“Values that are to be safeguarded”:

Meeting the challenge of improving the health of waterways on agricultural land.

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“The term ‘iconic’ is often used in conversations about Molesworth. It is valued for a range of reasons — its wide open landscape, the indigenous ecosystems and species it supports, its high country farming tradition and ongoing operation as New Zealand’s largest farm, and the historical and cultural heritage that travellers, both Māori and Pākehā, and graziers have left behind. Overlaid upon this set of values is a strong interest from the public to visit and experience Molesworth.

This management plan describes these (and other) values that are to be safeguarded.”

– Molesworth Management Plan, 2013

“One of the anomalies of modern ecology is that it is the creation of two groups each of which seems barely aware of the existence of the other. The one studies the human community almost as if it were a separate entity, and calls its findings sociology, economics, and history. The other studies the plant and animal community, [and] comfortably relegates the hodge-podge of politics to “the liberal arts.” The inevitable fusion of these two lines of thought will, perhaps, constitute the outstanding advance of the present century.”

– Aldo Leopold, 1935

Abstract

Aotearoa New Zealand's waterways are valued for many reasons. However, nationally, their health has been declining. Animal agriculture is a significant contributor to this decline.

The country's largest farm, Molesworth Station, is managed to safeguard its cultural, conservation, recreation, historical and farming values. For this reason, managers of the station's farming operation sought information on possible impacts of current animal agriculture on the habitat and water quality of Molesworth's streams and rivers, and recommendations on monitoring and improving the health of its waterways over time. This thesis found the health of streams and rivers on Molesworth to be good. It provides recommendations on monitoring and management, including areas where action could be taken to address the likely impacts of fine deposited sediment on waterways.

Given both the scale of Aotearoa New Zealand's animal agriculture, and its impact on freshwater quality and habitat, improving the health of waterways will require an increase in pro-environmental behaviour from farmers and will need to be sustained. This thesis also looks beyond Molesworth Station to investigate the influence of basic human values on pro-environmental behaviour in Aotearoa New Zealand's agricultural sector. It suggests that prioritisation and priming of certain basic human values are likely to suppress pro-environmental behaviour and posits that targeted values-sensitive communication could play a role in encouraging and increasing pro-environmental behaviour to meet the challenge of improving the health of waterways on agricultural land.

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For Rosemary Clare Prickett

"Aunty Bob"

21 April 1948 – 11 September 2018

Remembered with love and laughter

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Chapter 1: Introduction

1.1 Problem Statement

As a publicly-owned reserve, Molesworth Station is being managed to provide for conservation, recreation, culture, farming, and historical values. These are the “values that are to be safeguarded” (Department of Conservation, 2013. p. 3). As animal agriculture can impact the health of waterways in a number of ways, maintaining farming values (via the Landcorp-run beef operation) on the reserve could impact its other values; notably cultural, recreation and conservation values.

Improving the health of Aotearoa New Zealand’s waterways on agricultural land is proving challenging at a national scale. Scientists have identified the nature and extent of farming impacts and sought to provide mitigation options at farm, regional and national scale. However, pro-environmental behaviours are not always adopted and resource constraints do not always adequately explain why.

1.2 Aim of Research

The aim of this thesis is to facilitate improvement of freshwater quality and habitat on Molesworth Station, and identify lessons that could be applied elsewhere to meet the challenge of improving the health of waterways on agricultural land.

1.3 Objectives

1. Describe impacts of animal agriculture on the health of waterways.

2. Survey ecosystem health (water and habitat quality, and invertebrates) of rivers and streams on Molesworth Station.

3. Identify appropriate mitigation to improve water and habitat quality (ecosystem health) of waterways on Molesworth Station.

4. Investigate factors that may be limiting adoption of pro-environmental behaviour with respect to improving the health of waterways on agricultural land in Aotearoa New Zealand.

1.4 Contribution to knowledge

This thesis contributes to knowledge of Molesworth Station and provides recommendations on how the health of its waterways can be monitored and improved.

Using publicly available observed and expected data sets to prioritise work to improve sediment loss to waterways appears to be novel. The open access of the data could mean this is a relatively low-cost approach to identifying and prioritising areas for fine deposited sediment mitigation and could have some wider application, particularly for hill country farmers.

Investigation of the role of values in farmer decision making in an Aotearoa New Zealand context and their likely role in the suppression of pro-environmental behaviour among Aotearoa New Zealand farmers appears also to be novel.

1.5 Limitations

Limitations are identified within chapters.

1.6 Outline of thesis

In 2017, Landcorp commissioned the work of chapters three and four in order to identify any impacts on water quality on Molesworth Station from the beef operation run on the reserve. Commissioning the work came in response to complaints from the public about cattle in waterways on the property in summer 2016 and concern about the risk to human health while swimming from faecal contamination (M. Joy, Personal communication, February 2017). The then General Manager of Environment approached then Massey University Freshwater Ecologist Dr Mike Joy for advice on how best to monitor the health of waterways on the property, leading to the development of this master's project.

As a starting point, chapter two reviews the many ways that animal agriculture can impact the health of waterways. It focuses particularly on the impacts from pastoral farming – dairy, and sheep and beef.

Chapter three describes a survey of stream and river sites carried out on Molesworth Station in March 2018. It builds on three surveys conducted by the Cawthron Institute a decade earlier, while improving their approach by including parameters of habitat quality as well as water quality. The survey aimed to identify a representative sample of accessible stream and river sites that could be monitored over time, establish appropriate monitoring parameters and identify any impacts on the health of waterways likely to be influenced by farm activity. The survey found that, while water quality was generally good on the station (with no sites breaching primary contact guidelines), fine deposited sediment was likely to be impacting the health of some of the station's streams and rivers. Chapter three was presented as a report to Landcorp and Molesworth Station management in August 2018.

Chapter four recommends actions that would address the impact of fine deposited sediment in a way that is consistent with the values of the station (including protecting indigenous ecosystems and recreation opportunities). As a naturally highly erodible landscape, it was important to differentiate between sites where fine deposited sediment was more likely to be influenced by farm activity than natural processes alone. This led to a desktop analysis of observed versus expected data to identify where predicted natural conditions were significantly exceeded. Recommendations were then made based on this desktop analysis alongside knowledge from the literature, and insight on local conditions gained during the survey. Chapter four was presented as a report to Landcorp and Molesworth Station management in December 2018.

Finally, chapter five looks beyond Molesworth Station and investigates why, despite many reports providing farm-, regional- and national-scale recommendations for improving the health of waterways, there appears to be limited adoption of pro-environmental behaviour by the animal agriculture sector and the continued decline of the health of waterways in Aotearoa New Zealand. It takes a cue from Aldo Leopold who raised the need for *fusion of thought* (page iii – quoted in Heberlein, 2012) across ecology and social sciences. It attempts such a fusion of thought across disciplines in order to meet the challenge of improving the health of waterways on agricultural land. The chapter suggests that prioritisation and priming of certain basic human values (as identified by Schwartz) are likely to suppress pro-environmental behaviour in Aotearoa New Zealand farmers and posits that targeted values-sensitive communication may encourage and increase pro-environmental behaviour in order to improve the health of waterways.

Chapter 2: How does animal agriculture impact the health of Aotearoa New Zealand's waterways?

2.1 Introduction

Globally, animal agriculture has been identified as the most significant contributor to the degradation of waterways (Davies, Thompson, Biggs, & Williams, 2009; Flávio, Ferreira, Formigo, & Svendsen, 2017; OECD, 2012) Likewise, in Aotearoa New Zealand (Julian, de Beurs, Owsley, Davies-Colley, & Ausseil, 2017; Matthaei, Piggot, & Townsend, 2010). Despite Aotearoa New Zealand having legislation in place requiring the avoidance, mitigation or remedy of environmental impacts since 1991, the health of the country's waterways has declined over the last three decades, particularly where animal agriculture systems have intensified (Drummond, 2006; Ministry for the Environment and Statistics New Zealand, 2017).

Animal agriculture impacts the health of waterways by altering chemical, physical and biological parameters as well as disrupting ecosystem services provided by water bodies (Ballantine & Davies-Colley, 2014; Davies-Colley, 2013; Gluckman, 2017; Julian, de Beurs, Owsley, Davies-Colley, & Assail, 2017; Matthaei et al., 2010; Ministry for the Environment and Statistics New Zealand, 2015). These impacts can be more severe where agricultural operations have been intensified (Ballantine & Davies-Colley, 2014; Ballantine & Davies-Colley, 2014; Julian et al., 2017; Moller et al., 2008; Parliamentary Commissioner for the Environment, 2004).

Animal agriculture in Aotearoa New Zealand consists predominantly of sheep, beef, dairy, pig, deer, poultry and goat farming (Ministry of Primary Industries, 2017). This review focuses on Aotearoa New Zealand's three largest animal agriculture sectors (based on economic contribution) and their impact on the country's waterways (Ministry of Primary Industries, 2017). Therefore, the term *animal agriculture* will refer to sheep, beef and dairy production, unless otherwise stated. This review aims to refer primarily to Aotearoa New Zealand-based research produced in the last 20 years.

2.2 Animal agriculture in Aotearoa New Zealand

Aotearoa New Zealand has a history of animal agriculture beginning in the 19th Century (Pawson & Brooking, 2008). Towards the end of the century, the development of pastoral agriculture had contributed to the widespread deforestation of Aotearoa New Zealand (Parliamentary Commissioner for the Environment, 2012) and a burgeoning "grasslands revolution" (Pawson & Brooking, 2008). By the early 20th Century, pastoral agriculture covered 5.9 million hectares and the government began work to drain large areas of lowland wetlands to convert land to pasture (Brooking, Pawson, & Star, 2011; Parliamentary Commissioner for the Environment, 2012). This has been dubbed by agricultural historians as Aotearoa New Zealand agriculture's "expansion phase" (MacLeod & Moller, 2006).

Between 1920 and 1970, Aotearoa New Zealand entered the "intensification phase", which saw area in pasture remain stable but stocking rates increase by 150 percent facilitated by developments in soil science, plant and animal breeding techniques, and the increasing use of fertilisers (Brooking et al., 2011; MacLeod & Moller, 2006). The "later intensification phase" is identified as beginning in the 1980s and continuing today (MacLeod & Moller, 2006). Currently, 39.8 percent of Aotearoa New Zealand's land area is in exotic grassland (10,675,000 hectares) (Ministry for the Environment and Statistics New Zealand, 2015). The trend over the last decades has been towards intensifying agricultural practices, particularly in the dairy sector (Ballantine & Davies-Colley, 2014; Julian et al., 2017; MacLeod & Moller, 2006; Moller et al., 2008; Parkyn & Wilcock, 2004; Parliamentary Commissioner for the Environment, 2004).

Aotearoa New Zealand has had one of the highest rates of intensification in the world in recent decades, particularly in the dairy sector (Julian et al., 2017). The United Nations Food and Agriculture Organisation's definition of intensification is increasing the use of inputs (e.g. fertiliser, energy, water for irrigation, knowledge or capital) into farming systems to produce more product from the same area of land (Parliamentary Commissioner for the Environment, 2004). Aotearoa New Zealand academics Moller et al. (2008) offer a revised definition, proposing "any increase in farm inputs or farm production off-takes per unit area of land," in order to include operations where *economic* intensification had not occurred.

Over the last few decades, area in pasture has remained relatively static (Ministry for the Environment and Statistics New Zealand, 2015). However, the area used for dairy production increased by 283,700ha between 1996 and 2008, and again by 157,900 between 2008 and 2012 (Parliamentary Commissioner for the Environment, 2013, 2015). In a similar time period, the number of dairy cattle more than doubled (Statistics New Zealand, 2015). This change in land use and intensity has been facilitated by an increase in the use of fertilisers, particularly the nitrogenous fertiliser, as well as increases in imported feed and irrigation (Foote, Joy, & Death, 2015; Parliamentary Commissioner for the Environment, 2013). The use of nitrogenous fertiliser has increased 627 percent since 1990 in Aotearoa New Zealand (Statistics New Zealand, 2019b). Between 2002 and 2017, area in irrigated land increased by 94 percent (Statistics New Zealand, 2019a). This has meant that despite Aotearoa New Zealand having legislation in place requiring the avoidance, mitigation or remedy of environmental impacts since 1991, the health of the country's waterways has declined over the last three decades (Drummond, 2006; Ministry for the Environment and Statistics New Zealand, 2017).

2.3 Waterways in Aotearoa New Zealand

Aotearoa New Zealand has more than 413,000 kilometres of streams and rivers and 3800 lakes larger than 1 hectare (Gluckman, 2017). Of the total length of all streams and rivers in the country, 46 percent flow through pastoral land (Ministry for the Environment and Stats NZ, 2019). Climate and topography mean the western regions of the country tend to be wetter than the eastern regions. Gluckman (2017) describes Aotearoa New Zealand's aquifers and ground water as "extensive", particularly in the east. Natural characteristics of the regions have influenced land use and led to variable water quality and trends in waterway degradation across the country. For example, nitrate-nitrogen leaching from agricultural land has been estimated to be higher in the North Island than the South, except for Southland and Canterbury (Ausseil, Dymond, Kirschbaum, Andrew, & Parfitt, 2013).

Waterways in Aotearoa New Zealand have been significantly degraded from their natural state (Gluckman, 2017; Parliamentary Commissioner for the Environment, 2012). Of monitored groundwater sites, 23 percent have *Escherichia coli* (*E. coli*) counts that exceed drinking water guidelines (Daughney & Randall, 2009). Of the length of streams and rivers on running through pastoral land, 86 percent and 90 percent exceed natural conditions for total nitrogen and total phosphorus levels respectively (Ministry for the Environment and Stats NZ, 2019). Nitrate-nitrogen values have worsened at 55 percent of monitored sites nationwide and at 61 percent of monitored pastoral sites (Ministry for the Environment and Statistics New Zealand, 2017). Modelled data suggests that in the absence of human activity fine sediment would cover eight percent of riverbeds nationally (Ministry for the Environment and Statistics New Zealand, 2017). Using the same modelling, it was estimated that in 2011 that 29 percent of riverbeds is covered in fine sediment. Presently, 70 percent of the length of waterways in Aotearoa New Zealand fails to meet the Ministry of Health's primary contact guidelines for faecal contamination (McBride & Stoller, 2017).

2.4 Impact on physical parameters

2.4.1 Erosion and sediment

Underlying geology, rainfall and topography of a region are the main factors that influence erosion and the transport of sediment through a catchment (Basher, 2013). However, the deforestation of large areas of Aotearoa New Zealand, conversion to pasture and subsequent intensification of land use has led to the acceleration of these processes (Basher, 2013; Davies-Colley, 2013; Hughes, Quinn, & McKergow, 2012; Parliamentary Commissioner for the Environment, 2004; Quinn & Stroud, 2002). Four types of erosion are common in Aotearoa New Zealand:

- Surface erosion
- Gully erosion
- Mass-movement erosion
- Stream bank erosion (Basher, 2013).

Surface erosion is the loss of particulates from the top 10cm soil-layer (Basher, 2013; Fernandez & Daigneault, 2017). Where pasture has replaced previously forested land, interception and evapotranspiration rates are lowered, meaning more rain reaches the soil surface. This has the effect of increasing overland flow rates within a catchment, which increases the energy available to transport loosened particles across the soil surface to waterways (Basher, 2013; Cournane, McDowell, Littlejohn, & Condron, 2011). This can be further exacerbated where pasture is grazed heavily and soil is bare. Treading damage from livestock also reduces infiltration rates due to soil compaction and can increase surface erosion (Russell, Betteridge, Costall, & MacKay, 2001). Cournane et al. (2011) found that the type of livestock grazing within a catchment was less significant in determining surface erosion impact than *when* livestock were grazing, with winter grazing practices being particularly prone to accelerating surface erosion as pasture growth rates are slow, and soil is more likely to be saturated and prone to pugging damage. However, Julian et al. (2017) have found that the best predictor of a decline in water clarity from suspended sediment is the density of beef cattle within a catchment.

Gully erosion is described as linear features in a landscape where channelised run-off has occurred and amphitheatre-shaped mass-movements appear within gullies. Extensive gully erosion in Aotearoa New Zealand has been largely prompted by the clearance of indigenous forest and, as in the case of surface erosion, intensified as infiltration-excess overland flow increased under pasture (Basher, 2013; Marden, Arnold, Seymour, & Hambling, 2012). Likewise, the acceleration of mass-movement erosion (in its numerous forms – shallow and deep landslides, slumps and earthflows) has been contributed to by the loss of slope stability from widespread deforestation and the management of land under pasture (Dymond, Betts, & Schierlitz, 2010; Luckman, Gibson, & Derose, 1999). Mass-movement can increase surface erosion due to the exposure of bare soil where scarring has occurred (Basher, 2013).

Stream bank erosion has also been accelerated as a consequence of the removal of native vegetation. It can be worsened by the presence of livestock on riparian margins and their access to waterways (Basher, 2013; Hughes et al., 2012; Parkyn & Wilcock, 2004; Quinn & Stroud, 2002). Cattle treading damage weakens bank stability and stock access to waterways can mean the loss of remaining native vegetation, increasing bank instability, and can lead to bank collapse (Parkyn & Wilcock, 2004). Hugh and Quinn (2014) found that the most marked improvement in water clarity came when cattle were excluded from waterways and adjacent riparian margins. Julian et al. (2017) attributed the improvement in clarity over 35 of the 77 National Rivers Water Quality Network sites to the exclusion of dairy cattle from waterways and a reduction in the number of sheep nationally.

Acceleration of the transport of particulates from slopes to water bodies has a number of detrimental effects. Suspended sediment can interfere with the behaviours of wildlife (including feeding) where biota relies on visual clarity of water. Respiration of aquatic organisms can also suffer as gills may be damaged by fine suspended sediment (Davies-Colley, 2013). Fine sediment (>2mm) scatters light within the water column (Davies-Colley, 2013; Dymond, Davies-Colley, Hughes, & Matthaei, 2017; Matthaei et al., 2010). This can impact visual clarity as well as reduce the radiation available to aquatic plants for photosynthesis, thus changing the composition of aquatic communities (Dymond et al., 2017; Matthaei et al., 2010; Suren, 2005). Deposited sediment smothers habitat by covering lake, stream and riverbeds and is often more detrimental for biota than suspended material (Burdon, McIntosh, & Harding, 2013; Naden et al., 2016; Parliamentary Commissioner for the Environment, 2012) (Appendix F). It may clog interstitial spaces, cause the infilling of lakes and estuaries and impede hyporheic exchange in streams and rivers (Davies-Colley, 2013; Parliamentary Commissioner for the Environment, 2012).

As well as physical changes to waterways, an increase in sediment load can also induce chemical and biological changes in water quality, as particles can act as a vehicle for contaminants such as phosphates, heavy metals and pathogens (Cournane et al., 2011; Davies-Colley, 2013; Davies-Colley, Valois, & Milne, 2018).

2.4.2 Light and temperature

Removal of forest for pasture has led to changes in incident light and thermal regimes of waterways. Deforestation has led to a decrease in stream shading, leading to warmer waters in many pastoral catchments due to an increase in incident light reaching streams (Biggs, 2000; Marden et al., 2012; Quinn, Steele, Hickey, & Vickers, 1994).

Quinn et al. (1997) found that native and exotic forest cover allowed for one to two percent of incident light to reach streams, whereas 30 percent reached streams that ran through pasture. Pastoral streams tend to have a higher light exposure, particularly when compared to other first order streams with differing land use (as exposure tends to increase in all catchments in higher order streams as channels widen) (Davies-Colley & Quinn, 1998). Overhanging grasses can provide shade in pastoral streams (Davies-Colley & Quinn, 1998;

Harding & Winterbourn, 1995); remnant natives, willows and other plantings also feature in the literature (Davies-Colley & Quinn, 1998; Harding & Winterbourn, 1995; Quinn et al., 1997; Williamson, Smith, & Quinn, 1992). The depth of a channel and its orientation (e.g. flowing east to west) also has an influence on water's exposure to light (Rutherford, Blackett, Blackett, Saito, & Davies-Colley, 1997).

Pastoral streams have been found to have higher average temperatures than native and exotic forested streams (Quinn et al., 1997; Quinn et al., 1994; Young, Quarterman, Eyles, Smith, & Bowden, 2005). Quinn et al. (1997) found pastoral streams to be 2.2^{0}C higher than where native forest was dominant. Storey and Cowley (1997) found that pastoral streams that flowed into native forest remnants could have their temperature significantly lowered over a relatively short distance (600m). Animal agriculture has also been found to influence temperature directly in some cases, where point source discharges of relatively warm effluent may raise the temperature of the waterway into which it is released (Quinn et al., 1994).

Riis et al. (2012) found that light availability most strongly encouraged the growth of invasive aquatic plants in lakes and streams when compared to the influence of temperature. However, temperature associated with decreased shading in agricultural catchments influences algal growth and the success of fish and macroinvertebrate communities. Where excess algal growth occurs, the breakdown of the associated organic material can lead to aquatic environments being starved of dissolved oxygen causing mortality in invertebrates and fish (Parliamentary Commissioner for the Environment, 2012). Differing taxa respond differently to high temperatures, which can influence and disrupt macroinvertebrate communities where animal agriculture has changed thermal regimes of waterways. Some thermal limits of Aotearoa New Zealand taxa have been established by Quinn, Steele, Hickey and Vickers (1994). Their study also highlights that sub lethal increases in temperature influences the size and fecundity of invertebrates as well as their longevity.

2.4.3 Flow regime

Flow regimes determine the character and conditions of streams and rivers (the natural range and variation of flows within a catchment), and have a number of measures including the mean annual flood, number of floods above a threshold, mean annual 7-day low flow (Booker, Snelder, Greenwood, & Crow, 2015; Duncan & Woods, 2013). As in the case of the processes of erosion and deposition within a catchment, the principal factors governing flow (hydrological) regime are climate and geology (Duncan & Woods, 2013). However, vegetation and land cover are also important factors and are considerably altered by animal agriculture (Duncan & Woods, 2013). Along with indirect effects, pasture-based systems are responsible for directly disrupting flow regimes through abstraction and infrastructure designed to store or divert water for agricultural use.

Flow regimes may be altered by the conversion of indigenous vegetation to pasture in that rates of overland flow tend to be increased under pasture as interception and evapotranspiration are reduced. Where pasture has been introduced, both flood and base flows tend to increase due to the change in rates of run-off (Duncan & Woods, 2004). Conversion of land from exotic forest to pasture can increase flood flows by 80 percent (Duncan & Woods, 2013).

In Aotearoa New Zealand, three quarters of the consumptive use of fresh water is for irrigation (though not solely for animal agriculture) (Ministry for the Environment and Statistics New Zealand, 2015). This is similar to the global figure, irrigation being by far the largest use of abstracted fresh water worldwide (Frenken & Gillet, 2012). The Ministry for the Environment has reported that 60 percent of water for irrigation came from surface water and 35 percent from groundwater (Duncan & Woods, 2013). Water is used in animal agriculture for irrigation to improve pasture growth, for stock drinking water and wash down during milking in dairy production (Scarsbrook & Melland, 2015).

Abstraction can disrupt flow regimes in that it can both increase and decrease water volume in waterways. Because there is significant interaction between streams, lakes, rivers and aquifers, abstraction from both surface and groundwater influences flow patterns within waterways (Baalousha, 2012; Bekesi & Hodges, 2006; Donath, Daughney, Morgenstern, Cameron, & Toews, 2015; Olsen & Young, 2009). Those overseeing the management of freshwater resources are advised that managing these water bodies separately is not valid (Baalousha, 2012).

Where irrigation rates exceed water-holding capacity of soils, application of water can lead to increased run-off that can flow into surface water increasing discharge (Duncan & Woods, 2013). More commonly, abstraction lowers flows in surface water (Matthaei et al., 2010; Stefanidis, Panagopoulos, Psomas, & Mimikou, 2016). Dewson, James and Death (2007b) found in their study of small streams in Aotearoa New Zealand impacted by water abstraction that discharge decreased on average by 89-98 percent. In their review of the consequences of this decreased flow, Dewson, James and Death (2007a) found that velocity, depth and wetted width were impacted by abstraction. These changes to flow regime in turn influenced temperature (where there is a tendency for reduced discharge to lead to increased temperatures) and physical parameters (for example, increased sedimentation where the lowered velocity allows for more sediment to settle on a stream bed) (Dewson et al., 2007a).

Abstraction for agriculture has been identified as one of the key drivers of groundwater depletion in Aotearoa New Zealand (Gluckman, 2017). Land surface and river water are natural sources for aquifer (groundwater) recharge (Duncan, Srinivasan, & McMillan, 2016). Naturally, land surface recharge is determined by catchment soil types, climate and vegetation (Baalousha, 2009; Duncan et al., 2016). Water filters down through the soil surface and underlying rock to aquifers. This can be disrupted by animal agriculture as soil structure and patterns of soil wetness are modified under irrigation (Duncan et al., 2016). Where surface water is abstracted, aquifer recharge from rivers will likely be disrupted.

Flow regimes are an important determinant of waterways as habitat, as species of aquatic organism respond differently to conditions produced by varying volumes, floods frequency, low flows, velocity and other physical and chemical characteristic influenced by these variables (Biggs, Nikora, & Snelder, 2005; Dewson et al., 2007a; Duncan & Woods, 2013).

2.5 Impact on chemical parameters

2.5.1 Nutrients

The most significant nutrients in aquatic ecosystems are nitrogen (N) and phosphorus (P). Of particularly concern are nitrate-N and dissolved reactive phosphorus, as these are forms of nutrients that are readily available to aquatic plants (Dymond, Ausseil, Parfitt, Herzig, & McDowell, 2013). These nutrients occur naturally in waterways at low levels. The work of Death et al. (2016) found that Aotearoa New Zealand rivers in a state unaffected by anthropogenic activity have nitrate levels of <0.08 mg/L and DRP levels of <0.006 mg/L. The 2000 Australia New Zealand Environment and Conservation Council ((ANZECC, 2000)) guidelines recommended a limit of <0.167 mg/L and 0.444 mg/L of nitrate for upland and lowland waterways respectively. For DRP, the guidelines recommended <0.009 and <0.01 in upland and lowland waterways (ANZECC, 2000).

Increased nutrient inputs to waterways are commonly associated with agricultural land use (Ballantine & Davies-Colley, 2014; Gluckman, 2017; Julian et al., 2017; Parliamentary Commissioner for the Environment, 2004, 2012; Quinn & Stroud, 2002). The enrichment of water bodies with nutrients is known as eutrophication. Animal agriculture contributes to the eutrophication of waterways through the use of fertiliser, increased soil loss to water as well as diffuse and point source nutrient pollution from livestock excreta.

Fertiliser contributes both directly and indirectly to nutrient contamination of waterways. As a source of phosphorus and nitrogen for pasture growth in many farming operations, fertiliser is applied to the land either by tractor or aerially (Morton & Roberts, 2016; Roberts & Morton, 2016). If inaccurately applied, it can end up directly entering waterways (Roberts & Morton, 2016). It may also be transported to water bodies via overland flow or leaching and this can be particularly hazardous to waterways if it is applied not long before a drainage event (Morton & Roberts, 2016)

Fertilisers also impact water quality indirectly as they can allow for increased pasture production and higher stocking rates (Dymond et al., 2013; Foote et al., 2015). Along with feed supplements and irrigation, fertilisers can intensify animal agriculture by providing feed for a higher number of livestock than an area of land would have otherwise been able to support (Moller et al., 2008; Parliamentary Commissioner for the Environment, 2004; Scarsbrook & Melland, 2015). A large source of nutrients from animal agriculture is excreta and with a marked increase in livestock numbers over the last decades in Aotearoa New Zealand, this source has greatly increased.

Nitrogen and phosphorus in livestock excreta can enter waterways as point source or diffuse pollution. Dairy effluent systems remain the most common point source contributor to water pollution from animal agriculture, despite greater regulation and enforcement along with a shift to land application of effluent (Gluckman, 2017; Julian et al., 2017). However, diffuse pollution is overall a greater source of nutrients from animal agriculture in Aotearoa New Zealand and is a consequence of excreta deposited directly on the land by animals and where effluent is applied, which makes its way to waterways via subsurface and overland flow (Dymond et al., 2013; Gluckman, 2017; Snow, 2004).

Phosphorus is present in dung and commonly enters waterways attached to soil particles (Parliamentary Commissioner for the Environment, 2013). Where fertiliser, effluent and/or dung has been applied to land, subsequent erosion is likely to cause phosphorus to be transported to waterways (Parliamentary Commissioner for the Environment, 2013). A smaller amount of phosphorus can enter waterways dissolved in soil water as leachate (Dymond et al., 2013).

The urine of livestock, particularly dairy cattle due to their diet, is the greatest source of nitrogen in Aotearoa New Zealand waterways (Beukes et al., 2014; Dymond et al., 2013; Monaghan et al., 2007; Parliamentary Commissioner for the Environment, 2013). This source of diffuse nitrogen pollution enters surface and groundwater primarily as leachate (Dymond et al., 2013). Nitrate is not held strongly by soil and where it exceeds an amount that can be taken up by pasture (commonly in urine patches from livestock), it is lost in soil water through subsurface flow (Parliamentary Commissioner for the Environment, 2013). Dymond et al. (2013) identify agriculture as the largest contributor of nitrogen pollution in Aotearoa New Zealand, with the intensification of animal agriculture likely to increase nitrogen losses to waterways.

2.5.2 Heavy Metals

There are a number of heavy metals that can be introduced to aquatic environments via animal agriculture. Cadmium (Cd) is an element that is present in phosphatic fertilisers and can be introduced as where phosphate is applied (Gray, Laurenson, Monaghan, Orchiston, & Cavanagh, 2017). Overseas, it has been found to have toxic and carcinogenic effects on freshwater species (Hall, Scott, & Killen, 1998; Liu et al., 2018). In some species of fish, Cd has been found to produce skeletal deformities at low levels of exposure and in invertebrates it can inhibit calcium influx (Hall et al., 1998). Aotearoa New Zealand studies have shown that overland and subsurface flow can contribute to losses of Cd from land to receiving environments (Gray et al., 2017). Subsurface flow has been found to be a more significant pathway for Cd to surface water than run-off. However, flood-irrigation can amplify overland flow losses of Cd to waterways (Gray et al., 2017).

2.6 Impact on biological parameters

2.6.1 Pathogens

Sheep and cattle are carriers of zoonotic waterborne diseases (Moriarty, McEwan, Mackenzie, Karki, & Sinton, 2011; Snow, 2004). The primary source of pathogens from animal agriculture in fresh waterways is the faeces of livestock (Parliamentary Commissioner for the Environment, 2012). In Aotearoa New Zealand, the indicator organism, *E. coli*, commonly measures the presence of pathogens in fresh waterways. *E. coli* is a bacterium that is common in the faecal material of humans and animals. Generally speaking, higher levels of *E. coli* are expected to indicate a higher risk of illness to human, (though this is not true in all cases, as some sources of *E. coli* in waterways pose less of a risk to human health than others). *Campylobacter* spp. has shown some correlation with *E. coli.* However, it is only one of a number of pathogens that may be present in faecal material from livestock (Ministry for the Environment and Statistics New Zealand, 2015).

Stock can introduce faeces to waterways directly where they have access to water bodies or where there is a regular crossing (Collins et al., 2007). Davies-Colley et al. (2004) found that cows were over 50 times more likely to defecate directly into waterways, where they had access, than on land. Indirectly, faeces can be transported to water via overland or subsurface flow as a component of diffuse pollution from agricultural land (Collins et al., 2007). Hill country farming tends to contribute faecal contamination through run-off, particularly where soil compaction is more pronounced (as a result of farm tracks or treading damage) and infiltration rates are reduced (Collins et al., 2007). *E. coli* concentrations in pastoral streams are influenced by the time between when faeces are deposited on land (i.e. when pasture is grazed) and the first significant rainfall (Donnison, Ross, & Thorrold, 2004).

Dairy can also contribute to faecal loads in waterways via overland flow. Dairy shed effluent was once a common point-source polluter. The practice of applying farm-dairy effluent (FDE) to land has been encouraged. Where efficiently applied, FDE can be provide a beneficial cycling of nutrients within the farming system and matrix flow can offer microbial attenuation (Monaghan, Smith, & Muirhead, 2016; Weaver et al., 2016). However, FDE can also be a significant source of diffuse faecal contamination from dairy farms, especially where drainage events occur shortly after application (Collins et al., 2007; Wang & Bolan, 2004; Weaver et al., 2016). Soil macropores can increase the transport of pathogenic microbes to waterways where effluent is applied via the mechanism of preferential flow (Collins et al., 2007; Snow, 2004; Wang & Bolan, 2004). FDE subject to preferential flow through macropores to mole and pipe drainage has been found in some studies to contain concentrations of campylobacters similar to raw effluent, indicating that the benefits of matrix flow on reducing pathogenic contaminants in subsurface flow is of little relevance under these conditions (Snow, 2004; Weaver et al., 2016). Microbial attenuation appears to be highly dependent on soil type and structure (Monaghan et al., 2016; Weaver et al., 2016).

