Quantifying ecological effects of sedimentation in streams in differing land use management zones

by

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Submitted to
Victoria University of Wellington
in full for the requirements for a
Master of Science (Majoring in Environmental Science)

Victoria University of Wellington
Te Whare Wānanga o te Ūpoko o te Ika a Māui
2019

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Statement of Authorship

I hereby declare that this thesis is my own work and that all sources quoted, paraphrased or otherwise referred to, have been properly acknowledged in the references. To the best of my knowledge, this thesis neither contains material previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any other degree or diploma of the university or other institutes of higher learning, except where due to acknowledgement it has been made clear in the text.

1. Abstract

This ecological and geomorphological assessment of Horokiri Stream and Ration Creek was conducted across four longitudinal zones to explore the effects of sediment delivery, run-off, channel form, riparian and in-stream habitat. The Horokiri Stream channel has moved approximately 7 metres westward over the last 20 years, with both banks now covered in long grass, flaxes, natives with a mix of tall canopy trees. Looking at stream, Spearman's for Ration at Figure 27 (n = 16, rho -0.243, p = 0.36) as deposited sediment increased, MCI decreased, non-significant. Spearman's for Horokiri at Figure 28 (n = 16, rho 0.247, p = 0.35) as MCI increased with sediment, non-significant. Results from upstream of the riparian zones showed more deposited fine sediment. However, within both the riparian zones the sediment deposition was much lower. The native riparian planting along the stream banks had a positive effect on reducing sedimentation. The findings support the concept that the restoration of riparian zones with buffer widths exceeding 10 metres can improve stream habitat and invertebrate health. There was no relationship between flow and deposition rate P(*X2>241.84)* = 0.24. Figure 24 shows deposited sediment on MCI depending on land use groups (*X*2 = 11.81, df = 4, p = 0.019). No statistically significant differences were found (comparing the effect of sediment between different land use management groups).

An experiment investigated a disturbance hypothesis in both Ration Creek and Horokiri Stream was conducted during February 2019. The experiment was designed to be long enough to study the effects of four weekly pulse flushing events created by scrapping the stream bed with a drain drag tool and the effects of a press sustained disturbance on the macroinvertebrate community. I measured the sediment and the macroinvertebrate captured in each trap within the experiment site every seven days. My prediction was that macroinvertebrate communities subject to sustained fine sediment delivery (press disturbance) are affected by simulated pulse flushing events (pulse disturbance). A comparison of sediment depositional rate before and after the manipulative experiment (Figure 36) showed higher sediment deposition after the pulse flushing events (1.55 W/A/D) compared to before during the assessment phase (0.88 W/A/D) in Horokiri (t = 2.35, df = 8.95, p = 0.04), but no significant difference before (1.57 W/A/D) or after (1.38 W/A/D) in Ration (t = -0.818, df = 7.71, p = 0.44). It appeared that the smaller riparian buffer width of 2-5m at Ration Creek did not limit sediment deposition. The effects of sediment disturbance in the experiment reflect the rapid ability of macroinvertebrates to respond to sediment by drifting out of unsuitable areas. The weekly pulse disturbance events

resulted in increased sediment deposition compared to the background levels of sediment deposition (indicative of a press disturbance) in both streams. As pulse disturbance events increased, the number of macroinvertebrate taxa decreased. Horokiri Stream invertebrate communities declined by 33% compared to Ration Creek which declined by 50%.

2a. Introduction to ecological and geomorphological assessment

Streams are intimately related to the land use in their catchments (Allan et. al. 1997). Small changes in land use can lead to large changes in aquatic ecosystem health, as documented by changes in hydraulic, and biological variables (Roesner and Bledsoe 2003). Stream characteristics will change longitudinally (from headwaters to sea) over time, laterally across a river flood plain, vertically from the water surface to the hyporheic zone and in response to the flow (Figure 1). Physical stressors associated with different land uses can alter streams and compromise their biotic integrity, even before chemical stressors are detected. Many studies have examined the effects of agricultural development on streams (reviewed in Quinn et. al. 1997) where physicochemical changes to streams usually led to profound effects on stream biota and ecosystem processes (Allan et. al. 1997; Townsend et al. 1997).

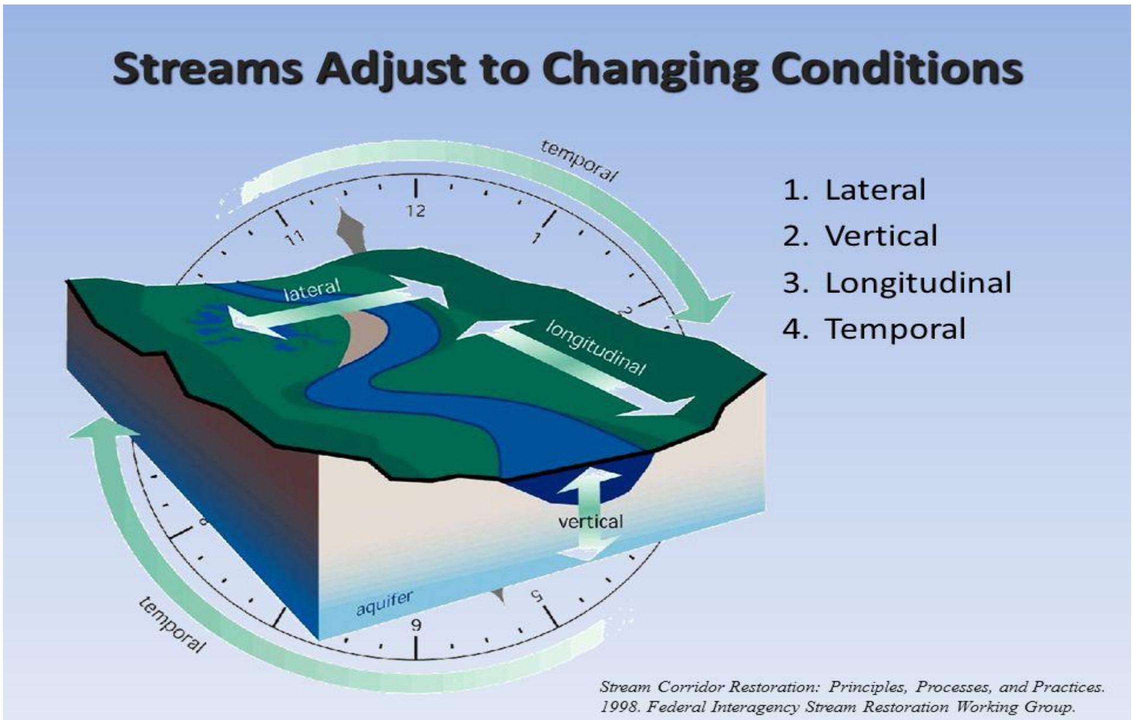

Figure 1: Diagram from the 1998 Federal Interagency Stream Restoration Working Group showing how streams adjust to lateral, vertical, longitudinal and temporal changing conditions.
(URL: https://www.uvm.edu/~swac/docs/mod26/SWAC_Streams_Morrissey_final.pdf).

In New Zealand, the role of ecosystem function for assessing ecological health has had little attention, although the role of biodiversity in the functioning of running-water ecosystems has been studied extensively (Clapcott et. al. 2010). For aquatic systems, it is important to look beyond individuals and populations to the context of the catchment (Fischman 2004) as freshwater habitats are influenced by upstream conditions which in turn effects the aquatic food web available to sustain the fish and invertebrate faunas Our current understanding of rivers and other ecosystems; increasingly incorporates a conceptual framework of spatially nested controlling factors where climate, geology, and topography at large scales influence the geomorphic processes that shape channels at intermediate scales and thereby create and maintain habitat important to the biota at smaller scales (Frissell et al. 1986, Snelder & Biggs 2002). Recognizing that rivers are complex mosaics of habitat types and environmental gradients, characterized by high connectivity and spatial complexity, riverine landscapes increasingly are viewed as “riverscapes” (Fausch et al. 2005, Schlosser 1991). A riverscape is a view of the river and surrounding land. The influence of the surrounding landscape on a stream manifests across multiple spatial scales and can be complicated by historical legacies or prior human activities. These multiple influences include water abstraction for industrial, domestic and agricultural needs (Poff et al., 1997 and 2018); changes in flow regime, channelization, sedimentation, and eutrophication (Carpenter et al. 1998; Allan 2004; Clapcott et al. 2012) and changes in riparian planting (Palmer et al. 2005 and Dudgeon 2010).

In New Zealand the health of freshwater ecosystems has declined substantially in recent years, with almost all water quality parameters measured via the national water quality monitoring network declining significantly over the last two decades (Julian et. al. 2017). A study of more than 300 lowland waterways showed that 80% of the sites in pasture catchments exceeded guideline levels for phosphorus and nitrogen (Larned et al. 2004), and 44% of monitored lakes in New Zealand are now classed as polluted with excess nutrients and sediment (Verburg et al. 2008). In general, deterioration in the health of fresh waters is related to agricultural impacts of excess sediment, phosphorus and nitrogen, as well as faecal pathogens (Ministry for the Environment, NIWA Client Report no. 2017071CH 2017).

2a.1 What is sediment and how is it transported

Sedimentation is a global issue where land-use change has resulted in excess sediment being delivered to and deposited on the beds of streams and rivers. The Cawthron Institute defines sediment as the collective term for particles that are transported by natural processes (wind, water, glaciers) and eventually deposited. In flowing water, sediment can be defined by its composition, locality and particle size. As such, sediment is organic or inorganic in nature and can be suspended in the water column (causing turbidity) or deposited on the streambed. Using the Wentworth (1922) classification system, sediment is characterised by particle size as mud and silt (<0.0625 mm) and sand (0.0625-2 mm). The natural supply of sediment is controlled by catchment, geology, topography, vegetation type and cover (Stromberg et al. 20097a and 2007b), rainfall, and catastrophic events, such as volcanic eruptions, earthquakes or extreme storms (Hicks and Griffiths 1992) and fires (Beaty 2011). Sediment inorganic particles are smaller than 2mm and their impact in rivers arise primarily as a result of local changes to catchment land use, intensification of land management, and external pressures such as climate change, all of which contribute to erosion of soils and enhanced delivery to receiving freshwaters (Jones et al., 2012a; Wood & Armitage, 1997). Excess sediment (more than the ecosystem can handle) directly affects the health of a waterway, decreasing its mauri or life-supporting capacity (Ryan, 1991). Increased sediment loads result in adverse effects in freshwaters through several modes of impact (Collins et. al., 2011). Fine suspended sediments change two key optical characteristics of water: visual clarity (the distance that humans and animals can see through water) and penetration into water of sunlight needed for aquatic plant photosynthesis (Davies-Colley and Smith. 2001). There are recent reviews of fine suspended sediment effects (notably Bilotta and Brazier 2008) that tabulate experiments and field observations over an extremely wide range of suspended sediment concentrations (e.g., more than 1000-fold for macroinvertebrates). Bilotta and Brazier (2008) reviewed suspended sediment in waters and effects on water quality and aquatic biota. They emphasised the large variability and uncertainty in reviewed research findings on effects of fine suspended sediment on three categories of river life: periphyton and macrophytes; invertebrate animals; and salmonid fish.

Sediments are most often transported by fluvial water processes. Whether sediment will be eroded, transported or deposited is dependent on the particle size, the flow rate and the degree of consolidation/embeddedness of the water. The amount of sediment and the size of the sediment particles that can be transported in a stream are related to the gradient (slope) of the stream channel and amount of water flowing in the stream channel at a particular time (Lane, Richards, & Chandler, 1996). Loadings of suspended sediment can be from two sources: upland eroded soils or in-stream sediment due to bank and bed erosion (Wolman 1967, Trimble

1997). Sedimentation is determined by stream power which equals gravity x discharge x slope (Clapcott 2011).

Types of sediment transport are dependent on stream velocity:

- Saltation – sediment transported by bouncing, rolling and sliding over an uneven stream bed
- Bedload – sediment transported by saltation in a flowing liquid
- Suspended load – sediment transported and uplifted within the stream flow, but not dissolved (fine grained like clay, silt or sand)
- Dissolved Load – sediment transported in solution (salts and minerals)

After entering a waterway, particles can be transported suspended anywhere within the water column, depending on the difference between the particles shear stress and settling rate. Sediment is not deposited evenly over the bed of a stream. It is the proportion of suspended load to bed load that is important for channel morphology. Unlike most pollutants, sediment is necessary for waterway function with ecosystems benefiting from both transport and deposition. Sediment does create aquatic habitats for spawning and benthic organisms, it is responsible for waterway morphology, making it an integral part of the ecosystem. Sediment provides nutrients to aquatic plants. With increases in overland flow, fine sediments are moved into channels during rain events. Despite the importance of fine inorganic sediment in freshwater systems, when excessive loads occur the negative impacts (outlined in section 2a.2) of sediment can be far reaching. Figure 2 shows a longitudinal summary related to erosion and sedimentation, dominated by gradient which in turn affects particle size on the streambed (Miller, 1990). Gradient = (elevation change/distance).

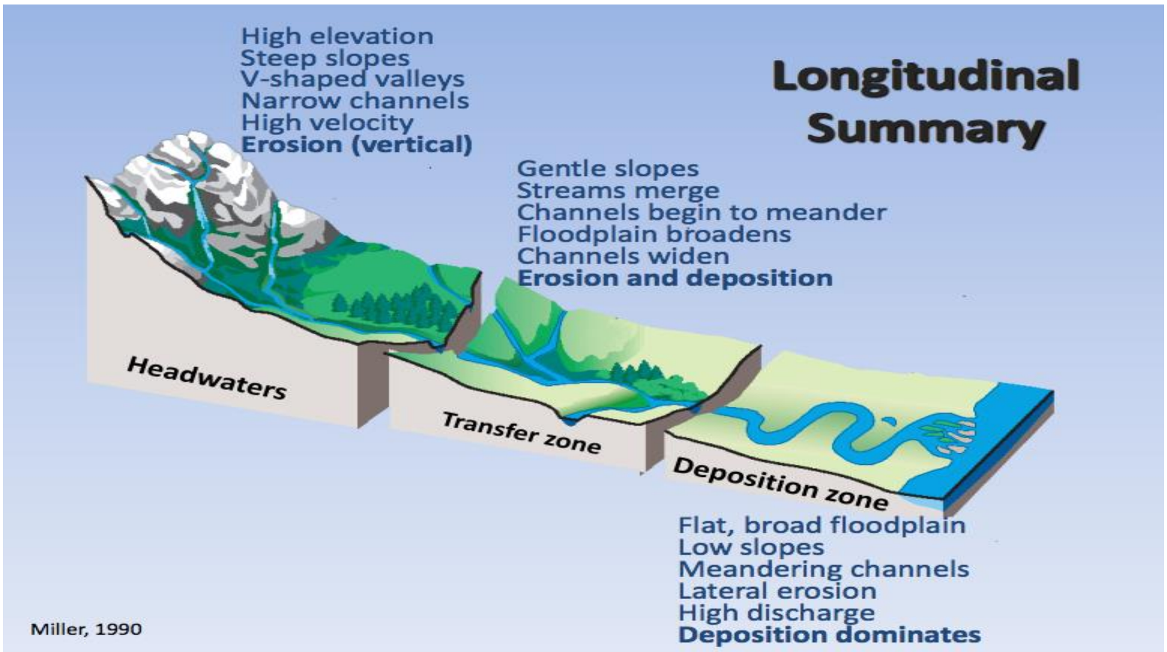

Figure 2: As rivers change grades down-valley, they switch from erosive to depositional (Miller, 1990).

2a.2 How sediment affects macroinvertebrates

Any changes in hydrology, suspended sediments, water quality, geomorphology or habitat represent a cascade of effects of land use change, which impact biotic communities. Macroinvertebrates (the aquatic insects, molluscs, crustaceans, and worms that live in streams) are commonly used as biological indicators of stream health due to their differing sensitivity to pollution and habitat conditions (Moore and Neale 2008; Wagenhoff, Shearer et al. 2016). Water quality testing often is a one-time sample, whereas benthic macroinvertebrate live in the stream all year long and are exposed to all the conditions (Stark 2001). Modelling of variables describing sediment affects showed habitat loss (study in New Zealand) was the key driver of changes to invertebrate communities (Burdon et al. 2013). Burdon et al. (2013) identified a change point at 20% sediment cover (estimated by in- stream visual assessment) in a regression with % EPT6 relative abundance based on a survey of 30 sites in Canterbury. Wood et al. (2005) showed that some EPT species were capable of surviving burial by experimental fine sediment additions until depth exceeded 10mm – after which EPT taxa were absent. Considering the multiple-lines-of-evidence available at the time, Clapcott et al. (2011) proposed a single deposited fine sediment benchmark of 20%. There is a wide range in responses of biota to increasing deposited fine sediment, due in part to the wide range of deposited fine sediment metrics used and response variables studied. Increased sediment has been reported to change invertebrate feeding and growth, behaviour, community composition, diversity and abundance (Ryan 1991; Waters 1995; Wood & Armitage 1997; Crowe & Hay 2004). Suspended sediment load also affects invertebrate drift. Drift is when benthic macroinvertebrates become suspended in the water column and are carried downstream by the current. Large reductions in invertebrate densities were attributed to drift and lower epilithon biomass, productivity, and degraded food quality (Quinn et al. 1992).

Fencing stream banks and planting riparian buffers have been proposed in New Zealand as a key option to mitigate freshwater contaminants that are altering invertebrate communities, (LAWF, 2015 and Dairy NZ, 2013), with buffers also having the potential to reduce the country's GHG emissions (Vibart et al, 2015). Collier et. al., 1995 outlines the role of riparian buffers in controlling sediment input in two documents written when he worked at NIWA in 1995 and provided information on how to improve the management of riparian zones along streams and rivers in modified and developed landscapes, particularly in agricultural areas stating "The influence of riparian zones is much larger than would be expected from their size relative to the rest of the catchment". Parkyn (2003) conducted a study in the Waikato Region, New Zealand called 'Planted Riparian Buffer Zones in New Zealand: Do They Live Up to Expectations?' This study concluded 'Improvement in invertebrate communities appeared to be most strongly linked to decreases in water temperature, suggesting that restoration of in-stream communities would only be achieved after canopy closure, with long buffer lengths, and protection of headwater tributaries'.

2a.3 Riparian management and sediment removal

The general objectives of most riparian planting schemes are to reverse the impacts of land use change by improving channel stability, aquatic habitat, and water quality and to improve both aquatic and terrestrial biodiversity (Parkyn. et. al., (2003). Riparian management is important because of the riparian buffers immediate and direct influences on stream condition via well documented pathways (Naiman & Decamps 1997) and because it promises benefits that are highly disproportionate to the land area required (Lowrance et al. 1984, Quinn et al. 1997). A riparian zone has been defined as "any land that adjoins or directly influences, or is influenced by, a body of water". Riparian fencing and planting are used widely in New Zealand and internationally for mitigating land use intensification effects on adjacent waterways and enhancing stream health (Greenwood, Harding et al. 2012).Vegetation is the easiest riparian attribute to manage. However, gaps in riparian planting allow invasion by weeds (Weller et al. 2011) and subsurface farm storm drains bypass the riparian zone and diminish its effectiveness

(Barton 1996, Osborne & Kovacic 1993). Since riparian vegetation affects in-stream biota primarily through its effects on benthic habitat, any changes caused by differing flows can see riparian vegetation falter or die off, leading to changes in species composition rather than diversity as niches collapse (Decamps et al., 2004, Gregory et al. 1991, Naiman and Decamps, 1997, Collier et. al., 1995). Fencing reduces stock access to the stream, thereby reducing bank erosion and sediment and faecal bacteria inputs, while plantings increase shading, reduce stream temperatures, intercept sediments, nutrients, and bacteria in run-off, increase inputs of leaves and wood, and enhance stream habitat (Parkyn, Davies-Colley et al. 2003; Wilcock, Betteridge et al. 2009; Greenwood, Harding et al. 2012).While slumped banks may not be active sources of sediment when grasses have grown over them, they will still be prone to erosion during flood events. The results of research conducted by NIWA (Report 2018051HN, 2018) indicate that the landscape-scale riparian restoration undertaken in the Taranaki region as part of the Riparian Management Programme has had a beneficial effect on water quality and downstream aquatic invertebrate communities, including improved invertebrate community composition and decreased E. coli concentrations.

Riparian zones are more effective over the long term when upstream pollution has been limited through good agricultural practices (MfE report 385, 2001). Riparian management helps avoid, remedy and mitigate some of the adverse effects of rural and urban land uses. It does this by intercepting contaminants before they reach rivers, reducing their effects on aquatic habitat if or when the reach water, and restoring areas of habitat that have been largely removed by development. The beneficial results are not always immediate and may take several years to become evident. The main improvements in functionality following riparian restoration is achieved through improvements to water temperature control (shading), organic matter input, habitat provision functions, riparian vegetation intactness and uptake of nutrients (Collier et. al., 1995).

Research conducted by the University of Maryland suggests that a buffer zone of 20-30m is the optimal width for sedimentation reduction, protecting banks allowing stream flow to move particles downstream (Correll, 1996). Optimal buffer widths are shown in Figure 3. Based on the Maryland Research, the Horokiri riparian buffer provides bank stabilisation, aquatic food web, water temperature moderation, nitrogen and sediment removal.

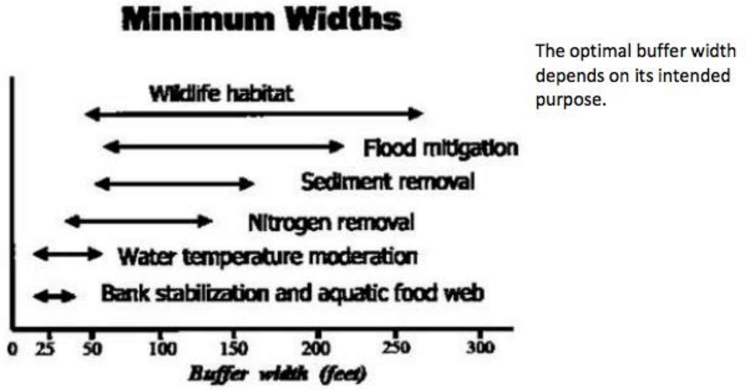

Figure 3: Minimum riparian buffer zone widths (University of Maryland – Correll, 1996)

The installed Greater Wellington Regional Council (GWRC) riparian vegetation buffer of 2-5m at Ration Creek comprises of cabbage trees, flax, grasses and Manuka installed as part of the council's previous Biodiversity and Streams Alive Programme (Report 09.223, 2008). The health of riparian areas is significant for Maori. To Maori, all parts of the natural world possess a mauri or life force (including humans) and all life is related. It follows that the health and wellbeing of the environment will affect the welfare of the people. The Ration Creek buffer, which had some straightening of the channel twelve years ago, provides bank stabilisation and aquatic food resources. Horokiri Stream has a woodland 20-30m buffer of native and exotic trees with understory planting which provide lots of root systems that absorb pollutants before they reach the stream. These appear to have a significant impact on the algae in the stream, which is a cornerstone species transferring a soil based micro nutrient into an edible food source for fish.

2a.4 How geology and hydrology influences New Zealand waterways

New Zealand is a narrow archipelago of islands, which lays on the boundary between the Pacific and the Indo-Australian plates and is part of the Pacific Ring of Fire (Coates and Cox 2002). The North Island is home to Taupo, a mega volcano which has produced two of the world's most powerful eruptions in geologically recent times (27,000 and 254,000 years ago) (Bailey and Carr 1994). New Zealand has an abundance of waterways of various forms (e.g., braided, meandering, glacial and spring fed) and with highly varied substrate compositions (e.g., greywacke, gneiss and marble), which are often highly localised (Thornton 2003). Human activities in catchments have resulted in increased delivery of fine sediment to watercourses, such that the loading of fine sediment to many rivers now far exceeds background (pre-industrial) conditions (Walling and Fang, 2003; Foster et al., 2011). These increased loads are having an impact on the ecology and geomorphology of freshwaters, leading to suggestions that fine sediment is one of the most widespread and detrimental forms of aquatic pollution (Ritchie, 1972; Lemly, 1982).

Precipitation, evaporation, vegetation or lack of it, ground water and surface runoff and the geology, shape the channel which is proportional to the volume of water that flows along that stream. Over time these do change. A stream channel, its bed, flow and depth show spatial and temporal changes in lotic systems provide a shifting mosaic of abiotic and biotic conditions (Resh 1988 and Winemiller 2010). Different channel forms, like boulder and cobble, alluvial gravel bed, alluvial sand bed have different responses to hydrologic disturbance.

The two experimental streams in this research are based in the Wellington Region of the North Island. The streams are close to the sea with strong winds that mean conductivity would be higher due to marine salt spray drift. Both of the studied streams follow channels formed by general erosion of the hillsides resulting in a complex network of waterways over time. The exposed land is subjected to erosion by frequent heavy rains, the result of which can now be seen in the dissected nature of the hills.

2a.5 Freshwater management in New Zealand

The National Policy Statement for Freshwater Management (NPS-FM) requires regional authorities, to set freshwater objectives that protect freshwater values in their regional plans, and also to set limits and promote management actions to achieve those objectives. The NPS-FM does not currently define sediment-related attributes despite the importance of this contaminant in New Zealand freshwaters. There are difficulties associated with defining nationally applicable freshwater objectives and attributes, which were not satisfactorily resolved when the 2014 NPS-FM was gazetted. These difficulties reflect the complexity of fine sediment as a contaminant. It has multiple mechanisms of impact and interacts with other contaminants such as elevated nutrients and temperatures (e.g., Piggott et al. 2012), and it varies markedly in its physical and chemical characteristics and thus environmental behaviour and ecological impacts. The development of sediment attributes has since been identified as a priority for any future revision of the NPS-FM (Ton Snelder from the Ministry for the Environment (MfE) pers. comm). Collins et al. (2011) reviewed management approaches for fine sediment in rivers, both suspended and deposited. They emphasised the multiple mechanisms of impact of fine sediment– which vary in relative importance with fine sediment properties such as particle size distribution and composition. The Collins et al. (2011) review is particularly notable for categorising fine sediment metrics. There are a number of regional councils who have recognised the need to collect sediment information and have started to include some measure of deposited sediment in their monitoring programmes (Clapcott, 2011). In the absence of any certified national guideline, different methodologies are currently being used. This lack of consistency may compromise any use of the data in any legal or regulatory context. Three of the protocols from Clapcott et al. (2011) provide measures of the spatial extent of deposited fine sediment on the stream bed (% cover: bankside visual assessment, in-stream visual assessment, Wolman pebble count). Two protocols assess the quantity of (re)suspendable fine sediment deposited on and in the stream bed (g/m3, index score), and one protocol measures deposited fine sediment depth (mm). In 2011, Clapcott et al. modelled the pre-colonisation reference state as 8% instream sediment bed cover, implying hard-bottomed streams dominated the New Zealand waterscape. The model predicted the national average in 2011 to be 29% (Clapcott et al. 2011); a significant increase, potentially due to anthropogenically driven land-use changes.

Together with an increase of the gradual accumulation of layers, fine sediment deposition results in changes to the composition of a stream bed. Where inputs of fine sediment to catchments are increased, the average size of particles becomes smaller, interstices between larger particles become filled and, where a surface drape of deposited sediment occurs, the stability of the bed may be reduced (Kaufmann et al. 2009).

2a.6 Resource Management (Governance of water abstraction)

New Zealand currently lacks any nationally consistent and comprehensive land-use information covering the full range of natural, production, and urban landscapes. Each independent local government has its own methods for land-use planning, policy and resource management, improve monitoring and reporting of land use and land-use change, as well as foster better outcomes at national (e.g., carbon monitoring, biodiversity protection), regional (e.g., Resource Management Act), and district/city (e.g., land use planning) values for waterways (Rutledge et al, 2008). Regional councils, under the RMA, have a legal obligation to protect the environment for future generations, and a number of reports like the Environment Aotearoa (2019) show they have failed to do that. Best practice dictates that an Environmental

Protection Authority should be independent to provide impartial governance, monitoring and audit system.

2a.7 Māori – the importance of a water partnership

Water is a taonga of huge importance to Māori and enhancing the health and wellbeing of all waterways is a priority for many Māori. Engagement with Māori is critical to identifying iwi/hapū (tribe/sub-tribe) priorities for the management of the region's waterways and surrounding catchments. Māori often consider their personal health and the health of the community as closely linked to the health of their local water bodies. Water acts as a link between the spiritual and physical worlds, and many waterbodies are associated with waahi tapu (sacred sites). All elements of the natural environment, including people, are believed to possess a mauri (life force) which Māori endeavour to protect. The well-being of an iwi is linked to the condition of the water in its rohe (territory) (Anzecc, 2000). Māori recognise water in all its forms evidenced by an extensive nomenclature of descriptors for water. These range from waimate (lifeless water) to waiora (lifegiving water) and include descriptors relating to spiritual properties, mahinga kai (food), source, direction, depth, proportions, temperature, colour, clarity, flow, taste, flora, salinity, morphology, navigability, utility, relation to boundaries, habitations, historic events and individuals. Water is recognised as contiguous hence the need to manage it as a catchment (from mountains to sea: ki uta ki tai). While the translation is not literal, the message is clear. The health of the people is intimately connected to the wairua (spiritual force) of the streams and rivers.

One of the greatest concerns for Māori, raised with the management of waterways is 'Impacts on mahinga kai'. Mahinga kai refers to my local iwi Ngāi Toa interests in traditional food and other natural resources and the places where those resources are obtained. During this research I collaborated with members of Ngati Toa who came out into the streams observing and advising my research. They believe current and future activity should always be guided by lessons of the past.

2a.8 Research scope and aims

The wellbeing of New Zealand's freshwater ecosystems is also under threat from climate change. Predicted changes in regional climate and further expansion of the dairy industry, however, will impose similar pressures on freshwater resources in northern New Zealand to those already acting to threaten freshwater biodiversity in the eastern South Island, Ling

(2010). Species loss and habitat degradation can make ecosystems less resilient to environmental change (Isbell et al, 2015) leading to further declines in biodiversity. High levels of biodiversity increase ecosystem resilience to moderate to extreme climate events (Isbell et al, 2015). Declines in biodiversity, however, can have the opposite effect (Oliver et al, 2015). The size of a stream at any point is related in part to the size (area) of the drainage basin upstream from that point and the rainfall that flows into the stream. Horokiri Stream has a much larger basin than Ration Creek and flows approximately three times faster. The Horokiri channel is mostly boulder and cobble, whereas the Ration channel has an alluvial gravel bed. Neither of the streams were sampled in the headwater due to lack of access and to reduce the impact of gradient/slope variance.

This assessment examines and quantifies the impacts of land use change in two streams with different physical and land use characteristics. A full list by zone of the differences in Horokiri outlined in Table 1 and Ration in Table 2. These two catchments contain a mix of land-cover types and land uses, including native vegetation, exotic forest, urban areas, golf course and open pasture, which affects water quality in different ways. Horokiri stream is a fourth order stream and Ration is a third order stream.

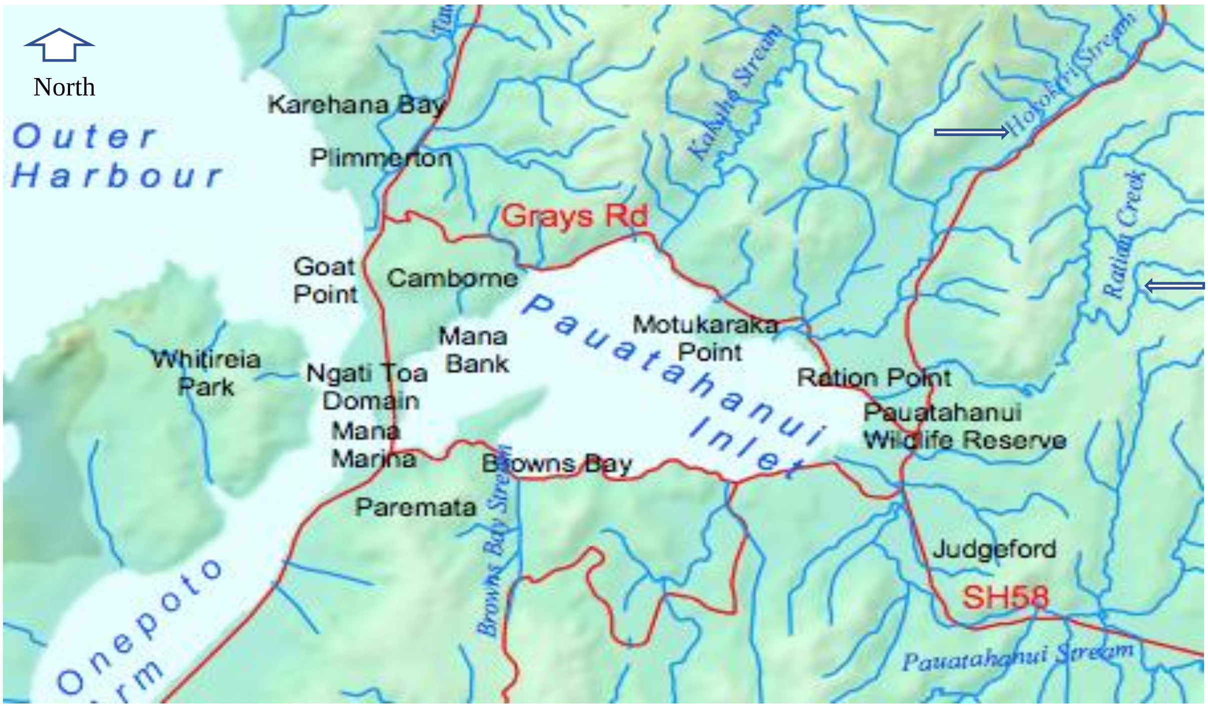

Figure 4: A Porirua City Council GIS map showing the location of the two stream sample sites and the Pauatahanui Inlet

The aim of this assessment was to test the following hypotheses:

H_{o1}: There was no relationship between flow and depositional rate depending on land use

H1: There is a relationship between flow and depositional rate dependant on land use

H_{o2}: Deposited fine sediment had no effect on the macroinvertebrate community index

H2: Deposited fine sediment had a negative effect on the macroinvertebrate community index

H_{o3}: The riparian planting in zone 2 had no effect on the daily depositional rate compared with the upstream land use management zones

H3: The riparian planting in zone 2 had a positive effect on the daily depositional rate compared with the upstream land use management zones

2b. Introduction to comparable manipulative experiments to study disturbance

In ecology, a disturbance is a temporary change in environmental conditions that can cause a change in an ecosystem. It was Darwin who first recognized more species of grass growing in a field that had been cut for hay, than in fields that had been left (Origin of Species, 1859). Disturbances often act quickly and with great effect to alter the physical structure or arrangement of biotic and abiotic elements. Disturbances can vary greatly over temporal and spatial scales and have traditionally been viewed as uncommon, irregular events that cause abrupt structural changes in natural communities, thus moving them away from static, near-equilibrium conditions (Sousa 1984). Pickett and White (1985) stated, "disturbance is relatively discrete event in time that disrupts ecosystem, community, or population structure, and that changes resources, availability of substratum, or the physical environment". However, Resh (1988) stated, "Disturbance strongly shapes community composition". Heraclitus (a Greek philosopher) says, " The only thing that is constant is change".

