in numbers, where a collective effort can be more effective, and a sense of security in a social group encourages confidence (Burton, 2004). Encouragement from neighbours and a collective want to improve water quality is the most agreed upon reason for forming a community catchment group, showing biosphere values towards the environment (Fien and Skoien, 2010). The collectivist values also inspire and encourage participation from more farmers in the catchment, as they do not want to be seen as lagging behind the rest of the community, even if their only connection is farming land in the same catchment. The collective notion places the catchment group in a good position to engage with a wider population, along with encouraging behaviour change in a less authoritative format than local government (Cook et al., 2012).

A further motivation for catchment groups, is the place attachment people feel to the land and the area they know, which causes a sense of responsibility and accountability to look after and better it, indicating altruistic environmental values. That notion stems from the sense of 'self-in-place' that individuals feel in the environment based on what it means to them, and how they see themselves interacting with it (Cantrill and Senacah, 2001).

Participant 10 outlined how the land they wanted to pass on had been in their family for generations, and they wanted to leave it to their children in good condition to continue their family legacy, emphasising the importance of a sense of place. These feelings contribute to the formation of a catchment group, as the responsibility felt promotes a sense of self-sufficiency through a community group of action, as well as being central to a farmer's identity, which is more than just individual farms as purely businesses (Oliver, 2001, Burton, 2004). The responsbility is even stronger when there is a perceived water quality problem that appears to be the result of agricultural practices in the catchment. Community members feel responsible for negative environmental effects and want to assess their options for improvement of the land that they know so well. The perceived threat of one's way of life, in the instance of the Waikaka, when farming as a livelihood is threatened by decreasing water quality stirs people to action (Ditton and Goodale, 1973, Oliver, 2001).

The Landcare Trust New Zealand has supported the formation of 21 Southland catchment groups. Therefore, the creation of such a group was easy for the Waikaka community to visualise, and support from formal organisations was forthcoming. There was also a perception of being the 'odd one out' if the community did not consider creating a catchment group, as Participant 1 stated: "it's sort of becoming the thing to be part of". Southland catchment groups have mobilised due to a perceived water quality problem, and have formed under similar challenges (Cook et al., 2013). The problem is stimulated by media coverage, which often throws negative attention on farmers and the agriculture industry. The negative attention has pushed a larger number of farmers to assemble, as it gives them a chance to combat damaging agricultural stereotypes, even when they perceive the water quality to be fine (Thomas et al., 2020).

Farmers want to better understand the current water quality situation to plan and make any necessary changes to their farm management practices. The catchment group is a platform through which information can be shared and made more accessible and palatable, avoiding often confusing, heavily scientific information (Xu et al., 2018). Using the combined knowledge of many farmers with support from other organisations is viewed as a winning situation for all parties (Fenemor et al., 2011, Cook et al., 2012).

Farmers in the Waikaka Catchment also feel threatened by incoming regulations from regional government. Water quality is perceived to be 'good', and therefore farmers often cannot see the benefit of such restrictions, only seeing the negative impacts that regulations will have on their business. A catchment group gives a community a chance to collectively come together against the perceived threat of outsiders, such as regional government, and media, as well as offering farmers a space for new ideas that are specific to their catchment, opposed to regional government who operate on a larger scale and therefore often have more generalised rules (Memon et al., 2010, Cook et al., 2012). Catchment groups are an example of bottom-up management, new in a world of euro-centric top-down approaches (Cook et al., 2012, Prager, 2015). Local knowledge allows a community to feel they have more power and can contribute more to the management of their environment, including local knowledge traditionally overlooked in favour of empirical and scientific knowledge (Duncan, 2013a, Anderson et al., 2019). A catchment group offers a formalised base for that knowledge to be communicated to authorities and other stakeholders in water management discussions (Cook et al., 2012).

5.2.2 Community management in New Zealand

Catchment groups vary around the country in form, function, name, and time operating. In Canterbury, groups have been involved in the environmental management process, establishing nutrient limits to assist land and water management (Duncan, 2013a). For example, the Hurunui River in Canterbury, saw a catchment community group work towards a zone implementation plan that was part of the wider Canterbury Water Management Strategy (Thomas et al., 2020). The experience of the Hurunui Catchment Committee was different from that of the Waikaka Stream Catchment Group, as the Southland groups have mostly been sparked not from the regional authority, but from the community itself with the support of regional authorities. The Hurunui Group also experienced deception from their regional authority, which destroyed trust and left the community feeling as though their time had been wasted in trying to contribute to the Canterbury Water Management Strategy, which was given legislative standing by Environment Canterbury (Thomas et al., 2020). Informed community engagement with the stakeholders who have place attachment results in the discovery of common ground and increased trust, which was not facilitated in the Hurunui Catchment (Memon et al., 2010). The Waikaka Stream Catchment Group in comparison, as stated by Participant 9, sees an opportunity to improve understanding between Environment Southland and local farmers, "I also think it's a possibility, that the catchment group has the opportunity to allow farmers to engage with authorities". The Canterbury experience in Hurunui, where Environment Canterbury chose to ignore some wishes of the committee to sustain the current economic model in the Hurunui, proves why trust is central to a positive outcome between community groups and regional authorities (Thomas et al., 2020). A lack of trust leads to limited social capital, and limited collaboration, which is the very thing that leads to the most positive environmental management outcomes (Fien and Skoien, 2010, Thomas et al., 2020). Environment Canterbury's actions ended up stifling community creativity. The Waikaka Stream group is a grassroots self-driven process, that does not follow the top-down approach of the Canterbury group, of considering just technical knowledge in freshwater management.

The Waikaka Catchment has seen a shift towards collective ownership of the stream, highlighting the socio-hydrology approach being undertaken in management. The shift in farmer thinking exemplifies the farmer acknowledgement that socio-economic actions and behaviours within the catchment are influencing the natural landscape and need to be addressed alongside physical causes of water quality issues. Participant 9 identified that information sharing between Environment Southland and farmers is a positive social opportunity facilitated by the catchment group. However, not all farmers in the Waikaka Catchment have shown so much willingness to become involved in the community management process. Participant 2 stated that the biggest challenge for the catchment group in the future was "farmer buy-in I suppose, and a lot of that's just, not really apathy but, maybe not far away from it" (See Section 5.3.1 for further discussion). The catchment group currently has around 20% representation of farmers in the catchment, and therefore a fifth challenge for environmental management is encouraging community buy-in to the management process.

5.2.3 Catchment groups and ICM principles

Catchment groups in New Zealand embody the holistic management principles of Integrated Catchment Management (ICM) (Fenemor et al., 2011). The catchment groups in Southland may provide an avenue for local engagement to increase in environmental management within the province. Having an already existing framework and relationship means that social capital exists to be able to work from, to improve water quality and other environmental issues (Oliver, 2001). The formation of a catchment group in the Waikaka Catchment shows some willingness to take collective action and responsibility for a local waterway (Ayre and Nettle, 2015). Catchment groups can ensure that local knowledge is incorporated in every management process, not only when it is convenient, or matches the political agenda of other organisations (Duncan, 2013a). Community resilience is a key part of ICM, and catchment groups fit into the ICM framework by facilitating wider participation in environmental management and healthy conflict and discussion (Schusler et al., 2003). The social capital utilised through catchment groups contributes to ICM and is a way for a community to extend their engagement in an issue and work together, rather than as individuals (Schusler et al., 2003). Tis approach has seen great success in the Motueka Catchment (Fenemor et al., 2008).

5.2.4 Can catchment groups fill a management gap?

The emergence of community catchment groups indicate a gap in current freshwater management (Cook et al., 2013). Community groups operate in the space between individuals and governmental authorities in the environmental management sphere (Figure 5.5). In the case of the Waikaka Stream, the gap exists between the local farmers, and regional council Environment Southland (Figure 5.5). Therefore, perceived discrepancy between individual farmers and regional authorities has stimulated the group formation. These groups address this perceived gap, by encouraging collaboration between stakeholders, which can facilitate shared learnings (Cook et al., 2012, Prager, 2015). Participant 6 discussed how “when someone does formalise a good idea, we tend to cotton onto it” indicating that knowledge sharing is occurring within the catchment. Participant 3 elaborated, stating that the community group was a useful way to share such ideas and formulate a plan based on different stakeholder notions, including those from both farmers, other community members, and Environment Southland. The group has therefore shown proof of facilitating information between stakeholders, due to its flexibility in being able to move between regulatory and farming spaces and discussions. This flexibility allows the group to lobby local government regarding regulations and push the agenda of farmers at the decision-making table, as well as using local government science to encourage community change in management practices for good outcomes, based on the trust being built between stakeholders (Prager, 2015). Participant 4 explained that they wanted simple information that would advise them on how to improve their farming style based on current knowledge and science, for which they did not always have access. The interactions between all stakeholders within a catchment group offers a space for developing joint values regarding local landscapes, that can blend the traditional functional roles of different stakeholders, and facilitate collaboration (Prager, 2015).

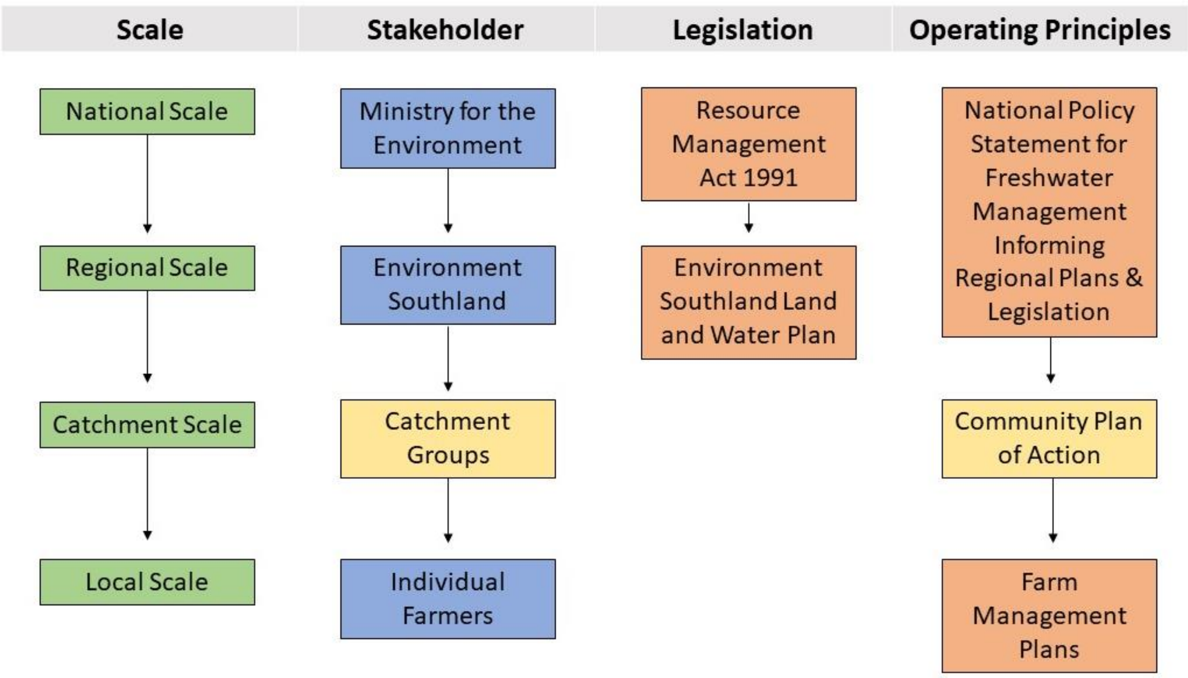

Figure 5.5: Schematic diagram showing the scales of governance in New Zealand and the governing legislation at each level. Catchment Groups are posed as the potential missing link in the management chain.

Additionally, catchment groups can act as vehicles for local knowledge, giving a more formal voice to local knowledge, and a format through which knowledge can be consolidated and passed on (Bowden et al., 2004). Participant 9 had hosted a field day on their property, showing local farmers the process of building a sediment trap to prevent losses to the nearby waterways. The field day allowed both farmers, and Environment Southland staff to see how a mitigation method had worked in one farm and could be scaled out to other similar farms. Farmer understanding of the local land and water connection is invaluable to the management of the stream, along with the link between the environment and farming practices, including localised knowledge of source areas in the catchment (Fenemor et al., 2011). The continuous small observations that farmers subconsciously make in their day to day lives provides a local perspective that can be used effectively to teach others improved management strategies (Duncan, 2014). Using participatory methods that can be facilitated through a catchment group does offer a level of governance that can validate local knowledge, and increase stakeholder voices in decision-making (Raymond et al., 2010).

In the Waikaka Stream, there is a lack of Tangata Whenua representation, which means that although local knowledge is contributed, cultural views are not well captured by the catchment group. Cultural perspectives are central to water management in New Zealand as mandated by the NPSFM, as they incorporate traditional land-based practical knowledge in a way that considers connections between freshwater and every other natural system, including human systems (Tipa and Nelson, 2008). This study has not captured local iwi perspective on the Waikaka Stream, which creates a gap of integrated knowledge that would help to enhance the management of freshwater and presents a sixth challenge identified by this study for freshwater management in the catchment (see Section 5.3.3 for further discussion).

Local perspective, flexibility, and the capacity to operate on the catchment or sub-catchment scale are strengths of the catchment group that regional government largely do not have, however, the mismatch of scales can cause frustration as they struggle to mesh the two levels for effective outcomes (Memon et al., 2010, Cook et al., 2012). The struggle to mesh scales can result in a lack of communication and clear outcomes. Many participants were focused on scientific results, implying that more information would allow all problems to be resolved. A focus on scientific results often distracts from more difficult systemic challenges that need to be addressed to make meaningful sustainable change. Therefore, if the group does not clearly define their role and seek to address widespread behaviour issues in the catchment, they may overlap the work of Environment Southland, creating more complications and setbacks, rather than simplifying the process and fulfilling a perceived gap. Groups in Southland could result in double handling and inefficiencies from a lack of clear catchment specific direction (Cook et al., 2012). For the catchment group to serve a purpose beyond the current environmental management framework in New Zealand, it must seek to address fundamental issues in the catchment, including the social change in behaviour that still needs to occur to achieve effective collaborative management.