Irrigation can also facilitate the transport of faecal contamination to waterways (Collins et al., 2007; Weaver et al., 2016). Irrigation can lead to increases in overland flow (where application is made at field capacity). Like fertiliser, irrigation has facilitated the intensification of animal agriculture by allowing for higher stocking rates. Therefore, irrigation has an indirect influence of increased pathogens in waterways as well as a direct influence. Pathogens can move through soil to waterways as well as being transported via overland flow. Both flood and spray irrigation can lead to *E. coli* being lost through the soil to groundwater (Weaver et al., 2016).

2.6.2 Periphyton

Periphyton is naturally occurring slime and algae in waterways (Biggs, 2000). Animal agriculture can disrupt the natural growth of periphyton by altering nutrient concentrations, flow regimes, light, temperature and sediment load in water bodies (Biggs, 2000; Harding, Young, Hayes, Shearer, & Stark, 1999; Hart, Biggs, Nikora, & Flinders, 2013; Snelder, Booker, Kilroy, & Quinn, 2014).

Where animal agriculture has increased nutrient concentrations in water, periphyton biomass may be increased beyond natural growth rates (Biggs, 2000; Harding et al., 1999). While nitrogen and phosphorus need to be present in concentrations that trigger excess growth, research has found that managing a single nutrient to control periphyton growth will not adequately address the risk of problem periphyton growth. This is because a limiting nutrient can fluctuate seasonally as well as within a catchment, and different species are triggered at differing nutrient concentrations (Parliamentary Commissioner for the Environment, 2013). Alterations to flow regimes from animal agriculture can influence the biomass and periphyton taxa present within waterways (Biggs, 2000; Hart et al., 2013). Increased incident light associated with pastoral streams and increases in water temperature can also lead to increased periphyton growth (Biggs, 2000; Quinn et al., 1997)

Increased sediment load and/or increased deposited sediment can have the effect of decreasing periphyton biomass as suspended sediment can intercept light, deposited sediment can smother habitat (rock surfaces and submerged woody debris, for example) and particulates can increase surface abrasion (Biggs, 2000). These may all impact habitat quality of aquatic species.

2.6.3 Macrophytes

Like periphyton, animal agriculture can disrupt natural macrophyte growth by altering nutrient concentrations, sediment load and incident light availability within aquatic ecosystems (Quinn, Croker, Smith, & Bellingham, 2009; Schallenberg & Sorrell, 2009). Native and exotic macrophytes respond differently to the changes in conditions brought on by agriculture, which again can alter natural ecosystems (Parliamentary Commissioner for the Environment, 2013).

Where nutrient concentrations have increased, macrophytes tend to respond with increased growth. Likewise, increased fine sediment loads in waterways can lead to extension of suitable habitat for macrophytes (Parliamentary Commissioner for the Environment, 2012). However, if suspended sediment is high, in some cases, conditions may favour periphyton and/or phytoplankton growth rather than macrophytes (Schallenberg & Sorrell, 2009). This is particularly relevant in lakes, as turbidity can limit light penetration required by macrophytes and wind may cause the resuspension of particles leading to a re-loading of nutrients in the water column (Schallenberg & Sorrell, 2009).

Quinn et al. (2009) found that small pastoral streams had higher percentage coverage of macrophytes when compared to equivalent streams in native forested catchments (>30 percent and zero percent respectively) in a study of Waikato streams. The investigation suggested that the difference in shading between catchments was the main driver for this.

2.6.4 Phormidium-dominated mats

Occurrences of the proliferation of cyanobacterial genus *Phormidium,* in the form of *Phormidium*-dominated mats, have been found to be increasing in Aotearoa New Zealand (McAllister, Wood, & Hawes, 2016). Proliferations are commonly associated with rivers in lowland agricultural catchments and are thought to be increasing due to changes in nutrient and sediment levels, changes to flow regimes (due to climatic changes and/or water abstraction), and habitat modification (McAllister et al., 2016). *Phormidium* can produce toxins that are harmful, and potentially deadly, to animals and humans (McAllister et al., 2016; Ministry for the Environment and Statistics New Zealand, 2017)

2.6.5 Macroinvertebrates

Macroinvertebrates display varied responses to changes in aquatic environments. For this reason, they can be used in as an indicator of water quality. Furthermore, macroinvertebrate indices, such as the Macroinvertebrate Community Index (MCI), provide a longer-term insight into the state of waterways than measurements of chemical parameters, which are more variable (Stark & Maxted, 2007). This is due to their lifecycles often lasting upwards of a year and the fact that they generally do not move great distances (Stark & Maxted, 2007). The impact of agriculture on waterways, increased sediment and nutrient loading, and changes to flow regime, can result in changes to both taxa richness and abundance (Dewson et al., 2007b; Matthaei et al., 2010; Quinn et al., 1997; Ramezani, Akbaripasand, Closs, & Matthaei, 2016).

Research has found there is link between high levels of deposited sediment and low ecological integrity in aquatic environments (Davies-Colley et al., 2015; Waters, 1995). Deposited sediment can impact aquatic life by smothering macroinvertebrates directly. It can reduce suitable habitat by filling the spaces between rocks where animals take refuge (Burdon et al., 2013; Davies-Colley et al., 2015) (Appendix F). It can also smother and bind with the periphyton (algae) that grows on rocks in rivers and streams, which can reduce the nutritional quality and availability of this important food source for macroinvertebrates. Invertebrate communities affected by increased sedimentation can be altered, losing more pollution-sensitive species such as Ephemeroptera and Plecoptera, and seeing an increase in chironomids and oligochaetes that can survive in deposited sediment (Matthaei et al., 2010; Wagenhoff, Townsend, & Matthaei, 2012).

Increases in nutrient concentrations can increase the abundance of taxa as algal biomass may increase and therefore a key macroinvertebrate food source (Niyogi, Koren, Arbuckle, & Townsend, 2007; Stark & Maxted, 2007; Townsend et al., 2008). Whereas, increased fine sediment loads more often have a negative relationship with abundance and taxa richness (Niyogi et al., 2007; Townsend et al., 2008). Increasing eutrophication can lead to excess algal growth and/or blooms leading to aquatic habitats being starved of dissolved oxygen as a result of the decomposition process of organic material. Like nutrient increases, changes in flow volumes and flow regime have been found in some cases to increase abundance and in others to decrease densities of macroinvertebrates (Dewson et al., 2007a). However, decreases in flow have commonly been found to decrease taxa richness (Dewson et al., 2007a, 2007b).

Furthermore, the interaction of these stressors can amplify their impact. Matthaie, Piggott and Townsend (2010) found that where low flows and increased sediment loading occurred the negative impact on invertebrate communities was greater than where low flows occurred without increased sedimentation. This suggests that in erosion-prone catchments or those with significantly disturbed soil, water abstraction may have more detrimental effects than in those where increased sediment loads are not an issue (Matthaei et al., 2010). Matthaie, Piggott and Townsend's findings were based on an experiment set up using artificially constructed channels. In their study on hill-country streams, Quinn et al. (1997) noted that it was difficult to identify a single cause of the differences in the communities in forested and pastoral land, and that it was more likely that it was a combination of impacts on habitat, including whether or not terrestrial habitat required for adult stages of invertebrate lifecycles had been lost.

2.6.6 Fish

Aotearoa New Zealand's waterways are home to native and introduced freshwater fish species. Some introduced species are considered pests (such as *Gambusia affinis* and *Cyprinus carpio Linnaeus*, 1758), while others (salmonids) have their populations actively managed for recreational purposes (McDowall, 2006). Almost three quarters of native freshwater fish species are in decline and this has been linked in part to intensifying agricultural activity (Weeks et al., 2016).

Like macroinvertebrates, freshwater fish display varied responses to changes in habitat where animal agriculture has caused increases in nutrients, fine sediment, temperature, algal and macrophyte growth and changes to flow regime (Canning, 2018; Joy, Foote, McNie, & Piria, 2019) Such disruptions to invertebrate communities impact fish populations as opportunities for predation change (Niyogi et al., 2007). The impact of eutrophication on freshwater fish is primary in its interference with respiration (it can cause levels of dissolved oxygen to fluctuate as low as to cause mortality) and feeding as it can also cause mortality and changes in communities of prey. Suspended sediment can disrupt aquatic animals that are visual feeders by reducing visibility (Lange et al., 2014). The gills of fish and invertebrates can be damaged by suspended sediment (Boubée, Dean, West, & Barrier, 1997).

Ramezani, Akbaripasand, Closs and Matthaei (2016) found that trout and native species densities in agricultural sub-catchments displayed a negative relationship with the increase of dairy prevalence. Lange, Townsend, Gabrielsson, Chanut and Matthaei (2014) in their study of the impacts of farming intensity and water abstraction on freshwater fish populations that trout density negatively corresponded to both increasing intensity and abstraction. While they were unable here to observe the same relationship in indigenous species, other studies have looked at the impact on land use and found land use influences richness and abundance of native species (Clapcott et al., 2012; Hans & Angus, 2006; Joy & Death, 2013). In terms of the impact of animal agriculture on pest fish, Lee, Simon and Perry (2017) found that the modification of stream environments attributable to pastoral land use facilitated the spread of the invasive species *Gambusia affinis.*

Aotearoa New Zealand has a high proportion of diadromous native fish species (those that migrate between fresh and salt water ecosystems). For this reason, native fish are found in higher densities closer to the coast than in low-order streams higher in river systems (Joy & Death, 2013). Animal agriculture, which has had a large impact on lowland waterways in Aotearoa New Zealand, has significantly degraded the more biodiverse habitat in terms of native fish species (Joy & Death, 2013; Weeks et al., 2016).

2.7 Disruption to ecosystem services

2.7.1 Drinking water – human/stock

The purification of water within the water cycle under unmodified conditions, including functioning wetlands, is considered an ecosystem service (Ausseil et al., 2013). Because animal agriculture contributes increased nutrients (and the subsequent effects of eutrophication), sediment, faecal contamination, and heavy metals to waterways, sources of human and stock drinking water can be compromised (Ausseil et al., 2013; Daughney & Randall, 2009).

2.7.2 Cultural values

The pollution of waterways by animal agriculture can impact on cultural, spiritual and recreational services provided by waterways (Ausseil et al., 2013). This is because contamination of waterways can lead to risk of illness from contact with fresh water, degrade aesthetic values or modify the environment to an extent that renders it untenable for cultural activities to be carried out (ANZECC, 2000; Ausseil et al., 2013; Parliamentary Commissioner for the Environment, 2012).

2.7.3 Food provision

Freshwater ecosystems are a source of food (fish, plants, etc.). They also are transporters of contaminants to estuaries and marine environments, which are also a source of food. Food provision can be disrupted by animal agriculture's influence on freshwater environments' ability to support species as well as through contamination of food sources (e.g. faecal contamination of shell fish in estuaries).

2.7.4 Habitat provision

The provision of habitat to maintain biodiversity, biological control of pests and disease as well as for cultural and aesthetic values (i.e. a functioning ecosystem) is in itself described as an ecosystem service by the Millennium Ecosystem Assessment (Ausseil et al., 2013; Fiedler, Landis, & Wratten, 2008).

A number of impacts from animal agriculture can disrupt the provision of habitat for indigenous species as described. For example, relatively small increases in nutrient concentrations can alter natural growth of aquatic plants in waterways and in higher concentrations nutrients can be toxic to aquatic life (Ministry for the Environment and Statistics New Zealand, 2017). Accelerated processes of erosion can smother habitat and, in combination, the stressors on waterways from animal agriculture can disrupt aquatic habitats from their natural state. Additionally, connectivity between terrestrial and aquatic habitats, important for many freshwater species lifecycles, may be disturbed where riparian and other vegetation is removed. The draining of wetlands has also been common practice on agricultural land.

2.8 Conclusion

This literature review has shown that animal agriculture impacts Aotearoa New Zealand's waterways in a number of ways that have led to the widespread degradation of fresh water quality and aquatic ecosystems. However, it is not exhaustive and excludes other relevant impacts, such as the development of roading, dams and the installation of culverts that can modify and pollute waterways. There are also indirect impacts such as animal agriculture's large contribution to national and global greenhouse gas emissions, which drive climate change that is disrupting and will continue to disrupt fresh water bodies.

Chapter 3: Molesworth – Ecosystem Health Survey March 2018

3.1 Abstract

This report presents results of an ecosystem health (water quality, habitat and invertebrate) survey undertaken at 19 waterways across Molesworth Station. This includes the headwaters of the Awatere, Wairau and Waiau Toa (Clarence) Rivers.

No sites breached primary contact (i.e. swimming) standards for *E. coli* and conductivity (an indicator of nutrient enrichment) was low across most sites.

Water clarity guidelines for in-stream biodiversity were breached at seven sites and fine deposited sediment was above 20 percent cover at 10 sites. This is of concern for macroinvertebrate and fish communities as sediment deposited on stream and river beds degrades habitat.

Macroinvertebrate Community Index (MCI) scores show most sites are excellent or good, with three sites fair.

Cyanobacteria observed at Tarndale Brook is reported due to the potential serious risk it poses to human and animal health.

The detrimental effects of fine deposited sediment on ecological health of streams and rivers, and link between sediment and *E. coli*, suggest sedimentation of waterways on Molesworth Station should be a focus for land management.

While there are erosion events that are beyond the control of land managers due to underlying geology, climate and topography of the station, there are parts of the station that could be managed to reduce the accumulation of fine deposited sediment on stream and riverbeds.

3.2 Introduction

Molesworth Station is Aotearoa New Zealand's largest farm at 180,787 hectares, running a beef cattle operation of approximately 30,000 stock units (Department of Conservation, 2013. J. Ward, personal communication, October 17, 2017). Molesworth Station is operated within Molesworth Recreation Reserve (the reserve and the Station being essentially synonymous as they occupy the same area). The land is leased from the Department of Conservation (DoC) to Pāmu (Landcorp Farming Limited), and managed by a steering committee of DoC, Pāmu and Ngāi Tahu representatives to protect conservation, cultural and historical values, foster recreational values and maintain primary production (Department of Conservation, 2013).

The station is located in the north east of the South Island at the headwaters of three major catchments; the Awatere, Wairau and Waiau Toa (Clarence) rivers (Figure 1). Within these rivers systems are a number of lakes, tarns and wetlands. Variation in annual rainfall across the station is high, with the western reaches tending to be wetter (2400mm/annum) than in the east (700mm/annum) (Olsen & Shearer, 2007).

A significant proportion of the station is classified as having "extreme erosion severity" (>20 percent in area), "very severe" (10-20 percent in area), and "severe" (five to ten percent in area) (Department of Conservation, 2013). Factors contributing to this erodibility include tectonic activity, underlying geology and soil types, climatic influences (including frost-heave, which leaves soil exposed), and types of vegetative cover and lack of suitable stabilising vegetation, as well as pest and stock disturbance. The underlying geology consists primarily of argillite mudstone and greywacke. Soil types vary across the station but tend toward gley and brown soils in the west, and oxidic and brown soils in the east (Department of Conservation, 2013).

This report presents the findings of a survey of 19 stream and river sites undertaken in March 2018 to assess water quality on the station. This will be used to develop a water quality monitoring protocol for Pāmu (Landcorp Farming, Limited), with the aim of informing land management decisions.

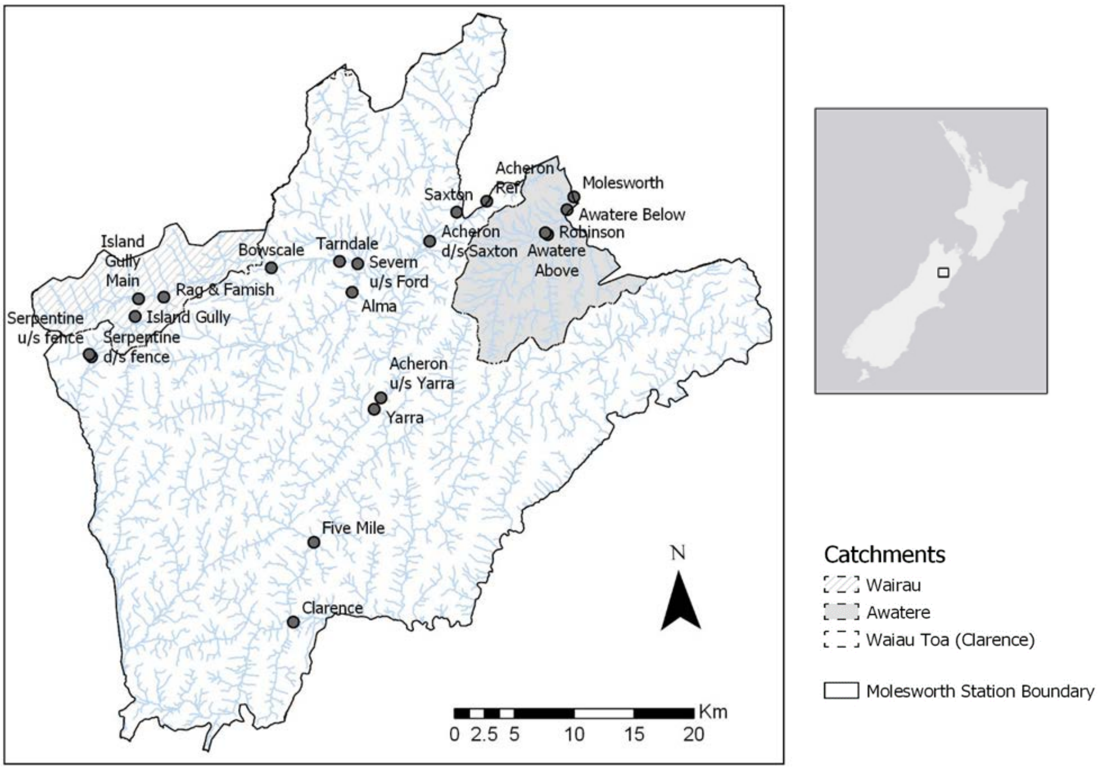

Figure 1: Map of March 2018 survey sampling sites. Molesworth Station is located in the South Island of New Zealand at the headwaters of three major river catchments; Awatere, Waiau Toa (Clarence) and Wairau Rivers.

3.3 Methods

3.3.1 Sampling sites

Samples were collected from 19 sites across the station (Figures 1, 2, 3, 4, 5 and 6). Sites were chosen from 66 sites sampled previously in 2007, 2009, and 2011 (Holmes; Olsen & Shearer; Shearer). Small and large waterways, geographical spread, winter and summer grazing sites as well as improved pasture and sites that have been fenced off from cattle were sampled. Reach length was determined by taking an average of five width lengths and multiplying by 20 – up to a maximum length of 150 metres (Table 1).

Table 1: Site location, date of sample, reach length, improved and non-improved pasture, grazing season and River Environment Classification (REC)

Site Name	Date	Catch-ment	Reach length (m)	Easting (Up)	Northing (Up)	Easting (Down)	Northing (Down)	Improved pasture?	Summer/ Winter grazing?	REC class
Robinson	16-Mar-18	Awatere	150	1619976	5337844	1619987	5337985	Y	Winter	G3
Awatere Below	16-Mar-18	Awatere	150	1621606	5339874	1621684	5339998	Y	Winter	G3
Awatere Above	16-Mar-18	Awatere	150	1619784	5338017	1619790	5338141	Y	Winter	G3
Molesworth	16-Mar-18	Awatere	86	1622266	5341117	1622295	5341045	Y	Winter	G3
Acheron u/s Yarra	4-Mar-18	Waiau Toa	150	1605654	5324892	1605531	5324875	N	Winter	H5
Yarra	4-Mar-18	Waiau Toa	150	1604851	5323899	1604933	5323944	N	Winter	G3
Five Mile	5-Mar-18	Waiau Toa	80	5199432	5313078	1599464	5313018	Y	Winter	G3
Tarndale	6-Mar-18	Waiau Toa	70	1602491	5336384	1602537	5336422	Y	Winter	H6
Severn u/s Ford	10-Mar-18	Waiau Toa	150	1603921	5336247	1604039	5336167	Y	Winter	H5
Acheron d/s Saxton	10-Mar-18	Waiau Toa	150	1610251	5337862	1610124	5337810	N	Winter	H5
Saxton	10-Mar-18	Waiau Toa	150	1612499	5340291	1612469	5340155	N	Winter	H5
Clarence	11-Mar-18	Waiau Toa	150	1597419	5306536	1597485	5306411	Y	Summer	G3
Serpentine d/s fence	13-Mar-18	Waiau Toa	115	1581536	5329362	1581527	5329266	N	Summer	H1
Serpentine u/s fence	13-Mar-18	Waiau Toa	64	1581295	5329512	1581349	5329480	Y	Summer	H1
Acheron Ref	17-Mar-18	Waiau Toa	150	1615086	534108	1615013	5340969	N	Winter	H6
Alma	17-Mar-18	Waiau Toa	150	-	-	1603478	5333802	Y	Summer	H1
Bowscale Lake Outlet	18-Mar-18	Waiau Toa	20	1596809	5336112	1596822	5336113	N	Summer	H6
Rag & Famish	13-Mar-18	Wairau	50	1587759	5334022	1621231	5340956	N	Summer	H1
Island Gully	14-Mar-18	Wairau	60	1585227	5332416	1585641	5333962	N	Summer	H1

Figure 2 (Clockwise from top left): Robinson site, Awatere below site, Molesworth site, Yarra site, Acheron u/s Yarra site, Awatere above site.

Figure 3 (Clockwise from top left): Five Mile site, Tarndale site, Acheron d/s Saxton site, Clarence site, Saxton site, Severn u/s Ford site.

Figure 4 (Clockwise from top left): Serpentine d/s fence site, Serpentine d/s fence site, Alma site Rag & Famish site, Bowscale Lake Outlet site, Acheron ref site.

Figure 5: Island Gully Main site.

Figure 6: Additional side channel sites (left) Severn u/s Ford side channel, (right) Island Gully, March 2018

3.3.2 Sampling conditions

On 20 February 2018, Cyclone Gita moved over the top of the South Island. This led to high flows in all three major catchments on the station. It is likely that river algae (periphyton) and macroinvertebrates communities would have been affected during this flooding. *Escherichia coli* is also likely to have been affected by flooding flows. However, all samples were taken after the prescribed 10 days after 7 x median flow (Stark, 2001). Awatere and Wairau catchment samples were taken three weeks after flooding flows (Figures 7 and 8). Samples from the Waiau Toa catchment were taken on average two weeks after flooding flows (Figures 9 and 10).

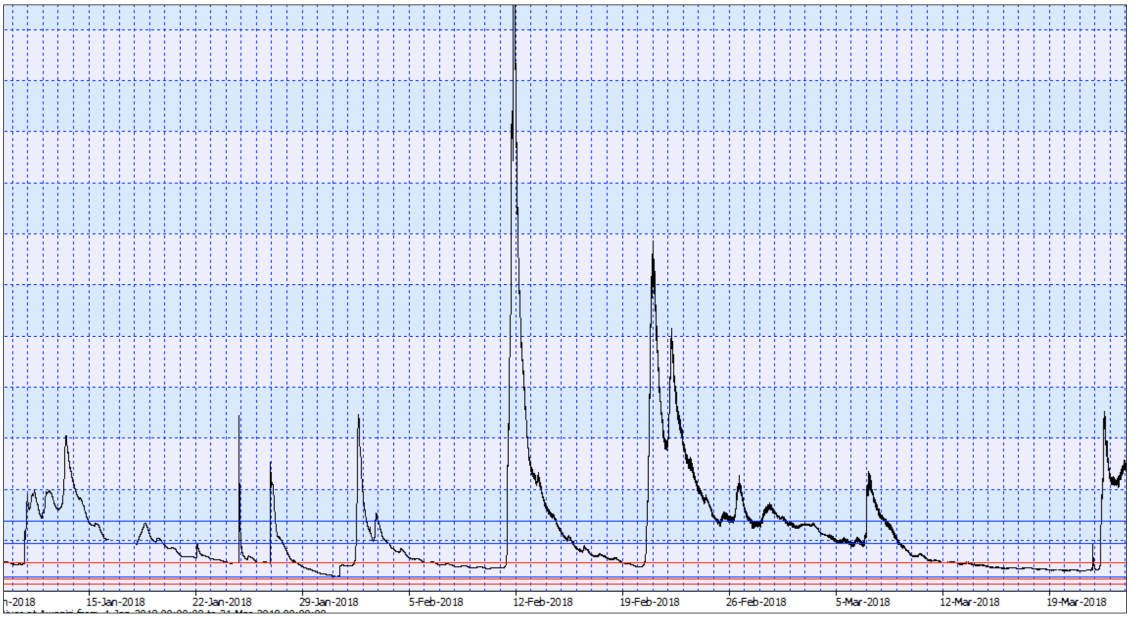

Figure 7: Awatere River flow at Awapiri from 1 January 2018 to 31 March 2018

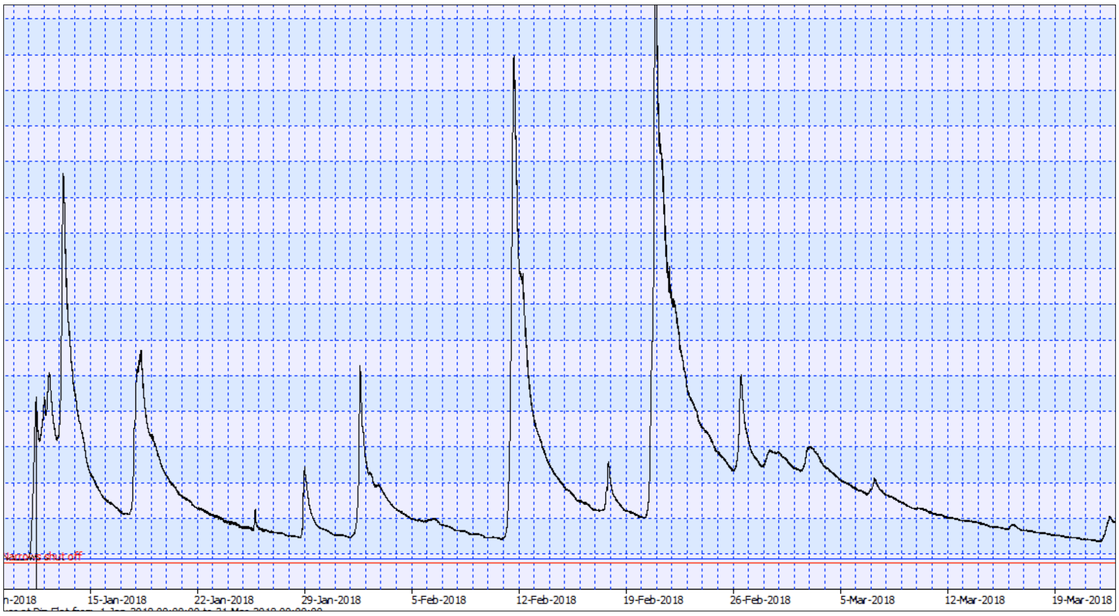

Figure 8: Wairau River flow at Dip Flat from 1 January 2018 to 31 March 2018

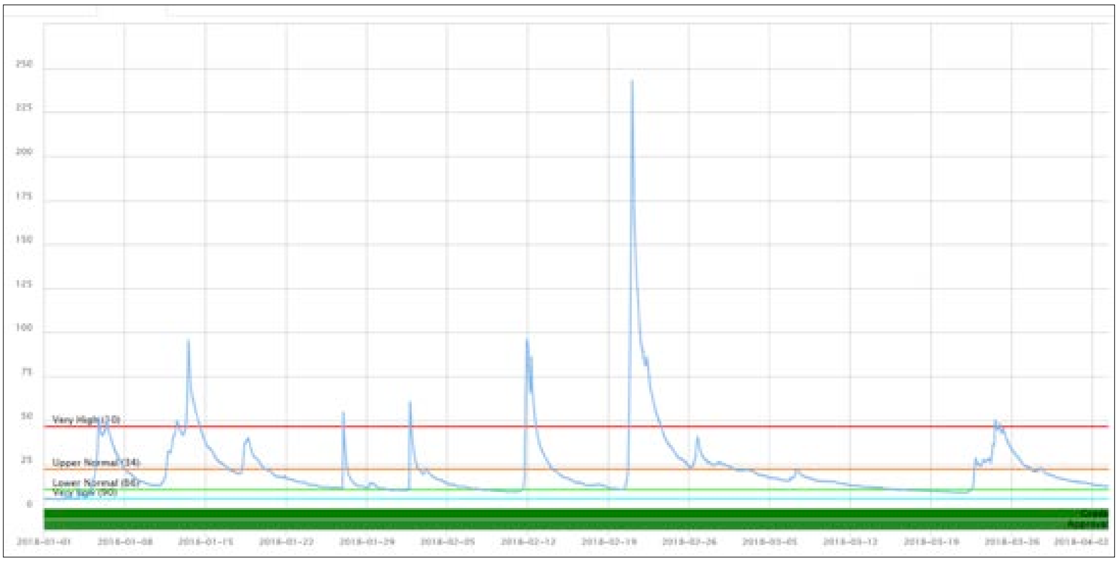

Figure 9: Acheron River flow from 1 January 2018 to 31 March 2018

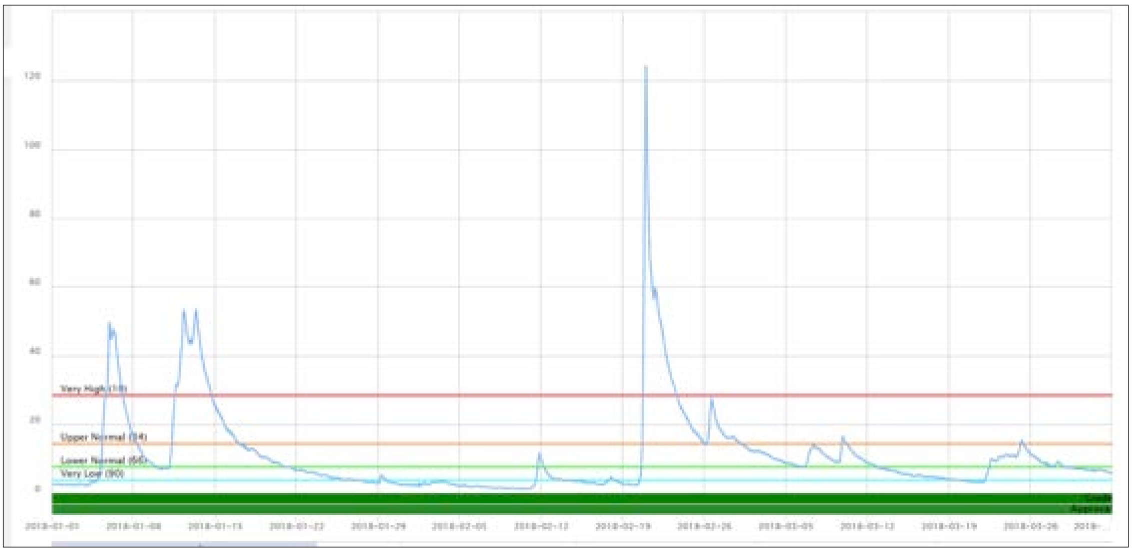

Figure 10: Waiau Toa River at Jollies Pass from 1 January 2018 to 31 March 2018

3.3.3. Field Methods

3.3.3.1 Macroinvertebrate sampling

A single semi-quantitative kick-net (0.5 mm mesh) sample was collected from sites using Protocol C1 (Stark & Maxted, 2007). Each sample was preserved with 70 percent ethanol.

3.3.3.2 Clarity

Background water clarity was taken once above each reach using a 1-metre clear tube, following the water clarity protocol of Kilroy, Biggs and Mulcock (1998).

3.3.3.3. Deposited Sediment

Two assessments of deposited sediment were taken. A bankside semi-quantitative visual assessment following SAM 1 (Clapcott et al., 2011).

3.3.3.4 Conductivity

Conductivity was measured with an Oakton ECTestr 11 Waterproof Conductivity Meter.

3.3.3.5 Temperature

Temperature was measured with glass spirit thermometer.

3.3.3.6 Shade

Shade cover was quantified as a percentage by estimating very low, low, moderate, high and very high coverage at ten transects along the reach, following the SEV protocol (Neale et al., 2011).

3.3.3.7 Macrophytes

Bankside and in-stream macrophyte cover was quantified as a percentage by estimating percentage cover at ten transects along the reach, following the Stream Ecological Valuation (SEV) protocol (Neale et al., 2011).

3.3.3.8. Periphyton

The percentage cover of the stream bed by different categories of periphyton was assessed using the Rapid Assessment Method 2 (RAM-2) described by Biggs and Kilroy (2000). This method involves estimating the periphyton percentage cover on single stones at five points across the river on ten transects within the reach.

3.3.3.9 Substrate composition

Substrate composition was estimated with bankside visual estimates in the categories of mud, sand, fine gravel, coarse gravel, cobbles, boulders and bedrock in pool, riffle and run sections of the reach where applicable.

