An integrated catchment management plan toward restoration: sustainable farming with a future focus in the Mangaone West

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Andree Beth Hickey-Elliott

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Abstract

Land cover change and land use management practices have caused environmental degradation of the Mangaone West catchment. A catchment management plan is needed to address the degradation. An integrated method was used to improve the likelihood of plan success. ArcMap and biophysical sampling were used to provide a knowledge base of current catchment conditions. Considerable environmental sampling was carried out, including MCI and QMCI indices, nutrient sampling of nitrogen and phosphorous, sediment assessment methods, riparian assessment and erosion assessment. A catchment meeting was held to form a consensus plan goal and view. The goal of 'sustainable farming in the Mangaone West, with a future focus' was established. The river styles framework and a traditional integrated catchment management plan framework were reviewed. Components for plan success were reviewed and integrated into the proposed plan. The catchment sampling found significant degradation with regard to its geomorphology, riparian margin and water quality. Erosion and connectivity of the upper catchment hillslopes and waterways is a significant issue. Much of the catchment is lacking a riparian margin. A combined plan is proposed, using a mixture of the river styles framework and traditional development structure. Best management practices need to be adopted by all landowners and riparian margins require significant restoration. Hillslopes of the upper catchment require stabilisation, and problematic willows in the lower catchment need to be removed. The local community needs to be involved throughout the plan implementation in order to maximise its success. With the proposed plan utilised, the Mangaone West could be restored to a sustainable environment.

Acknowledgements

I would like to thank my supervisor, associate professor Ian Fuller, for his guidance and advice during my study. Also deserving a significant mention is Alastair Cole for his help and advice. My family also helped me in completing this thesis, particularly John Elliott. Many numerous others were of great value during this process, so I sincerely thank my fellow peers and friends.

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Introduction

Environments change over time, with all organisms involved in the process, exerting an effect on their habitat (Vitousek, Mooney, Lubchenco, & Melillo, 1997). This is no less true of humans, which have essentially altered aspects of all the world's environments (Lambin et al., 2001; Vitousek et al., 1997). Worldwide, during the late to present-day Holocene, there have been many natural environment changes. However, anthropocentric change has become far more extensive and is dramatically accelerating climate change (Tett et al., 2002). New Zealand is no exception with rapid change from forest-dominated land to pasture after colonisation (Glade, 2003).

Problem

Over the past few years, stakeholders in the Mangaone West have begun carrying out environmental work to reduce the impacts of agriculture in the area. To provide the work being carried out with improved direction, and ensure actions are efficient, the development of an Integrated Catchment Management Plan (ICMP) is required. The acquisition of funding through the Manawatu River Accord and Sustainable Farming Fund have provided the monetary means for more significant and long-term environmental work. A more detailed description of the problems faced is in a later chapter.

Aim

This research has been conducted to assess the current environmental state of the Mangaone West, and develop an appropriate ICMP. The research in the catchment will examine the biophysical characteristics and processes occurring. From these findings, the extent of ecosystem function changes can be identified and a plan created to rectify the catchments degradation. The plan aims to restore and rehabilitate the catchment, and allow more sustainable farming, in an integrated manner. Landcare Trust (LCT) will be the user of this plan, as the acting facilitator in the catchment.

Objectives

1. Integrate as thoroughly as possible to gain a well-rounded approach to restoration.
2. Determine the current environmental state of the catchment with regard to land, water and natural processes occurring.
3. Mitigate factors causing degradation.
4. Find appropriate strategies to improve natural function.
5. Provide a plan approach which enables adaptation.

Importance

This document will enable further forward-planned environmental work in the catchment. The project will be provided with direction and focus on strategies which will more efficiently improve the environmental state and natural processes of the catchment. This will be important in ensuring work carried out is of use and makes the most positive impact possible. The use of ICMPs will become more prominent in future, as need for management will increase. While this plan has been suited to the Mangaone West, the framework for its development and some of the strategies will be applicable for other projects.

Limitations

The limitations of this work were mostly due to a lack of previous information on the catchment, and time constraints. Very little analysis of the Mangaone West has been carried out by the regional council or other bodies. The flow of the stream is not recorded and there was no historical data found. One university student had completed a resource inventory on the area, however it was not to a standard to be of use in this research. A landowner in the catchment did speak of previous data from regulatory monitoring of his point source discharge, but the information was not obtained after repeated attempts. Due to this lack of information a reference site was instead required to compare environmental states and form targets. Although that site was similar in character, awareness remains of the limitations associated with the use of an external reference site.

Collecting all the required data quickly and with monetary constraints did not allow long-term water quality assessment, which is of importance in agricultural catchments. However, sampling was taken during optimal season and weather to allow a fair representation of the streams' nutrient loadings.

A further minor limitation to the sampling was identification of some invertebrates for the MCI and QMCI indices. While not all the invertebrates identified were checked by other insect specialists, many with less certain identities were looked at and clarified by aquatic ecologists, in particular, Ian Henderson, of Massey University.

Thesis outline

There are seven chapters to this thesis, with further subdivisions within them. The following outline provides a brief synopsis.

Introduction

Introduces the research, providing the background, the problem statement, aim, objectives, and limitations.

Problem

The issues resulting in the need for the development of a catchment management plan are discussed. The historical changes to the catchment land cover, and land use are covered, and their impact on the functioning of the ecosystems within the catchment discussed.

Literature Review

The focus for the literature review is on catchment management plans (CMPs), integration, how literature recommends development (focus on Heathcote's (1998) traditional approach, and, the river styles framework). Aspects for more successful plans are included, and relevant New Zealand ICMPs are discussed. This chapter forms the basis for the plan development approach.

Approach and Methodology

The approach taken for assessing aspects of the environment, including geographical information system (GIS), and fieldwork, are stated. The methods used for data-analysis are described, and approach to plan option selection is explained.

Result
The findings of fieldwork, GIS and Google earth mapping are presented, existing information is collated, and the river styles framework results are included. The plan options are proposed with their fit to assessment criteria and the most suitable plan option is presented.

Discussion
The findings of the results are discussed with relation to the problem and literature. The preferred plan option is further developed with implementation strategies. The plan and strategies are linked closely with the findings in a manner to maximise biophysical improvement. Targets for improvement and timeframes are included.

Conclusion
A summary of the main findings and important plan recommendations are stated.

Background
The Mangaone West catchment is a tributary catchment to the Oroua River, which is also a sub-catchment to the Manawatu River of the Manawatu. The Mangaone West is west of the North Island's main divide and lies amongst two anticlines: the Mount Stewart-Halcombe and Fielding anticlines. The catchment borders lay roughly at the anticline axes (Figure 1). The Fielding anticline has well-preserved planar interfluves, which coincide with the upper Mangaone West headwater streams. As a result, the waterways drain westward, giving the upper catchment the characteristic parallel drainage pattern (Jackson, Van Dissen & Berryman, 1998). The drainage has been imposed by geology, and supported during tectonic uplift and southward tilting. The interfluves are the remnant marine surface from around 300,000 years ago. It is stated by Jackson et al. (1998) that the streams erode more vigorously on the northern side of valleys in the area affected by the anticline, leaving the southern valley steeper. The western flank of the catchment is steepened by the Mount Stewart-Halcombe anticline, which has promoted a more parallel drainage pattern where dendritic would have been previously prevalent (Jackson et al., 1998).

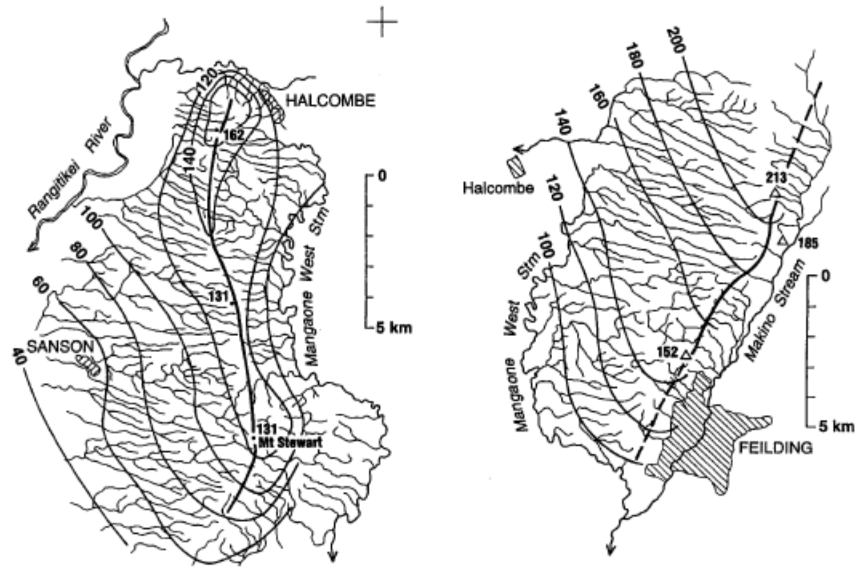

Figure 1. Drainage pattern maps
The Mount Stewart-Halcombe and Fielding anticlines, showing topographic contour lines, adapted from Jackson et al. (1998, page 380).

Originally the area was covered in podocarp forest, scrubland and wetland (Manawatu District Council, 2014). Early occupation of The Mangaone West was by people of the Aotea canoe, followed by the Rangitane tribe (Durie & Durie, 2012). The early 1800’s saw the more prominent arrival of Ngati Kauwhata tribe, which populated the area and town now called Halcombe (Manawatu-Wanganui Regional Council, 1997; D. Emery, personal communication, October 15, 2013). The European settlers then occupied the region and established Fielding in the mid to late 1800’s. Some deforestation and primitive agriculture had already begun, but mass clearance, via burning, removed the vast majority of native habitat in the catchment around 100 years ago. Clearance made way for pastureland for the Rangitane, then for the Europeans (Arrends, 2003). Wetlands were then drained and remaining forest felled by 1920 (Arrends, 2003). Since the clearing and draining, severe soil erosion has occurred. The Ngati Kauwhata and other hapu remain interested in the Mangaone West and its care, due to their cultural beliefs, and disapproved of the environmental state which deteriorated significantly with European colonisation (Manawatu-Wanganui Regional Council, 1997; Manawatu District Council, 2002).

The loss of native flora and fauna was significant in the Mangaone West, and more recently stakeholders have noticed the environmental impact of biodiversity loss, and agricultural practices. The steep nature of some of the catchment, combined with agriculture use, has meant top-soil loss is becoming an issue for the local farmers, reducing productivity and causing sedimentation and other in-stream impacts. Some work has already been carried out by locals and LCT, funded partially by government subsidies. This work has been largely fencing and riparian planting, and leads to a promising outlook for management (Landcare Trust, 2013; Barnett, 2014).

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Problem

The catchment requires management to improve its environmental state principally due to degradation following human disturbance. The most notable disturbance was historical forest clearance upon European arrival, as detailed in the introduction. Forest clearance diminished riparian margins and left steep hillslopes open, meaning that the connectivity of slopes and waterways increased, and exposure to erosion with it (MacLeod & Moller, 2006). Reduced bank stability has occurred, making the meandering stream more mobile. The large-scale forest clearance also reduced biodiversity of fauna and flora significantly, reducing ecosystem functioning (Foley, et al., 2007; De Marco & Coelho, 2004). The impeded ecosystem functions include nutrient cycling and retention (on land), hillslope stability, natural flow regulation, and freshwater filtering (Foley et al., 2007).

While land cover change was a major disturbance, further disturbance and degradation has occurred from agricultural practices. These practices, old and current, further impact on the catchment by increasing erosion (both stream bank and hillside) and by increasing nutrient, faecal and sediment inputs to waterways; topsoil structure compaction and peak flood exacerbation also result (Burgers, 1985; McLaughlin & Mineau, 1995).

The environmental degradation resulting from these issues leads to the need for improved management, and thereby, again highlights the need for a catchment management plan. The plan benefits the community by reducing the loss of the more productive topsoil, and reducing nutrient losses. This plan will be integrated to improve the uptake and changes necessary, as the more stakeholders and community involvement occurs, the better catchment management works (Palmer et al., 2005; Margerum, 1999). Social, economic and environmental aspects are taken into account during plan development, to improve the probability of success (Allen, Van Dusen, Lundy & Gliessman, 1991).

Biophysical issues

How water and landforms interact is altered by land cover and use, both current and previous (Allan, 2004). The reduction in surface heterogeneity and spatial complexity of land cover, due to conversion of land from forest to agriculture, has increased the ability of water and other factors such as wind to more rapidly alter the landscape and associated aquatic habitats (Allan, 2004). The rate of erosion and connectivity between terrestrial and aquatic environments has increased significantly, while decreasing productivity through loss of nutrients and minerals present in topsoil, and increasing sediment and nutrient delivery to waterways (Pimentel et al., 1995).

Biodiversity loss

Forest clearance directly altered the vegetation present, and indirectly altered the geomorphology of the land, the fauna present (birds, insects, microorganisms) and ecosystem functioning (Blaschke, Trustrum, & DeRose, 1992).

The loss of biodiversity, largely native, that results with large scale change in land use is immense; around 25% of native forest remains in New Zealand, while pasture now covers over 60% (Blaschke et al., 1992). The change in this catchment's land cover and use is reflective in the the GIS results; the ecosystems as a whole, have been significantly altered (Chapin et al., 2000). Exotic species flourish while native and endemic populations have been lost or significantly reduced in the area (Norton & Miller, 2000; Ministry for the Environment, 1997).

Entire plant species from the catchment have been lost and others have been reduced to levels where population-interspecies dynamics are altered (MfE, 1997). Along with intentional introductions, there has been an influx of other introduced and invasive species suited the new environment (Folke et al., 2004). Aquatic plant biodiversity was is impacted by land cover change; due to physical changes such as temperature (due to lost shading), sediment (deposited and suspended), altered peak and minimum flows, and chemical changes (nutrients, chemicals, pathogens) (Wood & Armitage, 1997).

The change in vegetation altered many aspects of the catchment: habitat, food sources, protection from predators, and increased competition among the fauna present. Biodiversity loss of native birds, fish, invertebrates and microbes was due to direct and indirect effects of the mass clearance (Folke et al, 2004; Wood & Armitage, 1997).

Terrestrial environments

Hillslope erosion and instability

Hillslope erosion and connectivity to waterways has increased due to higher peak flow rates and increased soil exposure. This has resulted from the reduction in plant life diversity and root complexity on hill slopes (Blaschke et al., 1992). Ground exposure to wind has also increased as a result, which increases the rate of topsoil loss from the slopes (Pimentel & Kounang, 1998). The amount of erosion reaching waterways, and thus connectivity, will have increased, negatively impacting both terrestrial and aquatic ecosystems (Pimentel et al., 1995).

Landslides

More, and generally larger landslides occur under pasture cover compared to forest and more dense, complex vegetative cover, as the root systems of pasture are less cohesive and stabilising than vegetation previously present (forest and shrub), and infiltration and saturation are faster (Fahey & Marden, 2000; Glade, 1998). More of these landslides are likely to connect with the waterways as there is less abrasive heterogeneous vegetation downhill to slow and catch the landslide movement (Borselli, Cassi, & Torri, 2008; Puigdefabregas, Sole, Gutierrez, del Barrio, Boer, 1999). Landslides are a predominant issue in the steeper upper catchment and reduce the productivity of the area involved, due to impaired ecological functioning (Blaschke, Trustrum, & Hicks, 2000).

Sheet

Sheet erosion is likely one of the most significant forms of erosion in the catchment and is widespread (GIS results). This process can occur through wind and surface flow, and has increased effect again due to the higher soil exposure to rain splashes and running water that occurs under pasture compared to previous vegetative coverage (Sidle et al., 2006; Pimental & Kounang, 1998; Pimentel et al., 1995).

Rill

Rill erosion can be seen occurring on some hillsides and is a common issue where there is little vegetative coverage. The pasture provides less protection than more complex structured vegetative cover and increased peak flows of water cause more soil particle entrainment and thereby, faster rilling (Sidle et al., 2006; Poesen, Nachtergaele, Verstraeten, & Valentin, 2003).

Gullying

Steeper hill slopes are prone to rill erosion transforming into gullying; the rate is increased under pasture compared to forest, naturally due to increased momentum of water and decreased support of soil cohesion from plant root systems (Poesen et al., 2003).