2b.1 What is disturbance?

Disturbance was not included into stream ecological research until the late 1980s, as demonstrated by several publication illustrating the ecological consequences of floods, concurrently emerging with research by Resh et al. (1988). However earlier ecologists understood the impacts of pollution events on stream ecology. Emily Stanley et al (2010) state, "Disturbance has gone from being rarely acknowledged to being the focus of intense research and recognized as a fundamental agent capable of shaping pattern and process in streams". Fires and floods are examples of natural disturbances that force change upon an ecosystem. These natural disturbances are beneficial in some cases; caused by diseases, severe storms, insects, volcanic activity, earthquakes, droughts, and long-term freezing or can be seasonal like resetting the equilibrium after winter ice. Since natural disturbances occur less often in the lentic benthos, differences in disturbance frequency may contribute to the high species richness of stream benthos when compared with most lakes and ponds (Resh et. al., 1988). Disturbance and its consequences challenge a dominant paradigm in ecological theory, which assumes that systems are at equilibrium (McIntosh 1985, 1987). Studies on disturbance cast at least some doubt on the assumptions of equilibrium in natural ecosystems (Pickett and White 1985).

Of the three major hypotheses about the role of disturbance in lotic community structure (i.e., the equilibrium model, the dynamic equilibrium model, and the intermediate disturbance hypothesis), the dynamic equilibrium model seems to be the most generally applicable hypothesis. The roots of this equilibrium model of communities stem from the Lotka-Volterra models of competition and predator-prey interactions derived from many studies of population ecology (Kingsland 1985). However, there is some disagreement as to whether the limited pool of available data supports it (e.g., Minshall et. al., 1985b). The key to this model, as applied to stream communities, is that the recurrence interval of disturbance events (spates, droughts, anthropogenic inputs, etc.) is shorter than the time necessary for competitive or predator-prey interactions to lead to the elimination of species (Resh, et. al., 1988). Most ecologists feel that the null hypothesis of a constant, disturbance-free environment can be rejected in most stream ecosystems but some spring-fed streams seem to have communities that fit these equilibria predictions of biotic interactions (Minshall et. al., 1985b). If disturbances are frequent enough then there is an equilibrium of sorts. The disturbance becomes a normal occurrence. Disturbance is increasingly being used as a tool to manage degraded systems. One of the first famous examples of this strategy was the managed flooding of the Grand Canyon in 1996 (Collier et al. 1997). Resh et al. (1988) pointed out that most streams and watersheds experience several different kinds of disturbance, and that the collection of disturbance types and their relative influences on streams vary as a function of geography, climate, and human activity.

Studies of disturbance have spanned levels of ecological organization from individuals to landscapes and the entire range of spatial and temporal scales considered in lotic research (Stanley et al. 2010). Disturbance may effect species at a community level. The frequency and size of a disturbance is often closely related to specific site conditions. Matthaei (2000) reports after flood disturbance, invertebrate densities and diversity were significantly higher on stable as opposed to unstable substrates. There is a gap in knowledge to recognise the links between geomorphic forms and processes and the ecology of disturbance. Natural disturbance in-stream experiments can contribute to improved scientific understanding and stewardship of streams and rivers.

There is great inconsistency in the use of the terms 'pulse' and 'press' when describing types of disturbances. Distinction between these two types of disturbance is crucial for management to prevent further impact. Thus, it is important to describe separately these two aspects of a disturbance.

2b.2 Pulse disturbance (simulated sediment flushing event)

A disturbance that occurs as a relatively discrete event in the short-term is referred to as a "pulse" disturbance. Examples of a pulse disturbance are fire, drought, or forest harvesting. Pulse disturbances are normally short and sharp in duration and intensity, such as major floods in constrained river channels which bring a pulse of turbidity. Some human activities result in prolonged turbidity, (e.g., mining, gravel quarrying) (Parkhill and Gulliver 2002), or increase the frequency of pulse events, e.g. mechanical clearance of macrophytes (Greer et al. 2016). Research shows the effect of pulse disturbances on stream invertebrate diversity may also be influenced by interactions with other factors including habitat heterogeneity (e.g., patchiness) and productivity (Death 2003 and Winterbourn 2004). Wilson, 1994 states, "There must be a trade-off between species' colonizing ability and competitive ability. At one extreme, patches that are frequently and/or intensely disturbed are expected to exhibit low species richness because few species are able to colonize during the brief periods between disturbances or tolerate the high intensities of their impact. At the other end of the scale, patches in which disturbances are infrequent and/or of low intensity are expected also to be poor in species because they become dominated by competitively superior taxa". A published manipulative experiment by Aspray (2017) entitled 'Organic sediment pulses impact rivers across multiple levels of ecological organization' revealed that short- term pulses of organic sediment in rivers can have broad effects on water quality and biota, from influences on the dispersal of individual organisms to the modification of ecosystem processes.

2b.3 Press disturbance

A press disturbance is defined as those that continue (cumulative) at a similar intensity following their initial occurrence. An example is water abstraction (if continuous) would be a press disturbance, reaching a constant level that is maintained over long periods. Prolonged low discharge (as in droughts) and anthropogenic factors (which can range from abiotic stresses such as site-specific effluent releases to biotic stresses such as species introductions) may also act as disturbances (Resh, et al. 1988). Stream ecosystems generally are considered to have low resistance but high resilience because of the short generation times of many stream taxa (Grimm and Fisher 1989). Stability describes ecosystem response to disturbance and involves resistance, the capacity to avoid change, and resilience, the ability to recover rapidly after disturbance (Webster, Waide & Patten 1975). The resulted press disturbance can disproportionately impact on one or a few species. These impacts invariably circulate to the remaining species in the food web. Each species interacts uniquely within the food web with some interacting with many species while others interact with few, and some are predators while others are producers. Wootton (1998) stated, "The trophic level of the disturbed species influenced which species went extinct, although this was modulated by the complexity of the food web". The disturbed species' traits were also important: Disturbance of a species with few interactions usually resulted in its own extinction, while disturbance of a species with many interactions more often caused the extinction of the disturbed species' predator(s). Both the traits of disturbed species and the complexity of the food web need to be considered in attempts to predict or manage the ecological impact of press disturbances. We must consider time scale of the disturbance and the macroinvertebrate response. A published example in the Environmental Monitoring and Assessment Journal by Glasby and Underwood 1996 shows, a disturbance lasting 10 years would be deemed a pulse for organisms with long lives but for macroinvertebrate that live for a couple of years this would be a press disturbance.

2b.4 Macroinvertebrate response to disturbance

Disturbance, can be linked to community assemblage with intermediate disturbance hypothesis (IDH), which predicts moderate amounts of disturbance, can provide the widest variety of habitats and therefore has the highest species diversity, i.e. of moderate intensity and/or frequency, locally reduces inter-individual competition for resources and thus allows less competitive species to avoid exclusion and to maintain in the community (Connell, 1979) . Disturbances control rainforest dynamics, and, according to the intermediate disturbance hypothesis (IDH), disturbance regime is a key driver of local diversity (Guitet. et. al., 2018). If these moderate disturbances (IDH) happen at the right time, of the right scale, they have the greatest effect on biodiversity (Mayor. et. al., 2015) . Even when our two stream disturbances occur in a similar area, same climate, at the same time the stochastic nature of the ecosystems means that the two areas might recover in completely different ways and a manipulative experiment should reveal this. An important consideration underlying a community's response to a disturbance is the complex network of interactions between the species within the community (Williams and Martinez 2000, Montoya et al. 2006, Neutel et al. 2007). Ecological communities are made up of interacting species and populations which, through time, are subject to periodic disturbances (Begon et al. 2006). Stream biota have evolved to withstand natural pulses and background levels of suspended sediment. However, once the norms are exceeded, suspended/deposited sediment becomes a biotic stressor, affecting population performance, community composition and ecosystem functions.

Research on the effect of fine sediment accumulation on macroinvertebrates has primarily been based on correlative fieldwork (e.g. Chessman et al., 2006; Death et al., 2003; Hogg & Norris, 1991; Kaller & Hartman, 2004; Quinn & Hickey, 1990). The problem with such studies is that they cannot establish definite causal relationships because of the difficulty of disentangling sediment effects from other changes associated with intensified land use, e.g. increased nutrient concentrations, light input or water temperature (Matthaei et al., 2006). A large-scale field experiment where sand was added to the river bed over 50m river reaches conducted by Matthaei et al. (2006) found that invertebrate taxon richness and richness of EPT taxa was reduced by sediment addition. The experiment was able to disentangle the impact of sediment addition from other land-use effects, such as nutrients and high organic content (Matthaei et al., 2006). Disentangling these effects may enable more specific understanding of the effects of fine sediment accumulation on macroinvertebrates. Prolonged sediment ramping (the continued increase of sediment accumulating) will lead to high levels of deposited sediment. Previous research by Macdonald, A., & Cote, D. (2014) shows that invertebrate populations can be less resilient to repeated flooding in streams than non-repeated disturbance. Storms transport significantly more sediment to streams during flooding. Deposition can directly bury or reduce the food quality for invertebrates (Luedtke and Brusven 1976, Richards and Bacon 1994, Danger et al. 2012). A US EPA report Cantilli et al., (2006) proposed a framework for developing water quality criteria for "suspended and bedded (fine) sediments" (SABS). The full Cantilli et al. (2006) report is perhaps most notable for presenting very useful and comprehensive conceptual model shown in Figure 5. A conceptual model of the proximate stressors and causal pathways that lead to a response in benthic invertebrates due to an increased deposited sediments, suggests that substrate size, interstitial space and coverage of fine sediment should be assessed when studying the effects of sediment on benthic macroinvertebrates. Figure 6 shows the impacts caused by both suspended and deposited particles on a mayfly (Jones et al. 2012).

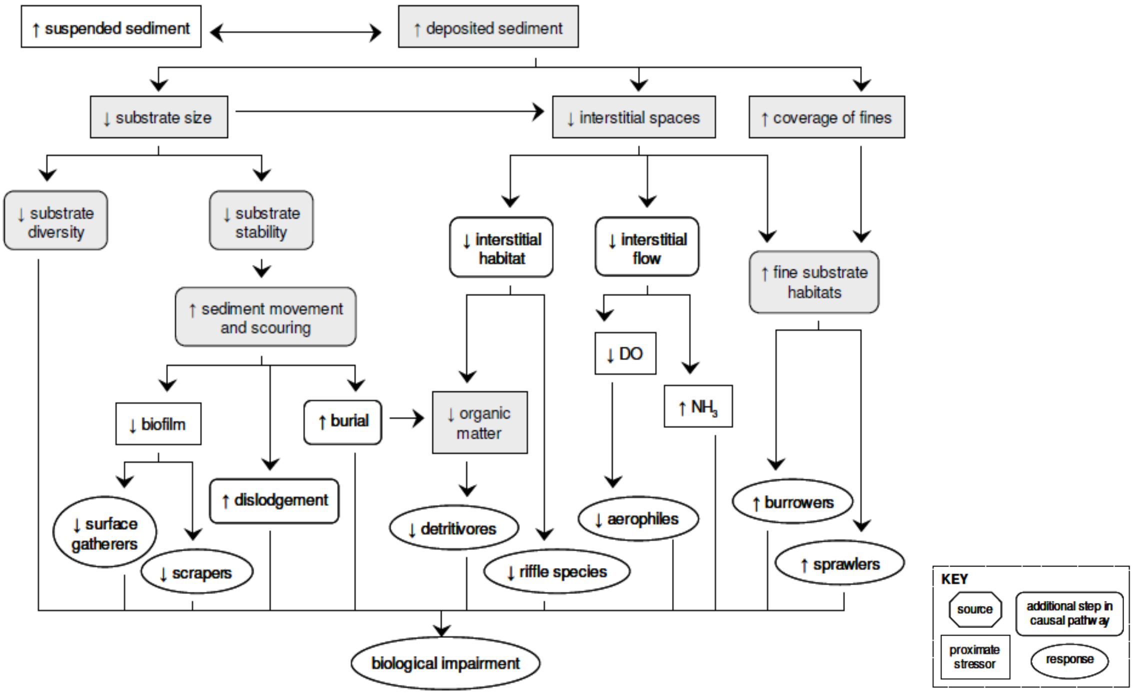

Figure 5: The model depicts the relationship between increased deposited sediment and the effects on in-stream biota (Cantilli et al. 2006).

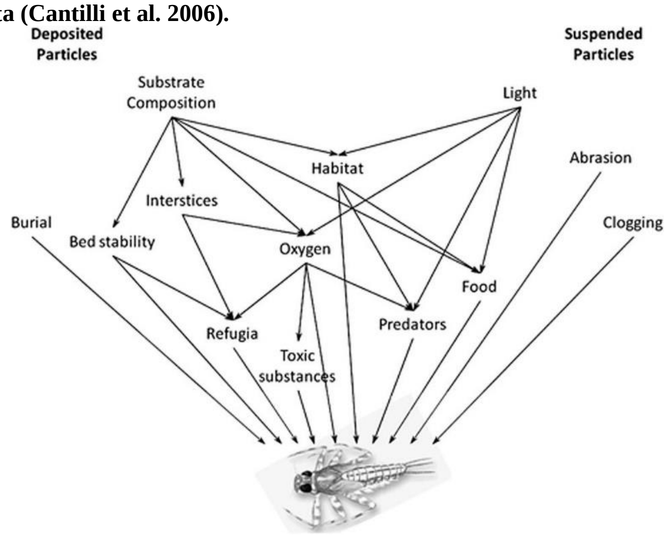

Figure 6: Diagram illustrating the direct and indirect mechanisms by which fine sediments impact upon macroinvertebrates. Impacts are caused by both suspended and deposited particles. Arrows show interacting effects and impacts on macroinvertebrates (Jones, 2012).

The aim of this experiment is to test the following hypothesis:

H_{o4}: Macroinvertebrate communities subject to sustained fine sediment delivery (press disturbance) are affected by simulated pulse flushing events (pulse disturbance)

H4 – Macroinvertebrate communities subject to sustained fine sediment delivery (press disturbance) are MORE resistant to simulated pulse flushing events (pulse disturbance)

Resh et al (1988) suggests that small-scale (<1 m^2) mechanical disturbances, such as turning over substratum, are easily applied (Clifford 1982, Reice 1985), have little lasting impact, and can be used to address fundamental questions in stream ecology because they can be adequately replicated. This experiment investigates the response of stream macroinvertebrates to a simulated pulse disturbance in both Ration Creek and Horokiri Stream created by raking the substratum over 28 days (4 x 7 day intervals) in February 2019. This research provides more realistic testing of the impact of fine sediment, by substrate raking, on macroinvertebrates in a natural stream setting. It is important to consider the response of macroinvertebrates to fine sediment accumulation from a variety of habitats. Riparian planting is used widely in New Zealand and internationally for mitigating land use intensification effects on adjacent waterways and enhancing stream health (Greenwood, Harding et al. 2012). From the ecological and geomorphological assessment I have chosen to use the two Riparian zones (HZ RIP and RZ RIP) to investigate the disturbance hypothesis. These two zones had the highest recorded abundance in macroinvertebrates out of the eight zones tested. My aim was to establish whether a low intensity pulse disturbance will result in reduced species richness compared to a normal press disturbance. As we remove the captured macroinvertebrates from our weekly traps, can I identify which species colonise the new vacant traps and which ones drift out of the disturbed site?

I created a manipulative experiment that a National Institute of Water and Atmospheric Research (NIWA) citizen scientist (or volunteer) could set up and conduct. Public participation in environmental monitoring, a form of citizen science, has increased dramatically around the world in the past 20 years. The reliability of volunteer data from citizen scientists was strongest when it came to measuring water temperature, electrical conductivity, visual water clarity, macroinvertebrate and the cover of thick periphyton growths. My methodology for this experiment is simple, robust and allows communities to be engaged and empowered to make a difference by conducting and guiding them through a simple experiment to create data that to draw reliable inferences.

3. Study sites

Five thousand years ago during the lowered sea levels of the last glacial period stream channels were down-cutting, subsequently flooded by rising sea levels resulting in the Pauatahanui Inlet we know today. From around 1840 the arrival of Europeans brought in milling and farming practices that, in the space of 40 years, denuded the natural forest cover leaving only a small percentage untouched. Changes in land use for the catchments over the last 60 years have been mapped using aerial photography (Page et. al., 2004). The earliest photographs are from 1941-42 and show that 83% of the catchment was grassland. Since this period, grassland has decreased and woody vegetation (of mixed native and exotic species) has increased from 16% to 42%. A rapid increase in exotic forest occurred between the 1970s and 1990s. Almost all of the indigenous vegetation now in the catchment is recent and naturally regenerated. Local habitat and biological diversity of streams are strongly influenced by landform and land use within the surrounding countryside at multiple scales. The streams follow channels that were formed by general erosion of the hillsides resulting in a complex network of waterways that drain the hills after heavy rains characteristic of our temperate climate. The exposed land was subjected to erosion by frequent heavy rains, the result of which can now be seen in the dissected nature of the hills. The wind and rain in our area produce strong erosive elements. I conducted an ecological and geomorphological assessment of 4 x 100m longitudinal zones in two streams to study the ecological response to sediment in a variety of land use zones. Appendix A shows diagrams of each zone in the completed site assessments (SEV). Both streams shown in Figures 7 and 8 are in close proximity, have similar climate, topographically, from the steep headwaters flowing down to lowland wetlands and out into the Pauatahanui Inlet. Figure 7 shows the Horokiri catchment and assessment zones. Figure 8 shows the Ration Creek catchment and assessment zones. Table 1 has descriptions of the four 100m zones in Horokiri Stream and Table 2 has the descriptions of the four 100m zones in Ration Creek. I predict that stream conditions and biotic health measures would decline or improve depending on the pattern of land use and its effects on stream characteristics, especially fine deposited sediment. By creating reliable data I am able to quantify the relationship between the ecological variables and land-use processes.

Figure 7: NZ Land cover Database map of Horokiri stream catchment and zones

Table 1: Description of the four 100m zones in Horokiri Stream

ID:240889 **Climate: CW** **NZReach:9009485**	**HZ WET**	**HZ RIP also** **Experiment site**	**HZ HOBBY** <10 cattle	**HZ AGRI** >800sheep
Longitude & Latitude	41"05'38'S 174"54'27'E	41"05'03'S 174"55'08'E	41"04'32'S 174"55'49'E	41"04'27'S 174"56'00'E
Description of zone	lowland tidal saltmarsh	Riparian, pastural, woodland & pine forest	scrubland & pasture	Semi intensive grazing
Source of flow[1]	L	L	L	L

[1] https://data.mfe.govt.nz/layer/51829-river-environment-classification-wellington-2010/data/

Geology[3]	HS	HS	HS	HS
Land cover[3]	W	EF	PF & P	P
Stream order[3]	4	4	4	4
Vegetation	Saltmarsh, flax & tussock	riparian buffer 20-25m	Pasture, flax & shrub	Pasture, flax & shrub
% agriculture	20%	70%	80%	95%
Width mm	4000-4800	6000-6320	4800-5100	4150-5150
Depth mm	28-350	320-330	140-290	200-800
Altitude m	16.33m	23.667m	32.667m	38m
Distance from the Inlet	0.5km	2.5km	3.5km	4.5km
Slope/gradient	0.5 degrees	1 degree	1.1 degrees	1.3 degrees
Riparian vegetation	20%	100%	5%	10%
Bank undercut	yes	yes	no	yes
Shade	20%	95%	5%	5%
Substrate size	sand/silt	20% gravel;10% sand; 40% small cobbles and 30 % large cobbles		
Slumps true left bank	2	1	>5	1
Slumps true right bank	2	0	>5	1
Stream Habitat Assessment (SHA)	0.65	0.76	0.6	0.5
Stock access	no	no	yes	no
Periphyton present	yes	no	yes	yes
Visible bank Erosion	yes	yes	yes	yes
Visible slumping	yes	no	yes	yes

Figure 8: NZ Land cover Database map of Ration Creek catchment showing zones

Table 2: Characteristics of Ration Creek zones of 100m

ID: 240994 **Climate: WW** **NZReach:9009533**	**RZ WET**	**RZ RIP also Experiment site**	**RZ HOBBY** <10sheep & 5 horses	**RZ GOLF**
Longitude & Latitude	41"05'53'S 174"55'02'E	41"05'50'S 174"55'06'E	41"05'47'S 174"55'11'E	41"04'55'S 174"55'58'E
Description of zone	Lowland tidal saltmarsh	Riparian, pasture & orchard	Pasture, shrub & woodland	Golf course – open land
Source of flow[2]	L	L	L	L
Geology[3]	SS	SS	SS	SS

[2] https://data.mfe.govt.nz/layer/51829-river-environment-classification-wellington-2010/data/

Land cover[3]	W	S	P	B
Stream order[3]	3	3	3	3
Vegetation	marsh & riparian with a number of dead Manuka	riparian buffer 2-5m with a number of dead Manuka	pasture & shrub with a number of dead trees	Greens Open land
% agriculture	0%	60%	90%	0%
Width mm	1800-2500	3600	4000-4200	1400-1800
Depth mm	40-600	300-320	220-320	40-200
Altitude m	2.667m	8m	12.667m	67.33m
Distance from the sea	0.3km	1km	2km	4km
Source of flow	L	L	L	L
Slope/gradient	0.5 degrees	1 degree	1.2 degrees	1.5 degrees
Riparian vegetation	50%	100%	10%	<5%
Bank undercut	yes	yes	no	no
Shade	50%	70%	10%	<5%
Substrate size	sand/silt	30% gravel;25% sand; 20% silt; 25% small cobbles		
Slumps true left bank	2	1	>5	>5
Slumps true right bank	1	1	>5	>5
Stream Habitat Assessment (SHA)	0.65	0.7	0.65	0.5
Stock access	no	no	yes	no
Periphyton present	no	no	yes	yes
Visible bank Erosion	yes	yes	yes	yes
Visible slumping	yes	no	yes	yes

3.1 Horokiri Stream catchment

Horokiri Stream has a catchment area of 3302ha, has a maximum elevation of 530m with an average channel slope in degrees of 1.3. The Horokiri Stream is the second largest of six tributaries discharging into Te Awarua-o-Porirua Harbour, with headwaters at Battle Hill on the edge of the Akatarawa Forest. These springs are driven by aquifers and often contain ancient groundwater. Horokiri tends to be stable, unless anthropogenic activities have had an effect on the aquifer (e.g. water quantity and quality) or the spring (e.g. water abstraction and riparian habitat modification). Horokiri has many land use management zones along its banks from agricultural, horticultural, hobby farms and forest. The National Institute of Water and Atmospheric Research (NIWA) carried out extensive electric-fishing surveys of freshwater eels over three successive summers,1996-1998. These surveys included comprehensive habitat characterisation, water temperature time series and a collection of macro-invertebrate samples. I reviewed all historical data of the Horokiri Stream, following their methods in similar sample reaches to compare the historical data with my yearlong research to evaluate what if any, are the changes and impacts quantified creating a difference. The streambeds consists of mud, silt, sand, gravel, small cobbles and boulders characterised as hard-bottomed stream bed. Table 1 identifies the characteristics of the zones.

3.2 Ration Creek catchment

Ration Creek with a catchment area of 677ha, has a maximum elevation of 260m with an average channel slope in degrees of 1.5 with two, 100m riparian buffer zones in the lowlands, a wildlife sanctuary, some wooded areas, a cleared forest block and the Pauatahanui Golf Course near the headwaters. I was unable to locate any research studies done on Ration Creek to compare historical data with my research. Ration Creek is a lowland spring-fed with low flow. Ration is the smallest of six tributaries discharging into Te Awarua-o-Porirua Harbour. The riparian buffer zone has two small weirs 10m and 20m downstream. These were constructed 15 years ago to prevent inflow from the tidal estuary and control the upstream water level. The concrete weir 10m downstream has fallen apart with chunks of concrete washed away. A small wooden weir 20m downstream was installed half way through the riparian zone, below the experimental site. A weir is a small dam built across a stream. There is a double culvert under Paekakariki Hill Road 20m upstream of the experiment site. Twelve years ago, before the installation of the riparian buffer zone, Ration Creek was straightened and controlled in places, to function as conducts for water abstraction and flood control. Table 2 identifies the characteristics of the zones.

The four Horokiri zones used during the assessment were similar to those used by Allen (1951) and Healy (1976). I predict that a review of the historical data and timeline from previous studies by 1951 Allen, 1980 Healy, Curry 1981, NIWA 1996 and GWRC 2004 on the Pauatahanui Inlet catchment, namely the Horokiri Stream will show signs of recovery in stream health when evaluating MCI indicators.

Horokiri Stream and Ration Creek were chosen due to their close proximity with similar stream channel form and substrate, differing land use and flow volume. Although the same anthropogenic disturbances may occur in all regions, their severity, frequency, and intensity may vary greatly in our two local survey streams. Does the length of the riparian buffer affect the deposited sediment found in traps during the experiment, remembering that Horokiri Stream is 20-30m and Ration Creek 2-5m in width? I conducted a pre-experiment assessment of the surface area of the streambed covered by sediment from 20 samples, working from down to upstream to avoid disturbance using a Bathyscope underwater viewer. I followed the Cawthron Sediment Assessment Method 2 (Clapcott et.al., 2011) to evaluate an In-stream visual estimate of % sediment surface cover.

Horokiri Stream: Average was 25%, Median 20%, 25thPercentile 10% 75th Percentile 33%
Ration Creek: Average was 65.25%, Median 60%, 25th Percentile 60% 75th Percentile 76%

The stream was halved to create control & pulse disturbance sites by driving two iron stakes into the stream bed, two metres apart with a frame of mesh (silt fence) strung between them. Figure 9 is a photograph of the two experimental sites. Stream measurements are shown in Table 3. Both sides of the central mesh frame are affected by the exact same water conditions but not disturbance sediment. The mesh diameter of 140gsm did act as a silt fence to protect the control site from the effects of the pulse disturbances. The frame was installed into both streams on the same day and left for four weeks to bed in and acclimatise the in-stream fish, eels to the structure before the experiment began. The depth in both sites was between 300-330mm. The Initial sketch of the experiment site is at Figure 13.

Table 3: Experiment study site specifications including measurements of riparian zones

Descriptions	Ration Creek	Horokiri Stream
Stream width	3600mm	6320mm
Site A control width	1800mm	3320mm
Site B width	1800mm	3000mm
Depth	300-310mm	320-330mm
Length of experiment site	2000mm	2000mm
Riparian buffer width	2-5m	20-30m
Canopy cover	partial	full
Canopy height	Up to 10 metres	Up to 40 metres
Density of plantings	Spread out through buffer	Highly concentrated in buffer
Riparian planting installed	2009	From 1967-1997
Gaps in vegetation	yes	no
Type of vegetation	Manuka, Cabbage tree, Flax, Pampas, Pittosporum and some Willow	Manuka, Poplar, Flax, Pine, Willow, Kaketia, Rimu, Tawa, Eucalyptus, Macrocarpa Pittosporum, lancewood, Tree fern, Stinging neetle and Coprosma Robusta
Weeds within buffer	yes	yes

 P1  P2

Figure 9: Photos of the Horokiri Stream (P1) and Ration Creek riparian experimental sites (P2)

These study sites may provide a true indication of whether a pulse disturbance effects the macroinvertebrates, taxa, abundance and MCI. Both experiment sites are situated in riparian zones of 100m in length about 20metres above sea level in Horokiri Stream and Ration Creek. I monitored upstream of the experiment site to reduce any confounding effects of variables. Continuous nitrate, dissolved oxygen and temperature were monitored using a TriOS TriBox3.

4. Methods

The assessment was conducted over sixteen weeks from 1st October 2018 to 31st January 2019 with community engagement. I interviewed ten landowners from across both catchments to better understand the historical morphology of the streams as changes evolved through time in response to a variety of geologic factors. I used seasonal data from the Transmission Gully Consultants Boffa Miskell Limited[3], reporting their 2018 findings to compare with my data which may indicate a pattern or trend. Appendix 4 shows the Boffa Miskell macroinvertebrate finds and MCI values. Waiting 72 hours after each heavy rainfall during our sampling period. Sample zones were categorised in our results and graphs as (HZ = Horokiri zone and RZ is Ration zone). A brief outline of each of the zones and the location of the sediment traps is below. The container traps act as collectors of suspended solids.

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[3] TG-CPBH-RPT-ALL-GE-9212-00 13/11/2018

Deposited sediment was captured and analysed using sieves of 63 μm (<2mm) size. My research assistant took photos as I conducted tasks.

Traps location in Ration Creek:	
Trap1a 41"05'52'S 174"55'06'E Metal bridge below L	stone/cobble zone 1a wetland
Trap1b 41"05'52'S 174"55'06'E Metal bridge below R	stone/cobble zone 1b
Trap2a 41"05'52'S 174"55'05'E Wooden bridge below L	stone/cobble zone 2a riparian
Trap2b 41"05'52'S 174"55'05'E Wooden bridge below R	stone/cobble zone 2b
Trap3a 41"06'46'S 174"55'10'E Boyds bridge above L	stone/cobble zone 3a hobby farm*
Trap 3b 41"06'46'S 174"55'10'E Boyds bridge above R	stone/cobble zone 3b
Trap4a 41"04'55'S 174"55'57'E Golf Club bridge L	sandy gravel zone 4a golf course
Trap4b 41"04'55'S 174"55'58'E Golf Club bridge R	sandy gravel zone 4b
Traps location in Horokiri Stream:	
Trap1a 41"05'38'S 174"54'27'E Greys bridge above L	stone/cobble zone 1a wetland
Trap1b 41"05'38'S 174"54'27'E Greys bridge above R	stone/cobble zone 1b
Trap2a 41"05'05'S 174"55'08'E Glovers bridge below L	stone/cobble zone 2a riparian
Trap2b 41"05'05'S 174"55'09'E Glovers bridge below R	stone/cobble zone 2b
Trap3a 41"04'32'S 174"55'49'E Diane bridge below L	stone/cobble zone 3a hobby farm*
Trap3b 41"04'33'S 174"55'49'E Diane bridge above R	stone/cobble zone 3b
Trap4a 41"04'27'S 174"56'00'E Turners bridge above R	stone/cobble zone 4a large sheep farm
Trap4b 41"04'26'S 174"56'00'E Turners bridge below L	stone/cobble zone 4b

4a.1 Methods to deploy sedimentation traps, evaluate rates and size fractionation

Two sediment traps were deployed in each zone in both streams from 1/10/18 to 31/1/19. Sediment trap deployment and analysis followed the methods of Wood et al. (2005). A total of 32 traps were installed, set and measured over 16 weeks. Each trap was labelled with a vivid marker.Each sediment trap, a blue 2.2-L plastic container, was filled with large cobbles at the bottom and, after washing to remove excess fine sediment, traps were filled with smaller cobbles and gravel Figure 10. Sediment traps were then placed in the bed of the river with the lids on, such that the top of the trap was level with the riverbed. Placing 2 traps into each zone to minimise the loss of data, in the event a trap was lost due to flooding. I installed two sediment traps in each zone (2 x 8 = 16 x 4 months, n=64 total traps or n=32 per stream). I replaced all traps that were lost due to flooding.

Once all sediment traps had been placed in the riverbed, starting with the downstream traps, the lids were removed and large cobbles were placed around the edge of each trap to keep it in place. Twenty one days after deployment, starting downstream each trap was removed and replaced. Four traps were lost in November due to flooding and these were replaced.