Both community groups and regional authorities are essential in freshwater management discussions, and both parties must commit themselves to the collaborative problem-solving process in a non-statutory arrangement, to break the impasse between groups, and reduce their potential overlap (Weber et al., 2011). Participant 6 stated that "you just need key people driving it… someone has to be informing us of the relevant information", emphasising the need for strong leaders to push the group in the right direction. Strong leaders are needed in all stakeholder groups to facilitate necessary community participation (Memon et al., 2010). Generating a consensus in a democratic group can prove a challenge, as conflicting objectives become increasingly difficult to reconcile in such a large group. Maintaining equity and transparency among members is essential to the function of a catchment group and is the strength of community management.

5.3 Advancing sociohydrological dynamics for sustainable water management

As identified in the previous sections (5.1 and 5.2), this study has acknowledged six challenges for environmental management in the Waikaka Stream:

1. Managing cumulative impacts across the catchment
2. Establishing who is responsible for managing wild pest populations (ducks and deer)
3. The misalignment of scale, as farmers manage their properties on the farm scale, but are held to account collectively by government regulations
4. The discrepancy between farmer perceptions and actual water quality, and the difficulty in getting landowners to understand the hidden risk in water quality
5. The difficulty of encouraging farmer buy-in across the catchment
6. A distinct lack of perspective from local Runanga

These challenges require a socio-hydrological approach to solutions, focusing on collaborative management and how the catchment group operates within the ICM framework to address those problems and improve freshwater outcomes for the Waikaka Stream. The following section will review these challenges in the socio-hydrological framework, to establish recommendations for the Waikaka Stream, and wider environmental management in the future.

5.3.1 Shift in farmer thinking

Farmer thinking with regards to the environment has shifted throughout the years of New Zealand's agricultural history, which has contributed significantly to the formation of community catchment groups. In interviews, participants indicated that the traditional way of farming was to focus on economic production, using new technologies and increasing stock numbers to maximise production (Burton, 2004). The environmental impacts of farming were always contemplated second, as the receiving environment seemed healthy, and a less important consideration than economic profit, especially in hard farming years (Thomas et al., 2020). These years increased the pressure to grow production so farming businesses and livelihoods would survive tough years. As economic pressure grew, so too did the pressure placed on land to increase production, which in turn increased the adverse impact felt in the local ecosystems (Thomas et al., 2020). The rise in dairy herd numbers and winter cultivation degraded the receiving environment. As these impacts were noticed, farming attitudes and priorities began to shift, subsequently changing the way farmers operate their business. More care was taken when considering land impacts, and farming decisions began to weigh environmental factors in more than they had previously (Duncan, 2013b). The shift in thinking has occurred gradually, and participants identified the dairy boom as the beginning of the transition. Environmental considerations have since become a substantially greater part of farmer thinking in the Waikaka Stream, as participants demonstrated through their awareness of best practice and the plans they had made to achieve those goals (Duncan, 2013b). The increased environmental awareness has contributed towards the changing nature of management in Southland through the formation of community catchment groups. Farmer priorities and regulation changes have driven action in the Waikaka Stream to form such a group, to help address any local water quality issues. However awareness has further yet to grow, as the buy-in to the Waikaka Stream Catchment Group is limited.

The shift in farmer thinking can be explained by several different factors. The first, as mentioned above is the heighted awareness of environmental concerns, which has evolved as knowledge has developed a better understanding of the impact of agriculture (Memon et al., 2010). Another factor is the shift in generational thinking. Participant 1 identified that a generation ago some of today's farming principles would not have been worth considering, but as environmental awareness heightened, environmental considerations moved much higher on farmers' priority lists, and a catchment group seems far more relevant to the community. The younger farmers have experienced an easier transition, as they do not have to change the way they have been living and working for most of their lives. Participant 6 noted that it was much harder for their father, an older farmer, to change his thinking when all his life they were told to prioritise maximum production at all cost (Thomas et al., 2020). As younger generations come through the farming industry, they bring new ideas and environmental principles that are part of the way they farm which creates resilience to changes that their predecessors may not have faced. Participant 4 outlined how they actively notice the areas that need to be fenced off and source areas for contaminants that they avoid putting stock on. These behaviours suggest that poor practices may still exist in the Waikaka Catchment but will phase out as older farmers retire and are replaced with younger farmers who have grown up with more environmental awareness. The younger farmers in the catchment were all very open to community management as a way of working towards improved water quality outcomes.

A further factor is the negative feedback from media and the public directed at farmers, stirring a large number to action, and at the very least, generating greater environmental consideration (Thomas et al., 2020). Whether farmers agreed with the opinions of the public or not, being made to be the public villain caused them to further investigate the environmental impact of their farm practice (Duncan, 2013a). Participant 3 stated that “most of us do care, contrary to media belief”, showing that they felt that the rural sector received unfair negative attention, stimulating individuals to take action, which in the Waikaka Stream, has been through a community catchment group. Farmers used to be seen as national heroes, and negative attention on them is a reflection on the individual, but in many cases it is also on the prior generations of family who contributed to the farming operation (Burton, 2004). Following on from public pressure is peer pressure amongst farmers. Not all farmers have adopted new management practices at the same rate, as with any large shift in thinking, action is generally staggered. As more farmers begin to see benefits in changing their management practices, they place pressure on those who have not acted as quickly to do so, including encouraging individuals to get involved with the catchment group to better addressing cumulative impacts. A further reason that farmer thinking has changed over time is the pressure and discussions from regional government around impending regulations to enforce changes deemed necessary. The threat of regulations often causes farmer backlash but also triggers heightened awareness and farm practice consideration. These factors combined have caused water quality to be of greater consideration in farmer thinking, leading to community catchment groups, and contributing to the changing face of management in

New Zealand. Farmer consideration of land management now aligns with the socio-hydrology framework, as economic imperatives, water quality impacts, and social dynamics all contribute to the decision making of farmers towards best practice.

5.3.2 Implementing farm best practice

Despite heightened environmental awareness and management consideration, farmers in the Waikaka Catchment acknowledged that best practice was not always implemented. Farmers who work in harsh terrain, such as the hill country in the upper reaches of the Waikaka Catchment, cited that regular thunderstorms wash away entire slope faces and stock fencing. The practicalities of fencing off every stream, and in the headwaters, every gully that flows to the Waikaka Stream, would be very expensive and seem pointless for fences only to be washed away in the next storm. This practical issue exemplifies the need for more collaboration between farmers and regional councils. Environmental managers need to engage with farmers to address their concerns and help move past barriers to effective on-farm practice changes (Schusler et al., 2003, Prager, 2015). Community catchment groups have the potential to facilitate the engagement and communication between these stakeholders, to better consider all social, economic, and environmental factors in an ICM framework (Prager, 2015). The Waikaka Stream Catchment Group could work with Environment Southland to establish better ways for farmers to develop land so that their contaminant source areas are utilised for other uses, while the areas that have the capacity for intensification, can support the increase. Land management can be better targeted if farmers are given support and advice from regional government and other environmental management players.

Money can often be a barrier for any farmer looking to implement best practice management, due to many farmers taking on large amounts of debt to buy a farm, and therefore have limited spending funds (Fenemor et al., 2011). Most spare money is funnelled into increasing production so that the debt can be paid off. The collective attitude also impacts the likelihood of best practice being implemented. Farmers often become disheartened if they see neighbours or other farmers not implementing practices that have been recommended when they are. Implementing changes is difficult, timeconsuming, and costly, so if an individual perceives themselves to be the only one making such changes it is hard to stay motivated when it feels like it will make no overall difference to water quality. The catchment group may be able to better advise and assist farmers in where their money should be best invested for the most gain, alongside empowering farmers to work together on projects that benefit the catchment, reducing the individual cost per farmer. Collaboration such as this could be possible due to farmer thinking shifts towards environmental outcomes and assist in overcoming the barriers to good management implementation (Schusler et al., 2003).

5.3.3 Power and decision making

Decision making has been shifting over the last decade, and around the world it has become increasingly more decentralised (Cook et al., 2012). In many regions, decentralisation has contributed to the rise of local community volunteer groups. The response of groups empowered by the current decision-making framework is unknown, and there are questions around whether the support and assistance they will receive from regional authorities (Cook et al., 2013). Environment Southland has been very supportive of catchment groups, offering advice and backing where possible. Statutory groups have recognised value in community-led movements in moving towards ICM, resulting in an offer of support (Cook et al., 2012). However, it is unclear how the catchment group fits into the current environmental management structure, which still sees significant water quality troubles, despite decades of regulations and assessments in New Zealand's history.

Unlike New Zealand catchment boards from the 1970s, catchment groups have no regulatory power, or water monitoring responsibility (Knight, 2016). There is potential for catchment groups to try to re-invent the wheel, in terms of becoming modern-day catchment boards, only with less responsibility and decision-making authority (Cook et al., 2013). Catchment groups could represent an entirely new form of management, but if directions are not clear, their use could become void, causing groups to lose momentum at the lack of action (Cook et al., 2013). The group has no current authority, and the perceived lack of power results in catchment groups feeling redundant. However, the role of new catchment groups is to empower individuals to make change, particularly farmers in their management practices, and to use their connections to encourage participatory management as part of ICM. Their advantage is the existing social capital and trust between community members, which can be used for advocacy and information sharing, without the regulatory hand that many farmers resent of regional government (Fien and Skoien, 2010). Assigning catchment groups more authority may result in a limited reach into informal connections, which is a key part of a community group, and the strength that regional authorities do not have (Cook et al., 2013). Despite seeming to have no power, catchment groups have considerable influence as stakeholders in the environmental management discussion, especially if they are organised, focused, and informed. The agricultural industry is an influential stakeholder in New Zealand resource management decisions, and often sways decisions past the recommendations of scientists and research, exemplifying the social power that can be exercised in a democratic water governance system (Swyngedouw, 2009, Mitchell, 2020). However, that sway comes from multinational companies, and large national cooperatives, and thus catchment groups can serve as the forum for which to enable and formalise small landowner power.

As a comparison to the lack of authority that Southland catchment groups have, in the Hurunui Catchment community groups were given legislative power by Environment Canterbury to create the Canterbury Water Management Strategy (CWMS) in 2009. However, their plans were altered by Environment Canterbury, which left the catchment committee feeling as though their work had been wasted and undermined (Thomas et al., 2020). Having more standing was not effective in the Hurunui Catchment, as the group invested time, resources, and energy into a plan that was not utilised in the way they intended. It is unknown what would occur in the Waikaka Catchment and wider environmental sphere if community catchment groups were to be given more power. There are suggestions that it would be an unfair responsibility to give to those groups who have neither the resources nor authority to carry out a more regulatory purpose (Cook et al., 2012). In the Hurunui Catchment, more authority meant the group felt they could achieve some positive change, but ultimately power still lies with the regional authority, which is why their work on the CWMS could be changed and undermined. The role of catchment groups within the current environmental management framework in New Zealand needs to be clearer, to allow groups to function at full capacity. The management responses are the socio-political dynamics of the natural system and the human interactions with the system, therefore socio-hydrology is an essential framework to the freshwater management process (Swyngedouw, 2009). The power dynamics of freshwater management should be contested and not accepted, to ensure fair decision making by all stakeholders, including local Runanga, as they directly influence the hydro-social interactions, and would therefore address key environmental management challenges.

5.3.4 Where do regulations belong in New Zealand environmental management?

Regulations play a central role in New Zealand's current environmental management structure, and the emergence of catchment management groups brings forth questions of how those two structures operate alongside each other. The perceptions among farmers in the Waikaka Catchment is that current regulations are applied as too much of a blanket, when in fact they should be tailored towards each catchment's specific problems and needs (Mitchell, 2020). Participant 5 stated that "they've got a list of rules, and what we would say is you don't need a rule if our data is clean, but they're saying the rules have to be obeyed regardless," showing that because regional government look after such a large area, their focus is region-wide, which is reflected in their regulations. The community perceives their water quality to be good, and thus blanket regulations seem unnecessary to them, causing tension between individuals and local government, which leads to the challenge of scale, and the challenge of hidden water quality issues. All water quality indicators are exceeded at some point in space and time in the Waikaka Stream, reflecting the cumulative issue present with nutrient concentrations, which is a further challenge as previously discussed. Therefore regulations and bottom lines are important for the stream health to improve, but a major challenge lies in enforcing a catchment-wide regulation when the area is managed property by property, highlighting the importance of, and the gap that catchment groups should aim to fill. Absolute values are important to ensure that irreversible damage is not done to freshwater ecosystems, however, guideline values could be more targeted and specific, with increased consultation to establish community values, to ensure thresholds are appropriate and attainable. The goal of limit setting in New Zealand is to improve freshwater outcomes, so if stakeholders are not in agreeance to work towards those goals, the limits serve no purpose in environmental management, other than causing upset between government and community. Negotiation between stakeholders is essential to establishing associated freshwater values, and therefore suitable guidelines, which are constantly contested and changing in New Zealand. The changing nature of regulations in New Zealand poses a further challenge, as the lack of transparency alongside the complicated format that regulations are communicated makes it very difficult for communities to work towards. The expectations are not clear and are constantly updated and changed, creating a difficult task for community groups with limited social and financial resources.

The best management scenario would handle water quality issues at the farm and catchment scale, which, if reflected in policy and regulations, would make for more targeted environment management (Duncan, 2014). However, that approach is not feasible due to the scale of problems across the province that are managed by Environment Southland. There is potential for new catchment groups to plug a gap between the regional and local levels of governance in Southland, and potentially across the country. Current policy is based solely around numbers, which leaves out a very important socio-political element to environmental management (Duncan, 2014). Cultural and social dynamics have not typically factored into regulations from regional government, thus depoliticising the very political issues of water quality. Catchment groups may be a method of bringing that dimension into policy and decision making, for the benefit of the entire ecosystem, proving the usefulness of taking a socio-hydrology approach to research (Duncan, 2014, Anderson et al., 2019). The catchment group can bring into light the lack of democratic governance, and expose existing power relations that are often hidden by water management that focuses on economic competence through science and technology, removing politics and social components from the debate (Swyngedouw, 2009).