Aquatic aspect

Stream bank instability

Bank erosion

Stock currently have access to many of the waterways in the mid and upper catchment, and will eat as well as tread on the streambank. The bank stability reduction due to loss of cohesive roots from plants in the riparian margin, and stock tread, results in increased stream bank erosion, causing stream widening, and often an associated shallowing (Thorne, 1990). This slowly erodes land adjacent to the waterway, reducing productive land area.

Meander movement increased

The decreased bank stability due to supportive root cohesion of soil results in the mobility of the waterway increasing laterally; while this process is natural, the rate is accelerated and inconveniences those with adjacent land (Micheli, Kirchner, & Larsen, 2004; Naiman & Decamps, 1997).

Sediment load increased

Agricultural pastoral land has much a higher sedimentation rate than naturally occurs (Fahey & Marden, 2000). Connectivity increase and erosion acceleration increase both suspended sediment (fine sediments carried in the water column) and deposited sediment (which settles on the waterway bed, covering and infilling the heterogeneous bed and hyporheic zone) (Wood, Armitage, 1997). The resulting ecological issues follow on from altered and reduced habitat, reduced sunlight, increased turbidity, and organism gill clogging (Cordone & Kelley, 1961; Newcombe & MacDonald, 1991).

Flow regime

Land cover change causes hydrologic change, and therefore, flow regime change. Flow regime is regulated in part by the land cover present, as increased vegetative complexity on land slows the drainage process of water into waterways (Poff, Bledsoe, & Cuhaciyan, 2006). Peak waterway flows are higher with less complex land cover, and reduced soil water holding capacity, as the movement of water through a catchment is accelerated (Allan, 2004; Poff et al., 2006; Sparks, 1995). Flow minimums may be higher due to lowered levels of evapotranspiration, but maximums are also higher, and flashy flow becomes more of an issue (Poff et al., 2006). Different organisms and communities exist after flow regime change; many native fish species and populations decline, while exotic or invasive fish increase in prominence (Biggs et al., 1990; Biggs, Ibbitt, & Jowett, 2008; Clausen & Biggs, 1997; Joy & Death, 2013).

Land use practices

Agricultural practices have changed significantly since farming originally started in the catchment. Intensity has increased, with a rise in stocking rates, requiring more energy than the land naturally possessed, leading to the import of feed and use of nutrients to boost plant and stock growth (Macleod & Moller, 2006).

Externally-sourced energy and nutrients enter the catchment; external inputs of resources further present ecological issues (Moller et al., 2008). With the increase in inputs, the increases in losses from the system have risen as well. The rate of nutrient and soil loss from increased stocking rates and increased exo-sourced supplements worsens environmental degradation; these losses enter the waterways, leading to flow-on effects downstream (Björklund, Limburg, & Rydberg, 1999).

Reducing the impact of human activities, mostly from agricultural practices, on the terrestrial and aquatic environments is of significant importance for improvement in ecological state and functioning, both in the catchment and on a larger scale. Reducing energy losses from the system, such as nutrients, and thereby productivity, reduces the need for external inputs, and thus improves the sustainability of animal agriculture. This is therefore one of the prime issues for the plan to address.

Climate change

Climate change will largely alter seasonality, inducing more extreme weather, as well as a slow, gradual increase in temperature (Palmer & Räisänen, 2002). The summers are likely to become more drought-prone and increase winter rainfall with greater flood risk (Easterling et al., 2000). Cumulative human activities have resulted in this phenomenon, which is occurring already, and may have significant impacts (Bellard, Bertelsmeier, Leadley, Thuiller, & Courchamp, 2012). The changes in temperature, and weather will impact on the productivity of agriculture in the catchment, probably reducing plant growth in drier months, as well as having effects on the remaining native bush, and aquatic ecosystems (Walther et al., 2002; Easterling et al., 2000). The need for improved management to provide resilience to change and reduce impacts is evident Barnosky et al., 2011).

Impact on ecosystem functioning

A change in one aspect of an ecosystem can cause a change in other aspects: cascading effects occur due to interconnectivity, and the complexity of biological processes and relationships (Björklund et al., 1999; Hooper et al., 2005; Woodward, 2009). It is not often considered by general public, but many ecosystems carry out processes which benefit humankind, as well as other species (Cumming & Peterson, 2005). When ecosystem functioning is impaired certain natural processes do not occur as they should, further degrading the environment via knock-on effects (Cumming & Peterson, 2005; Peterson, Carpenter & Brock, 2003).

The reduction, removal and change in species of vegetation impacts on both the hill slopes and the waterway ecosystems and their processes. The hydrologic and geomorphological changes induced are largely concerned with process acceleration; run off, erosion, and sediment inputs to waterways (Newcombe & MacDonald, 1991).

Both ecological and downstream cumulative effects show the importance of biodiversity and land use practices in connectivity levels and landform stability. The issues occurring do not just affect the catchment at hand, but also contribute to larger environmental issues faced globally (Moller et al., 2008; Macleod & Moller, 2006). Specific functions or processes impaired in this catchment are detailed below, but are not exhaustive.

Ecosystem functions and processes

Nutrient cycling

Cycling of compounds such as carbon, nitrogen and phosphorous are vastly important and when this function is impaired, there can be build-ups, or pooling and loss of essential compounds (Davari, Ram, Tewari, & Kaushish, 2010). Microbes, flora and fauna are all invested in the cycling, playing varying roles. When there is instability in an ecosystem due to drastic change, as has occurred in the Mangaone West, cycling can under these conditions become inefficient and transfer the energy and resources from one ecosystem to another (Likens & Bormann, 1974).

Terrestrial

The soil naturally had higher nutrient and mineral levels before conversion. Plant biomass removal caused productivity decreases and changes in soil ecosystems, including microbe and invertebrate communities which cycle nutrients (Fahey & Marden, 2000). The land is unable to maintain productivity levels and nutrient turn-over when complexly structured vegetation is removed (Fahey & Marden, 2000).

The nutrient cycles on much agricultural land are leaky and often poorly managed under current land use practices (Likens & Bormann, 1974). The significant losses of nitrogen and phosphorous from the system due to production uses cause farmers to add more and more nutrients to compensate for the losses (Tilman, Cassman, Matson, Naylor, & Polasky, 2002). However this does not solve the problem; the cycling is inefficient due to the anthropogenic changes in the ecosystem, and much money is wasted on nutrients that are lost immediately after application (Lochab, Pathack, & Raghuram, 2007; Peoples, Herridge, & Ladha, 1995).

Aquatic

The geomorphic and ecological changes that ensued impacted on the waterway systems; losses from the terrestrial ecosystems often entered nearby aquatic ecosystems via runoff (Daniel, Sharpley, & Lemunyon, 1998; Cooper, 1993). With more added nutrients to compensate for poor cycling efficiency on land, and inadequate riparian margins, sediment nutrient loads increased (Osborne & Kovacic, 1993). This impacts on the nutrient cycling of the waterway. The build-up of nutrients overwhelms the system, which can only process so much at a time, resulting in excess concentrations of nitrogen and phosphorous, and thereby eutrophic pollution (Daniel et al., 1998; Osborne & Kovacic, 1993). Increased sediments cause higher turbidity and lower the capability of benthic plants to photosynthesise, diminishing that process of removing nutrients from the waterway (Wood & Armitage, 1997). Ecosystem integrity, and therefore functioning, has been compromised; the community present has been altered and decreased in variability and complexity (Wood & Armitage, 1997).

Hillslope stability

One of the functions of vegetation on steeper slopes includes stabilising the soil to reduce erosion rates (Reuben, Poesen, Danjon, Geudens, & Muys, 2007). Hill slope instability is much higher due to the change in vegetation to more simple grasses; this change reduced the ability of the ecosystem to withstand other acting forces, such as gravity, causing higher erosion losses (Reuben et al., 2007). The native forest ecosystem functionally aided in stabilising the land; the change to a pasture significantly reduced ecosystem functioning in this aspect, due to the loss of deeper rooting plants, leaving the area prone to landslides and higher rates of smaller scale erosion.

Flow regulation

The vegetative structure of the previous ecosystem present was more complex spatially, both above and below ground level. Vegetation was higher, more dense and included canopy, emergent and undergrowth juvenile layers, as well as forest floor plants; these slowed the infiltration of water into the ground and waterways during rainfall events, and took up some of the water (Andréassian, 2004). This reduced the saturation rates of land, thereby reducing likelihood of mass movements, and reduced the peak flow by slowing the rate at which rainfall reached the water bodies. The pasture-based ecosystem is unable to significantly slow down infiltration; it also absorbs less water, and results in higher, flashier peak flows in the waterways, as well as higher vulnerability to mass soil erosion such as landslides (Andréassian, 2004).

Freshwater processing

Waterways have the function of breaking down matter and filtering and cycling nutrients (De Groot, Wilson, & Boumans, 2002; Winterbourn, Rounick, & Cowie, 1981). The ability of aquatic systems to carry out ecosystem functions changes when the terrestrial system is altered, due to their inherent connection. There are fewer inputs of plant matter to provide for habitat and food sources, altering microbe and invertebrate and predator species (Dudgeon, 2010; Ballinger, & Lake, 2006). The filtering and cycling abilities of the waterway become overwhelmed, owing to the influx of different microbes, matter, and nutrients being higher than what the system can process efficiently. The excess nutrients result in growth of unwanted algal and macrophytes which can further add to freshwater system deterioration because of the change they cause in plant species composition, habitat, and flow (Smith, Tilman, & Nekola, 1999; Carpenter et al., 1998).

Sociological issues

Relationships between stakeholders

Farmer-farmer

While some farmers are environmentally proactive, others are not, which causes discrepancies, as sometimes there are disadvantages to those making an effort to farm sustainably. If a farmer is environmentally conscious and follows best management practices, while another downstream does not, the difference the conscientious farmer makes is counteracted. It is likewise if the practices upstream are poor, however sustainably farming an individual is, poor practices lead to polluted water regardless (Scherer, 1990). Some farmers have warned of poor practices in the catchment, due to the water colour and clarity passing by, as well as witnessing poor farming practices. The disadvantages to the proactive farmer can include monetary loss, continued bad rapport with the public for the sectors' image, and poor relations with non-complying neighbours (Lewis, 2008).

Farmer-council

The regulatory role of both the regional and the district council makes the landowners ill at ease due to mistrust, fears of judgement, punishment and dislike of costs and rules implemented by the councils (Hall & Pretty, 2008). The landowners do not like feeling told what to do, or new rules and tighter regulations on their farms by councils; which sometimes come across as disconnected from the farming community (Hall &Pretty, 2008). It is however a necessary role, especially that of the regional council, to govern the effects of human activities on the environment, as voluntary self-regulation of the agricultural industry has proved unsuccessful in environmental management in many cases (Marquis & Toffel, 2014; Kalfagianni & Pattberg, 2013).

Governing bodies

The relationship between Horizons and the Manawatu District Council also has periods of strain due to the delegation of land management to the District Council, because effects of this management impact on water and air (Horizons governed). The connectedness of land to water and air makes the transition in management difficult, and accountability of actions and effects on one environment pass between councils, occasionally resulting in legal action (Horsley, 2012). Tension also arises between local and central authorities, as central government has legislative control over local government (Palmer & Palmer, 2004). This sometimes impairs the ability of the local government to carry out its role when conflicting legislation occurs. This has occurred recently in the Manawatu as Horizons was directed to upgrade and implement freshwater policy under the National Policy Statement for Freshwater (NPSFW) (Ministry for the Environment, 2011b).

The NPSFW was ordered by central government to examine freshwater environmental state, and recommend regulation for local government to improve the environmental degradation occurring (Ministry for the Environment, 2011a). After long and costly consultation and legal issues, the Oneplan was formed, in accordance with the NPSFW (MfE, 2011b). However, implementation has been constrained even with the council taking the proactive course, and conflict remains between central government, the regional council, and the farming community. (Joy, 2014).

There has, however, been the creation of the Manawatu River Leaders' Accord, established 2010, under government funding. The action plan developed has resulted in care groups such as the Oroua Catchment Care Group. Some work has already begun, with progress of initiative implementation recently released (Manawatu River Leaders' Accord, 2014). This collaborative approach has positive potential to effectively manage and environmentally improve the Manawatu River and its sub-catchments, especially when Horizons implement water quality standards (Manawatu River Leaders' Accord, 2011).

Environmental care group-famers

The environmental care group for the Mangaone West includes landowners and others with an interest in its state. While there are some farmers in the catchment which are environmental stewards, and proactive, as previously stated, some others are not so forward. Only a few instances of negative attitude were encountered in this study, but there is an awareness of a few individuals carrying out practices that reduce the positive environmental impact this group has; the group acknowledges that there is the occasional less proactive individual upstream.

Plan adherence and adoption

The geomorphic and ecological issues presented make the need for environmental management clear. The formation of a catchment management plan is necessary in order for effective, structured and co-ordinated management. Many catchment management plans have an issue concerning plan adoption by those carrying out activities in the catchment. It is not always easy to get everyone to participate and adhere to advisory practices and adopt the plan. As well as getting individuals to participate initially, the continued adherence by all is important for plan success. Certain aspects of a plan can aid in its likelihood of success: environmental improvement relies on a well-developed plan, but also on an effective implementation.

Many cases where environmental improvement could occur have faltered due to the lack of plan adoption and continued adherence to CMP's (Hillman, 2009). As this is clearly important in the catchment's environmental progress, this issue will be addressed carefully. To rectify losses faced by projects in past catchment management plans, the objective aim must incorporate the understanding and thoughts of the local community. Integration of stakeholder thoughts and aspirations in catchment management is integral to management implementation and thereby environmental improvement (Margerum, 1999). Community buy-in, acceptance and participation are potentially the most difficult component of ICM projects and their success.

Economic-social misconceptions

There is a perception that environment and economy are at odds with each other, and compete rather than co-exist (Bernhardt et al., 2006). There is a common belief that altering practices and improving ecological aspects of the land will cause agriculture to be unprofitable (Norton & Miller, 2000). While it is possible for this to occur, it has also been shown that environmental work and sustainable farming can be profitable, with revenues in line with conventional farming (Yule et al., 2013). Changing this belief requires evidence of successes as proof that good management can allow both economic and environmental success for farmers. Studies are becoming more prevalent which support the hypothesis that economic and environmental protection are not mutually exclusive. The sustainable farming fund, which has led to environmental improvement in multiple New Zealand catchments including the Aorere, is an example of agri-environmental cohesion (Robertson, 2012). Behavioural change, being one of the most important aspects of improving environmental degradation of land and water, means that it is necessary to reduce the stigma of sustainable farming.

Regulatory issues

Constraints to regulation have meant that many human activities occur with environmental impacts and go unmonitored and uncontrolled. There are many reasons this has occurred in the past, many due to the minimal impacts of activities of lower population and density, which now is a cumulative issue. Economic gains from using resources have also caused environmental regulation to be less balanced, with the theory of later wealth meaning environmental improvements will occur to compensate (Panayotou, 2003). This means agricultural practices may have occurred or still occur within the catchment which are causing environmental degradation and need to be altered or remediated.

Environmental regulation legislation

While economic development of many areas has boomed over recent years, the legislation for effective environmental regulation, and implementation of environmental legislation (Resource Management Act, 1991), has lagged, which is shown in significant environmental degradation (Barnett & Pauling, 2005). Many economic systems rely on the user-pays system of the free market; however with agriculture this system fails, as environmental costs of practices are not internalised by the industry (Joy, 2014). While an attempted reform to better manage water resources was initiated in 2011 with the NPSFW, this has failed to be of much effect as yet, due to suggestions for baseline national water quality standards being poorer than almost all of our most polluted waterways, ICM, however, may compensate for such deficiencies as individual catchments may choose high standards to sustain ecosystem function (Joy, 2014).

Feasibility difficulties for governed monitoring and regulation

The staffing and costs of monitoring and regulating human activities and their environmental impacts are high, and governing bodies do not currently have the financial ability or number of employers required to effectively monitor most areas; they simply do not have the capacity. This is highlighted in the Department of Conservation and the Ministry for the Environment, and translates down through local authorities (Ericksen, 2003). When Horizons Regional Council are able to monitor more waterways, collaboration with this project could improve by information sharing; benefitting both parties.