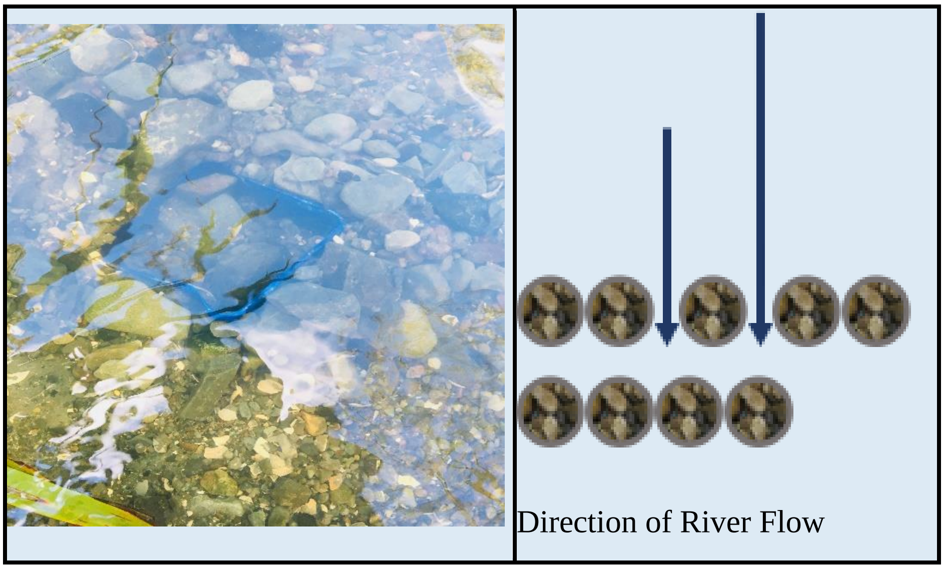


Figure 10: Sediment Trap in position within the river bed at Ration Creek

4a.2 Installation methods for sediment traps

Detailed descriptions of existing sedimentation rate sampling sites and methods are provided in Robertson and Stevens (2008, 2009, 2010 & 2011). Sediment trap deployment and analysis followed the methods of Wood et al. (2014).

Sediment traps were then placed in the bed of the river with the lids on, such that the top of the trap was level with the river bed. Once the sediment traps had been placed in the riverbed, the lids were removed and cobbles were placed around the edge of each trap to keep it in place. At the end of each seven day weekly cycle the lid was placed onto the sediment trap whilst in the stream. Once the contents were contained it was lifted gently and a second container placed under the holed one to stop any sediment from flowing out. Another new clean sediment trap was installed into the vacant substrate site with its lid on. Once the trap was firmly secured into the substrate the lid was removed, the streambed raked and the trap left for a 7-day cycle. The disturbed traps were removed weekly. I chose not to remove the control press trap weekly to avoid any disturbance in the controlled side during the installation and extraction process.

To carry out size fractionation, the contents of the sediment traps were firstly washed over 2-mm sediment sieves into 20-L buckets. Cobbles and gravels with a grain size larger than 2 mm were discarded, and the remaining sediment was left in the buckets for five days to allow fine sediment to settle. Water was siphoned out of the buckets, and the remaining gravel and sediment was hand-sieved using decreasing mesh sizes (2 stages: 125 μm, 63 μm, retaining the fraction <63 μm) and weighed. The silt/sand boundary of 63 μm is typically taken as the upper cut-off for fine suspended sediment, that is, particles in the clay or silt range. The Wet-Wash Preparation Method involved agitating the sample as it is sprayed with water. Using gentle, controlled water pressure to prevent accidental sample loss. The agitation was done by hand using a wet wash sieve under water running from a faucet in the field laboratory. Using mesh fine sieves to remove particles 125 μm then a second sieve of 63 μm, retaining the fraction <63 μm (<2mm). Excess water runs off leaving wet particles of <2mm for weighing.

A wet sieving method has the potential for sample loss during the process. Some material may be washed away during agitation or decanting, or may be forced into crevices of the sieve and become trapped. The percentage loss was very small and thus the accuracy and efficiency of wet sieving compared to dry sieving was worth the process.

Sedimentation daily rates were calculated using the following equation: $= \left(\frac{W}{A}\right) / D$

- - *W* is the total weight of wet <2mm sediment for each size fraction in each sediment trap.
- - *A* is the surface area of the sediment trap: square, 170mm x170mm = 289 cm^2
- - *D* is the number of days each sediment trap was deployed: 21 days

4a.3 Stream Ecological Valuation (SEV)

The Stream Ecological Valuation or SEV was developed for assessing stream functions. 'A really useful part of the SEV process is that it not only gives you an idea of the functions that might be lost by development affecting a stream, it also allows you to predict improvements in stream function if you are restoring a stream,' says Parkyn (2016). These SEV function scores enable stream and catchment managers to understand the range of ecological services a stream provides. I conducted a SEV assessment for all eight zones using the SEV methodology, Story et al (2011). I walked through the zones conducting a visual assessment to identify any erosion, slumps or stream gauging. Bank erosion was assessed and photographed along our 100m zones for both the true left and true right of the stream bank. Where possible the cause and type of erosion was noted (e.g. bank slumping or stock access). Both the Hobby farm owners allow stock (<10) access to the stream. There was no land use change to any of the zones during our

16 week survey. Conducted a NIWA Site Assessment of each zone (Total 8, shown at Appendix1)

4a.4 Method to collect, quantify and identify macroinvertebrates

Four macroinvertebrate samples were collected within each zone (n = 32) during the 16 week assessment. Samples collected with the use of a Surber $0.1m^2$ net (0.5mm mesh size) following Protocol C1 of the national macro-invertebrate sampling protocols (Stark et al, 2001), which has extensive guidelines on selecting the most appropriate method. The Surber sampler (Surber 1937) is a net fastened around a square frame which permits the user to isolate a known area of stream bed for sampling. The Surber sampler framing directs the current and organism into a collecting 'sock'. NIWA protocols to identify macroinvertebrates were followed[4]. Specimens were compared with descriptions in the Invertebrate identification index, NIWA, Landcare Research and/or DOC websites. More detailed guides to genera are also available online at www.niwa.co.nz/our-science/aquatic-biodiversity-and-biosecurity/tools. If I was unsure, I asked for a second opinion from Dr Mike Joy. All identifications were double checked and verified before entering confirmed data. Examples of macroinvertebrates can be seen at Figure 11. Randomly selected surber sampling sites in each zone for macroinvertebrates (n=32). During the pulse experiment I collect, quantify and identify macroinvertebrates weekly from each stream (n=4).


P1


P2

Figure 11: Photos of macroinvertebrate caught (P1:Mayfly and P2: Megaloptera)

Invertebrate samples within the traps were removed from the field and placed in buckets. In the field laboratory the invertebrates were removed from the traps and identified to species

[4] https://www.niwa.co.nz/freshwater/management-tools/water-quality-tools/stream-health-monitoring-and-assessment-kit/identification

wherever possible, using the Protocol C1 of the national macroinvertebrate sampling protocols (Stark et al, 2001). In the interests of safety all sampling was done in pairs with a research assistant. I followed NIWA identification sheets to identify macroinvertebrates to the genus level. The Macroinvertebrate Community Index (MCI) has recently been included as an indicator of stream health in the latest NPS-FM (MfE 2017). The total taxon richness, or abundance of species, is also frequently used as an indicator of stream health, as degraded streams typically contain fewer species. The following indices were calculated for each site: Total abundance, Taxa richness and Macroinvertebrate Community Index (MCI).

4a.5 Water quality testing

Water temperature, pH, dissolved oxygen, and specific conductivity were recorded approximately 20 cm below the water surface using a handheld YSI Professional Plus multiparameter four probe meter (YSI Incorporated, USA). I conducted eight water quality samples per zone (n=64), at same location, same depth of 20cm and over 16 weeks on different days and conducted daily during the experiment.

4a.6 Cross-sectional flow velocity

The velocity of the stream was measured using a Swoffer flow meter (Swoffer Instruments, Inc., Washington USA). I conducted three flow velocity transect sites (left, centre and right) in each zone to determine flow regimes. Cross sectional area was determined by measuring stream width and depth at various intervals. The discharge can then be calculated by multiplying the cross-sectional area by the flow velocity. Systematic sampling of flow velocity from 3 cross-sectional transects (left, centre, right) at the same location in each zone. Three cross-sectional transects = one variable of median flow in m3/s cumecs. Total samples in each stream n=32. These were conducting daily during the 28 day experiment n=28 each stream .

4a.7 Methods for visual clarity using black disk

Visual clarity test is a primary regulator of biological and ecological functions in aquatic systems (Vinyard and O'Brien 1976, Lloyd et al. 1987, Gregory 1991). Visual clarity of water can be quantified by the maximum horizontal sighting distance (extinction distance) of a black target because this approximates sighting ranges of practical importance, such as fish reactive distance. The black disc method (Davies-Colley 1988) is well-proven and the method is well described in various publications, notably the MfE (1994) guidelines on colour and clarity of waters. The National guidelines recommend Black Disk as the preferred sampling methodology for water clarity assessment, see Figure 12.

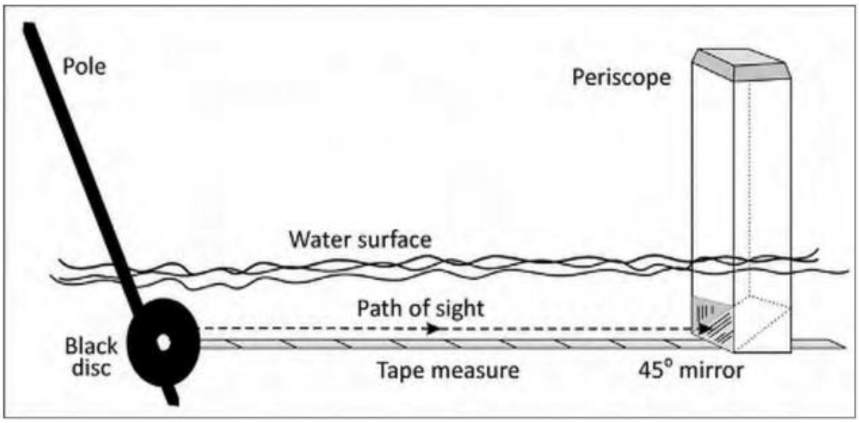


Figure 12: Schematic of black disk method of water clarity measurement (Rob Davis-Colley, 1988)

The manipulative experiment was conducted during February 2019 over 28 days. This Press disturbance of normal flushing events provides a new challenge to develop metrics that can reasonably quantify and measure how disturbances influence stream and river dynamics. For this experiment the control (defined as a press disturbance) was installed for 21 days then removed due to weather forecast.

4b.1 Sediment trap and placement during experiment

Using a spade dig a hole in the stream bed to install a container (170mm x 170mm x 85mm square) on each side of the mesh frame into the stream substrate, filled with cleaned stones and cobbles as shown in Figure 15. Containers without holes were used as sediment traps during the assessment. By adding holes, I created a trap suitable for a range of invertebrates, thereby increasing the capacity of the experiment. On the side of each trap I drilled 6 x 8mm holes above a 20mm marked line, creating a total of 24 holes in each trap as shown in Figure 14. The 20mm holding space in the trap was to allow the deposited sediment to accumulate and prevent fine sediment being washed in or out of the trap during installation or extraction. The holes allowed free movement of water through the trap. I used an 8mm drill bit for the holes as previously caught macroinvertebrate from these streams ranged from 0.25mm to 10mm in size. The holes were randomly placed in the side of each trap to allow invertebrates to drop in or burrowing invertebrate to transverse through the substratum in and out of the trap. Sediment traps were placed in the streambed, level with the river bed. Lids were removed once the trap was secured in location. The whole of site A is raked with the drain drag tool.

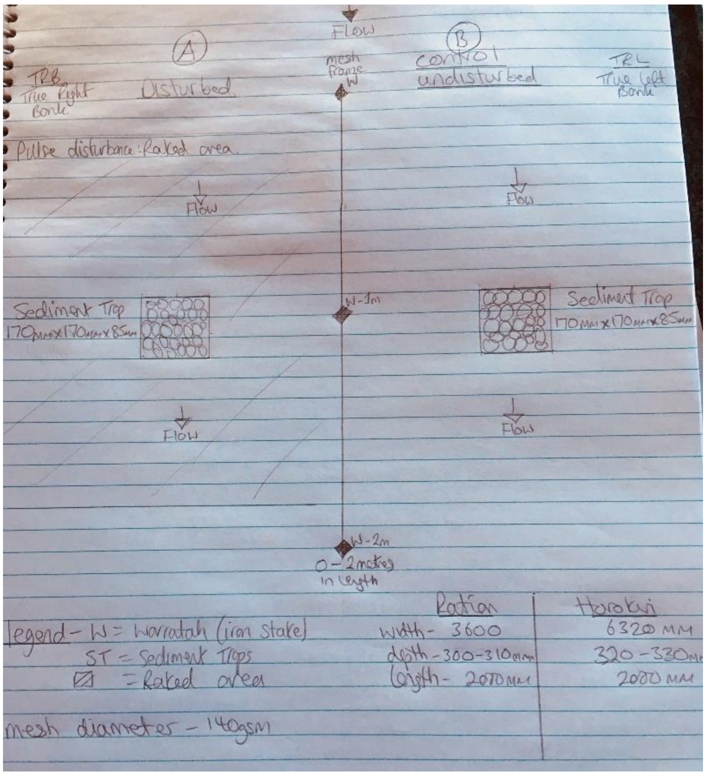


Figure 13: Initial sketch of the experiment site layout (site A is the pulse disturbed and site B is the control press)

Figure 14: Photograph of the prepared sediment traps with 8mm drilled holes.

4b.2 Methods to clean gravel, cobbles or rocks before the experiment started

Each sediment trap, a 2.2l plastic container, was filled with washed cobbles and gravel. The traps would act as collectors of suspended solids. The cobbles and gravel were washed, dried and removed before being inserted into the traps ready for installation as shown in Figure 15.

- Collect deposited dry gravel, cobbles or rocks from the side of the stream into buckets.
- Take the buckets to the field lab to wash, brush and clean the collected gravel, cobbles and rocks using water through a hose and nozzle system.
- Clean off mud, sand or debris from all surfaces

- Using a sieve, clean the gravel, cobbles or rocks for a second time using a facet over a basin or clean surface that is drained
- Once the gravel, cobbles or rocks are cleaned and dried randomly drop them into sediment traps ready for the experiment. (Do not pack the gravel, cobbles or rocks into the trap)
- Each trap is filled to the top randomly, without uniformity.
- Place the lid of the trap onto the trap ready to be installed into the stream bed.

Figure 15: Photograph of Horokiri Stream (black traps) and Ration Creek (blue traps) ready for installation with clean fill

4b.3 Methods on how to use the drain drag to rake the stream bed

I used a drain drag tool which has right angle forks to rake the stream bed (Figure 16). The tool is heavy but very good at creating a pulse disturbance with its long forks. I raked the stream bed by starting at the stream bank and moving towards the mesh divider. This process scraped the bed of the stream uplifting macrophytes from the bed and thereby releasing plumes of suspended sediment causing a pulse flushing event. Each plume was calculated using the Cawthron Sediment Assessment Method 2 (Clapcott et.al., 2011) to evaluate an In-stream visual estimate of % sediment surface cover at the time of raking.

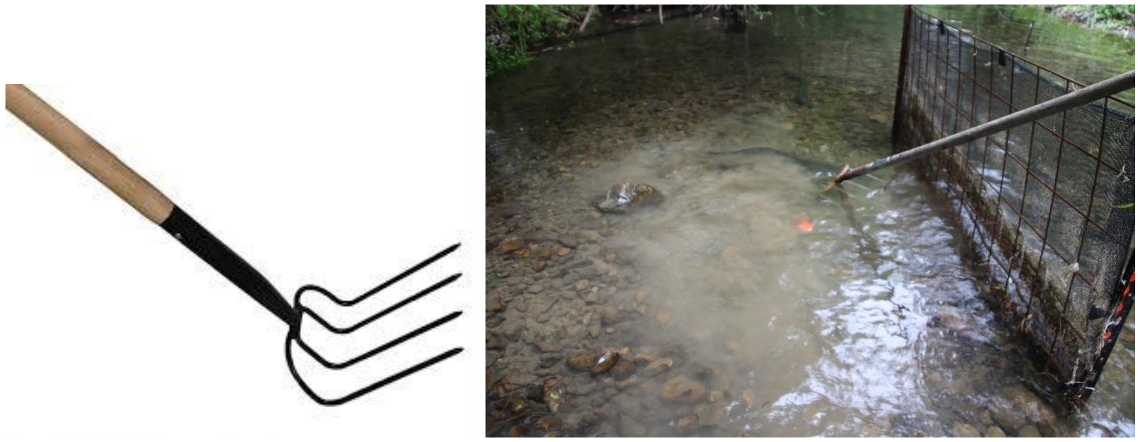


Figure 16: Photo of a drain drag tool (source: google) and photo of a disturbance showing the plume of resuspendable sediment in the water column in Horokiri Stream after raking.

4b.4 Sediment assessment method – resuspendible sediment (plume)

I used Sediment Assessment Method 5 (Clapcott et al. 2011) to assess how much sediment was deposited in the streambed. This method is best applied in an area where flow is between 0.2 0.6 m/sec and depth is between 20 and 50 cm. Depth and velocity may be estimated and are mainly recorded to ensure the method was applied in appropriate and comparable conditions. This rapid qualitative assessment of the amount of total resuspendible solids deposited on the streambed results in a score from 1- 5, where 1 = little/no sediment and 5 = excessive sediment. I assessed each plume after the weekly disturbance by raking, remembering that a plume is affected by flow and rainfall.

4b.5 Assessment of disturbance

A weekly simulated pulse disturbance was created by raking the streambed to create a resuspendible sediment plume in the water column over the experiment sites. By installing traps which are free from sediment filled with cobbles and gravel into the stream substrate we captured deposited fine sediment over a seven day interval. By removing and examining these traps weekly to calculate the deposited sediment (<2mm) in grams and identify any macroinvertebrate that had moved into the new vacant habitat (trap) within the stream substrate. Assuming the 21 day press control trap would have the same amounts of deposited fine sediment and macroinvertebrate as the cumulative result from 3 x weekly flushing traps on the opposite side of the experiment mesh fence. The term sediment refers to fine inorganic material less < 2 mm in size, encompassing, sand (< 2000 to > 63 μm), silt (< 6 to > 4 μm) and clay < 4 μm). Monitoring upstream of the experiment site to reduce any confounding effects of variables caused by other land owners. One half of the stream was the control which had a sediment trap installed in the stream bed for three weeks. The other side has a weekly pulse disturbance manipulation at seven-day intervals to determine and calculate the rate of sediment deposition and its effects on streambed ecology by collecting and correctly identifying the macroinvertebrates in the traps. The manipulation treatment of raking cobbles along the disturbed side by a metal garden rake to simulate a pulse flushing event. Side A (control) is left undisturbed. Townsend, 1996 states, Disturbances in streams often take the form of bed movements during periods of high discharge; because of differences in flow regimes and in the substrata of stream beds, some stream communities are disturbed more frequently and to a greater extent than others. Care must be taken to quantify disturbances in terms of characteristics of the event itself (e.g., the magnitude of a flood). For this reason, the pulse flushing events of raking the streambed, triggered every Friday at 0900am in Ration Creek and 0930am in Horokiri Stream required quantitative measurements of disturbance so that further comparisons can be made in the future. New methods by Poff and Ward (1989, 1990) offered a rigorous quantitative framework that expanded the typical monthly to annual scope of study to interannual scales and the spatial extent from individual reaches to regional and continental scales.

- Intensity: Four prongs of the drain drag pulled through the substratum in strokes of one – two metres by the same person throughout the experiment. Low intensity.
- Duration: continued raking between the bank and mesh fence pulling the drain drag towards you from upstream to down then repeated. Five-minute duration.
- Frequency: Once a week at 9am on each Friday during February 2019. Disturbance Interval one Friday 0900am 1-8/02/19, interval two Friday 0900am 8-15/02/19 and interval three Friday 0900am 15– 22/02/19 and interval four Friday 0900am 22-28/02/19.
- Weather: Rainfall and flow was recorded daily. There was no significant rainfall during the experiment in February.

4b.6 Continuous water quality testing

Temperature, dissolved oxygen and nitrate-nitrogen were recorded every 15 m using a TriOS TriBox3 centralised sensor controller with hyperspectral process sensor[5] (Trios, Germany). Trios specifications are covered in this page footnote. This type of continuous monitoring provides minimum and maximum levels of temperature, dissolved oxygen and nitrate-nitrogen levels in each stream so that we can compare 24-hour fluctuations over seven days. The sensor

[5] https://www.controlcomponents.com.au/Open-File/1063/TriBox%20Mini%20-%20datasheet.pdf

was elevated 10cm off the streambed and placed on bricks to allow the current to flow through the hyperspectral sensor in both the riparian zones during the experiment in February and was set to record every 15 seconds.

4b.7 Other methods replicated in the experiment from the assessment phase

- 4a.2 Methods to deploy sedimentation traps, evaluate rates and size fractionation
- 4a.3 Installation methods for sediment traps
- 4a.5 Method to collect, quantify and identify macroinvertebrates
- 4a.6 Water quality testing
- 4a.9 Methods for visual clarity using black disk

4b.8 Data analysis

Parametric correlation and linear mixed effect models were used to relate stream characteristics to each other and to the measures of catchment development (Harraway, 1993). Multiple regression was used to assess effects of two or more variables on responses. Proceeding with model selection if the global model provided a reasonable fit to the data [likelihood ratio test (F-test) comparing fit of global model and null model significant at a = 0Æ05]. R (Version 1.1.456 – © 2009-2018 RStudio, Inc.) was used for these statistical analyses. For several biotic responses, regression analysis for data from all four zones was combined. In these instances, the data were not independent as stream sites were located upstream or downstream from each other. This lack of independence was included in the statistical model when interpreting the results, examining the responses in both catchments and among all zones. I do not report statistics for regressions within catchments given the small sample sizes (4 zones), but provide a qualitative assessment of the pattern in relation to trends with all sites.

Spearman's rank correlation was used to explore correlation of each biological variable with an environmental variable, as data were not normally distributed. Values closer to zero indicate weak or no correlation. The relationships among physical variables were explored by correlation analysis (Pearson's r), applying Bonferroni-adjusted probability values were reported to provide protection for multiple tests. The Bonferroni post-hoc correction (adapted by Quinn & Vickers 1992)was used to reduce the chances of obtaining false-positive results (type I errors).

A two-way analysis of variance (ANOVA) to test the effect of daily rate to flow by zone was conducted but residuals were non normal. Then a Kruskal-Wallis one -way analysis of variance merging stream and land use data. These were followed by a Wilcox rank sum test with the Wilcox method for handling ties to see where differences were using ‘planned comparisons’.

A linear mixed model was used to relate stream characteristics to each other, assessing effects of the variable flow (x) and the daily depositional rate (y) of fine sediment in our graphs. The data was not independent as stream sites were located upstream or downstream from each other, providing a qualitative assessment of the pattern in relation to trends in all zones (n=32 from each stream). The low summer flow at Ration Creek led to a fairly silty/sandy streambed dominated by snails from fine sediment deposition and in-filling. I conducted a linear mixed effect model to determine the interaction between flow and daily depositional rate. I conducted likelihood tests shown in Figures 23 and 24. After accounting for flow, does the rate differ between streams? A regression of visual clarity was conducted with the predictors flow and rainfall. The R^2 value of the model is shown as a model of best fit. The histogram showed a right skew. These variables are not independent. Maximum likelihood or restricted maximum likelihood (REML) estimates of the parameters in linear mixed-effects models can be determined using the lmer function in the lme4 package for R. T-tests using the Satterthwaite's method to determine the interaction between MCI, land use and total deposited fine sediment were conducted. An Anova was also performed to find a likelihood ration test between MCI and weekly deposited fine sediment from all eight disturbed traps (not the control) for the experiment.

A Bray Curtis dissimilarity calculation was used to quantify the differences in species populations between two different streams (Bray and Curtis, 1957) . A Bray Curtis dissimilarity is a statistic used to quantify the compositional dissimilarity between two different sites, based on counts at each site. It’s used primarily in ecology and biology, with the same size sites, where C_{ij} is the sum of the lesser values for only those species in common between both sites. S_i and S_j are the total number of specimens counted at both sites. The index can be simplified to 1-2C/2 = 1-C when the abundances at each site are expressed as proportions, though the two forms of the equation only produce matching results when the total number of specimens counted at both sites are the same.

$$BC_{ij} = 1 - \frac{2C_{ij}}{S_i + S_j}$$

When information is available prior to a potential impact, the design is often referred to as a Before-After Control-Impact (BACI) design. Smith (2002) states, “The purposes of impact assessment are to evaluate whether or not a stress has changed the environment, to determine which components are adversely affected, and to estimate the magnitude of the effects”. The simplest approach involves collection of data prior to the activity and compares it with data after the activity. I conducted a Before (results taken from 16 week assessment) After (results taken from the experiment) design analysis to determine the impact of the pulse disturbance on taxa and deposited fine sediment in both streams. A Welch Two Sample t-test was conducted, not assuming constant variance on before (assessment results) and after (experiment pulse results) total deposited sediment, taxa richness and depositional rate using a BACI design.

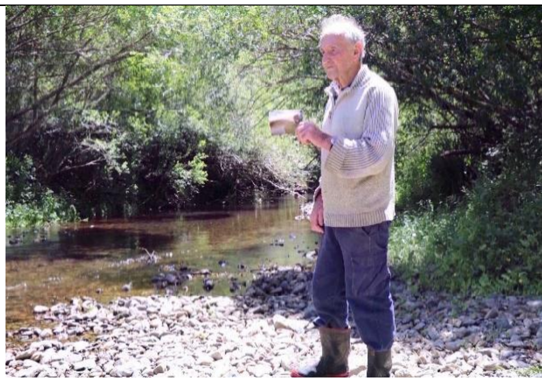
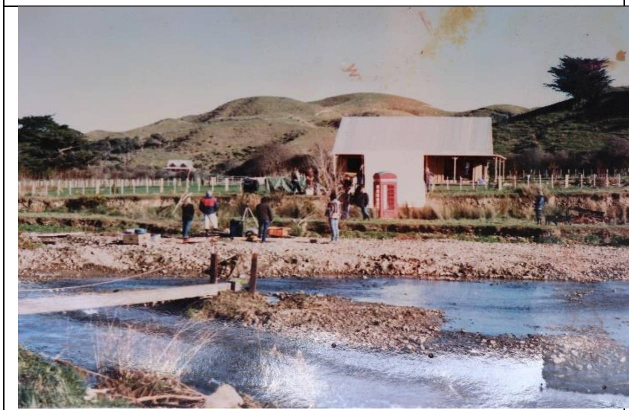
5a. Results of ecological and geomorphological Assessment

5a.1 Photographic comparison of riparian and vegetation cover

Mr Glover provided historical photographs as a qualitative comparison of Horokiri Stream zone 2 from 1967 to 2019 in Table 4.

Table 4: A historical photographical comparison of Horokiri Stream

	
1964 Horokiri Stream looking south from Glover Hill. The Macracarpa seen next to Horokiri Stream ↑ & ↓	2018 Horokiri Stream looking south from the top of Glover Hill

	
1964 Horokiri Stream looking north from Glover ford	2018 Horokiri Stream looking north from Glover ford
	
1975 Foot bridge across Horokiri Stream to Peters House	2018 Ford across Horokiri Stream to Peters House
	The driven-in iron girder in the photograph to the left, is an indicator of the change in the Horokiri Stream since 1974. The iron girder in the photo to the left (identified by arrow) is the exact same girder in the photo above left, seen in the middle of the stream. The stream channel has moved approximately 7 metres westward with both banks now covered in long grass, flaxes, natives and tall canopy trees. The flow and depth of the stream appears much less today.

Mr J Glover provided an aerial photo of the Glovers property taken in 1967 (Figure 17). There are many open fields, a few trees and bushes in the black and white photo. Note the new colour photo in (Figure 18) taken from Google Maps in December 2018 shows installed riparian zones, woodland, wetlands, wind breaks all planted by Mr Jim Glover over the last 50 years and by the early1980s influx of smaller lifestyle blocks.

Figure 17: Glovers homestead Sept 1967 (Mr Glover aerial photo)

Figure 18: Glovers Homestead December 2018 (Porirua City Council GIS maps)

SEV Scores out of 10 for each zone are shown in Table 5. The SEV scores show that the riparian zones (RZ RIP and HZ RIP) had the highest score with the wetlands having the lowest.

Table 5: SEV scores by zone

HZ WET - 0.65	HZ RIP – 0.76	HZ HOBBY – 0.6	HZ AGRI – 0.5
RZ WET – 0.65	RZ RIP – 0.7	RZ HOBBY – 0.65	RZ GOLF – 0.5

Figure 19 shows two photos of Ration Creek pre and post riparian planting. Note the tree stump and the lines of apple trees in the background are in both photos. The small concrete weir is visible in both photos at the stream bend. The riparian buffer was installed in 2009 by the GWRC Biodiversity and Streams Alive Programme. These two photos represent a before and after span of 20 years. Figure 20 shows pre and post riparian planting in Ration Creek Orchard spanning 10 years. The stock (20 sheep) have been fenced out since 2009.

Figure 19: Photos of Ration Creek from Reidy 1998 and Mair 2018 (large tree stump in both photos)

Figure 20: Pre-riparian planting June 2009 compared to post riparian zone 2019 (Gate to orchard on left)

5a.2 Flow and sediment

The lowest flow rate in Ration Creek during the assessment was 0.08 cumecs, Horokiri Stream was 0.11 cumecs (n = 64). Figure 21 shows the recorded flow rate during the assessment.

Figure 22 shows the interaction between average daily deposition rate and deposited fine sediment by land use zones (n = 64, R^2=0.86). To calculate the 21 day depostional rate, the trap deposited sediment weight in grams/2.89^2/21. Highest depositional rate was RZ GOLF of 3.82, with a total deposited fine sediment of 626g (cumulation of 4 x 21-day tests). Results from up and downstream of the riparian zones showed a higher deposited fine sediment. Both the riparian zones had the lowest total deposited fine sediment and lowest depositional rate. The riparian planting in zone 2 in both streams had a positive effect on the daily depositional rate compared to the upstream land use management zones.

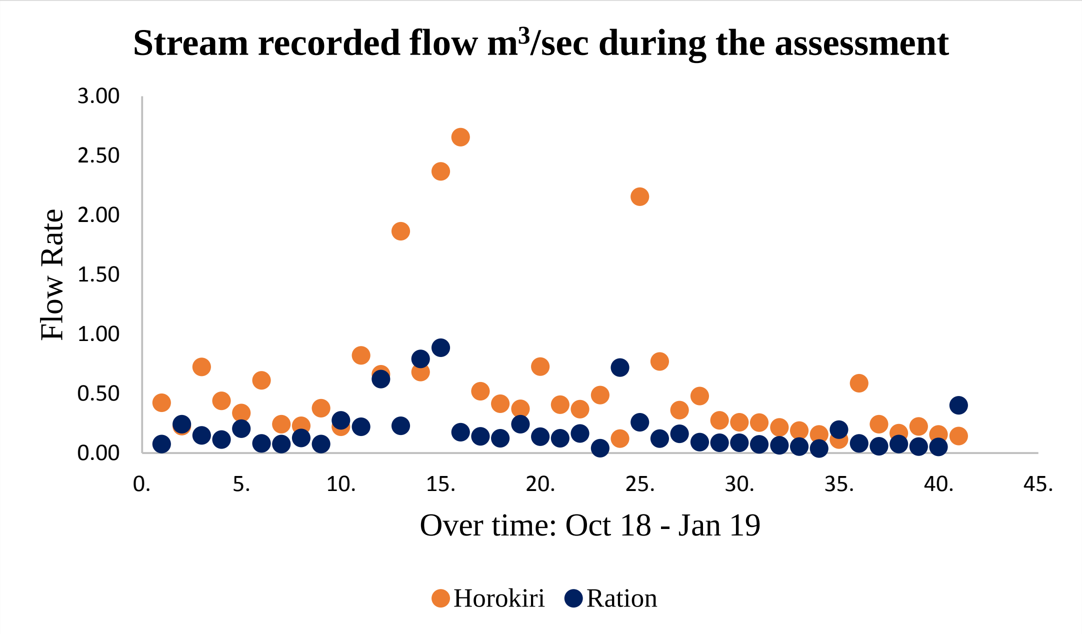


Figure 21: Recorded flow rate in m^3/sec over the assessment (n=84). They are not independent.

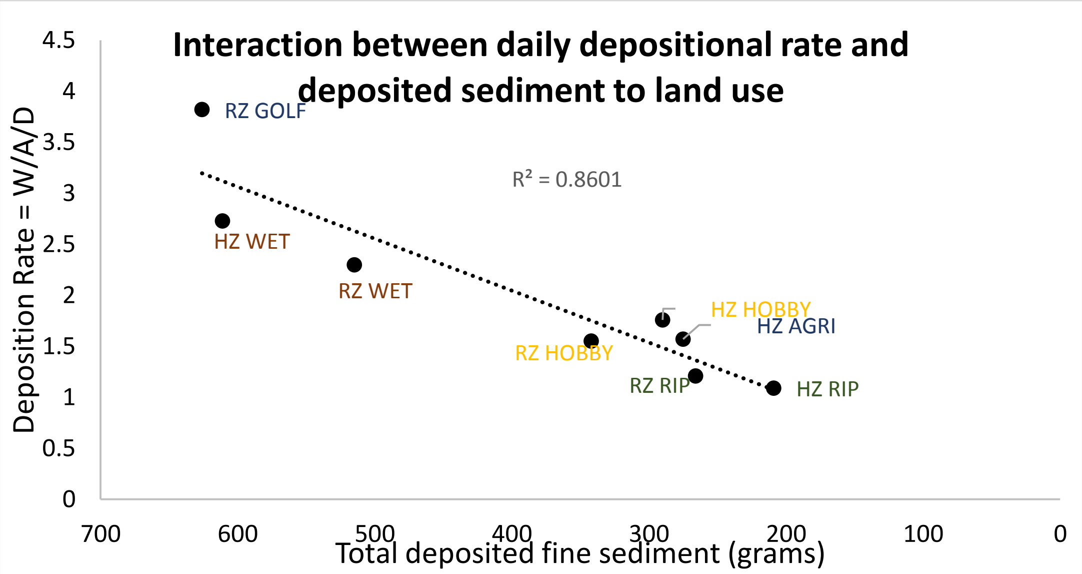


Figure 22: Interaction between daily deposition rate and deposited fine sediment (n=64) across land use zones. The R^2 value of the model is shown as a measure of model best fit. These variables are not independent. Each marker

represents a land use management zone along a stream. X-axis reversed. The deposition rate (x-axis) is calculated from the traps deposited sediment weight in grams divided by 2.89^2 divided by 21 ranging from 0.5 to 4.