5.4 Evaluation of the study

5.4.1 Recommendations

The results of this study have identified key challenges to environmental management in the Waikaka Stream. The challenges include the disparity between the scale of monitoring and management. Monitoring is done at the catchment level and focuses on physically measurable but visually unattainable variables, where management is done at the farm scale, and perceptions are built from visual stream factors, creating a discrepancy in water quality understanding and opinion between local farmers and regional authorities. In turn, this discrepancy cause stakeholders to misunderstand the risks in the Waikaka Stream. Both monitoring and management lack the cultural consideration of Runanga. The wild deer and duck population creates a challenge by bringing to light the lack of responsibility placed on either the community or regional government. Community groups struggle to get farmer buy-in, limiting their ability to enact behaviour change. These challenges have informed recommendations to continue to improve freshwater management and ultimately the water quality of the Waikaka Stream. These recommendations will assist Environment Southland, the Waikaka Stream Catchment Group, and individual community members in their future endeavours to improve water quality and the agricultural footprint in Southland.

- Land practices and management should engage with adaptive management philosophies based on scientific research and known source areas, through attempting management practice and following up with monitoring to observe potential good outcomes. *E. coli* will continue to exceed guidelines unless pest control is undertaken in the upper reaches of the catchment. Where practical, recommended best practice management should be exercised, including fencing off waterways, closely monitoring fertiliser use, and providing buffer strips to reduce the impact of cumulative pollutants, and decrease the likelihood of bank collapses. Cultivation and intensive grazing should be minimised in steep areas to reduce the transport potential of contaminants. Farmers should endeavour to reduce intensification in areas that are high risk to the stream, while intensifying lower risk areas, to better target land use for the optimisation without adverse effects to the Waikaka Stream.

- The Waikaka Stream Catchment Group would benefit from establishing a formal structure and institutional framework for succession. An expanded committee would allow support to the chairperson and devolve workload amongst more community members, as well as offering a succession plan. The spread would also allow for the creation and development of more ideas, removing the pressure for action from one individual. Complete transparency in decision making would include all group members, but large groups can often be a barrier to progress, so a diverse committee would condense this issue while ensuring all community perspectives are brought to the decision-making table (Oliver, 2001).
- The group faces significant issues with farmer buy-in, where individuals do not engage because they perceive a lack of group action, and in turn, action is limited due to the lack of buy-in (Cook et al., 2012). To encourage collective action, catchment groups should engage with as many community members as possible, to build social capital and grow human resources and ideas. They also should diversify the voices within their group, including engaging Māori perspectives to capture their interconnected worldview in relation to environmental management. Runanga engagement is currently lacking and needs to be increased for accurate representation, and building of social capital and shared learnings.
- Catchment groups require further support and guidance from regional authorities and private business institutions to formulate their goals and action plans. Increased sharing of ideas between groups can be facilitated by designated authorities or institutions, to ensure that successes are shared and scaled out to other regions. One such area where guidance could be given is around monitoring that can be carried out by the community group, providing a higher resolution of water quality data. Institutions could also offer funding and support through resources to assist groups in moving forward with plans to better water quality. Environment Southland should continue to work with groups on education, to try and address the disconnect in water quality perceptions and scientific results.
- For improved management of freshwater in the Waikaka Stream, Weber *et al.* (2011) suggest that all stakeholders commit to non-statutory collaboration to

establish sustainable solutions that can then be implemented by Environment Southland, as was suggested for Environment Canterbury in local case studies. The same recommendation can be made in Southland catchments to ensure that decisions are based on all perspectives, and stakeholders build trust to be able to work more efficiently together for the benefit of the environment (Fien and Skoien, 2010) (Weber et al., 2011). Power dynamics will also be more balanced, resulting in a democratic freshwater management system. Stakeholders in the Waikaka Catchment should aim for small successes, which will offer tangible proof to the community that the process is effective, building trust and confidence between participants in the management process (Weber et al., 2011).

- More research is required into the nature of catchment groups in New Zealand, predominantly into their function within the current environmental management framework, due to the rapidly changing nature, and diversification of community catchment groups. Further research is needed into how catchment groups work with regional government, and where the balance lies between being involved in decision making, advocacy, awareness, and education. It is unclear how catchment groups can be most useful, and there is overlap potential with so many stakeholders becoming involved, leading to some groups becoming redundant, or duplicating the work of other institutions.

5.4.2 Limitations and future direction

One limitation of this study was the lack of detailed spatial data over time. Water quality records in the Waikaka Stream, date back to 1995 for some water quality variables, with more recent dates for others. The Environment Southland data, therefore, provides nearly 25 years of context for some variables, with shorter records for others, and does not account for the years prior to 1995. In this study samples were only collected monthly over a one-year period, resulting in a data set that only accounts for variation across a year. Any abnormal weather may have skewed results from the normal water quality levels at that time of year. The Environment Southland data fills that gap, but to a lower resolution than the data from this study. Monitoring should continue at as high a resolution as resources allow, to better establish hotspots of poor water quality that lie over safe levels to give the community a guide as to whether they need to make changes or continue a transitional pathway. Further detail in water sampling would also better identify the relationships between intrinsic characteristics of the land and water quality trends. The work is also limited by the lack of assessment of the ecosystem form and function including a macroinvertebrate index across the entire catchment.

Other data that would have been very useful to this research, to provide context and explanations, would have been extensive land use, and land management practice data. Specific land management data was not feasible to attain from all properties in the Waikaka Catchment, as there are over 140 properties in the area, many of which have changed ownership in the time in which land use and land management practice has also changed. Specifically, future research should aim to understand the sources of high sediment and *E. coli* levels in the headwaters. This would allow for characterisations as to whether they are natural levels or the result of agricultural practices, giving direction to stakeholders as to whether to focus on agricultural improvement, or if regulations should be reconsidered to reflect natural conditions. More thought should be put to interventions in the headwaters to protect streams, such as plantings, and wild deer and duck control.

Sampling practicalities meant that sampling was limited to river access points that were safe and practical to regularly take water samples from. Sampling sites were chosen according to criteria to ensure as best representation in sampling as possible, although the nature of the stream limited the extent to which this could be done. Efforts were made in the interview strategy to best represent the demographics of the catchment, although some perspectives may have been missed, namely those of Tangata Whenua. The lack of iwi perspective of the Waikaka, in local context, and relevance to Tangata Whenua is a major limitation. Cultural values are a key part of environmental management and freshwater management in New Zealand which is mandated in the NPSFM. Therefore, future work should aim to incorporate a cultural perspective within the catchment bounds to represent Runanga in freshwater and management perspectives.

6 Conclusion

The Waikaka Stream is a catchment with both an identified physical water quality issue, and a community with growing awareness of problems and a desire to take action to improve freshwater outcomes. A socio-hydrology lens was applied in this study, recognising the interconnectedness of the social, political, economic, and ecological systems. The aim of this study was to understand the contribution of community catchment management to wider environmental management in New Zealand, within a constantly evolving water quality setting. The research aim was addressed via a mixed methodological approach of water quality sampling and community interviews.

Six key challenges were identified through this study, including the difficulty of managing cumulative impacts, especially when regulations are aimed at the catchment scale while farmers operate at the individual property level. Wild populations also pose a challenge in establishing who is responsible for high contaminant concentrations that may not directly result from agriculture in the catchment. The catchment group formation process has also proved that there is a distinct lack of buy-in from farmers and community members into the collaborative management process. Improving landowner understanding of the hidden risk of water quality is a further challenge, as is the distinct lack of Tangata Whenua perspective in the Waikaka Stream. This study has suggested that the Waikaka Stream Catchment Group can be a vehicle to address these challenges if transparency and trust exists between all stakeholders involved in the freshwater management of the stream. The individuals within the catchment need to take collective responsibility, which means that all farmers in the catchment must be involved in the planning and implementation of management strategies. The group must work with support groups, utilising all knowledge and resources to the benefit of the collective, in an Integrated Catchment Management framework. This study posed three specific research aims, of which the main findings are summarised below.

Objective 1: *To investigate the spatial variability of the Waikaka Stream water quality through in-field sampling techniques, and to evaluate the representativeness of Environment Southland's single monitoring site.*

Based on current freshwater contaminant thresholds, the Waikaka Stream exhibits poor water quality, as variables exceed regulatory thresholds at multiple sites. The water quality index rates all sites except one in the 'poor' category, concurring with Environment Southland monitoring, which places the Waikaka Stream in the lowest quartile of lowland rural streams. Nutrients (nitrogen and phosphorus) showed high concentrations further down the catchment, while *E. coli* and sediment hotspots were recorded in the headwaters of the catchment. Nutrient trends are indicative of cumulative impacts, likely due to the impacts of agricultural management of the land, both historical and present day. Sediment and *E. coli* hotspots indicate that the source material may be the result of natural causes and wild populations in the hill country. The measured variability of water quality variables indicated that although the Environment Southland monitoring site represents the overall water quality leaving the catchment, it does not capture the nuances of the stream. The lack of spatial resolution leaves locals and environmental managers with a challenge of addressing a largely uncharacterised problem. The missing understanding creates a further challenge, as there are questions around where the responsibility for managing the catchment and improving the water quality lie, when monitoring is carried out at a catchment level, but management is done on the smaller farm scale.

Objective 2: *To explore community values and perceptions of water quality, how these compare to scientific results, and how they affect freshwater management.*

Community perceptions of water quality do not match the measured variables. The community generally perceives water quality to be 'good', acknowledging some issues, but overall believing the quality is fine. Farmers make their judgement of the water based on their own senses, recreational use, and understanding of good farm practice to conclude that the Waikaka Stream shows 'good' water quality. The observed discrepancy between perceived and actual water quality highlights a key environmental challenge, in making local communities understand the threat of hidden water quality issues and showing that further understanding is required to further address environmental issues. The divergence of understanding in the Waikaka Stream has led to distrust and upset, which makes the collaborative management process much more difficult, as social capital is lacking from which to build an integrated management framework. Legislative thresholds enforced on communities who perceive their water quality to be 'good' causes further issues in the relationship between communities and regional government. The misinterpretation of water quality by local farmers causes them to question the need for guidelines that restrict the operation of their farming business. The frustrated community, who receive negative media and social attention have therefore been motivated to form a community catchment group, indicating that farming communities are eager to take collective action towards their local freshwater management.

Objective 3: *To examine the role and function of community catchment groups in Southland, and their potential role as stakeholders in environmental management in New Zealand.*

The emergence of the Waikaka Stream Catchment Group indicates a perceived gap in current resource management, but the group offers a chance to build social capital and trust between stakeholders to work towards improving collaborative management in the catchment. There is potential for catchment groups to overlap work being carried out by Environment Southland, and as such clear and transparent communication between the two will help to direct the group to best function alongside other stakeholders, for the best outcomes for the Waikaka catchment. The groups' predominant role is to offer support to farmers, alongside educating and informing the community with the support of governmental and industry stakeholders. Future management requires consideration and inclusion of all types of knowledge, to ensure that all stakeholders are involved in the process, including tangata whenua, who are currently underrepresented in the Waikaka Catchment. Further engagement within the catchment must be encouraged, and public participation must reach as widely as possible, to best ensure collaborative success towards Integrated Catchment Management. The catchment group must continue to establish a formal structure, to ensure longevity and clear goals to work towards, inspire action, and further outreach into the community. The groups' predominant role is to offer support to farmers, alongside educating and informing the community with the support of governmental and industry stakeholders.

The future of the Waikaka Stream depends on the ability of stakeholders to come together to establish goals for the catchment, values that must be considered in management, and therefore practical measures that can be taken to improve freshwater in the catchment. This study has contributed a greater understanding of the interactions between humans and the natural environment in the Waikaka Stream, leading to targeted recommendations for future management in the catchment.

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8 Appendix

Appendix A: Ethics Application

UNIVERSITY OF OTAGO HUMAN ETHICS COMMITTEE APPLICATION FORM: CATEGORY B

1. **University of Otago staff member responsible for project:**

   Dr Sarah Mager
   Dr Sean Connelly

2. **Department/School:**

   The School of Geography

3. **Contact details of staff member responsible:**

   Email: sarah.mager@otago.ac.nz
   Tel: x4222
   Email: sean.connelly@otago.ac.nz
   Tel: x8771

4. **Title of project:**

   A mixed methodological approach to understanding water quality in the Waikaka Stream, Southland, New Zealand

5. **Indicate type of project and names of other investigators and students**:

Staff Researcher	**Names**	Dr Sarah Mager
		Dr Sean Connelly
Student Researcher	**Names**	Jessica McIntyre
Level of Study		Masters

6. When will recruitment and data collection commence?

Beginning of June 2019

When will data collection be completed?

End of September 2019

7. Brief description in lay terms of the aim of the project, and outline of the research questions that will be answered:

Environment Southland (ES) monitor water quality at a single point in the Waikaka Catchment and characterise the water quality as 'very poor'. However, little is known about the spatial and temporal variation of water quality in the Waikaka Stream, as ES do not monitor more than a single point within the catchment. As such, there may be considerable variations in nutrients across the catchment that reflect either different sources of contaminants, or different critical source areas that might be targeted for mitigation. In light of frustrations and uncertainties about how to implement change and respond to regulatory limits, a community-led catchment group has formed in the catchment, in response to the perceived water quality problem.

The aim of this research is to address water quality issues in the Waikaka Stream using a mixed methodology. In doing so, water quality perceptions will be investigated, to understand the community perspective of their local water quality. The formation of the catchment group will be investigated to understand potential management approaches, and future trajectory for water quality in the catchment. These qualitative data will be combined with a more detailed catchment wide assessment of water quality, to collate a catchment-wide perspective on the Waikaka catchment. To address these points, four research questions have been formulated:

1) What are the current concentrations of nitrogen, phosphorus, sediment and *E. coli* in the Waikaka Stream, and how do they vary spatially and temporally?
2) What are the critical source areas in the Waikaka Catchment, and how are contaminants being transported from their sources to the waterways?
3) What are the community perceptions of water quality, and what are the concerns regarding water quality?
4) What is the role of the Catchment Group in management of the Waikaka Stream, why has the group formed, and what is the future of management including the Catchment Group?