3.3.3.10 Stability

Substrate stability was assessed using the Pfankuch method adapted for Aotearoa New Zealand conditions by Collier (1992). A rating of stability is derived from scores based on a visual assessment of the physical condition of the upper bank, lower bank and stream substrate that are weighted by perceived importance. The final score being an indication of the capacity of a reach to resist the detachment of bed and bank materials, and to recover from potential changes in flow and/or increases in sediment production" (Collier, 1992), where low scores indicate high stability.

3.3.2 Laboratory Methods

3.3.2.1 Microbial analysis

E. coli counts were assessed by Hills Laboratories. Samples were chilled and delivered to laboratories within 24hrs from time of collection. An MPN count was made for each sample using Colilert (Incubated at 35°C for 24 hours), or 1-4 Colilert 18 (Incubated at 35°C for 18 hours),

3.3.2.2 Macroinvertebrate analysis

Samples of macroinvertebrates were filtered washed 500µs mesh sieve. All macroinvertebrates were identified to MCI level.

Table 2: Water quality guidelines for Aotearoa New Zealand freshwaters

Variable	Unit	Trigger value	Source
E. coli – primary contact Faecal coliform – stock drinking water	*E. coli*/100mL	>260 (single sample) >550 (single sample) 100 (median of at least five samples collected within a 30-day period)	(ANZECC, 2000)
Clarity	Metres (m)	Upland rivers "trigger" value >0.8 Recreational contact guidelines >1.6	(Davies-Colley, 2000) (ANZECC, 2000)
Deposited Sediment (bankside visual estimate)	percent coverage	<20 percent– to protect in-stream biodiversity value <10 percent – to protect in-stream Salmonid spawning habitat value <25 percent – to protect in-stream amenity value	(Clapcott et al., 2011)
Macroinvertebrate Community Indices	MCI SQMCI	>120 – Excellent 100-120 – Good 80-99 – Fair <80 – Poor >6 – Excellent 5-5.99 – Good 4-4.99 – Fair <4 – Poor	(Stark & Maxted, 2007)

3.3.3 Note on spot testing

Due to the dynamic nature of rivers and streams, water quality and physiochemical characteristics can fluctuate, even over a short period of time (diurnally). Therefore, it is important to apply some caution to interpretation of spot tests of water quality variables using samples taken from the water column (e.g. *E. coli,* clarity). Regular monitoring over time is required to establish baseline conditions of a site. For this reason, unlike previous Cawthron surveys (Holmes, 2009; Olsen & Shearer, 2007; Shearer, 2011), this survey sought to assess variables that fluctuate with less frequency and to record indicators of habitat quality, and restrict spot tests to those variables that were significant for recreation. This survey did not spot test for nitrogen or dissolved reactive phosphorus in the water column as the consequences of long-term elevation of these nutrients are expected to be more effectively assessed through biological measures (e.g. Macroinvertebrate Community Indices and periphyton).

3.4 Results and Discussion

3.4.1 Microbiology

3.4.1.1 *E. coli*

No *E. coli* measures were found to be above primary contact guidelines (Figure 11). However, it is important to note that while single samples are used in the management of recreational sites, 'swimmability' is determined by multiple samples of a number of years. The exact nature of this is likely to change with the coming reform of the National Policy Statement for Freshwater Management.

Tarndale and Island Gully sites have higher *E. coli* levels (Figure 11). This could be due to the proximity of cattle to the streams at the time of sampling. Cattle as a source could be evaluated by further faecal source tracking. Popular swimming sites near Molesworth and Clarence campground were also tested and found to meet the acceptable primary contact standard.

Awatere Above and Robinson sites also have elevated *E. coli* (Figure 11). However, as winter grazing sites, direct deposition of faeces by cattle is unlikely to be the cause. The sites' poor clarity may be linked with these elevated levels of faecal contamination, as sediment can transport *E. coli* and act as a reservoir for the bacteria within channels (Davies-Colley, Valois, & Milne, 2018; Muirhead, Davies-Colley, Donnison, & Nagels, 2004).

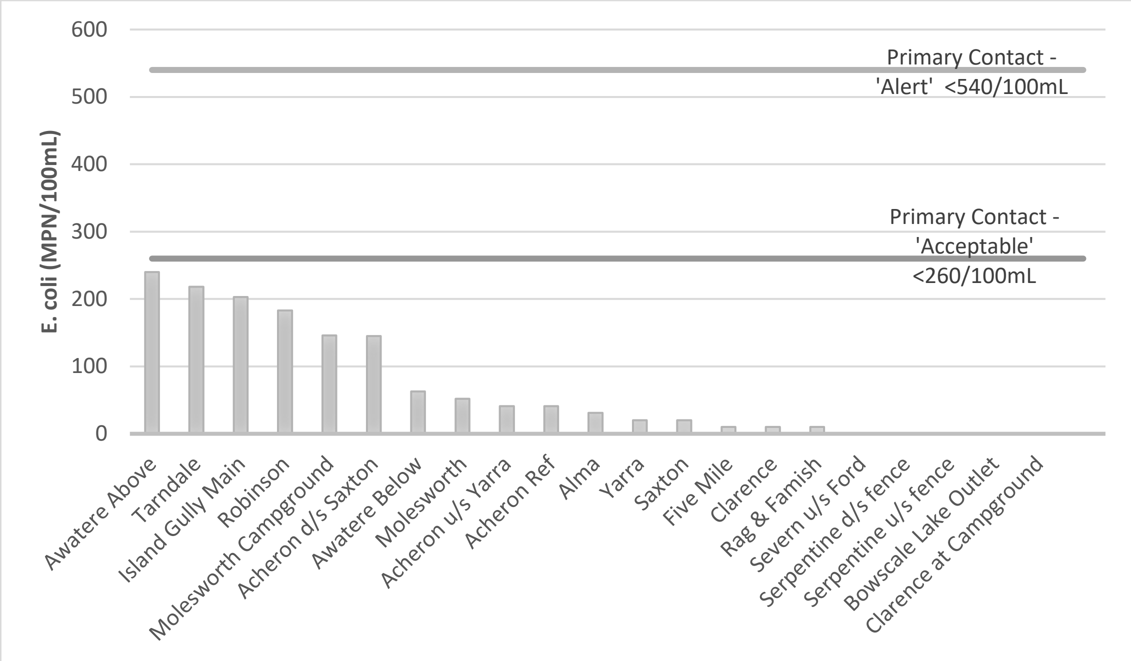

Figure 11: *E. coli* measured at 21 rivers and streams in Molesworth Station in March 2018. Absent bars indicate a result <10 MPN/100mL.

It is not possible to assess stock drinking water standards as protocol requires a median of a minimum of five samples over a 30-day period. Six of the sites were above the value of <100/100mL.

Additional samples were taken from swimming sites at the campsites on the Waiau Toa (Clarence) River and Molesworth stream as these are sites that are likely to be significant in term of recreation. In this instance, both sites were below recreational guidelines, though the site adjacent to the camping group at Molesworth was relatively elevated at 146/100mL (Figure 11).

3.4.1.2 Cyanobacteria

At Tarndale Brook two genera of cyanobacteria, *Oscillatoria* and *Phormidium,* were present (Figures 12, 13, 14 and Appendix A). Both have the potential to produce cyanotoxins that can be dangerous to humans, dogs and stock (McAllister et al., 2016; Wood, Puddick, Fleming, & Heussner, 2017). In Aotearoa New Zealand, there are documented cases of cattle and dog deaths caused by the ingestion of cyanobacteria (McAllister et al., 2016; Wood et al., 2017).

It poses a risk to drinking water and to humans using waterways recreationally (Harland, Wood, Broady, Gaw, & Williamson, 2014). There is also evidence to suggest that toxins produced by cyanobacteria can accumulate in the tissue of species that are harvested as mahinga kai (Dolamore, Puddick, & Wood, 2017). Cyanobacterial mats do not always contain toxins and, where toxins are present, concentration within mats is highly variable and difficult to predict (McAllister et al., 2018). Therefore, it is recommended to treat all cyanobacterial mats with caution.

Cyanobacterial mats are increasing in proliferation and frequency in Aotearoa New Zealand (McAllister et al., 2016). Stable flows, high temperatures and slightly elevated dissolved inorganic nitrogen (DIN) concentrations positively influence *Phormidium* proliferation (Aristi et al., 2017; McAllister, Hawes, Wood, & Atalah, 2018; Wood, Depree, Brown, McAllister, & Hawes, 2015) However, as DIN and dissolved reactive phosphorus concentrations continue to increase, they inhibit the growth of cyanobacterial mats (McAllister et al., 2018). There is some evidence that increased fine sediment also increases the growth of these mats (Wood et al., 2015).

Figure 12: Tarndale site upstream, March 2018

Figure 13: Dark brown cyanobacterial mats, Tarndale Brook, March 2018

Figure 14: Dark brown cyanobacterial mats, Tarndale Brook, March 2018

3.4.2 Water quality

3.4.2.1 Clarity

Suspended sediment, measured as clarity, can interfere with wildlife behaviour (including feeding) where animals rely on vision. Respiration of aquatic organisms can also suffer as gills may be damaged by fine suspended sediment (Davies-Colley, 2013). Fine sediment (>2mm) scatters light within the water column (Davies-Colley, 2013; Dymond et al., 2017; Matthaei et al., 2010). This can reduce radiation available to for photosynthesis, thus changing the composition of aquatic communities (Dymond et al., 2017; Matthaei et al., 2010; Suren, 2005).

Sites that have clarity measuring less than 0.8m (Robinson Creek, Acheron Reference site, Awatere River sites, Acheron downstream of Saxton River and upstream of the Yarra, and Island Gully) are considered have breached the Aotearoa New Zealand river's "trigger" value for upland rivers. Where the median values are found to be greater than 0.8m in upland rivers, this is intended to trigger action by land and water managers (Davies-Colley, 2000).

A limitation of the clarity tube method is that it was not possible to measure clarity beyond 96cm. Those sites with clarity recorded as >96cm, having the greatest clarity possible in the application of this method. Nine of the 19 sites (not including side channels) had clarity of less than 96 cm (Figure 15). These nine sites do not pass recreational guidelines that state clarity should be greater than 1.6 metres (ANZECC, 2000).

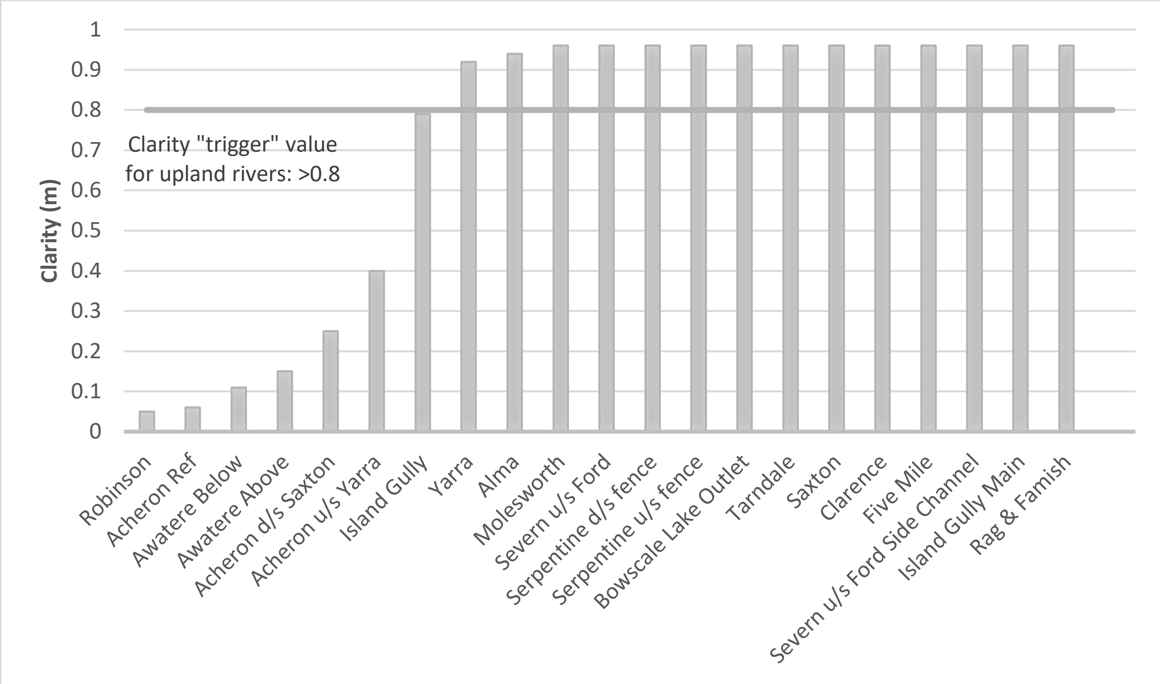

Figure 15: Clarity measured at 19 rivers and streams in Molesworth Station in March 2018.

3.4.2.2 Conductivity

Conductivity is a measurement of the ability of water to conduct an electrical charge. This is relevant in the monitoring of water quality as the increased concentration of ions (such as nutrient ions, nitrate and phosphate) in water will increase water conductivity. Conductivity does not give an indication of which ions are present. However, it can indicate where nutrient pollution may be a factor. Conductivity was thought to be preferable as previous studies (Holmes, 2009; Olsen & Shearer, 2007; Shearer, 2011) indicated very low nutrient levels across the station.

Conductivity across the station was consistently low in the Wairau and Waiau Toa catchments (Figure 16). However, Molesworth Stream had an elevated in conductivity, possibly due to its proximity to stockyards. The Robinson Creek and Awatere River measurements were also elevated and this could be due to suspended sediment in the water column increasing the phosphate concentration.

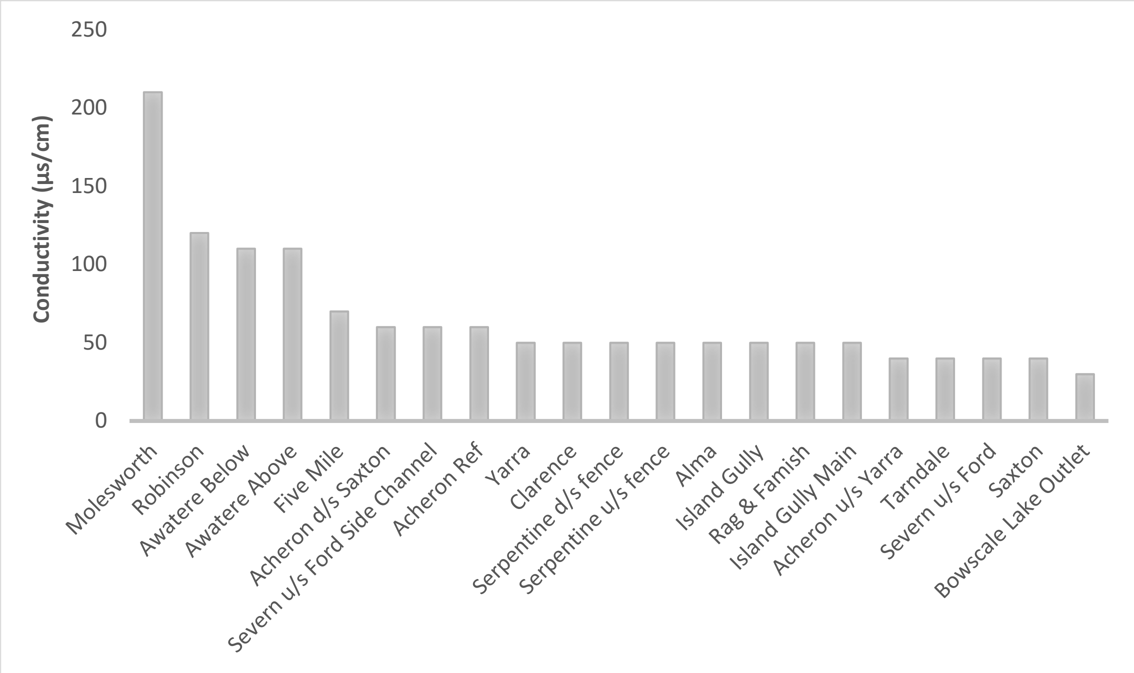

Figure 16: Conductivity measured at 20 sites in Molesworth Station, March 2018.

3.4.3 Habitat quality

Ecosystem health of rivers and streams is determined not only by water quality but also by habitat quality. Aquatic life requires suitable habitat as well as good water quality to thrive. The measurements below provide some indication of habitat quality.

3.4.3.1 Deposited sediment

While clarity is a measurement of sediment in the water column, it is the sediment that settles on the bed of a rivers or stream that can be most damaging for aquatic biota as it fills in the spaces between and under rocks where invertebrates and fish seek refuge (Figure 17) and can smother food sources such as the thin films of algae present on rocks in natural systems. Deposited sediment is often more detrimental for biota than suspended material (Burdon et al., 2013; Naden et al., 2016; Parliamentary Commissioner for the Environment, 2012).

Current guidelines suggest that a maximum of 20 percent fine sediment cover of river and stream beds is appropriate to protect biodiversity values and that a bankside visual estimate of coverage provides sufficiently accurate data to monitor coverage (Clapcott et al., 2011). Ten sites exceeded this ecosystem health guideline (Figure 20). At the Acheron reference site (Acheron Ref) clarity was too poor to be able to conduct a bankside visual estimate of deposited sediment as the riverbed was not visible (Figure 21).

Figure 17: Molesworth site deposited sediment: 16 March, 2018.

Acheron downstream of the reference site (Acheron u/s Yarra and Acheron d/s Saxton) and all Awatere River sites had relatively high levels of deposited sediment (Figures 17, 18, 19, 22 and 23). The Awatere River site above Robinson Creek (Awatere Above) had the highest level of deposited sediment (Figures 22 and 23). Slow flows and severe bank erosion in the reach contributed to this (Figures 23). The pool pictured in Figure 23 had a thick layer of mud on the bed.

Figure 18: Acheron u/s Yarra site deposited sediment (sunglasses on rock for scale), March 2018

Figure 19: Awatere below site deposited sediment, March 2018

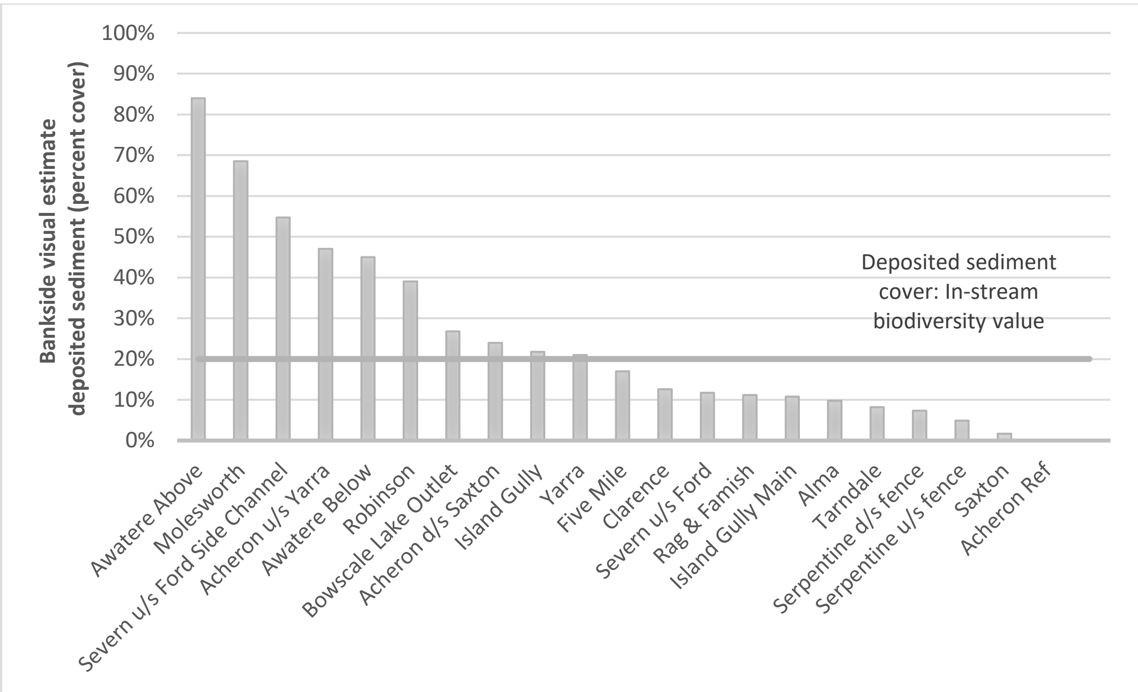

Figure 20: Bankside visual estimate deposited sediment (percent cover) recorded at 20 sites in Molesworth Station, March 2018.
** Acheron Ref site clarity too poor for bankside visual estimate to take place, river bed not visible.

Figure 21: Acheron Ref site downstream end of monitored reach, 11 March 2018

Figure 22: Awatere River site above Robinson Creek (Awatere Above) downstream end of monitored reach, 17 March 2018.

Figure 23: Awatere River site above Robinson Creek (Awatere Above) upstream end of monitored reach, 17 March 2018.

3.4.3.2 Temperature and shade

Because of variability, 'spot test' measurements of temperature are not sufficient to indicate impacts of warmer water temperatures on ecosystem health. The most significant measurement, if possible, would be hottest temperatures over the hottest days of the year. The highest temperature in this sampling of 21°C was recorded in Tarndale Brook (Appendix B). Shading of reaches was found overall to be very low to low across most sites surveyed with the exception of Five Mile Stream and the Awatere Above site, where willows were abundant (Figure 24).

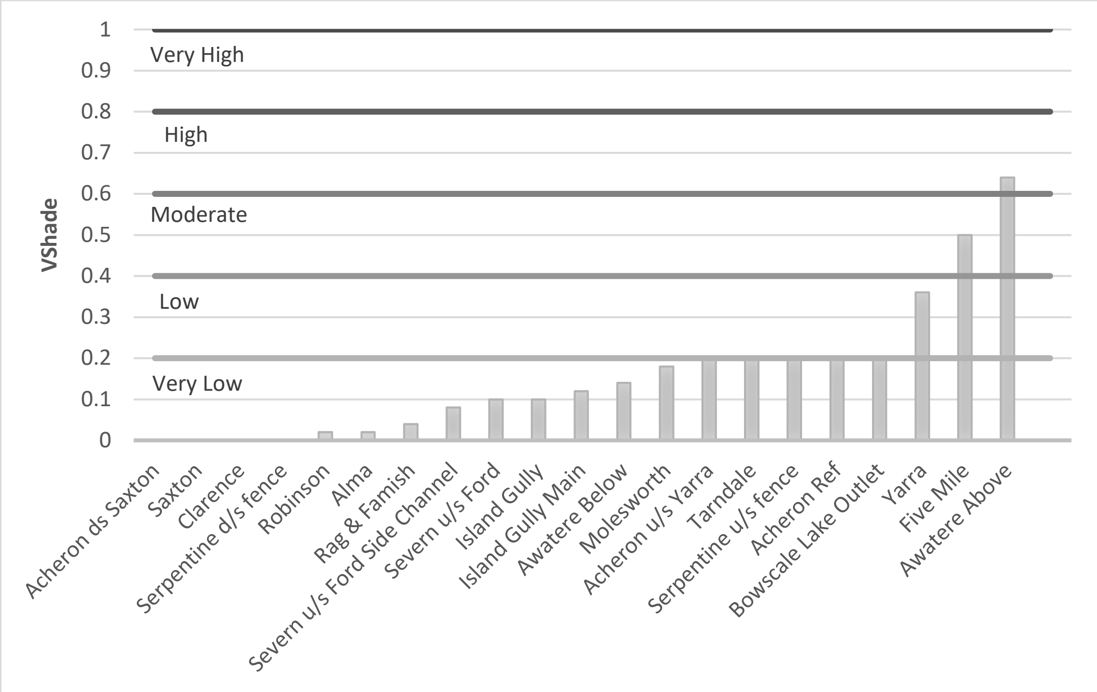

Figure 24: Shade visual estimate recorded at 20 rivers and streams in Molesworth Station in March 2018.

Temperature is highly variable in space and time. Temperature can influence the growth of periphyton and levels of dissolved oxygen. Invertebrates display different thermal tolerances, there are limits to the maximum temperature and duration of exposure to maximum temperatures for species. (Quinn et al., 1994). Relatively sensitive invertebrates like species of Ephemeroptera (mayflies), for example, in lab tests have been found to survive relatively short exposures (24hrs) to 26.8 °C but to struggle to survive longer exposures to temperatures above 22.6 °C (Quinn et al., 1994). Pastoral streams have been found to have higher average temperatures than native and exotic forested streams largely due to a lack of shading (Quinn et al., 1997; Quinn et al., 1994; Young et al., 2005). Long term impacts from thermal stress may be indicated through low MCI values, where sensitive species are not found in sampling.

3.4.3.3 Macrophytes

The growth patterns and abundance of native and exotic macrophytes (aquatic plants) can be influenced by land management and subsequent changes in conditions within the channel. This can lead to impacts on aquatic ecosystems. In this survey, however, the occurrence of macrophytes across the sites was found to be minimal (Appendix C).

3.4.3.4 Periphyton

Periphyton is naturally occurring slime and algae in waterways (Biggs, 2000). Land use can disrupt the natural growth of periphyton by altering nutrient concentrations, flow regimes, light, temperature and sediment load in water bodies (Biggs, 2000; Harding et al., 1999; Hart et al., 2013; Snelder et al., 2014). The results of the RAM for the assessment of periphyton show lower values than those recorded by Cawthron in 2011. This could be for a number of reasons but it is also important to recall the large storm event in the month prior to sampling. High flows can cause algae to become detached from the substrate and be washed away. Figure 25 shows the lowest scores for periphyton at the Acheron Reference site. This is likely a result of abrasion from high sediment loads in the water (c.f. poor clarity results) and/or the same high sediment loads limiting light penetration to the riverbed.

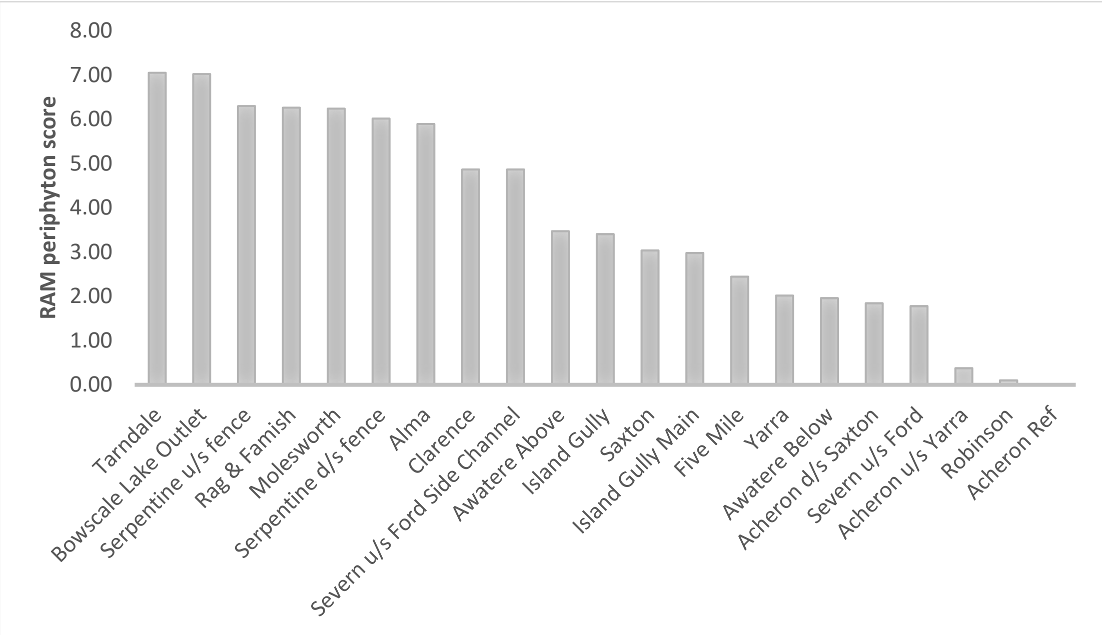

Figure 25: Periphyton rapid assessment recorded at 20 rivers and streams in Molesworth Station in March 2018.

Highest scores (and therefore the greatest coverage of periphyton recorded) was found at Tarndale Brook (Figure 25). Periphyton growth at this site is likely to be influenced by slow flows, high temperatures and lack of shade. More analysis is needed of the categories of periphyton recorded to develop a full picture of the drivers of periphyton growth at these sites, however, this is beyond the scope of this report.

3.4.3.5 Substrate and stability

Substrate measurements were converted to an index where the higher the number the larger the substrate (Appendix E). Sites at Tarndale Brook (Tarndale) and Serpentine Creek upstream of the fence (Serpentine u/s fence) had the largest substrates, while the Island Gully main site and Robinson had the smallest substrate (Appendix E).

Stability was assessed using a Pfankuch assessment method where low scores indicate high stability (Collier, 1992). Stability in the context of habitat quality is significant in that it influences the taxonomic richness and abundance of aquatic invertebrates as well as the growth of periphyton (Collier, 1992). The lowest scored and therefore relatively highly stable site was Serpentine Creek upstream of the fence (Figure 26).

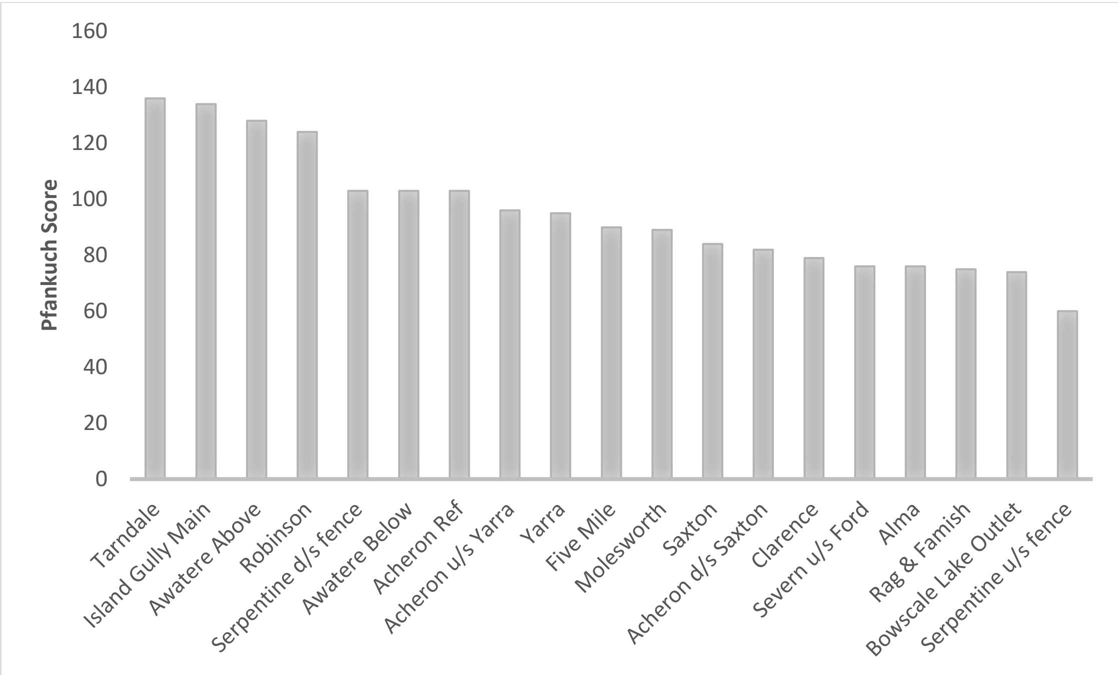

Figure 26: Stability assessment recorded at 19 rivers and streams in Molesworth Station in March 2018

3.4.4 Macroinvertebrates

3.4.4.1 Macroinvertebrate Community Index

The Macroinvertebrate Community Index (MCI) and Quantitative Macroinvertebrate Community Index (QMCI) gives a score for a site based on the presence and abundance of taxa collected (Table 3). The MCI score gives an indication of how impacted a site is by nutrient enrichment and/or organic pollution as taxa respond differently to these impacts.

Table 3: Interpretation of MCI and QMCI (Adapted from (Stark & Maxted, 2007b)

Quality Class	Description	MCI	QMCI
Excellent	Clean water	>119	>6
Good	Doubtful quality or possible mild pollution	100 – 119	5 – 5.99
Fair	Probable moderate pollution	80 – 99	4 – 4.99
Poor	Probable severe pollution	<80	<4

Figure 27 shows that the majority of sites were found to be good or excellent based on MCI. Bowscale and Molesworth sites both scored 99 and Rag & Famish scored 90 (Appendix D). The Bowscale site is an outlet of a lake and therefore likely to have a different composition of invertebrates may explain the low score at this site.