There was no difference between streams P(*X2>241.84)* = 0.19. Data shown in Figures 23 and 24. Did flow have an effect? After accounting for stream, did the flow affect depositional rate? P(*X2>241.84)* = 0.24. ANOVA on deposition rate to flow by land use zone (n = 64, p = 0.41) ns. Below is the complete line by line ANOVA calculation from R of several independent variables being tested in different models.

```
## test, after accounting for stream, does the flow effect rate?
> reg4 <- lmer(Dep~stream+(1|Zone),data=Data_for_R)
> anova(reg4,reg2)
refitting model(s) with ML (instead of REML)
reg4: Dep ~ stream + (1 | Zone)
reg2: Dep ~ Flow + stream + (1 | Zone)
     Df    AIC    BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
reg4  4 251.22 259.86 -121.61   243.22
reg2  5 251.84 262.63 -120.92   241.84 1.3827      1     0.2396
## does flow have an effect?
> reg3 <- lmer(Dep~Flow+(1|Zone),data=Data_for_R)
> reg5 <- lmer(Dep~1+(1|Zone),data=Data_for_R)
> anova(reg5,reg3)
refitting model(s) with ML (instead of REML)
reg5: Dep ~ 1 + (1 | Zone)
reg3: Dep ~ Flow + (1 | Zone)
     Df    AIC    BIC  logLik deviance Chisq Chi Df Pr(>Chisq)
reg5  3 250.26 256.74 -122.13   244.26
reg3  4 251.58 260.21 -121.79   243.58 0.686      1     0.4075
```

I cannot reject Ho_1 as there was no relationship between flow and depositional rate depending on land use. Visual clarity was not associated with flow (n = 64, R^2 = 0.14). Figure 23 trendlines by zone shows RZ1 Wet, RZ3 Hobby & RZ4 Golf are all positive with RZ2 Rip was negative for Ration. Figure 24 showing trendlines by zone for HZ1 Wet, HZ3 Hobby & HZ4 Agri are positive with HZ2 Rip stable in Horokiri.

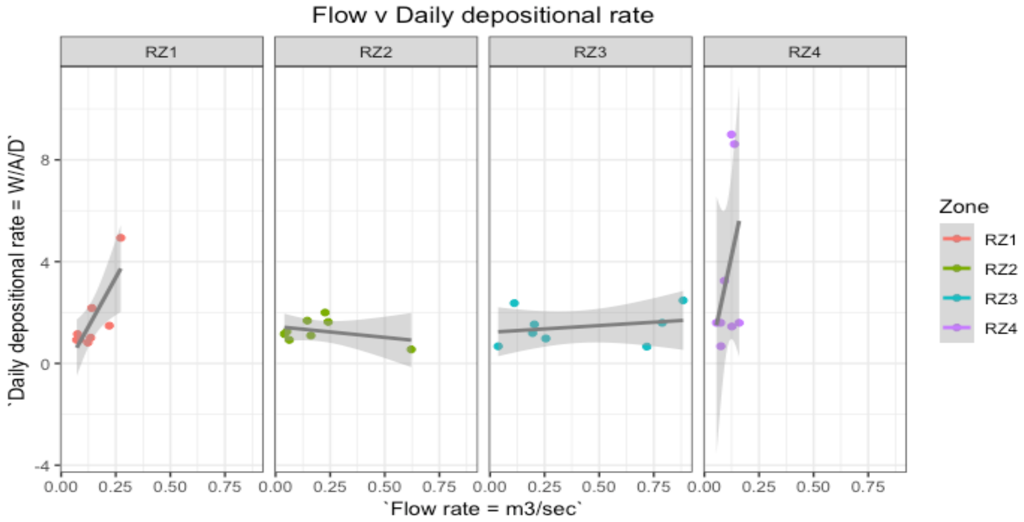


Figure 23: These zones are not independent of each other. Samples of flow in relation to the daily depositional rate in each zone (n=8) per zone. The shading shows the 95% confidence level. RZ1 Wet, RZ2 Rip, RZ3 Hobby & RZ4 Golf

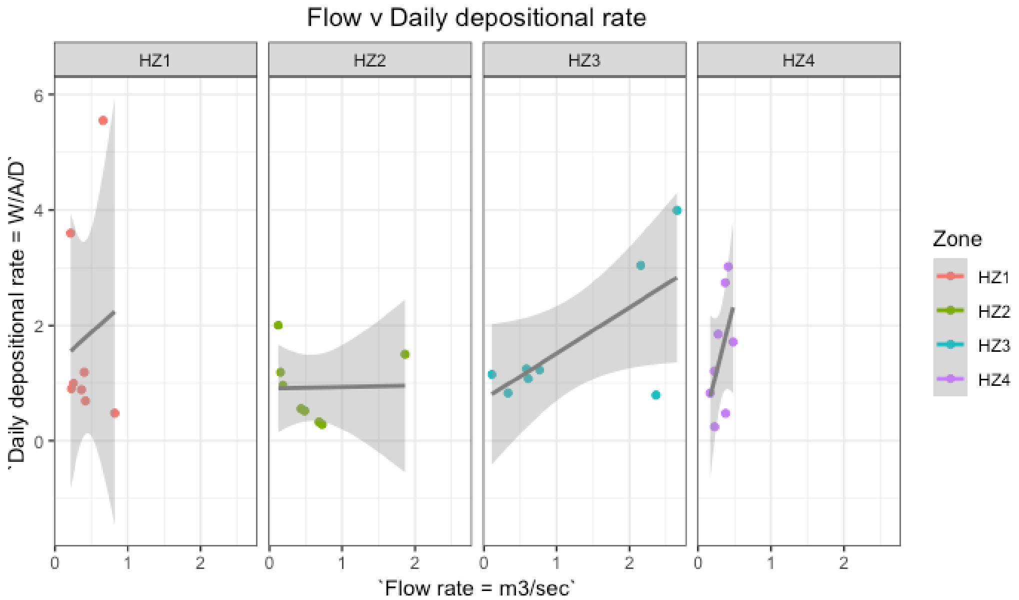


Figure 24: These zones are not independent of each other. Samples of flow per zone in relation to the daily depositional rate (n=8) per zone. The shading shows the 95% confidence level. HZ1 Wet, HZ2 Rip, HZ3 Hobby & HZ4 Agri.

Figure 25 shows the zones with lower elevation (in metres) where deposition dominates did. RZ Golf had the highest elevation point and according to Miller (1990) an erosional (vertical) zone. Our data showed the golf course at an elevation of 67.33m had the highest deposited fine sediment and depositional rate. A regression between elevation and daily depositional rate by zone (n = 8, $R^2 = 0.46$).

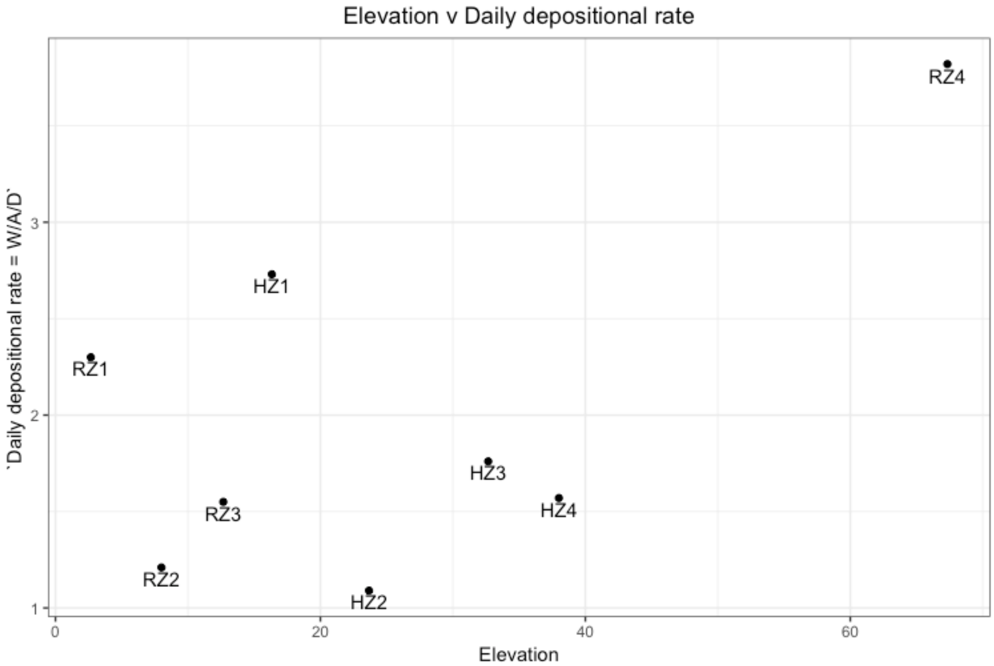


Figure 25: Graph shows elevation in metres (x-axis) compared to the average daily depositional rate (y-axis). Each marker is the median of eight samples within that zone over 16 weeks (n=64). RZ = Ration Creek zones 1=Wet, 2=Rip, 3=Hobby, 4=Golf and HZ = Horokiri Stream zones 1=Wet, 2=Rip, 3=Hobby, 4=Agri

5a.3 Macroinvertebrates

Figure 26 shows deposited sediment on MCI depending on land use groups. Positive trend (as sediment increases, MCI increases) for Riparian and Agri semi intensive sheep grazing. These two groups had the lowest recorded deposited sediment. Negative trend (as sediment increases, MCI decreases) for golf course, hobby farm and wetland. Golf course and wetland had the highest deposited sediment. There were more mayflies in Horokiri Stream with more stick caddisflies in Ration Creek with figures 29 and 30 illustrating the abundance of each taxon in each stream. Both streams had large abundance of the common mud snail Potamopyrgus (Molluscs). The median MCI score was higher in Horokiri Stream (115.38) than Ration Creek (112.5). Total abundance was 2542 at Horokiri, compared with 1293 at Ration during the assessment. The abundance of invertebrates was not the same in each zone. Conducting a Spearman rank correlation between MCI and deposited sediment. Results plotted in Figure 25 (n = 32, rho -0.0036, p = 0.98) non-significant. Looking at stream, Spearman's for Ration at Figure 27 (n = 16, rho -0.243, p = 0.36) as deposited sediment increased, MCI decreased, non-significant. Spearman's for Horokiri at Figure 28 (n = 16, rho 0.247, p = 0.35) as MCI increases with sediment, non-significant. Measuring MCI by analysing the interaction between land use and sediment. The two models are significantly different which means the interaction term is important to include. A likelihood ratio test determined that the effect of deposited sediment (in grams) on MCI depends on the land use, ($X2$ = 11.81, df = 4, p = 0.019). Note the difference between Hobby farm Ration with <10 sheep to Hobby farm Horokiri with <10 cattle. Cattle are bigger, heavier beasts than sheep and appear to have a greater negative effect on MCI as shown in column two.

The effect of sediment (in grams) on MCI depending on land use

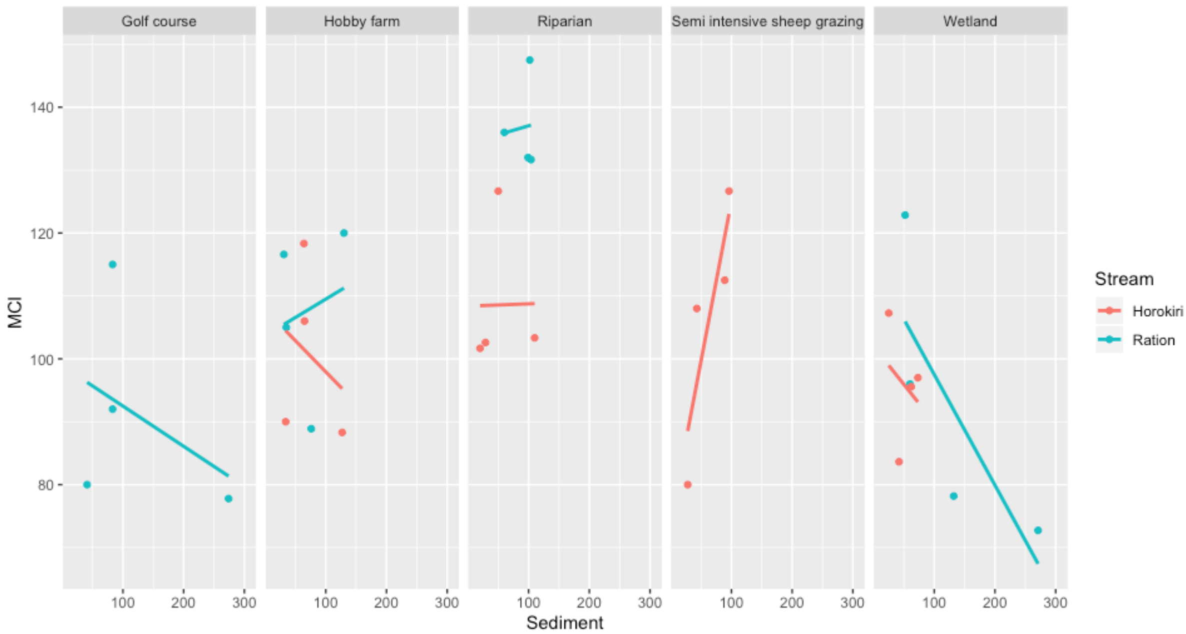


Figure 26: The columns show land use zones with Horokiri stream in red and Ration creek in blue. There are trendlines in each column showing the effect of sediment on MCI.

Figures 27 and 28 illustrate the relationship between MCI and sediment in each stream. There was more deposited sediment in Ration Creek (275g) with extreme values (outliers) compared with Horokiri Stream (125g).

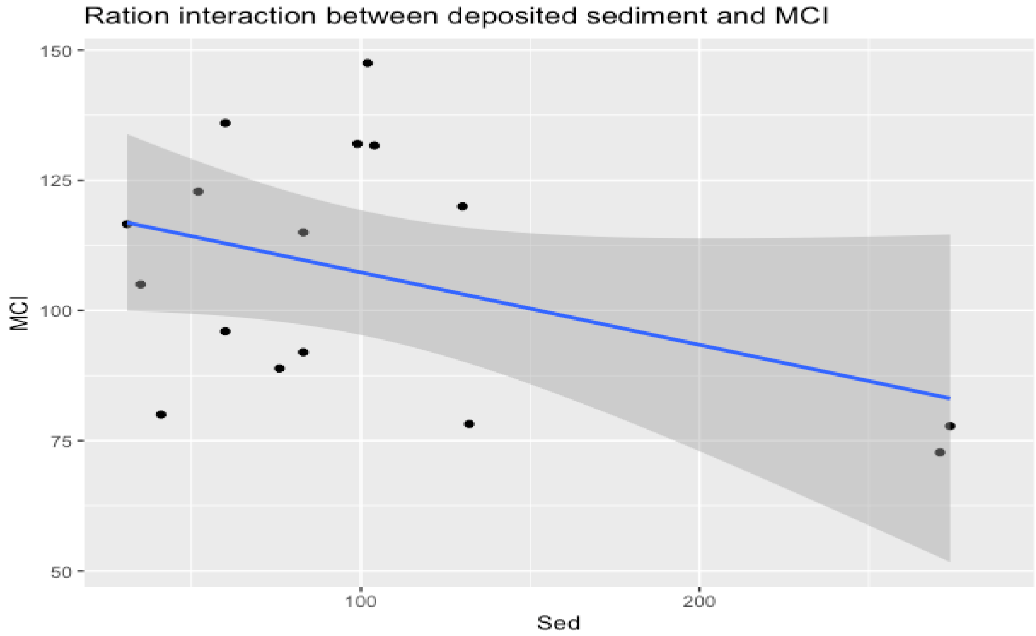


Figure 27: Ration Creek interaction between MCI scores and 'Sed' deposited sediment (in grams) in our traps across 4 zones(n=16). More deposited sediment (up to 275g) in Ration Creek. Each coloured plot was a Surber sample. The shading in the graph show the 95% confidence interval. The negative trendline shows as deposited sediment increased, MCI decreased.

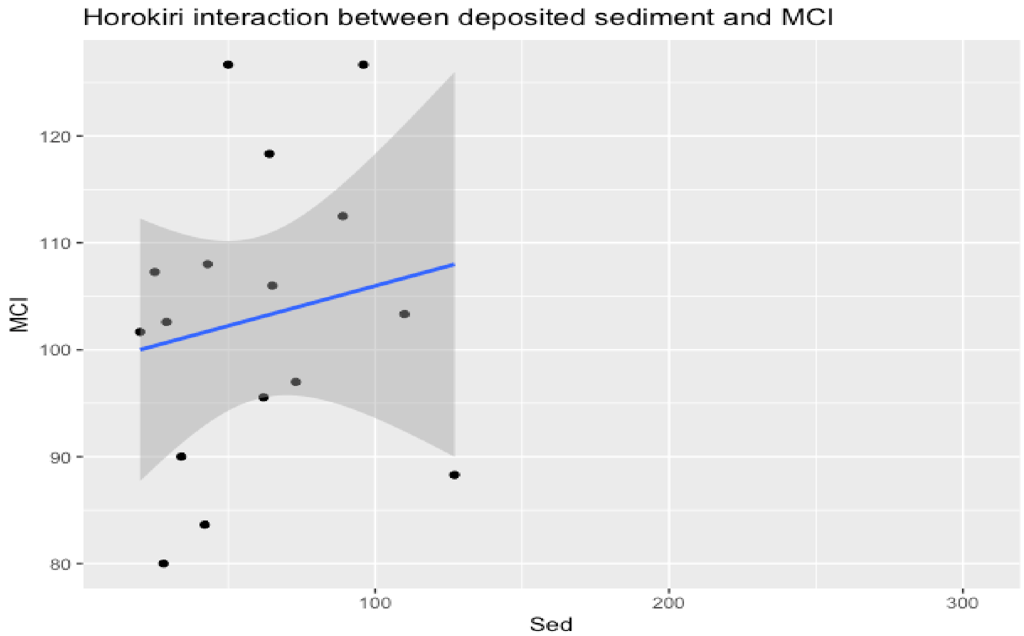


Figure 28: Horokiri Stream interaction between MCI scores and 'Sed' deposited sediment (in grams) in our traps across 4 zones(n=16). Less deposited sediment (<125g) in Horokiri Stream. Each coloured plot was a Surber sample. The shading in the graph show the 95% confidence interval. The positive trendline shows as deposited sediment increased, MCI increased.

Figures 29 and 30 show the macroinvertebrate community composition in Ration and Horokiri during the 6 months of the assessment and experiment. Ration had 50% of the total taxa captured in traps. Horokiri had 89% of the total taxa captured in traps.

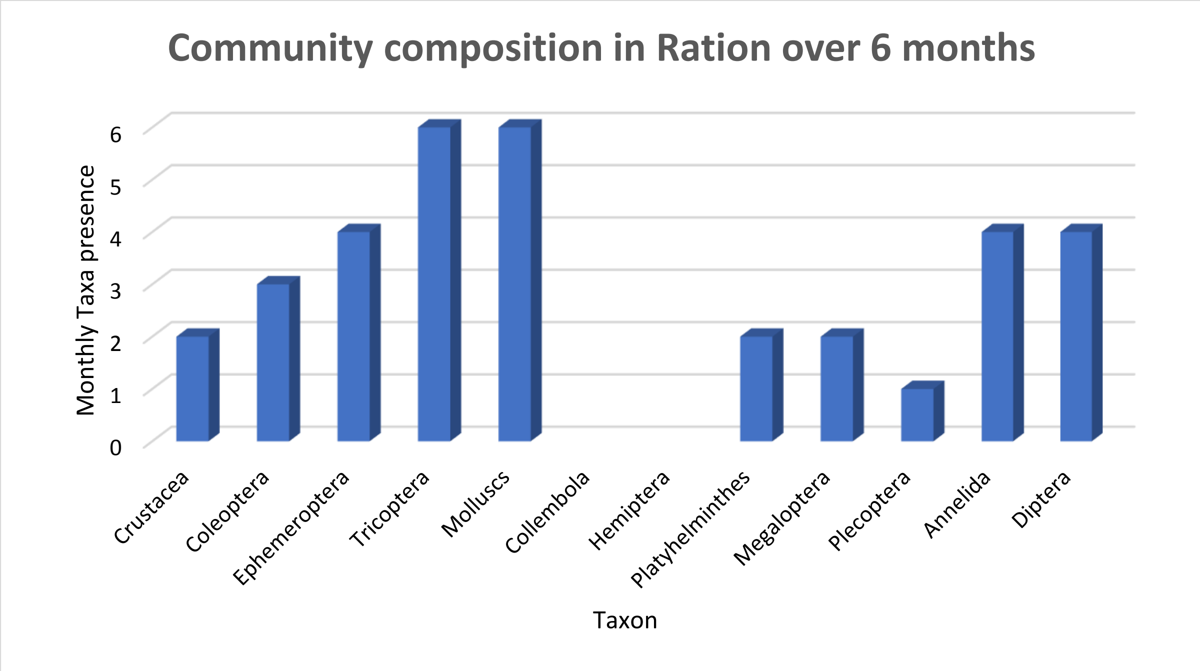


Figure 29: Macroinvertebrate community composition in Ration Creek during the 6month research.

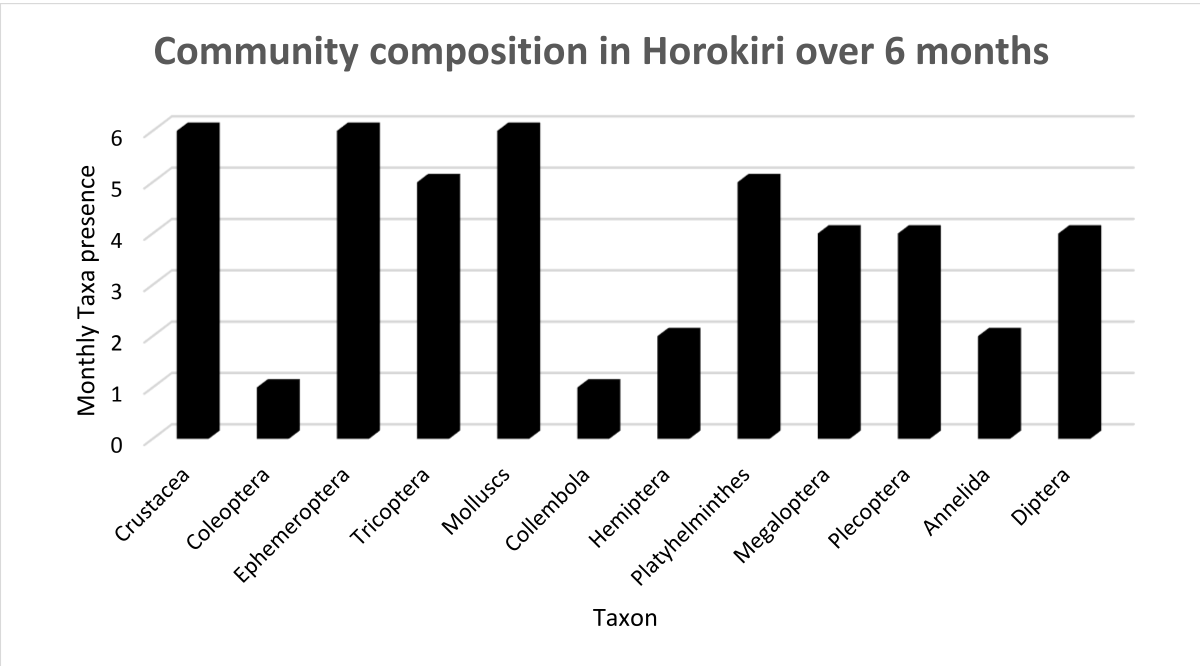


Figure 30: Macroinvertebrate community composition in Horokiri Stream during the 6month research.

5a.4 Water quality testing

Water quality is a suite of spot measurements of a range of parameters. There was a difference in temperature, specific conductivity and total dissolved solids (TDS) between zones in both Horokiri and Ration. Temperature, conductivity and TDS did decrease from zone 1 upstream to zone 4. Conductivity and TDS scores were higher in Ration changing weekly. Differences in pH, TDS and conductivity scores were different between streams as shown in Figure 31, showing the relationship between land use and four water quality variables plotted. There were differences between riparian HZ RIP and RZ RIP and hobby farm HZ HOBBY and RZ HOBBY. Zone 1 is wetland, zone 2 riparian, zone 3 hobby farm and zone 4 Horokiri Stream is semi-intensive grazing with golf course at Ration zone 4. Horokiri Stream had higher pH values in the upstream sampling zones. Raw spot sampling data at Appendix 2.

The pH was different across land use zones depending on the stream ($F_{(1,56)} = 4.9899$, $p = 0.01$). I created a continuous variable of land use, which was broken down to stream. The effects of land use on dissolved oxygen (DO) mg/L is non-significant depending on stream ($F_{(1,56)} = 0.1614$, $p = 0.85$). The effects of land use on conductivity is non-significant depending on stream ($F_{(1,56)} = 3.4682$, $p = 0.01$). The effects of land use on total dissolved oxygen is significant depending on the stream ($F_{(1,56)} = 3.7781$, $p = 0.03$). Statistical results for the effect of land use (riparian and hobby farm) on water quality variables pH, DO, TDS and Conductivity in Table 6.

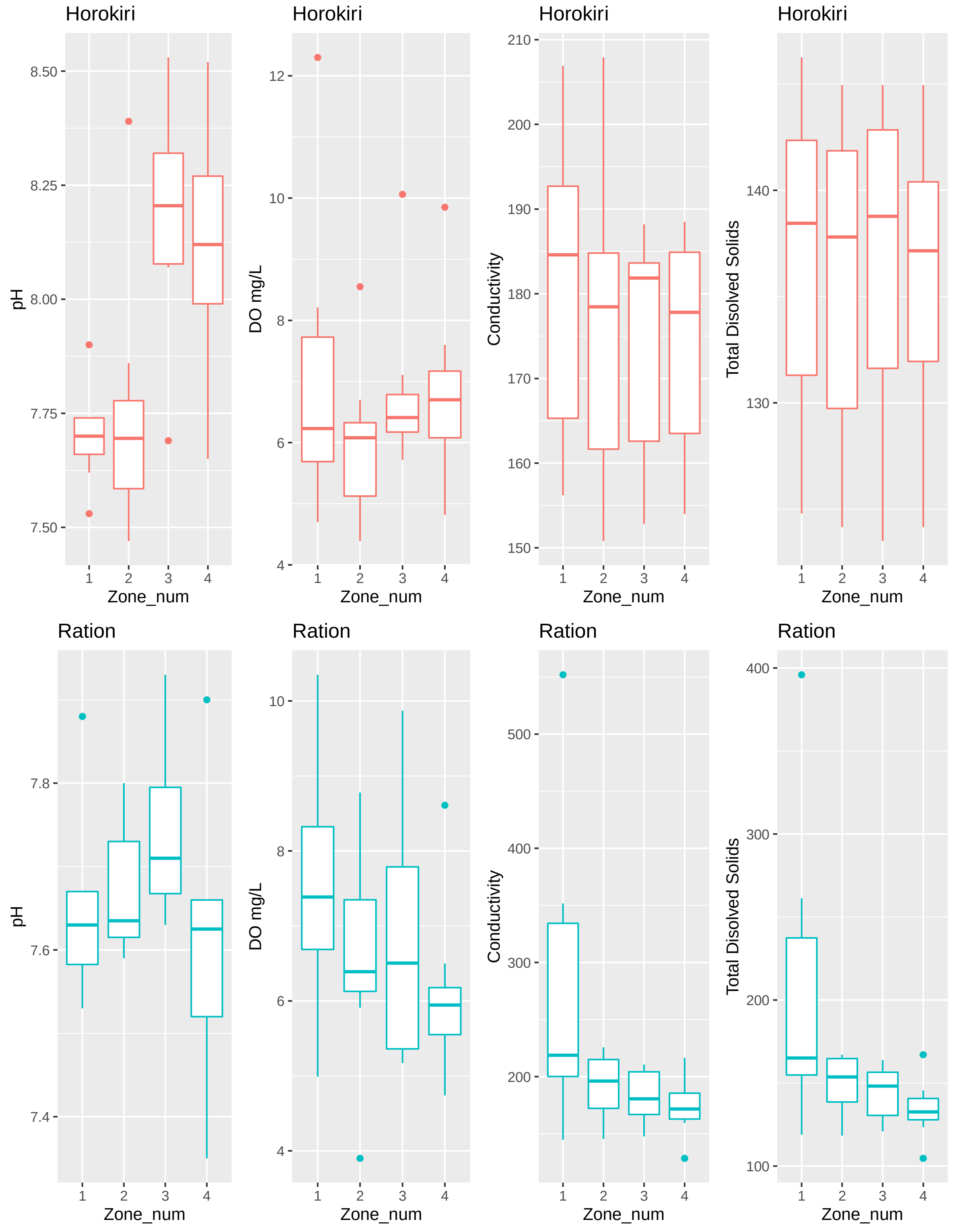


Figure 31: Eight boxplots show the results for the effect of Land use on four water quality variables of pH, DO mg/L, Conductivity and TDS. Eight samples were taken per zone (n=64). Conducted at the same location, same depth of 20cm and same time each day. The stripe shows median, boxes show inter-quartiles and whiskers show range. Zones 1 are Wet, 2 are Rip, 3 are Hobby Ration 4 Golf and Horokiri 4 is Agri.

Table 6: T-test with p-values of planned comparison on the Riparian and Hobby Farm zones using Welch two sample t-test from 64 samples. Description of Non-significant = n.s.

T-test n=64	HZ RIP (Buffer 20-30m) & RZ RIP (Buffer 2-5m) Riparian planned comparison	HZ HOBBY (<10cattle) & RZ HOBBY (<10sheep) Hobby farm planned comparison
pH	*P value* 0.001(**significant**) Mean: Horokiri 7.752 Ration 7.670	*P value* 0.45 (n.s) Mean: Horokiri 8.177 Ration 7.741
DO mg/L	*P value* 0.96(n.s) Mean: Horokiri 6.325 Ration 7.350	*P value* 0.41 (n.s) Mean: Horokiri 6.832 Ration 6.797
Conductivity	*P value* 0.46 (n.s) Mean: Horokiri 175.85 Ration 190.62	*P value* 0.27 (n.s) Mean: Horokiri 174.47 Ration 181.92
TDS	*P value* 0.24 (n.s) Mean: Horokiri 136.05 Ration 148.60	*P value* 0.13 (n.s) Mean: Horokiri 136.90 Ration 144.46

Table 7 shows RZ RIP riparian (intermittent canopy) had a lower temperature range than HZ RIP riparian (total canopy cover) during the 16 week assessment. The Golf course RZ GOLF had the smallest Diurnal Temperature Range (DTR). Zones 1 were affected by tidal wash. Land use appeared to have an effect on the water quality.

Table 7: A quick reference table outlining the DTR across all zones. The temperature range reduced as we sampled upstream. Ration results are on the left (beige colour) and Horokiri on the right in yellow.

Temperature	Min	Max	**Range**	Temperature	Min	Max	**Range**
RZ WET	14.1	20.8	**6.7**	HZ WET	14.8	21.5	**6.7**
RZ RIP	14.1	18.9	**4.8**	HZ RIP	15.1	21.5	**6.4**
RZ HOBBY	12.7	18.1	**5.4**	HZ HOBBY	14.3	18.5	**4.2**
RZ GOLF	14.4	18.1	**3.7**	HZ AGRI	13.7	17.9	**4.2**

I was unable to locate continuous flow data from either Allen or NIWA's research, however there was spot measurements of nutrients. Table 8 shows a historical review. The historical analysis comparison revealed a recovering community of invertebrate in Horokiri Stream in Figure 32. Allen (1951) analysed 162 benthic invertebrate samples taken with a 1 square foot 'sledge' which was pulled upstream for one foot. Allen (1951) analysed the invertebrate both numerically and gravimetrically which was published long before the MCI was invented. This made some comparisons difficult to correlate with the current MCI standards. During Allen's summer survey in 1939 the weather was fine and the stream levels low. Allen (1951) divided the stream into five zones on the basis of similarity of physical features. NIWA conducted research in 1996, choosing eight 200m sections of stream and sampled five randomly chosen 10m sites within each section. A comparison of the data showed that Allen's study of 162 samples and NIWA's study of 42 samples showed a number of changes. The difference in recorded caddisflies from the data sets 50.8% in 1939 and 18.4% in 1996 and the drastic reduction in helicopsyche from 33.8% of the fauna in 1939 compared to 0.2% in 1996. The MCI values and methodology to quantify 'Allen's Taxa' is outlined in the NIWA report No83: Horokiri stream 50 years on page 15 (1996). Allen (1951) used six zones, NIWA (1996) used 5 zones and I was able to secure access to 4 zones along Horokiri Stream to compare the MCI scores. NIWA and this study used Surber sampling protocols. This study conducted 32 samples during both winter and summer 2018-2019.