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Literature Review

Land-use and resource management

Over recent decades, land-use management has become more important due to the increased conversions from natural ecosystems, and increased human usage of resources (Foley et al., 2005). Strategies for management have become more developed and streamlined in an attempt to balance economic, health, and ecological requirements (Feeney, Allen, Lees, & Drury, 2010).

Catchment management

A watershed is arguably the most appropriate spatial unit to use for most river restoration (Wohl, et al., 2005; National Research Council, 1999). This is because of the complexity of processes occurring over land and water and the interconnection between the two, across both space and time, which need to be considered (Palmer, Bernhardt, Allan, & The National River Restoration Science Synthesis Working Group, 2005; Poff et al., 1997; Sear, 1994; Stanford & Ward, 1992; Wohl et al., 2005).

Dividing areas into more manageable sizes is necessary to identify characteristics and issues that require management focus. Some areas require much more stringent management regimes than others, due to different physical characteristics, predominant land-use, and intensity of use. Using catchment boundaries to define management sections works with nature, using topography, drainage pathways, hydrology and geomorphologic aspects. This is a sensible management unit approach as the movement of water, and the associated land involved can be coherently and consistently managed from land-fall to catchment exit, and complex biophysical interactions considered (Lovell, Mandondo, & Moriarty, 2003). Using catchment boundaries for management units, particularly by governing bodies has become a common approach (Feeney, Allen, Lees, & Drury, 2010). The morphology, related ecology, and uses of a catchment contribute aspects which need to be managed; social and economic aspects contribute to the appropriate approach needed for management (Dodd, Wilcock, & Parminter, 2009).

Many catchments have predominant agricultural land use in New Zealand; rural catchments require management strategies suited to the particular confounding stressors presented by this type of land use. Important environmental stressors in agriculture are largely related to the initial large-scale change in land use, and the production pressures which have increased significantly over the past 40 years (MacLeod, & Moller, 2006;

Moller et al., 2008). Management practices on land can be a major issue in degrading water quality, requiring community behavioural changes based on an understanding of the catchment system (Daly & Fenemor, 2007).

As agriculture has expanded and intensified with increased human demands from population growth, so too has the need for better management of agricultural practices for many reasons, especially due to associated environmental degradation (Boserup, 2005; Ehrlich & Holdren, 1971). Literature shows there have been changes to farming management philosophy over time, from volume-based production to productivity-based efficiency, and, currently, movement toward more sustainable farming (Guerin & Guerin, 1994).

There is now the need to reduce the impacts associated with food-production activities, to maintain future production, and retain important biogeochemical processes. Council resource managers have recognised land practice management, as well as water quality, as key issues for integrated catchment management (Daly & Fenemor, 2007). Stakeholder participation, particularly that of land-users, in management frameworks has been shown to be beneficial for progress, and is becoming more sought after (Reed, 2008; Stringer, Reed, Dougill, Rokitzki, & Seely, 2007).

In New Zealand, the management of agricultural catchments has become more important, and more difficult, with expansion and intensification, with up to 70% of land managed unsustainably (Craig et al., 2000; Mitchel & Craig, 2000). Reviewing literature shows there is a lag in legislation and its implementation to adequately regulate agricultural catchments in the country; governance is currently deficient (Barnett, & Pauling, 2005; Fenemor, Neilan, Allen, & Russell, 2011). Regulatory bodies, in particular regional councils, struggle to carry out their functions of monitoring and upholding environmental legislation, due to the rapid development of intensive land-use, insufficient financing and staffing, and difficulties of enforcing behaviours and practices on land-users, as well as constraints to monitoring.

Important large-scale management paradigms include top-down regulation by centralised and local governmental authorities; other economic instruments occurring nationally include voluntary self-regulation, free-market-based economic regulation, and independent bodies forming grass-roots-based management (Denne, 2005). Currently, none of these systems on their own are either implemented effectively, or large-scale enough to combat the imbalance between economic development and environmental degradation, shown by continued decline in freshwater ecosystems, native biodiversity, and ecosystem functioning (Cullen, Hughey, Kerr, 2006; World Wildlife Fund, 2012). In some instances the disparity is still increasing, especially in freshwater systems, which are subject to impacts of human use on both land and water, due to ecosystem interconnectedness (WWF, 2012).

Environmental management of agriculture has room for vast improvement, and could do so through effective catchment management plans, some of which are already completed, or active. There is a clear need for widespread catchment management plans throughout New Zealand.

Catchment management plans

Catchment management plans have emerged as an arguably effective approach to better manage environments, and restore sustainability and conserve important ecosystems and their functioning (Feeney et al., 2010; Wohl et al., 2005). According to Heathcote (1998), effective catchment management should provide for sustainable water supply over many years, maintain water quality or enhance it to meet government or societal demands, and allow sustainable economic development.

CMP development frameworks provide a structured way to resolve conflicts over differing use in multi-functional management (Chandler, 1994). The aims and need for CMPs differ between catchments dependent on primary uses, catchment size and character. In New Zealand, large scale CMPs are generally used to restore or rehabilitate rural catchments that contribute disproportionate amounts of contaminated and degraded water (Lake Taupo catchment for example). Smaller scale CMPs tend to be more informal, usually community-led initiatives where landowners become dissatisfied with the visible quality of water (for example, the Sherry River).

Catchment management plans for conservation purposes vary in the degree of intervention required and techniques involved dependent on the management approach and degree of improvement needed (Brierley & Fryirs, 2005).

Soft versus hard engineering are techniques used to alter biophysical character of water in catchments. Traditionally, infrastructural or architectural (hard) engineering has been used to exploit resources or control natural processes; over the decades, with better understanding of natural systems, this has shifted to a more ecocentric-based ‘working with nature’ approach (soft engineering) (Gardiner, 1988; Gregory, 2006). Harder, command-control approaches have been reduced, while geomorphology-based (soft) approaches to return waterways to a more natural character are increasing (Gregory, 2006).

The aim of restoration can require economic sacrifice in more degraded catchments; in some cases the effort to restore is too high and costly, or otherwise impossible (Gore & Shields, 1995). In a compromise, the aim where it is either unfeasible or unlikely that restoration would work, rehabilitation, or creation (river styles approach) can be a compromise (Brierley & Fryirs, 2005). The idea is to improve the ecosystems affected until they are self-sustaining and functioning appropriately, as they naturally would, but not expecting a complete return to the previous natural form (Wissmar & Beschta, 1998).

River styles framework

Catchment management plans can be approached in many ways, but giving consideration to the factors influencing the basic geomorphological and ecological functioning provides a robust framework to base management on: this is shown in much of Brierley and Fryirs' work; the river styles approach (2000; 2005; 2009). The focus on natural dynamics of environments allows management to work with natural systems rather than the previously used ‘command and control’ approach. This is now commonly suggested (Brierley & Fryirs, 2009; Hillman & Brierley, 2005).

Owing to the natural boundary catchment units, planning for restoration at the catchment level is logical. Fryirs and Brierley’s river styles approach recommends assessing the catchment and geomorphic setting, this is also suggested in other literature: Applying Geomorphology to Environmental Management (Anthony, 2001). Existing information on the catchment and study of the catchment is needed. Setting assessment includes various aspects: stream order, constrained versus unconstrained, slope gradient, valley shape, discharge, channel pattern, slope aspect and soil type and underlying geology. This allows the differentiation of landscape units within the catchment, which determines waterway character and function - an integral aspect for managing an area appropriately (Fryirs & Brierley, 2005). These parameters’ analyses identify the river styles present in a catchment, taking into account the diversity and variability in river systems possible (Fryirs & Brierley, 2009). The different river styles are mapped throughout the catchment, with summary info for each type. The recognition of sediment processes and transport regimes are then possible, from combined knowledge of sediment, contribution area and discharge.

From the typology and collated information, the potential for restoration or improvement can be estimated, through assessment of sensitivity, determined by the channel attributes. Many attributes are taken into account in this framework, giving the potential of river adjustment. These can be found in Brierley & Fryirs (2005). A reference condition created for each river style provides relevant comparison and contrast for geomorphic conditions. Assessment of representative river-style reaches are used detailing evolutionary history and extent/irrevocability of change. If a shift of state has occurred and a different style is now present, the management needs to be tailored to the existing style. The extent of alteration can be graded, based on reversibility of alteration and extent of anthropogenic changes, providing guidance for management goals.

Identification of limiting and constraining factors and human pressure is important for tailoring management that can address issues and causation, rather than symptoms, as can occur without thorough investigation (Brierley & Fryirs, 2005). As the catchment is a dynamic system, occurrences in one area must be assessed in relation to impacts in other areas as well. From the reference and compared current conditions, trajectory and extent of adjustment along with timeframes can be estimated. The areas with confounding issues versus areas with high-recovery potential can be identified, and management priorities targeted. In some areas a halt to degradation may become a priority, rather than restoration.

Priorities for management are derived from feasibility and maximum effect: collaboration is then needed. Stakeholders are involved to form a desired long-term vision for the catchment. The creation of objectives, goals, and implementation strategies requires the future vision for a basis. Remaining realistic with regard to human pressures and limitations is required, and considering findings from preceding assessment aids this. Identification of target conditions for short to mid-term change ensure the continued process of restoration or rehabilitation; the target conditions must also be framed with regard to river style and conditions present, as well as reference conditions. Areas of higher geomorphic condition may act as a guide for those of lower condition, given that they are of the same style. Timeframes are formed with relation to the extent of interference and recovery level expected, with more intensive management requiring longer recovery timeframes. Priority-based management with regard to rehabilitation and restoration provides the ability to maximise recovery potential and positive effects of work while minimising effort and financial inputs. The greatest success potential is where management focus begins in this framework, with descending priority with lessening likelihood of success. In descending focus, management is prioritised in the following manner: rare, remnant or unique areas; areas threatening degradation to other areas (geomorphic condition irrespective); high potential recovery areas or areas connected to conservation land (extensive connectivity of good condition areas); good condition areas isolated from others; moderate recovery potential areas; low recovery potential areas.

Techniques used to influence the desired environmental change vary, based on the issue of the area, and the river style present, so approach must be so suited (Fryirs & Brierley, 1998). Once strategies have been implemented and conditions begin changing, monitoring becomes necessary and the plan must be able to be adjusted, especially target conditions, based on monitored responses of the catchment. Momentum of the implementation must be maintained to retain community engagement; maintenance and monitoring allow recorded successes, and improvements to less effective techniques.

A well-developed use of the river styles framework was carried out on the Bega Catchment, NSW, Australia (Brierley & Fryirs, 2005; Brierley & Fryirs, 2000). The catchment is assessed and well described, the key river styles are present, and processes are framed in light of their condition and extent of change. The priorities for the catchment based on these biophysical traits indicated where management focus should be on conservation, versus for rehabilitation for more impacted areas. The areas requiring conservation, smaller tweaks, and significant change are mapped. Although the actual plan approach for these areas is not stated, some suggestions are made. The framework is for assessment purpose and prioritising areas of importance, and assists in creating a plan (Brierley & Fryirs, 2000).

Support for geomorphic and the river-styles-based approach is shown by ecological superiority in unaltered geomorphic areas compared to disturbed; twice as many taxa appeared to favour sites in good geomorphic condition as sites in poor condition. Many of the taxa associated with sites in poor condition are alien taxa introduced to Australia since European settlement (Chessman, Fryirs, & Brierley, 2006).

Integrated watershed management: practice and principles

This guide was also used in helping develop a catchment-specific, feasible, and well-informed plan. From the more generalised ecological and social-science-based approaches to catchment management, this literature was particularly practitioner usable. The approach of Heathcote is rooted in rational decision-making, using systematic development and comparative analysis. Dividing the process into 11 sections gave a linear approach, but could be revisited due to the dynamic nature of planning process. While some new technologies have emerged, the foundations embedded in this literature remain relatively unchanged since its publishing in 1998; since then a large amount of scientific literature has acknowledged the approach and regarded the process for further studies and applications. While the approach is designed for more large-scale, development catchment-based projects, much of the approach is applicable in this smaller, conservation-based catchment plan.

The early steps focus on understanding catchment character, processes, and water users. The components and sampling involved in a resource inventory are discussed; the various elements that can be important in catchment management are sectioned, including: physical features and landform, soils, infiltration and runoff, stream flow and groundwater, water quality, plant and animal communities, land use, and social and economic drivers. There may also be valued features or activities within the catchment to be considered. Defining the problems and the setting of goals is highlighted afterward, with consideration to current water uses and demands, followed by setting targets for future use. Water quality and quantity can be important considerations here, with an array of components which vary in importance depending on catchment character and use. For ecology and conservation purposes, areas can be divided by use for priority management (a similarity to the river styles approach): rare or endangered species and habitats, valued historical sites, areas of great natural beauty, disturbance susceptible sites (wetland, floodplains), nature reserves. The associated values and priorities can be assigned through consultation or community consensus. The scoping of the plan involves defining each problem, declaring specific goals for restoration, and gaining community consensus.

The consultation process highlights the need for public involvement and provides principles. The ideal extent of public involvement varies, depending on the community of the catchment and the perceived problem and values (Heathcote, 1998). Critical factors of participation are stated for all of the planning and implementation process, including those needed before beginning, in plan administration, in data collection and analysis, and in general communication. Providing the opportunistic areas for public involvement and communication as well as involving appropriate stakeholders can alter how well a plan succeeds, therefore making appropriate inclusion in each catchment is vital (Heathcote, 1998).

Strategies for developing management options are provided, and depend on the prominent pollution types and sources. It is suggested that all management options are listed, and all feasible combinations listed, and then shortlisted for evaluation. The determination of the best management option requires the evaluation constraints and criteria, to determine option limitations and likely effectiveness and suitability (Heathcote, 1998). The practical limitations of an option to be a solution are defined as the constraints, and considered 'musts' of the plan (financial). The constraint application is considered the first screening stage of management options, while criteria often measure desirable characteristics. The measure of each criteria is also required to be comparable to other plan options in some way. The criteria can also be weighted by priorities and separate options with similar results.

Simple assessment methods and detailed assessment methods are provided for advice on characteristics which may need assessment; depending on the size of the catchment, funding and time, in-depth rigorous sampling may or may not be required. The cost and financial considerations when planning are also discussed and methods commonly used provided. Smaller-scale projects with less development focus may require less rigorous analysis than large-scale plans for infrastructural development. Legislative considerations and framework considerations are included; scale and project objectives may drive the need of legal considerations needed. For development based projects, environmental assessments are discussed to aid in project judgement by decision makers.

The last chapters move back toward plan development, in again highlighting how to choose the best plan, and in implementation. More complex approaches to determine optimal plan options (including modelling scenarios) are presented. It is recommended that while one strategy is more developed and proposed as a best option, another strategy is considered as a back-up. The performance of each plan option against constraints and planning criteria should be documented, with any weighting assigned to all criteria considered. Supporting documentation for implementation considerations should also be included. Considerations include the 'implementability' of the plan as perceived by public. The more the wider community perceive the plan as ‘doable’, the more successful implementation will be.

According to Heathcote, implementation requires: an agreed plan of action, indicators of progress toward goal(s), allocated tasks, allocated costs, agreed periodic review and revisions of management activities under way in the catchment. There are some elements suggested for successful implementation that are highly relevant for this plan; it is suggested that a single agency takes lead as advocate and facilitator to cater for: clear timetables, responsibilities and costs, ongoing tracking of the degree of plan implementation and success, ongoing reporting and monitoring of progress (both for maintaining interest and plan enthusiasm), ongoing public education and programs to enhance consensus, periodic plan review and revision, and adequate funding.

The approach of Heathcote has been drawn on many times for aid in decision-making processes in catchment management, including restoration projects, in supporting practitioners to form realistic goals (Ehrenfeld, 2000). Some further literature has built on the approach for further decision-making support, such as the analytical hierarchy process (De Steiguer, Duberstein, & Lopes, 2003).

New Zealand catchment management plans

Most CMP’s in New Zealand are conservation-, rehabilitation- or restoration-based. Most have been or are in place under regional councils, and a few are completed with information available (Daly & Fenemor, 2007). New Zealand Landcare Trust (LCT) is a lead, non-government agency involved in smaller grass-root ICM, which has aided projects in many rural areas. Landcare Research, is another key agency which has facilitated completed notable ICMP's. The grass-roots (non-governing origin) catchment management plans tend to be less formal and treated as projects, or initiatives. Due to the similar nature of the Mangaone West project origin and agencies, these projects will be considered and discussed due to their high relevance.