8. Brief description of the method.

Catchment Surveys:

To obtain an understanding of the farm dynamics across the Waikaka Catchment, surveys will be sent out, asking farmers in the area about their farm type and management practices. The surveys will assess the demographics of those in the catchment, and their length of time spent living and working in the catchment. The surveys will be sent out by the Catchment Group Chairperson, and the data will be held by the group. The researcher will help to co-ordinate this and use the resultant information as a data source. All information will be anonymised, so that farmer information cannot be linked to any one individual. This information will be used to gain an overall understanding of the social dynamics of the farming community in the Waikaka Stream catchment.

Farmer Interviews:

Semi-structured interviews will be conducted with farmers in the Waikaka Catchment. Semi-structured interviews will focus on pre-determined broad themes but will not follow a script of written questions to allow for a more natural conversation and to be responsive to participant’s interests and responses and to avoid leading the participants to pre-determined answer. It will also allow for open discussion around many aspects of management in the Waikaka Stream, and the newly formed catchment group. The interviewer will use an interview guide to ensure that the important topics are discussed, as a way of guiding the conversation to best meet the research objectives.

The interviewees will be farmers who live in the Waikaka Catchment, and will include a mix of farming types, reflective of the farm type distribution across the wider catchment. Participants will be identified mainly through snowball sampling, with the use of the

Catchment Group member list as a sampling frame. The sampling frame will allow for a distribution of farmers spatially across the catchment. Approximately 10 farmers will be interviewed. The farmers will be asked to reflect on their experience in the catchment, and their observations of the Waikaka Stream over time. They will be asked about their perceptions of water quality, along with any testing they have had done on their property. They will also be asked about their management practices, and how they think management affects water quality. As members of the catchment group, they will be asked why they wanted to join the group, and what they see as the best use of the catchment group, and therefore, what they would like to see the group doing in the future.

The researcher has grown up in this area and so has an established base of contacts. Her family is involved in the community catchment group, including her father who serves as the chairman of this group.

Informed consent is an important part of the research and will be obtained with all participants. Each participant will be provided with an Information Sheet which states the key information requirements surrounding the research including the aims and objectives of the project and how the data will be used. The Information Sheet will inform each participant that the School of Geography has given approval for the broad themes and topics (as outlined above and in Appendix), but the Committee has not reviewed the specific questions to be asked.

The interviews for all participants will be recorded with the permission of each interviewee. Participants will be free to withdraw from the interview at any stage and may refrain from answering any question (s) posed to them by the researcher. It will also be made known to them that they can withdraw their data up until the 31st October, 2019. All data gathered through interviews (e.g. recordings and transcription), will be stored on a computer with secure password protection, only accessible by the researcher and their supervisors. Once the research has been completed, the MSc thesis will be available for public viewing, and the results will be presented back to the Waikaka Stream Catchment Group.

9. Disclose and discuss any potential problems and how they will be managed:

All informants will be made aware that they will remain anonymous as much as possible, so that no one individual can be identified. They will be informed that although their names will not be mentioned, the nature of a small community may mean that some people may be identified by what they have said in their interview, although this will be minimised as much as possible. They will also be made aware that their data will be kept secure, and only accessible by the researcher and their supervisors.

There is also the potential for conflict of interest as the student lives in the catchment, and so may be biased towards certain views in the community. This also means that the researcher has a connection to many individuals in the catchment who will be participants. To address the potential of conflict of interest, the researcher will be conscious of potential bias in the writing up of data and engage with participants in an open and neutral manner, so as not to lead participants to any predetermined answer. The researcher acknowledges that because of her close links to this community and group, there might be some people who feel obliged to take part in interviews even though they may not wish to. The researcher will attempt to remove any sense of obligation from participants by assuring them that there is no necessity for anyone to participate if they do not feel comfortable to do so.

Health and safety protocol according to the School of Geography will also be followed on all field work. Health and safety plans will be submitted to the School prior to field work commencing to be approved.

Applicant's Signature: ....

Name (please print): …………………………………………………….

Date: ....

ACTION TAKEN

☐ Approved by HOD ☐ Approved by Departmental Ethics Committee

☐ Referred to UO Human Ethics Committee

Signature of Head of Department*:* ....

Name of HOD (please print): …………………………………………………….

Date: ....

Departmental approval: *I have read this application and believe it to be valid research and ethically sound. I approve the research design. The research proposed in this application is compatible with the University of Otago policies and I give my approval and consent for the application to be forwarded to the University of Otago Human Ethics Committee (to be reported to the next meeting).*

Appendix B: Information Sheet for Participants

A Mixed Methodological Approach to Understanding Water Quality in the Waikaka Stream, Southland, New Zealand

INFORMATION SHEET FOR PARTICIPANTS

Thank you for showing an interest in this project. Please read this information sheet carefully before deciding whether to participate. If you decide to participate, we thank you. If you decide not to take part, there will be no disadvantage to you, and we thank you for considering our request.

What is the Aim of the Project?

This study is being conducted as part of the requirement for a Master of Science in environmental management, through the School of Geography at the University of Otago. The overall aim of the research is to identify the potential approaches for management in the Waikaka Stream catchment. It will do this by monitoring physical water quality, and investigating water quality perceptions of the community, considering changes in space and over time. The research also aims to understand the motivations behind the formation of the Waikaka Stream Catchment Group, and to assess the future plans for the group, as well as identify potential actions to mitigate any water quality problems in the Waikaka Stream.

Participant Information

Participants are farmers who live in the catchment and belong to the catchment group. Participants will be recruited through contacts in the catchment. The results of the research will be available through the catchment group, as a resource for them.

What will Participants be asked to do?

If you agree to take part in this project, you will be asked to participate in a semi-structured interview with the researcher. You will be asked about your perceptions of water quality in the Waikaka Stream, as well as about your on-farm management practices, and your involvement with the Waikaka Stream Catchment Group. The precise questions are not set, as the project involves an open-questioning technique, and so questions will evolve with the interview, but the broad nature of the topics are those above. The School of Geography has given approval for the broad themes and topics to be discussed, but the Ethics Committee has not reviewed the specific questions to be asked. The interviews are expected to take approximately 60 minutes.

If at any stage you feel uncomfortable, you have the right to not respond to a question or stop the interview completely. Please be aware that you may decide not to take part in the project without any disadvantage to yourself. You are able to withdraw your data from the study up until October 31st, 2019.

What Data or Information will be collected and what use will be made of it?

Written notes may be taken during the interview, and with your permission the interview will be audio recorded. The data that is collected will be stored on a secure computer at the University of Otago, only accessible by the researcher and their supervisors. The interview will be transcribed, and the data will then be processed, for use by the researcher in their thesis. Data obtained through the research will be retained for at least 5 years in secure storage. At the completion of the project, any personal information will be destroyed immediately (including audio recordings). Personal information may include personal details such as age and gender, and information about the individual's farm, and farm management practices. However, the data gained from the research (in most cases) will be kept for much longer or possibly indefinitely.

Direct quotes may be used to provide evidence supporting key points made in publications. Every effort will be made to ensure that individual identities are not revealed, and that anonymity is preserved, although this cannot be guaranteed. Results of this research may be published and will be available in the University of Otago Library (Dunedin, New Zealand) but you will not be identifiable in these publications. If you would like, a copy of the final report can be made available to you. The results will contribute towards a written thesis, and a report will be given to the catchment group. The study is partly funded by the New Zealand Hydrological Society (Hydrosoc), and as such the results from the research will be presented in the Hydrosoc 2019 conference.

Can Participants change their mind and withdraw from the project?

You may withdraw from participation in the project at any time during the interview without any disadvantage to yourself. You may withdraw your data up until the 31st October 2019.

What if Participants have any Questions?

If you have any questions about our project, either now or in the future, please feel free to contact either:

Jessica McIntyre
School of Geography
0278157387
Mcije355@student.otago.ac.nz

Sarah Mager
School of Geography
+64 3 479 4222
Sarah.mager@otago.ac.nz

Sean Connelly
School of Geography
+64 3 479 8771
Sean.connelly@otago.ac.nz

This study has been approved by the Department stated above. However, if you have any concerns about the ethical conduct of the research you may contact the University of Otago Human Ethics Committee through the Human Ethics Committee Administrator (ph +643 479 8256 or email gary.witte@otago.ac.nz). Any issues you raise will be treated in confidence and investigated and you will be informed of the outcome.

Appendix C: Consent Form for Participants

A Mixed Methodological Approach to Understanding Water Quality in the Waikaka Stream, Southland, New Zealand

CONSENT FORM FOR PARTICIPANTS

I have read the Information Sheet concerning this project and understand what it is about. All my questions have been answered to my satisfaction. I understand that I am free to request further information at any stage.

I know that:

1. My participation in the project is entirely voluntary.

2. Personal identifying information [audio recordings] will be destroyed at the conclusion of the project but any raw data on which the results of the project depend will be retained in secure storage for at least five years.

3. This project involves an open-questioning technique. The general line of questioning is aimed at water quality perceptions, farm management practices, and catchment group involvement. The precise nature of the questions has not been determined in advance but will depend on the way the interview progresses.

4. In the event that the line of questioning develops in such a way that I feel hesitant or uncomfortable I may decline to answer any particular question(s) and/or may withdraw from the project without any disadvantage of any kind, by the 31st October, 2019.

5. The results and findings of this research will be presented to participants through the catchment group in the form of a report. They will also be presented in a thesis, and at the 2019 Hydrological Society Conference.

6. The results of the project may be published and will be available in the University of Otago Library (Dunedin, New Zealand) but every attempt will be made to preserve my anonymity.

I agree to take part in this project.

....

(Signature of participant) (Date)

……………………………………………………………….
(Printed Name)

Appendix D: Participant Semi-structured Interview Guide

A Mixed Methodological Approach to Understanding Water Quality in the Waikaka Stream

Section 1: Introduction

- What type of farm do you own?
    - What is the size of the farm/what are your stock numbers?
- How long have you farmed here?
    - How long have you lived in the catchment?

Section 2: Water Quality Perceptions

- What do you think about the local water quality?
- Have you seen any changes in water quality over the years you have farmed here?
- Do you think water quality changes at different times of the year/at different locations along the stream?
- Have you ever had any water quality tests done?

Section 3: On Farm Management

- Have you seen water quality change in response to on farm management practices?
- Do you have any form of environmental plan?
- Do you use any tools for management? Eg apps, Overseer etc

Section 4: Critical Source Areas

- Can you identify critical source areas on your farm?

Section 5: Management

- What are your thoughts on the governance of the Waikaka Stream?
    - What is good about current management in the stream?
    - Where are the gaps in management?

Section 6: Catchment Group

- Why did you want to get involved with the catchment group?
- What would you like to see the catchment group doing?
    - What do you want the outcomes of the catchment group to be?

Section 7: Broader Perspective

- What do you think the trajectory is for the future of the Waikaka Stream?
- Do you think issues facing the Waikaka Stream are the same across the province, and across the country?

Appendix E: Turbidity and Suspended Sediment Relationship

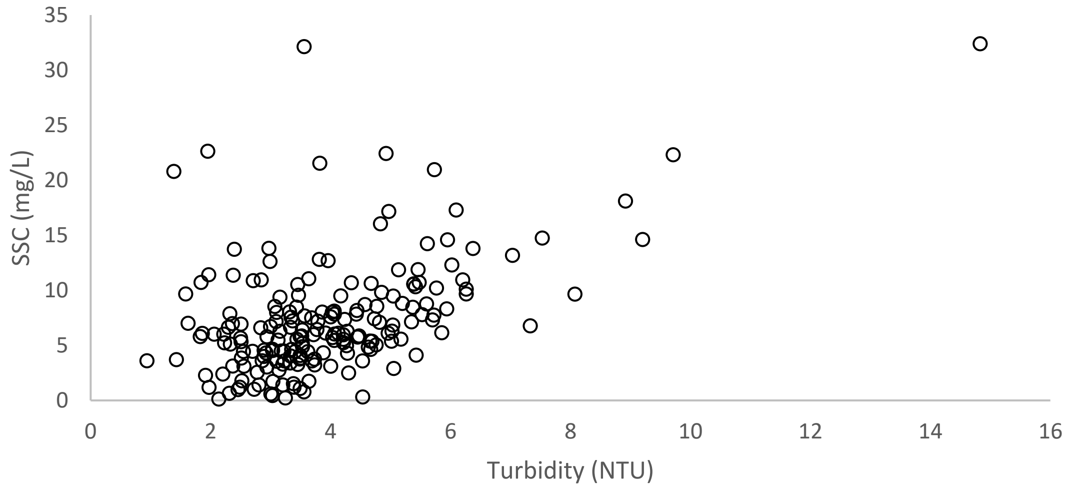


Figure 8.1: Scatterplot of turbidity (NTU) measurements against SSC (suspended sediment concentration).

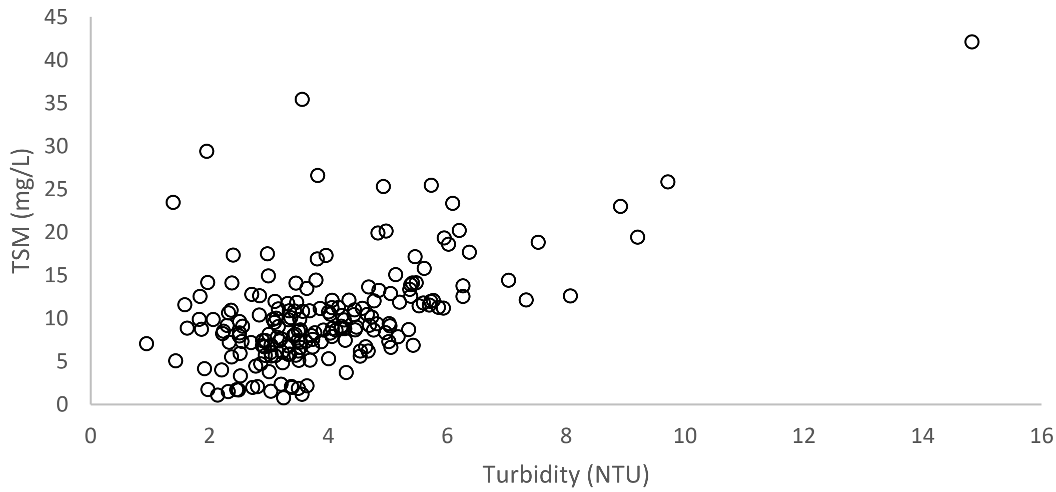


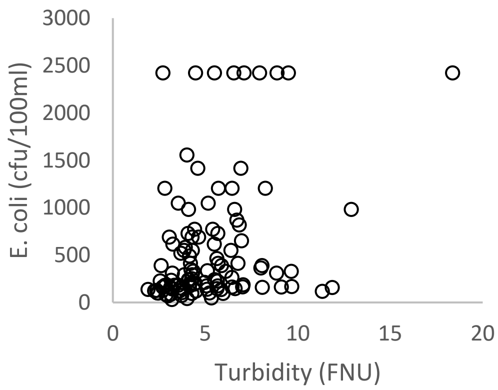
Figure 8.2: Scatterplot of turbidity (NTU) measurements against TSM (total suspended material).