Table 8: Review of historical data found in literature. Allen used 6 zones, NIWA used 5 and I had access to four zones in Horokiri Stream. The scores below show a pattern/trend over time and space (Allan 1951, Healy 1976, NIWA Horokiri Stream Report 1996 and Sinclair 2010)

Horokiri $32.9km^2$	Nitrate g/m^3	Ammonia g/m^3	Phosphate g/m^3	Flow velocity m^3/s	Temp-Celsius	pH	MCI	Turbidity
Allen 1951	0.3		0.18				115.8	
Healy 1976	0.7		0.025	0.81			119	
NIWA 1996	0.5	0.05	0.004		11.8	7.3	96	1.2
Sinclair 2010	0.3	0.01		0.304	8.34	7.175	102	1.5
Mair 2018	0.7	0	0	0.494	10.75	7.285	115	1.7

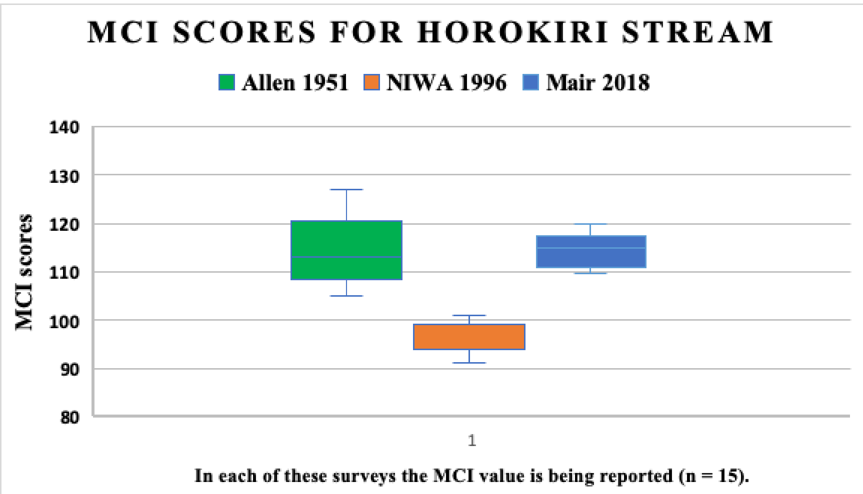


Figure 32: MCI historical comparison of longitudinal zones in Horokiri Stream (Allen used 6 zones, NIWA used 5 zones and Mair used 4 zones). The stripe shows median, boxes show inter-quartiles and whiskers show range.

5b. Results of the manipulative experiment

5b.1 Photographical comparison of the manipulative experiment

There was more observed deposited fine sediment in Ration Creek than in Horokiri Stream before the experiment started. The manipulative experiment took place in riparian zones known as RZ Rip and HZ Rip from the 16 week assessment study. A photographical comparison shown at

Table 9: Photographical comparison between streams per week. First column is Horokiri Stream photos. The second column is Ration Creek photos. Table 9 includes the assessment rating of the resuspendible sediment (plume) after each pulse disturbance in this table.

Table 9: Photographical comparison between streams per week. First column is Horokiri Stream photos. The second column is Ration Creek photos.

<table>
<tr><th>Horokiri Stream – riparian zone</th><th>Ration Creek – riparian zone</th></tr>
<tr><td>
Week 1 disturbed
Resuspendible sediment (plume): 3</td><td>
Resuspendible sediment (plume): 4</td></tr>
<tr><td>
Week 2 disturbed
Resuspendible sediment (plume): 3</td><td>
Resuspendible sediment (plume): 4</td></tr>
</table>

 Week 3 disturbed Resuspendible sediment (plume): 3	 Resuspendible sediment (plume): 4
 Week 4 disturbed Resuspendible sediment (plume): 3	 Resuspendible sediment (plume): 4
 Control: undisturbed (No plume)	

5b.2 Flow and sediment

Flow in Figure 33 was consistent over 21 days then a rain event occurred in week 4 washing through the site. There was no significant change in flow during the 21 days in February 2019, however in week four flow increased due to heavy rain. The weekly pulse disturbance events resulted in increased sediment deposition compared to the background levels of sediment deposition (indicative of a press disturbance) in both streams (Figure 34). I took the control trap out after 21 days, meaning I could only compare 3 x weekly pulse disturbances with a press disturbance of 21 days. The cumulative total deposited sediment after 21 days in Ration Creek stream was 81 g from traps affected by weekly pulse disturbance compared with 60 g from control press trap. In Horokiki, the cumulative deposited sediment in traps affected by weekly pulse disturbance was 84 g compared with 47 g in the control press trap. Figure 31 shows the flow in Ration and Horokiri during the manipulative experiment (n = 28). Despite Horokiri having consistently 0.08 m/sec higher flow on average than Ration, there was no relationship between deposited sediment and flow ($F=1.23$, $df_{1,6}$ $p = 0.3$). Stream had a significant interaction on deposited sediment ($p = 0.001$).

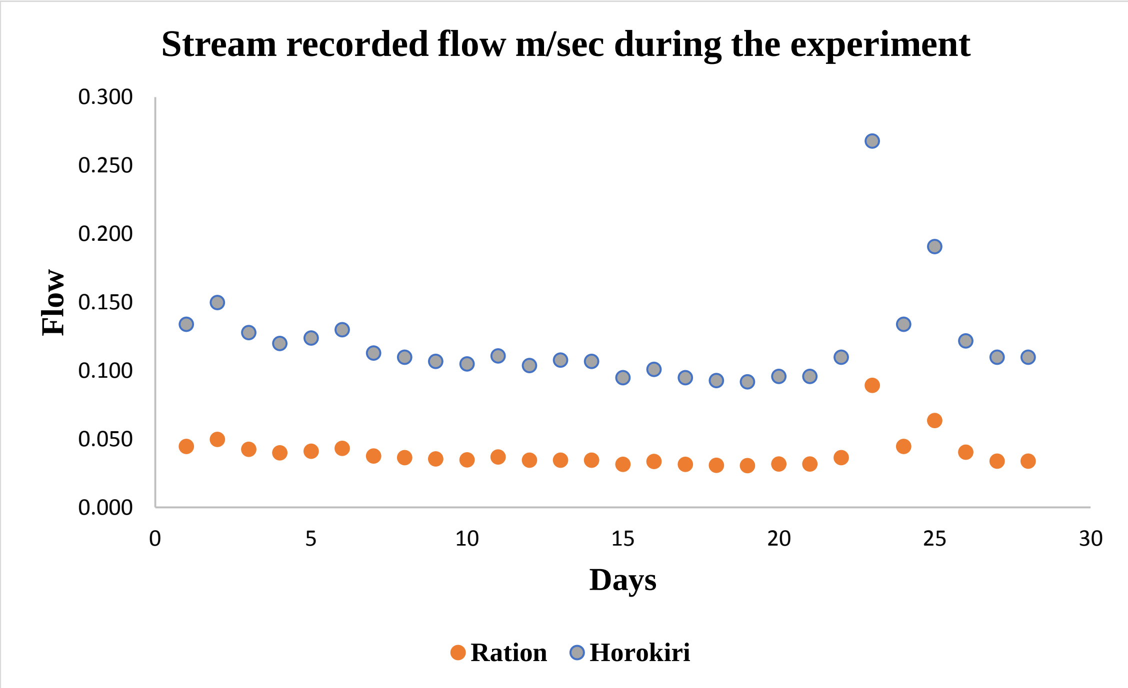


Figure 33: Recorded flow rate in m^3/sec over the experiment (n=28).

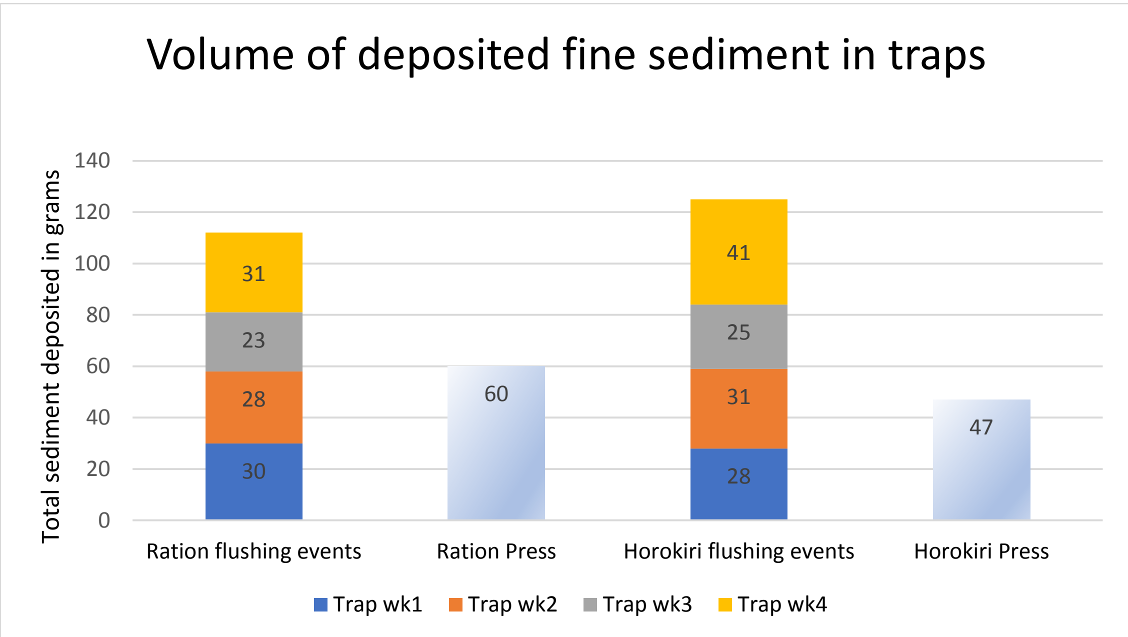


Figure 34: The control was the press disturbance showing the actual weight of total deposited sediment captured in trap over 4 x 7 days in grams. The press disturbance is the background delivery observed in the control side of the experiment. The accumulation of deposited sediment in response to three pulse disturbances was greater than that observed from press disturbance over 21 days.

Figure 35 shows the interaction between flow rate (m^3/sec) and deposited sediment (grams) in both streams.

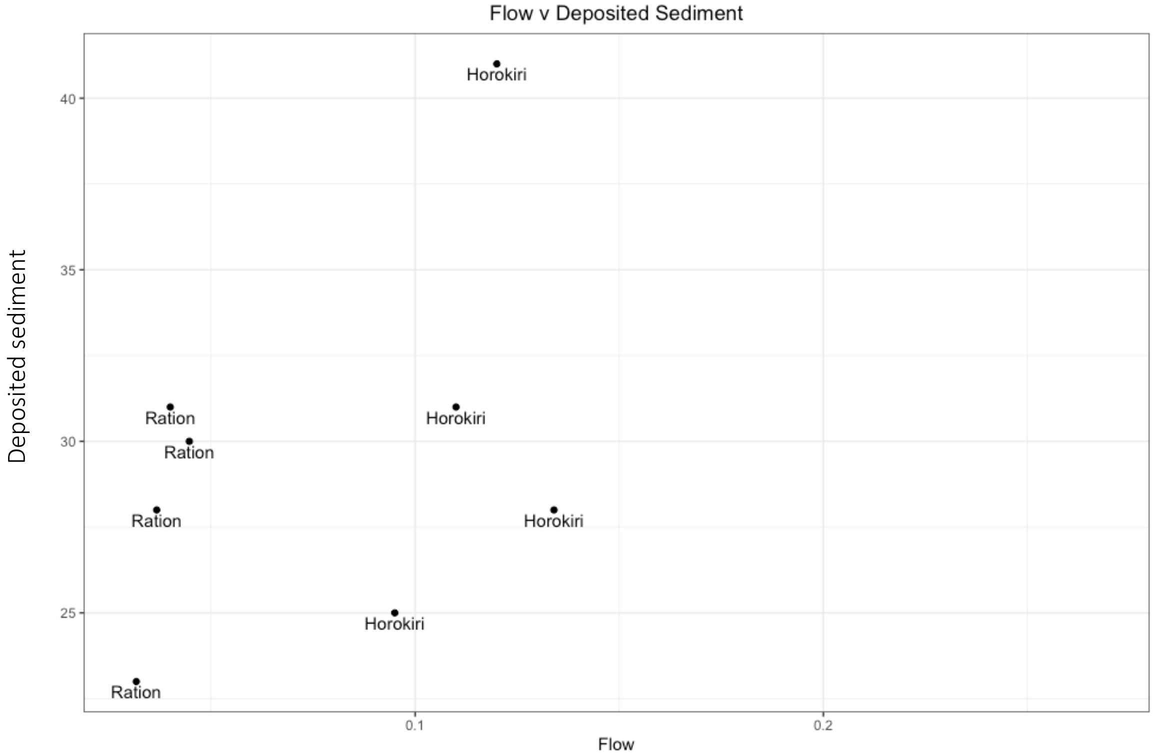


Figure 35: Graph shows how the daily recorded Flow Rate in m^3/sec affected deposited sediment in grams captured in weekly traps, during the experiment (n=4) each stream.

I did conduct a Control before and after test but did not test if interaction is the same, in each treatment (control + intervention) across time. A comparison of sediment depositional rate before and after the manipulative experiment (Figure 36) showed higher sediment deposition after the pulse flushing events (1.55 W/A/D) compared to before during the assessment phase (0.88 W/A/D) in Horokiri ($t = 2.35$, $df = 8.95$, $p = 0.04$), but no significant difference before (1.57 W/A/D) or after (1.38 W/A/D) in Ration ($t = -0.818$, $df = 7.71$, $p = 0.44$). In contrast, a comparison of total deposited sediment before and after the manipulative experiment (Figure 37) showed no significant difference ($t = -1.68$, $df = 5.22$, $p = 0.15$) before (71g) and after (31g) in Horokiki, but significantly more sediment before (92g) compared to after (28g) in Ration ($t = -4.56$, $df = 5.16$, $p = 0.005$). Depositional rate (the rate suspended sediment in the water column settles into a trap) = W/A/D calculated as recorded sediment weight divided by 2.89cm^2 divided by 7 days. Total deposited sediment is the actual weight of sediment captured in each trap in grams.

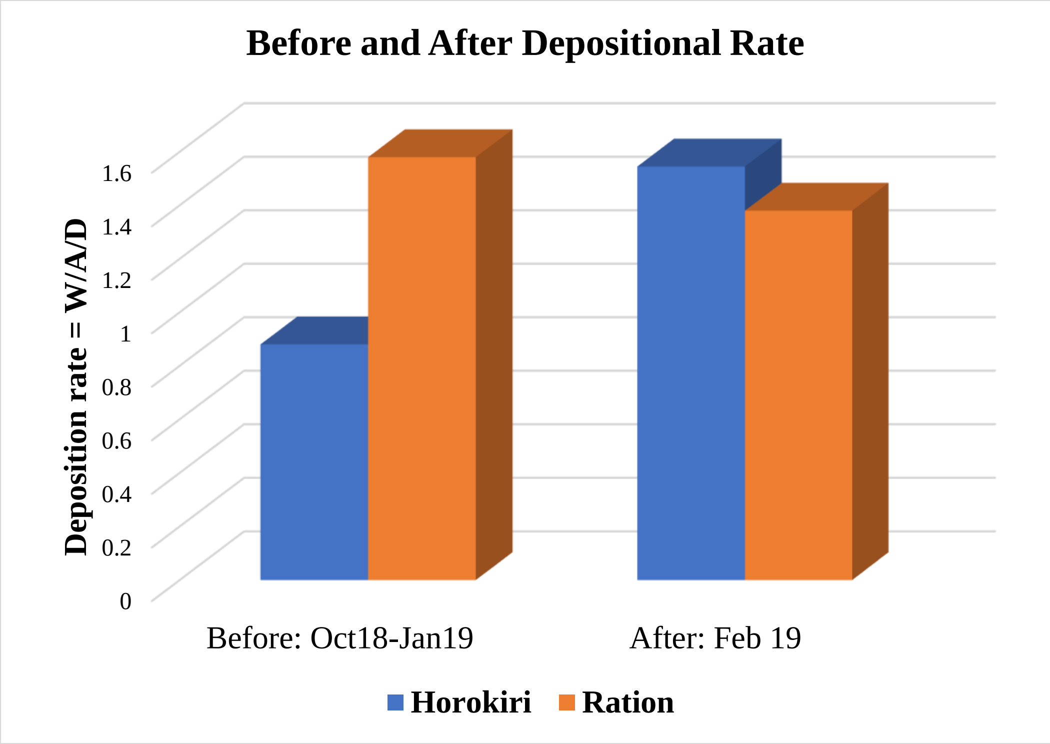


Figure 36: The effects of depositional rate over time. Before is results from 16week assessment and the After are results from pulse experiment.

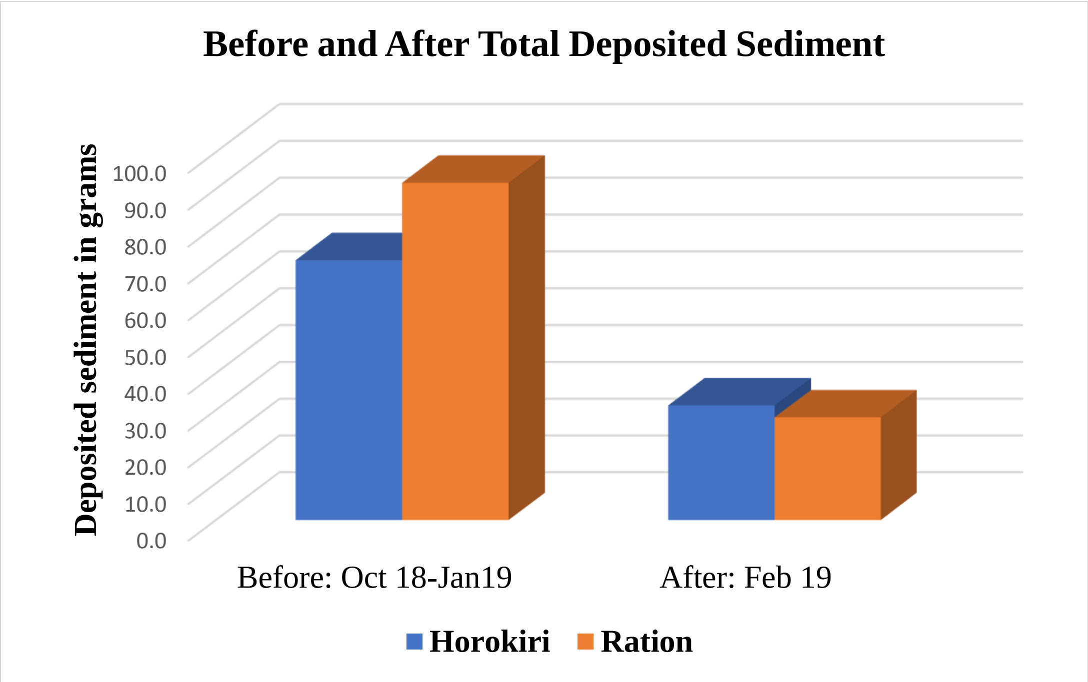


Figure 37:Total deposited sediment in grams over time. Before is results from 16week assessment and After are the results from pulse experiment.

5b.3 Macroinvertebrates

Figure 38 shows MCI versus Weekly deposited fine sediment over 28 days. Anova was performed to find a likelihood ratio test between MCI and weekly deposited fine sediment from all eight traps (not the control), shows F(1,6) = 2.342, p = 0.17. The streams are significantly different which means the interaction term is important to include. The effect on MCI differs when considering stream. A residual 'R' plot was conducted. There was no obvious patterns. In Horokiri, a linear regression showed a negative correlation between the weekly deposited fine sediment (g) with MCI (n = 4, R^2 = 0.62). In Ration, a linear regression showed a significant correlation between the weekly deposited fine sediment (g) and MCI (n = 4, R^2=0.92). There was a positive effect of deposited sediment on taxa richness during the pulse disturbance in Ration (R^2 = 0.91, p = 0.27), but less so for Horokiki (R^2 = 0.33, p = 0.79). Table 10 shows the macroinvertebrate metrics. No Diptera were found in any of the traps during the 28 day experiment. The EPT Index is named for three orders of aquatic insects that are common in the benthic macroinvertebrate community: Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). These are shown in Table 11 with an asterix.

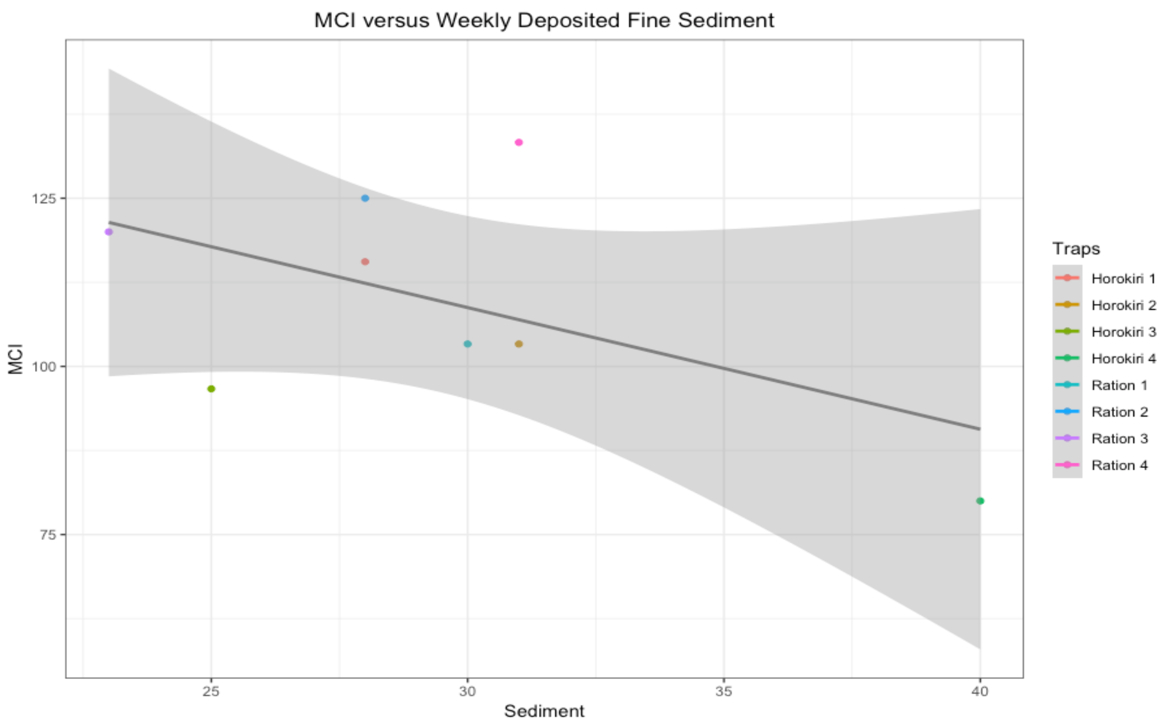


Figure 38: MCI versus Weekly deposited fine sediment over 28 days. Each marker is the result from a recovered trap. A negative trendline shows Sediment increased from the pulse disturbance raking as MCI values decreased. The shading in the graph show the 95% confidence interval n=8 (Four weekly traps in each stream). Heavy rainfall was experience during week 4.

Table 10: Macroinvertebrate metrics during the 4week pulse disturbance. Control was in-situ for 21 days only due to weather forecast. The control is the press disturbance.

Pulse Flushing Results	**Ration Creek**	**Horokiri Stream**
Week 1 Abundance	104	164
Week 2 Abundance	272	170
Week 3 Abundance	138	71
Week 4 Abundance	74	43
Press sustained: Abundance	89	189
Week 1 Taxa	6	9
Week 2 Taxa	4	7
Week 3 Taxa	3	6
Week 4 Taxa	3	6
Press sustained: Taxa	5	11
Week 1 MCI	103.33	115.56
Week 2 MCI	125	113.33
Week 3 MCI	120	96.66
Week 4 MCI	133.3	80
Press sustained: MCI	112	127.27
wk1 EPT%	4.81	14.02
wk2 EPT%	2.21	8.09
wk3 EPT%	2.17	4.22
wk4 EPT%	9.46	6.98
Control EPT%	6.74	23.81

Weekly pulse disturbance resulted in a decrease in taxa richness in each stream over 28 days (Figure 39). There is no significant interaction, the effect of pulse disturbance on Taxa is approximately the same in each stream $F(1,2) = 0.203$, $p = 0.697$. There was a 50% reduction in taxa richness in Ration and a 33% reduction in taxa in Horokiri. Two taxa disappeared from Horokiri after Week 1 pulse event and in Ration, 4 taxa disappeared after week 1, but two other taxa had appeared. After the Week 2 pulse event, one taxa disappeared in each stream. The benthic macroinvertebrate community composition in each stream was different (Bray Curtis Dissimilarity 54.83%).

Figure 40 shows taxa richness over time. Taxa has declined over time compared with the impact of four pulse flushing events during February 2019. Table 11 shows taxa richness captured in traps. Trichoptera and Molluscs were the dominant species present in both streams. The data does not support the hypothesis that macroinvertebrate communities subject to sustained fine sediment delivery (press disturbance) are MORE resilient to simulated pulse flushing events (pulse disturbance) because differing patterns were observed across the two streams; Ration had three resilient taxa (50%) and Horokiri had six resilient taxa (33%) of total taxa richness. Raw macroinvertebrate data from the experiment shown at Appendix 5.

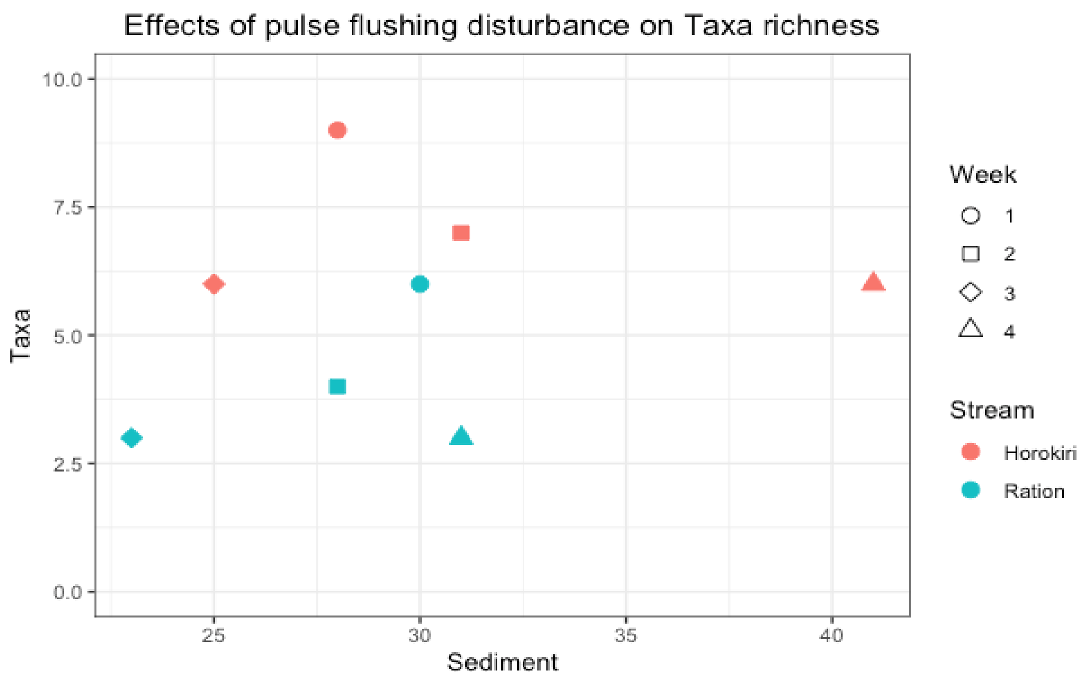


Figure 39: The effects of a pulse flushing disturbance on taxa in each stream. Each marker denotes a weekly pulse flushing disturbance. Weekly flushing increased deposited sediment in grams, on the x-axis with taxa richness reducing on the y-axis. Symbols are Circle=wk1, square=wk2, diamond=wk3 and triangle=wk4.

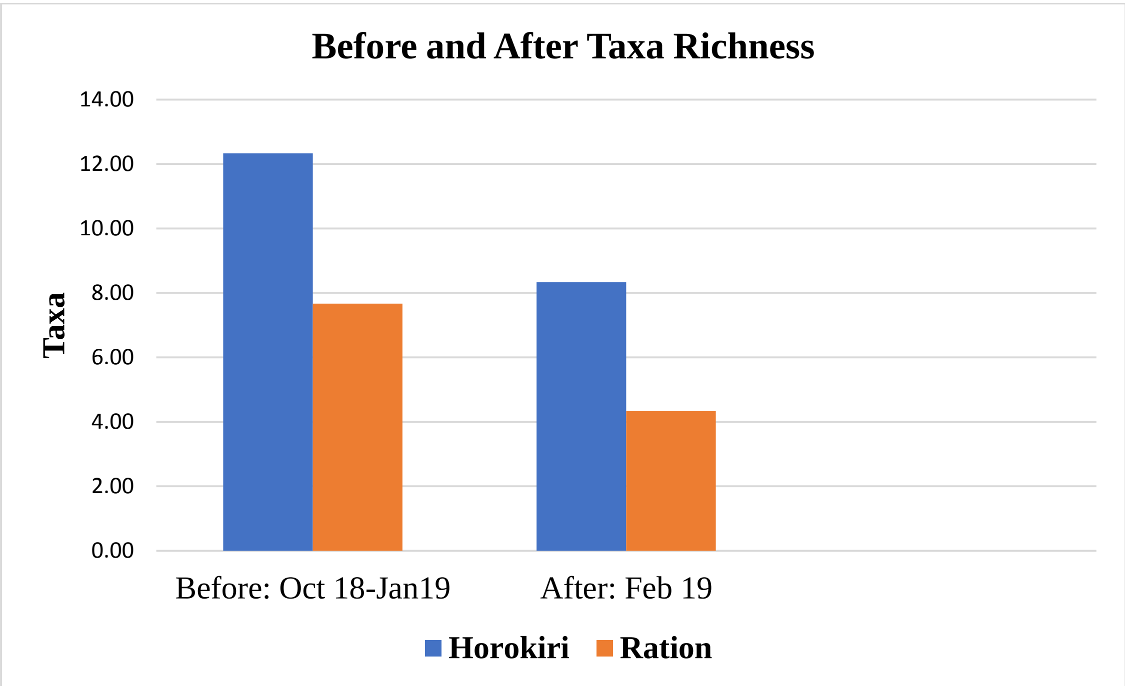


Figure 40: Taxa has declined over time compared with the impact of four pulse flushing events during February 2019. Difference in Taxa Richness from Before assessment results compared to results After the experiment.

Table 11: Benthic macroinvertebrate community composition in each trap, during February 2019 experiment. Ration traps described as R1-R4 or H1-H4 with RC or HC being the control (sustained press).

Species in Traps	R1	R2	R3	R4	RC	H1	H2	H3	H4	HC	Presence
Crustacea											6/10
Coleoptera											2/10
Trichoptera*											10/10
Hemiptera											3/10
Megaloptera											1/10
Platyhelminthes											6/10
Molluscs											10/10
Plecoptera*											1/10
Ephemeroptera*											9/10
Diptera											0/10
Nemertea											0/10
Annelida											0/10

5b.4 Water quality testing

Table 12 has an overview of all of the spot sampling results. Heavy rainfall contributing to the maximum recorded flow rate in week four. The diurnal temperature range (DTR) was the difference between the daily maximum and minimum temperature. The DTR, pH, conductivity and TDS was lower during the February experiment compared to the Oct-Jan assessment. Dissolved oxygen was also higher.

Table 12: Overview of the spot water sampling range showing median, minimum and maximum for both streams

Horokiri	Visual Clarity	Temp celsius	pH	DO mg/L	Conductivity	TDS	Salinity	flow m/sec	rainfall ml
min	1860	12.8	7.42	3.84	176.7	139.75	0.1	0.092	0
max	3120	18.8	7.73	10.59	207.7	157.95	0.12	0.99	12.3
median	2600	16.5	7.51	6.195	187.65	145.275	0.11	0.11	0
Ration									
min	880	11.6	7.47	3.49	209.1	174.85	0.13	0.031	0
max	2220	18.3	7.8	10.3	244.3	190.45	0.14	0.330	12.3
median	1710	15.8	7.6	5.615	225.7	179.075	0.13	0.037	0

Figures 41 through to 43 shows boxplot of the results from water sampling of dissolved oxygen (DO), conductivity and total dissolved solids (TDS), n = 28 for each stream using spot sampling between 9-10am daily.