Notable, successful integrated plans include Motueka project, the smaller Sherry Catchment and the Aorere project (Fenemor, 2013; Robertson, 2012; Stuart, 2010). The Motueka River integrated research programme was carried out from 2000 until the early 2010's. The project was relatively large-scale, led by Landcare Research with collaboration from Cawthron and the Tasman District Council, and many other contributing agencies (Fenemor, 2013). The origins were based in researching water management and the integrated approach to conflicting water uses (Bowden, Fenemor, & Deans, 2004). The project had many positive environmental outcomes, improving the catchment's water quality, making it a successful initiative. The project was well-integrated, with significant social engagement of the local community, and collaborative learning to improve environmental stewardship (Fenemor, 2013). The local support originated with land owners' knowledge that water quality was affecting the downstream aquaculture, reducing the growth and viability of those producing shellfish at the Motueka mouth (Fenemor, 2009). The knowledge base was created for establishing current knowledge of the Motueka, assessing its conditions and issues. After the issues were assessed, management then focused on integration to build local participation and capacity.

Tools were used for stakeholder involvement to promote participation; the social science aligned well with some suggestions from Heathcote (1998). The combination of science (including biophysical analysis) and social science of integrating agencies, the public, and the local community, made the implementation clearly succeed. The success is documented by the improvements in water quality: faecal coliform reductions, deposited sediment reductions, nutrient level reduction (Fenemor, 2009). The catchment waterway quality has improved with the research and plan implementation, however, after the plan, the council monitoring shows room for improvement remains (Tasman District Council, 2013).

The Sherry River project followed on from the initial Motueka project, and was facilitated through Landcare Trust and Landcare Research. The grass-roots approach in this smaller catchment again assessed the biophysical character, identified issues, and integrated the local community into the project. Adaptive management meant the planning stage was less rigidly structured than suggested by more traditional approaches such as promoted in Heathcote (1998). The aim of meeting recreational use guidelines through BMP's was formed (Nagels et al., 2012). Water quality monitoring was carried out in long term assessment of the waterway conditions and issues. The problems were identified as high E.coli levels, sedimentation, suspended solids and lack of waterway shade (Landcare Trust, 2014). Farming practices were identified as the source of the issues, including stock access to waterways. The removal of stock from waterways was the initial step in implementation, with bridges for cow-crossings installed, and then further management implemented after the exemplified improvement of water quality with stock removal (Landcare Trust, 2014). Farm plans were used and BMP's began implementation in 2008; riparian buffers have now also been implemented. The project improved water quality, in particular E.coli levels have been significantly reduced, after initial 50% reductions (Fenemor, 2013; Nagels et al., 2012).

The Aorere project was initiated in 2006, running until 2012. The native vegetation dominates the catchment, with 16% in agriculture, predominantly dairy farming. The catchment was identified as a high-level polluter, particularly with regard to bacterial contamination, and had been associated with the local shellfish harvest reduction from around 70% to 30% (Robertson, 2012). The pollution allegations aimed at the farming community resulted in investigation of the catchment's waterways and issues. Landcare Trust acted as a facilitator. The project began with the development of tailored farm plans and implementation of BMPs within the catchment, and a neighbouring catchment subsequently joined the project.

Robertson (2012) provides an evaluation of the project's success with regard to change in farmer actions, and improvements in water quality, the following findings are from the document. The evaluation indicated success in both aspects. Farmers had reduced herd size (average from 369 to 310), though stocking rate was still slightly above regional average (2.74>2.61 cows/ha). The use of outdated travelling irrigators was reduced, waterway fencing was increased significantly, with stock excluded from 91% of waterway length in the catchment. The farmers had a significant change of focus in the issues they faced, with 90% mentioning economic factors dropping to 24% in 2012. The nutrient, climate, and regulatory issues were all increased in mention, showing a change in attitude toward their farming. The facilitation by Landcare Trust was shown to be an important factor to the project, with nearly 97% of people finding their involvement useful. The evaluation also found the dairy farmers identify themselves as clearly understanding their practices and implementation to protect water quality. The understanding that on-farm costs should not exceed benefits of improved water quality was also much increased during the project (from 38% to 63%), showing further attitude and awareness changes. The farmers' efforts to improve effluent practice as a predominant BMP change indicate an understanding of the nutrient cycles, processes and issues associated with dairy farming. Efforts were also increased over the project to exclude stock from waterways and plant riparian margins.

Water quality increase was observed through the marked increase in shellfish harvesting, which was reported to be harvesting at 75% as compared to 28% in 2005 (Robertson, 2012). The peaks in bacterial coliforms that were polluting the water and impacting on the downstream aquaculture were quickly and significantly reduced. This project was a definite success as the farmer-behaviours changed and the downstream effects of dairy farming were significantly reduced on aquaculture. However, more monitoring of other water quality parameters and how they changed over the project could have been useful for further support of the water quality improvement.

Motupipi catchment is also in the Tasman district - a smaller catchment, even than the Sherry sub catchment (2700ha versus 7800ha respectively). The issues of the catchment included high nutrient levels (N and P), high faecal bacterial counts, low dissolved oxygen (DO), high amounts of deposited sediment, excessive algal and other plant growth in summer, poor invertebrate community health, and impoverished native fish populations (Fenemor, Fenemor, & Gaul 2008). The project aimed to understand nutrient dynamics, and address nutrient levels through ICM to assist landowners in identifying and changing practices (Fenemor et al., 2008). This ICMP has had a singular focus on the nutrient levels: the approach was tailored to this singular focus, so assessment involved nutrient analysis throughout the catchment, including sink source analysis, OVERSEER use, and GIS mapping.

The findings of the analysis were then provided to landowners and solutions developed individually by farm. Farm environmental plans were created and made to cater for the farmer and the setting in the catchment. Management goals, recommendations and targets have been suggested, based on measurable scientific monitoring and assessment (Fenemor et al., 2008). Since the nutrient management project document, no further publications could be found on project progress. The State of the Environment Report (2010) identified the catchment consistently as having poor water quality. It is unknown how the project is progressing and if headway has been made due to the lack of information available. The insight the project provides on the approach to New Zealand catchment management plans at a small, grass-roots level remains valid. The high-level integration with other agencies, and involvement of local public and the Motupipi landowners is again prominent as with the Motueka and Sherry Catchment Projects.

Local governing bodies, largely regional councils, have and are using ICMPs, but the scale is generally much larger than grass-root formed projects. Environment Waikato required two dairy catchments of the Upper Waikato River to implement an IMCP due to rapid declines in water quality; nitrogen leaching was one of the key issues to be managed (Fenemor et al., 2008; Longhurst and Smeaton, 2008). Lake Taupo catchment also had a plan implemented to reduce nutrient pollution to the lake, which was necessary due to the nutrients (in particular N) threatening the water quality of a lake of national importance (Environment Waikato, n.d). The assessment of character and issues was in-depth, and farming land-use at high intensity found to be the major contributor to increased nutrients and water-quality decline. The plan included strategies such as nitrogen capping and trading, as well as infrastructure upgrades to sewage treatment plants. The plan did successfully reduce the nitrogen pollution, though since its completion, deterioration has increased again.

Smaller catchment management plans include coastal tributaries, such as the Waiotahi, which take a traditional assessment of current biophysical character and environmental state, identify issues, and give plan recommendations tailored to the specific catchment and its issues, with less integration during initial plan development (Banks, 2011). The Waiotahi CMP had a significant amount of biophysical assessment including land-unit types, soil character, land-use capability (LUC) assessment, land cover assessment, erosion risk assessment, riparian assessment, water-quality assessment, and high-value ecological site evaluation (Banks, 2011). The recommendations for the plan were then made, however the strategies for implementation were not documented, and few specific recommendations were made. The approach of both council CMPs and grass-root CMPs discussed previously will be integrated in the Mangaone West plan to attempt to gain the benefits of both approaches: depth of scientific understanding, and community approval and involvement.

Integration

The integrated approach to catchment management is becoming more prominent with the realisation that behavioural change is needed as well as traditional engineering strategies (Wohl et al., 2005). There is also the argument that the participation of more stakeholders can lead to better, fairer decisions, and holistic approaches (Reed, 2008). The implications are that natural resources are managed at catchment level in context of multiple considerations including social, economic, political, and scientific (Bowden, 2002). The Ministry for the Environment's recent review of ICM in New Zealand (2010) provides insight into its components: "Integrated management of natural and physical resources requires consideration of the complex relationships between natural and physical resources (flora and fauna, geology and hydrology, soils and the biosphere and the biosphere and the atmosphere) and social, cultural, economic and political matters." Through assessment of catchment management-associated regional and district council members, Daly and Fenemor (2007) found their general definition to be "the management of natural resources in a catchment... in a holistic manner." Important aspects included were partnerships (community and government), and long-term management (Daly & Fenemor, 2007). The complexity of point source and non-point source pollution is high; integrated strategies can approach this in a more diverse manner, improving control over water quality (Heathcote, 1998).

Integrated management has a significant issue in that failures are often due to lack of leadership (Hooper, McDonald & Mitchell, 1999). While integration is necessary and multiple agencies need to collaborate and work together, one agency must take lead, and be supported by the other bodies involved, in driving decisions and action (Hooper, McDonald & Mitchell, 1999). Strong leadership is also listed by Hooper et al. (1999), who also discuss the assumed ‘need for integration’, which may be less necessary in some plans, or in some areas of plans, depending on the issues faced and the simplicity of solutions. For integration to be productive, governing agencies and other bodies must also work together, co-ordinate effectively and power-share. Harmony among the agencies involved is needed though many have different mandates and interests; previous bureaucratic differences can otherwise undermine the capabilities of catchment management (Hooper et al., 1999). Alignment of catchment management plans with governing regulations and legislation is also required, and contributes in maintaining a unified view, reducing confusion and disparity between bodies (Heathcote, 1998; Hooper et al., 1999).

Scott (2007) found New Zealand integration to be more successful with the following attributes: community leaders are used; the community involved is understood (motives, attitude, values); collaborative learning approaches are used with flexibility for engagement, and there is formal group structure for leadership.

Multiple disciplinary approach

Multiple discipline integration is supported by the review of catchment scale stream rehabilitation (Hillman & Brierley, 2005), which points to the transdisciplinary approach combining biophysical and social factors. This is also suggested by Dodd, Wilcock and Parminter (2009).

In management, disciplines become interrelated due to the bidirectionally-fed relationships of physical, ecological and anthropological aspects. “Whilst landforms and physical processes drive the dynamics of biological communities, certain living organisms or communities may significantly modify or modulate geomorphic processes (i.e. sediment erosion, transport and deposition) and have strong controls on landform dynamics” (Corenblit, Tabacchi, Steiger & Gurnell, 2007). With human activities and effects now prominent almost everywhere on earth, anthropogenic factors also must be integrated.

A few difficulties with stakeholder involvement have arisen; some find the collaborative decision meetings to be unproductive, and stakeholder disillusionment post-participation can be an issue, with people feeling unengaged after their original inclusion (Reed, 2008). Reed suggests these issues can be tackled by ensuring correct, effective and engaging facilitation of meetings, and maintaining relationships with stakeholders through notification of project progress (2008).

Ecology

New Zealand's catchment management plans have some common key lessons according to Dodd et al. (2009). One significant theme is that stream homogenisation of waterway structure and habitat is a large factor in degradation: more diverse waterways have more diverse communities which uphold environmental values; some small but significant areas act as critical source or sinks with disproportionate roles contributing to or reducing contamination; stock waterway exclusion significantly reduces direct contaminant inputs; riparian vegetation and its state is crucial for land-use mitigation; land use has far reaching impacts; and lags for environmental response are to be expected with catchment management.

Ecological functioning is a crucial aspect of environments and their sustainability, as well as the services, amenities provided, and processes occurring (Cadotte, Carscadden & Mirotchnick, 2011; Fisher, Turner & Morling, 2009; Costanza & Folke 1997). For example, hillside management restores vegetation's natural role of erosion control, which in turn retains topsoils of higher productive value for other uses such as agriculture. Vegetation influences the erosion process by root reinforcement of sediment, therefore hillside plantings can act as a management technique (Corenblit et al., 2007).

Geomorphology

Given that geomorphology is a significant reason for catchment character and behaviour, assessment is necessary to understand the physical processes occurring, and any impairment or change indicating environmental degradation. Geomorphology provides the physical template of a catchment, and therefore must be considered in environmental assessment and resource inventory building. Many projects may fail if geomorphological aspects are not taken into account, as was found by the National Research Council (1992), which reviewed projects in the United States (Kondolf, 1998). The geomorphic aspect is also previously discussed in the river styles section.

Sociology

As Wohl et al., (2005) state, restoration is as much about social aspects as ecological (Anderson, Hilborn, Lackey & Ludwig, 2003; Kates et al., 2001). For a project to be considered, the stakeholders involved must see it as necessary. In the case of catchment restoration and rehabilitation, this means that stakeholders see environmental degradation in the catchment to be an issue (Wohl et al., 2005). The stakeholders' desire for the project and contribution are integral aspects, and relationships need to remain nurtured and interactive during the project process (Reed, 2008). Fenemor, Young, Bowden & Phillips (2011) found participation of various stakeholders needed to be ongoing through the plan and implementation process.

Adoption of best management practices, behavioural changes and activities were found to have occurred and projects succeeded better when landowners were included and educated on such matters (Curtis & De Lacy, 1996). A key benefit to the social aspect of ICM is that social learning, from participators, can proliferate knowledge though the local community and wider society as well, influencing behaviour in individuals who managers cannot reach (Reeds, 2008; Blackstock et al., 2007; Pahl-Wostl and Hare, 2004).

In their review, Dodd et al. (2009) also found some social aspects to be a fundamental part of catchment management; landowners need to all work cooperatively with one other and agencies, as no single property can resolve non-point source pollution. Furthermore, the collective decision on environmental priorities is needed, and the best approach to altering land-owner behaviour and adoption of management practices is one-on-one engagement. Good relationships between stakeholders are important and require maintenance. The structure for social engagement needs to be defined and maintained to uphold integration. Upholding social aspects of integration builds the capacity for the local community to adapt to the CMP, improving its implementation.

The engagement levels can vary significantly, depending on how much integration occurs, and how much the local community is required to be involved - also depending on objectives and strategies for a project (Reed, 2008). The communication between stakeholders, other bodies and the lead agency generally requires open facilitation through a strong local leader or lead agency (Hooper et al., 1999). With lower levels of engagement, lack of information availability can still cause disillusionment and disappointment with less inclusive projects; the open availability of plan decisions, implementation strategies, progress and monitoring data should be made readily available (Hooper et al., 1999). This would also benefit other catchment initiatives as public documentation can be lacking.

Adaptive Management

Adaptive management can be considered as applied experimental management; the test, evaluate, respond, alter- approach has become more popular since its development for environmental management (Lee, 1999). This strategy involves practical applied policy and strategies, with periodic review. Holling (1978) and Walters (1986) were concerned in management of ecosystems and natural resources, and their assessment and management regimes. While some view this as a defence for less scientific evaluation, the focus remains on reviewing plans and policy during the implementation progress to assess effectiveness and allow alternative management where an approach has been inefficient (Allan & Curtis, 2005; Lee, 1999). This experimental management design has begun to be used more widely, but as McLain (1996) and Lee (1999) found, it still remains flawed in practice for some projects with limited use of multiple knowledge sources. It has the potential to combine well with integrated management, which provides more relationship development and knowledge sources (Mclain, 1996). The Aorere catchment project, for example, could be seen as adaptive, due to the development and expansion once the project had commenced. The original scope and purpose was expanded in time, depth and size with another catchment added in: Rai Catchment (Roberston, 2012).

Successful strategy components

For an adaptive ICMP to succeed, aside from the already discussed integration, and adaptability, certain components have been linked to more successful outcomes and restorations. There are numerous components suggested for success in literature; the most prominent, recurring themes are discussed below.

Measurable outcomes

"Without conducting such evaluation and widely disseminating the results, lessons will not be learned from successes and failures, and the field of river restoration cannot advance. Post-project evaluation must be incorporated into the initial design of each project, with the choice of evaluation technique based directly upon the specific project goals against which performance will be evaluated." (Kondolf & Micheli, 1995).