Table 8.1: Correlation coefficients and P values for the correlations between SSC and Turbidity, and TSM and Turbidity

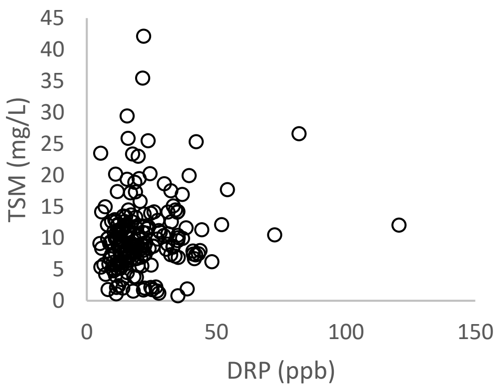
Variables correlated	Kendall's Correlation Coefficient	P value (significance)	Number of samples
SSC and Turbidity	0.307	0.00	192
TSM and Turbidity	0.330	0.00	192

Appendix F: Correlation Graphs

A)



B)



C)

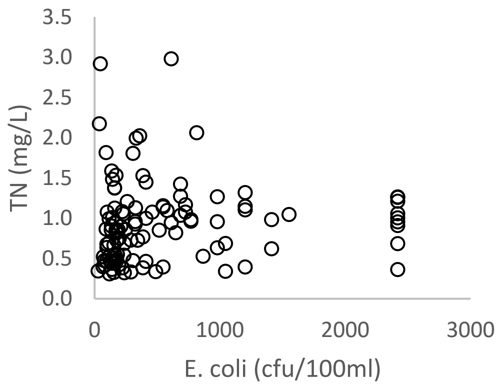


Figure 8.3: Scatterplots show correlations between water quality variables. A) Correlation between turbidity (FNU) and E. coli (where instrument saturation is 2419.6) B) Correlation between dissolved reactive phosphorus (ppb) and total suspended material (mg/L) C) Correlation between E. coli (where instrument saturation is 2419.6) and total nitrogen (mg/L).

Appendix G: Cluster Analysis Results

Table 8.2: Site characteristics, including the distance from the confluence, physiographic zone, geology, and soil type. The resultant clusters of hierarchical cluster analysis are identified by shading.

Site Number	Distance from Confluence (km)	Physiographic Zone	Geology	Soil Type
1	59.6	Riverine – fed by bedrock/hill country	IQa – Late Quaternary alluvium and colluvium	Recent (fed by brown)
2	52.2	Riverine – fed by bedrock/hill country	Tc – Triassic sedimentary rocks	Brown
3	40.5	Riverine – fed by bedrock/hill country	IQa - Late Quaternary alluvium and colluvium (border of OleM – Oligocene to Miocene marine rocks Eastern Province (Caples Terrane))	Recent (fed by pallic)
4	33.7	Gleyed – fed by bedrock/hill country and lignite-marine terraces	IQn – Late Quaternary terrace cover and beach deposits	Recent (fed by pallic)
5	26.9	Oxidising – fed by gleyed and lignite-marine terraces	IQn - Late Quaternary terrace cover and beach deposits	Recent (fed by pallic)
6	27.0	Oxidising – fed by gleyed	IQn - Late Quaternary terrace cover and beach deposits	Recent (fed by pallic)
7	27.7	Oxidising – fed by gleyed	IQn - Late Quaternary terrace cover and beach deposits	Recent (fed by pallic)
8	22.1	Gleyed – fed by gleyed (small parts oxidising)	IQn - Late Quaternary terrace cover and beach deposits	Recent (fed by pallic)
9	21.1	Oxidising – fed by gleyed	IQn - Late Quaternary terrace cover and beach deposits	Recent (fed by pallic)
10	21.5	Oxidising – fed by gleyed	IQn - Late Quaternary terrace cover and beach deposits	Recent and gley (fed by pallic)
11	18.4	Oxidising – fed by gleyed	IQn - Late Quaternary terrace cover and beach deposits	Recent (fed by pallic and gley)
12	13.0	Oxidising – fed by gleyed	IQn - Late Quaternary terrace cover and beach deposits	Recent (fed by pallic)
Key	Cluster 1	Cluster 2	Cluster 3	Cluster 4

Site Number	Distance from Confluence (km)	Physiographic Zone	Geology	Soil Type
13	12.9	Oxidising – fed by gleyed	IQn - Late Quaternary terrace cover and beach deposits	Recent (fed by pallic)
14	6.2	Gleyed – fed by lignite-marine terraces and gleyed and oxidising	IOIMe - Oligocene to Miocene marine rocks Eastern Province (Caples Terrane)	Recent (fed by pallic)
15	6.2	Gleyed– fed by lignite-marine terraces and gleyed and oxidising	IOIMe - Oligocene to Miocene marine rocks Eastern Province (Caples Terrane)	Recent (fed by pallic)
16	0.4	Riverine – fed by all types bar bedrock	IQn - Late Quaternary terrace cover and beach deposits	Recent (fed by pallic)
Key	Cluster 1	Cluster 2	Cluster 3	Cluster 4

Table 8.3: Rotated component matrix table resulting from PCA (Principle component analysis). The rotation method used was varimax with Kaiser Normalization and the rotation converged into 3 iterations.

Variable	**Component**	
	1	**2**
TSM	0.919	-
E. coli	0.909	-
Total coliforms	0.877	-
SSC	0.864	-
Turbidity (NTU)	0.809	0.311
POM	0.793	-
TN (ppm)	-	0.975
TP (ppb)	-	0.919
DRP (ppb)	-	0.860
NH4+ (ppm)	-	0.857
NO3 (ppm)	-	0.765

Appendix H: Environment Southland Data Over Study Period

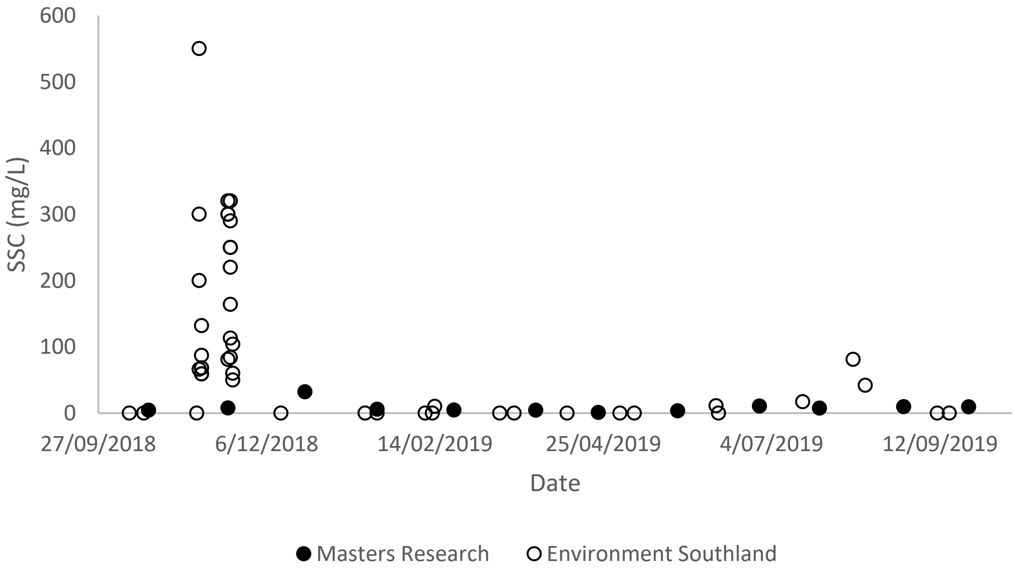


Figure 8.4: Scatterplot of suspended sediment concentration over the sampling period, as recorded by this study (site 16, closest to the ES monitoring point), and Environment Southland.

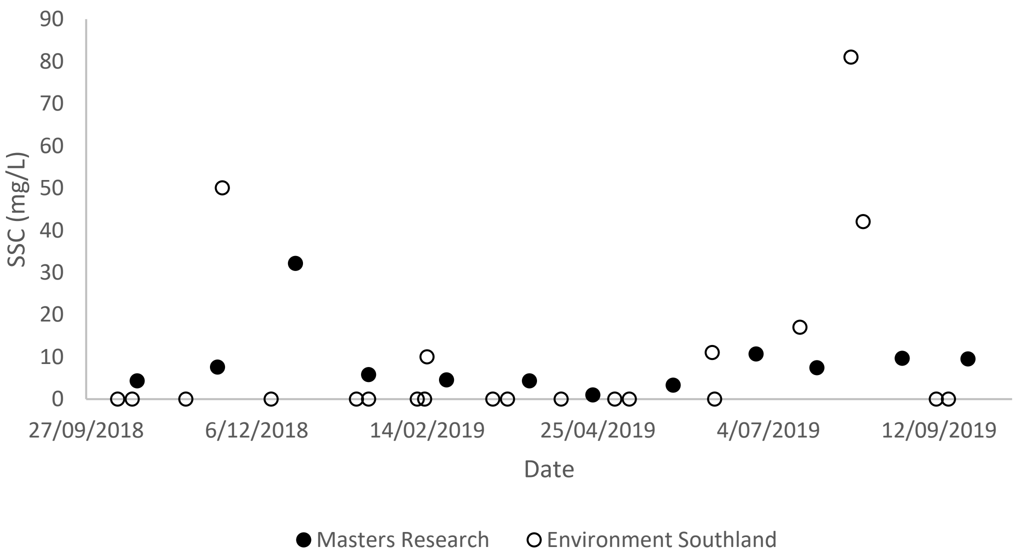


Figure 8.5: Scatterplot of suspended sediment concentration over the sampling period, as recorded by this study (site 16, closest to the ES monitoring point), and Environment Southland. Data is adjusted to only represent base flow, rather than event flow.

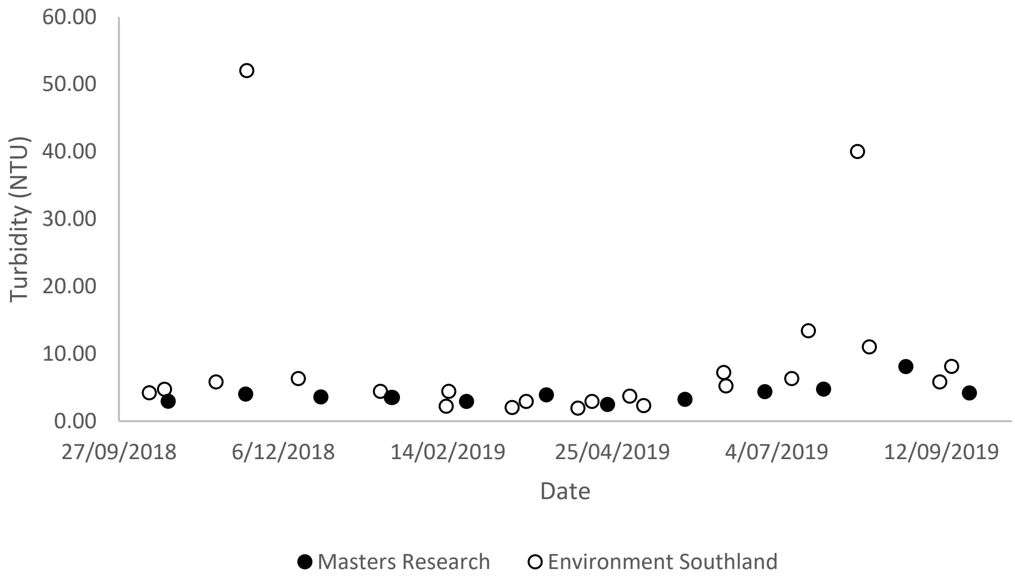


Figure 8.6: Scatterplot of turbidity over the sampling period, as recorded by this study (site 16, closest to the ES monitoring point), and Environment Southland.

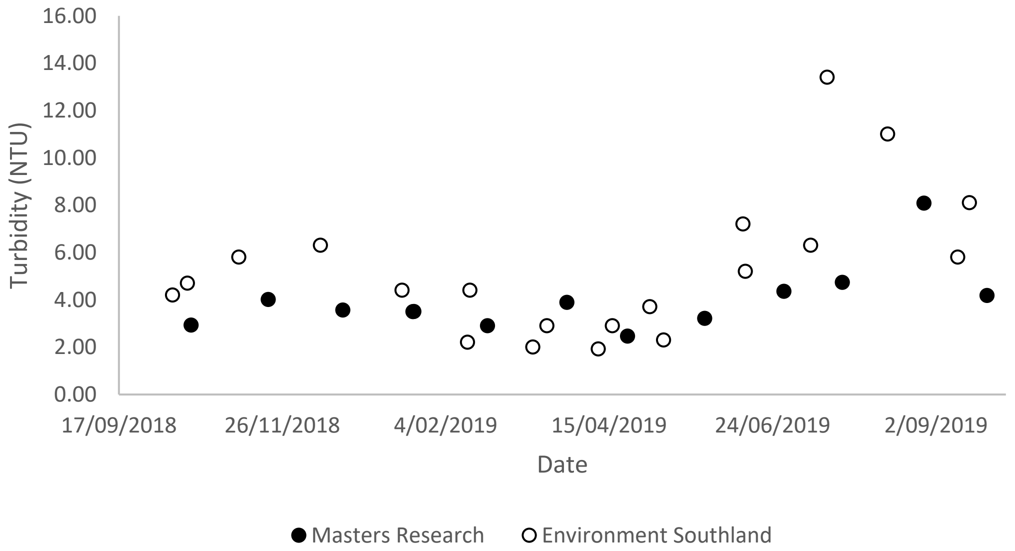


Figure 8.7: Scatterplot of turbidity over the sampling period, as recorded by this study (site 16, closest to the ES monitoring point), and Environment Southland. Data is adjusted to only represent base flow, rather than event flow.