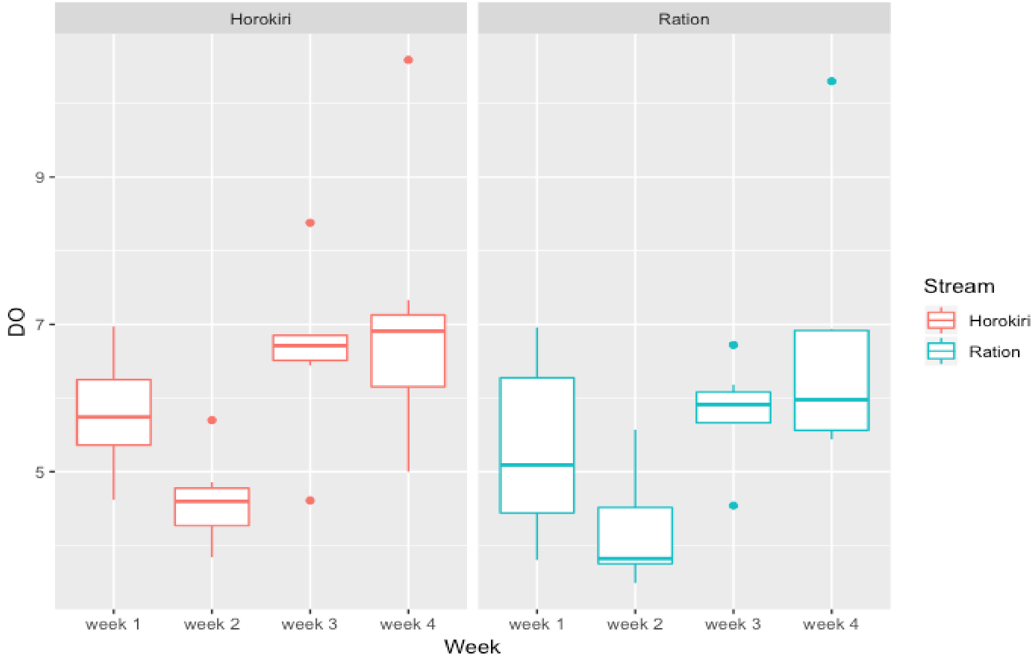


Figure 41: A boxplot graph, the stripe shows median, boxes show inter-quartiles and whiskers show range of DO, dissolved oxygen in both streams, by weeks during February 2019. Conducted at the same location, same depth of 20cm between 9-10am each day (n=28) per stream.

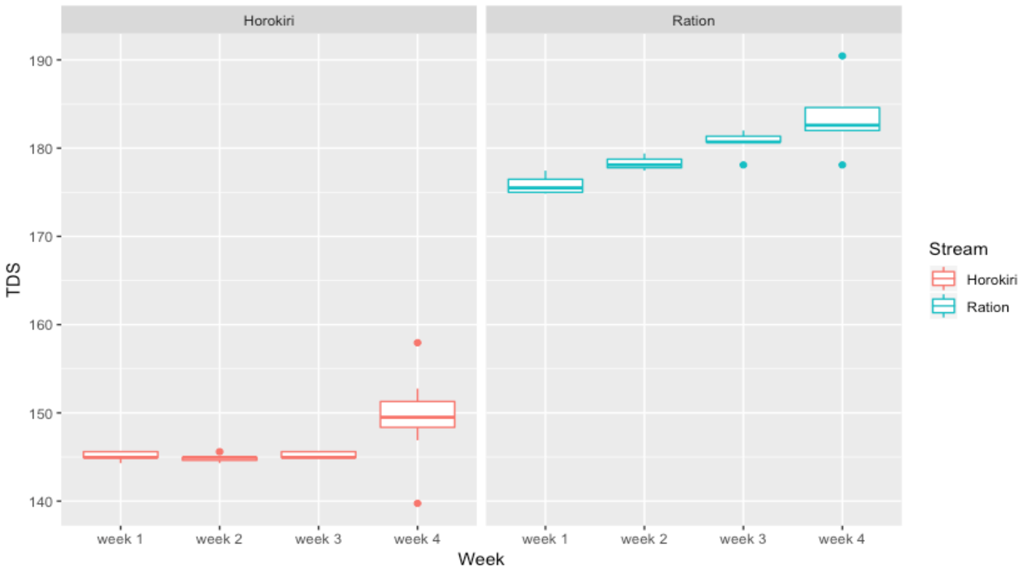


Figure 42: A boxplot graph, the stripe shows median, boxes show inter-quartiles and whiskers show range of TDS, total dissolved solids in both streams, by weeks during February 2019. Conducted at the same location, same depth of 20cm between 9-10am each day (n =28). Significantly different range of results for each stream.

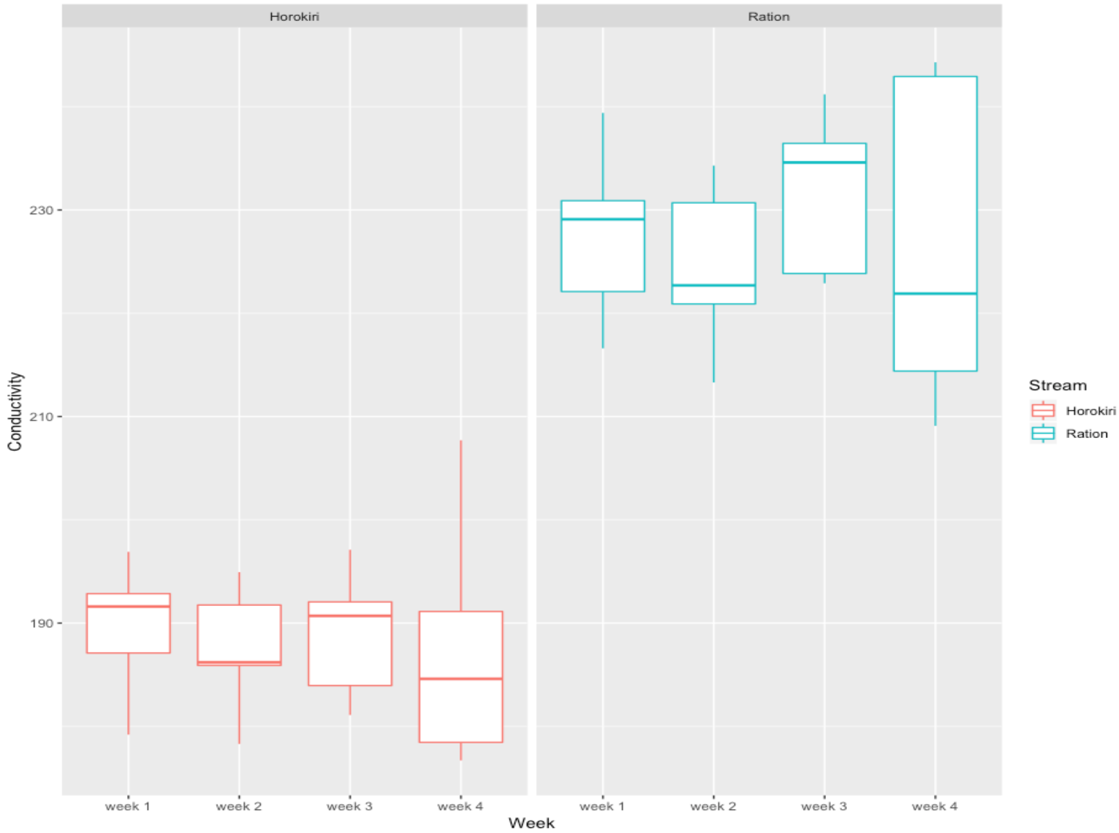


Figure 43: A boxplot graph, the stripe shows median, boxes show inter-quartiles and whiskers show range of Conductivity in both streams, by weeks during February 2019. Conducted at the same location, same depth of 20cm between 9-10am each day (n =28). Significantly different range of results for each stream.

Results from the daily spot sampling data:

- The Do mg/L was non-significant depending on stream; $F_{(1,56)} = 0.0424$, $p = 0.84$.
- The conductivity is significantly different depending on the stream; $F_{(1,56)} = 276.54$, $p < .0001$.
- The TDS is significantly different depending on the stream; $F_{(1,56)} = 1450.5$, $p < .0001$.

Figures 44 to 47 show detailed daily boxplots of continuous water testing over seven days in each stream. Horokiri Stream had a DTR of 15-21° Celsius with Ration Creek 11-18° Celsius. The temperature in Ration Creek over the 28 day experiment was on average four degrees cooler than Horokiri Stream. Ration Creek had a slightly higher dissolved oxygen range (7-10mg/L) than Horokiri Stream (7-9mg/L). The data shows that as temperature increased the dissolved oxygen decreased. The Trios instrument was calibrated as per the manufacturers recommendations and installed in one position, 5cm above the streambed, recording for seven days. Note, the tool was NOT installed in both streams at the same time. The tool was installed over consecutive weeks. Each boxplot shows a 24 h period of 15 m intervals of continuous monitoring using a TRIOS tool (n = 1290).

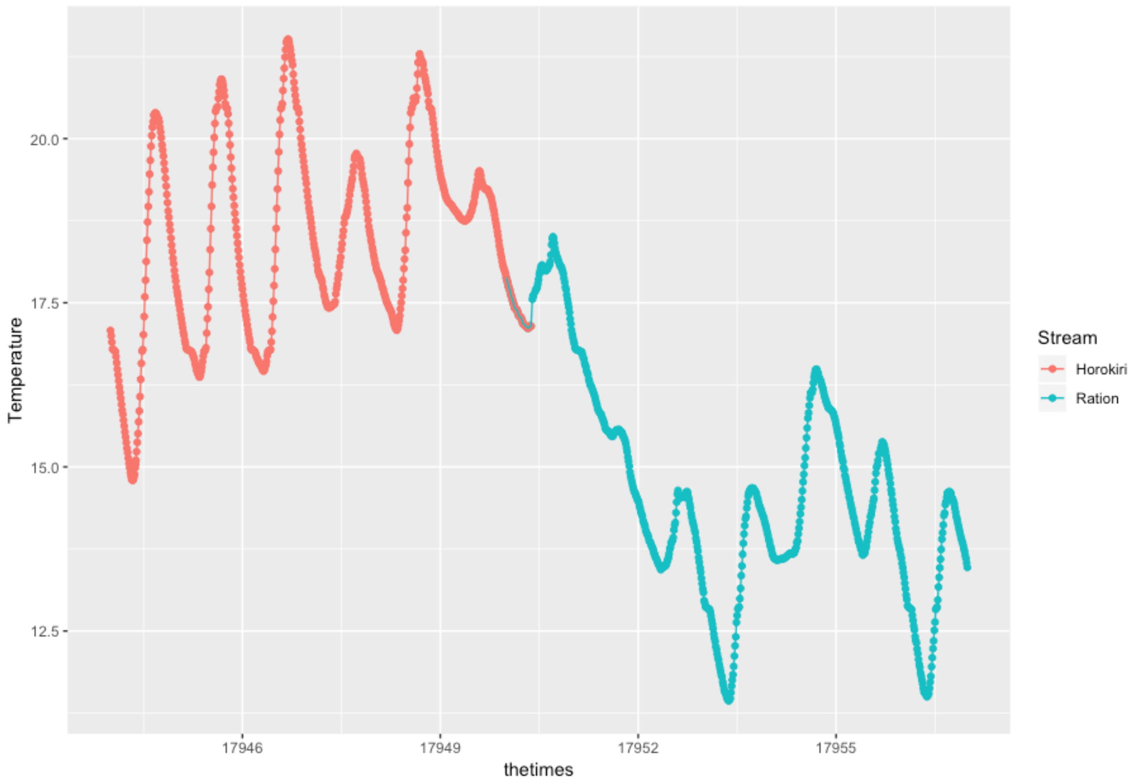


Figure 44: Temperature (Celsius) fluctuations in both streams recorded at 15-minute interval continuously for 7 days. Horokiri in red and Ration in blue.

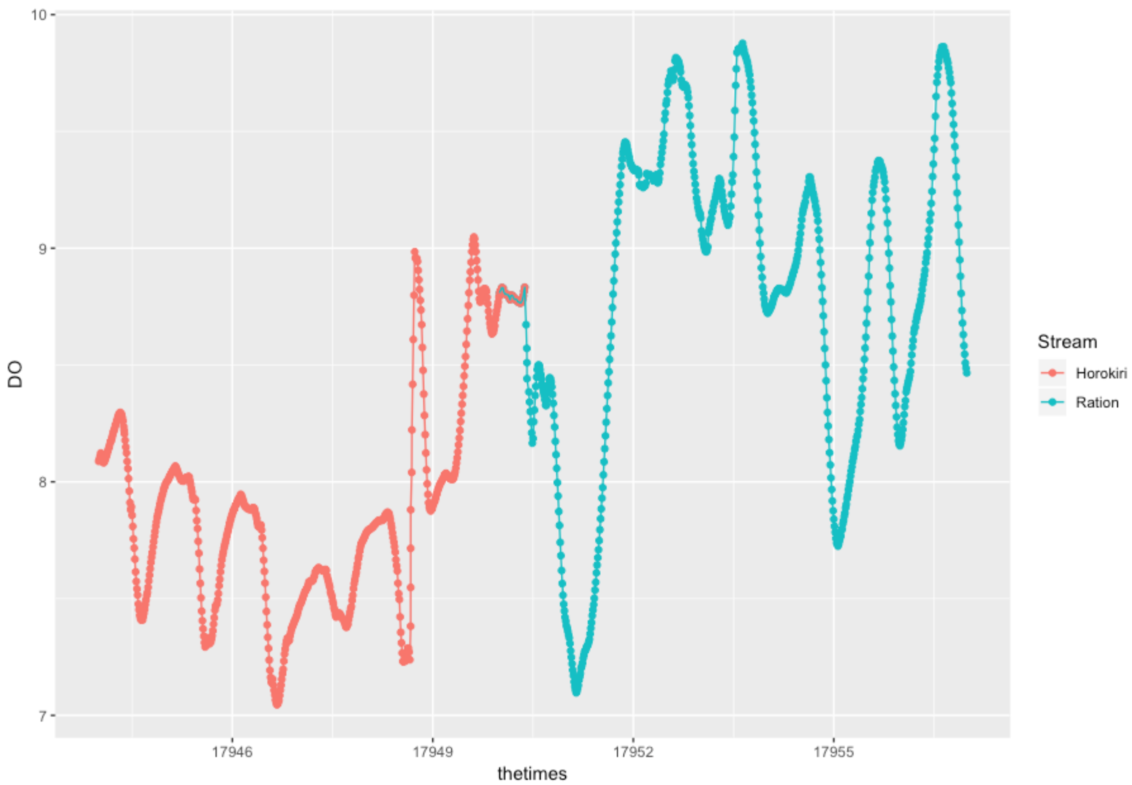


Figure 45: DO mg/L fluctuations in both streams recorded at 15-minute interval continuously for 7 days. Horokiri in red and Ration in blue.

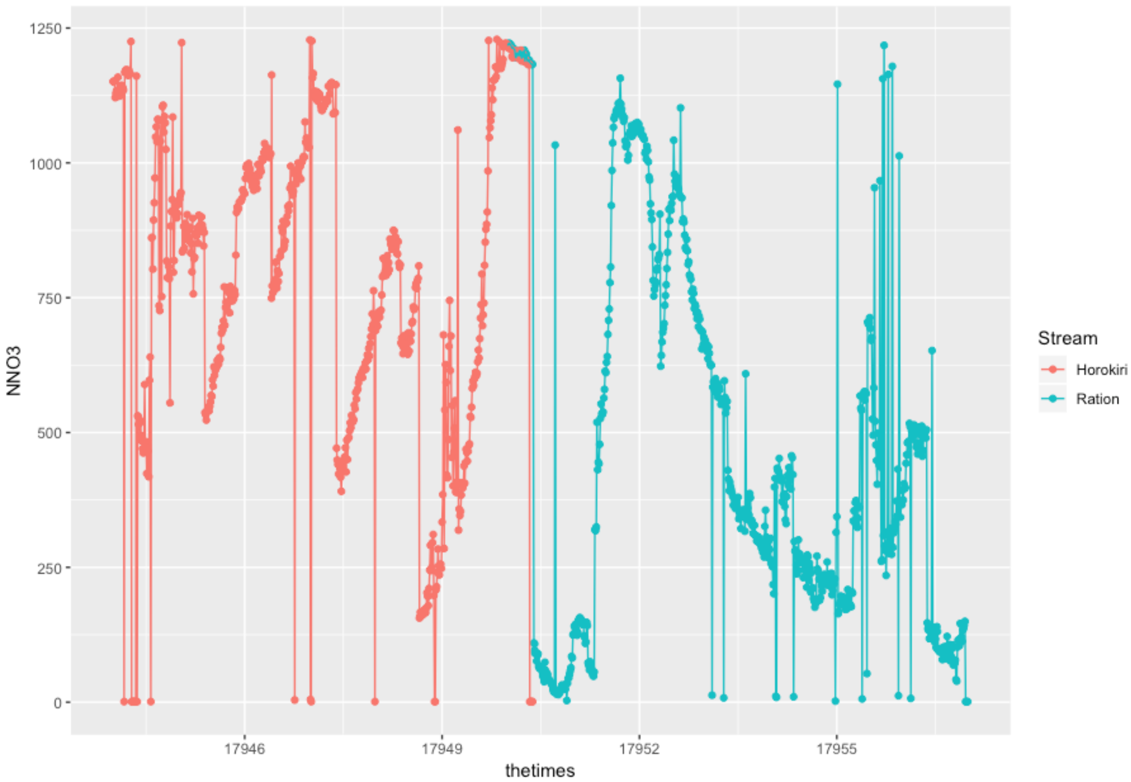


Figure 46: NNO3 mg/L fluctuations in both streams recorded at 15-minute interval continuously for 7 days. Horokiri in red and Ration in blue.

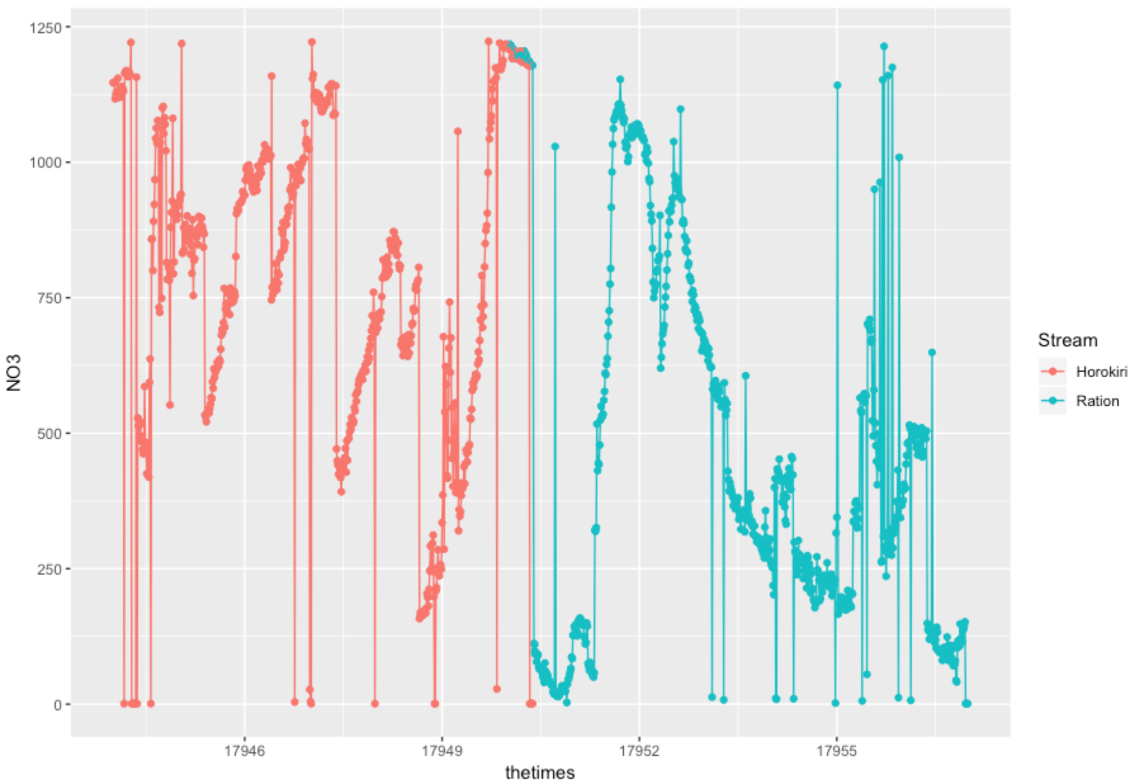


Figure 47: NO3 mg/L fluctuations in both streams recorded at 15-minute intervals continuously for 7 days. Horokiri in red and Ration in blue.

5b.5 Spot versus continuous testing

To show spot sampling as a representation of the stream conditions versus continuous sampling at 15 minute intervals over 7 days, I created 2 graphs of Temperature at Figure 48 and Dissolved Oxygen at Figure 49. The continuous sampling shows the fluctuations over 24 hours reflecting transpiration and photosynthesis, whereas spot sampling does not. The graphs provide evidence of the recorded results. We could conduct multitude t-tests but this would create problems with type I errors. The graphs clearly show the disparity between the two sampling methods. The graph demonstrates the fact that the spot sampling is much lower than the median recorded in Horokiri and Ration. Note, the small boxplots on 23/02/19 are due to the Trios instrument being moved from Horokiri at noon then transferred into Ration to record 12 noon to midnight. On 23/02/19 each stream was recorded for 12 hours only. The spot sampling was conducted every day between 9-10am over 7 days in both streams. This is a time of minimum temperature. Both instruments were in the water during 9-10am and I would expect both instruments to record the same temperature, however this was not the case. See Figure 50 for details.

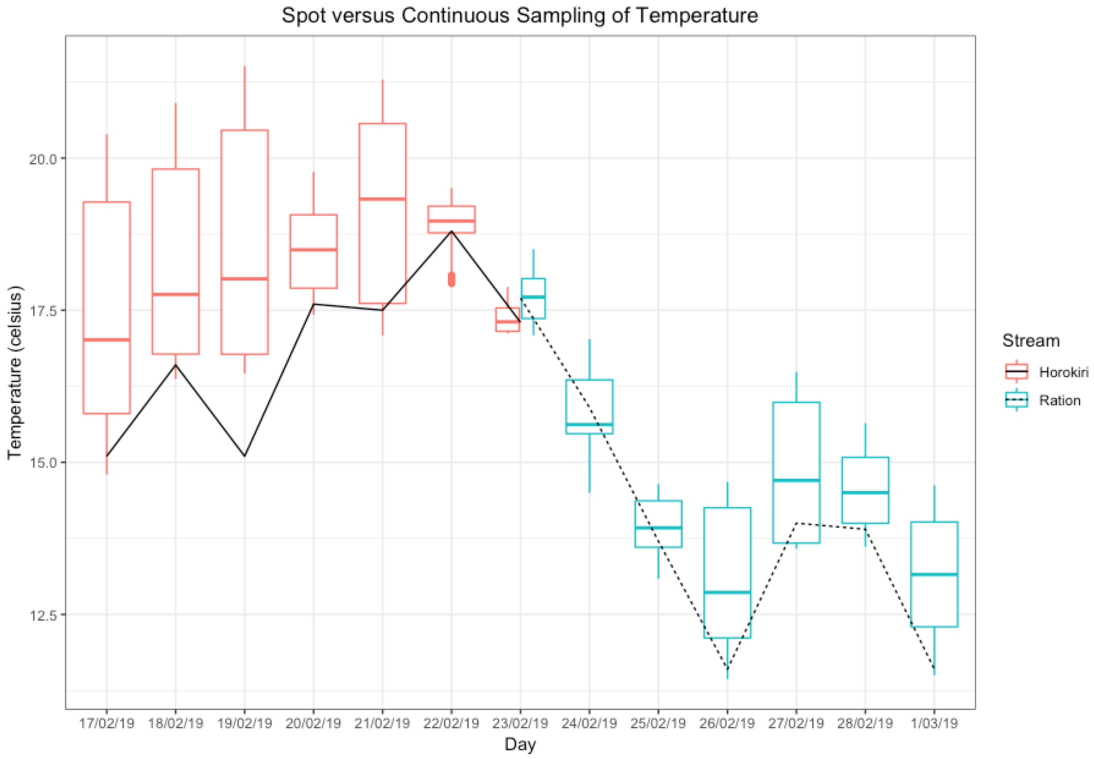


Figure 48: Temperature boxplot of continuous sampling (every 15 minutes over 7 days) with a secondary black line of spot sampling every day between 9-10am over 7 days in both streams. Horokiri has solid black line. Ration has dotted black line. The boxplot thick stripe shows median, boxes show inter-quartiles and whiskers show range of Temperature in both streams.

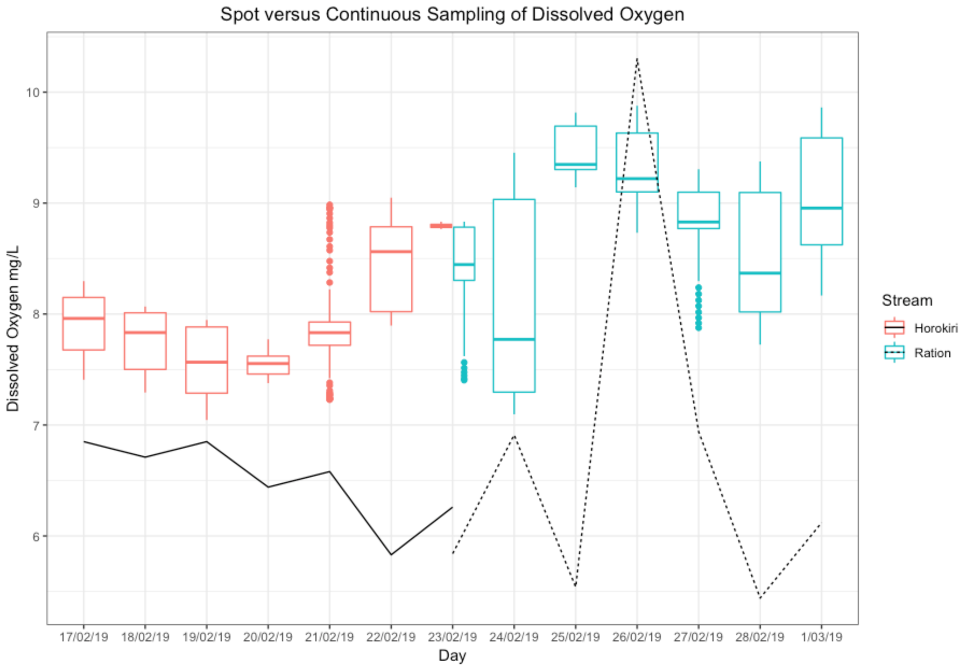


Figure 49: Dissolved Oxygen boxplot of continuous sampling (every 15 minutes over 7 days) with a secondary black line of spot sampling every day between 9-10am over 7 days in both streams. Horokiri has solid black line. Ration has dotted black line.

6. Discussion and synthesis

Managing both fine sediment and nutrient inputs from agriculture is crucial to achieve good stream condition but priority should be given to minimizing fine sediment (Wagenhoff, Townsend, Matthaei, 2012). In the absence of any certified national guideline, different methodologies are currently being used. This lack of consistency may compromise any use of the data in any legal or regulatory context. Our results show a decline in pollution-sensitive taxa leading to changes in community composition strongly associated with deposited fine sediment (<2 mm).

6.1 Limitations

There is a lack of independence between samples both in space and time during the assessment. Land use did not have a negative interaction with water quality in all zones. There were so few data points (n = 32) it was hard to get a significant P value. Increasing the number of streams would produce a true replication of the experiment. The size and quality of the pulse disturbances was conducted by myself, with the same tool, at the same time of week using the same effort for a duration of 5 minutes. The recorded resuspendible sediment plumes in Ration was graded at 4 with Hoirokiri at 3 during the experiment. If I replicated the experiment, future changes would be:

- Remove both the disturbed and undisturbed trap each week, creating a direct correlation between disturbed and undisturbed zones. I would not leave the control undisturbed trap in for 28 days. The mesh frame was a good barrier against the fine sediment plumes. I could have compared disturbed v undisturbed on a weekly basis.
- This experiment was too short, the 21 days did not create enough data to provide empirical scientific results. It would have been more beneficial to run the manipulative experiment for eight to twelve weeks.
- Measure and trap downstream of the experiment site to quantify downstream impact of the flushing events caused by the resuspendible sediment plume.
- Consider installing two traps in each side, one trap with holes and one without, to identify which invertebrate enter which type of trap. By drilling holes into the sides of the trap, I captured a small elver for the first time. Growth rates are generally slow for elvers, averaging 2-3 cm/year Jellyman (2007), meaning the captured elver was approximately 3-4 years old. Going forward, we could explore hole size correlated with the type of caught invertebrate from drift or burrowing method of entry.
- Consider lab-determined water quality figures to compare the validity of the Trios and YSI instrument data.
- Further research on light spectrum reflection that may prohibit invertebrate entering traps based on colour (black in Horokiri Stream and blue in Ration Creek for ease of quantifying and identifying macroinvertebrate per stream correctly). This is highly relevant with the witnessed installation of black heavy-duty plastic triple culverts for Ration Creek and Horokiri Stream streams under the new Transmission Gulley highway for invertebrates and fish passage.

6.2 Sediment

Changes to land use, management regimes, and impacts from acidification and climate change in river catchments have contributed to a continuing elevation in sediment delivery rates to river networks worldwide (Piggott et al., 2015; Wood & Armitage, 1997). Ration Creek zone 4 (upstream) showed the highest deposited fine sediment rate at the golf course. A place that locals believe showcases the natural beauty of the area, but in actual fact this is a place that contributes negatively to the waterway with the resource consented extraction of 44,000 litres a day (GWRC Report) to water greens with additional fertilisation use was reported to pollute and contribute towards the observed algal biomass. This abstraction rate has major implications on flow, reducing the power of the stream to redistribute sediment which increases in-stream sediment deposition. Streams that experience low flows as a result of water abstraction for irrigation and drought can also have increased levels of fine sediment deposition (Wood and Petts 1994). GWRC have recognised this and had recently installed an automatic cut-off switch at the abstraction point. The golf course had relatively high levels of sediment presumably due to the management system of mowing grass right up to the stream edge and spraying herbicide along the stream banks. Growing grass right to the water's edge at the golf course increases sediment deposition from bank slumping. Increased sediment loads, result in an increase in the abundance of invasive macrophytes. Clearing the macrophytes, with either herbicide sprays or mechanically, disrupts fish and other biota (Greer et al. 2016). Maintenance of the golf course includes spraying the banks of the stream with herbicide, to minimise golfers losing balls. Whilst herbicide sprays, do not disturb the bed, they leave the decaying macrophytes in the waterway. High levels of phosphate and nitrate cause eutrophication, leading to reduced dissolved oxygen concentrations. The maintenance of a putting green constitutes a very intensive form of plant production. Although nitrogen is distinctly desirable as an ingredient of putting green fertilizers, its use can be easily overdone with great damage to the stream ecosystem.

A comparison of sediment depositional rate before and after the manipulative experiment (Figure 36) showed higher sediment deposition after the pulse flushing events (1.55 W/A/D) compared to before during the assessment phase (0.88 W/A/D) in Horokiri. The sediment depositional rate was greater from our man-made pulse flushing events in Horokiri than under natural conditions during the 16 week assessment. The raking during the experiment did cause a visible and evaluated sediment plume which was carried downstream. The sediment was not settling within the site but further downstream. In hindsight, I would install a further trap out of the experiment site to capture the sediment in the water column which is carried downstream.

6.3 Riparian

I predicted that the riparian forest along Horokiri Stream and Ration Creek would lead to improvements in stream health. Table 2 and 3 show the size and type of planting in each zone. Fine sediment percent cover was reduced in the forested riparian zone 2, which correlated with increases in the MCI values. Many other studies have noted increases in stream health with riparian vegetation, for example Storey & Cowley (1997) reported declines in fine sediment and increases in MCI scores along three 2nd-order streams flowing through native forest remnants near Auckland, New Zealand. In both streams at riparian RZ RIP and HZ RIP there was minimal observed algal biomass compared with the other zones. Parkyn et al. (2003), in a recent study in New Zealand that considered planted riparian buffers, found less significant improvements in water quality and macroinvertebrate health. They suggested that high stream temperature was still a stressor to invertebrates, and that shading by riparian vegetation may improve the situation with time after canopy closure over the stream. Horokiri Stream had good canopy cover however Ration Creek did not.

Riparian at Horokiri Stream: Mr Glover who runs the sheep farm in zone 2 has installed riparian buffers and planted trees along the headwater springs and down into the valley. Mr Glover has spent 50+ years planting trees, flax, grasses, shrubs with small, mid and high canopy trees along his waterways detailed in

Table 3. Glover's riparian zone with willow tree root systems protects the soil, creating seed beds for native plants. The areas between the trees are filled with Robusta, stinging neetle and flax. Horokiri Stream has a woodland like buffer of trees and understory planting providing lots of root systems that absorb pollutants before they reach the stream. These appear to have a significant impact on the algae in the stream, which is a cornerstone species transferring a soil based micro nutrient into an edible food source for fish. Research from the University of Maryland suggests that a buffer zone of 20-30m is the optimal width for sedimentation removal. Optimal buffer widths shown in Figure 3. Based on this research the Horokiri riparian planting provides bank stabilisation, aquatic food resources, water temperature moderation and nitrogen and sediment removal. Future research to determine the length, width, and composition of riparian zones required to enhance stream conditions and health needs more attention.

Riparian at Ration Creek: The installed GWRC riparian vegetation buffer (2-5m each bank) at Ration Creek comprises of low and mid canopy trees. The Ration Creek buffer at best provides bank stabilisation and aquatic food resources. Buffer intactness is the assessment of gaps in the managed vegetation that may reduce the effectiveness of the riparian vegetation in providing habitat and intercepting contaminant inputs. Certainly in Ration Creek there was more evidence of gaps in canopy, vegetation and more observed weeds.