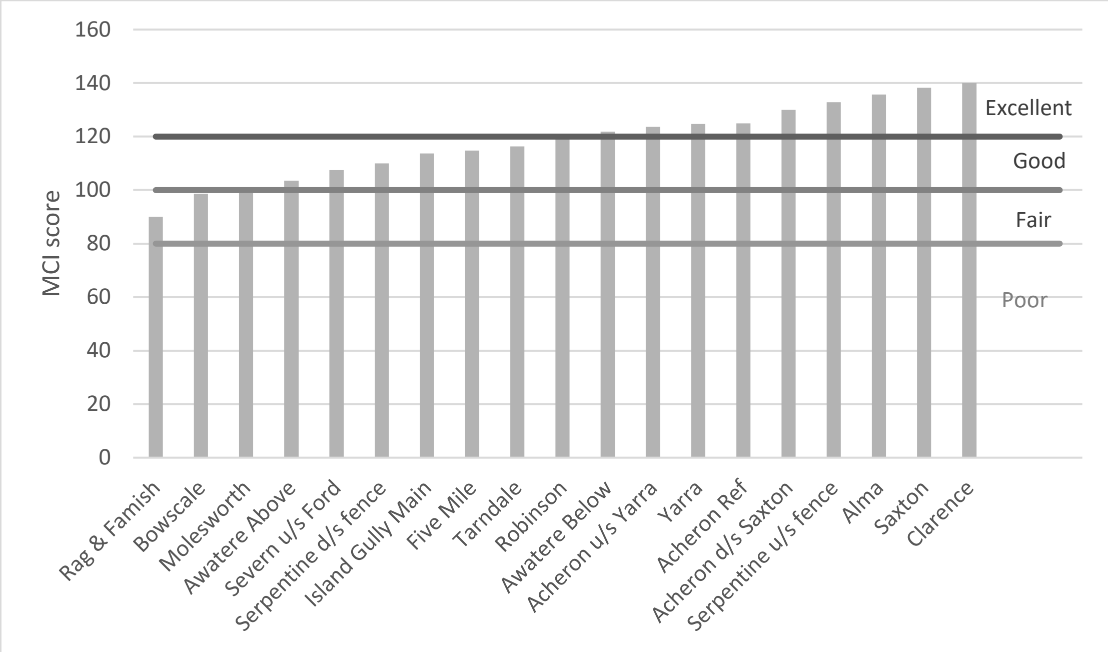

Figure 27: MCI recorded in 19 streams in Molesworth Station collected in March 2018.

3.5 Conclusion and Recommendations

This survey of physiochemical, biological and microbiological parameters of 19 rivers and streams on Molesworth Station indicated that water quality on the station is generally good.

There is indication that there may be some pressure on ecosystem health by fine deposited sediment and that human and stock health could be put at risk by cyanobacteria.

In the interests of managing waterways to be consistent with the values and policies described in the Molesworth Management Plan (2013), the author makes the following recommendations:

3.5.1 Recommendation 1

Using Geographic Information System (GIS), develop mapping that identifies erosion risk across the station. Using this risk modelling, identify areas where it would be practical to address erosion and manage land to reduce fine sediment loss to waterways. Prioritise future land management projects through this process.

3.5.2 Recommendation 2

Produce and introduce cyanobacteria training materials for Pāmu and DoC staff. Develop protocols for Molesworth Station involving Pāmu and DoC staff to limit risk to the public and animals. Cyanobacteria should be monitored by both Pāmu and DoC staff through a system of shared recorded observations.

3.5.3 Recommendation 3

Consistent with the management plan, establish and maintain a three-yearly monitoring programme in order to track changes over time. Each round of monitoring should result in a substantive report such as this one and monitoring should include *E. coli,* deposited sediment, conductivity, clarity, MCI, temperature, shade, periphyton, macrophytes, and substrate composition.

3.5.4 Recommendation 4

In order to respond to localised concerns for waterways on the station in terms of ecosystem health, a conductivity meter can be purchased for the station as a first indicator in cases where nutrient contamination may be suspected.

3.5.5 Recommendation 5

In order to respond to localised concerns of the suitability of waterways for recreation and/or stock drinking water, a guide to *E. coli* sampling and testing should be produced and made available to Pāmu and DoC staff.

Chapter 4: Molesworth – Identifying action areas for sediment loss mitigation

4.1 Abstract

Molesworth Station is a large beef operation in the high country of the South Island, operating on land leased from the Department of Conservation to Pāmu (Landcorp Farming, Ltd.)

Overall, water quality on the station has been found to be very good. However, sediment loss to waterways has been identified as a likely pressure on ecosystem health within the station's streams and rivers.

This report identifies action areas on the property and presents six recommendations to address sediment loss to waterways on Molesworth Station.

The six recommendations are:

- Fence small northern Awatere River tributaries.
- Plant between Molesworth Stream and stockyards.
- Observe Robinson Creek.
- Fence seep near Tarndale Brook.
- Survey to compare small streams on Molesworth and St James Stations.
- Maintain three-yearly monitoring programme.

4.2 Introduction

Chapter three reported that sampling on Molesworth Station in March 2018 found sediment loss to waterways was likely to be impacting the ecosystem health of streams and rivers on the property. Sediment loss to waterways and its transfer downstream are natural processes, however, increased sediment loads in streams and rivers can result from agricultural activity and lead to a multitude of adverse effects.

Molesworth Station is a very large beef operation operating on 180,787ha of high country, with significant areas of naturally highly erodible landscapes. In general, water quality on the station is good; the majority of sites sampled showing MCI values that indicate good or excellent water quality. However, in parts of the station the coverage of streambeds in deposited fine sediment is high and water clarity is poor. March 2018 sampling found that in-stream biodiversity guidelines for water clarity were breached at seven of nineteen sites sampled. Guidelines for fine sediment (<2mm) cover were breached at ten sites.

Research has found there is link between high levels of deposited sediment and low ecological integrity in aquatic environments (Davies-Colley et al., 2015; Waters, 1995). Deposited sediment can impact aquatic life by smothering animals, (fish and macroinvertebrates) directly. It can reduce suitable habitat by filling the spaces between rocks where animals take refuge (Burdon et al., 2013; Davies-Colley et al., 2015). It can also smother and bind with the periphyton (algae) that grows on rocks in rivers and streams, which can reduce the nutritional quality and availability of this important food source for macroinvertebrates. Invertebrate communities affected by increased sedimentation can be altered, losing more pollution-sensitive species such as mayflies and stoneflies, and seeing an increase in chironomids and oligochaetes that can survive in deposited sediment (Matthaei et al., 2010; Wagenhoff, Townsend, & Matthaei, 2012).

Suspended sediment in the water column, indicated in this report by water clarity measured in centimetres, also impacts the health of aquatic ecosystems. Suspended sediment can disrupt aquatic animals that are visual feeders by reducing visibility (Lange et al., 2014). The gills of fish and invertebrates can be damaged by suspended sediment (Boubée, Dean, West, & Barrier, 1997). It can also diminish the quality and quantity of periphyton by reducing light penetration through water, which can disrupt macroinvertebrate communities as an important source of food is altered (Davies-Colley, 2013; Matthaei et al., 2010).

Molesworth Station has a stream and river network of approximately 2,672km across three major catchments, Waiau Toa (Clarence), Wairau and Awatere (Figure 28). A significant proportion of the station is classified as having "extreme erosion severity" (>20 percent in area), "very severe" (10-20 percent in area), and "severe" (five to ten percent in area) (Department of Conservation, 2013). Factors contributing to this erodibility include tectonic activity, underlying geology and soil types, climatic influences (including frost-heave, which leaves soil exposed), types of vegetative cover, and lack of suitable stabilising vegetation, as well as pest and stock disturbance.

The natural erodibility of a large proportion of the station means mitigation of soil loss to waterways is not always appropriate or practical. Chapter three recommended using Geographic Information System (GIS) software to identify areas where it would be beneficial and practical to mitigate erosion to reduce fine sediment loss to waterways in order to inform future land management decisions.

Using national data sets for deposited fine sediment in waterways, it is possible to identify areas of the station where observed deposited fine sediment values are significantly higher than would be expected under natural conditions and, therefore, areas where human activity is more likely to be a factor in sediment loss to waterways.

This report maps these areas and overlays them with national data for in-stream biodiversity values to identify action areas. These are areas of the property where mitigation of sediment loss is practical and likely to be most effective in improving ecosystem health of waterways on Molesworth Station and beyond its boundary.

From this, in combination with current freshwater research and information gathered during sampling in March 2018, six recommendations are made to address sediment loss to waterways on Molesworth Station.

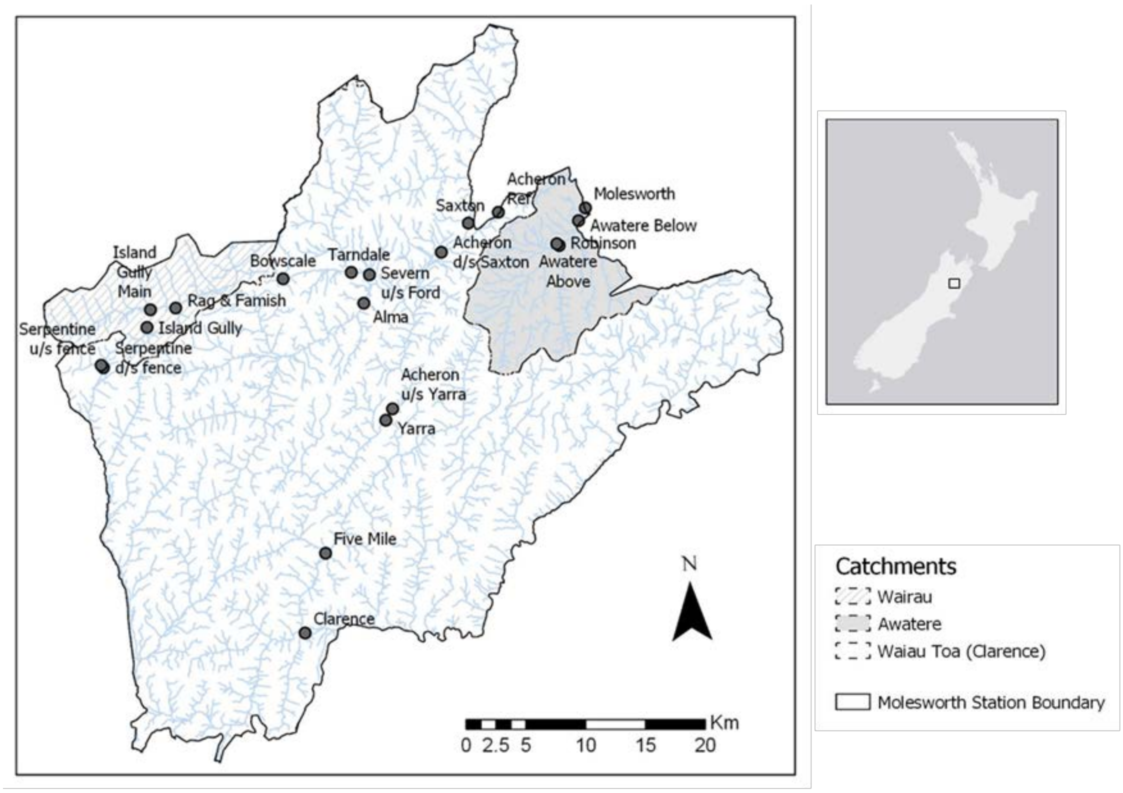

Figure 28: Molesworth Station is located in the South Island of Aotearoa New Zealand at the headwaters of three major river catchments; Awatere, Waiau Toa (Clarence) and Wairau Rivers.

4.3 Methods

4.3.1 National datasets

Predicted streambed sedimentation datasets are publicly available through Ministry for the Environment's data site, as is the national dataset for predicted average Macroinvertebrate Community Index (MCI) scores (Ministry for the Environment, 2016a, 2016b, 2016c). Predicted expected scores for MCI, used for this report, are not currently publicly available. Predicted native fish data was also considered for use in this report but, due to the altitude of Molesworth Station and therefore its limited number of fish species, it was found not to be appropriate (Canning, 2018).

4.3.2. Predicted Streambed Sedimentation 1990 – 2011

A national dataset for observed fine sediment cover has been developed using 21-years of field observations from 10,026 sites around the country. Streambed sedimentation is recorded as a percentage of the bed covered in fine sediment (particulates <2mm in diameter) (Ministry for the Environment, 2016a).

A national dataset for expected streambed sedimentation (i.e. fine sediment cover under natural conditions) has been developed using a regression model taking into account observed measurements and predictors such as slope, climate and vegetative cover (Ministry for the Environment, 2016b).

Current guidelines suggest that a maximum of 20 percent fine sediment cover of river and stream beds is appropriate to protect biodiversity values and that a bankside visual estimate of coverage provides sufficiently accurate data to monitor coverage (Clapcott et al., 2011).

For this report, sites where expected fine sediment cover is greater than 20 percent have been excluded as this suggests these sites are naturally high in deposited fine sediment and, therefore, would be less likely to respond to mitigation. Sites where observed streambed sedimentation is less than 20 percent have also been excluded as fine sediment cover is below the guidelines' threshold for impact on in-stream biodiversity.

Sites that remain have expected values of less than 20 percent and observed values greater than 20 percent.

4.3.3 Predicted average Macroinvertebrate Community Index score, 2007 – 2011

A national dataset for predicted observed average MCI scores has been developed using monitoring data from 513 sites around the country in combination with predictive factors such as land cover, elevation, climate and geology (Clapcott et al. 2017). A national dataset for predicted expected MCI scores (i.e. the expected score under natural conditions) has been developed using monitoring data from 1033 sites and environmental data including land cover, flow, temperature, slope and geology.

It is important to note that the MCI commonly used in Aotearoa New Zealand has been developed to indicate the effects of nutrient enrichment on streams and rivers not sediment. However, Quantitative Macroinvertebrate Community Index (QMCI) has been shown degrade in response to increasing sedimentation.

4.3.4 Collected data, March 2018

Ecosystem health surveys were conducted at 19 sites across the station (chapter 3). Sites were chosen from 66 sites sampled previously by the Cawthron Institute (Holmes, 2009; Olsen & Shearer, 2007; Shearer, 2011). Small and large order waterways were sampled taking into consideration geographical spread, winter and summer grazing sites as well as improved pasture and sites that have been fenced off from cattle. Reach length was determined by taking an average of the lengths of five widths of the water body along a reach and multiplying by 20 – up to a maximum length of 150 metres (Table 2).

4.3.5 Observed/Expected ratios

Natural variability of landscapes and waterways means, in the case of MCI, a score that is considered fair for one river type may be considered good for another (Clapcott et al., 2017). Likewise, predicted streambed sedimentation may be above the 20 percent guideline for in-stream biodiversity in some reaches under natural conditions due to underlying geology, topography or climate.

To overcome this variability, this report uses ratios of observed versus expected values. This ratio is calculated by dividing observed values by expected values (O/E). Using O/E, the impact on waterways is measured by the extent to which observed conditions differ to reference (expected) conditions.

For example, where a site is found to have 40 percent fine sediment cover and its expected percentage cover is the same, it would be said to have a 1:1 ratio. There is no difference in what is observed and what is expected. Whereas a site that has an expected cover of two percent but an observed cover of 40 percent would have a 20:1 ratio. In this case, streambed sedimentation could be said to be 20 times higher than expected. Sites with high ratios are more likely to be influenced by human activity on the land.

In the case of MCI, low ratios indicate a more impacted waterway because scores are worse (lower) than expected. For MCI, an O/E value of less than one would suggest sites may be impacted, where the smaller the ratio, the greater the impact.

4.4 Limitations of report

This report does not include information or recommendations for lakes and tarns on the property.

4.5 Results and Discussion

4.5.1 Observed/Expected streambed sedimentation

Figures 29 and 30 shows the output of observed/expected streambed sedimentation using a model derived from a national dataset. Where O/E is less than five, sites have not been coloured. This means that only sites where observed streambed sedimentation is greater than five times the expected cover are coloured on the map. Dark red sites have between 50- and 100-times higher streambed sedimentation than expected. Only a few sites have an 0/E value this high. However, values between 10- to 50-times higher than expected are common (dark orange).

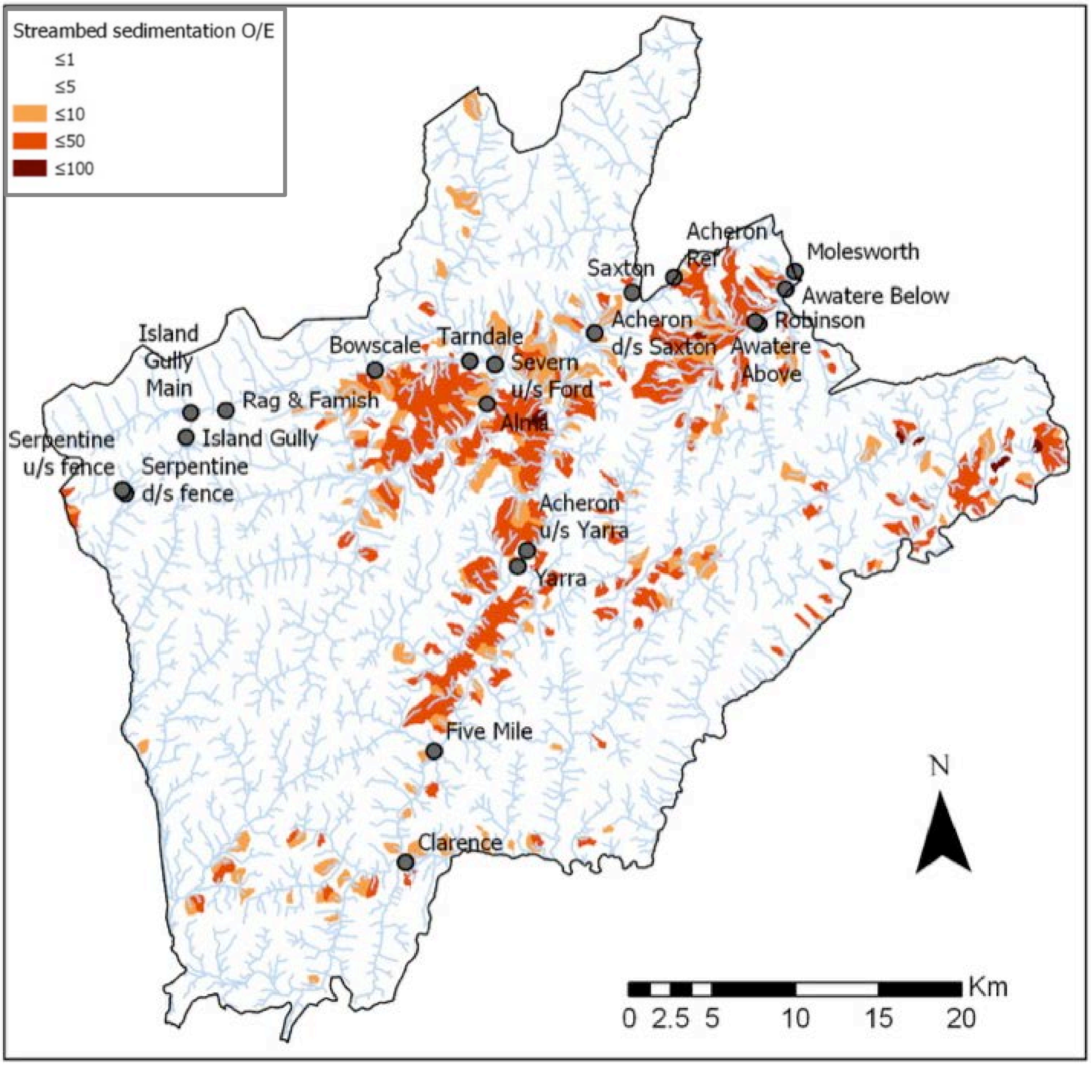

Figure 29: Map of predicted streambed sedimentation O/E output showing sites where O/E ≤10

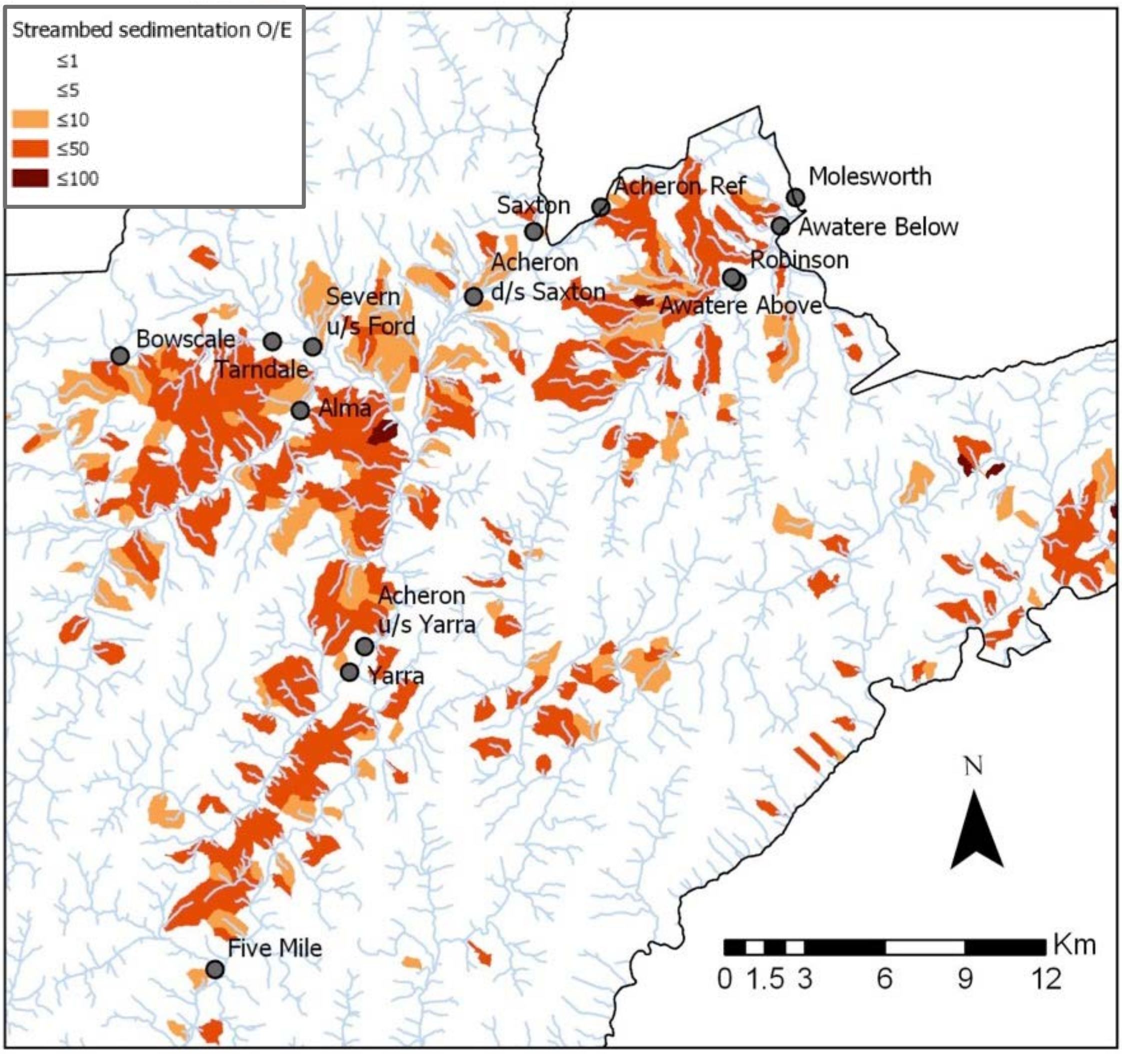

Figure 30: Detail of predicted streambed sedimentation O/E output showing sites where O/E ≤10

Higher values are clustered in the Awatere River catchment, Travellers Valley (between the Bowscale Lake Outlet, Tarndale and Severn u/s Ford sites) as well as below the Alma and Severn Rivers confluence. High values are also scattered through lengths of the Acheron River, far eastern edges of the property and some smaller tributaries of the Waiau Toa (Clarence) like the Leader Dale. The Wairau River catchment shows low values using these national datasets.

Appendix F shows some effects of streambed sedimentation and appendix G shows examples of deposited fine sediment at Molesworth Station sites.

4.5.2 Observed/Expected MCI scores

Figures 31 and 32 shows the output of observed/expected MCI scores using national datasets. Where O/E is greater than 0.85, sites have not been coloured.

Similarly, to Figures 29 and 30, these maps show clustering of poor O/E values in the Awatere River catchment, and between Bowscale Lake Outlet, Tarndale and Severn u/s Ford sites. However, the Wairau catchment also appears to have clustering of poor values along with the upper reaches of the Waiau Toa (Clarence) River at Serpentine Creek. Low values are scattered across the station including on the Guide River and eastern edges of the property.

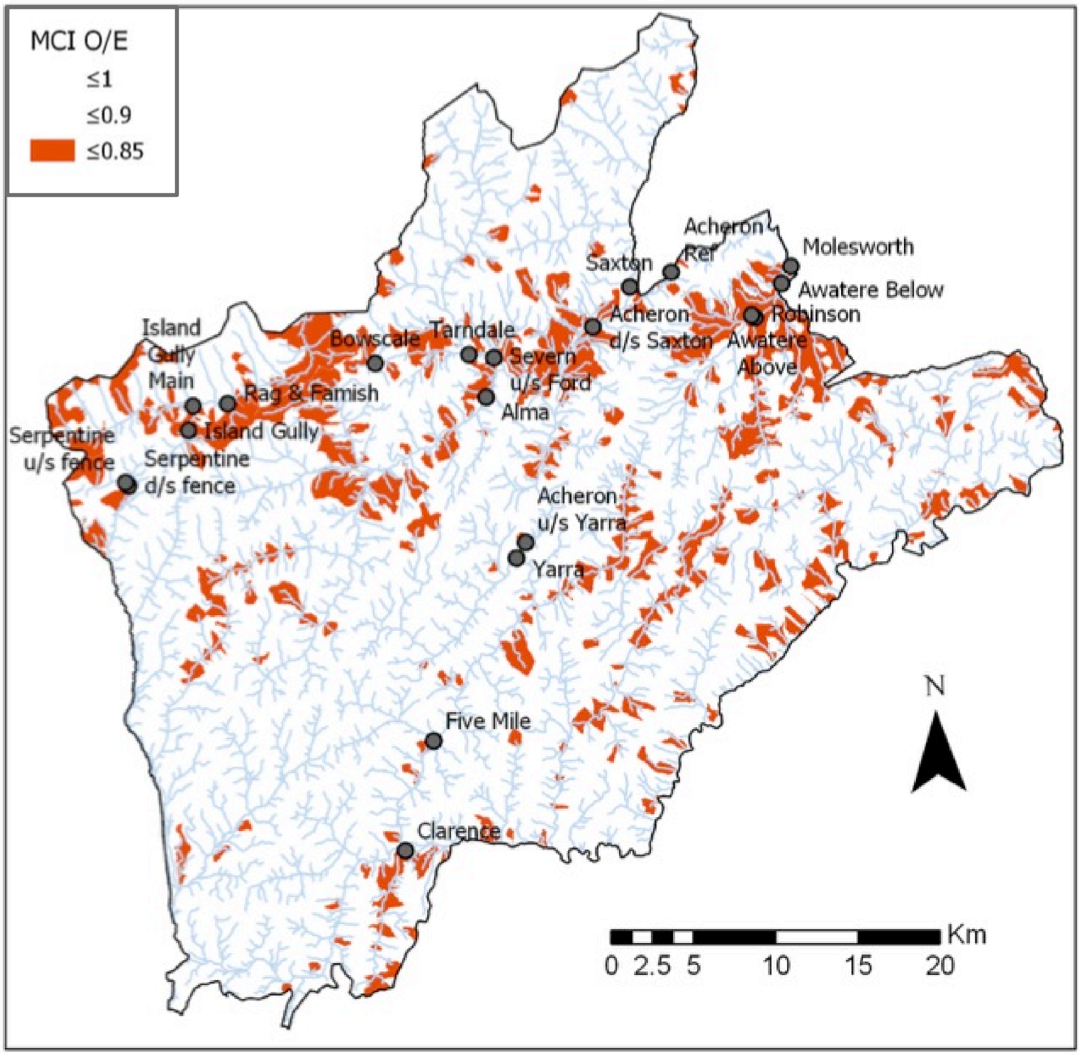

Figure 31: Map of predicted MCI O/E output showing sites where MCI O/E is ≤0.85

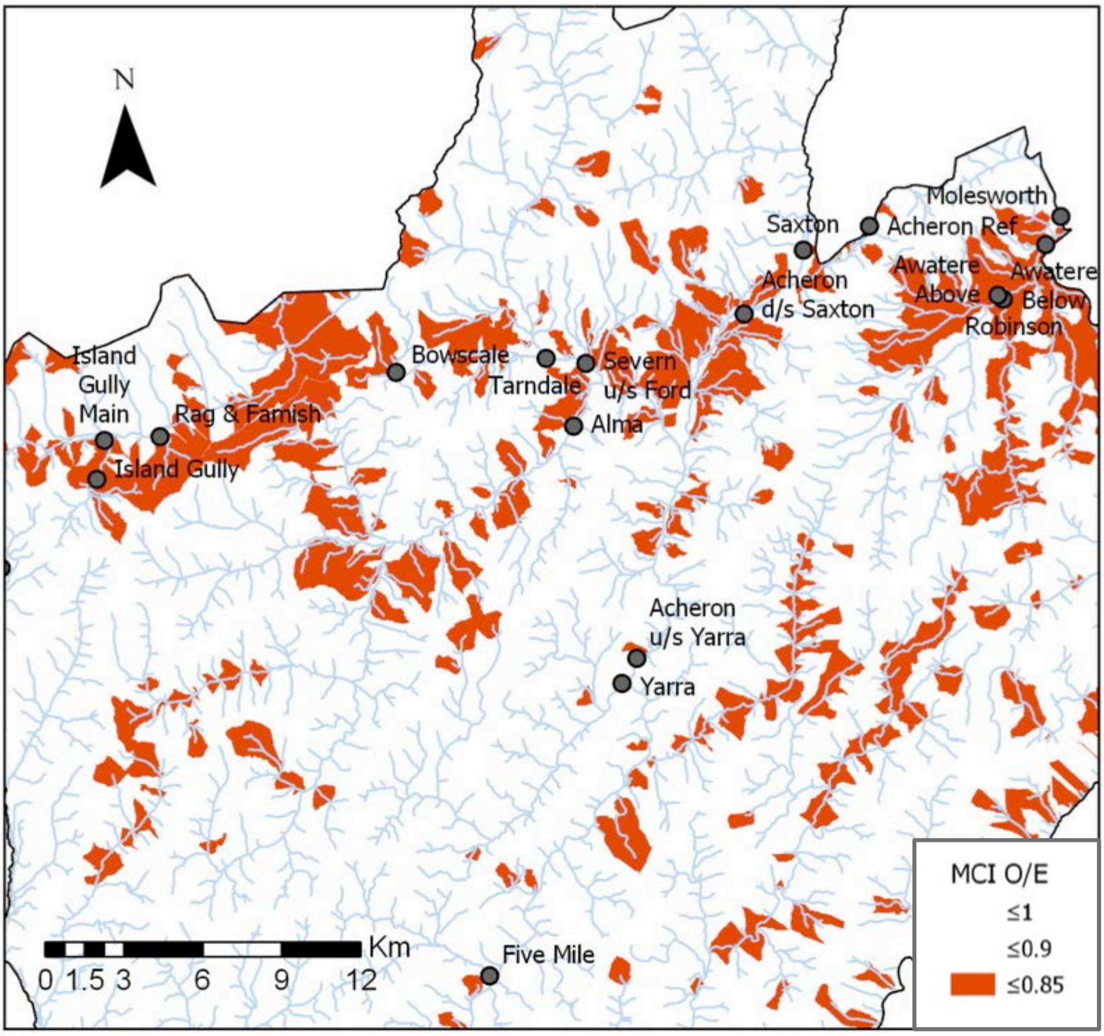

Figure 32: Detail of predicted MCI O/E output showing sites where MCI O/E is ≤0.85

The lower MCI O/E values in the Wairau River and upper Waiau Toa (Clarence) catchment are likely due to the change in stream shading due to deforestation over time. For example, predicted historic values for riparian shade on Island Gully Stream were between 70 and 80 percent, while predicted current shading for the stream are less than 15 percent (Ministry of Health, 2016c). This is supported by March sampling, where shade for Island Gully sites was recorded as *very low* (VShade = <2).

4.5.3 Collected data/Expected MCI scores

Table 4 shows observed data collected in March 2018 over expected data from the national dataset where subsequent MCI O/E values were found to be ≤0.85. These O/E values using

March 2018 should be used with some caution as collected data is from one-off sampling. However, it does show some confirmation of pressure on Awatere River catchment sites with Awatere Above and Molesworth sites showing values below 0.85. Travellers Valley sites (Bowscale Lake Outlet and Severn u/s Ford) also have low values. Rag & Famish shows an exceptionally low MCI 0/E using March 2018 data.