The desired outcomes must be identified and be measurable. It is more difficult to determine progress, success and completion without measurable outcomes. Outcomes such as enhanced water quality can be measured through biophysical parameters, to show plan success (Sinner, Fenemor, & Baines, 2006). Reducing erosion can also indicate success of stability strategies; there may be multiple indicators for plan success, and often community acceptance or participation is included, and can be evaluated through surveying (Daly & Fenemor, 2007; Robertson, 2012).

Clear objectives and goals

Restoration of processes should be focused on, and ensuring these are occurring sustainably before completion (Wohl et al., 2005). Included are: self-regenerating riparian vegetation; natural water quality maintenance and processing; more natural sediment regimes; and flows. These can be assessed through monitoring of factors including: nitrogen and its form; oxygen levels (assesses plant and algal community production); and faunal communities present. Kondolf (1998) suggests individualised geomorphic and ecological processes need focus, rather than blind uptake of classification systems which take into account less of the inherent variability of natural systems. What works in one catchment may not work in another.

Objectives give outcomes expected which can be assessed and thereby give direction, and focus the project to reach its objectives: projects without decisive direction are common but less successful, as judgement of progress can be impaired (Downs & Kondolf, 2002).

Monitoring and Evaluation

Without monitoring, adequate assessment of progress and outcomes is not possible. Understanding how the project went with regards to successfully achieving goal and objectives is hindered, and provides less information to future catchment management restoration plans (Downs & Kondolf, 2002).

Monitoring shows the understanding of spatial, temporal and process linkages of an area, and assesses performance of the project, which should not be ignored (Wohl et al., 2005).

The monitoring may take years to show any significant and meaningful results to better guide implementation. None the less, monitored results should be evaluated to ensure the plan is effective and efficient, and if lacking in some aspects, altered (Dodd et al., 2009). The temporal consideration for monitoring and plan implementation length is often too brief, given that the time scale for degradation to plan implementation to improvements observed can often be on a scale of decades rather than years (Hooper et al., 1999).

Assessment and Understanding of Present Environment

Planning needs to be based on knowledge of catchment, including geomorphic, ecological character and uses, rather than blind implementation (Kondolf, 1998). Assessing the context and reducing the assumptions or standardised approach to implementation of restoration needs to be considered as every place is different (Hooper et al., 1999). Custom design for specific solutions for specific conditions are necessary.

Assessment is needed to determine the current environmental state, and potential for improvement. For effective management, both physical and biological environmental aspects must be taken into account to give adequate environmental insight, and an understanding of cause-effect relationships (Fryirs, Arthington & Grove, 2008). The need for geomorphic assessment supports use of river styles framework, as well as ecological-functioning assessment such as bio-indicators and riparian presence. The river styles framework is supported in as a geomorphic assessor; Wohl et al. (2005) suggest its usefulness in generalising river systems, and in ensuring that appropriate questions and responses are made.

The assessment of the present biophysical state of the area is important for scientific understanding of the environment and its ecosystem processes and functioning, which must be understood in order to be restored or improved effectively. Understanding the difference between the degraded system the project began with, and the later system at plan completion, is needed in restoration projects for success rates to be evaluated. (Wohl et al., 2005). Baseline surveying of current conditions conveys issues, and is found to give better direction and focus to objectives (Downs & Kondolf, 2002).

Reference site or pre-disturbance information

Fryirs, Arthington and Grove (2008) make a logical argument for historical or selected site references; data from before the disturbance to the environment began, or a relevant reference site, are important to assess progress, extent of degradation, and improvement potential. (Reference sites must be similar in biophysical character).

A project's success may be constrained if there is a lack of pre-project data or a relative reference site, as understanding how the project is progressing is more difficult and less meaningful without such information. Downs and Kondolf's review of the Moore's Gulch project exemplified the need for this information for reference use; some catchments which had no previous data or reference site were compared to those that did, and showed less improvement (2002).

The literature reviewed here is by no means exhaustive, there is a vast amount of literature on ICM and CMPs; this review attempted to gather and discuss as much relevant literature as possible. One could spend much more time with literature, but for the time constraints imposed, this was carried out as efficiently as possible.

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Approach and Methodology

Literature Review

Reviewing studies and techniques already implemented to restore and manage catchments was critical in the formation of this CMP. To increase the likely success of the catchment management plan, previous relevant and successful work was studied and considered to inform the direction and approach of the plan. Scholarly and peer-reviewed material was focused on, with consideration to relevancy in New Zealand.

Geographical Information Systems:

ArcGIS 10.1 was used with Massey university GIS sourced files to obtain information about the Mangaone West catchment. This included important data about soil type, slope, land use capability (LUC), land cover, erosion risks, and waterway information. It also was used to predict nitrogen concentration in waterways; advise appropriate stocking rates; and advise on suitable land usage.

The catchment was mapped at a local scale and then cropped. Information was displayed on the map by changing the data set shown. Technical publications for deciphering results were used.

Google Earth

Google earth was also used to assess riparian shading at the reach scale, erosion-active and risk areas in the upper catchment, and also the presence of willow trees in the riparian margins. The scale for assessing riparian shading was small. The catchment was divided into five regions to allow viewing close enough to estimate shade coverage of the stream. Shade coverage considered how much of the waterway was visible, and riparian width (one plant or several) as well as the type of vegetation covering it (native coverage was usually thicker than deciduous, willow cover). The area of waterway was covered accordingly to the amount of shading (both sides); red colouring indicated little to no riparian shading (zero to thirty percent), yellow indicated some shading (30-70%), and blue indicated riparian coverage appeared lush (70-100%).

The scale was set to include the entire catchment for the willow JPEG image however willow identification was checked during field sampling. Most willows were identifiable by the lack of green leafage visible over the winter months and in some cases the shadows showed the branch structure typical of a willow. Trees identified as willow were marked white on the map. Willows were identified due to the environmental issues they can pose when proliferated in a catchment: bank erosion, damming and clogging can occur.

The upper catchment shows area of active rilling, gullying and landslides, these areas were identified in red, with the area affected coloured in. The period of satellite mapping was used to full extent to expose these erosive zones. This was necessary to evaluate the extent of hillside erosion and indicate where hillside plantings are most needed in the catchment to reduce landslide and gulling, and thereby topsoil loss and sediment inputs to waterways.

Fieldwork and data analysis

In order to assess all aspects of the catchment's important waterway characteristics, the main trunk of the Mangaone West stream was walked from a headwater tributary to its confluence with the Makino stream. This allowed for comprehensive sampling of different factors of the waterway simultaneously. Aspects relevant to catchment form and function were selected to determine the current state of the environment, and allow for projections and targets to support measurable improvements. These parameters follow many suggested in literature from previous projects, such as Parkyn et al. (2010).

The fieldwork began in the springtime when rainfall is sufficient to allow flow of the upper ephemeral waterways. From the seventh of November over four days the geomorphic characteristics were noted and water quality data were collected.

Geomorphology

Geomorphologic aspects which were likely currently acting were considered important due to the large influence such factors can have on waterway form and function. Bank stability was a significant factor considered, as bank erosion creates more sediment inputs into the waterways and is undesirable to farmers due to the potential for continued loss of productive land.

Areas with recent bank erosion were noted in position and severity. Older scars with vegetative regrowth were not considered as important due to the changing areas of pressure caused by stream power, which shifts in meandering waterways.

Areas with significant bank erosion indicate bank instability and could be areas to focus on stabilising with techniques such as vegetative planting, or rock barriers in severe cases. The amount of riparian cover was also noted, as well-established riparian growth on the banks indicates stability. Bank erosion was also assessed by sight, which allowed visual comparison of current trends and positions of erosion to those that were identified by GIS.

Water quality

Water quality was assessed using different techniques: invertebrate sampling, chemical sampling and physical characteristics: sediment coverage, and habitat shading. The waterway's path was closely followed and seven sites were assessed using all three techniques. The first site selected was where water began to flow; sites following were expected to be around five kilometres downstream from the previous site. Variation in distances was allowed for in order to find a suitable site, with the characteristics necessary to sample for invertebrates. Each site's location was recorded and marked on the catchment map.

Invertebrate sampling

Macroinvertebrate sampling was used as a biotic qualitative indicator of stream health, allowing stream site comparisons and catchment pollution detection (Joy & Death, 2002; Stark, 1993). At the seven sites kick-net sampling was carried out for 60 seconds, and repeated three times to account for random variation. Kick- netting required the net to be placed immediately downstream of the area to be disturbed by kicking, and held firmly to the streambed. At each sampling site kick-netting began downstream and moved upstream to avoid disturbing and influencing repeat test results. The samples were then preserved in three separate, labelled containers filled with 95% ethanol, a recommended preservative (Stark, Boothroyd, Scarsbrook, Maxted & Harding, 2001).

Each sample was later drained and invertebrates counted and identified (lowest reliable taxonomic level) using invertebrate identifying resources such as the Landcare research online guide, and New Zealand identification books (Moore, 1997; Moore, 2013; Taranaki Regional Council, 2009; Winterbourn, Gregson, Dolphin, 2006). Stark's Macroinvertebrate Index (MCI) and quantitative version, QMCI (1985), were performed. Standard full counts were carried out, with vastly abundant species estimated through sub-sampling (Stark et al, 2001). The associated MCI scores were recorded for each invertebrate. Carrying out invertebrate samples gives an indication of the water quality over time, as the invertebrates have different tolerance ranges for different environmental factors. Therefore, sampling invertebrate gives an indication of the long term chemical, physical and ecological factors of the waterway (Joy & Death, 2002).

The MCI index score was calculated for each sample at each site, using the standard equation:

MCI = sum(total of invertebrate taxa MCI scores (number of taxa present) × 20 (Stark, 1985).

The QMCI index score was also calculated as it takes into account the proportional abundance of the invertebrates:

QMCI = sum(invertebrate taxa MCI score × proportional abundances) (Stark, 1985).

The 21 MCI site scores were then tested via regression analysis in order to determine any downstream trends. The model output an R-squared value and P-value. These were used to determine the fit of the regression and whether there was a significant relationship between MCI scores and distance downstream. This process was repeated for the QMCI scores. The MCI and QMCI scores for each site were also averaged and tabulated to visually show score change.

Chemical sampling

At each site three watertight, sterilised containers were filled with a water sample. The samples were taken from the higher flow stream area (generally near the middle), near to the surface, as recommended by the United States Environmental Protection Agency

(2012). The samples were frozen after collection to maintain the chemical composition as closely as possible to when it was sampled, as chemical compositions may change and alter results of particular nutrient levels if kept at room temperature (Silk & Curina, 2005).

These samples were then sent to Central Environmental Laboratories for analysis of nitrogen (total oxidized nitrate, nitrite), and phosphorus (dissolved reactive). Taking chemical samples allows easy assessment of water quality, but only gives an indication of water quality only at the particular time of sampling (Allan et al., 2006). A later resample was required, where total nitrogen and ammonia were included. The same protocol was followed but without repeats due to financial constraints, the samples likely remained fair representatives of the water due to close protocol following.

As three samples were taken from each site, these will again be regressed for nitrogen content (total oxidized nitrogen, nitrate and nitrite), phosphorous (dissolved reactive). R-squared values, P-values were calculated to assess any nutrient relationships-site or trends occurring with distance downstream. Total nitrogen and ammonia were later singularly sampled from each site, sent to the same laboratory, then had the same data analysis carried out. The nutrient samples for each site were also averaged and tabulated to visually identify any patterns.

Sediment coverage

Assessing the amount of sediment coverage on the riverbed gives a clear indication of deposited sediment levels, and thereby the amount of erosion and run-off occurring within the catchment or certain areas within the catchment, and shows the capability of the system to transport sediment; overwhelmed systems can be identified. As deposited sediment can have an influence on biogeophysical factors and processes, it was important to assess sedimentation in the Mangaone West (Milliman, Yun-Shan, Mei-e, & Saito, 1987).

Deposited sediment was assessed using a Cawthron Institute recommended technique: the bank-side visual estimate of percentage sediment cover (Clapcott et al., 2011). The habitat length (in meters) and the percentage of streambed covered by sediment (of over two millimeters depth), was estimated from the streambank using three different locations at each site. The sediment estimates had the same regression analysis procedure carried out to establish downstream trends, with results averaged per site after analysis and again tabulated.

Habitat shading

The percentage of waterway shading at each site was recorded as shade can be considered a major factor in a waterway health, due to its influence on temperature and oxygen concentrations (Beschta, 1997). Waterway shading (by percentage coverage) of the reach at each site was assessed from three positions; immediately upstream, directly at the site, and immediately downstream to representatively reflect the habitat. Regression analysis was carried out as described with the previous sampling methods, again each sites scores were averaged and tabulated.

Uncontrolled-uncontrolled variable regression

To establish any relationships between the variables, the sampled parameters were then each regressed against one another as well. While this cannot establish causality, it gave the potential to reveal important factors indicating water quality change due to habitat change. Any significant relationships were included in the results.

Weed and pest species

Pest and weed species occurring within the catchment were noted; samples were collected where possible, and photographs taken to identify species so control and management strategies could be created.

River styles assessment

The river styles framework was used on the Mangaone West to assess the geomorphic condition, recovery potential, and provide priority management strategies. The protocol of Brierley and Fryirs (2005) was used as a guide to assess the main channel from the headwaters to the confluence with the Makino. The four stages and steps are described further in the book; Geomorphology and River Management: Applications of the river styles framework (2005). The upper Kahuterawa was used in the estimations for expected and what good geomorphic condition would be like to compensate for the lack of historical information on the Mangaone West.

Existing information and data

Horizons were approached for relative information and data that would aid in describing environmental catchment conditions. While previously the council had more information about the Mangaone West, restructuring meant some useful environmental information had been lost over the years. Horizons were however, able to give accurate rainfall data from a station based near the centre of the Mangaone West catchment. Rainfall data was plotted from the years 1999 to 2012. This information is important for understanding seasonal variation of rainfall in the catchment and allowing for future planning of crop and pasture management as climate change increases variation. Monthly rainfall data was averaged to decipher any relationship between the season and rainfall, and a regression analysis was carried out to assess this. The yearly rainfall was also plotted over time and a regression analysis of this was carried out to determine if rainfall was changing over time.

Flow data from stations upstream and downstream of the Mangaone West with the Makino confluence were also provided to estimate the contributing flow of the Mangaone West stream, as it is the only major contributor of flow between the two stations. 20 years of collected data spanning from 1992 to 2012 was used to find the Mangaone West mean annual flow. This was possible by subtracting the flow upstream from the flow downstream of the confluence, and averaging the result.

Reference site

Reference sites are suggested for comparison to during monitoring to assess catchment improvements, particularly when pre-disturbance information about the restoration catchment is unavailable (Lake, 2001). A site of similar character to the Mangaone West was assessed for aspects of water quality to determine roughly how impacted the Mangaone West may be compared to a site with low impacts from human activities. The selected site (Kahuterawa stream) was then used to provide targets and projected estimates of potential improvement the catchment could expect under the developed catchment management plan's implementation. The use of a nearby reference site was the closest match to reality as there was an inability to use historical data of the Mangaone West before human activities impacted the catchment, as no data is recorded historically in the area. Data from 2009 to 2013 was provided by the regional council and was analysed for the basis of the reference site. Estimated potential improvements for the Mangaone West were formed by logically considering the difference in states of the two sites and considering other studies' projection and restoration information, as well as the timing of plan implementation aspects.

ICMP development

Approach

Present literature, and previous catchment management studies review suggest that a stakeholder-integrative, adaptive plan, with measured outcomes and monitoring, should produce the best environmental outcomes (Heathcote, Edwards, Greener, Coombs, 1998; Gregersen, Ffolliott & Brooks, 2007). After studying relevant theory, the importance of gaining a plan goal formed by the stakeholders was apparent. From meeting with stakeholders the consensus view and goal of ‘developing more sustainable farming within the catchment with a future focus’ was formed. The plan objective is important for guiding plan development and maintaining focus. The fieldwork and sampling was to give an idea of the current state of the environment, and allow for improvement projection aims. Having a goal and targets to work toward may improve restoration success (Ferrier & Jenkins 2009).