Without measured data on erosion rates or the extent of human-induced erosion there is limited quantitative understanding of how effectively mitigation strategies, like riparian planting and soil conservation planting, are working (Aotearoa Report, 2019). Riparian projects need to be carefully assessed for suitability prior to planting, with identification of the external drivers affecting water quality and monitored for about 10 years after. This ensures that an effective canopy is created to shade and increase leaf matter into the stream allowing native plants a chance to grow and take over, whilst limiting vegetation gaps and the invasion of weeds.

6.4 Macroinvertebrates

Like Matthaei et al., 2010; Castro Vasconcelos & Melo, 2008; Larsen & Ormerod, 2010, I expected sediment addition to have predominantly negative effects on the benthic invertebrate community. The results from the assessment indicate that multiple drivers are associated with variation in MCI. As the level of sediment increases, taxa that favour stony habitat such as EPT taxa (Ephemeroptera, Plecoptera and Trichoptera) are replaced by burrowing taxa such as Chironomids and worms (Wood & Armitage 1997; Rabeni et al. 2005; Townsend et al. 2008). Increased sediment deposition can lead to the short-term increase in invertebrate drift (Larsen & Omerod 2009; Molinos & Donohue 2009). Taxa follow similar lifecycles in both streams because of the similar topography, location and climatic conditions. Wagenhoff et al (2016) is developing a sediment-sensitive invertebrate community metric but is yet to validate metrics nationally. Further research could be valid where we insert traps at different depths, of different colours with or without holes.

During the experiment more mayflies and stony caddis flies were captured in Horokiri Stream. Ration had more stick caddisflies and snails. There was no Diptera, Nemertea or Annelida found in any of the traps during the 28 day experiment. The traps were installed 10cm beneath the stream bed substrate, 30cm below water level. The Diptera larvae spend 2-7 weeks burrowed in sediment, however our traps were installed clear of sediment and replaced after 7 days. After the pulse disturbances was conducted the taxa richness declined a further 50% in Ration, leading to a core taxa richness of three species. The taxa results in Ration would indicate a degrading creek. The dominant taxa found in all traps over 6 months in Ration were Mollusca and Tricoptera. The caddisflies are leaf shredders and algae grazers and the snails eat all types of algae. Horokiri taxa declined by a further 33% after pulse disturbances and had a core taxa richness of six species. The dominant taxa found in all traps in Horokiri was Molluscs, Crustacea and Ephemeroptera. The streams are different as shown in results section (5a) showing no relationship. The graph at Appendix 4 is the Transmission Gully Fish Catch and Macroinvertebrate 2018 Results Summary by Boffa Miskell Ltd (Report TG-CPBH-RPT-ALL-GE-9212 written by T Strange) . Note their macroinvertebrate findings are similar to these.

Our historical analysis showed that the Horokiri Stream has a recovering community of invertebrate. From our historical investigations I discovered a piggery business operating along the Horokiri Stream above zone 4 in the 1990s, negatively affecting many aspects of the stream ecosystem. Catchment landowners were very critical of the practices used at the Piggery and this business closed in 1998.

6.5 Water quality

The World Health Organisation defines water quality as the chemical, physical, biological, and radiological characteristics of water. Water quality is influenced by a combination of temperature, slope and flow variables. Temperature affects the rate of photosynthesis of aquatic plants which are the base of the aquatic food web. Flow velocity is influenced by the slope of the surrounding terrain, the depth of the stream, the width of the stream, and the roughness of the substrate or stream bottom. Stream flow is an important factor in the stream ecosystem and is responsible for many of the physical characteristics of a stream. Flow affects turbidity and high flow rates keep particles suspended instead of letting them settle to the bottom. Increased turbidity levels can be due to land use with increased levels of exposed soil and decreased vegetation, increasing the opportunities for runoff and erosion into a stream. Agricultural runoff leads to an increase in nutrients which fuels the growth of algal blooms.

This assessment conducted during summer had very low flow rates. When river water quality fluctuates over relatively short periods of time relative to sampling frequency, the collection of spot samples may be inappropriate for characterising average water quality. This type of sampling reflects a point in time when the sample was collected. The analysis of our data from the YSI instrument represents the average.

Pollution takes place when silt and other suspended solids like soil run-off from construction, logging, agriculture, urban areas and eroded river banks after rain. The pollution of streams with chemical contaminants has become a critical environmental problem causing a domino effect of destruction. Whilst I did not collate data or analyse Periphyton, I did write the Periphyton zone values of non, slippery, obvious, abundant and excessive in my SEV according to the NIWA protocols set out in Report 111 (2002). Algal biomass is often related to concentrations of nutrients (Biggs 1996). High levels of nitrate along with phosphate, can overstimulate the growth of aquatic plants and algae, causing higher dissolved oxygen consumption, killing fish and other aquatic organisms (eutrophication). There was a higher observed algal biomass recorded as excessive in HZ zones Hobby and Agri as shown in Figure 50 (P2) compared to HZ RIP the riparian zone (P1) downstream recorded as slippery.


P1


P2

Figure 50: Photographs of the stream bed in HZ Rip (P1) compared with HZ Hobby & HZ Agri (P2) which has abundant brown short filament algae. Photos show a clear difference in what was observed in relation to the land use zones and algal biomass.

Dissolved oxygen (DO) is temperature dependent, it is a critical parameter affecting the abundance and diversity of organisms within a river ecosystem. We know in freshwater streams, dissolved oxygen concentrations will vary by season, location and water depth. Measurements of daily changes in dissolved oxygen are useful for determining rates of primary production and ecosystem respiration in river systems, if collected regularly over at least a 24-hour period (Schallenberg et. Al. 2011). Oxygen concentrations can vary by minute and diurnal patterns resulting from photosynthesis and, therefore, single sample measurements are of limited value, at best our data show an average or pattern. Photosynthesis was the primary process affecting the dissolved-oxygen/temperature relationship in the wetland and riparian zones. Just as low dissolved oxygen can cause problems, so too can high concentrations. Pollutants can become more toxic at higher temperatures. Water temperature is an important factor for assessing the potential for cyanobacterial growth. We expect to see more Cyanobacteria and Benthic algal blooms in the future in both streams through climate change and increased agricultural practices. Algal blooms can reduce a river's dissolved oxygen, stop light entering the water, and change the composition of plant and animal species that live in the waterway.

6.6 Land use management through the RMA

Rivers are degrading around New Zealand according to the Ministry of the Environment and scientists, possibly due to population growth as land development spreads away from cities. New Zealand needs new measurement standards to measure and monitor waterways for sediment accumulation and nutrient leaching in the case of repair or restoration of stream ecosystems. Repairing an issue after the fact can become a major restoration and takes time for the ecosystem to bounce back. It is better for local government to monitor and audit land use changes catching a problem before it is out of control, and adaptive management enables local government and landowners to change, and to address any problems. Under the RMA, local government have delegated responsibility for the everyday management of land, freshwater and other resources, and for ensuring that growth and development occurs within the environmental bottom lines. Gaining an improved understanding of sediment effects on rivers is necessary for the conservation and restoration of river habitats.

Irrigation has already increased; for example, from 1999 to 2006 water allocation grew by 50%, mostly for irrigation, and this is likely to increase substantially (Joy, 2009). Altered flow regimes, including reduced flows, due to poor governance of water abstraction (Memon 1997), combined with increased sediment inputs (Walling 1983) have resulted in a build-up of deposited sediment. Regulations are set to change, these include amendments to the Resource Management Act and the National Policy Statement on Fresh Water (MfE, 2017b). Certainly scientists have recognised the need for a comprehensive and consistent approach to measuring freshwater ecosystems around New Zealand (Clapcott et al, 2018). It is time to review the RMA resource consent process and protect New Zealand waterways for the future, as these impacts on freshwater biodiversity will accelerate as the rivers run dry. The Resource Management Act (RMA) and Resource Consent process around waterways requires a review. The RMA Section 15 (1) states "No person may discharge any contaminant or water into water or into land ….." The law is clear, yet rarely are landowners, developers or contractors fined or prosecuted after a contamination. There are thousands of breaches of the RMA every year, yet under 100 are prosecuted a year. Should these RMA breaches be called criminal offences? Certainly the witnessed impacts on the environment could have immediate through to inter-generational impacts.

There is a view that the effects of individual activities are well managed under the Act through the consenting process. However, the cumulative effects, despite being explained in the Act are widely interpreted in case law. Milne (2008) explored this view and argued that it is somewhat overstated, and that the RMA is properly designed to handle cumulative effects. Nevertheless, Milne argued, there is a need to use more effectively the tools provided under the Act. There does appear to be a conflict between the management of cumulative effects, which requires a catchment-wide approach, and the granting or declining of individual applications for resource consent. EDS Senior Researcher Dr Greg Severinsen says “We have cross-party interest in change and a recognition that the present system is not delivering adequately for town or country. Environmental Defence Society chief executive Gary Taylor felt there was a need for a dedicated, independent national enforcement agency. "This could be the Environmental Protection Authority, with expanded governance, powers, obligations and resources." Environment Minister David Parker acknowledged compliance, monitoring and enforcement actions was "somewhat variable" across local government.

Housing availability is a pressing social challenge as our cities sprawl into the countryside”. Urban growth is reducing versatile land and native biodiversity leading to heavy metals entering waterways that can be toxic to fish and invertebrates. Future proofing developments with detailed design stages that are outcome focused are imperative to integrate water innovation and sustainability. Integrating water into developments will reduce the frequency of stormwater run-off, reducing demand on portable water supply whilst improving the amenity of the urban environment.

6.7 Māori water values

As kaitiaki, Iwi and hapū have an inherent responsibility to sustainably manage their natural resources for the benefit of both current and future generations. Maōri must be able to practice their ways of caring for their particular environment within their own belief systems, while understanding western logic and legal systems, in order to work together efficiently. A strong cultural voice regarding waterways empowers and reconnects, creating social awareness. Partnerships are critical to achieve more, iwi partnerships are vital, and now required by statute. Common concerns iwi have raised with the management of waterways include:

- Over-allocation
- Impact of flood protection works

- Diversions • discharges
- Land management impacting on water quality
- Water quality
- Lack of iwi involvement in decision making
- Impacts on mahinga kai
- Erosion
- Interference with natural flow of the river
- Access to water
- Failure to recognise and provide for traditional values

Iwi issues are resolved through effective negotiations towards regulatory solutions. One of these future issues could be allowing people to trade their water rights. Is water trading a commodity of the future? Could a capped system of tradeable water rights improve water quality? Future research in hydrological mapping allows the system to know the effects of upstream water drawing and could generate different prices for water (to trade) along a waterway in the system. Are Iwi on the verge of being the most powerful and active force for conservation in the country? Further research and engagement with Iwi is critical to identifying Iwi priorities for the management of the regions waterways and surrounding catchments creating a strong cultural voice regarding waterways.

6.8 Looking to the future

Freshwater habitats are particularly vulnerable to climate change because both water temperature and availability are climate-dependent (IPCC 2001). Fluctuating patterns of precipitation (Vecchia et al. 2005) alter both surface flows and aquifer recharge. Climate change can dry out waterways through summer months and increase water temperature lowering dissolved oxygen which can cause eutrophication. Future predictions of the decline of freshwater taxa raise serious concerns which need to be addressed. In the future, climate change will increase sediment inputs by altering vegetation composition (Stromberg et al. 2009), increasing forest fires (Beaty 2011), and glacial recession (Micheletti and Lane 2016), in combination and more frequent extreme weather events (IPCC 2001). Planting riparian buffers with canopy cover for shade is a priority to reduce the effects of climate change. The data collected in HZ RIP shows evidence of a ‘good’ riparian buffer with a wider buffer of 20-

30metres associated with higher flow velocities leading to the recorded lower levels of deposited sediment.

Future land management could lead to initiatives for landowners or farmers along waterways to balance economics with restoration, with changes made primarily in response to identified issues. The goal is to improve water quality and biodiversity and to reduce soil loss and GHG emissions, while maintaining productive pasture area. Areas of trees and wetlands can be increased as necessary and stocking rates reduced to counterbalance GHG emissions. A few initiatives are Scarps with marginal productivity planted in either productive forestry or native revegetation. Integrating water management for urban developments by planting native shrubs for road screening or rain gardens to capture road run-off which reduce the frequency of stormwater run-off. If every home had rain water tanks installed that create household and community resilience.

A recent survey of 30 streams in the Canterbury region of New Zealand, suggested that the condition of the riparian margin affected pollution-sensitive EPT invertebrate taxa via habitat change and by alterations to food quality or quantity. This relationship was driven by fine sediment inputs that smothered the streambed and clogged interstitial spaces, modifying and reducing habitat heterogeneity. The invertebrate community became dominated by sediment tolerant species once sediment bed cover exceeded 20% (Burdon et al. 2013). This is important, because such changes associated with deposited sediment may penetrate up to higher consumers (Osmundson et al. 2002). Furthermore, the same changes in taxonomic structure identified in invertebrate communities were likely to be mirrored in sediment driven changes to fish.

7. Conclusion

The assessment undertaken to quantify the ecological effects of sedimentation in differing land use management zones showed land use was the main driver and flow also a positive effect on the deposition rate of sediment. Land use was a major contributor to fine sediment deposition during our assessment at RZ Golf where clearing vegetation and water abstraction caused bank slumping. The decline in benthic macroinvertebrate communities resulted from a cascade of multiple stressors due to land use changes. Our results are consistent with the view that large-scale landscape factors affect the biota via their influence over local-scale physical conditions.

The assessment showed the larger width of riparian vegetation at Horokiri (HZ RIP) had a beneficial effect on water quality and downstream aquatic invertebrate communities from the extensive riparian vegetation and large canopy trees. Choosing the right vegetation to provide canopy cover with a buffer width of >10 m is a key feature to improve a stream's health. A better choice may be a combination of both canopy cover for shade and nitrogen absorption trees. Future research to Improve waterways by increasing the length, width, and composition of riparian vegetation to remove sedimentation and nutrients is needed.

Overall, deposited fine sediment seems to have acted as a stressor in the experiment, with negative effects on some invertebrate taxa. The weekly pulse disturbance events resulted in increased sediment deposition compared to the background levels of sediment deposition (indicative of a press disturbance) in both streams. As pulse disturbance events increased, the number of taxa decreased. The experiment has shown that the relationships between sediment, water quality and macroinvertebrate response variables are not always straightforward.

The data collected during this experiment showed that continuous monitoring is the key step for any freshwater monitoring system in the management of nutrient and fine sediment assessment, providing a 'real time' view of water quality, providing accurate data to assess and better understand water quality conditions over time. Continuous monitoring allows verification of water quality data, because any anomalies will rapidly become apparent and the data can be disregarded. Invariably some data could be lost or not collected whilst the instrument is off line. The more frequently we sample and test, the greater the chance of identifying contamination events that occur – such as seepage or spray drift from farming activities, or contamination from road and other surface runoff. The reliance on spot sample data for the purpose of water quality assessment and modelling is not sufficient. The quality of data provided by a spot sampling program can be misleading, and such data should be used cautiously in water quality assessment and modelling.

Harrison (2016) states, "To improve our understanding of the impact of fine sediment on macroinvertebrate communities, research is required on the responses of individual taxa to fine sediment accumulation, the influence of different flow habitats, disentangling its impact from other associated land-uses, and the relationship between fine sediment accumulation and macroinvertebrates at a regional scale". The experiment demonstrated this. Assessing how fine sediment increased during a disturbance at a regional scale is important for ongoing efforts to maintain and improve river health whilst indicating the effects on macroinvertebrates. Over twelve months we witnessed an increase of fine sediment cover on the Ration stream bed through the riparian zone, meaning that the interstitial spaces were saturated with sediment which leads to increases of sediment-tolerant macroinvertebrate and a reduction of sediment-sensitive taxa. Regardless of the progress toward understanding disturbance in lotic ecosystems, there are significant opportunities for future research with beneficial outcomes.

If Māori rights and interests can be addressed, there could be a role for making greater use of tax instruments to address water quality with the current tools, especially for nitrogen, and in regions struggling with excessive discharges. The founding principles of Te Tiriti o Waitangi are partnership, participation and protection, requiring the Government to act reasonably and in good faith towards Māori, the indigenous people of the land who culturally look at the past to move forward. Any potential water taxes will need to take account of Māori rights and interests in water. For example, catchment-level nitrogen discharge trading schemes have already been used in the Lake Taupo catchment, and are planned for the Rotorua Lakes; an alternative might be a national tax levied on estimated emissions with catchment-level variation in rates. By continuously monitoring all fixed variables in a stream we identify the 'major' inputs which might identify whether water can be taxed or for example a fertiliser tax, a sediment tax or water abstraction tax would be best. Applying a framework to water pollution[6] (Future of Tax interim report, 2018) provides opportunities for abatement which will vary by catchment, as will the environmental benefits. Buy-in from local government would have to be gained, as council-owned sewage systems would be governed by the new tax framework. Similarly, if this system overflowed, a council would have to buy emission credits.

8. Acknowledgements

Beyond grateful to:

- The Rotary Hutt City for their kind donation of $5,000 towards my MSc Fees.
- The Guardians of the Pauatahanui Inlet who donated $100 towards testing equipment.
- Mr & Mrs P Reidy who allowed me to set up a field lab on-site in one of their orchard sheds and set up my experiment in their reach of the Ration Creek.
- Mr J Glover for allowing me to set up the experiment in his reach of the Horokiri Stream.

[6] https://taxworkinggroup.govt.nz/sites/default/files/2018-09/twg-interim-report-sep18.pdf

- Mr Benjamin Smith for his friendship, motivating speeches and guidance (unofficial supervisor).
- Mr Hugh Oakley-Browne who taught me self-belief, teaching the tools to overcome barriers to smart thinking that created high impact results.
- Dr Lisa Woods for her time, tutoring and expertise in teaching statistical R Studio.

The scientific research that is being conducted today, including this research, is only possible because of the work of ecologists who went before. In the case of this research, my thanks goes to Dr Mike Joy, Dr Joanne Clapcott and Professor James Renwick who kept it real and helped me through my steep scientific learning curve. To my two research assistants, Mrs Janet Reidy and Ms Stephanie Rugg, thank you for sharing the journey.

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Appendices:

Appendix 1: Site Assessments (SEV): RZ WET=0.65

NIWA
Taihoro Nukurangi

Site state assessment

Site RATION ZONE 1	Site Code R21	Date JAN 2019	Length (m) = 100M
GPS Top: E 41 05 535 N 174 55 02' E	Bottom: E	N	

Gen. land use left side (native forest planted forest) sheep beef deer dairy horticulture peri-urban urban WETLAND

Gen. land use right side (native forest planted forest) sheep beef deer dairy horticulture peri-urban urban WETLAND

Riparian land use (mark R for right & L for left bank) conservation ✓ filter strip ✓ woodlot urban stopbank whitebaiting

cattle sheep deer crop hort esplanade reserve waterfowl shooting engineered floodway Other= SALTMARSH

Widths (m) **Water=** 25 **Channel=** 8 **Bankfull=** 16 **valley bottom=**

Channel plan shape channelised straight (meandering) sinuous **Valley form** V U (plain)

Flow ephemeral intermittent perennial regulated (wetland) **Stream shade (%) =** 70%

Sketch stream plan, cross-section & comments: (including where planting zones occur, position of current fencing)

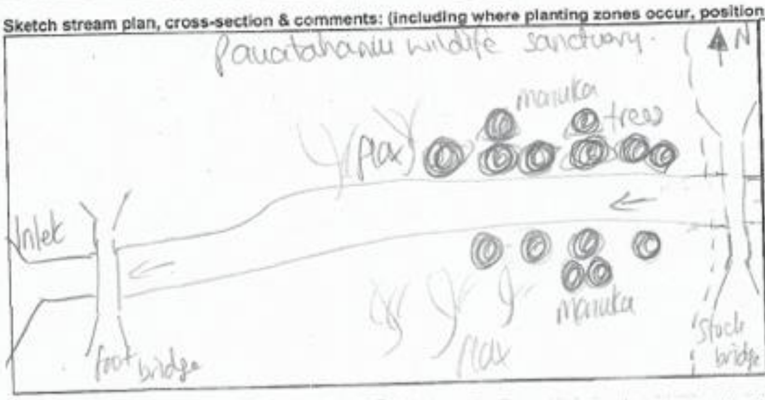


Photo numbers and descriptions

Streambed clay (mud) (silt) (sand) (gravel) cobble boulder bedrock **% riffle/run/pool** / /

Bank left Height (m) lower= upper= **Stability** %stable= %undercut= %slumping= %earthflow=

Bank right Height (m) lower= upper= **Stability** %stable= %undercut= %slumping= %earthflow=

Stabilised by Left grasses (shrubs) (sedge/rushes) (trees) bedrock riprap/artificial

Right grasses (shrubs) (sedge/rushes) (trees) bedrock riprap/artificial

Macrophytes **% cover =** <10 **Type =**

Periphyton (none) slippery obvious abundant excessive, Fil Alg>30% **Wood** absent sparse (common) abundant

Live-stock access to stream & bank damage Left Y / (N) **Left damage** none minor moderate extensive **Other damage**

Right Y / (N) **Right damage** none minor moderate extensive

Riparian veg: mark left (L) & right (R) rock bare soil annuals grass L+R toetoe L+R flax L+R

treeferns low shrubs L+R high shrubs native trees L+R coniferous deciduous exotic other= seepage riparian wetland

Dominant riparian plant species Left = CABBAGE TREE + FLAX Right = CABBAGE TREE + FLAX

Local runoff potential Left slope length (m) **Left land slope class** <2° 2-5° 5-10° 10-15° 15-25°

Right slope length (m) **Right land slope class** <2° 2-5° 5-10° 10-15° 15-25°

Riparian wetlands Left absent sparse common extensive **Right** absent sparse common (extensive)

Riparian Function Assessment Field Sheet John Quinn, NIWA 13/11/2009

depth: 400-600MM D. NAIR

30

Field manual for Riparian Management

SEV Score: RZ RIP=0.7

NIWA
Taihoro Nukurangi

Site state assessment

Site: RATION CREEK ZONE 2 | Site Code: RZ2 | Date: JAN 2019 | Length (m) = 150M

GPS Top: S 41 05 50 S E 174 55 06 E | Bottom: E N

Gen. land use left side: native forest, planted forest, (sheep), beef, deer, dairy, (horticulture), peri-urban, urban

Gen. land use right side: native forest, planted forest, (sheep), beef, deer, dairy, (horticulture), peri-urban, urban

Riparian land use (mark R for right & L for left bank): conservation, (filter strip), woodlot, urban, stopbank, (whitebaiting), cattle, sheep, deer, crop, hort, esplanade reserve, waterfowl shooting, engineered floodway, Other=

Widths (m): Water= 3-6m | Channel= 8m | Bankfull= | valley bottom= 8m Fence to fence

Channel plan shape: channelised, (straight), meandering, sinuous | Valley form: V, (U), plain

Flow: ephemeral, (intermittent), perennial, regulated, wetland | Stream shade (%) = 84%

Sketch stream plan, cross-section & comments: (including where planting zones occur, position of current fencing)

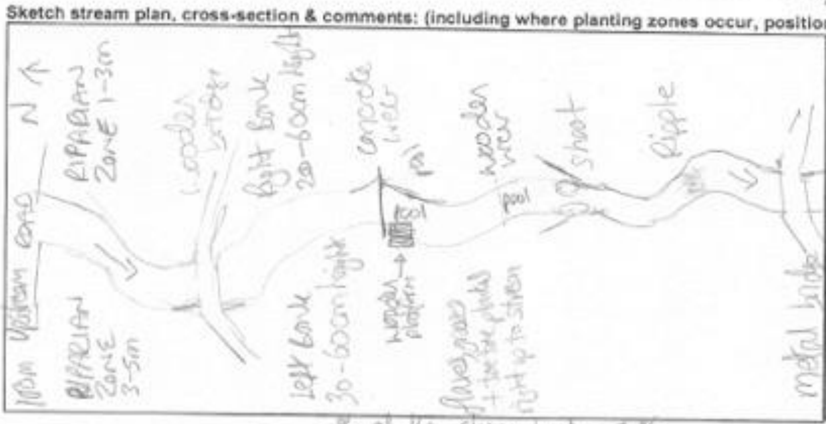


Photo numbers and descriptions

% of the stream bed — 50%

Streambed: clay, mud, (silt), (sand), (gravel), (cobble), boulder, bedrock | % riffle/run/pool: 10-10-40-40 % = 100

Bank left: Height (m) lower= 30 upper= 60cm | Stability %stable= %undercut= %slumping= %earthflow=

Bank right: Height (m) lower= 10 upper= 60cm | Stability %stable= %undercut= %slumping= %earthflow=

Stabilised by: Left (grasses) (shrubs) sedge/rushes (trees) bedrock riprap/artificial; Right (grasses) (shrubs) sedge/rushes (trees) bedrock riprap/artificial

Macrophytes: % cover = <20% Type = Brown short filaments

Periphyton: none, (slippery), obvious, abundant, excessive, Fil Alg>30% | Wood: absent, sparse, (common), abundant

Live-stock access to stream & bank damage: Left Y (N) Left damage (none) minor moderate extensive | Right Y (N) Right damage (none) minor moderate extensive | Other damage: Fenced riparian.

Riparian veg: mark left (L) & right (R): rock, bare soil, annuals, grass R, toetoe L+R, flax L+R, treeferns L+R, low shrubs, high shrubs, native trees L+R, coniferous L+R, deciduous, exotic, other=

Dominant riparian plant species: Left = CABBAGE TREE + FLAX | Right = CABBAGE TREE, FLAX + WILLOW

Local runoff potential: Left slope length (m) 5m | Left land slope class <2° 2-5° 5-10° 10-15° (15-25°); Right slope length (m) 3m | Right land slope class <2° 2-5° 5-10° 10-15° (15-25°)

Riparian wetlands: Left absent sparse common (extensive) | Right absent sparse common (extensive)

Riparian Function Assessment Field Sheet | John Quinn, NIWA | 13/11/2009

depth: 300-3200MM | D. MAIR

Field manual for Riparian Management 30

SEV Score: RZ HOBBY=0.65

NIWA
Taihoro Nukurangi

Site state assessment

Site: RATTON CREEK ZONE 3	Site Code: RZ3	Date: JAN 2019	Length (m) = 100M
GPS Top: E 4106325 N 174 55 10E	Bottom: E 4105486	N 174 55 09E	

Gen. land use left side: native forest, planted forest, sheep ✓, beef, deer, dairy, horticulture, peri-urban urban, horse ✓

Gen. land use right side: native forest, planted forest, sheep ✓, beef, deer, dairy, horticulture, peri-urban urban, horse ✓

Riparian land use (mark R for right & L for left bank) conservation, filter strip, woodlot (L+R ✓), urban, stopbank, whitebaiting, cattle, sheep, deer, crop, hort, esplanade reserve, waterfowl shooting, engineered floodway, Other= (horse)

Widths (m)	Water= 4.1	Channel= 7.5	Bankfull= 10 / valley bottom=
Channel plan shape	channelised, straight, **(meandering)**, sinuous	Valley form	V, **(U)**, plain
Flow	ephemeral, **(intermittent)**, perennial, regulated, wetland	Stream shade (%) = 64%	

Sketch stream plan, cross-section & comments: (including where planting zones occur, position of current fencing)

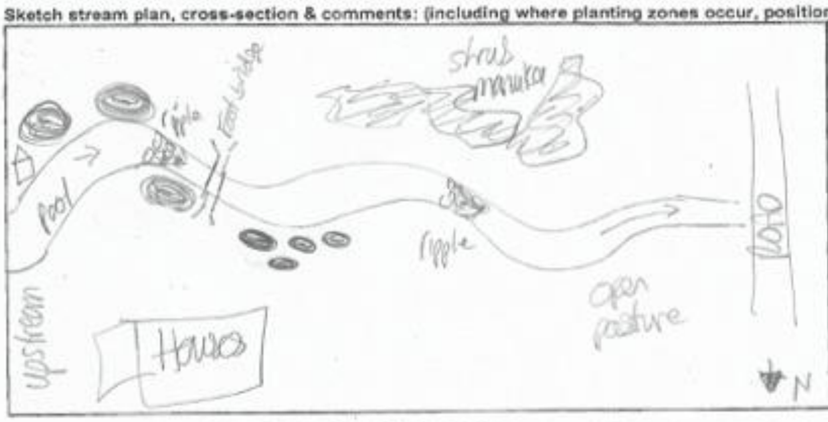


Photo numbers and descriptions

Streambed	clay, mud, **(silt)**, **(sand)**, **(gravel)**, **(cobble)**, boulder, bedrock	% riffle/run/pool	/ /	
Bank left	Height (m) lower= upper=	Stability %stable=	%undercut=	%slumping= %earthflow=
Bank right	Height (m) lower= upper=	Stability %stable=	%undercut=	%slumping= %earthflow=
Stabilised by	Left: grasses ✓, shrubs, sedge/rushes	trees native x 4	bedrock	riprap/artificial
	Right: grasses ✓, shrubs, sedge/rushes	trees x 2	bedrock	riprap/artificial
Macrophytes	% cover = 30	Type = Brown short filament		
Periphyton	none, **(slippery)**, obvious, abundant, excessive, Fil Alg>30%	Wood	absent, sparse, **(common)**, abundant	

Live-stock access to stream & bank damage: Left **(Y)** / N — Left damage: none, **(minor–moderate)**, extensive; Right **(Y)** / N — Right damage: none, **(minor–moderate)**, extensive. Other damage: hoof tracks – sheep, horse; slumping

Riparian veg: mark left (L) & right (R): rock, bare soil, annuals, grass (L+R ✓), toetoe, flax, treeferns, low shrubs, high shrubs, native trees (L+R), coniferous, deciduous, exotic, other=

Dominant riparian plant species Left = Right =

Local runoff potential	Left slope length (m)	4m	Left land slope class – steep	<2°	2-5°	5-10°	10-15°	**(15-25°)**
	Right slope length (m)	3m	Right land slope class – steep	<2°	2-5°	5-10°	**(10-15°)**	15-25°
Riparian wetlands	Left	**(absent)**, sparse, common, extensive	Right	absent	**(sparse)**	common	extensive	

Riparian Function Assessment Field Sheet — John Quinn, NIWA — 13/11/2009

depth 220-320mm

D. MAIR

Field manual for Riparian Management 30

SEV Score: RZ GOLF=0.5

NIWA
Taihoro Nukurangi

Site state assessment

Site	RATION CREEK ZONE 4		Site Code	R24		Date JAN 2019	Length (m) = 100M		
GPS	Top: S 41 04 555 N 174 55 58E		Bottom: E 41 05 57 S N 174 55 58E						
Gen. land use left side	native forest planted forest	sheep	beef	deer	dairy	horticulture	peri-urban urban	GOLF COURSE	
Gen. land use right side	native forest planted forest	sheep	beef	deer	dairy	horticulture	peri-urban urban	GOLF COURSE	
Riparian land use (mark R for right & L for left bank)	conservation	filter strip	woodlot	urban	stopbank	whitebaiting	OPEN PASTURE L+R		
cattle	sheep	deer	crop	hort	esplanade reserve	waterfowl shooting	engineered floodway	Other=	
Widths (m)	Water= 1.62m	Channel=	3.4m	Bankfull=	6	valley bottom=			
Channel plan shape	channelised	(straight)	meandering	sinuous	Valley form	V	(U)	plain	
Flow ephemeral	intermittent	(perennial)	(regulated by GWRC)	wetland	Stream shade (%) = <20% open				

Sketch stream plan, cross-section & comments: (including where planting zones occur, position of current fencing)

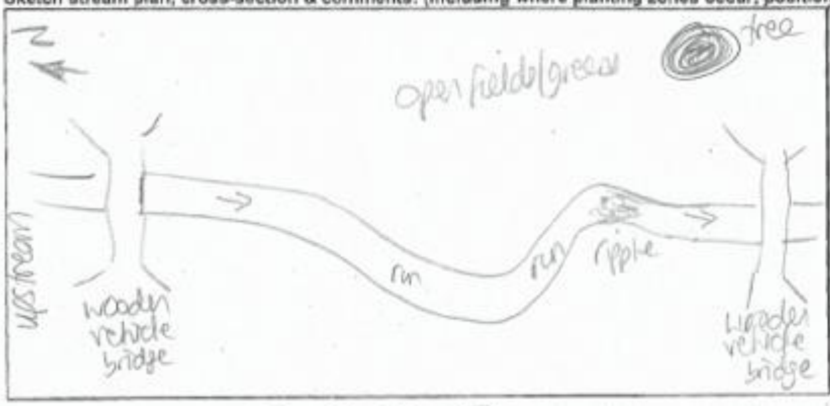


Photo numbers and descriptions

Streambed	clay	mud	(silt)	(sand)	(gravel)	(cobble)	boulder	bedrock	% riffle/run/pool / /
Bank left	Height (m) lower= 1m	upper= 2m	Stability	%stable= 60	%undercut=	%slumping= 40	%earthflow=		
Bank right	Height (m) lower= 1m	upper= 2m	Stability	%stable= 60	%undercut=	%slumping= 40	%earthflow=		
Stabilised by	Left	grasses ✓	shrubs	sedge/rushes	trees	bedrock	riprap/artificial		
	Right	grasses ✓	shrubs	sedge/rushes	trees	bedrock	riprap/artificial		
Macrophytes	% cover = 60%	Type = Brown short + long filament + Green short filament							
Periphyton	none	slippery	(obvious)	abundant	excessive, Fil Alg>30%	Wood	(absent)	sparse	common abundant
Live-stock access to stream & bank damage	Left Y / (N)	Left damage	none	minor	moderate	extensive	Other damage		
	Right Y / (N)	Right damage	none	minor	moderate	extensive			
Riparian veg: mark left (L) & right (R)	rock	bare soil	annuals	L+R grass ✓	toetoe	flax			
treeferns	low shrubs	high shrubs	native trees	coniferous	deciduous	exotic	other=		
Dominant riparian plant species	Left = Nil					Right = Nil			
Local runoff potential	Left slope length (m)		Left land slope class	(<2°)	2-5°	5-10°	10-15°	15-25°	
	Right slope length (m)		Right land slope class	(<2°)	2-5°	5-10°	10-15°	15-25°	
Riparian wetlands	Left	(absent)	sparse	common	extensive	Right	(absent)	sparse	common extensive