Table 4: Predicted reference MCI and March 2018 sampling MCI scores used to produce a MCI O/E value.

Site	Predicted Reference MCI score	March 2018 MCI score	MCI O/E (using March 2018 data)
Awatere Above	126	103.56	0.821
Severn u/s Ford	131.8	107.5	0.816
Bowscale Lake Outlet	124.2	98.67	0.794
Molesworth	128.7	98.89	0.768
Rag & Famish	133	90	0.677

4.5.4 Collected data/Expected streambed sedimentation

Figures 33 and 34 uses observed data collected in March 2018 over expected data from the national dataset. Again, this map should be used with some caution as collected data is from one-off sampling. However, it does offer some useful confirmation of modelled data. Figure 7 shows the Awatere River catchment sites have significantly higher deposited fine sediment cover than would be expected under natural conditions, as does a site on the Acheron just above the Yarra River confluence.

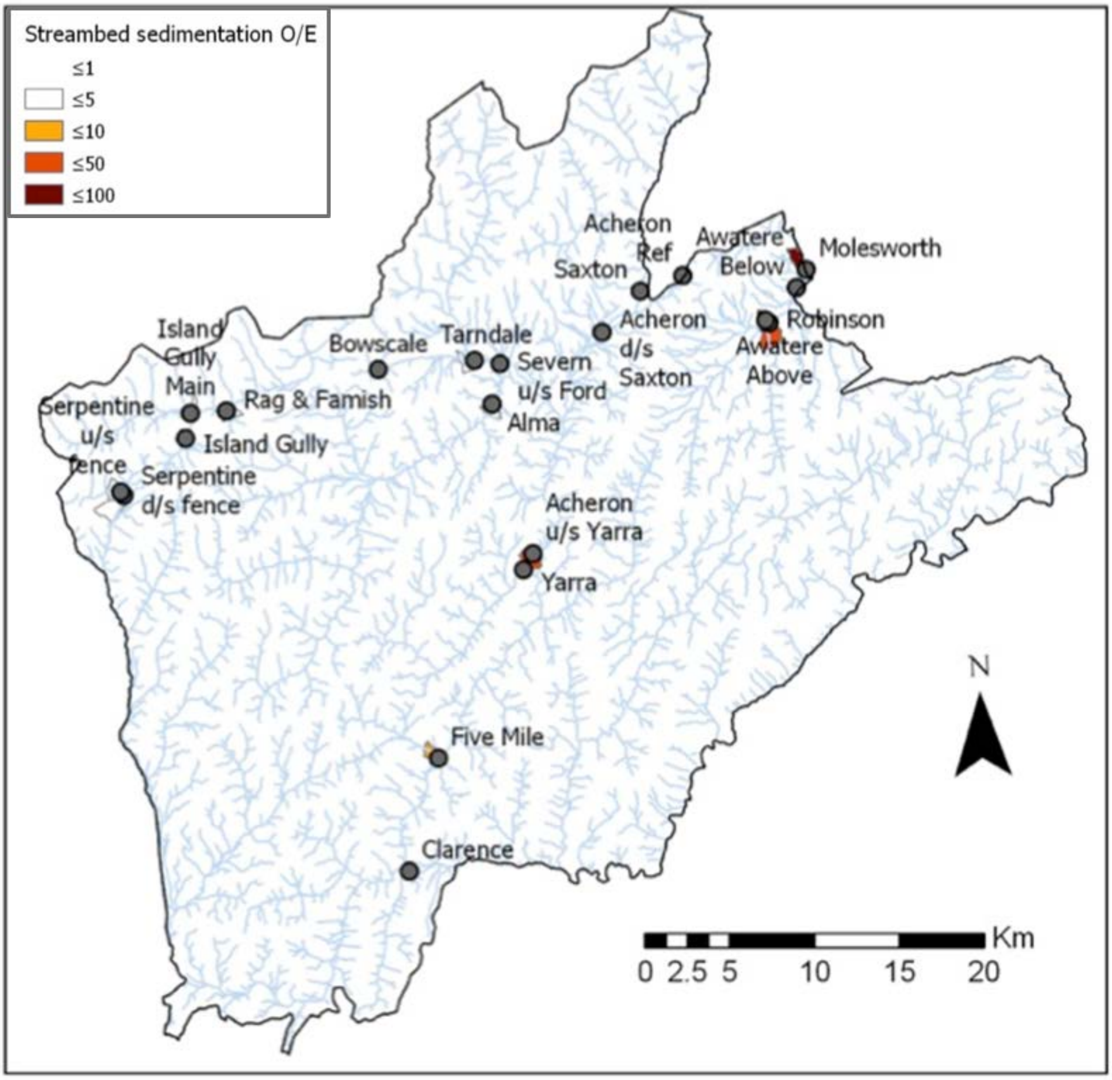

Figure 33: Map of streambed sedimentation O/E output using data collected in March 2018 showing sites where O/E is ≤10

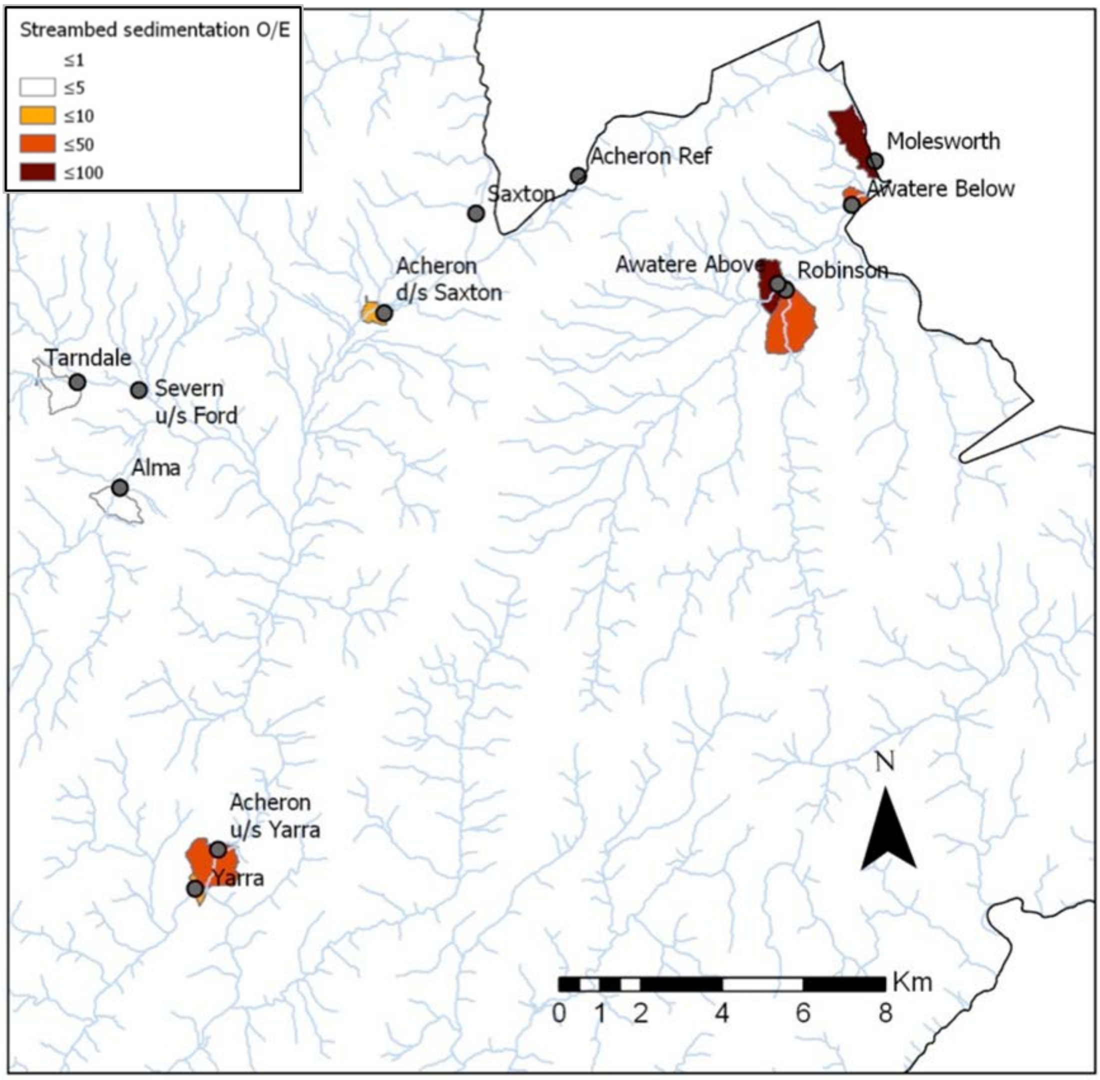

Figure 34: Detail of streambed sedimentation O/E output using data collected in March 2018 showing sites where O/E is ≤10

4.5.5 Intersection of streambed sedimentation and MCI O/E

Figure 35 and 36 highlight areas where the stream sedimentation O/E and MCI O/E maps intersect. These areas have both a lower than expected MCI and higher than expected deposited fine sediment, using national datasets. Sites with this intersection are likely to be impacted by increased deposited sediment due to human activity and may have the greatest potential to improve measures of biodiversity with mitigation and changes in land management.

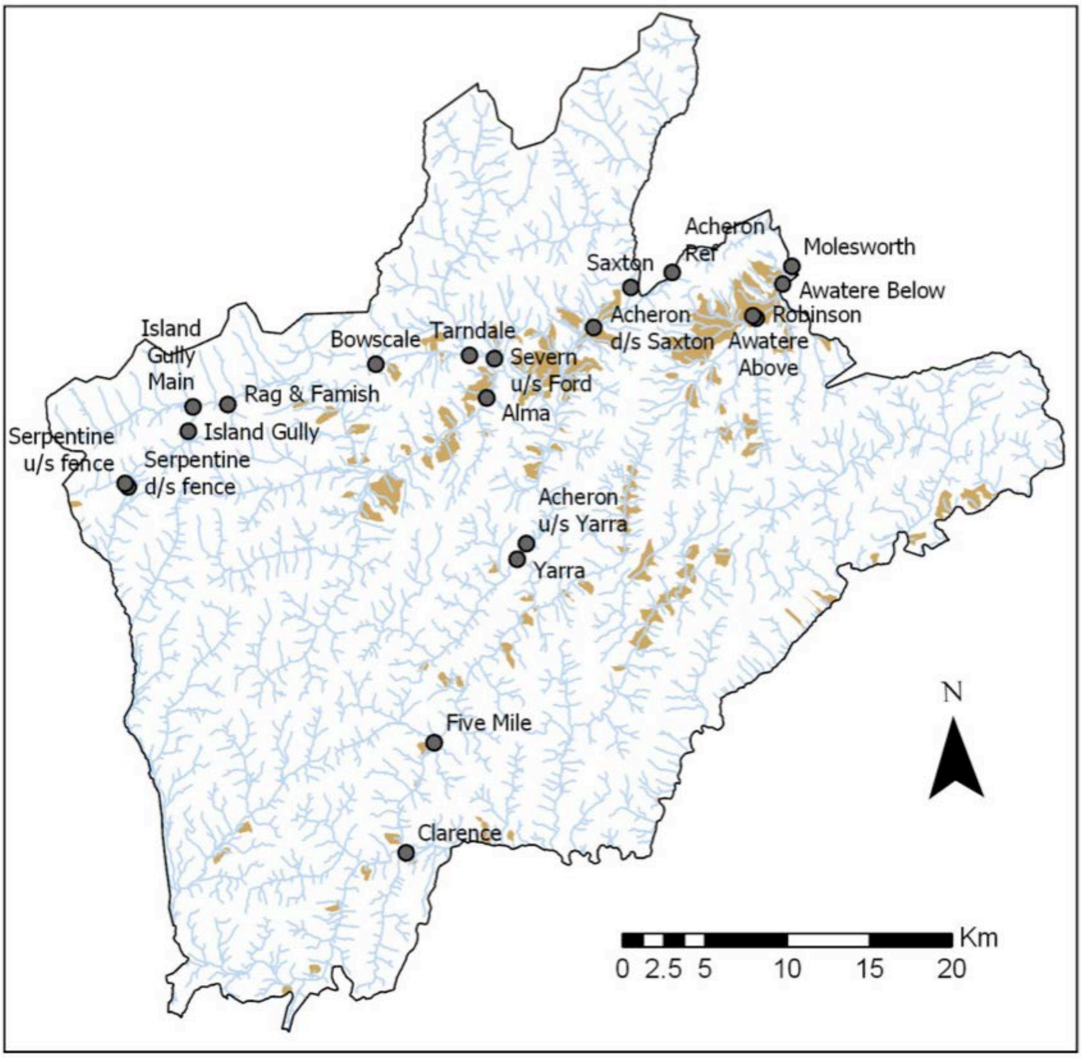

Figure 35: Map of intersection of streambed sedimentation O/E (ratio ≤10) and MCI O/E (ratio ≤0.85) output using national datasets.

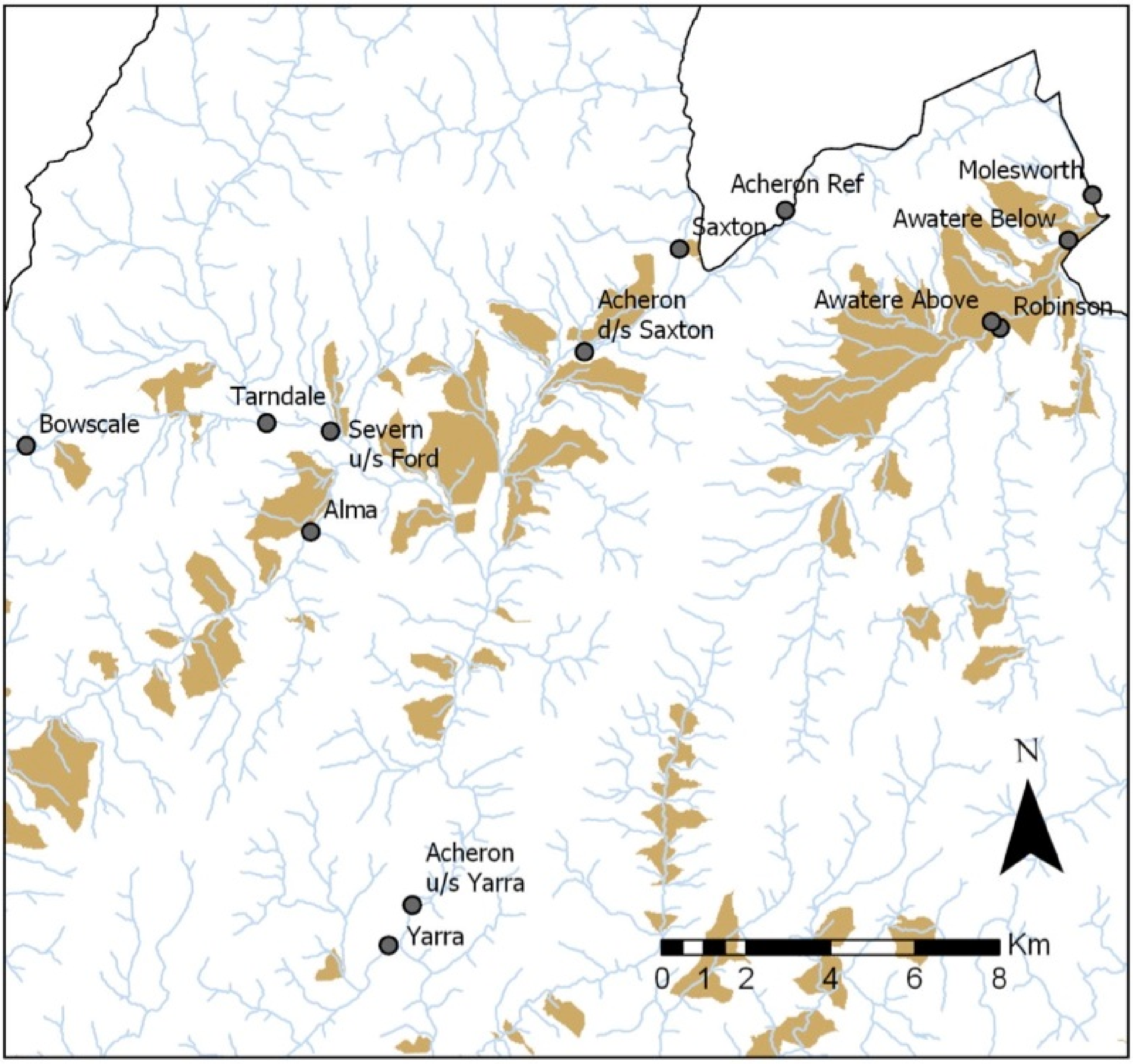

Figure 36: Detail of intersection of streambed sedimentation O/E (ratio ≤10) and MCI O/E (ratio ≤0.85) output using national datasets.

4.5.6 Identifying actions areas

The areas of intersection of streambed sedimentation and MCI O/E identified in Figure 35 cover a large area (approximately 8,028ha). Based on current research, it is possible to narrow this area down to reaches of the river network that could be considered more vulnerable to impacts, more likely to respond to mitigation and more likely to have a flow on effects in improving the health of waterways on Molesworth Station and beyond.

It is also appropriate to use information gathered in the water quality survey of March 2018 and apply some basic knowledge of how people and livestock interact with waterways on

Molesworth Station to identify appropriate areas to take action. This report considers the following factors in identifying action areas for erosion mitigation.

4.5.6.1 Headwaters – small streams

Biodiversity

Headwaters are small intermittent or first and second order streams. They have been found to contain proportionally greater biodiversity than larger waterways and contribute significantly to the biodiversity of whole river systems (Clarke, Mac Nally, Bond, & Lake, 2008; Meyer et al., 2007). Small streams are both a source diversity and a refuge (seasonally and at stages in the lifecycles of certain species) for macroinvertebrates (Meyer et al., 2007). Research suggests that maintaining the health of headwater streams is vital to the biological integrity of whole river networks and that small streams are particularly sensitive to impacts from surrounding land use (Clarke et al., 2008; Death & Collier, 2010; Greenwood, Harding, McIntosh, & Niyogi, 2012; Meyer et al., 2007)

Contaminants

Small streams in pasture (<1 m wide, 30 cm deep) have been found to account on average for 77 percent of the national load of contaminants in Aotearoa New Zealand (McDowell, Cox, & Snelder, 2017). These contaminants (including sediment, *E. coli,* phosphorus and nitrogen) originating in small headwater streams can accumulate in downstream reaches of a river network (Greenwood et al., 2012; McDowell et al., 2017).

4.5.6.2 Areas of concentrated livestock activity

Previous studies investigating water quality on Molesworth Station undertaken by the Cawthron Institute showed ‘hot spots’ of contamination where cattle numbers had been concentrated for short periods of time (Holmes, 2009; Olsen & Shearer, 2007; Shearer, 2011). March 2018 sampling also suggested that where there is concentrated livestock activity, local water quality may be impacted.

For example, Molesworth Stream showed high levels of deposited sediment and had the highest conductivity of all sites across the station. It is likely that this is due to concentrated livestock activity within stockyards above the site and overland flow to the stream. An image taken from Google Earth, shows the proximity of the stockyards to Molesworth Stream and a flow path from ponded water above past the yards towards the stream (Figure 37) (Google Earth Pro, 2018). Likewise, the Tarndale site showed signs (high periphyton growth and cyanobacteria) of local impacts, which are likely to be due to livestock activity at the seep above the site (McAllister et al., 2018; Wood et al., 2015).

Figure 37: Google Earth image showing location of stockyards, Molesworth Stream monitoring site and campground in relation to each other and Awatere River. Pooled water can be seen in the top left-hand corner of the image with a flow path moving down towards the stockyards and then towards the stream. (Google Earth Pro, 2018)

4.5.6.3 Risks to human health

Molesworth Station is also a recreation reserve and is open to the public over the warmer months. During this time people come into contact with waterways. While no samples taken in March 2018 breached swimming standards for *Escherichia coli (E. coli),* two Awatere River catchment sites were found to have elevated *E. coli*. It is possible that this elevation is due to the correlation between high suspended sediment and *E. coli.* The proximity of these sites to the campground this may be an additional rationale for a focus on this area.

The proximity of the stockyards and their drainage into Molesworth Stream could pose a risk to human health as the campground is downstream and people regularly use the stream as a swimming hole in the summer months (Figure 37).

The Tarndale site was the highest recorded *E. coli* in March 2018 sampling, likely due to the proximity of livestock at the time of sampling. However, risk to human health from faecal contamination at this site is likely to be low as the public do not have access to this area of the farm. However, cyanobacteria were discovered at the site and its proliferation there could be due to the activity of cattle above the stream at a seep (as this activity is likely to have led to increased deposited fine sediment and some elevation of nutrients) (McAllister et al., 2016). While the public may not be at risk from these cyanobacteria, due to restricted access, staff and their animals (dogs, horses) may be.

4.6 Conclusion and Recommendations

Taking into account the O/E results from national datasets and March 2018 sampling, as well as research on freshwater ecology and restoration of waterways and some basic knowledge of how people and stock interact with waterways on Molesworth Station, the following recommendations are made.

4.6.1 Awatere River Catchment

Recommendation 1: Fence small northern Awatere River tributaries

It is recommended that the small order northern tributaries of the Awatere River are fenced.

These streams have been highlighted in a cluster in Figures 35 and 36 as reaches of the catchment that have both high streambed sedimentation O/E values and low MCI O/E values. This is consistent when also using March 2018 data as the observed value (Figure 33 and

Table 4). Fencing has been found to have relatively rapid influencing in reducing sediment loss to streams (Hughes & Quinn, 2014; McDowell et al., 2017).

These streams are not only of value to local biodiversity but, because of their position in the headwaters of the Awatere River catchment, they are likely to be significant to the biological integrity of the whole river network. Small streams are more sensitive than large order rivers to activities on adjacent land and, because these streams are within the hectares of improved pasture on the station, they are likely to be more at risk than small streams outside areas of improved pasture. An example of land use pressure on these streams can be seen in Figure 38.

Figure 38:Example of pugging damage in headwaters in improved pasture, Awatere River catchment, October 2017

Small streams within pasture contribute a high proportion of contaminants to overall catchment load and restoration of rivers is likely to be more successful if efforts are focused on headwaters and upstream sites rather than short reaches in lower parts of the catchment.

Ground-truthing the extent of these small streams will be needed as smaller reaches above the areas highlighted in Figures 35 and 36 are likely to also need to be fenced for mitigation to be most effective. Using GIS data alone, and including reaches above the areas mapped, gives a total waterway length of approximately 52.9 km (approximately 1.9 percent of the total length of waterways on the property).

Because of the length of waterways in question and the costs associated with fencing, it is likely that this work will need to be conducted in stages. Taking an ecological approach, the fencing project would start from the top, smallest streams, working downstream. However, there may be logistical or operational considerations that mean another approach may be more practicable.

Recommendation 2: Plant between Molesworth Stream and stockyards

It is recommended to carry out planting of appropriate native species on the flow paths between the stockyards and Molesworth Stream.

The Molesworth Stream site was found to have high deposited sediment in March 2018. It also had the highest conductivity of all sites across the station, indicating elevated nutrients. *E. coli* was also found to be elevated at the site in March. It is likely that the source of these contaminants is the adjacent stockyards.

Because of the indication of pressure on ecosystem health and the potential risk to the public and staff who swim in Molesworth Station downstream from the stockyards, planting between the yards and the stream could reduce contaminants reaching the stream via overland flow (sediment – Figure 39 – and *E. coli*) as well as reduce nutrient contaminants. Planting close to the stream may also, over time, improve stream shading (Figure 40).

Figure 39: Streambed sedimentation and periphyton in Molesworth Stream, March 2018**.**

Figure 40: Molesworth Stream looking downstream towards Awatere River, March 2018. Slope between stockyards and stream on the right.

Recommendation 3: Observe Robinson Creek

It is recommended to continue to observe Robinson Creek and assess in future if erosion mitigation is possible.

Robinson Creek was found in March 2018 to have very low clarity due to high sediment load (Figure 41). It was not clear at the sampling site, nor from a survey using Google Earth, what the source was for such a high sediment load. However, Molesworth Station management have investigated and believe this is due to a large slip upstream in the sub-catchment. At this time, observation may be the only appropriate action with follow up and re-assessment to come in three years (March 2021) with the next water quality survey.

Figure 41: Suspended sediment in Robinson Creek, March 2018.

4.6.2 Seeps

Recommendation 4: Fence seep near Tarndale Brook

It is recommended that the seep above Tarndale Brook is fenced off.

The seep above the Tarndale Brook site (Figure 42) appears likely to be impacting the health of the stream and may be encouraging the growth of cyanobacteria at the site. The site is part of the monitoring protocol and so will be surveyed again in three years, after the fencing has occurred, to assess the efficacy of fencing the seep. Other seeps may also be identified by management that would benefit water quality by being fenced off.

Figure 42: Seep above Tarndale Brook, March 2018.

4.6.3 Monitoring

Recommendation 5: Survey to compare small streams on Molesworth and St James Stations

It is recommended that a survey of small streams on Molesworth and St James Stations is carried out in February or March 2019 to gather baseline data for mitigation work in the Awatere River headwaters and for comparison between small stream sites on the two stations.

The survey should include first and second order streams in currently grazed reaches (summer grazing), reaches that were grazed six months ago (winter grazing) and reaches on St James that have not been grazed for 10 years.

Recommendation 6: Maintain three-yearly monitoring programme

It is recommended to maintain a three-yearly monitoring programme.

As in chapter three, to be consistent with the management plan and in order to track changes over time a monitoring programme should be maintained recording *E. coli,* deposited sediment, conductivity, clarity, MCI, temperature, shade, periphyton, macrophytes, and substrate composition.

Chapter 5: Could targeted values-sensitive communication encourage pro-environmental behaviour in Aotearoa New Zealand's farmers?

5.1 Introduction

Despite Aotearoa New Zealand having legislation in place since 1991 requiring the avoidance, mitigation or remedy of environmental impacts, the health of the country's waterways has declined over the last three decades (Drummond, 2006; Ministry for the Environment and Statistics New Zealand, 2017). Diffuse pollution from animal agriculture is a major contributor to this decline (chapter two). Decisions made by farmers to intensify operations have been particularly damaging (chapter two). The degradation of waterways by animal agriculture has impacted cultural well-being, recreational opportunities and ecosystem health (chapter two; Ministry for the Environment and Stats NZ, 2019). Many would argue that, as on Molesworth Station, these are values that are to be safeguarded nationally.

Given both the scale of animal agriculture and its impact on freshwater quality and habitat, improving the health of Aotearoa New Zealand's waterways will require an increase in pro-environmental behaviour from farmers will need to be sustained. Many reports and papers have been produced to provide farm-, regional-s and national-scale recommendations to improve the health of waterways on agricultural land (e.g. Death & Collier, 2010; Mueller, McBride, Hamilton, Doole & Abell, 2019; Tanner & Kloosterman, 1997; Weeks et al. 2016). However, farmers may not adopt pro-environment recommendations even where scientific method has identified the nature and extent of farming impacts and an approach to mitigation provided. Resource constraints do not always adequately explain why (Journeaux et al., 2018; Mills et al., 2017; Smith, Kelly & Rhodes, 2008).

This chapter attempts the *fusion of thought* between ecology and social sciences advocated by Aldo Leopold in 1949 (page iii, as quoted in Heberlein, 2012) and investigates the influence of basic human values on pro-environmental behaviour in Aotearoa New Zealand's agricultural sector. It suggests that prioritisation and priming of certain basic human values (as identified by Schwartz, 1992) are likely to suppress pro-environmental behaviour in Aotearoa New Zealand farmers. The chapter posits that targeted values-sensitive communication could play a role in encouraging and increasing pro-environmental behaviour to meet the challenge of improving the health of waterways on agricultural land.

5.2 Limitations

Discussion of Aotearoa New Zealand farmer values is likely to be bias towards pākehā farmers and, therefore, will be limited. Pākehā are more likely to be represented in the literature cited, through surveys and *gaze*.

Additionally, this is a discussion rather than an empirical approach to the topic and, therefore, limited to presenting an idea rather than proof of concept.

5.3 Beyond the boundaries of Molesworth Station

Chapters three and four were presented as reports to Landcorp and Molesworth Station management. Chapter three was presented in August 2018 and, in discussion with Landcorp and Molesworth management, the approach for chapter four was developed. Management was interested in identifying areas for action and received chapter four in December 2018. Following the two reports, Landcorp commissioned an agricultural consultant to develop a whole farm environment plan considering a larger suite of domains and factors within the station (including Land Use Capability, greenhouse gas emissions, climate resilience, animal health, farm policies and goals, etc.), as well as the habitat quality and water quality of streams and rivers. Sections in the plan on improving waterways are likely to be largely based on chapter three and four. However, the final version of this plan is not available at the time of writing.

Because of this, using Molesworth Station as a case-study of the adoption of pro-environmental behaviour is premature. Molesworth could serve in future as a useful study of land-management that aims to support multiple land uses and values, as described, and may provide some further lessons, particularly if monitoring of stream and river sites continues.

Rather than providing a case study of why pro-environmental behaviour may or may not be adopted on Molesworth Station, this chapter goes beyond its boundaries to investigate why farmers may not adopt pro-environmental behaviour. While there are pro-environmental behaviours being adopted by farmers in Aotearoa New Zealand, their current extent appears unlikely to stop the national decline of the health of waterways, particularly where they are undermined by increasing intensification and climate change (Brown, Daigneault, & Dawson, 2019; Mitchell, 2019; Royal Society of New Zealand, 2016; Quinn, Monaghan, Bidwell, & Harris, 2013). Scientists and others working to provide information on state of waterways and recommendations for actions that would improve their health can be surprised and frustrated where recommendations are not adopted, particularly if resource constraints are not evident.

This chapter discusses the role of values in behaviour, and identifies that existing prioritised basic human values and priming of certain values may be suppressing pro-environmental behaviour in farmers. It does so in order to identify alternative approaches to communication, beyond simply the provision of information, for those seeking to encourage pro-environmental behaviour to improve the health of waterways on agricultural land.

5.4 Factors influencing behaviour change in farmers

It can be assumed by ecologists and others that farmer behaviour is primarily a response to financial considerations (economic incentives or costs) and that providing farmers with appropriate information will lead to greater adoption of pro-environmental behaviour. However, while resource constraints must certainly factor into decision making, research has found that they do not always adequately explain decision making and behaviour change (Journeaux et al., 2018; Mills et al., 2017; Smith, Kelly & Rhodes, 2008). Behaviour and behaviour change in all populations is complex and multifactorial (Michie, Atkins, & West, 2014). Likewise, in farmers (Mills et al. 2017). Behaviour change in farmers has been the subject of considerable study, particularly in the latter part of the 20th century as it became evident that the intensification of farming practices was contributing to worsening environmental problems and the need for the greater adoption of pro-environmental behaviour was identified (Burton, 2004; Mills et al., 2017). Mills et al. (2017) distinguished three groups of factors influencing decision making (and, therefore, behaviour change) in farmers: farmer engagement, ability to adopt and willingness to adopt (Figure 43).