With the plan objective in mind various plan options were considered: inactive approach; riparian; hillslope planting; steep slope retirement; BMPs; complete restoration; complete riparian with hillslope planting; and a combination approach. These options were then ranked against a selection of relevant constraints and criteria for fit, as recommended in Heathcote et al. (1998). A full description of the plan options is available in the results section.

Constraints and criteria included relevant factors for plan decision-making: implementation cost, difficulty, time, productive land loss, effect on waterway, effect on soil and effect on native biota.

Using rational decision-making, the plan options were scaled from one to 10 based on how well the approach would likely match the criteria upon plan completion, relative to other plan options. For example, how well would approach X improve freshwater system functioning once carried out to completion? And how would this compare to plan Y?

Cost meant the capital and running costs of the project until completion. Difficulty meant the amount of effort and work implementation would require, and time was based on how long the plan would take to be successfully carried out. Land compromised is based on how much of the land currently in use by farmers would be lost from production. Waterway improvement regarded the positive impact on waterway functions and water quality. Geomorphic improvement regarded the improvement in geomorphology of the catchment (erosion, waterway characteristics). Biodiversity improvement was meant with regard to native species, both flora and fauna. The scores were totalled and the lowest scoring option selected as the best plan approach. The next-lowest scoring option was selected as a backup option.

The chosen option and alternative option were then weighted for the overall positive benefits, as their total scores were close. This clarified that one option was superior to the other. Strategies and implementation methods for both options were then developed, based on results, with emphasis on the preferred plan option. The implementation of the preferred plan was then created in a manner to maximize time efficiency as well as minimally impact onsite farmer disturbance, disruption and costs.

Integration

The integration aspect of catchment management is important for plan success as environmental management, particularly water management, requires social change and therefore consensus is necessary (Bishop 1970, Heathcote et al. 1998). Multiple stakeholders were approached and involved but integration will need to further increase for implementation. The plan also integrated various aspects of important geomorphic, ecological and social factors to take a more holistic approach. The economic factors have been less focused on because on future uncertainty in funding and government subsidy from the Sustainable Farming Fund.

Stakeholder Engagement

Massey University

Lecturers from Massey University with experience in freshwater systems and management were involved and contributed advice with expertise in given fields. This involvement was important in aiding with efficient fieldwork research conducted to attain information on the present environmental state of the catchment.

New Zealand Landcare Trust

New Zealand Landcare Trust, as an independent organisation aiding in catchment management projects, had already been working in the catchment improving riparian planting and fencing. Manawatu-Wanganui Regional Coordinator, Alastair Cole, was involved throughout much of the project through email and contributed in fieldwork assessments, as well as organising interaction with public and landowners. Advice and information on landowners and approaching individuals was supplied.

Horizons Regional Council

The regional council was approached for any existing information on the Mangaone West; unfortunately after a restructure much had been lost and only rainfall data and downstream flow data was available. The council's rainfall data was acquired and analysed for trends both monthly and yearly.

Oroua Catchment Care Group

The Oroua catchment care group includes the Mangaone West and is formed by regional and district council members, local Iwi, landowners, Massey University representatives, as well as a fish and game member, a Landcare Trust employee, and an interested local. The care group was created under the Manawatu section of the Fresh Start for Freshwater Cleanup fund. This diverse group was originally met with early in the project and members Ossie Latham, Alastair Cole and Ian Fuller remained in contact for representation. Denis Emery, Iwi member of the board, also contributed a piece on the cultural history of the catchment.

Local Community

Catchment management plans are more likely to be successful when the local community is included in the process; therefore the Mangaone West community was approached for inclusion. Locals were notified of the project occurring within their catchment and invited to meet and discuss plan objectives and catchment management options. The meeting took place on the third of October (2013) with supper provided as an incentive. A short presentation on the cause for the meeting and the project was given, and then the group was asked for ideas on what the local community thought would benefit the catchment. Ideas for inclusion and objectives of the plan were recorded and then the group was asked to decide on one view to be put forward for inclusion. This strategy ensured a more synonymous view on the objectives and aims of the plan and also provided aid in how to go about reaching the aim.

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Results

Geographical Information Systems (GIS)

ArcMap was able to output various mapped scientific information on the catchment. Useful data layers from land resource information systems (LRIS), land environments of New Zealand (LENZ), freshwater environments of New Zealand (FENZ), and land cover database (LCDB) were collected and clipped where possible to the catchment borders. The colour coding system for different areas showed differences of character in the land useful for management decisions.

The LRIS comprises several physical resource themes: LUC, Lithology, Soil, and more. These themes are founded on the New Zealand Land Resource Inventory (NZLRI) a single spatial (polygon) layer with national coverage, supplemented with numerous soil survey layers of local coverage (Newsome, Wilde, & Willoughby, 2008). Together they make up the most comprehensive spatial archive of New Zealand's physical resource information.

LENZ identifies climatic and landform factors likely to influence the distribution of species. LENZ uses these factors to group together sites that have similar environmental conditions. The scale of grouping can be varied, based on the practicality for different studies (Leathwick et al., 2002). Such classifications can then be used in aiding management decisions.

FENZ database is a set of spatial data layers describing environmental and biological patterns in New Zealand's freshwater ecosystems. These layers were designed as a resource providing information about freshwater ecosystems, including geographical locations, physical and biological attributes, and current condition.

LCDB is a thematic classification of land cover and land use classes, currently containing 33 different classes to describe New Zealand's different environments.

Land Use Capability (LUC)

LUC uses LRI to assess critical factors of the land concerned in regards capacity for long term sustainable use; rock type, soil, slope angle, dominant erosion type, and vegetation coverage. The land is categorised based on these factors into one of eight LUC classes predicting its suitability for uses and is subclassed for versatility and limitations to its usage (Lynn et al. 2009) (Figure 2.).

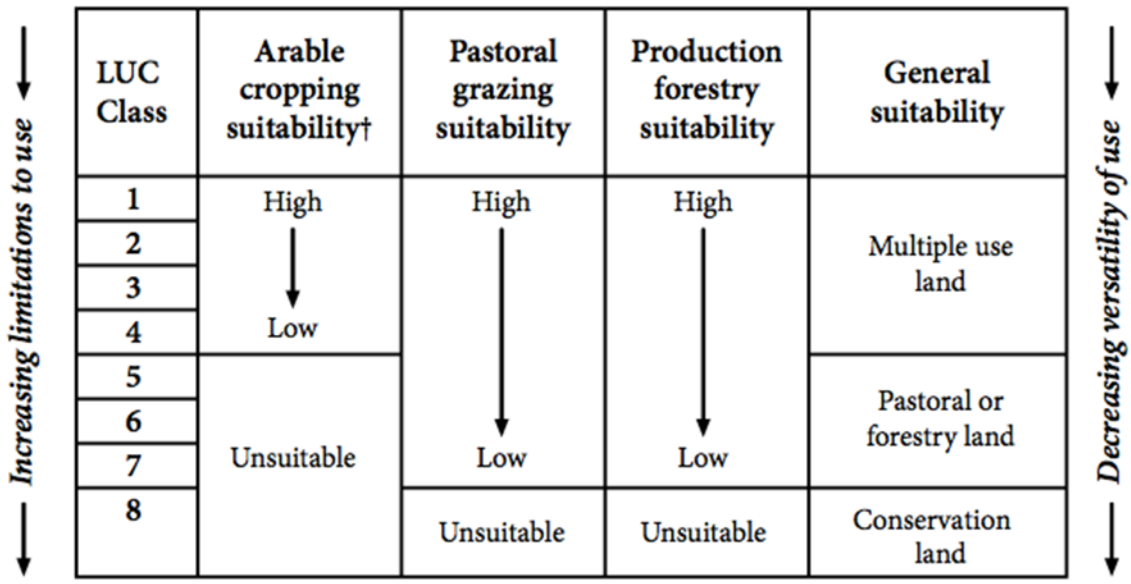

Figure 2. LUC class diagram
(pg. 9, Lynn et al. 2009).

The Mangaone West catchment varied in LUC class from two to six (Figure 3.). Much of the upper catchment in the headwaters was categorised as 6E12. The edges of the catchment are dominated by class 6E2, with some mid and upper catchment pockets of class 4E4. A middle section of the catchment constitutes class 3E4, the least limited land of class 2E2 covers the lower Mangaone main channel and is otherwise scattered in small areas throughout the catchment, including adjacent to much of the 6E2 land in the upper catchment. The dominant hazard and limitation to the catchment is erosion (denominated by the letter E after the land class number) The LUC areas are described in further detail in order of increasing limitations.

LUC two is considered to have only slight limitations to arable use, which can be controlled and minimized through management and soil conservation. It is well-suited for many cultivated crops, pasture or forestry. Limitations include: slight susceptibility to erosion (wind, sheet, rill, and potential for stream bank) under cultivation, moderate soil depth, unfavoured soil structure (difficulty working) in loamy sand and clay textured soils, weak to very weakly saline, occasional flood overflow, slight climatic limitations. Soils are derived mainly from alluvium and recent loess, although some in the North Island have developed on fine-textured, andesitic and basaltic ash. Class 2 land normally occurs below 500m (NI), and where annual rainfall is between 800 and 2000mm.

Class three land has moderate physical limitations to arable use, restricting the choice of crops and the intensity of cultivation, and making special soil conservation practices necessary. There is moderate erosion susceptibility under cultivation (wind, sheet and rill stream bank). The soil has a low moisture holding capacity and slow draining leading to waterlogging susceptibility. Slopes are undulating to rolling (4-15˚), soil has low fertility and is shallow or stony soil (20-45cm), the moderately unfavourable soil characteristics include clay and sandy loam textures with weak salinity. Elevation is generally bellow 750m (NI) moderate climatic limitations (annual rainfall 800>2500mm), causing occasional damaging overflow.

Class four land has extensive distribution, generally below 1000m. It severe limitations for arable use, the range and rate of cropping and management and intensive soil conservation practices are necessary. Generally the land is only suitable for occasional cropping (once in five years maximum), but remains suitable for pasture, tree crops or production forestry. Under cultivation the land is moderate to highly susceptible to erosion (wind, sheet, rill and gully), and waterways may incur slight to moderate stream bank erosion. Slopes range up to strongly rolling (0-20˚), an important factor in erosion severity. The soil has a very low moisture holding capacity, is very shallow (<20cm), and is stony to very stony (35-70%). Unfavourable soil types include clay, sand textures, and loamy sand. The soil is also moderately saline, with low fertility (difficult to correct). Due to these soil properties, excessive wetness after drainage remains, and severe climatic conditions (800<3000mm average rainfall) render the land susceptible to frequent flooding.

Direct drilling of crops and pasture can be used to significantly reduce the erosion risk on land limited for cropping by steepness, and on flat and rolling land susceptible to wind erosion. In Northland and Westland some Class 4 land is limited by excessive wetness, or low natural fertility. Class 4 also occurs on the shallower stony soils of the river terraces and outwash surfaces where cultivation is marginal, and on flat and rolling land in Central Otago where cropping is limited by low rainfall.

Class six land is generally stable, productive hill country, but is unsuitable for arable use, with slight to moderate limitations and hazards under pasture and forestry. Erosion is the dominant limitation, but it is controllable by soil conservation and pasture management. Common limitations include: moderate erosion hazard, steep to very steep slope (>26˚), very shallow soils (>20cm) or very stony soils (35-70%) with low moisture holding capacity and moderate to strong salinity. The soil type can leave the land prone to excessive wetness and moderate climatic conditions allow frequent flooding.

Also included, but not as common, are flat to gently undulating stony and shallow terraces and fans, rolling land with a significant erosion risk, or a wetness or climatic limitation too great to allow sustainable arable cropping. Land may be cultivated infrequently for pasture establishment or renewal (<one year in 10).

Soil conservation applicable to Class 6 hill country includes space-planted trees, conservation fencing, water control structures, over sowing and topdressing, and appropriate winter cattle management.

‘Cultivation for cropping’ and ‘arable use’ implies capability of land to produce crops at least once in every four to five years. But it is common practice to leave such areas in pasture for 5 to 10 years, or longer. Direct drilling, minimal tillage and no-till techniques to establish crops and pastures can significantly reduce erosion susceptibly and risk.

Figure 3. LUC categorised map of the catchment.
Red=town, orange= 6e14, yellow= 6e2, lime= 4e4, green= 3e4, dark green= 2s2. The first number categorises the land by decreasing capability, the letter e signifies the dominant limitation/hazard, being erosion, and the later numbers the increasing extent of limitations on the land.

Slope category

LRIS assesses the steepness of terrain providing the slope class of an area. The slopes in the catchment range in steepness and are categorized with similar other slopes of similar steepness. The middle to lower catchment is in general far less steep than the upper catchment and its edges (Figure 4.). The red down bottom is Fielding town, red-orange area to right of upper is category F+E, meaning mostly 26-35 degrees with some 21-25 degrees. Much of upper catchment is bright orange, being category F, meaning steep at 26-35 degrees, some is orange (E + D), meaning the dominant slope is moderately steep at 21-25 degrees but with some strongly rolling at 16-20 degrees. Areas at the sides of the valley are light orange (category E), with slopes of 21-25 degrees. Areas to the side of the catchment are also a yellow-orange (category D+E) with slopes mostly 16-20 degrees, some 21-25 degrees. Small areas around the outer of the catchment are categories D+C and D, with slopes varying from mostly 16-20 degrees (D), with some slopes 8-15 degrees (C). In the mid-lower catchment, to the left of the main channel area, the slope angle is higher; the lime green present in much of the mid to lower catchment is slope C+D, being rolling to strongly rolling with a dominant slope of 8-15 degrees and some 16-21 degrees. The mid trunk of the Mangaone West stream is a slightly darker green of category B+C with mostly undulating slopes of four to seven degrees but with some areas rolling at 8-15 degrees. Small patches in the mid catchment are B or A+B, undulating to flat at four to seven and zero to three degrees. Also the darker green areas on the western side of the catchment are category A+B whereas dark green areas on the east side of the catchment are category A (flat to gently undulating). The lower end of the main trunk is also category A. The catchment's varying slope from steep to flat with distance downstream from the headwaters is a usual catchment characteristic (Leopold, Wolman & Miller, 2012).

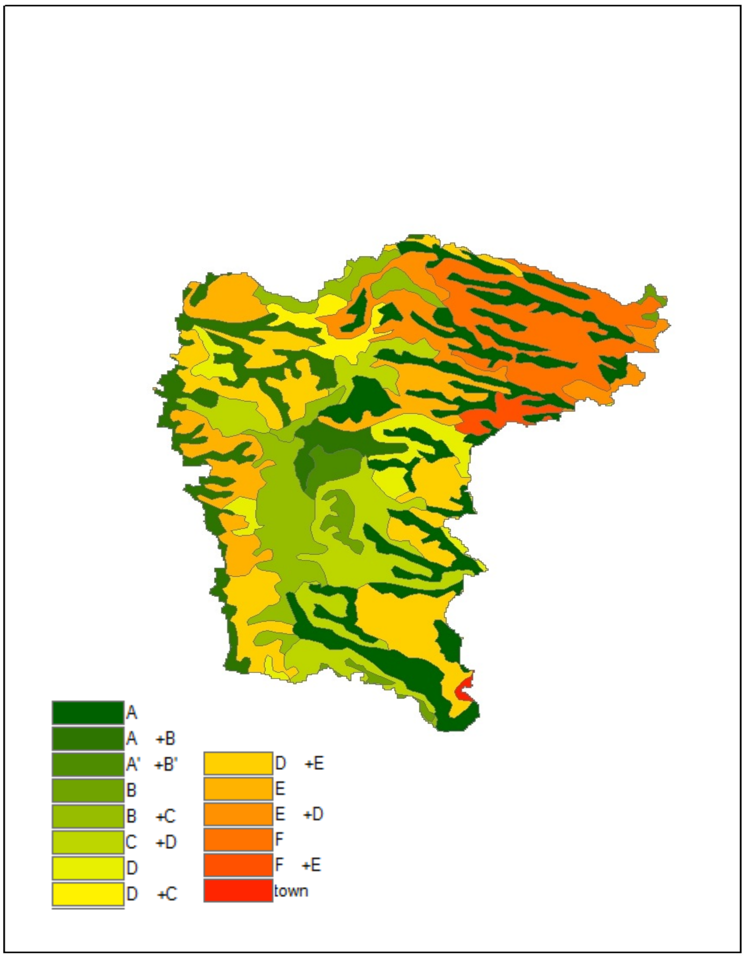

Figure 4. Catchment slope categories.
Measured in degrees, dominant slope within unit defines category. A=0-3 ˚, B=4-7 ˚, C=8-15 ˚, D=16-20 ˚, E=21-25 ˚, F=26-35 ˚ (pg. 21, Lynn et al. 2009).