Riparian Function Assessment Field Sheet — John Quinn, NIWA — 13/11/2009

depth: 40-200mm

D. MAIR

Field manual for Riparian Management

30

SEV Score: HZ WET=0.65

NIWA
Taihoro Nukurangi

Site state assessment

Site: HEROKIRI STREAM ZONE 1	Site Code: H21	Date: JAN 2019	Length (m) = 100M
GPS Top: S 41 05 05S E 174 55 09E	Bottom: S 41 05 38 S	E 174 54 20 E	

Gen. land use left side: native forest | planted forest | sheep | beef | deer | dairy | horticulture | peri-urban | urban

Gen. land use right side: native forest | planted forest | sheep | beef | deer | dairy | horticulture | peri-urban | urban

Riparian land use (mark R for right & L for left bank): conservation | filter strip | woodlot | urban | stopbank | whitebaiting | cattle | sheep | deer | crop | hort | esplanade reserve | waterfowl shooting | engineered floodway | Other=

Widths (m)	Water= 4.3m	Channel= 8m	Bankfull= 12m	valley bottom= plain
Channel plan shape	channelised, straight, meandering, sinuous	Valley form	V, U, plain
Flow	ephemeral, intermittent, perennial, regulated, wetland	Stream shade (%) =	64%

Sketch stream plan, cross-section & comments: (including where planting zones occur, position of current fencing)

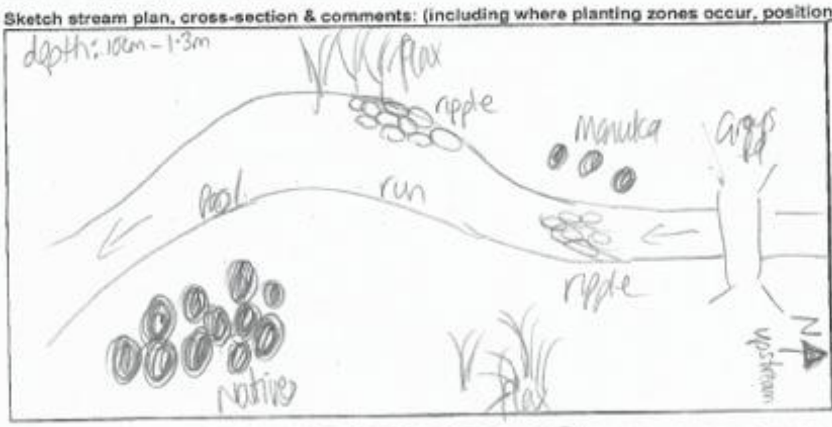


Photo numbers and descriptions

Streambed	clay, mud, silt, sand, gravel, cobble, boulder, bedrock	% riffle/run/pool	/ /		
Bank left	Height (m) lower=	upper= 1.5m	Stability %stable= 80	%undercut= 20	%slumping=	%earthflow=
Bank right	Height (m) lower= 0.0m	upper= 1m	Stability %stable= 80	%undercut= 20	%slumping=	%earthflow=
Stabilised by Left	grasses	shrubs	sedge/rushes flax	trees manuka	bedrock	riprap/artificial
Stabilised by Right	grasses	shrubs	sedge/rushes flax	trees native	bedrock	riprap/artificial

Macrophytes: % cover = 50% Type = Brown short filaments + small patches of green filament

Periphyton: none, slippery, obvious, abundant, excessive, Fil Alg>30% | Wood: absent, sparse, common, abundant

Live-stock access to stream & bank damage	Left Y / N	Left damage	none	minor	moderate	extensive	Other damage
	Right Y / N	Right damage	none	minor	moderate	extensive	

Riparian veg: mark left (L) & right (R): rock | bare soil | annuals | grass | toetoe L+R | flax L+R | treeferns | low shrubs | high shrubs | native trees L+R | coniferous | deciduous | exotic | other= seepage riparian wetland

Dominant riparian plant species: Left = | Right =

Local runoff potential	Left slope length (m)	2m	Left land slope class	<2	2-5°	5-10°	10-15°	15-25°
	Right slope length (m)	2m	Right land slope class	<2	2-5°	5-10°	10-15°	15-25°

Riparian wetlands: Left: absent, sparse, common, extensive | Right: absent, sparse, common, extensive

Riparian Function Assessment Field Sheet — John Quinn, NIWA — 13/11/2009

depth: 28-350mm

D. MAIR

Field manual for Riparian Management 30

SEV Score: HZ RIP=0.76

NIWA
Taihoro Nukurangi

Site state assessment

Site	Hokokiri STREAM ZONE 2	Site Code H22	Date JAN 2019 Length (m) = 100 M
GPS	Top: E 41 05 CDE N 174 55 08 E	Bottom:	41 0503 E N 174 55 08E
Gen. land use left side	native forest planted forest ✓ sheep ✓ beef	deer dairy horticulture peri-urban urban	
Gen. land use right side	native forest planted forest ✓ sheep ✓ beef	deer dairy horticulture peri-urban urban	
Riparian land use (mark R for right & L for left bank) conservation		filter strip woodlot (L+R) urban stopbank whitebaiting	
cattle (L) sheep (L+R) deer crop hort esplanade reserve waterfowl shooting		engineered floodway Other=	
Widths (m)	Water= 6320 Channel= 11.5	Bankfull= 15	valley bottom=
Channel plan shape	(channelised) straight meandering sinuous	Valley form V U (plain)	
Flow	ephemeral intermittent (perennial) regulated wetland	Stream shade (%) = 95%	

Sketch stream plan, cross-section & comments: (including where planting zones occur, position of current fencing)

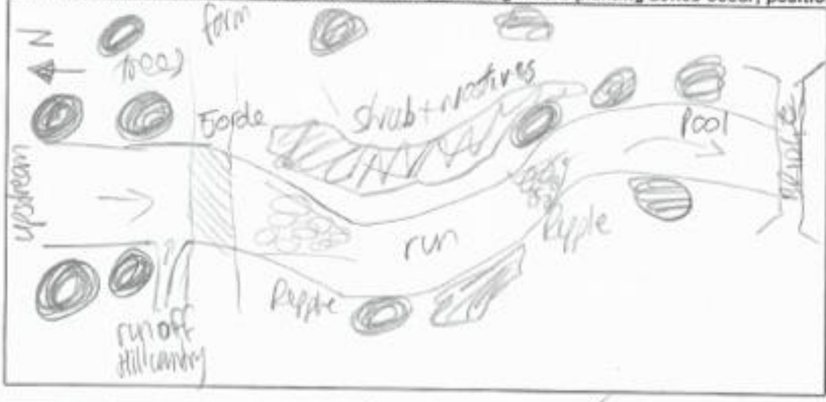


Photo numbers and descriptions

Streambed	clay mud silt sand ✓ gravel ✓ cobble ✓ boulder ✓ bedrock	% riffle/run/pool	/ /		
Bank left	Height (m) lower= 10cm upper= 1m	Stability %stable= 60%	%undercut= 40%	%slumping=	%earthflow=
Bank right	Height (m) lower= 2cm upper= 1.6m	Stability %stable= 80%	%undercut=	%slumping= 20%	%earthflow=
Stabilised by	Left: grasses ✓ shrubs ✓ sedge/rushes	trees ✓	bedrock ✗	riprap/artificial ✓	
	Right: grasses ✓ shrubs ✓ sedge/rushes ✓	trees ✓	bedrock ✓	riprap/artificial ✓	
Macrophytes	% cover = <20% Type = Green long filaments				
Periphyton	none (slippery) obvious abundant excessive, Fil Alg>30%	Wood absent sparse (common) abundant			
Live-stock access to stream & bank damage	Left Y / (N) Left damage (none) minor moderate extensive	Other			
	Right Y / (N) Right damage (none) minor moderate extensive	damage			
Riparian veg: mark left (L) & right (R)	rock bare soil annuals grass toetoe flax				
	treeferns low shrubs high shrubs native trees ✓ coniferous deciduous exotic ✓ other= willow + poplar				
Dominant riparian plant species	Left = eucalypt	Right = pine + mimosa, volunteer native			
Local runoff potential	Left slope length (m) 20	Left land slope class Hill <2° (2-5°) 5-10° 10-15° 15-25°	Soakage		
	Right slope length (m) 30	Right land slope class Flat (<2°) 2-5° 5-10° 10-15° 15-25°	seepage		
Riparian wetlands	Left absent sparse common (extensive)	Right absent (sparse) common extensive			

* extensive wetland up Hill tributary

Riparian Function Assessment Field Sheet — John Quinn, NIWA — 13/11/2009

depth 320-330 MM Extensive Riparian Planting - Very stable

Field manual for Riparian Management 30

D. MAIR

SEV Score: HZ HOBBY=0.6

NIWA
Taihoro Nukurangi

Site state assessment

Site	Hokokiri Stream Zone 3		Site Code	H23	Date Sept 2019		Length (m) = 100m	
GPS	Top: E 41 04 325 174 55496		Bottom: E 410433		N 1745548			
Gen. land use left side	native forest planted forest	sheep	beef ✓	deer	dairy	horticulture	peri-urban urban	
Gen. land use right side	native forest planted forest	sheep	beef ✓	deer	dairy	horticulture	peri-urban urban	
Riparian land use (mark R for right & L for left bank) conservation			filter strip L+R	woodlot	urban	stopbank	whitebaiting	
cattle L+R ✓	sheep	deer	crop	hort	esplanade reserve	waterfowl shooting	engineered floodway	Other=
Widths (m)	Water= 486		Channel= 19m		Bankfull= 22		valley bottom=	
Channel plan shape	channelised	straight	(meandering)	sinuous	Valley form	V	(U)	plain
Flow	ephemeral	intermittent	(perennial)	regulated	wetland	Stream shade (%) = <20%		

Sketch stream plan, cross-section & comments: (including where planting zones occur, position of current fencing)

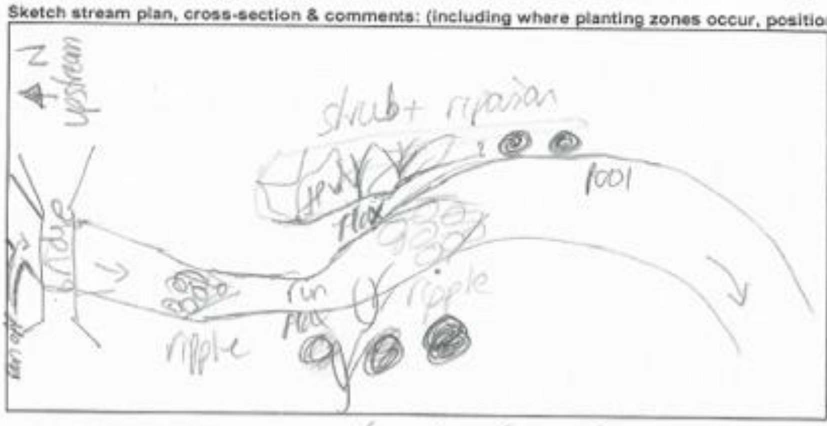


Photo numbers and descriptions

Streambed	clay	mud	silt	sand ✓	gravel ✓	cobble ✓	boulder ✓	bedrock	% riffle/run/pool / /
Bank left	Height (m) lower= 20cm upper= 1M		Stability	%stable= 60	%undercut= 20	%slumping= 20%	%earthflow=		
Bank right	Height (m) lower= 1m upper= 1.5m		Stability	%stable= 60	%undercut= 20	%slumping= 20%	%earthflow=		
Stabilised by	Left	grasses ✓	shrubs	sedge/rushes ✓	trees ✓	bedrock	riprap/artificial ✓		
	Right	grasses	shrubs ✓	sedge/rushes ✓	trees ✓	bedrock	riprap/artificial		
Macrophytes	% cover = 80%	Type = Brown short filaments							
Periphyton	none	slippery	obvious	abundant	(excessive) Fil Alg>30%	Wood	absent	(sparse)	common abundant
Live-stock access to stream & bank damage	Left (Y)/ N	Left damage	none	(minor)	moderate	extensive	Other damage	hoof tracks	
	Right (Y)/ N	Right damage	none	(minor)	moderate	extensive		slumping	
Riparian veg: mark left (L) & right (R)	rock	bare soil	annuals	grass	toetoe L+R	flax L+R			
treeferns	low shrubs	high shrubs	native trees	coniferous	deciduous	exotic	other= willow		
Dominant riparian plant species	Left = Flax				Right = Flax				
Local runoff potential	Left slope length (m)	15	Left land slope class	(<2°)	2-5°	5-10°	10-15°	15-25°	
	Right slope length (m)	12	Right land slope class	(<2°)	2-5°	5-10°	10-15°	15-25°	
Riparian wetlands	Left	absent	(sparse)	common	extensive	Right	absent	(sparse)	common extensive

Riparian Function Assessment Field Sheet — John Quinn, NIWA — 13/11/2009

depth: 140-290mm — D. MAIR

Field manual for Riparian Management — 30

SEV Score: HZ AGRI=0.5

NIWA
Taihoro Nukurangi

Site state assessment

Site	HOROKIRI STREAM ZONE 4		Site Code	HZ4	Date	JAN 2019	Length (m) =	100M
GPS	Top: E 41 04 26 S	N 174 56 00E	Bottom: E	410427		N 1745557		
Gen. land use left side	native forest	planted forest	sheep ✓	beef	deer	dairy	horticulture	peri-urban urban
Gen. land use right side	native forest	planted forest	sheep ✓	beef	deer	dairy	horticulture	peri-urban urban
Riparian land use (mark R for right & L for left bank) ✓	conservation			filter strip	woodlot	urban	stopbank	whitebaiting
cattle	sheep	deer	crop	hort	esplanade reserve	waterfowl shooting	engineered floodway	Other=
Widths (m)	Water= 4240		Channel= 15		Bankfull= 27		valley bottom=	
Channel plan shape	channelised	(straight)	meandering	sinuous	Valley form	V	(U)	plain
Flow	ephemeral	intermittent	(perennial)	regulated	wetland	Stream shade (%) = <20%		

Sketch stream plan, cross-section & comments: (including where planting zones occur, position of current fencing)

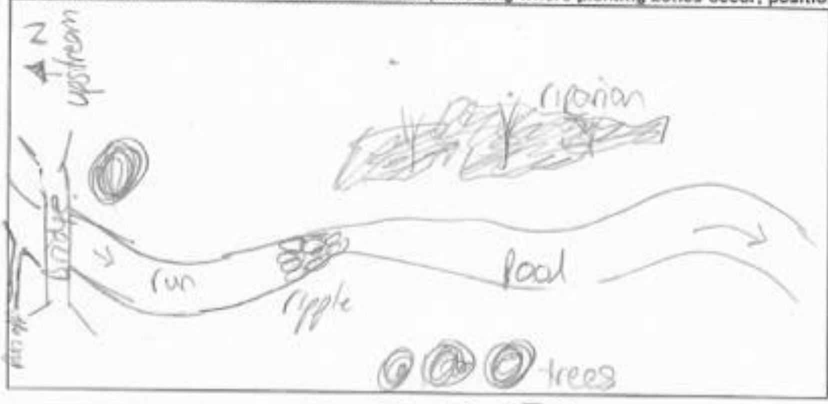


Photo numbers and descriptions

Streambed	clay	mud	silt	(sand)	(gravel)	(cobble)	(boulder)	bedrock % riffle/run/pool / /
Bank left	Height (m) lower=10m upper=3m		Stability	%stable=	%undercut=	%slumping=	%earthflow=	
Bank right	Height (m) lower=20m upper=1M		Stability	%stable=	%undercut=	%slumping=	%earthflow=	
Stabilised by	Left	grasses ✓	shrubs	sedge/rushes	trees ✓	bedrock	riprap/artificial ~	
	Right	grasses ✓	shrubs ✓	sedge/rushes	trees	bedrock	riprap/artificial ✓	
Macrophytes	% cover = 80	Type = Brown short filaments						
Periphyton	none	slippery	obvious	abundant	(excessive), Fil Alg>30%	Wood	(absent)	sparse common abundant

Live-stock access to stream & bank damage	Left Y / (N)	Left damage	none	(minor)	moderate	extensive	Other
	Right Y / (N)	Right damage	none	(minor)	moderate	extensive	damage
Riparian veg: mark left (L) & right (R)	rock	bare soil	annuals	grass L+R	toetoe	flax L+R	
treeferns	low shrubs L+R	high shrubs (L)	native trees	coniferous	deciduous	exotic	other= Pine + willow (R)
Dominant riparian plant species	Left = Pine + Flax + gorse			Right = Flax + Manuka			
Local runoff potential	Left slope length (m) 15M	Left land slope class	(<2°)	2-5°	5-10°	10-15°	15-25°
	Right slope length (m) 12m	Right land slope class	(<2°)	2-5°	5-10°	10-15°	15-25°
Riparian wetlands	Left absent	(sparse)	common extensive	Right absent	sparse	(common)	extensive

Riparian Function Assessment Field Sheet — John Quinn, NIWA — 13/11/2009

depth: 200-800mm

D. MAIR

Field manual for Riparian Management — 30

Appendix 2: Water quality testing results from the assessment

Median, maximum and minimum values of water quality variables taken weekly over a 16-week period between 1 October 2018 and 31 January 2019. The median is from 16 temporal samples in each of the four spatial zones. Values were recorded at the same time and depth each week. * highlights low results that were investigated

Horokiri Stream	**Median**	**Min**	**Max**	**Ration Creek**	**Median**	**Min**	**Max**
HZ WET tidal				**RZ WET**	**tidal**		
Temperature (°C)	16.85	14.8	21.5		17.3	14.1	20.8
pH	7.675	7.53	7.9		7.63	7.53	7.88
DO%	70.05	49.4	121.6		77.6	52	132.3
DO mg/L	6.735	4.7	12.3		7.385	4.99	10.35
Conductivity (μs cm-1)	176.7	156.2	206.9		210.45	144.7	222
Total Dissolved Solids mg/L	135.2	124.8	146.25		160.55	118.95	229.45
Salinity ppt	0.1	0.09	0.11		0.12	0.09	21.8
SHMAK clarity result	0.9	0.8	0.99		0.99	0.7	0.99
HZ RIP	**Median**	**Min**	**Max**	**RZ RIP**	**Median**	**Min**	**Max**
Temp degrees C	16.5	15.1	21.5		15.8	14.1	18.9
pH	7.665	7.47	8.39		7.635	7.59	7.8
DO%	56.45	44.8	85.7		67.25	39.1	89.9
DO mg/L	5.49	4.39	8.55		6.39	3.9*	8.78
Conductivity (μs cm-1)	169.6	79.8	207.9		196.1	145.4	225.6
Total Dissolved Solids mg/L	133.575	124.15	144.95		153.725	118.3	167.05
Salinity ppt	0.1	0.09	0.11		0.115	0.09	0.12
SHMAK clarity result	0.99	0.99	0.99		0.99	0.30*	0.99
HZ HOBBY	**Median**	**Min**	**Max**	**RZ HOBBY**	**Median**	**Min**	**Max**
Temp degrees C	16.5	14.3	18.5		16.2	12.7	18.1
pH	8.08	7.6	8.53		7.665	7.63	7.93
DO%	63.3	56.3	102.8		73	51.1	99.3
DO mg/L	6.21	5.72	10.06		7.415	5.17	9.87
Conductivity (μs cm-1)	170.6	152.8	188.2		205.2	147.6	216.4
Total Dissolved Solids mg/L	131.95	123.5	144.95		156.975	120.9	167.05
Salinity ppt	0.1	0.09	0.11		0.115	0.09	0.12
SHMAK clarity result	0.89	0.8	0.92		0.99	0.8	0.99
HZ AGRI	**Median**	**Min**	**Max**	**RZ GOLF**	**Median**	**Min**	**Max**
Temp degrees C	16.7	13.7	17.9		16	14.4	18.1
pH	8.12	7.65	8.52		7.6	7.35	7.9
DO%	68.5	49.9	101.8		59	48.1	84.5
DO mg/L	6.7	4.82	9.85		5.82	4.74	8.61
Conductivity (μs cm-1)	177.8	154	188.5		169.9	128.4	185.8
Total Dissolved Solids mg/L	137.15	124.15	144.95		130	104.65	145.6
Salinity ppt	0.1	0.09	0.11		0.09	0.08	0.11
SHMAK clarity result	0.85	0.46*	0.99		0.99	0.85	0.99

Appendix 3: Water quality testing results during the 28-day experiment

Stream	Weather	Dates	Visual Clarity	Temp	pH	DO%	DO	Conductivity	TDS	Salinity	Flow m/sec	Rainfall ml
Horokiri Stream	cloudy 21	1/02/19	2400	18.8	7.47	68.5	6.37	196.9	144.95	0.11	0.134	0
Horokiri Stream	sunny 20	2/02	2300	17	7.58	57.5	5.55	190.3	145.6	0.11	0.15	3.4
Horokiri Stream	sunny 18	3/02	2240	15.9	7.48	51.5	5.17	183.9	144.95	0.11	0.128	0
Horokiri Stream	cloudy 20.5	4/02	2430	17.6	7.56	64.2	6.13	191.6	144.94	0.11	0.12	0
Horokiri Stream	sunny 21	5/02	2720	17.8	7.54	73.4	6.97	193.1	145.6	0.11	0.124	0
Horokiri Stream	cloudy 15.3	6/02	2560	17.6	7.48	48.6	4.62	192.6	145.6	0.11	0.13	0
Horokiri Stream	sunny 17.5	7/02	2680	14.9	7.43	56.3	5.74	179.2	144.3	0.11	0.113	0
Horokiri Stream	sunny 18	8/02	2820	14.6	7.56	42.3	4.29	178.3	144.3	0.11	0.11	0
Horokiri Stream	sunny 20	9/02	2530	16.4	7.49	49.8	4.86	186	144.95	0.11	0.107	0
Horokiri Stream	sunny 20	10/02	2730	16.4	7.54	47.5	4.6	185.8	144.3	0.11	0.105	0
Horokiri Stream	sunny 18	11/02	2950	16.4	7.58	39.4	3.84	186.2	144.95	0.11	0.111	0
Horokiri Stream	cloudy 18.6	12/02	2250	17.2	7.5	48.7	4.69	189.9	144.95	0.11	0.104	0
Horokiri Stream	sunny 20.5	13/02	2930	18.2	7.54	60.5	5.7	194.93	145.6	0.11	0.108	0
Horokiri Stream	sunny 20	14/02	1950	18	7.49	44.2	4.25	193.6	144.95	0.11	0.107	0
Horokiri Stream	cloudy 20	15/02	2880	18.7	7.48	49.4	4.61	197.1	145.6	0.11	0.095	0

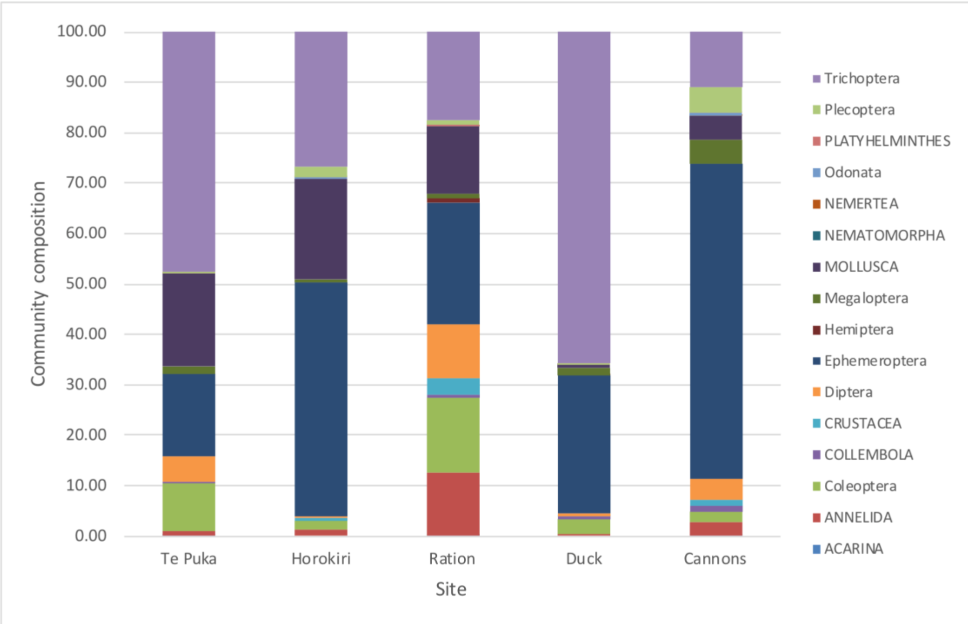
Horokiri Stream	cloudy 18.2	16/02	2610	17.3	7.47	87.5	8.38	190.7	144.95	0.11	0.101	0
Horokiri Stream	sunny 16	17/02	2470	15.1	7.47	68.3	6.85	181.1	144.95	0.11	0.095	0
Horokiri Stream	sunny 18	18/02	2960	16.6	7.46	68.8	6.71	186.8	144.95	0.11	0.093	0
Horokiri Stream	sunny 20	19/02	2470	15.1	7.47	68.3	6.85	181.1	144.95	0.11	0.092	0
Horokiri Stream	cloudy 18	20/02	2570	17.6	7.42	67.7	6.44	192.5	145.6	0.11	0.096	0
Horokiri Stream	cloudy 22	21/02	2590	17.5	7.45	68.6	6.58	191.6	145.6	0.11	0.096	0
Horokiri Stream	cloudy19.6	22/02	3020	18.8	7.5	62.6	5.83	199	146.9	0.11	0.11	0.9
Horokiri Stream	cloudy 17	23/02	1920	17.3	7.58	64.5	6.26	207.7	157.95	0.12	0.268	1.6
Horokiri Stream	rain 13.8	24/02	1860	16.1	7.55	60.7	5	178.6	139.75	0.1	0.134	2.7
Horokiri Stream	rain 12.3	25/02	2440	13.7	7.67	65.7	6.83	184.2	152.75	0.11	0.191	12.3
Horokiri Stream	sunny 17	26/02	3120	12.8	7.53	101.2	10.59	178	150.8	0.11	0.122	0
Horokiri Stream	cloudy 15	27/02	2910	15.5	7.52	73.4	7.33	188.5	149.5	0.11	0.11	0
Horokiri Stream	cloudy 16	28/02	2900	14.8	7.57	69	6.99	185	149.5	0.11	0.11	0
Ration Creek	cloudy 21	1/02/19	1600	18.3	7.61	74.4	6.96	239.4	176.8	0.13	0.045	0
Ration Creek	sunny 20	2/02	1500	16.9	7.76	50.1	4.84	229.1	176.15	0.13	0.05	3.4
Ration Creek	sunny 18	3/02	1810	15	7.71	50.5	5.09	217.6	174.85	0.13	0.043	0

Ration Creek	cloudy 20.5	4/02	1900	16.5	7.61	60.5	5.89	226.6	175.5	0.13	0.04	0	
Ration Creek	sunny 21	5/02	1540	17.4	7.71	69.4	6.66	231.9	175.15	0.13	0.041	0	
Ration Creek	cloudy 15.3	6/02	1560	17.3	7.69	39.2	3.8	229.9	174.85	0.13	0.04	0	
Ration Creek	sunny 17.5	7/02	1540	14.2	7.55	49.6	4.04	216.6	177.45	0.13	0.04	0	
Ration Creek	sunny 18	8/02	2130	13.6	7.56	48.8	5.05	213.3	177.45	0.13	0.04	0	
Ration Creek	sunny 20	9/02	1910	15.2	7.57	37.4	3.74	221.8	177.45	0.13	0.036	0	
Ration Creek	sunny 20	10/02	1940	14.7	7.58	35.1	3.82	220	178.1	0.13	0.035	0	
Ration Creek	sunny 18	11/02	1810	15.3	7.47	55.8	5.57	222.7	178.1	0.13	0.037	0	
Ration Creek	cloudy 18.6	12/02	1670	16.1	7.53	35.6	3.49	227.7	178.75	0.13	0.035	0	
Ration Creek	sunny 20.5	13/02	1520	17.1	7.62	42.1	3.98	233.7	178.75	0.13	0.035	0	
Ration Creek	sunny 20	14/02	1600	17.1	7.6	39.1	3.76	234.3	179.4	0.13	0.035	0	
Ration Creek	cloudy 20	15/02	1640	18.1	7.53	48.1	4.54	241.2	180.7	0.13	0.032	0	
Ration Creek	cloudy 18.2	16/02	1760	16.8	7.6	64	6.18	236.3	182	0.13	0.034	0	
Ration Creek	sunny 16	17/02	2150	14.4	7.6	58.3	5.91	222.9	181.35	0.13	0.032	0	
Ration Creek	sunny 18	18/02	1740	15.7	7.61	69.2	6.72	224.8	178.1	0.13	0.031	0	
Ration Creek	sunny 20	19/02	2150	14.4	7.6	58.3	5.67	222.9	181.35	0.13	0.031	0	

Ration Creek	cloudy 18	20/02	1760	16.9	7.57	58.3	5.66	234.6	180.7	0.13	0.032	0
Ration Creek	cloudy 22	21/02	1710	17	7.52	61.4	5.98	236.6	180.7	0.13	0.032	0
Ration Creek	cloudy 19.6	22/02	1530	18.3	7.6	60.6	5.57	244.3	182	0.13	0.037	0.9
Ration Creek	cloudy 17	23/02	1270	17.7	7.54	61.2	5.84	244.2	184.6	0.14	0.089	1.6
Ration Creek	rain 13.8	24/02	1380	15.9	7.51	70.1	6.91	242.5	190.45	0.14	0.045	2.7
Ration Creek	rain 12.3	25/02	880	13.7	7.8	63.3	5.54	222.6	184.6	0.14	0.064	12.3
Ration Creek	sunny 17	26/02	1340	11.6	7.77	94.3	10.3	209.1	182.55	0.13	0.041	0
Ration Creek	cloudy 15.3	27/02	1710	14	7.7	67.3	6.94	215.9	178.1	0.13	0.034	0
Ration Creek	cloudy 16	28/02	1830	13.9	7.76	52.5	5.44	221.2	182.65	0.13	0.034	0

Appendix 4: Graph of Transmission Gully fish and macroinvertebrate 2018 results summary by Boffa Miskell Ltd. (Report TG-CPBH-RPT-ALL-GE-9212 written by T Strange).

This site is 500m upstream of my Ration Golf site at Pauatahanui Golf Course which is 3km upstream of the riparian experiment site.



The Boffa Miskell Ltd report shows the highest average MCI score was in Duck Creek, while the lowest MCI score was recorded in Ration Creek. Average MCI has decreased across all sites except Ration (which has remained stable) when compared to the winter 2017 results. Macroinvertebrate metric data below:

	Te Puka			Horokiri			Ration		
	A	B	C	A	B	C	A	B	C
Total abundance	2401	1050	2337	4370	2131	2146	2596	2170	1225
Number of taxa	29	26	29	30	24	23	44	32	29
Number of EPT taxa	15	16	16	15	13	11	16	14	14
MCI score	113.1	121.5	114.5	121.3	120.8	108.7	102.4	97.6	104.8
QMCI	5.3	5.4	5.2	6.2	6.2	6.5	4.7	5.2	5.5

Appendix 5: Raw macroinvertebrate data from the experiment

BM Reported	Ration Creek Experiment	Known name	wk 1	wk2	wk3	wk 4	control: 21 days	control: addtl wk4
Crustacea	Ostracoda	shrimps	1					
Ephemeroptera	Coloburiscus	spiny gilled mayfly						1
Coleoptera	Elmidae	Beetles	1					
Trichoptera	Olinga	smooth cased caddis	2	1	1	5	4	5
Molluscs	Potamopyrgus	mud snails	97	266	135	67	79	115
Ephemeroptera	Deleatidium	mayfly	1	2		2	1	5
Trichoptera	Triplectidina Leptoceridae	stick caddis	2	3	2		1	
Platyhelminthes	Platyhelminthes	flatworms					4	

BM Reported	Horokiri Stream Experiment	Known name	wk 1	wk2	wk3	wk 4	control: 21 days	control: addtl wk4
Crustacea	Ostracoda	shrimps	50	30	20	16	29	30
Collembola	Collembola	Springtails	10					
Ephemeroptera	Coloburiscus	spiny gilled mayfly	1				1	
Hemiptera	Notonectidae	Backswimmer			10			
Trichoptera	Olinga	smooth cased caddis					6	
Molluscs	Potamopyrgus	mud snails	71	123	36	9	111	172
Trichoptera	Oeconesidae	stony cased caddis	1					
Plecoptera	Zelandobius	stonefly					1	
Ephemeroptera	Deleatidium	mayfly	16	4	2	1	34	6
Trichoptera	Hydrobiosidae: Neurochorema	Free living caddis	5	7	1	2	2	2
Trichoptera	Triplectidina Leptoceridae	stick caddis		3			1	3
Coleoptera	Elmidae	beetle	2					
Hemiptera	Hemiptera	aquatic bug		3		5	1	4
Platyhelminthes	Platyhelminthes	flatworms/leeches	8	3	2	10	2	4
Megloptera	Archichauliodes	Dobsonfly					1	