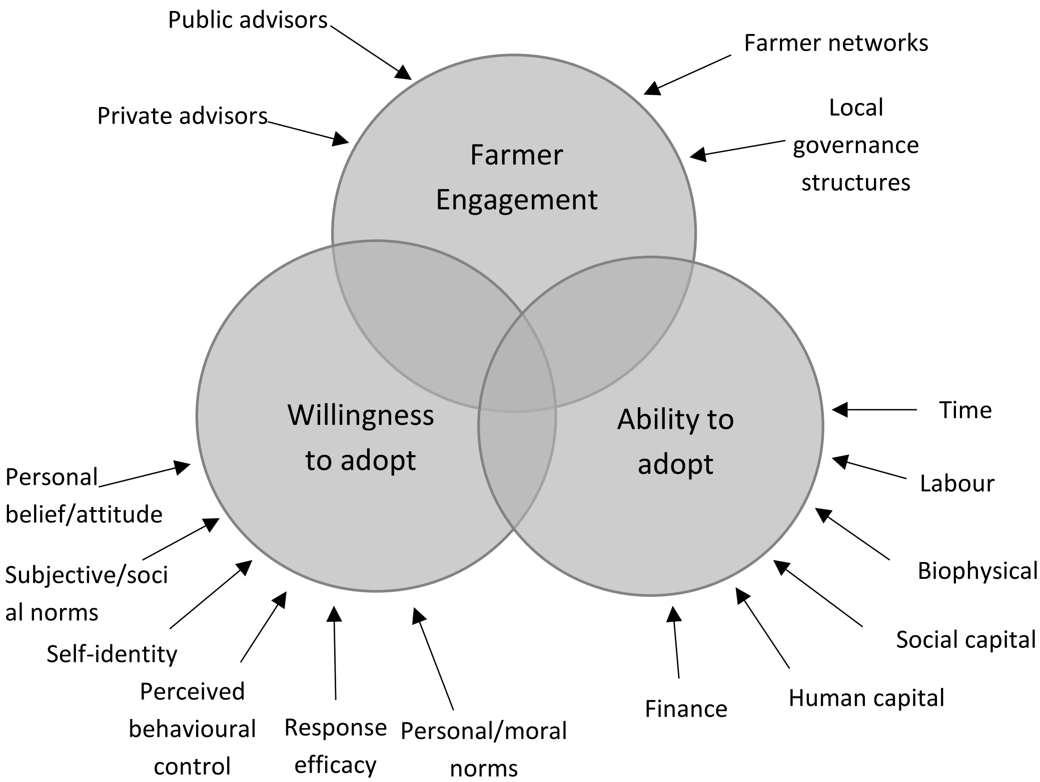

Figure 43: Factors influencing farmers' decision making (Based on Mills et *al.* 2017)

Figure 43 includes resource constraints (finance, labour, biophysical) as factors influencing farmer decision making. Interestingly, however, it does not identify access to information as a factor. The paper assumes that 'good information' will be provided through farmer engagement factors. Scientists have been found to assume, frequently and widely, information deficit as the major limitation to behaviour change (Simis, Madden, Cacciatore, & Yeo, 2016). The information deficit model posits that by overcoming a lack of information, beliefs and behaviour of individuals and groups will change. The assumption of information deficit is persistent in the scientific community despite some decades of research that have shown its limitations (Nadkarni et al., 2019; Seethaler, Evans, Gere, & Rajagopalan, 2019; Simis et al., 2016). It is understood that good decision making will use information that best reflects current scientific understanding (Dietz, 2013; Journeaux et al, 2018). However, it is important to note that even where such information is available, decisions made will be value-competent (i.e. consistent with the decision makers' values) (Dietz, 2013; Hiberlein, 2012; Smith, Kelly, Rhodes, 2008). Where the science available contradicts or, equally importantly, is perceived to contradict the decision maker's values, scientific information may be resisted, rejected or avoided (Dietz, 2013; Steg et al., 2014; Kahan et al., 2012; Kahan, 2010).

5.5 Theory of basic human values and value development

The theory of basic human values developed primarily from the work of Schwartz (1994; Schwartz & Bilsky, 1987; 1992). Values can be defined as "(a) concepts or beliefs, (b) about desirable end states or behaviours, (c) that transcend specific situations, (d) guide selection or evaluation of behaviour and events, and (e) are ordered by relative importance" (Schwartz & Bilsky, 1987). Schwartz argued that human values previously identified in the literature could be grouped into ten basic values: self-direction, stimulation, hedonism, achievement, power, security, conformity, tradition, benevolence, and universalism (Table 5).

Table 5: Schwartz's ten basic human values (1992)

Self-direction	Choosing, creating and exploring to achieve independence in thought and action.
Stimulation	Having a varied and exciting life with lots of novelty and challenge.
Hedonism	Seeking pleasure and sensuous gratification to enjoy life.
Achievement	Personal success through demonstrating competence according to social standards.
Power	Attaining social status and prestige, getting access to and control of people and resources.
Security	Obtaining safety, harmony and stability in society in relationships with others, and self.
Conformity	Exercising self-restraint in actions, inclinations, and impulses likely to upset, or harm others, and violate social norms.
Tradition	Building respect, commitment and acceptance of the customs and ideas found by sharing cultures and religions.
Benevolence	Preserving and enhancing the welfare of people that provide frequent personal contact.
Universalism	Understanding, appreciating, tolerating and protecting the welfare of all peoples, and of nature.

These ten basic values have been further grouped as values relating either to self-transcendence or to self-enhancement, and to either openness to change or conservation (meaning in this instance, and henceforth referred to as, conservatism to avoid confusion) (Figure 44). Self-transcendent values are sometimes called "pro-social values" and are those values that relate to concern for the welfare of others, including the natural world. Self-enhancement values are concerned with social status. Conservatism and openness to change are values that indicate priorities of stability and novelty, respectively. Research has found considerable stability in the theory when applied across different cultures (Schultz et al., 2005; Schwartz, 2012; Schwartz et al., 2012). Variability is expressed in individuals and cultures through differing prioritisation of values, while all values are present to some degree (Schultz et al., 2005; Schwartz & Zanna, 1992).

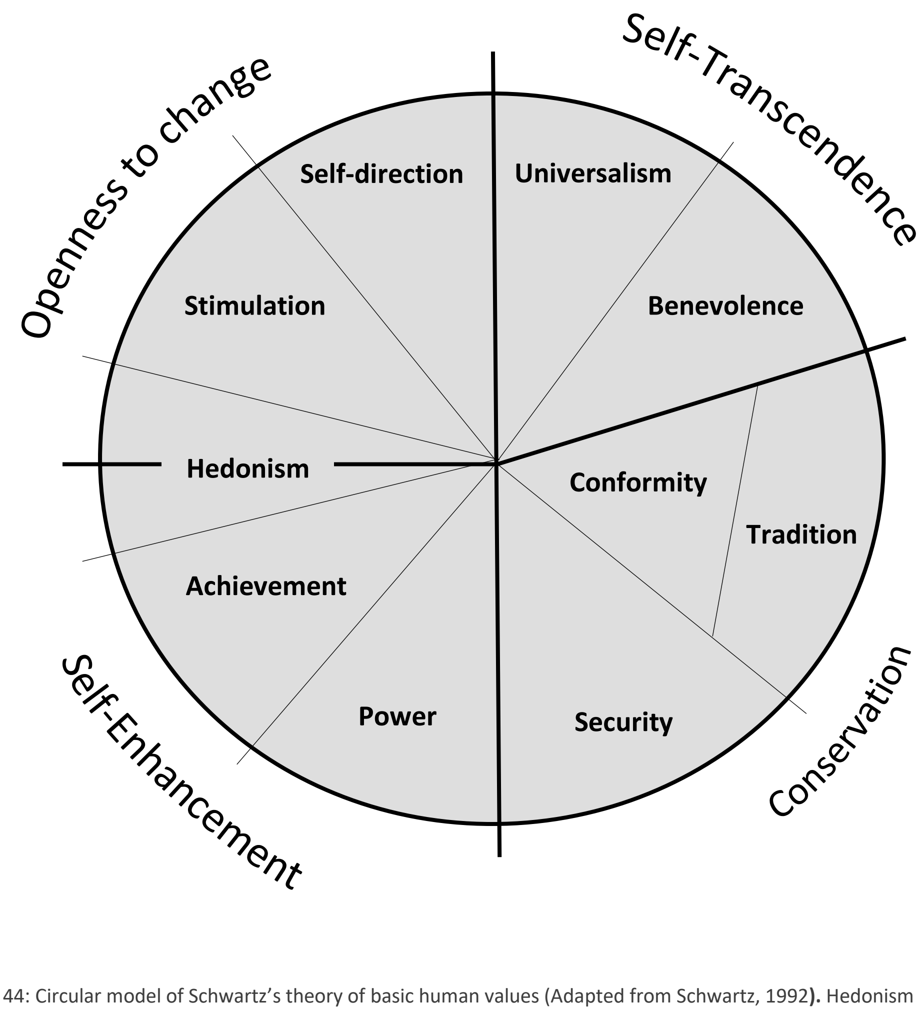

Figure 44: Circular model of Schwartz's theory of basic human values (Adapted from Schwartz, 1992**).** Hedonism is considered indicative of both self-enhancement and openness to change.

Schwartz illustrated the dynamic between values using a circular model (Figure 44). The closer the values are within the model the more compatible they are with each other and, therefore, the more likely they are to be similarly prioritised by an individual or culture (Schwartz et al., 2012). Conversely, the further they are from one another the less compatible they are and less likely to be simultaneously highly prioritised by the culture or individual. Schwartz (2012) described this dynamic of "shared motivational emphases of adjacent values" (p. 9). He gives examples of this such as where values of power and achievement are prioritised there is a likely emphasis on social superiority and esteem, and where values of benevolence and tradition are priorities the emphasis is likely to be on devotion to one's in-group.

Values have been found to adapt people to their social and physical environments (Inglehart & Welzel, 2005; Manfredo et al., 2017). Cultural values are a response to external influences to best adapt a group to survive within particular conditions (Inglehart & Welzel, 2005; Manfredo et al., 2017; Schwartz & Zanna, 1992). Studies have found that the development of cultural values can be influenced by many biophysical factors including the prevalence of pathogenic risk (Corey, Randy, Damian, & Mark, 2008), the dominance of particular crops (Talhelm et al., 2014) and other factors such as population density, conflict and environmental threats (Michele et al., 2011). Individual values are an adaptation to support the provision of a person's biological needs, the need for social interaction, as well as for the survival and welfare of the group (Schwartz & Zanna, 1992).

Manfredo et al. write that "values include what goes on in the mind (e.g., one's fundamental goals, what one believes is true, what one believes is important), but they are also integrated with everything in one's environment" (2017. p. 775). Values in the environment are verbal and non-verbal symbols, communication patterns, daily routines and social institutions. Values are an integral part of social-ecological systems, and their expression "in the mind" and "in one's environment" are mutually reinforcing (Manfredo et al., 2017; Van Riper et al. 2018). That is to say, values develop in response to surroundings and are then expressed via processes in the mind that influence behaviour, which in turn shapes the environment that then reinforces one's values.

This expression and reinforcement of values through social-ecological systems make them somewhat resistant to change and largely stable across generations (Manfredo et al., 2017; Sagiv, Roccas, Cieciuch & Schwartz, 2017; Schwartz, 2012). Incremental changes are more commonly documented, though large values shifts have been identified where major events or changes in circumstances have required sudden revaluation due to drastic change (e.g. 19th Century colonisation) (Manfredo et al. 2017; Ye & Ng, 2019). Similarly, in individuals, values display stability throughout life; though values shifts have been commonly observed in people who have migrated to another country or who have experienced impactful events (e.g. war) (Sagiv, Roccas, Cieciuch & Schwartz, 2017; Ye & Ng, 2019).

It is well-documented that values influence pro-environmental behaviour. However, given their stability, aiming to change values in order to induce pro-environmental behaviour may not be possible (Heberlein, 2012; Manfredo et al. 2017; Sagiv, Roccas, Cieciuch & Schwartz, 2017). However, there is a significant and growing body of research that suggests that, while changing values profoundly over a short space of time may be difficult, appealing to values that are already present though perhaps less prominent can encourage pro-environmental behaviour. Additionally, understanding the role of values in behaviour and the receptivity of groups and individuals to information, could help avoid the inadvertent suppression of pro-environmental behaviour.

5.6 The influence of values on pro-environmental behaviour

Groups and individuals that prioritise self-transcendent values have been found to be more likely to demonstrate pro-environmental behaviour (Abrahamse, 2019; Mills et al., 2017; Sanderson & McQuilkin, 2017; Steg, Bolderdijk, Keizer, & Perlaviciute, 2014; Steg & de Groot, 2012). Pro-environmental behaviour has been found to be negatively correlated with the prioritisation of self-enhancement and conservatism (Abrahamse, 2019; Steg et al., 2014).

Research (particularly from Stern and Dietz, and de Groot and Steg) has found that within self-transcendent values, it is possible to distinguish empirically between values related to the natural world (*biospheric*) and towards others (*altruistic*) (Stern, Dietz, Abel, Guagnano, & Kalof, 1999; Steg et al., 2014; Steg & de Groot, 2012). This approach has been reinforced by the recent refinement of the theory of basic human values, which has made a similar distinction; universalism now including three variants; nature, concern and tolerance (Schwartz, 2012). Like self-transcendent values, biospheric and altruistic values are a better predictor of pro-environmental behaviour than *egoistic* (self-enhancement equivalent) values. However, where groups and individuals prioritise biospheric and altruistic values, one may be more strongly emphasised than the other. In situations where biospheric and altruistic values may be in competition, those with more strongly held biospheric values are more likely to display pro-environmental behaviour (Steg & de Groot, 2012).

In their review of the literature, Steg et al. (2014) suggest that values influence pro-environmental behaviour in three main ways. Firstly, values influence how important an individual or group believes pro-environmental behaviour to be. This will affect their evaluation of the consequences of behaviour that is not pro-environmental as well as their motivation to seek out information on pro-environmental behaviour. Those who prioritise values such as achievement or power (values that are not correlated to pro-environmental behaviour) may consider the consequences of not acting pro-environmentally relatively insignificant and are, therefore, less likely to seek out information on pro-environmental behaviour.

Studies have found that communication that stresses the negative consequences of not adopting pro-environmental behaviour is more likely to motivate those who already prioritise self-transcendent and/or biospheric values because consequences will be considered greater (Steg et al., 2014). Where biospheric values (particularly) are strong, pro-environmental behaviour is more likely to be prioritised even if the behaviour is more challenging than not behaving pro-environmentally (Steg et al., 2014; van der Werff, Steg, & Keizer, 2013). Those who do not prioritise self-transcendent values may not respond to information around consequences of not adopting pro-environmental behaviour as they do not see the consequences as important. Overall, negative messaging has been found likely to be less effective in encouraging pro-environmental behaviour than positive messaging regardless of prioritised values (Chen, 2016; Jacobson et al, 2019)

Secondly, values elicit feelings of obligation around behaviour. Consequently, when individuals behave in a manner that is consistent with their values it can give rise to positive emotions like pride. Conversely, negative emotions (e.g. guilt) may be experienced when behaviour is not consistent with values (Chen, 2016. Dietz, 2013; Steg et al, 2014; van der Werff, Steg, & Keizer, 2013). This motivates people to seek value-competent decisions. Finally, values mould self-identity. The presence of strongly held self-transcendent values encourage a view of the self as someone who *is* pro-environmental and, therefore, as someone who behaves pro-environmentally. Pro-environmental behaviour would, therefore, be congruent with one's self-identity (Carfora, Caso, Sparks & Conner, 2017; Steg et al, 2014; van der Werff, Steg, & Keizer, 2013)

5.6.1. Priming values

Priming is defined as "a change in the ability to identify or produce an item as a result of a specific prior encounter with the item" (Guath & Juslin, 2014). Values may be "activated incidentally or unobtrusively in one context, to influence what comes next without the person's awareness of this influence" (Bargh, 2006. p.147). Priming makes values more "cognitively accessible" (Steg & de Groot, 2012. p. 11). Research has found that priming values can lead to improved expression of the same and related values in behaviour as well as suppression of opposing values (Capaldi & Zelenski, 2016; Guath & Juslin, 2014; Maio, Pakizeh, Cheung, & Rees, 2009b). Values can be primed in a number of ways such as visual cues or semantic cues, both written and aural.

In 2009, Maio et al. conducted five experiments, which led them to conclude that "priming a particular value has predictable effects on different values and on behaviours that express different values" (2009b. p. 713). In one experiment, priming consisted of being asked to memorise words associated with either achievement (e.g. ambitious, capable, successful) or benevolence (e.g. forgiving, honest, helpful). The participants, who had all been paid to participate, were then asked to perform a word puzzle (a measure of achievement) and subsequently asked if they would be willing to participate in such experiments in future voluntarily as the researcher had run out of funding (a measure of benevolence). Maio et al. (2009b) found that those primed with semantic cues for achievement performed better at the word puzzle but were less willing to help the researcher and the opposite was true for those primed with benevolence.

Semantic priming using words associated with values that negatively correlate with pro-environmental behaviour can lead to a reduction in an expression of pro-environmental behaviour (Capaldi & Zelenski, 2016; Corner, Markowitz, Pidgeon, 2014; Maio et al., 2009b). Considering the place of values in the social-ecological system ("integrated with everything in one's environment" – Manfredo et al. 2017) it is not difficult to see that values are being primed constantly through everyday interactions with a range of visual and written stimuli, from media to conversation.

5.6.2. Value instantiations

Additionally, research has found that individuals' and groups' instantiations of values matter; meaning those examples or mental representations brought to mind when values are primed (Hanel, Vione, Hahn, & Maio, 2017). As Maio et al. (2009a) explain "to bring a value to bear in a specific situation, the gap from the abstract representation of the value to the concrete representation of the situation must be bridged" (p. 598). Individuals and groups may share the same or similar values but their instantiations of these values may be different, which influences expression of values through behaviour (Hanel et al., 2018). Where an instantiation of a value is not readily available, expression of a value may be difficult (Hanel et al., 2017; Hanel et al., 2018; Maio et al., 2009a).

Unsurprisingly, values are weakened or strengthen by the instantiations provided by observing others. Experiments have found that observing another voluntarily pick up rubbish makes it less likely that an individual will drop rubbish themselves (Steg et al., 2014). Furthermore, the same observation makes it more likely that the observer will help others generally (Keizer, Lindenberg, & Steg, 2013). In other words, observing pro-environmental behaviour encourages the expression of other compatible values (i.e. benevolence as self-transcendent value, as modelled in Figure 46). Experiments have also found in places where there is a lot of rubbish (i.e. evidence of others not adopting pro-environmental behaviour), people are more likely drop rubbish (Steg et al., 2014).

Interestingly, where a lot of rubbish has been dropped, signage requesting that people do not drop rubbish is likely to result in more rubbish being dropped than the same conditions without a sign (this effect has been replicated across other scenarios). Steg et al. (2014) suggest this is to do with the salience of a value or behaviour (i.e. dropping rubbish is more front of mind where rubbish has been dropped and semantic activation draws attention to the behaviour). It may, however, also relate to the source of the semantic activation (i.e. who is asking for rubbish not to be dropped and what is their relationship to the observer?).

5.7 Why information might be resisted, avoided or rejected

As touched upon, values determine receptivity to information where certain information may be considered more or less important. Values play a significant role in what information will be sought out and from where. While information may be scientifically-sound, where it is not value-competent or perceived to be contrary to one's values, its acceptance may be resisted, it may be avoided or even rejected (Kahan, 2010; Kahan, Jenkins, & Braman, 2011; Kunkle & Monroe, 2018; Torcello, 2016). Information is interpreted through values and reinterpreted to be consistent with values (Steg et al, 2014; Torcello, 2016). The influence on groups' and individuals' receptivity to information is sometimes called 'cultural cognition' (Kahan, 2010) or 'motivated reasoning' (Torcello, 2016).

Political orientation can influence an individual's receptiveness to information. The information deficit model implicitly suggests that more education (access to more information) would make individuals more likely to hold views consistent with scientific consensus. However, level of education does not necessarily predict alignment of behaviour or beliefs with scientific understanding. In fact, a higher level of education can predict a negative correlation with scientific consensus where individuals strongly identify with a political leaning and an issue has become politicised (Ehret, Sherman, & Sparks, 2017; Kahan et al., 2012).

For example, Ehert, Sparks and Sherman (2017) found that while support "for the environment" generally varied across the political spectrum somewhat predictably (i.e. more green liberals than green conservatives), in American liberals it increased with increasing education but decreased with increasing education in conservatives. Belief in climate change followed a similar pattern. Liberals exhibited a 13 percent increase in belief in climate change between a high school diploma and a post-graduate degree, while between conservatives with a secondary school and post-graduate education there was a 14 percent decrease in belief in climate change. They found evidence that this was due to an awareness of elite cues in those who more strongly identified with one particular leaning over another.

Elite cues could be from many sources, they said; politicians' speeches, political pundits or partisan news outlets. Not only the communication of information but the *source* of information can activate values within individuals and groups leading them to be more or less receptive to information provided (Kahan, 2010; Petersen, Slothuus, & Togeby, 2010). However, importantly, they found that individuals who identified less strongly with any particular political party (moderates) were more likely to respond as the information deficit predicts (an eight percent increase in belief in climate change between high school and post-graduate with a similar trend in "support for the environment"). That is to say, higher education in moderates made them more likely to "support the environment" and believe in climate change. These findings are supported by other studies, including from Aotearoa New Zealand (Jacob, 2016; Milfont, Harré, Sibley, & Duckitt, 2012; Owens & Lamm, 2017).

5.8 Aotearoa New Zealand farmers' values

Aotearoa New Zealand farmers' values are not definitively established in the literature. Some studies have highlighted the prioritisation of self-enhancement values within the farming community while others have identified shifting values between generations of farmers.

A 1997 survey of Aotearoa New Zealand farmers, using Schwartz's theory of basic human values, found that farmers were likely to prioritise self-enhancement values (Parminter & Perkins). Participants were asked to rank goals from most important to least important and goals were then clustered by the values to which they were most strongly related. The survey found that of the more than 600 farmers surveyed, 43 percent identified production goals (articulated most commonly as "maximising farm profits") as their most important farming goals. Parminter and Perkins determined that these goals were related to the value of achievement (Table 5). The second-equal most important goals were farm capital value and autonomy. Business goals were identified as the next most important goals and were associated with power. The authors concluded that goals relating to power and achievement (i.e. self-enhancement values) were most important to those surveyed. The survey suggested, therefore, that farmers prioritised values that suppress pro-environmental behaviour.

In 1997, seven percent of those surveyed identified environmental goals (related to universalism or biospheric values) as their most important goal and environmental goals were, with some consistency, ranked relatively highly by farmers (mean ranking of 4.3 out of 20) (Parminter & Perkins, 1997). Fairweather, Roisin, Hunt and Campbell (2009) found clusters of farmers with strong environmental orientation across sectors in Aotearoa New Zealand, with the largest proportion of farmers with strong environmental priorities within the sheep and beef sector.

It is possible that Aotearoa New Zealand farmer values may have shifted over the last two decades (while recognising that major shifts are not common in the literature as noted). Analysis of results from the 2015 Rural Decision Makers Survey led some researchers to conclude that more strongly held pro-environmental values existed in younger respondents and that this may indicate a generational shift in likelihood of adopting pro-environmental behaviours (Brown, Daigneault, & Dawson, 2019). They argued that this values shift, along with the projected changes in demographics of farmers in Aotearoa New Zealand over the coming decades, would likely lead to improvements in water quality irrespective of government intervention, through greater adoption of nutrient management plans and sediment management plans. Although, through their modelling they found the adoption of nutrient management plans would only lead to a seven percent national reduction in nitrogen leaching by 2075, which is unlikely to provide for ecosystem health in many parts of the country (Brown, Daigneault, & Dawson, 2019).

Further analysis of farmer values through the Rural Decision Makers Survey, from Small, Brown and Munguia’s (2016), found that 84.9 percent of those surveyed in 2015 reported taking care of the environment as being highly important to their self-identity. However, of that 84.9 percent, 65 percent identified that being highly productive was also important to their self-identity. Figure 44 suggests that these self-identities express opposing values (self-transcendent versus self-enhancement). This is likely to have an impact on decision making and adoption of pro-environmental behaviour and why it is important to consider which values may be more "cognitively accessible" through priming.

It may also be important to consider the effects of political identities of Aotearoa New Zealand farmers on pro-environmental behaviour given the findings of Ehret, Sherman and Sparks (2017) and the fact that rural voters are more likely to vote for Aotearoa New Zealand's conservative party (New Zealand National Party) (Greaves et al., 2017). Farmers who strongly identify with the party may exhibit the same resistance as American conservatives to information on the environment (as indicated in Milfont et al., 2012). It is, of course, important to note that of those farmers who vote for the New Zealand National Party not all will strongly identify with the party. There are likely to be moderate farmers who may vote for the New Zealand National Party but respond, as American moderates do, to more information and/or education.

5.8.1 Value priming of Aotearoa New Zealand farmers

Discussion here is not exhaustive nor empirical but rather seeks to record the most obvious value priming of Aotearoa New Zealand farmers. It does so to highlight how individual values that suppress pro-environmental behaviours are likely to be primed by common semantic cues. Much has been made of the focus of Aotearoa New Zealand's agricultural sector, particularly the dairy industry, on its high production (*volume over value*) approach. In a culture where the value of achievement ("personal success through demonstrating competence according to social standards" – Table 5) is already prioritised, it is not difficult to see how a focus on high and/or increasing production could provide a useful measure of achievement and demonstrating competence. Increasing production would be consistent with prioritised values and would, therefore, be supported by feelings of pride.

The first paragraphs of the DairyNZ *Chairman's review* in the industry body's annual reports provide an example of how the value of achievement may be reinforced by consistent semantic priming (Table 6) (DairyNZ, 2008; DairyNZ, 2009; DairyNZ; 2010; DairyNZ 2011). The language in Table 6 is common to the dairy industry. The standard reference to the milk price appears likely to activate existing achievement and power values. Being "world-class" appears to indicate and cue achievement and power values, likewise the reinforcement of the goal of producing milk efficiently and more of it. The environment is mentioned in the paragraph from the 2010/2011 annual report. However, given the research described above where more cognitively accessible values are more likely to influence behaviour, it is likely that pro-environmental behaviour is suppressed by this type of semantic priming.

Table 6: First paragraphs of the "Chairman's review" message from DairyNZ annual reports (2007 – 2011)

Financial year	First paragraph of *Chairman's review*
2007/2008	This has been a landmark year for DairyNZ, with its creation as a new organisation to lead innovation in world-class dairy farming, enabling New Zealand dairy farmers to continue to be the best in the world.
2008/2009	Times have changed significantly since I sat down to write DairyNZ's first annual review in August last year. Then farmers had enjoyed the highest payout on record in the 2007/08 season, although this had been affected by drought and high farm working expenses. This year, thanks to the global recession and the high New Zealand dollar, we've seen a return to lower payout levels. There is no doubt that the 2009/10 season will be difficult for many farmers, and while the medium-term outlook is positive, DairyNZ's economics group predicts this season and the next will be tough. DairyNZ is committed to helping ensure farmers' focus is on producing milk more efficiently, while not losing sight of the other important parts of running a business – including environmental responsibility and ensuring the industry continues to attract and retain quality people.
2009/2010	The 2009/10 season has been one which has brought the word "volatility" back into every dairy farmer's vocab. From a $4.10 per kgMS forecast milk price in June last year to $4.60 in September to $5.70 in November, culminating in $6.10 in May reinforced why industry leaders are saying the only thing that's certain about the future is that it's going to be a volatile one.
2010/2011	The 2010/11 season happily turned out to be a far better season than any of us – especially in the North Island – were anticipating in the first few months. Positive world dairy prices, combined with a great autumn enabled farmers to recover well from the dry conditions before Christmas. These factors culminated in New Zealand cows producing more milk than ever before, with record milk supply figures for the season of 1,513 million kilograms of milksolids, a 5.2% increase on 2009/10.

Over a similar period, examples from the then Minister for Agriculture David Carter show a consistent focus on economic performance as, if not the only indicator, certainly a key indicator of success. Interestingly, even at events that are aimed at celebrating pro-environmental behaviour, Carter leads with statements on the economy and productivity. His opening remarks at the Ballance Farm Environment Awards in 2009 talk about balancing "productivity, profitability and environmental advancement" (Table 7). His first statement at the New Zealand Farm Environment Award Trust Forum stresses the value of the dairy industry to the Aotearoa New Zealand economy. His statements frequently include words associated with achievement and power (e.g. advancement, being the best, economic growth, biggest, moving up the ladder, lion's share) (Table 7).

Table 7: Examples of opening remarks from four speeches given by then Minister for Agriculture David Carter

Year	Event	Opening remarks of speech
2009	Ballance Farm Environment Awards (Carter, 2009)	Firstly, it's about showing what can be done to balance productivity, profitability and environmental advancement. Secondly, it's about dispelling the negative myths some special interest groups and political parties perpetuate around farming practices - and instead acknowledging the good work being done by our top farmers. And, thirdly, it's about using the best to lead the rest. We are celebrating those who are expanding new ideas, and we are highlighting what can be achieved.
2010	DairyNZ Farmers' forum (Carter, 2010a)	This Government's firm focus is on economic growth. This is about more jobs, boosting incomes, and lifting the living standards of all New Zealanders. The world does not owe us a living. If this country really wants to move itself up the OECD ladder, and if we want to catch up with Australia, there must be a concerted effort by all New Zealanders. The dairy industry is an integral part of the New Zealand economy. It's actually our biggest engine. The dairy industry contributed over $10 billion in the year to December 2009; 27 percent of New Zealand's total merchandised export value.
2010	New Zealand Farm Environment Award Trust Forum (Carter, 2010b)	Here in the Waikato, I certainly don't need to tell this audience how vitally important the dairy industry is to the New Zealand economy. As I've said previously, South Africa has diamonds, Australia has minerals, Saudi Arabia has oil – and in New Zealand we have farming based on pasture. Dairy holds the lion's share of our primary production system. Last year dairy products were responsible for more than $10 billion, or 27 per cent of our merchandise export earnings.
2012	Beef + Lamb NZ Future Farming Conference (Carter, 2012)	I know it's a cliché to say that we live in 'interesting times' and I could start any speech to an annual meeting by saying this – but for sheep and beef farmers it's very true. 2011/12 was a bumper season for most farmers. Despite the recent sharp decline in sheep meat prices, it was certainly the best that I have seen in my farming career. Farmer confidence is high as our industry continues to reduce debt and undertake some of the overdue maintenance on our farms.

From 2007 to 2012, the period these examples cover, dairy cattle numbers increased by over 20 percent nationally and almost doubled in Canterbury (Statistics NZ, 2015). Nitrogen fertiliser use increased by 55,000 tonnes nationally over the same period (Statistics New Zealand, 2019b). This is not to claim that intensification is a result only of value priming but to suggest that decisions to intensify animal agricultural systems are likely to have been supported by value priming (particularly when value priming by elites reinforces existing prioritised values) as decisions would be value-competent. Priming has regularly been priming of achievement and decisions to intensify are not pro-environmental.

5.8.2 Instantiations of pro-environmental behaviours in Aotearoa New Zealand's agricultural sector

Further to a likely prioritising of self-enhancement values and priming of these values within the animal agricultural sector, it appears likely that instantiations of pro-environmental behaviours may be limited within animal agricultural sectors. The "Industry-agreed good management practice relating to water quality" (IAGMPRWQ) (2015) provides a valuable example of existing (and likely dominant) instantiations of pro-environmental behaviours within the agricultural sector with regards to water quality on agricultural land. The IAGMPRWQ identifies 21 good management practices for improving water quality, which have been agreed to by primary sector groups including DairyNZ and Beef and Lamb.

Interestingly, while its name indicates the document has been developed to address water quality, its forward and introduction providing background on its development does not mention improving the health of waterways or minimising impacts on water quality from agriculture. Both sections indicate that:

> "The project aims to quantify the typical nutrient losses that are expected to occur from the range of farming systems, soils and climates across Canterbury when managed to good management practice. This information is important for two key reasons: to provide more reliable nutrient loss estimates that can be used for catchment modelling, and for regulatory purposes to indicate that all farmers are operating at GMP [good management practice]." (*Industry-agreed Good Management Practice relating to water quality,* 2015. p. 4)

There is no cue that this for the health of waterways or of benefit to the environment.

Some practices in the IAGMPRWQ are clearly linked to reducing losses. For example, “Retire all Land Use Capability Class 8” (*Industry-agreed Good Management Practices relating to water quality*, 2015). Class 8 land is known to be highly erodible and so its exclusion from a farm’s effective area is highly likely to result in reduced losses of sediment (and associated phosphorus and pathogenic losses) to waterways. Others may however, in some cases, increase contaminant loads to waterways, such as, “Design, calibrate and operate irrigation systems to minimise the amount of water needed to meet production objectives” (p.9. note a semantic cue to production). The practice refers explicitly to both new and existing irrigation and no indication is given in the document that with increasing irrigation there is a high risk (particularly within animal agriculture) of increasing losses to waterways.

Similarly, the 2003 Dairying and Clean Streams Accord and subsequent 2013 Sustainable Dairying: Water Accord (*Sustainable Dairying: Water Accord,* 2017) largely focused on stock exclusion, nutrient budgets, nutrient management plans and effluent management. Depending on how this work is carried out, the benefits to the health of waterways will be variable and, in some cases, very limited. As previously mentioned, a predicted uptake of adoption of nutrient management plans by younger farmers would still only result in seven percent national reduction in nitrogen leaching from farms by 2075 (Brown, Daigneault, Dawson, 2019). The 2017 annual report of the Sustainable Dairying: Water Accord claimed that of the 293 farms converted to dairy between 2013 and 2016, 91.3 percent met environmental compliance requirements. This instantiation suggests that conversion to dairying can be a pro-environmental behaviour.

5.8.3 Sources of Information and elite cues in Aotearoa New Zealand’s agricultural sector

Farmers who strongly identify with political parties may negatively respond to information if it contradicts elite cues. Elite cues may come from politicians as discussed (such as former Minister for Agriculture David Carter). However, moderate farmers (i.e. those who do not strongly relate to a particular political party) may respond to the provision of more information and more education. The 2015 Rural Decision Makers survey (referred to previously) found that veterinarians were the most trusted source of information among all farmers, with central and local government being the least trusted source (Small, Brown & Munguia., 2016).