Erosion

Under the LUC modelled erosion, the dominant form of erosion in the catchment is predicted to be mass movement via soil slip, occurring in the upper catchment (Figure 5.). Between half a percent and two percent of the area is likely to be affected by soil slips. At the very beginning of headwaters there are some orange areas (upper east edge of the catchment), these areas will experience sheet erosion (on one to 10% of the land) as well as the soil slips as indicated in the yellow areas. Much of the catchment is modelled to have no significant erosion (dark green), with less than one percent of the area affected by any form of erosion, this is mostly in the mid to lower catchment. The west side of the catchment may experience sheet erosion affecting up to 10% of the area coloured lime green, however, 5-25% of the topsoil in the affected areas may be lost over time. The mid-lower trunk of the Mangaone is green and is likely to experience slight bank erosion affecting one to five percent of the reaches and lateral erosion likely between half a metre and one metre.

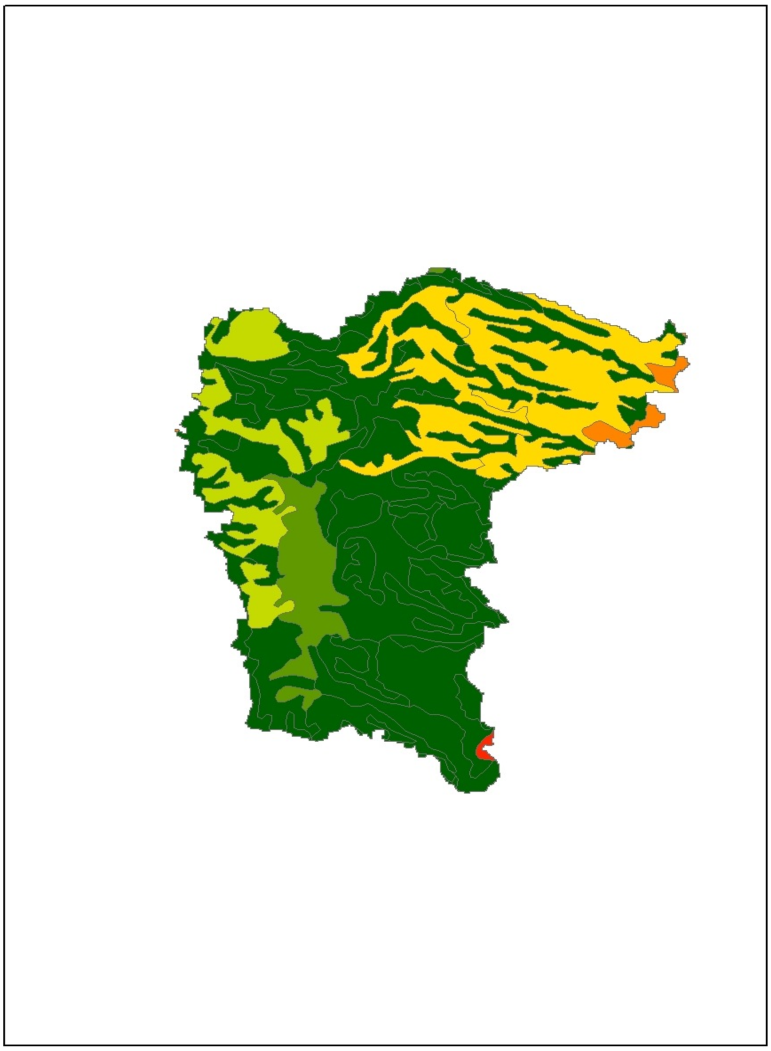

Figure 5. Map of erosion risk.
Dark green indicates no significant erosion; green indicates 1sb, lime green; 1sh, yellow; 1ss, orange; 1ss1s and red, down the bottom, the town.

Stock Carrying Capacity (CC)

Stock carrying capacity acts as a function of productivity and is an output of LRIS. Carrying capacity values can range from zero to 25 SU. The carrying capacity is measured as the stocking unit (SU), equivalent to the number of ewes (Woodford, & Nicol, 2005). The average carrying capacity (CCAV) output for the Mangaone West was mapped and showed the varying capability of the land to sustainably support stock. Carrying capacity varied from nine to 14. Stocking rates of 14 are shown in red (Figure 6.) and are prominent in the mid trunk of the catchment and areas with low angled slopes. Areas in orange were slightly less productive, probably due to increased slope, and these areas are also close to the middle of the catchment as expected. Yellow areas, dominant the west and east corridors of the catchment, have an estimated carrying capacity of 10 SU, while the upper catchments hills' carrying capacity is reduced further to 9 SU.

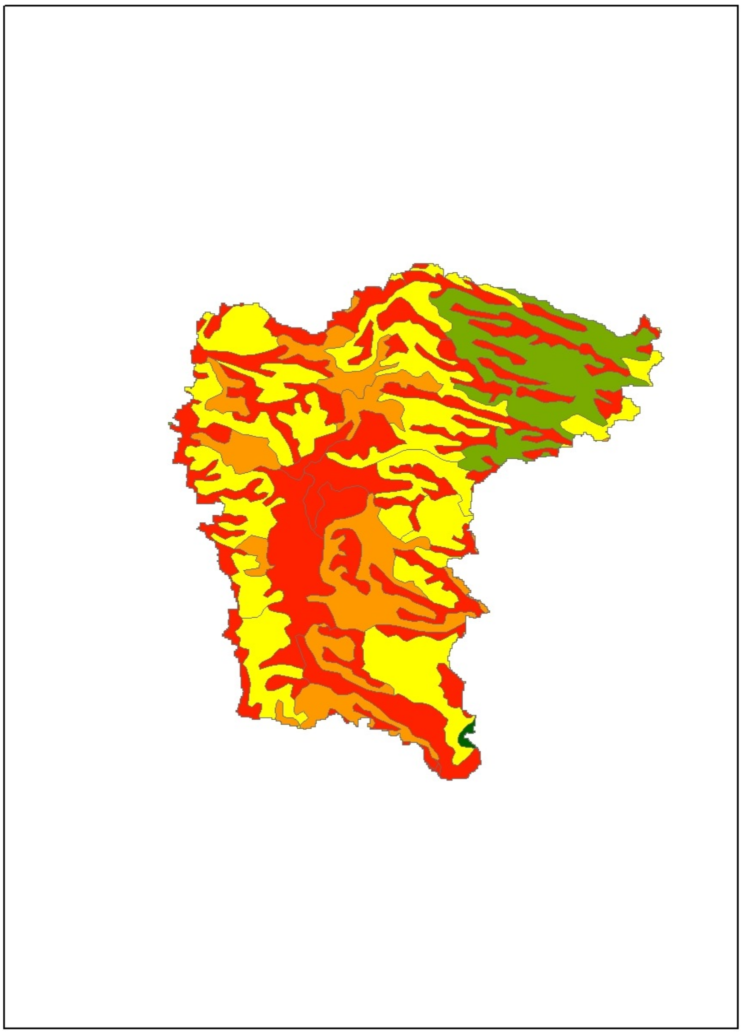

Figure 6. Average carrying capacity.
Dark green denotes the town, green=9 SU, yellow=10, orange=13, red=14.

Drainage

Soil drainage is described as a class by LRIS; classes are assessed using criteria of soil depth and duration of water tables inferred from soil colours and mottles, based on the NZ Soil Classification (Hewitt 1993). Yellow indicates moderately well drained soil of class four, however, most of the catchment is light green indicating imperfect drainage and mottled soil, class three (Figure 7.). Much of the main channel's immediate area is indicated to be poorly drained of gley profile with shallow topsoil, less than 15cm (dark green). Many hilltops are also class two, these are far more isolated. Much of the catchment is therefore prone to waterlogging and pugging, particularly the main channel trunks adjacent land.

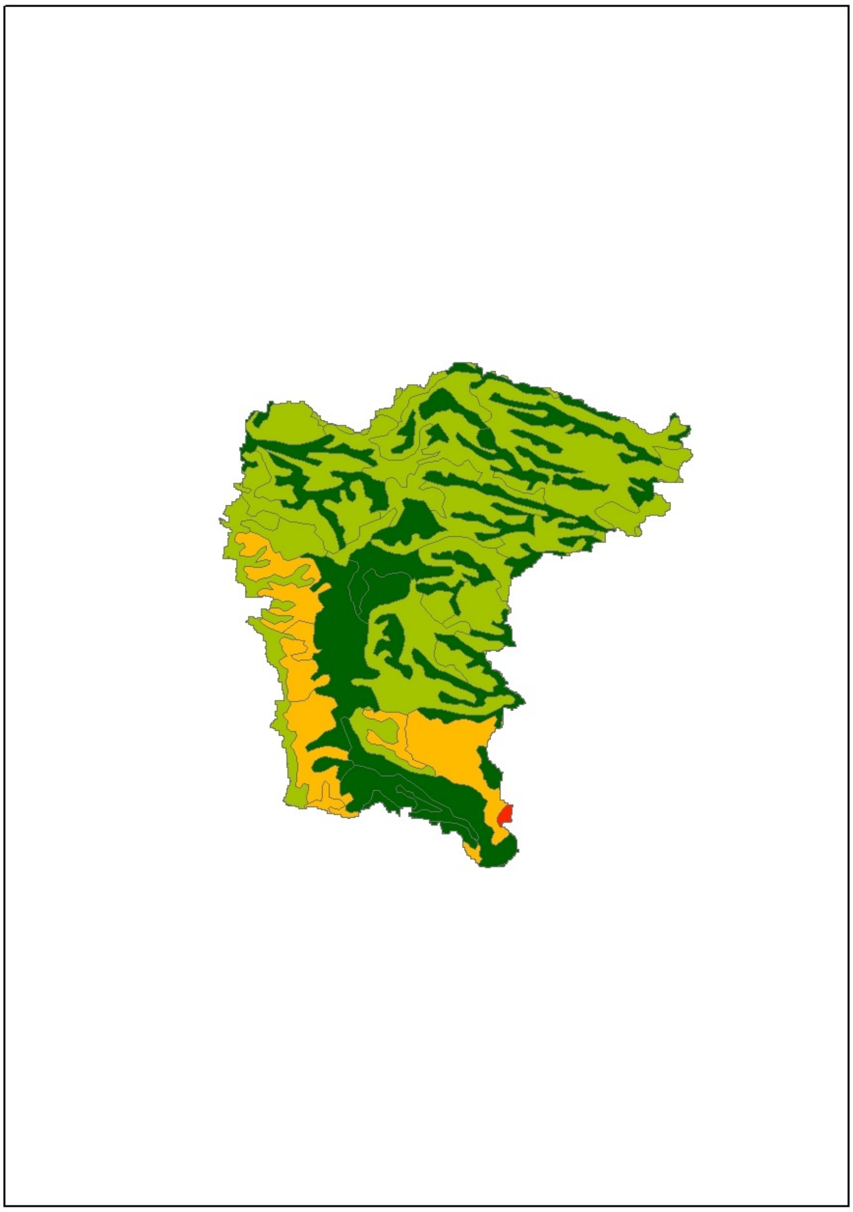

Figure 7. Drainage Classification.
Red represents the township. Yellow = class four; moderately well drained, soils that have either a reductimorphic horizon between 60 and 90 cm, or a redox-mottled horizon between 30 cm and 90 cm. Light green = three; imperfect drainage, up to and above 15cm topsoil, soils that have a mottled profile form. Dark green = two: poorly drained, less than 15cm topsoil, soils with a gley profile form.

Soil Type

Soil type, constructed by LRIS indicates the different character of soils present in the catchment (Figure 8.). The majority of the catchment is silt loam, coloured green, however the distribution of loam, coloured yellow, is patchy and appears to be mostly on hilltops, with a significant area in the centre of the catchment. Fine sandy loam (red) occurs along the edge of the left (west) of the catchment in significant portions, as well as a large amount on the right side of the lower catchment. Silt loam constitutes a low percentage of clay (<20%), a moderate amount of sand (0-50%) and a high amount of silt (50-88%) (AgriInfo, 2011). While loam still includes a low amount of clay (7-27%) the sand and silt composition is more even (23-52% and 28-50% respectively), usually composed of roughly 40% silt: 40% sand: 20% clay (Kaufmann & Cleveland, 2008). Sandy loam contains more of the larger sand particles than the other loams, allowing better drainage (43-80% sand: 0-50% silt: 0-20% clay) (Lerner, 2000; AgriInfo, 2011). As most of the land in the catchment constitutes small individual particles (silt and clay) the majority of the catchment shows poor to imperfect drainage as described above. The ability of the soils to retain water is normal however there is high solar radiation and temperatures over summer months so the catchment is prone to drying out (Cowie &Rijkse, 1977).

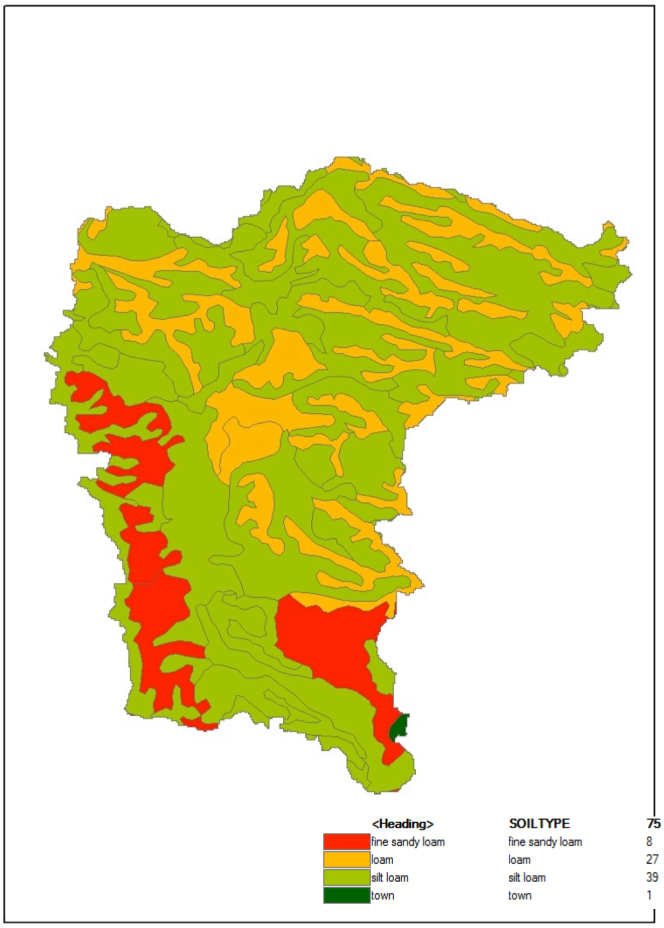

Figure 8. Map of soil type produced by LRIS.

Soil

LRIS was able to provide further detailed information and predictions about the soils present. The general soil survey correlated map provides the gensoil number for soil name and associated information on limitations. The very exit of the waterway from the catchment is Kairanga soil (2), the area is minute but is sandy loam and has the limitation of requiring some drainage (Figure 9.). In the lower catchment, the area surrounding the main channel is Ohakea silt loam (12, dark green), and limitations to intensive land use include drainage and summer dry-out. In the mid and lower catchment, again mostly adjacent to the main Mangaone West channel, is Milson silt loam, with some rolling phase (light green, 13a). This soil also has drainage limitations, slight sheet erosion and dries out in summer. Halcombe silt loam (13b, yellow) occurs in patches with a large area in the mid-lower catchment and another significant area surrounding the main channel of the mid to mid-upper catchment. This soil may have sheet erosion if cultivated and again has drainage and summer dry-out limitations.

Halcombe hill soils (13bH, light orange) constitute silt loam (and fine sandy loam in the lower catchment) and covers the most area, particularly in the upper catchment and along the sides of the catchment. Its main limitation is its slope, and slip erosion may occur. Marton silt loam, some in rolling phase, has the potential for sheet erosion, and has drainage and dry-out limitations (Cowie & Rijske, 1977).