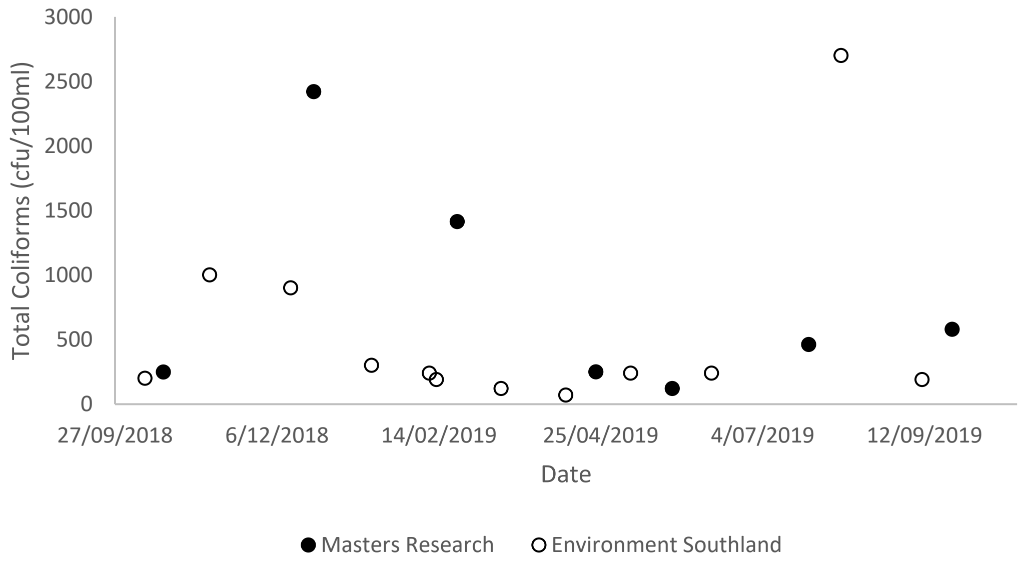


Figure 8.8: Scatterplot of total coliforms over the sampling period, as recorded by this study (site 16, closest to the ES monitoring point), and Environment Southland.

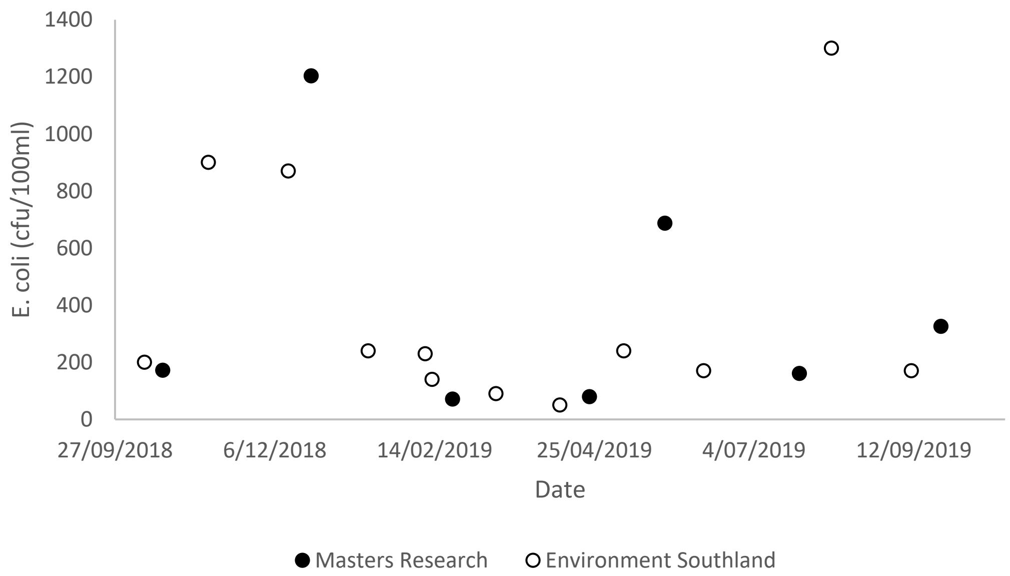


Figure 8.9: Scatterplot of E. coli over the sampling period, as recorded by this study (site 16, closest to the ES monitoring point), and Environment Southland.

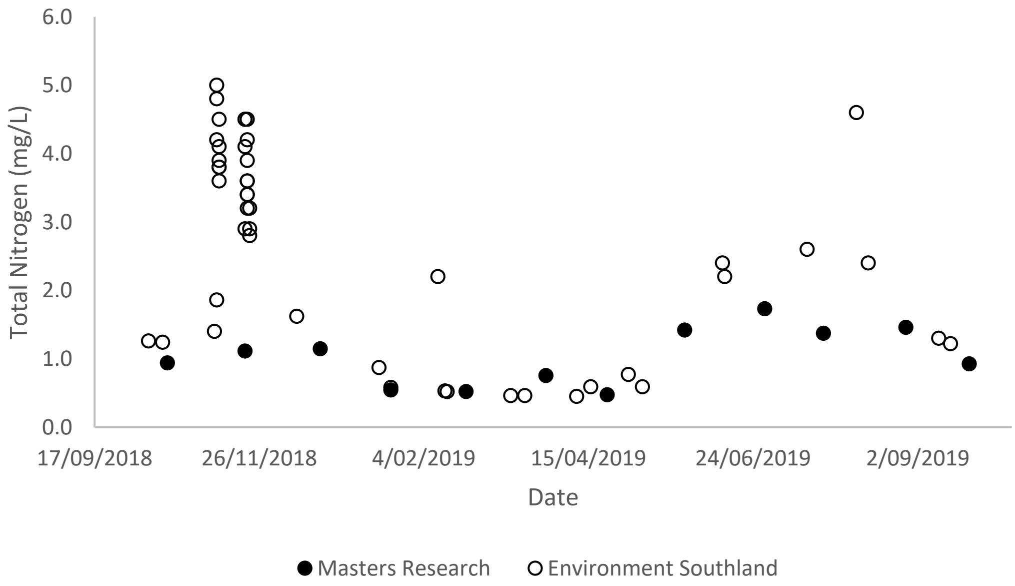


Figure 8.10: Scatterplot of total nitrogen over the sampling period, as recorded by this study (site 16, closest to the ES monitoring point), and Environment Southland.

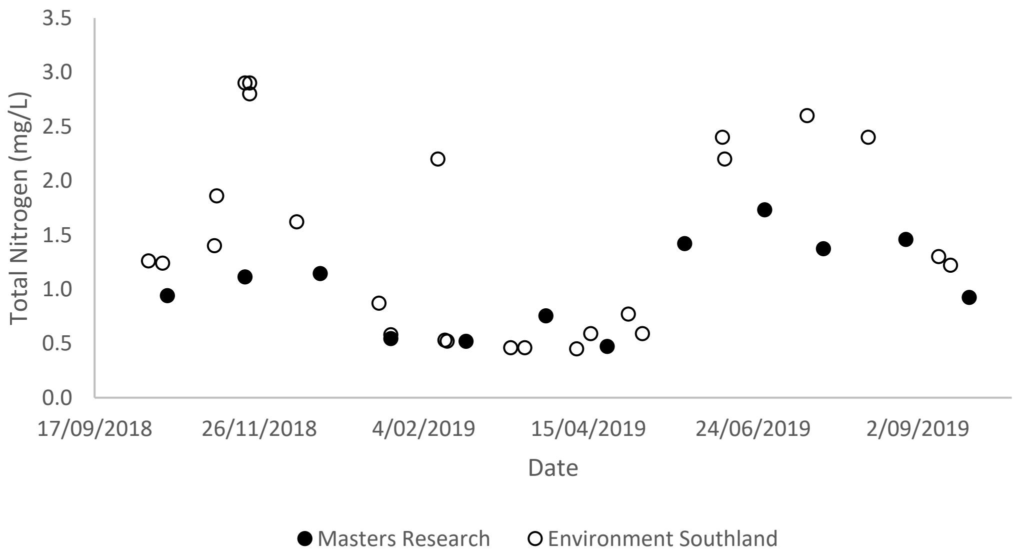


Figure 8.11: Scatterplot of total nitrogen over the sampling period, as recorded by this study (site 16, closest to the ES monitoring point), and Environment Southland. Data is adjusted to only represent base flow, rather than event flow.

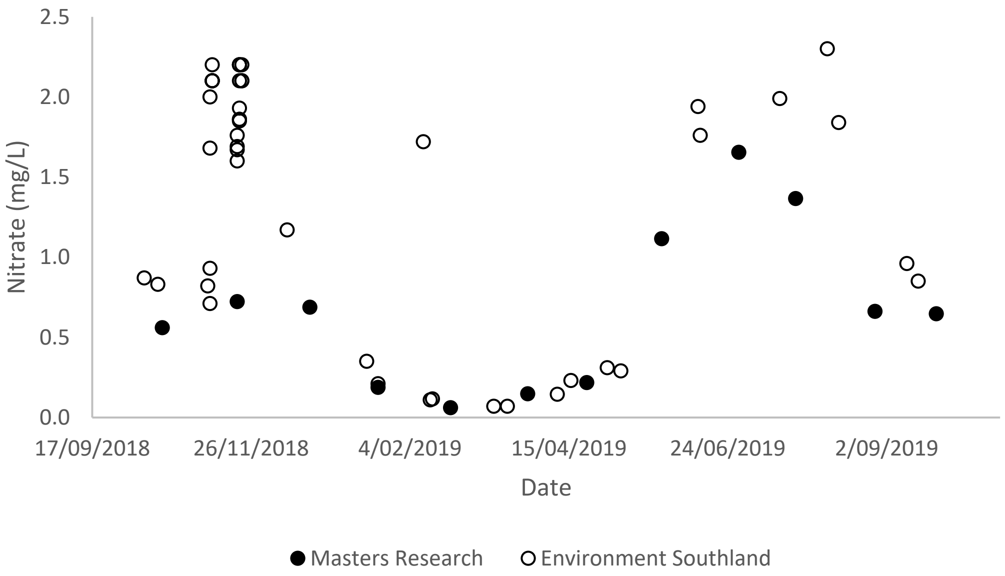


Figure 8.12: Scatterplot of nitrate over the sampling period, as recorded by this study (site 16, closest to the ES monitoring point), and Environment Southland.

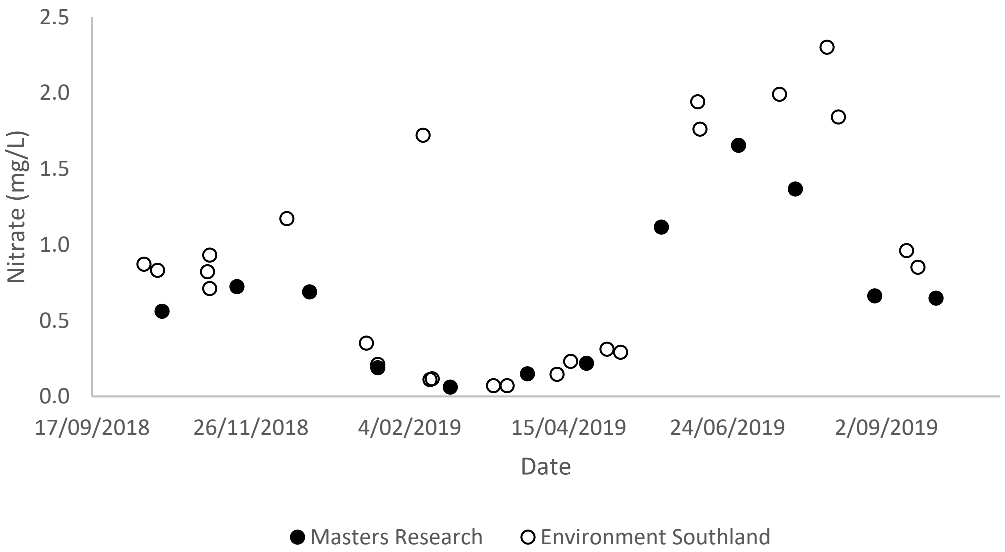


Figure 8.13: Scatterplot of nitrate over the sampling period, as recorded by this study (site 16, closest to the ES monitoring point), and Environment Southland. Data is adjusted to only represent base flow, rather than event flow.

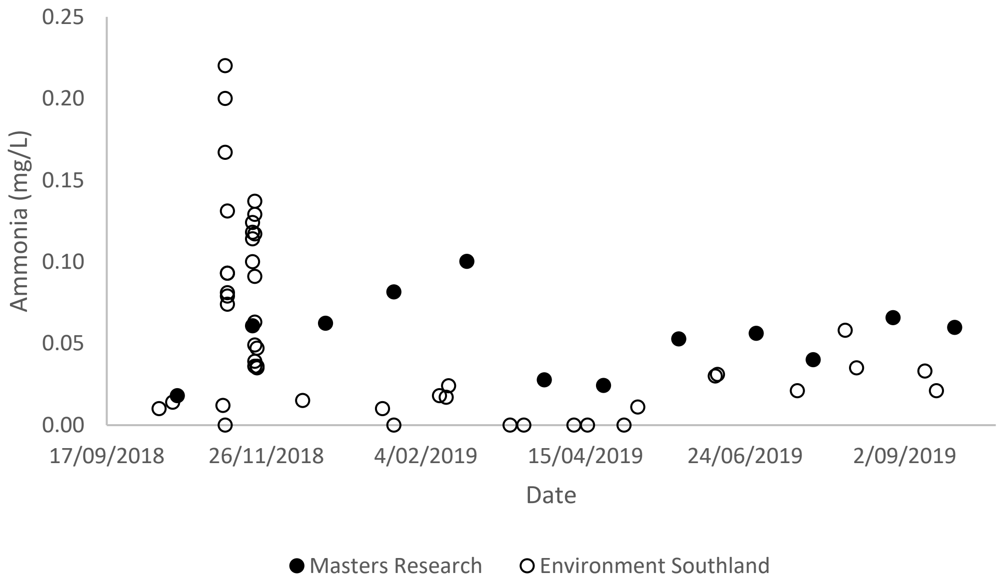


Figure 8.14: Scatterplot of ammonia over the sampling period, as recorded by this study (site 16, closest to the ES monitoring point), and Environment Southland.