However, there was some variation in the trust of other sources of information. The survey asked participant how important being highly productive was to their sense of self-identity and how important it was to their self-identity that they were someone who takes good care of the environment. From the results of these two questions, Small, Brown and Munguia (2016) categorised participants into four groups; high environment/high production farmers, high environment/low production farmers, low environment/high production farmers and low environment/low production farmers. Those participants who self-identified as having high environmental values and low production values were found to trust scientists and other farmers second equal (after veterinarians). While participants who self-identified as having high environmental and high production values trusted scientists the least of all groups of participants. Self-identified high environment and high production participants trusted other farmers and financial advisors second equal (after veterinarians), followed by organisations that represent industry, with scientists the fifth most trusted group out of eight sources (followed by cooperatives then media and, in last place, central and local government).

It is interesting, then, to compare the adoption of pro-environment behaviour between the two high environmental self-identifying groups of participants in the context of the instantiations provided through the Dairying and Clean Streams and Sustainable Dairying accords described. Those with high production values were most likely of all groups to have nutrient management plans (54 percent of participants in that group) and have fenced streams (77 percent). While those with low production values were most likely of all groups to reduce stocking rates, reduce nitrogen-based fertiliser and plant riparian buffers. This may be an indication of receptivity to certain sources of information over others (organisations that represent the industry over scientists).

5.9 Developing targeted values-sensitive communication

It appears likely that prioritised self-enhancement values held by Aotearoa New Zealand farmers may present some limitations to the adoption of pro-environmental behaviour and that value priming, elite cues and limited pro-environmental instantiations may suppress pro-environmental behaviour in Aotearoa New Zealand's agricultural sector (of course, as discussion, it is likely that the author's own prioritised values are reflected here). Where a social-ecological system reinforces values that are negatively correlated to the adoption of pro-environmental behaviour, the introduction of recommendations on improving the health of waterways may have limited effect. This is, of course, not to ignore other external motivators of farmer behaviour (central and local government regulation, and a range of market factors such as land value, for example) but rather to provide some insight into why pro-environmental behaviours may not be adopted where resource constraints are not evident.

There is evidence of biospheric values being held by farmers in Aotearoa New Zealand and a significant proportion of farmers self-identify as people who care for the environment (Small, Brown & Munguia., 2016). Additionally, research has shown that values are prioritised over others rather than being mutually exclusive and may be primed (Corner, Markowitz, Pidgeon, 2014; Maio et al., 2009). For these reasons, it appears likely that the development of targeted values-sensitive communication could be a path to increasing and sustaining pro-environmental behaviour in the agricultural sector to improve the health of waterways on agricultural land.

Values-sensitive communication would consider priming existing self-transcendent values and seek to avoid priming values that suppress pro-environmental behaviour (e.g. achievement). A targeted approach might consider the political identity of an audience to avoid reinforcing resistance to information and to identify those who are most receptive to information as well as consider who might be most effective at delivering information.

Those communicating with farmers on improving the health of waterways on agricultural land would benefit from further investigation of existing values as well as effective semantic and visual priming of self-transcendent values in communication on the heath of waterways. It may also be useful to further investigate cues that activate achievement and power values in order to avoid these in communication relating to improving the health of waterways on agricultural land. It also appears likely that identifying moderate farmers and those not strongly identified with a right-wing party and providing them with information on how to improve the health of waterways.

5.9.1 *Some initial thoughts*

- From the starting point of self-transcendent values, explain why recommended pro-environmental behaviour should be adopted not only what it should be or how it will be done.
- Not all self-transcendent priming will resonate with those who identify with the political right and so may trigger avoidance. Research has found that community health and duty to the next generation (benevolence) do resonate with those on the political right (Corner, Markowitz, Pidgeon, 2014; Corner, A. n.d.).
- Start with positive reasons why one would adopt pro-environmental behaviour before describing negative consequences (while being clear and accurate about consequences).
- Avoid priming self-enhancement values by providing financial costs/benefits or achievement as the rationale for adopting pro-environmental behaviour. As discussed, this is likely to suppress pro-environmental behaviour (not only in relation to waterways). Note: this is different from helping farmers consider financial constraints. Financial costs/benefits will inevitably enter into decision making but it does not have to be the reason for taking action.
- Establish in communication that pro-environmental behaviour is something everybody does together rather than something an individual does for others (Cialdini, 2003; Steg et al. 2014).
- Choose words that prompt familiar and concrete mental images so that instantiations easily come to mind. For example, for most people 'waterway' does not easily bring to mind an image (it is too abstract). However, a river or a lake is specific and easy to imagine.
- Consider who is likely to be the audience's most trusted sources of information and whether a trusted source is available to communicate the recommendations.

5.10 A note of caution

Undisputedly, good science communication is not simply the provision of information. To be effective in its purpose, communication on improving the health of waterways should consider its audience. And while there appears to be value in further investigation of the role of values in improving communication around the health of waterways, it is important to go carefully. If not well-examined, there is room for such communication to become or (equally significantly) appear manipulative. Persson, Sahlin and Wallin (2015), in their critique of the literature on cutural cognition, sound this warning around values-based communication. It is vitally important that any communication methods do not undermine scientific method or veracity. Poorly done, they argue, it is possible that values-based communication could erode trust in science, which would be counterproductive for meeting the challenge of improving the health of waterways on agricultural land (as well as having broader negative social consequences).

It is for this reason, this chapter has put forward the term *values-sensitive* communication, rather than the common *values-based* communication. Values-sensitive communication understands the role of values in encouraging and suppressing pro-environmental behaviour. It aims to avoid inadvertently suppressing pro-environmental behaviour and to highlight existing values that might encourage pro-environmental behaviour but its primary intent is not the priming of values. The literature warns us that, while values guide behaviour, values are not behaviour. Behaviour change requires consideration of more than values alone (c.f. Figure 43) (Heberlein, 2012; Mills et al., 2017).

5.11 Conclusion

It is a challenge to improve the health of waterways on agricultural land in Aotearoa New Zealand. The efforts by ecologists to do so have been considerable but the challenge is clearly greater than the traditional foci of ecology. Basic human values are an important component of the social-ecological systems farmers operate in and this discussion may help to explain why the provision of information has limitations in its effect on the adoption of pro-environmental behaviour. Additionally, recognition of the role of basic human values could inform communication to encourage and sustain pro-environmental behaviour in Aotearoa New Zealand farmers in order to improve the health of waterways on agricultural land. Given the consequences of values and political identity on pro-environmental behaviour more frequent *fusion of thought* across disciplines appears to be vital to meet this and the many other challenges facing the natural world.

References

Abrahamse, W. (2019). Chapter 3 - Behaviour Change Interventions. In *Encouraging Pro-Environmental Behaviour* (pp. 27-45). San Diego: Academic Press.

ANZECC. (2000). *Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Volume 1: The Guidelines*. Retrieved from http://www.mfe.govt.nz/fresh-water/technical-guidance-and-guidelines/anzecc-2000-guidelines

Aristi, I., Elosegi, A., Wood, S. A., Clapcott, J. E., Young, R. G., Acuna, V., & Mills, H. (2017). Forestry affects the abundance of Phormidium-dominated biofilms and the functioning of a New Zealand river ecosystem. *Marine and Freshwater Research, 68*(9), 1741-1751.

Ausseil, A. G. E., Dymond, J. R., Kirschbaum, M. U. F., Andrew, R. M., & Parfitt, R. L. (2013). Assessment of multiple ecosystem services in New Zealand at the catchment scale. *Environmental Modelling and Software, 43*, 37-48.

Baalousha, H. M. (2009). Stochastic water balance model for rainfall recharge quantification in Ruataniwha Basin, New Zealand. *Environmental Geology, 58*(1), 85-93.

Baalousha, H. M. (2012). Modelling surface-groundwater interaction in the Ruataniwha basin, Hawke's Bay, New Zealand. *Environmental Earth Sciences, 66*(1), 285-294.

Ballantine, D. J. & Davies-Colley, R. J. (2014a). Water quality trends in New Zealand rivers: 1989–2009. *Environmental Monitoring and Assessment, 186*(3), 1939-1950.

Ballantine, D. J., & Davies-Colley, R. J. (2014b). Water quality trends in New Zealand rivers: 1989–2009. *Environmental Monitoring and Assessment, 186*(3), 1939-1950.

Bargh J. A. (2006). What have we been priming all these years? On the development, mechanisms, and ecology of nonconscious social behavior. European journal of social psychology, 36(2), 147–168.

Basher, L. R. (2013). Erosion processes and their control in New Zealand. In J. R. Dymond (Ed.), *Ecosystem services in New Zealand: conditions and trends* (pp. 363–374). Lincoln, New Zealand: Manaaki Whenua Press.

Bekesi, G., & Hodges, S. (2006). The protection of groundwater dependent ecosystems in Otago, New Zealand. *Hydrogeology Journal, 14*(8), 1696-1701.

Beukes, P. C., Gregorini, P., Romera, A. J., Woodward, S. L., Khaembah, E. N., Chapman, D. F., Nobilly, F., Bryant, R.H., Edwards, G.R., Clark, D. A. (2014). The potential of diverse pastures to reduce nitrogen leaching on New Zealand dairy farms. *Animal Production Science, 54*(12), 1971-1979.

Biggs, B. J. (2000). *New Zealand periphyton guideline : detecting, monitoring and managing enrichment of streams*: Wellington, N.Z. : Ministry for the Environment, 2000.

Biggs, B. J., Kilroy, C., & Mulcock, C. M. (1998). *New Zealand Stream Health Monitoring Assesment Kit: Stream monitoring manual.* Retrieved from https://www.niwa.co.nz/our-science/freshwater/tools/shmak/manual/6doing

Biggs, B. J., Nikora, V. I., & Snelder, T. H. (2005). Linking scales of flow variability to lotic ecosystem structure and function. *River Research and Applications, 21*(2-3), 283-298.

Booker, D. J., Snelder, T. H., Greenwood, M. J., & Crow, S. K. (2015). Relationships between invertebrate communities and both hydrological regime and other environmental factors across New Zealand's rivers. *Ecohydrology, 8*(1), 13.

Boubée, J. A. T., Dean, T. L., West, D. W., & Barrier, R. F. G. (1997). Avoidance of suspended sediment by the juvenile migratory stage of six New Zealand native fish species. *New Zealand Journal of Marine and Freshwater Research, 31*(1), 61-69.
Brooking, T., Pawson, E., & Star, P. (2011). *Seeds of empire : the environmental transformation of New Zealand*: London : I.B. Tauris, 2011.
Brown, P., Daigneault, A., & Dawson, J. (2019). Age, values, farming objectives, past management decisions, and future intentions in New Zealand agriculture. *Journal of Environmental Management, 231*, 110-120.
Burdon, F. J., McIntosh, A. R., & Harding, J. S. (2013). Habitat loss drives threshold response of benthic invertebrate communities to deposited sediment in agricultural streams. *Ecological Applications, 23*(5), 1036-1047.
Burton, R. J. F. (2004). Reconceptualising the 'behavioural approach' in agricultural studies: a socio-psychological perspective. *Journal of Rural Studies, 20*(3), 359-371.
Cialdini, R. B. (2003). Crafting normative messages to protect the environment. *Current Directions in Psychological Science, 12*, 105-109.
Canning, A. D. (2018). Predicting New Zealand riverine fish reference assemblages. *PeerJ*. https://doi-org.ezproxy.massey.ac.nz/10.7717/peerj.4890
Capaldi, C. A., & Zelenski, J. M. (2016). Seeing and Being Green? The Effect of Money Priming on Willingness to Perform Sustainable Actions, Social Connectedness, and Prosociality. *Journal of Social Psychology, 156*(1), 1-7.
Carfora, V., Caso, D., Sparks, P., & Conner, M. (2017). Moderating effects of pro-environmental self-identity on pro-environmental intentions and behaviour: A multi-behaviour study. Journal of Environmental Psychology, 53, 92–99
Carter, D. (2009). *Speech: Balance Farm Environment Awards*. Retrieved from https://www.beehive.govt.nz/speech/ballance-farm-environment-awards-0
Carter, D. (2010a) *Speech: Address to DairyNZ Farmers' Forum.* Retrieved from https://www.beehive.govt.nz/speech/address-dairynz-farmers%E2%80%99-forum
Carter, D. (2010b) *Speech: New Zealand Farm Environment Award Trust Forum.* Retrieved from https://www.beehive.govt.nz/speech/new-zealand-farm-environment-award-trust-forum
Carter, D. (2012). *Speech: Beef + Lamb NZ Future Farming Conference.* Retrieved from https://www.beehive.govt.nz/speech/speech-beef-lamb-nz-future-farming-conference
Chen, M.-F. (2016). Impact of fear appeals on pro-environmental behavior and crucial determinants. *International Journal of Advertising*, 35(1), 74–92
Clapcott, J. E., Collier, K. J., Death, R. G., Goodwin, E. O., Harding, J. S., Kelly, D., Leathwicke, J.S., Young, R. G. (2012). Quantifying relationships between land-use gradients and structural and functional indicators of stream ecological integrity. *Freshwater Biology, 57*(1), 74-90.
Clapcott, J. E., Goodwin, E. O., Snelder, T. H., Collier, K. J., Neale, M. W., & Greenfield, S. (2017). Finding reference: a comparison of modelling approaches for predicting macroinvertebrate community index benchmarks. In (Vol. 51, pp. 44-59).
Clapcott, J. E., Young, R. G., Harding, J. S., Matthaei, C. D., Quinn, J. M., & Death, R. G. (2011). *Sediment Assessment Methods: Protocols and guidelines for assessing the effects of deposited fine sediment on in-stream values.* Retrieved from http://www.cawthron.org.nz/media_new/publications/pdf/2014_01/SAM_FINAL_LOW.pdf

Clarke, A., Mac Nally, R., Bond, N., & Lake, P. S. (2008). Macroinvertebrate diversity in headwater streams: a review. In (Vol. 53, pp. 1707-1721).
Collier, K. J. (1992). *Assessing river stability : use of the Pfankuch Method*: Wellington, N.Z. : Head Office, Dept. of Conservation, c1992.
Collins, R., McLeod, M., Hedley, M., Donnison, A., Close, M., Hanly, J., . . . Matthews, L. (2007). Best management practices to mitigate faecal contamination by livestock of New Zealand waters. *New Zealand Journal of Agricultural Research, 50*(2), 267-278.
Corey, L. F., Randy, T., Damian, R. M., & Mark, S. (2008). Pathogen Prevalence Predicts Human Cross-Cultural Variability in Individualism/Collectivism. *Proceedings: Biological Sciences, 275*(1640), 1279.
Corner, A. , Markowitz, E. and Pidgeon, N. (2014), Public engagement with climate change: the role of human values. WIREs Clim Change, 5: 411-422.
Corner, A. (n.d.). A new conversation with the centre-right about climate change: Values, frames and narratives. Retrieved from http://www.truevaluemetrics.org/DBpdfs/ClimateChange/COIN-A-new-conversation-with-the-centre-right-about-climate-change.pdf
Cournane, F. C., McDowell, R., Littlejohn, R., & Condron, L. (2011). Effects of cattle, sheep and deer grazing on soil physical quality and losses of phosphorus and suspended sediment losses in surface runoff. *Agriculture, Ecosystems and Environment, 140*, 264-272.
Dairying and Clean Streams Accord. (2003) Retrieved from http://gdsindexnz.org/wp-content/uploads/2019/04/84.-Dairying-and-Clean-Streams-Accord-2003.pdf
DairyNZ. (2008). *DairyNZ Annual Report 2007-2008*. Retrieved from https://www.dairynz.co.nz/publications/dairynz-corporate/
DairyNZ. (2009). *DairyNZ Annual Report 2008-2009*. Retrieved from https://www.dairynz.co.nz/publications/dairynz-corporate/
DairyNZ. (2010). *DairyNZ Annual Report 2009-2010*. Retrieved from https://www.dairynz.co.nz/publications/dairynz-corporate/
DairyNZ. (2011). *DairyNZ Annual Report 2010-2011*. Retrieved from https://www.dairynz.co.nz/publications/dairynz-corporate/
Daughney, C., & Randall, M. (2009). *National Groundwater Quality Indicators Update: State and Trends 1995-2008* Retrieved from Wellington, New Zealand:
Davies, B., Thompson, S., Biggs, J., & Williams, P. (2009). Making agricultural landscapes more sustainable for freshwater biodiversity: A case study from southern England. *Aquatic Conservation: Marine and Freshwater Ecosystems, 19*(4), 439-447.
Davies-Colley, R. J. (2000). *"Trigger" values for New Zealand rivers*. Retrieved from https://www.mfe.govt.nz/sites/default/files/media/Environmental%20reporting/"Trigger"%20values%20for%20New%20Zealand%20rivers.pdf
Davies-Colley, R. J. (2013). River water quality in New Zealand: An introduction and overview. In J. R. Dymond (Ed.), *Ecosystem services in New Zealand: conditions and trends* (pp. 423-447). Lincoln, New Zealand: Manaaki Whenua Press.
Davies-Colley, R. J., Hicks, M., Hughes, A., Clapcott, J. E., Kelly, D., & Wagenhoff, A. (2015). *Fine sediment effects on freshwaters, and the relationship of environmental state to sediment load: A literature review.* Retrieved from https://www.mfe.govt.nz/publications/fresh-water/fine-sediment-effects-freshwaters-and-relationship-environmental-state

Davies-Colley, R. J., Nagels, J. W., Smith, R. A., Young, R. G., & Phillips, C. J. (2004). Water quality impact of a dairy cow herd crossing a stream. *New Zealand Journal of Marine and Freshwater Research*, 38(4), 569–576.

Davies-Colley, R. J., & Quinn, J. M. (1998). Stream lighting in five regions of North Island, New Zealand: Control by channel size and riparian vegetation. *New Zealand Journal of Marine and Freshwater Research, 32*(4), 591-605.

Davies-Colley, R. J., Valois, A., & Milne, J. (2018). Faecal contamination and visual clarity in New Zealand rivers: correlation of key variables affecting swimming suitability. *Journal of Water and Health, 16*(3), 329-339.

Death, R. G., & Collier, K. J. (2010). Measuring stream macroinvertebrate responses to gradients of vegetation cover: when is enough enough? Freshwater Biology*, 55*(7), 1447-1464.

Death, R. G. J., C. J. Magierowski, R. Tonkin, J. D. Canning, A. (2016). Clean but not green: a weight-of-evidence approach for setting nutrient criteria in New Zealand rivers. *Manuscript submitted for publication*.

Department of Conservation. (2013). *Molesworth Management Plan*. Wellington, New Zealand

Dewson, Z. S., James, A. B. W., & Death, R. G. (2007a). A Review of the Consequences of Decreased Flow for Instream Habitat and Macroinvertebrates. *Journal of the North American Benthological Society*(3), 401.

Dewson, Z. S., James, A. B. W., & Death, R. G. (2007b). Invertebrate responses to short-term water abstraction in small New Zealand streams. *Freshwater Biology, 52*(2), 357-369.

Dietz, T. (2013). Bringing values and deliberation to science communication. *Proceedings of the National Academy of Sciences, 110*(Supplement 3), 14081.

Dolamore, B., Puddick, J., & Wood, S. A. (2017). Accumulation of nodularin in New Zealand shortfin eel (Anguilla australis): potential consequences for human consumption. New Zealand Journal of Marine and Freshwater Research*, 51*(3), 321-332.

Donath, F. M., Daughney, C. J., Morgenstern, U., Cameron, S. G., & Toews, M. W. (2015). Hydrochemical interpretation of groundwater-surface water interactions at catchment and local scales, Lake Rotorua catchment, New Zealand. *Journal of Hydrology (New Zealand)*(1), 11.

Donnison, A., Ross, C., & Thorrold, B. (2004). Impact of land use on the faecal microbial quality of hill-country streams. *New Zealand Journal of Marine and Freshwater Research, 38*(5), 845-855.

Drummond, L. (2006). Managing the Environmental Effects of Agriculture under the Resource Management Act: Non-point Source Discharges. *New Zealand Journal of Environmental Law*, 255.

Duncan, M. J., Srinivasan, M. S., & McMillan, H. (2016). Field measurement of groundwater recharge under irrigation in Canterbury, New Zealand, using drainage lysimeters. *Agricultural Water Management, 166*(Supplement C), 17-32.

Duncan, M. J., & Woods, R. A. (2004). Flow regimes. In J. Harding, P. Mosley, C. Pearson, & B. Sorrell (Eds.), *Freshwaters of New Zealand*. Christchurch, New Zealand: Caxton Press

Duncan, M. J., & Woods, R. A. (2013). Water Regulation. In J. R. Dymond (Ed.), *Ecosytem Services in New Zealand - conditions and trends*. Lincoln, New Zealand: Manaaki Whenua Press.

Dymond, J. R., Ausseil, A. G. E., Parfitt, R. L., Herzig, A., & McDowell, R. W. (2013). Nitrate and phosphorus leaching in New Zealand: a national perspective. *New Zealand Journal of Agricultural Research, 56*(1), 49-59.
Dymond, J. R., Betts, H. D., & Schierlitz, C. S. (2010). An erosion model for evaluating regional land-use scenarios. *Environmental Modelling & Software, 25*(3), 289-298.
Dymond, J. R., Davies-Colley, R. J., Hughes, A. O., & Matthaei, C. D. (2017). Predicting improved optical water quality in rivers resulting from soil conservation actions on land. *Science of The Total Environment, 603*, 584-592.
Egri, C. P., Khilji, S. E., Ralston, D. A., Palmer, I., Girson, I., Milton, L., . . . Mockaitis, A. (2012). Do Anglo countries still form a values cluster? Evidence of the complexity of value change. *Journal of World Business, 47*(2), 267-276.
Ehret, P. J., Sherman, D. K., & Sparks, A. C. (2017). Support for environmental protection: an integration of ideological-consistency and information-deficit models. *Environmental Politics, 26*(2), 253-277.
Fairweather, J. R., Rosin, C. J., Hunt, L. M., & Campbell, H. R. (2009). Are Conventional Farmers Conventional? Analysis of the Environmental Orientations of Conventional New Zealand Farmers. *Rural Sociology, 74*(3), 430-454.
Fernandez, M. A., & Daigneault, A. (2017). Erosion mitigation in the Waikato District, New Zealand: economic implications for agriculture. *Agricultural Economics, 48*(3), 341-361.
Fiedler, A. K., Landis, D. A., & Wratten, S. D. (2008). Maximizing ecosystem services from conservation biological control: The role of habitat management. *Biological Control, 45*, 254-271.
Flávio, H. M., Ferreira, P., Formigo, N., & Svendsen, J. C. (2017). Reconciling agriculture and stream restoration in Europe: A review relating to the EU Water Framework Directive. *Science of The Total Environment, 596*, 378-395.
Foote, K., Joy, M., & Death, R. (2015). New Zealand Dairy Farming: Milking Our Environment for All Its Worth. *Environmental Management, 56*(3), 709-720.
Frenken, K., & Gillet, V. (2012). *Irrigation water requirement and water withdrawal by country*. Retrieved from http://www.fao.org/3/a-bc824e.pdf
Gluckman, P. (2017). *New Zealand's fresh waters: Values, state, trends and human impacts*. Retrieved from http://www.pmcsa.org.nz/wp-content/uploads/PMCSA-Freshwater-Report.pdf
Google Earth Pro. (2018). *Molesworth Stockyards, Molesworth Stream and campground. 42°04'57.70"S, 173°16'03.94"E, elevation 878M.* Imagery date 20 November 2016
Gray, C. W., Laurenson, S., Monaghan, R. M., Orchiston, T., & Cavanagh, J.-A. (2017). Cadmium losses in overland flow from an agricultural soil. Environmental Science and Pollution Research*, 24*(30), 24046-24053.
Greaves, L. M., Cowie, L. J., Osborne, D., Houkamau, C. A., Sibley, C. G., & Robertson, A. (2017). Predicting party vote sentiment: Identifying the demographic and psychological correlates of party preference in two large datasets. *New Zealand Journal of Psychology, 46*(3), 164-175.
Greenwood, M. J., Harding, J. S., McIntosh, A. R., & Niyogi, D. K. (2012). Improving the effectiveness of riparian management for aquatic invertebrates in a degraded agricultural landscape: stream size and land-use legacies. *Journal of Applied Ecology, 49*(1), 213-222.

Guath, M., & Juslin, P. (2014). Do We Recommend Lower Electricity Consumption after Priming with Pro-social and Intrinsic Values? (36).

Hall, L. W., Scott, M. C., & Killen, W. D. (1998). Ecological risk assessment of copper and cadmium in surface waters of Chesapeake Bay watershed. *Environmental Toxicology and Chemistry, 17*(6), 1172-1189. doi:10.1002/etc.5620170626

Hanel, P. H. P., Maio, G. R., Soares, A. K. S., Vione, K. C., Coelho, G. L. d. H., Gouveia, V. V., . . . Manstead, A. S. R. (2018). Cross-Cultural Differences and Similarities in Human Value Instantiation. In (Vol. 9).

Hanel, P. H. P., Vione, K. C., Hahn, U., & Maio, G. R. (2017). Value Instantiations: The Missing Link Between Values and Behavior? In *Values and Behavior: Taking a Cross Cultural Perspective* (pp. 175-190). Cham: Springer International Publishing.

Hans, S. E., & Angus, R. M. (2006). Habitat Loss through Disruption of Constrained Dispersal Networks. *Ecological Applications*(3), 987.

Harding, J. S., & Winterbourn, M. J. (1995). Effects of contrasting land use on physico-chemical conditions and benthic assemblages of streams in a Canterbury (South Island, New Zealand) river system. *New Zealand Journal of Marine and Freshwater Research, 29*(4), 479-492.

Harding, J. S., Young, R. G., Hayes, J. W., Shearer, K. A., & Stark, J. D. (1999). Changes in agricultural intensity and river health along a river continuum. *Freshwater Biology, 42*(2), 345.

Harland, F. M. J., Wood, S. A., Broady, P. A., Gaw, S., & Williamson, W. M. (2014). Polyphasic studies of cyanobacterial strains isolated from benthic freshwater mats in Canterbury, New Zealand. *New Zealand Journal of Botany, 52*(1), 116-135. doi:10.1080/0028825X.2013.846266

Hart, D. D., Biggs, B. J. F., Nikora, V. I., & Flinders, C. A. (2013). Flow effects on periphyton patches and their ecological consequences in a New Zealand river. *Freshwater Biology, 58*(8), 1588-1602.

Heberlein, T. A. (2012), Navigating Environmental Attitudes. Conservation Biology, 26: 583-585

Holmes, R. (2009). *Effect of cattle grazing on water quality in Molesworth Station*. Retrieved from https://www.cawthron.org.nz/publication/science-reports/effect-cattle-grazing-water-quality-molesworth-station/

Hughes, A. O., & Quinn, J. M. (2014). Before and After Integrated Catchment Management in a Headwater Catchment: Changes in Water Quality. In (Vol. 54, pp. 1288-1305).

Hughes, A. O., & Quinn, J. M. (2014). Before and after integrated catchment management in a headwater catchment: changes in water quality. *Environmental Management, 54*(6), 1288-1305.

Hughes, A. O., Quinn, J. M., & McKergow, L. A. (2012). Land use influences on suspended sediment yields and event sediment dynamics within two headwater catchments, Waikato, New Zealand. *New Zealand Journal of Marine and Freshwater Research, 46*(3), 315-333.

Industry-agreed Good Management Practices relating to water quality. (2015). Retrieved from https://beeflambnz.com/knowledge-hub/PDF/industry-agreed-good-management-practices-relating-water-quality

Inglehart, R., & Welzel, C. (2005). *Modernization, Cultural Change, and Democracy : The Human Development Sequence*. Cambridge, UK: Cambridge University Press.

Jacob, S. (2016). The Effect of Elite Polarization: A Comparative Perspective on How Party Elites Influence Attitudes and Behavior on Climate Change in the European Union. *Sustainability*(1), 39.
Susan K. Jacobson, Nia A. Morales, Beida Chen, Rebecca Soodeen, Michael P. Moulton & Eakta Jain (2019) Love or Loss: Effective message framing to promote environmental conservation. *Applied Environmental Education & Communication*. 18:3, 252-265
Journeaux, P., van Reenan, E., Pike, S., Manjala, T., Miller, D., Austin, G. (2018). Literature Review and Analysis of Farmer decision making with regard to Climate Change and Biological Gas Emissions. Retrieved from https://www.mpi.govt.nz/dmsdocument/32137-farm-behaviour-ghg-literature-review-final-dec-2018
Joy, M. K., & Death, R. G. (2013). Freshwater biodiversity. In J. R. Dymond (Ed.), *Ecosystem services in New Zealand: conditions and trends.* (pp. 448–459). Lincoln, New Zealand: Manaaki Whenua Press.
Joy, M. K., Foote, K. J., McNie, P. & Piria, M. Decline in New Zealand's freshwater fish fauna: effect of land use. *Mar. Freshw. Res.* **70**, 114–124 (2019).
Julian, J. P., Beurs, K. M. d., Owsley, B., Davies-Colley, R. J., & Ausseil, A. G. E. (2017). River water quality changes in New Zealand over 26 years: response to land use intensity. *Hydrology and Earth System Sciences,* 21(2), Pp 1149-1171
Kahan, D. M. (2010). Fixing the communications failure: People's grasp of scientific debates can improve if communicators build on the fact that cultural values influence what and whom we believe. *Nature*(7279), 296.
Kahan, D., Jenkins, S. H., & Braman, D. (2011). Cultural cognition of scientific consensus. Journal of Risk Research, 14(2), 147–174
Kahan, D. M., Peters, E., Wittlin, M., Slovic, P., Ouellette, L. L., Braman, D., & Mandel, G. (2012). The polarizing impact of science literacy and numeracy on perceived climate change risks. *Nature Climate Change, 2*, 732.
Kasser, T., Cohn, S., Kanner, A. D., & Ryan, R. M. (2007). Some costs of AmericaN Corporate Capitalism: A Psychological Exploration of Value and Goal Conflicts. *Psychological Inquiry, 18*(1), 1-22.
Keizer, K., Lindenberg, S., & Steg, L. (2013). The importance of demonstratively restoring order. PloS one, 8(6), 65137.
Lange, K., Townsend, C. R., Gabrielsson, R., Chanut, P. C. M., & Matthaei, C. D. (2014). Responses of stream fish populations to farming intensity and water abstraction in an agricultural catchment. *Freshwater Biology, 59*(2), 286-299.
Lee, F., Simon, K. S., & Perry, G. L. W. (2017). Increasing agricultural land use is associated with the spread of an invasive fish (Gambusia affinis). *Science of The Total Environment, 586*, 1113-1123.
Liu, Z., Li, X., Tai, P., Sun, L., Yuan, H., & Yang, X. (2018). Toxicity of ammonia, cadmium, and nitrobenzene to four local fishes in the Liao River, China and the derivation of site-specific water quality criteria. *Ecotoxicology & Environmental Safety, 147*, 656-663.
Luckman, P. G., Gibson, R. D., & Derose, R. C. (1999). Landslide erosion risk to New Zealand pastoral steeplands productivity. *Land Degradation & Development, 10*(1), 49-65.
MacLeod, C. J., & Moller, H. (2006). Intensification and diversification of New Zealand agriculture since 1960: An evaluation of current indicators of land use change. *Agriculture, Ecosystems & Environment, 115*(1), 201-218.