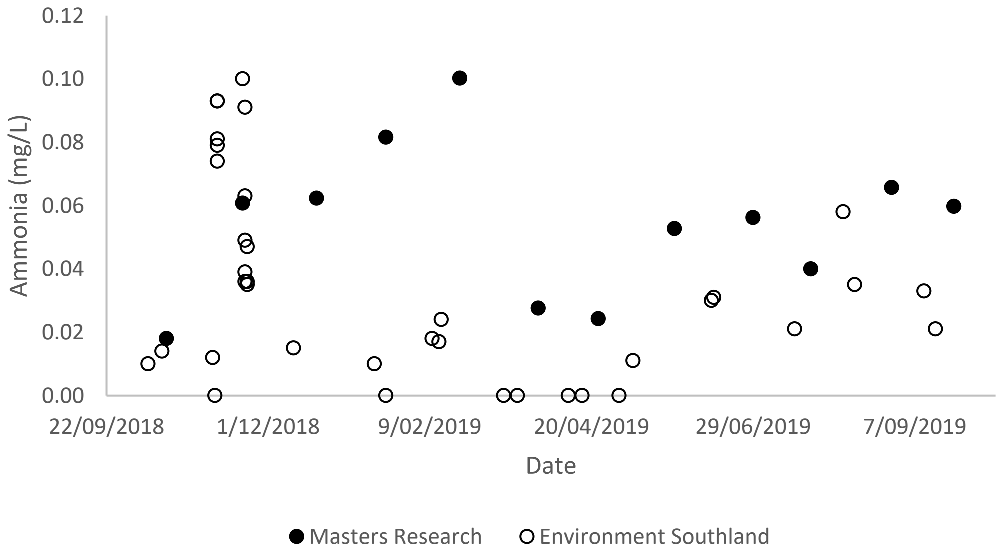


Figure 8.15: Scatterplot of ammonia over the sampling period, as recorded by this study (site 16, closest to the ES monitoring point), and Environment Southland. Data is adjusted to only represent base flow, rather than event flow.

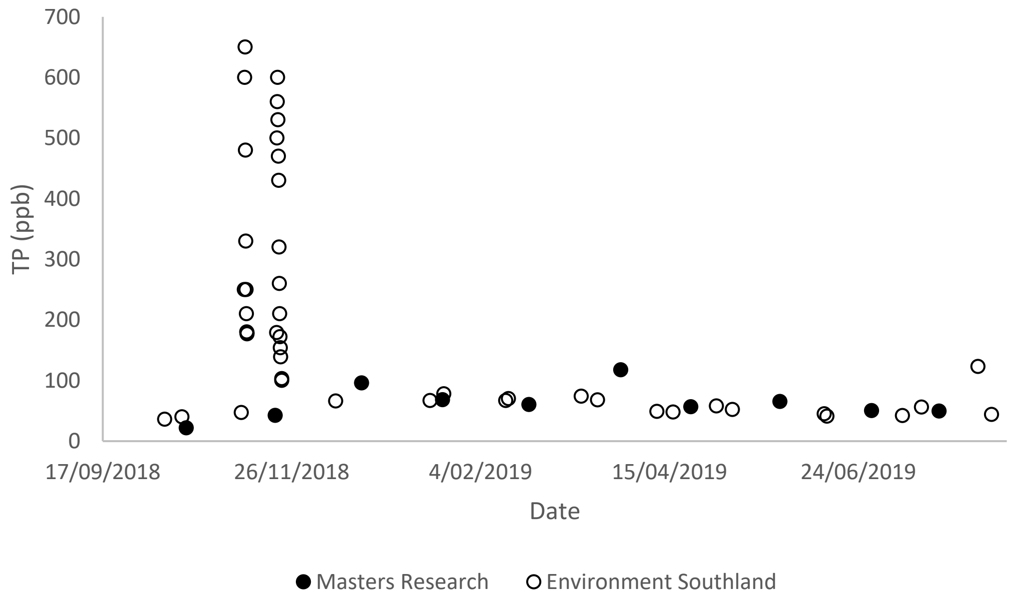


Figure 8.16: Scatterplot of total phosphorus over the sampling period, as recorded by this study (site 16, closest to the ES monitoring point), and Environment Southland.

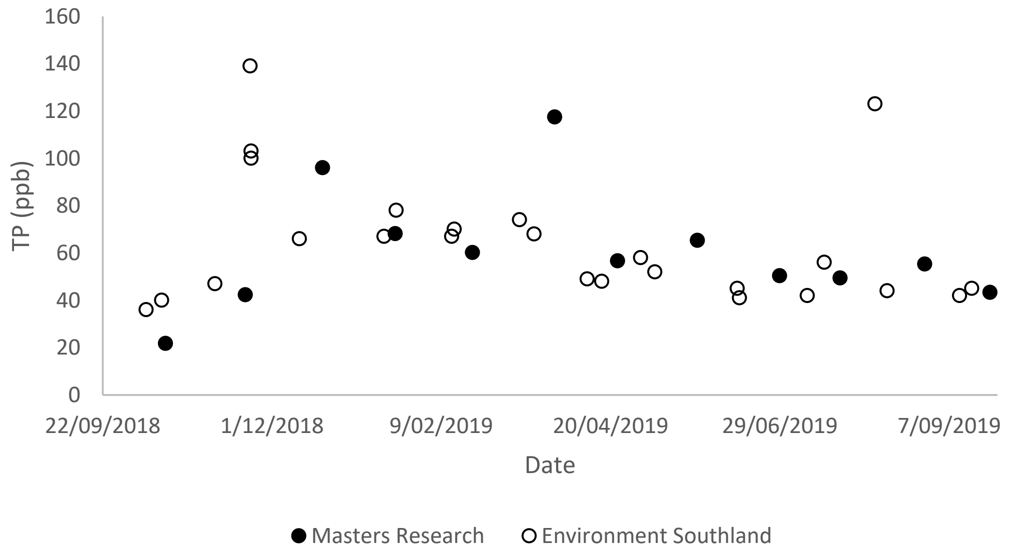


Figure 8.17: Scatterplot of total phosphorus over the sampling period, as recorded by this study (site 16, closest to the ES monitoring point), and Environment Southland. Data is adjusted to only represent base flow, rather than event flow.

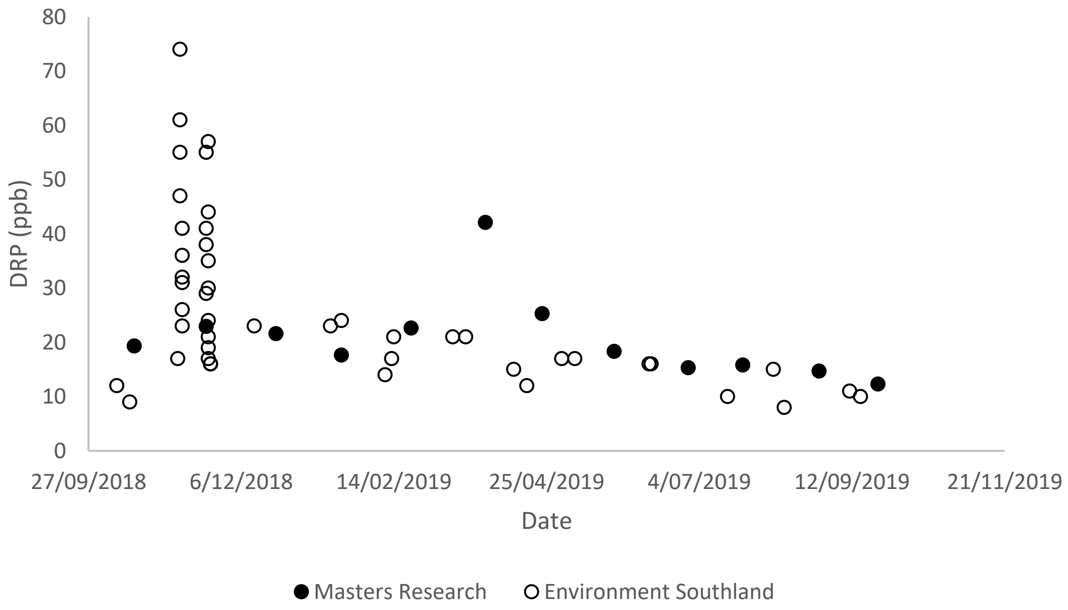


Figure 8.18: Scatterplot of dissolved reactive phosphorus over the sampling period, as recorded by this study (site 16, closest to the ES monitoring point), and Environment Southland.

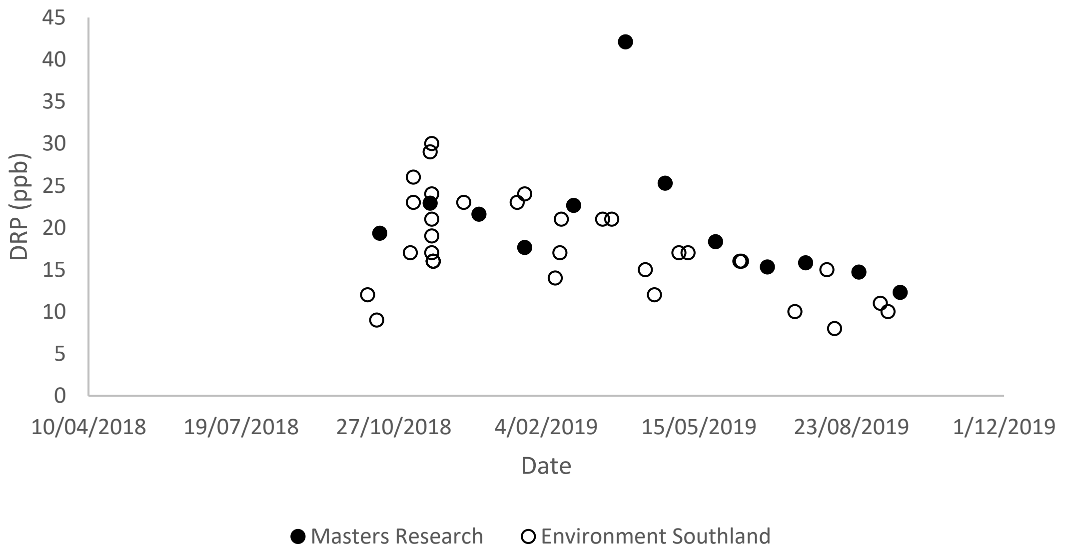


Figure 8.19: Scatterplot of dissolved reactive phosphorus over the sampling period, as recorded by this study (site 16, closest to the ES monitoring point), and Environment Southland. Data is adjusted to only represent base flow, rather than event flow.

Appendix I: Historical Waikaka Stream Data

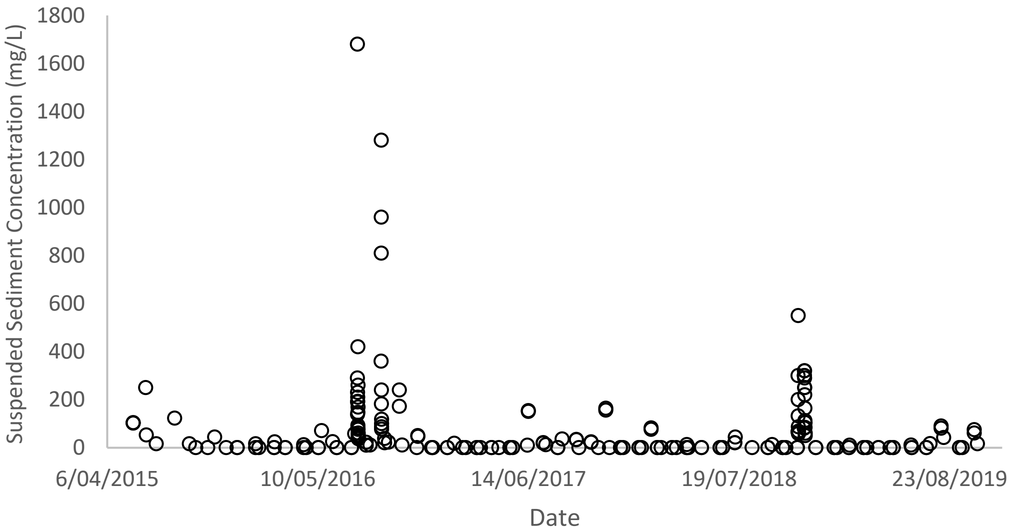


Figure 8.20: Time series graph of the historical suspended sediment concentration in the Waikaka Stream, based off the Environment Southland monitoring site at the bottom of the catchment.

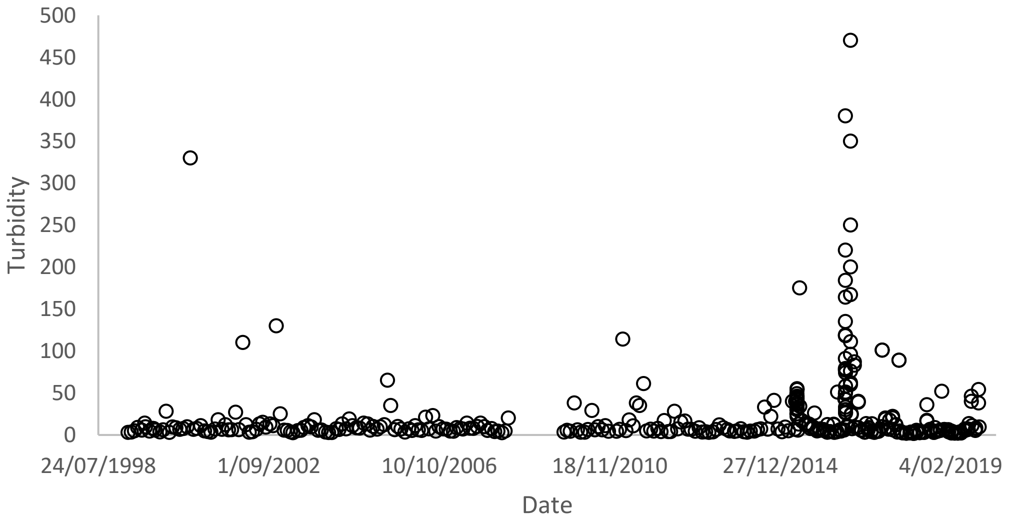


Figure 8.21: Time series graph of the historical turbidity in the Waikaka Stream, based off the Environment Southland monitoring site at the bottom of the catchment.

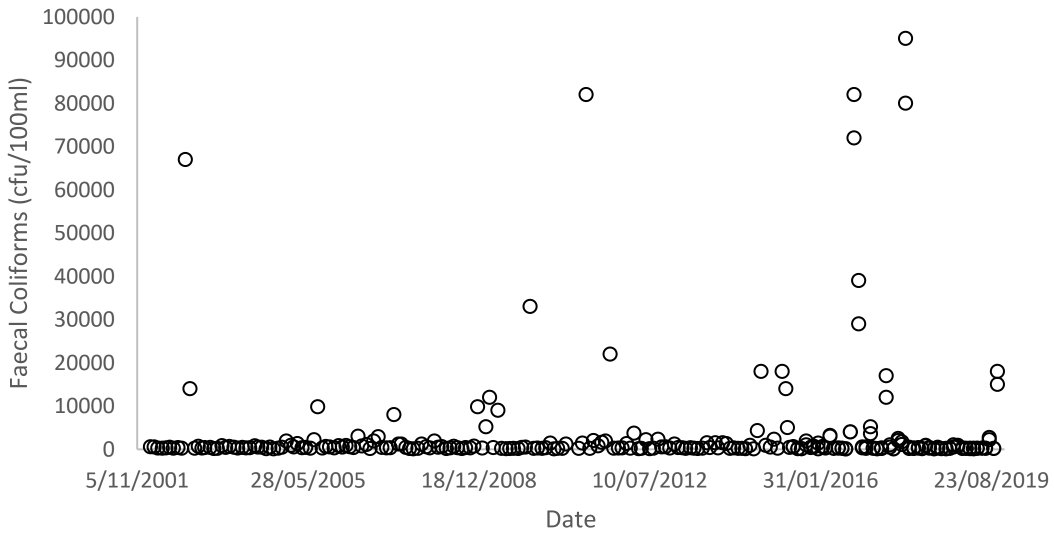


Figure 8.22: Time series graph of the historical faecal coliform levels in the Waikaka Stream, based off the Environment Southland monitoring site at the bottom of the catchment.

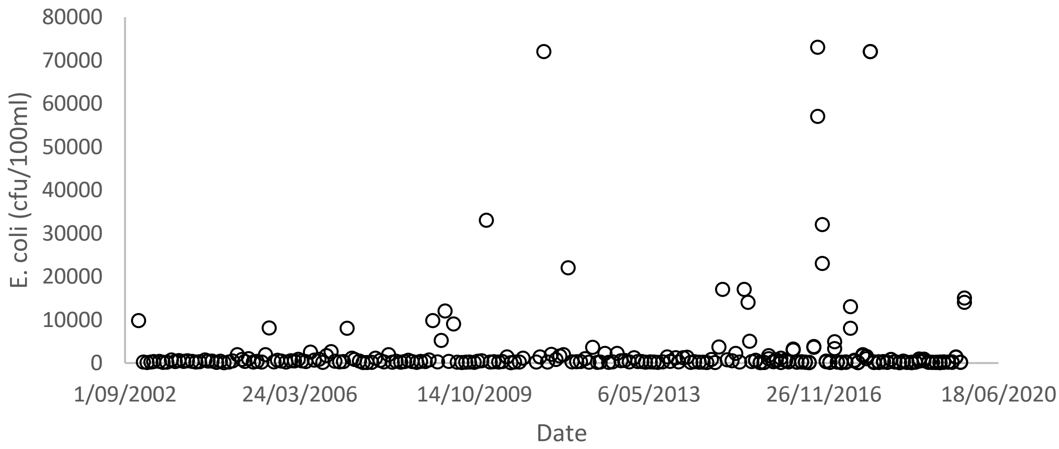


Figure 8.23: Time series graph of the historical E. coli levels in the Waikaka Stream, based off the Environment Southland monitoring site at the bottom of the catchment.

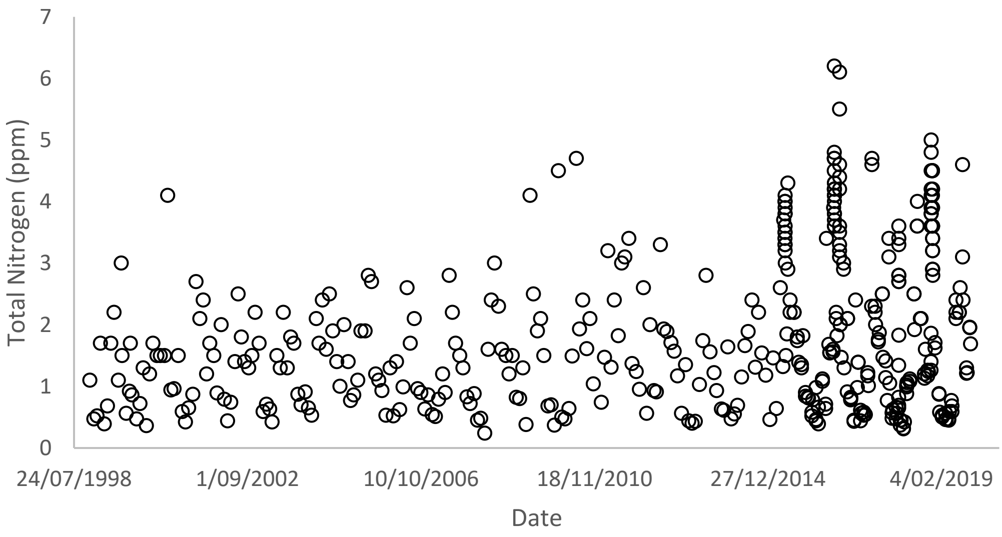


Figure 8.24: Time series graph of the historical total nitrogen concentration in the Waikaka Stream, based off the Environment Southland monitoring site at the bottom of the catchment.

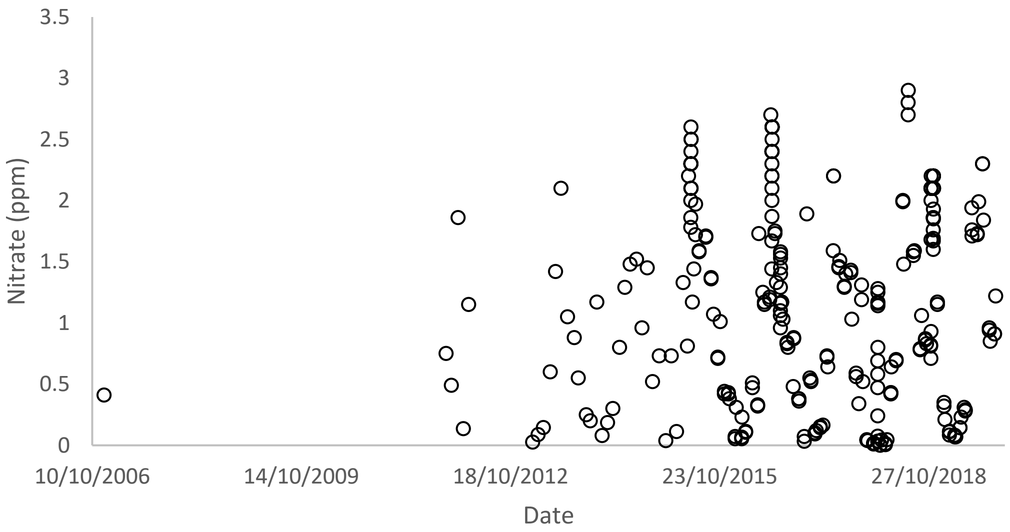


Figure 8.25: Time series graph of the historical nitrate concentration in the Waikaka Stream, based off the Environment Southland monitoring site at the bottom of the catchment.

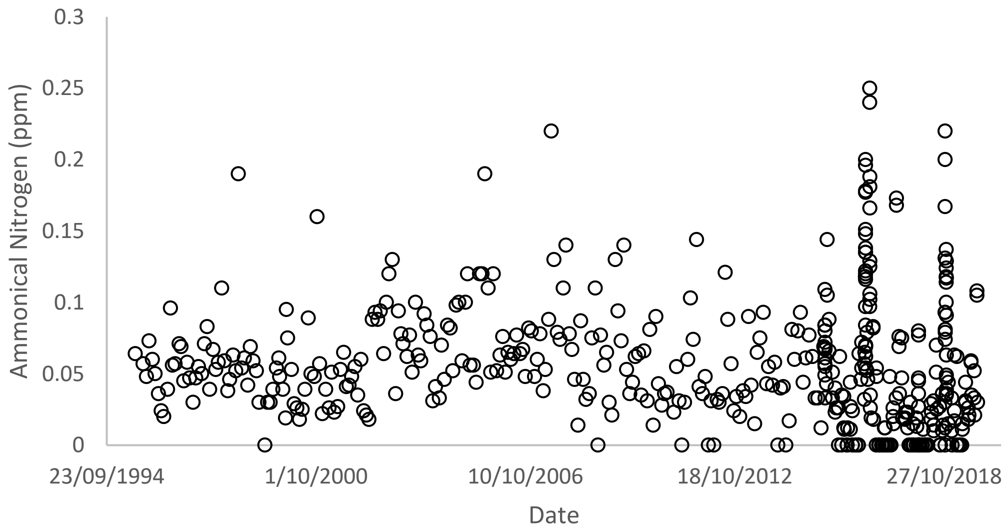


Figure 8.26: Time series graph of the historical ammonical nitrogen concentration in the Waikaka Stream, based off the Environment Southland monitoring site at the bottom of the catchment.

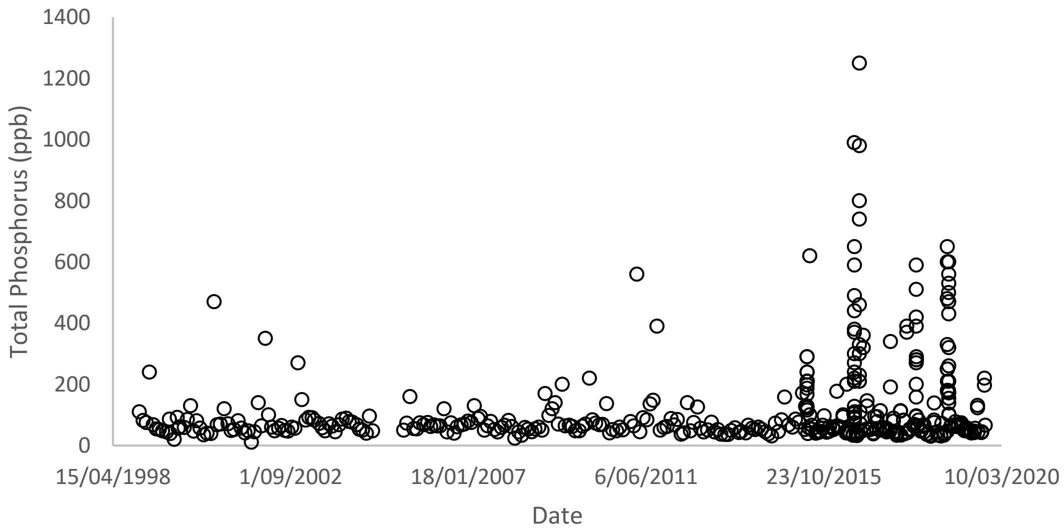


Figure 8.27: Time series graph of the historical total phosphorus concentration in the Waikaka Stream, based off the Environment Southland monitoring site at the bottom of the catchment.

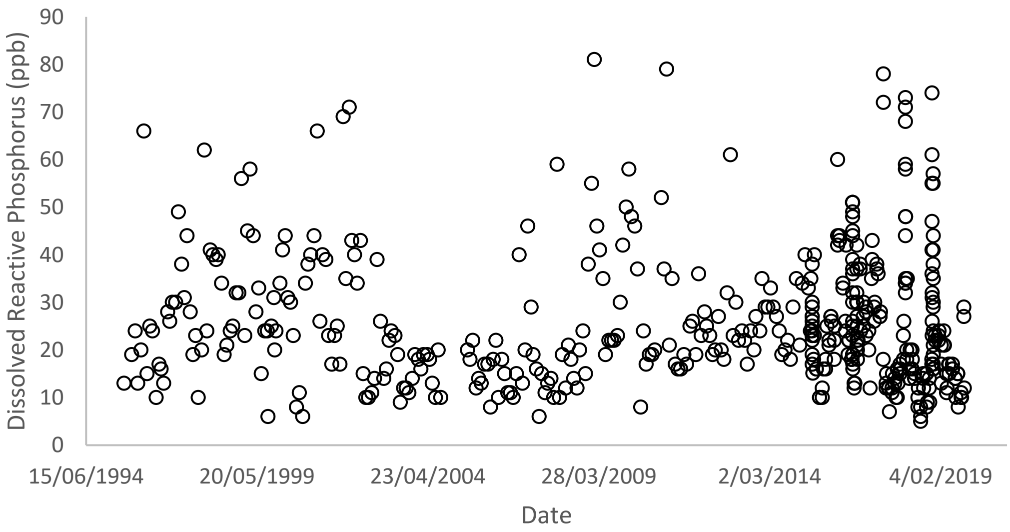


Figure 8.28: Time series graph of the historical dissolved reactive phosphorus concentration in the Waikaka Stream, based off the Environment Southland monitoring site at the bottom of the catchment.