Maio, G. R., Hahn, U., Frost, J. M., & Cheung, W. Y. (2009a). Applying the Value of Equality Unequally: Effects of Value Instantiations That Vary in Typicality. *Journal of Personality and Social Psychology, 97*(4), 598-614.
Maio, G. R., Pakizeh, A., Cheung, W. Y., & Rees, K. J. (2009b). Changing, priming, and acting on values: effects via motivational relations in a circular model. *Personality and Social Psychology, 97*(4), 699-715.
Manfredo, M. J., Teel, T. L., Sullivan, L., Bruskotter, J. T., Fulton, D., Schwartz, S. H., . . . Kitayama, S. (2017). Why social values cannot be changed for the sake of conservation. *Conservation Biology, 31*(4), 772-780.
Marden, M., Arnold, G., Seymour, A., & Hambling, R. (2012). History and distribution of steepland gullies in response to land use change, East Coast Region, North Island, New Zealand. *Geomorphology, 153-154*, 81-90.
Matthaei, C. D., Piggot, J. J., & Townsend, C. R. (2010). Multiple stressors in agricultural streams: interactions among sediment addition, nutrient enrichment and water abstraction. *Journal of Applied Ecology*(3), 639.
McAllister, T. G., Hawes, I., Wood, S. A., & Atalah, J. (2018). Spatiotemporal dynamics of Phormidium cover and anatoxin concentrations in eight New Zealand rivers with contrasting nutrient and flow regimes. *Science of the Total Environment, 612*, 71-80.
McAllister, T. G., Wood, S. A., & Hawes, I. (2016). The rise of toxic benthic Phormidium proliferations: A review of their taxonomy, distribution, toxin content and factors regulating prevalence and increased severity. *Harmful Algae, 55*(Supplement C), 282-294.
McBride, G., & Stoller, J. (2017). *Technical Background for 2017 MfE 'Clean Water' Swimmability Proposals for Rivers*. Retrieved from https://niwa.co.nz/news/niwa-technical-background-report-for-mfe-clean-water-swimmability-proposals-for-rivers
McDowall, R. M. (2006). Fish, fish habitats and fisheries in New Zealand. *Aquatic Ecosystem Health & Management, 9*(4), 391-405.
McDowell, R. W., Cox, N., & Snelder, T. H. (2017). Assessing the Yield and Load of Contaminants with Stream Order: Would Policy Requiring Livestock to Be Fenced Out of High-Order Streams Decrease Catchment Contaminant Loads? *Journal of Environmental Quality, 46*(5), 1038-1047.
McLaughlin, P., & Dietz, T. (2008). Structure, agency and environment: Toward an integrated perspective on vulnerability. *Global Environmental Change, 18*(1), 99-111.
Meyer, J. L., Strayer, D. L., Wallace, J. B., Eggert, S. L., Helfman, G. S., & Leonard, N. E. (2007). The contribution of headwater streams to biodiversity in river networks. In (Vol. 43, pp. 86-103).
Michele, J. G., Jana, L. R., Lisa, N., Lisa, M. L., Janetta, L., Beng Chong, L., . . . Susumu, Y. (2011). Differences Between Tight and Loose Cultures: A 33-Nation Study. *Science, 332*(6033), 1100.
Michie, S., Atkins, L., & West, R. (2014). *The Behaviour Change Wheel: A guide to designing interventions*. U.K.: Silverback Publishing.
Milfont, T. L., Harré, N., Sibley, C. G., & Duckitt, J. (2012). The climate-change dilemma: Examining the association between parental status and political party support. *Journal of Applied Social Psychology, 42*(10), 2386-2410.

Mills, J., Gaskell, P., Ingram, J., Dwyer, J., Reed, M., & Short, C. (2017). Engaging farmers in environmental management through a better understanding of behaviour. *Agriculture and Human Values, 34*(2), 283-299.

Ministy for the Environment. (2016a). Observed streambed sedimentation, 1990–2011. [Vector multipolygon]. Retrieved from https://data.mfe.govt.nz/layer/52678-observed-streambed-sedimentation-19902011/

Ministry for the Environment. (2016b). Predicted streambed sedimentation, 1990–2011. [Vector multipolygon] Retrieved from https://data.mfe.govt.nz/layer/52679-predicted-streambed-sedimentation-19902011/

Ministry for the Environment. (2016c). Predicted average Macroinvertebrate Community Index (MCI) score, 2007–2011. [Vector point]. Retrieved from https://data.mfe.govt.nz/layer/52713-predicted-average-macroinvertebrate-community-index-mci-score-20072011/

Ministry for the Environment and Statistics New Zealand. (2015). *New Zealand's Environmental Reporting Series: Environment Aotearoa 2015.* Retrieved from https://www.mfe.govt.nz/publications/environmental-reporting/environment-aotearoa-2015

Ministry for the Environment and Statistics New Zealand. (2017). *Our fresh water 2017*. Retrieved from http://www.mfe.govt.nz/sites/default/files/media/Environmental%20reporting/our-fresh-water-2017_1.pdf

Ministry of Primary Industries. (2017). *Situation and Outlook for Primary Industries: March 2017*. Wellington, New Zealand: Ministry for Primary Industries

Mitchell, C. (2019, February 2). New Zealand's disappearing wetlands continue to be destroyed. *The Press*. Retrieved from https://www.stuff.co.nz/environment/110263799/muddy-damp-and-disappearing-wetlands-continue-to-be-destroyed

Moller, H., McLoed, C. J., Haggerty, J., Rosin, C., Blackwell, G., Perley, C., . . . Gradwohl, M. (2008). Intensification of New Zealand agriculture : implications for biodiversity. *New Zealand journal of agricultural research (Online)*.

Monaghan, R. M., Hedley, M. J., Di, H. J., McDowell, R. W., Cameron, K. C., & Ledgard, S. F. (2007). Nutrient management in New Zealand pastures— recent developments and future issues. *New Zealand Journal of Agricultural Research, 50*(2), 181-201.

Monaghan, R. M., Smith, L. C., & Muirhead, R. W. (2016). Pathways of contaminant transfers to water from an artificially-drained soil under intensive grazing by dairy cows. *Agriculture, Ecosystems & Environment, 220*, 76-88.

Moriarty, E. M., McEwan, N., Mackenzie, M., Karki, N., & Sinton, L. W. (2011). Incidence and prevalence of microbial indicators and pathogens in ovine faeces in New Zealand. *New Zealand Journal of Agricultural Research, 54*(2), 71-81.

Morton, J., & Roberts, A. (2016). Fertiliser use on New Zealand sheep and beef farms: The principles and practice of soil fertility and fertiliser use on New Zealand sheep and beef farms. In F. A. o. N. Zealand (Ed.), (Fourth ed.). Wellington, New Zealand: Fertiliser Association of New Zealand.

Muirhead, R. W., Davies-Colley, R. J., Donnison, A. M., & Nagels, J. W. (2004). Faecal bacteria yields in artificial flood events: quantifying in-stream stores. *Water Research, 38*, 1215-1224.

Mueller, H., McBride, C., Hamilton, D., Doole, G., & Abell, J. (2019). Economic and ecosystem costs and benefits of alternative land use and management scenarios in the Lake Rotorua, New Zealand, catchment. *Global Environmental Change*, *54*, 102–112.

Naden, P. S., Murphy, J. F., Old, G. H., Newman, J., Scarlett, P., Harman, M., . . . Jones, J. I. (2016). Understanding the controls on deposited fine sediment in the streams of agricultural catchments. *Science of The Total Environment, 547*, 366-381.

Nadkarni, N. M., Weber, C. Q., Goldman, S. V., Schatz, D. L., Allen, S., & Menlove, R. (2019). Beyond the Deficit Model: The Ambassador Approach to Public Engagement. *BioScience, 69*(4), 305.

Neale, M. W., Storey, R. G., Rowe, D. K., Collier, K. J., Hatton, C., Joy, M. K., . . . Quinn, J. M. (2011). *Stream Ecological Valuation (SEV): A User's Guide*. Retrieved from http://www.knowledgeauckland.org.nz/assets/publications/GD2011-001-Stream-ecological-valuation-SEV-users-guide-reprint-Nov-2015.pdf

Niyogi, D., Koren, M., Arbuckle, C., & Townsend, C. (2007). Stream Communities Along a Catchment Land-Use Gradient: Subsidy-Stress Responses to Pastoral Development. *Environmental Management, 39*(2), 213-225.

OECD. (2012). Water Quality and Agriculture : Meeting the Policy Challenge. In: Éditions OCDE / OECD Publishing. Retreived from https://www.oecd.org/publications/water-quality-and-agriculture-9789264168060-en.htm

Olsen, D. A., & Shearer, K. A. (2007). *Molesworth freshwater baseline survey*. Cawthron Institute

Olsen, D. A., & Young, R. G. (2009). Significance of river-aquifer interactions for reach-scale thermal patterns and trout growth potential in the Motueka River, New Zealand. *Hydrogeology Journal, 17*(1), 175-183.

Owens, C. T., & Lamm, A. J. (2017). The Politics of Extension Water Programming: Determining if Affiliation Impacts Participation. *Journal of Agricultural Education, 58*(1), 54-68.

Parkyn, S., & Wilcock, B. (2004). Impacts of agricultural land use. In J. Harding, P. Mosley, C. Pearson, & B. Sorrell (Eds.), *Freshwaters of New Zealand*. Christchurch, New Zealand: Caxton Press.

Parliamentary Commissioner for the Environment. (2004). *Growing for good: Intensive farming, sustainability and New Zealand's environment*. Retrieved from https://www.pce.parliament.nz/publications/archive/1997-2006/growing-for-good-intensive-farming-sustainability-and-new-zealands-environment

Parliamentary Commissioner for the Environment. (2012). *Water quality in New Zealand: Understanding the science*. Retreived from https://www.pce.parliament.nz/publications/water-quality-in-new-zealand-understanding-the-science

Parliamentary Commissioner for the Environment. (2013). *Water quality in New Zealand: Land use and nutrient pollution*. Retrieved from https://www.pce.parliament.nz/publications/update-report-water-quality-in-new-zealand-land-use-and-nutrient-pollution

Parminter, T., & Perkins, A. (1997). *Applying an understanding of farmers' values and goals to their farming styles.* Paper presented at the Proceedings of the conference of New Zealand Grassland Association.

Pawson, E., & Brooking, T. (2008). Empires of Grass: Towards an Environmental History of New Zealand Agriculture. *British Review of New Zealand Studies*, 95.
Persson, J., Sahlin, N.-E., & Wallin, A. (2015). Climate change, values, and the cultural cognition thesis. In (Vol. 52, pp. 1-5).
Petersen, M. B., Slothuus, R., & Togeby, L. (2010). Political Parties and Value Consistency in Public Opinion Formation. *Public Opinion Quarterly*, 74(3), 530–550
Quinn, J. M., Cooper, A. B., Davies-Colley, R. J., Rutherford, J. C., & Williamson, R. B. (1997). Land use effects on habitat, water quality, periphyton, and benthic invertebrates in Waikato, New Zealand, hill-country streams. *New Zealand Journal of Marine and Freshwater Research, 31*(5), 579-597.
Quinn, J. M., Croker, G. F., Smith, B. J., & Bellingham, M. A. (2009). Integrated catchment management effects on flow, habitat, instream vegetation and macroinvertebrates in Waikato, New Zealand, hill-country streams. *New Zealand Journal of Marine and Freshwater Research, 43*(3), 775-802.
Quinn, J. M., Steele, G. L., Hickey, C. W., & Vickers, M. L. (1994). Upper thermal tolerances of twelve New Zealand stream invertebrate species. *New Zealand Journal of Marine and Freshwater Research, 28*(4), 391-397.
Quinn, J. M., & Stroud, M. J. (2002). Water quality and sediment and nutrient export from New Zealand hill-land catchments of contrasting land use. *New Zealand Journal of Marine and Freshwater Research, 36*(2), 409-429.
Quinn, J. M., Monaghan, R. M., Bidwell, V. J., & Harris, S. R. (2013). A Bayesian Belief Network approach to evaluating complex effects of irrigation-driven agricultural intensification scenarios on future aquatic environmental and economic values in a New Zealand catchment. *Marine and Freshwater Research. 64*(5), 460–474.
Ramezani, J., Akbaripasand, A., Closs, G. P., & Matthaei, C. D. (2016). In-stream water quality, invertebrate and fish community health across a gradient of dairy farming prevalence in a New Zealand river catchment. *Limnologica, 61*, 14-28.
Riis, T., Olesen, B., Clayton, J. S., Lambertini, C., Brix, H., & Sorrell, B. K. (2012). Growth and morphology in relation to temperature and light availability during the establishment of three invasive aquatic plant species. *Aquatic Botany, 102*(Supplement C), 56-64.
Royal Society of New Zealand. (2016) *Climate Change implications for New Zealand.* Retrieved from https://royalsociety.org.nz/assets/documents/Climate-change-implications-for-NZ-2016-report-web3.pdf
Russell, J. R., Betteridge, K., Costall, D. A., & MacKay, A. D. (2001). Cattle Treading Effects on Sediment Loss and Water Infiltration. *Journal of Range Management, 54*(2), 184-190.
Rutherford, J. C., Blackett, S., Blackett, C., Saito, L., & Davies-Colley, R. (1997). Predicting the effects of shade on water temperature in small streams. *New Zealand Journal of Marine and Freshwater Research, 31*(5), 707.
Sagiv, L., Roccas, S., Cieciuch, J., & Schwartz, S. H. (2017). *Personal values in human life. Nature Human Behaviour, 1(9), 630–639.*
Sanderson, R., & McQuilkin, J. (2017). Many Kinds of Kindness: The Relationship Between Values and Prosocial Behaviour. In *Values and Behavior: Taking a Cross Cultural Perspective* (pp. 75-96). Cham: Springer International Publishing.
Scarsbrook, M. R., & Melland, A. R. (2015). Dairying and water-quality issues in Australia and New Zealand. *Animal Production Science, 55*(7), 856-868.

Schallenberg, M., & Sorrell, B. (2009). Regime shifts between clear and turbid water in New Zealand lakes: environmental correlates and implications for management and restoration. *New Zealand Journal of Marine & Freshwater Research, 43*(3), 701.

Schultz, P. W., Gouveia, V. V., Cameron, L. D., Tankha, G., Schmuck, P., & Franěk, M. (2005). Values and their relationship to environmental concern and conservation behavior. *Journal of Cross-Cultural Psychology, 36*(4), 457-475.

Schwartz, S. H. (2007). Commentaries: Cultural and Individual Value Correlates of Capitalism: A Comparative Analysis. *Psychological Inquiry, 18*(1), 52-57.

Schwartz, S. H. (1994). Are there universal aspects in the structure and contents of human values? *part of a symposium on: Human values and social issues, 50*, 19-45.

Schwartz, S. H. (2012). An overview of the Schwartz theory of basic values. In (Vol. 2). Online readings in Psychology and Culture.

Schwartz, S. H., & Bilsky, W. (1987). Toward a universal psychological structure of human values. *Journal of personality and social psychology*(3), 550.

Schwartz, S. H., Vecchione, M., LÖNnqvist, J.-E., Konty, M., Fischer, R., Ramos, A., . . . Verkasalo, M. (2012). Refining the Theory of Basic Individual Values. *Journal of personality and social psychology*(4), 663.

Schwartz, S. H., & Zanna, M. P. (1992). Universals in the Content and Structure of Values: Theoretical Advances and Empirical Tests in 20 Countries. In *Advances in Experimental Social Psychology* (Vol. 25, pp. 1-65): Academic Press.

Seethaler, S. s. u. e., Evans, J. H., Gere, C., & Rajagopalan, R. M. (2019). Science, Values, and Science Communication: Competencies for Pushing Beyond the Deficit Model. *Science Communication, 41*(3), 378-388.

Shearer, K. A. (2011). *Cumulative effects of cattle grazing in the Acheron River catchment, Molesworth Station*. Retrieved from https://www.cawthron.org.nz/publication/science-reports/cumulative-effect-cattle-grazing-acheron-river-molesworth-station/

Simis, M. J., Madden, H., Cacciatore, M. A., & Yeo, S. K. (2016). The lure of rationality: Why does the deficit model persist in science communication? *Public Understanding of Science, 25*(4), 400-414.

Small, B., Brown, P., & Munguia, O. M. d. O. (2016). Values, trust, and management in New Zealand agriculture. In (Vol. 14, pp. 282-306).

Smith, W., Kelly, S., Rhodes, T. (2008) *Information, Decision and Action - The Factors that Determine Farmers Environmental Decision-making.* Retrieved from https://mpi.govt.nz/funding-and-programmes/farming/sustainable-land-management-and- climate-change-research-programme/sustainable-land-management-and-climate-change- slmacc-research-reports/

Snelder, T. H., Booker, D. J., Kilroy, C., & Quinn, J. M. (2014). Predicting Periphyton Cover Frequency Distributions across New Zealand's Rivers. *Journal of the American Water Resources Association, 50*(1), 111-127.

Snow, V. (2004). A review of literature on the land treatment of farm-dairy effluent in New Zealand and its impact on water quality. *New Zealand Journal of Agricultural Research, 47*(4), 499-511.

Stark, J. D. (2001). *Protocols for sampling macroinvertebrates in wadeable streams*: [Wellington, N.Z. : Cawthron Institute, 2001].

Stark, J. D., & Maxted, J. R. (2007a). *A User Guide for the Macroinvertebrate Community Index*. Retrieved from https://www.mfe.govt.nz/sites/default/files/mci-user-guide-may07.pdf

Statistics New Zealand. (2015). *Livestock numbers.* Retrieved from http://www.stats.govt.nz/browse_for_stats/environment/environmental-reporting-series/environmental-indicators/Home/Land/livestock-numbers.aspx

Statistics New Zealand (2019a). *Irrigated land.* Retrieved from https://www.stats.govt.nz/indicators/nitrogen-and-phosphorus-in-fertilisers

Statistics New Zealand (2019b). *Nitrogen and Phosphorus in fertilisers.* Retrieved from https://www.stats.govt.nz/indicators/nitrogen-and-phosphorus-in-fertilisers

Stefanidis, K., Panagopoulos, Y., Psomas, A., & Mimikou, M. (2016). Assessment of the natural flow regime in a Mediterranean river impacted from irrigated agriculture. *Science of The Total Environment, 573*, 1492-1502.

Steg, L., Bolderdijk, J. W., Keizer, K., & Perlaviciute, G. (2014). An Integrated Framework for Encouraging Pro-environmental Behaviour: The role of values, situational factors and goals. *Journal of Environmental Psychology, 38*, 104-115.

Steg, L., & de Groot, J. I. M. (2012). Environmental Values. In S. D. Clayton (Ed.), *The Oxford Handbook of Environmental and Conservation Psychology*: Oxford University Press.

Stern, P. C., Dietz, T., Abel, T., Guagnano, G. A., & Kalof, L. (1999). A value-belief-norm theory of support for social movements: The case of environmentalism. *Human Ecology Review*, 6(2), 81–97.

Storey, R. G., & Cowley, D. R. (1997). Recovery of three New Zealand rural streams as they pass through native forest remnants. *Hydrobiologia, 353*(1), 63-76.

Suren, A. M. (2005). Effects of Deposited Sediment on Patch Selection by two Grazing Stream Invertebrates. *Hydrobiologia, 549*(1-3), 205-218.

Sustainable Dairying: Water Accord (2017) Retrieved from https://www.dairynz.co.nz/media/5791340/water-accord-progress-report-4-years-on-dnz-40-011-web.pdf

Tanner, C. C., & Kloosterman, V. (1997). *Guidelines for constructed wetland treatment of farm dairy wastewaters in New Zealand*. NIWA. Retrieved from https://www.niwa.co.nz/sites/niwa.co.nz/files/import/attachments/st48.pdf

Talhelm, T., Zhang, X., Oishi, S., Shimin, C., Duan, D., Lan, X., & Kitayama, S. (2014). Large-Scale Psychological Differences Within China Explained by Rice Versus Wheat Agriculture. In (Vol. 344, pp. 603-608).

Torcello, L. (2016). The Ethics of Belief, Cognition, and Climate Change Pseudoskepticism: Implications for Public Discourse. Topics in Cognitive Science, 8(1), 19–48. https://doi-org.ezproxy.massey.ac.nz/10.1111/tops.12179

Townsend, C. R., Uhlmann, S. S., & Matthaei, C. D. (2008). Individual and Combined Responses of Stream Ecosystems to Multiple Stressors. *Journal of Applied Ecology*(6), 1810.

van der Werff, E., Steg, L., & Keizer, K. (2013). It is a moral issue: The relationship between environmental self-identity, obligation-based intrinsic motivation and pro-environmental behaviour. Global Environmental Change, 23(5), 1258–1265.

Van Riper, C. J., A. Thiel, M. Penker, M. Braito, A. C. Landon, J. M. Thomsen, and C. M. Tucker. (2018). Incorporating multilevel values into the social-ecological systems framework. *Ecology and Society* 23(3):25.

Wagenhoff, A., Townsend, C. R., & Matthaei, C. D. (2012). Macroinvertebrate responses along broad stressor gradients of deposited fine sediment and dissolved nutrients: a stream mesocosm experiment. In (Vol. 49, pp. 892-902).
Wang, H., & Bolan, N. (2004). An overview of the environmental effects of land application of farm effluents. *New Zealand Journal of Agricultural Research, 47*(4), 389-403.
Waters, T. F. (1995). *Sediment in streams : sources, biological effects, and control*: Bethesda, Md. : American Fisheries Society, 1995.
Weaver, L., Karki, N., Mackenzie, M., Sinton, L., Wood, D., Flintoft, M., . . . Close, M. (2016). Microbial transport into groundwater from irrigation: Comparison of two irrigation practices in New Zealand. *Science of The Total Environment, 543*, 83-94.
Weeks, E. S., Death, R. G., Foote, K., Anderson-Lederer, R., Joy, M. K., & Boyce, P. (2016). Conservation Science Statement. The demise of New Zealand's freshwater flora and fauna: a forgotten treasure. *Pacific Conservation Biology, 22*(2), 110-115.
Williamson, R. B., Smith, R. K., & Quinn, J. M. (1992). Effects of riparian grazing and channelisation on streams in Southland, New Zealand. 1. Channel form and stability. *New Zealand Journal of Marine and Freshwater Research, 26*(2), 241-258.
Wood, S. A., Depree, C., Brown, L., McAllister, T., & Hawes, I. (2015). Entrapped Sediments as a Source of Phosphorus in Epilithic Cyanobacterial Proliferations in Low Nutrient Rivers. *PLoS ONE, 10*(10), 1.
Wood, S. A., Puddick, J., Fleming, R., & Heussner, A. H. (2017). Detection of anatoxin-producing Phormidium in a New Zealand farm pond and an associated dog death. *New Zealand Journal of Botany, 55*(1), 36-46.
Ye, S., & Ng, T. K. (2019). Value change in response to cultural priming: The role of cultural identity and the impact on subjective well-being. International Journal of Intercultural Relations, 70, 89–103.
Young, R. G., Quarterman, A. J., Eyles, R. F., Smith, R. A., & Bowden, W. B. (2005). Water quality and thermal regime of the Motueka River: influences of land cover, geology and position in the catchment. *New Zealand Journal of Marine and Freshwater Research, 39*(4), 803-825.

Appendices

Appendix A: Tarndale Brook, Algal Taxa Richness Report

Site name: Tarndale Brook

Date: March 11, 2018

Sample: algal mats on the exposed surface of stony substrates

Taxon list

No.	Phylum	Taxon name
	Bacillariophyta (Diatoms)	
		Cymbella sp.
		Gomphoneis sp.
		Gomphonema sp.
		Hantzschia sp1.
		Hantzschia sp2. (?)
		Melosira sp.
		Nitzschia sp.
		Synedra sp.
	Chlorophyta (Green Algae)	
		Geminella sp.
		Klebsormidium sp.
		Oedogonium sp1.
		Oedogonium sp2. (?)
		Scenedesmus dimorphus
		Scenedesmus microspina
		Spirogyra sp.
		Stigeoclonium sp.
		Stigeoclonium tenue
	Cyanobacteria (Blue-Green Algae)	
		Oscillatoria sp.
		Phormidium sp.

Comments:

- The cyanobacterial species *Oscillatoria* sp. and diatom species *Melosira* sp. create thick mats covering the stony substrates; and green algae, e.g., *Spirogyra* sp., *Stigeoclonium* spp., and *Oedogonium* spp., made long/short green filaments attached to the mats. Other abundant species include *Cymbella* sp., *Hantzschia* sp1. and *Gomphonema* sp.

- Both cyanobacterial genera of *Oscillatoria* and *Phormidium* can potentially produce cyanotoxins and cause harmful blooms (Burkholder, 2009).

- Other genera also can cause harmful blooms, e.g., *Scenedesmus*, *Spirogyra, Oedogonium*, *Melosira,* and *Cymbella* (Burkholder, 2009 and Moore, 2000).

- This is a very snap-shot on the periphyton, the taxa richness can be higher than 19.

6. References

Burkholder, J. M. (2009). Harmful algal blooms. In G. E. Likens (Ed.), *Plankton of Inland Waters:* Academic Press.

Moore, S. C. (2000), Photographic Guide to the freshwater algae of New Zealand, Otago regional council

Appendix B: Physiochemical, water quality and periphyton results at 20 sites sampled in the Awatere, Waiau Toa and Wairau catchments from between 4 - 18 March

Date	Time	Site Name	Catchment	*E. coli* (MPN/ 100mL)	Conductivity (µs/cm)	Temp (°C)	Clarity (m)	Periphyton Score
16.03.18	1055	Awatere Above	Awatere	240	110	14	0.15	3.47
16.03.18	900	Robinson	Awatere	183	120	14	0.05	0.1
16.03.18	1530	Awatere Below	Awatere	63	110	19.5	0.11	1.96
16.03.18	1445	Molesworth	Awatere	52	210	18	0.96	6.24
10.03.18	830	Severn u/s Ford	Waiau Toa	<10	40	9.5	0.96	1.78
13.03.18	1400	Serpentine d/s fence	Waiau Toa	<10	50	15.5	0.96	6.02
13.03.18	1600	Serpentine u/s fence	Waiau Toa	<10	50	14	0.96	6.30
18.04.18	930	Bowscale Lake Outlet	Waiau Toa	<10	30	16.5	0.96	7.02
06.03.18	1400	Tarndale	Waiau Toa	218	40	21	0.96	7.05
10.03.18	1530	Acheron d/s Saxton	Waiau Toa	145	60	19	0.25	1.84
04.03.18	1330	Acheron u/s Yarra	Waiau Toa	41	40	19	0.40	0.38
17.03.18	1100	Acheron Ref	Waiau Toa	41	60	21	0.06	0.00
17.03.18	1100	Alma	Waiau Toa	31	50	14.5	0.94	5.89
04.03.18	1000	Yarra	Waiau Toa	20	50	15.5	0.92	2.02
10.03.18	1300	Saxton	Waiau Toa	20	40	15	0.96	3.04
11.03.18	1000	Clarence	Waiau Toa	20	50	12.5	0.96	4.87

Date	Time	Site Name	Catchment	*E. coli* (MPN/ 100mL)	Conductivity (µs/cm)	Temp (°C)	Clarity (m)	Periphyton Score
05.03.18	830	Five Mile	Waiau Toa	10	70	14	0.96	2.44
10.03.18	1100	Severn u/s Ford Side Channel	Waiau Toa	*	60	16	0.96	4.86
13.03.18	1050	Island Gully Side Channel	Wairau	*	50	13	0.79	3.41
14.03.14	1500	Island Gully Main	Wairau	203	50	16	0.96	2.98
13.03.18	830	Rag & Famish	Wairau	10	50	11	0.96	6.26

* E. coli samples only taken from main channel, not from side channels.

Appendix C: Observed macrophyte results

Site Name	Vmacro
Tarndale	0.48
Five Mile	0.58
Severn u/s Ford Side Channel	0.84
Yarra	0.86
Island Gully	0.88
Acheron u/s Yarra	0.89
Bowscale Lake Outlet	0.89
Awatere Above	0.96
Robinson	0.97
Molesworth	0.97
Serpentine d/s fence	0.97
Island Gully Main	0.98
Awatere Below	0.98
Acheron Ref	0.99
Rag & Famish	0.99
Serpentine u/s fence	0.99
Alma	1.00
Saxton	1.00
Clarence	1.00
Severn u/s Ford	1.00
Acheron d/s Saxton	1.00

Appendix D: Macroinvertebrate results

	EPT	MCI	Rag & Famish	Bowscale	Robinson	Molesworth	Yarra	Island Gully Main	Awatere Below	Serpentine u/s fence	Five Mile	Serpentine d/s fence	Acheron u/s Yarra	Awatere Above	Clarence	Severn u/s Ford	Acheron d/s Saxton	Saxton	Acheron Ref	Alma	Tarndale
Aoteapsyche	e	4		114	1	17	77	9	7		89	3	63	116	25	37	17	37	1	74	90
Austroclima	e	9		11							10		41		3					8	1
Coloburiscus	e	9		7			12				7			6		1		1			11
Costachorema	e	7	1																	8	
Deleatidium	e	8	5	252	45	149	221	258	480	228	205	88	105	139	229	147	149	212	52	286	255
Hudsonema	e	6				7			1												3
Hydrobiosis	e	6		2		3	7	10	2	19	3	7		16		9		2		3	2
Nesameletus	e	9					11			1	4		34	1		6		1		12	
Neurochorema	e	6						1			1										
Olinga	e	9				1	46		2					14			1	2		19	42
Oxyethira	e	2						4								16					
Psilochorema	e	8		7			2	4	6	2	3	1									
Pycnocentria	e	7		88		17	33	3	1		62		41	340							88
Pycnocentrodes	e	5		44		252	13	10	1		1		2	565		3					2
Stenoperla	e	10						1												4	
Zelandobius	e	5					1	120		83		23	10			11	2	4			3
Zelandoperla	e	10					1	9		44	28	48	11		11	2	5	4		23	2
Archichauliodes		7				2	4			1	7			4	2	1	2	1	2		
Austrosimulium		3		5		3	45	24		19	95	16		5	20	4	4	27		8	4
Chironomus		1				1								1							
Collembola		5				1															
Culicidae		3				3															
Elmidae		6					12	226	9	2		34	32		2	5	67	41	5	6	1
Eriopterini		9						2		1					3					1	
Gyraulus		3		5																	
Hydraenidae		8				2				1							1				5
Maoridiamesa		3		2				2													26
Microvelia		5				37	5	1	7	1	4			3							
Molophilus		5												1							13
Muscidae		3									1			4							3
Nematomorpha		3				1						1									
Neocurupira		7								4		2									
Oligochaeta		1	1	27				3			9			6		1					
Orthocladiinae		2	3	14		1	25	2		4	9	1	7	49		7				8	207
Physa		3		16																	
Potamopyrgus		4				20					64	1		4		1					18
Ptilodactylidae		8						6													
Sphaeriidae		3		1																	
Tabanidae		3					1		1		5										
Tanytarsini		3				1							4							3	37
Sum			10.00	595.00	46.00	518.00	516.00	695.00	517.00	410.00	607.00	225.00	350.00	1274.00	295.00	257.00	249.00	332.00	60.00	463.00	819.00
Taxa			4.00	15.00	2.00	18.00	17.00	19.00	11.00	14.00	19.00	12.00	11.00	17.00	8.00	16.00	10.00	11.00	4.00	14.00	22.00
MCI			90.00	98.67	120.00	98.89	124.71	113.68	121.82	132.86	114.74	110.00	123.64	103.53	140.00	107.50	130.00	138.18	125.00	135.71	116.36
QMCI			5.80	8.43	9.02	7.39	8.11	5.98	8.82	7.26	7.50	6.39	7.86	7.76	8.60	8.28	7.21	7.99	8.38	8.49	6.36
EPT_taxa			2.00	8.00	2.00	7.00	11.00	11.00	8.00	6.00	11.00	6.00	8.00	8.00	4.00	9.00	5.00	8.00	2.00	9.00	12.00
pEPT_taxa			50.00	53.33	100.00	38.89	64.71	57.89	72.73	42.86	57.89	50.00	72.73	47.06	50.00	56.25	50.00	72.73	50.00	64.29	54.55
pEPT_animals			60.00	88.24	100.00	86.10	82.17	61.73	96.71	91.95	68.04	75.56	87.71	93.96	90.85	90.27	69.88	79.22	88.33	94.38	61.05

Appendix D continued: 2007, 2009, 2011 and 2018 MCI results comparison table

Site	2007	2009	2011	2018
Robinson	115	-	-	120
Awatere Below	120	-	-	122
Awatere Above	101	-	-	104
Molesworth	115	-	-	99
Acheron u/s Yarra	-	-	120	124
Yarra	117	-	123	125
Five Mile	112	-	113	115
Tarndale	-	-	119	116
Severn u/s Ford	109	-	123	108
Acheron d/s Saxton		-	129	130
Saxton	123	-	118	138
Clarence	122	-		140
Serpentine d/s fence	119	-		110
Serpentine u/s fence	126	-		133
Acheron Ref	-	-	130	125
Alma	133	-	120	136
Bowscale Lake Outlet	85	-		99
Rag & Famish	116	-		90
Island Gully	118	-		114

Appendix E: Substrate index (SI)

Site	SI
Acheron Ref	*
Serpentine u/s fence	8.25
Tarndale	7.75
Alma	6.40
Acheron u/s Yarra	6.05
Rag & Famish	5.29
Severn u/s Ford	4.72
Yarra	4.60
Saxton	4.60
Molesworth	4.18
Five Mile	4.11
Acheron d/s Saxton	3.52
Clarence	3.36
Awatere Below	3.22
Serpentine d/s fence	3.15
Bowscale	2.37
Awatere Above	1.96
Robinson	1.11
Island Gully Main	0.80

Appendix F: Effects of sedimentation

Figure F(a): Kōura (*Paranephrops* spp.) struggling in deposited sediment.

Figure F(b): Banded kōkopu (*Galaxias fasciatus*) struggling in deposited sediment.

Figure F(c): Stream substrate with interstitial spaces partly clogged with deposited sediment.

Appendix G: Examples of deposited fine sediment at monitoring sites on Molesworth Station, March 2018.

Figure G(a): Awatere Above site streambed sedimentation and bankside erosion, March 2018.

Figure G(b): Yarra River deposited fine sediment, March 2018.

Figure G(c): Yarra River deposited fine sediment, March 2018.

Figure G(d): Acheron u/s Yarra site streambed sedimentation (sunglasses for scale), March 2018.

Figure G(e): Close up of streambed sedimentation and periphyton in Molesworth Stream, March 2018.