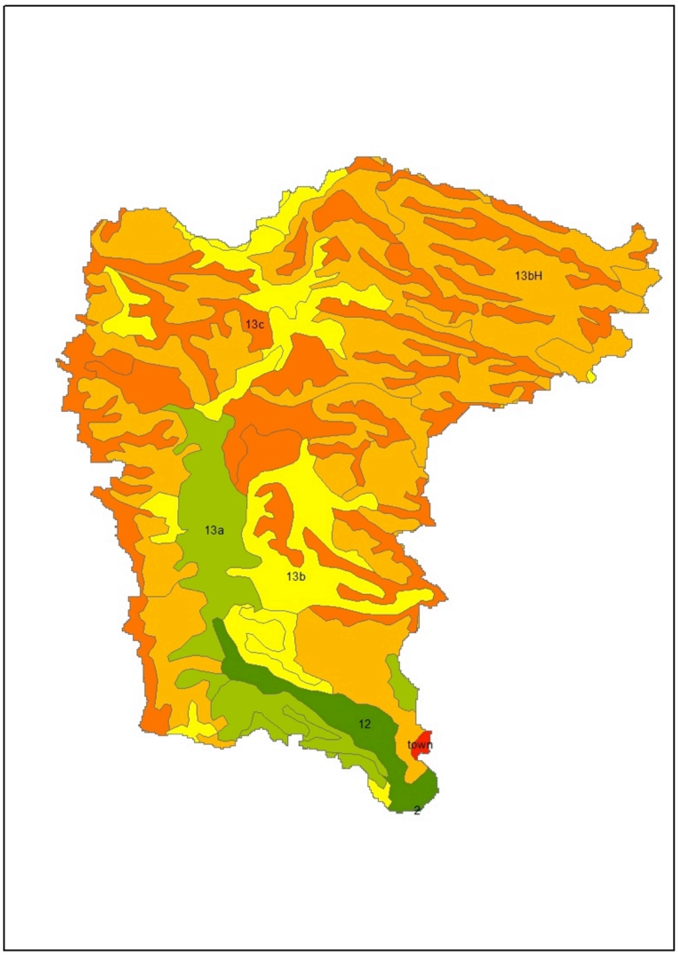

Figure 9. Mapped general soil survey of the catchment.
Two: Kairanga, 12: Ohakea, 13a Milson, 13b: Halcombe, 13bH: Halcombe Hill, 13c: Marton.

Bedrock

The underlying geology influences the environment significantly, LRIS produced a map of the bedrock type of the catchment (Figure 10.). The upper catchment has loess (lo), sandstone (sandstone) and unconsolidated to moderately so silts (Us), and loess. The mid to lower outer edges of the catchment differ to the centre of the catchment in that there is sandstone mixed in with the loess. The bottom of the catchment, the area the main channel occupies, is composed of undifferentiated floodplain alluvium. The geology is important in influencing the organisms occupying the land, and the surface water and groundwater of the area.

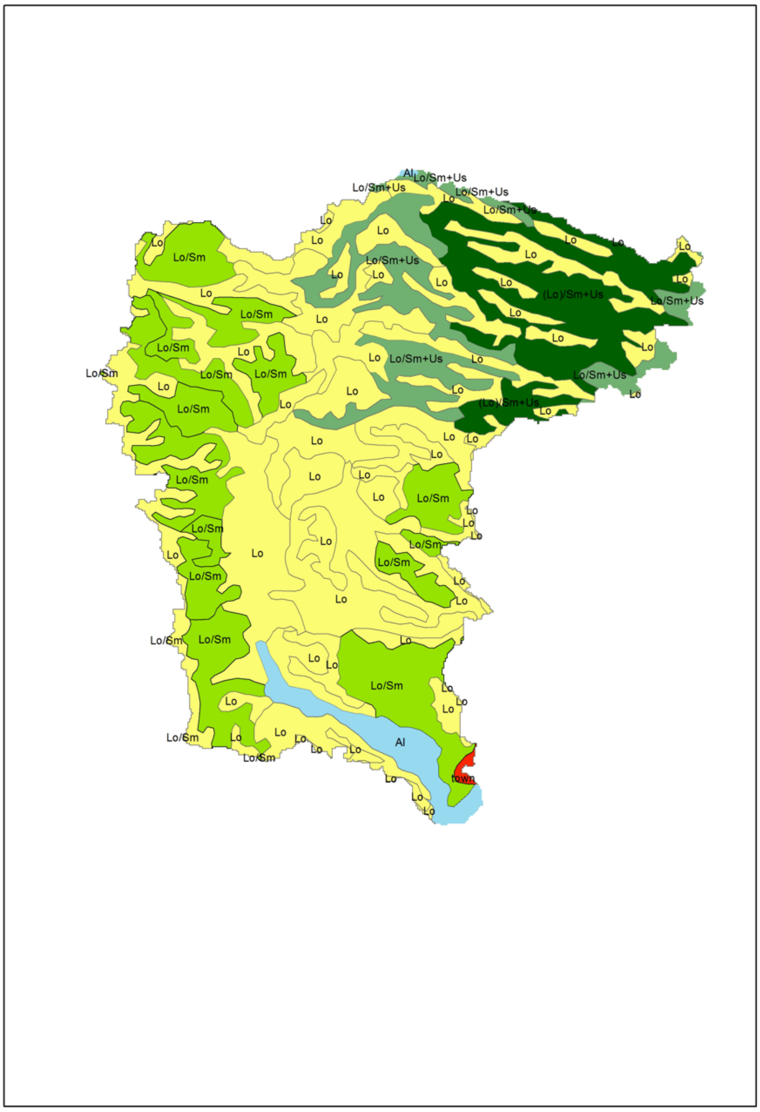

Figure 10. Bedrock type.
Colour coordinated in green for likeness, of assemblage. Lo= loess, Sm= sandstone, Us= unconsolidated silts, Al= alluvium.

Waterway slope

Using FENZ, the segment slope (degrees) is derived from GIS calculation using length and difference between upstream and downstream elevation (for each segment) (Figure 11.).

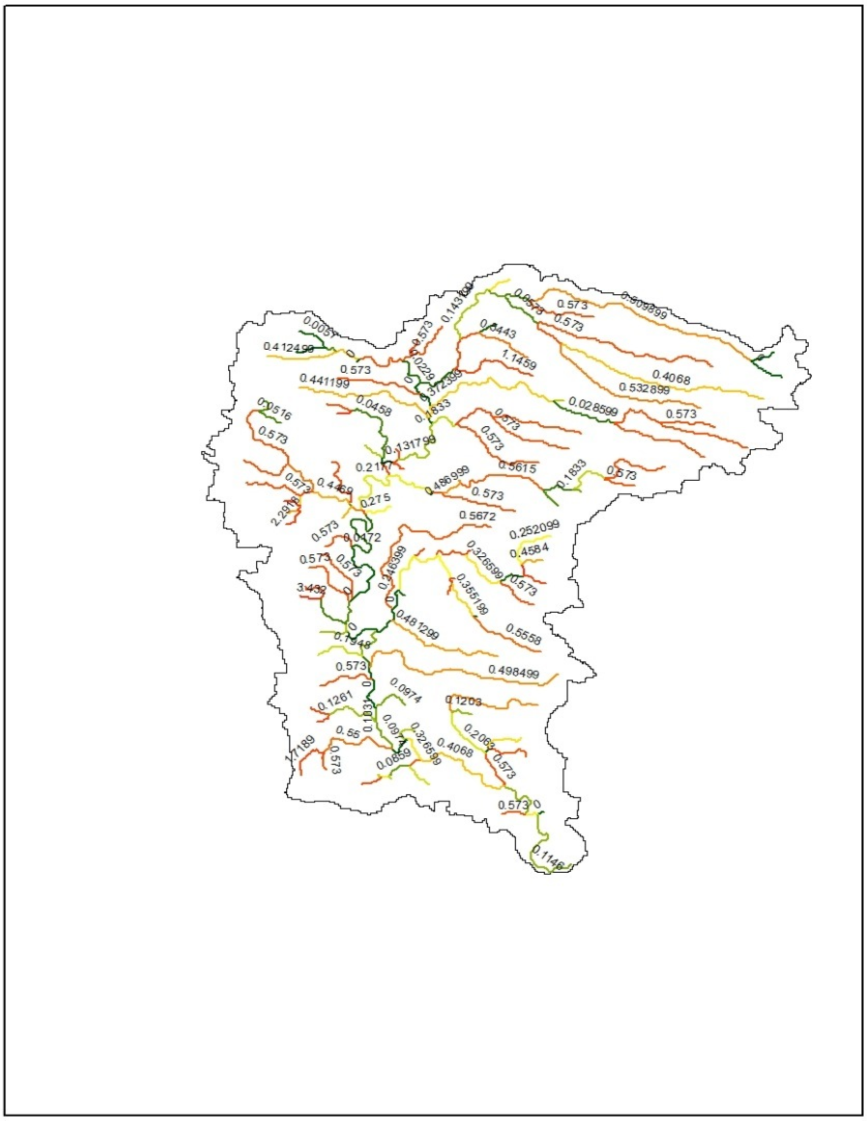

Figure 11. Waterway segment slope.
Measured in degrees. A segment includes an entire tributary, or a portion of the stream.

Average slope in the upstream direction (degrees), derived from FENZ, the trend may imply catchment-driven modification of flow variability. The elevation changes show the steeper areas of the catchment to be in the upper catchment (in red, Figure 12.).The elevation of the main channel reduces progressively in steepness with distance downstream, as one would expect.

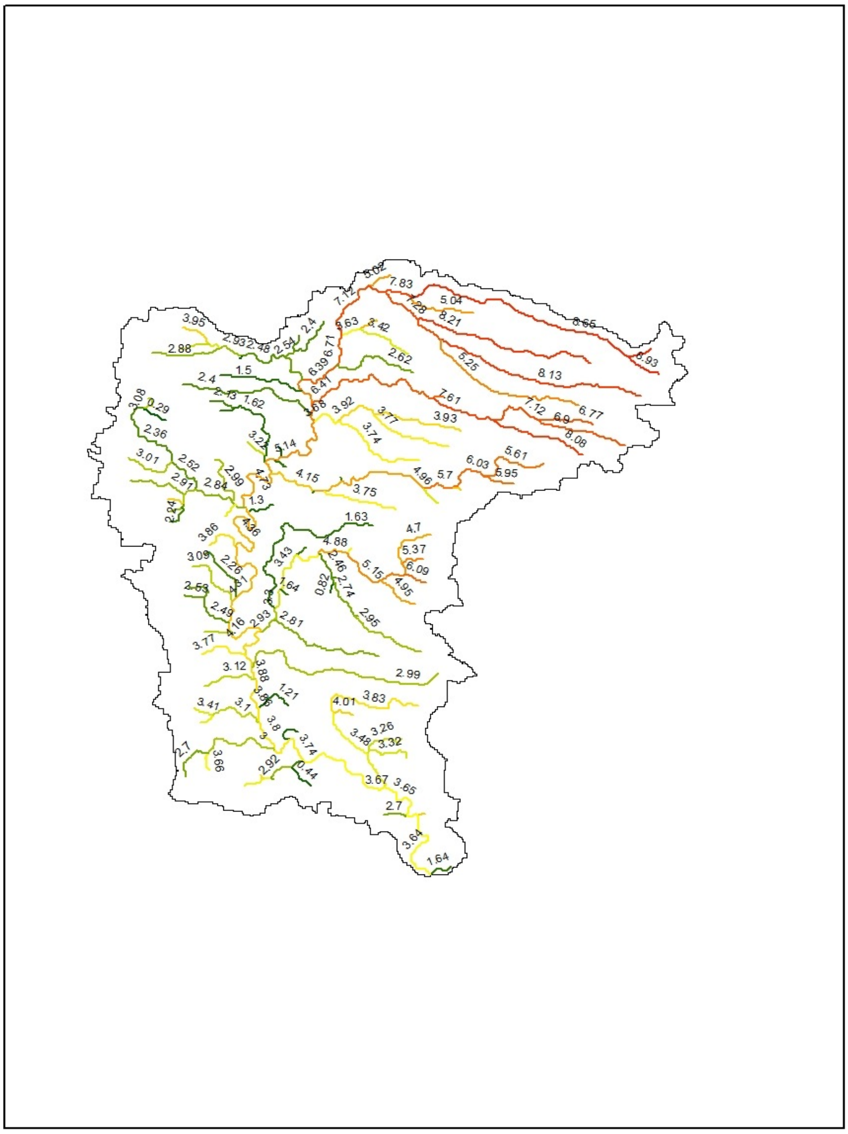

Figure 12. Average upstream slope.
Measured in degrees.

River and stream Classification:

Waterway segments with similar environmental conditions are grouped into categories (Figure 13.). Environmental data was combined with the two biological datasets (native freshwater fish and fresh-water macro-invertebrates). Classification results are supplied at four levels of detail containing 20 (capital letter), 100 (first number), 200 (number after decimal) and 300 (lower case end letter) groups respectively, the most relevant classification for the Mangaone West was the fourth level with the most detail. The characteristics of waterway segments were analysed and categorised by the river environment classification system (RECS), stream segments with similar characteristics are grouped under the same category to provide a system to manage areas of waterways more effectively. It showed the majority of the segments to be of one class; A4.3a, while most of the upper catchment was grouped as A4.1(b and a). The lower catchment has some areas classed A4.3b. These classifications are practical in use as one may cater management to a group and expect a similar response, potentially simplifying and increasing monitoring efficiency.

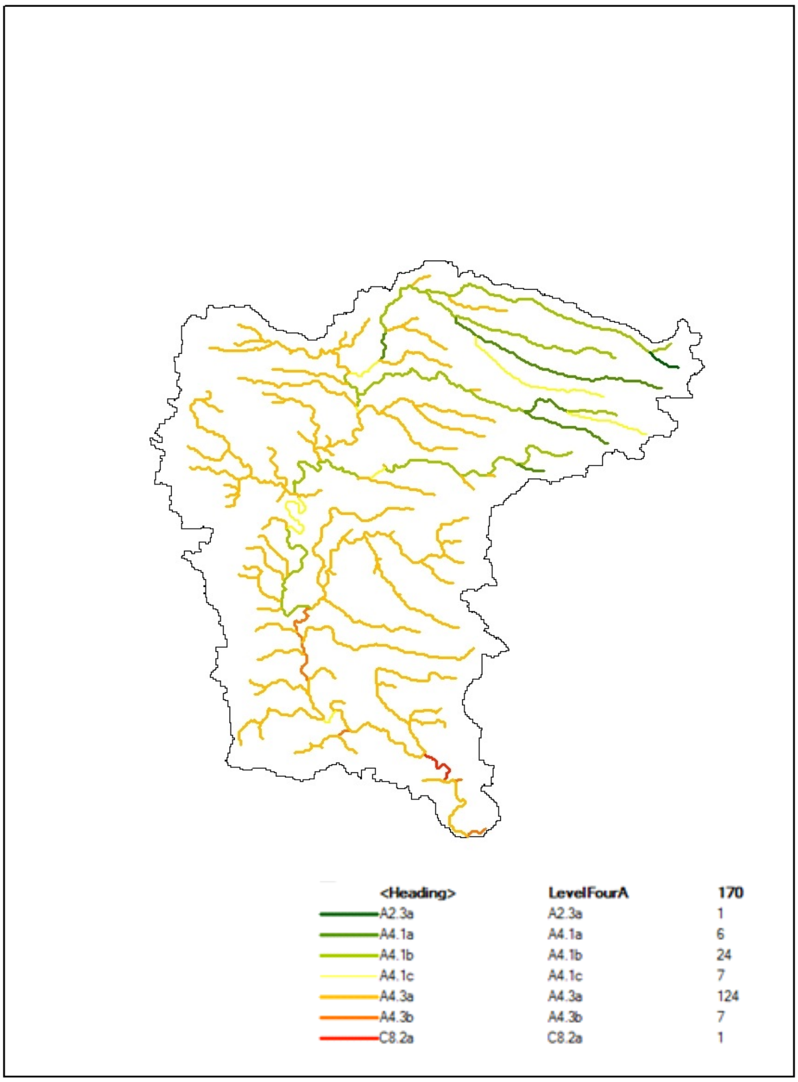

Figure 13. River classification level four.
Waterway segments with similar characteristics are categorized.

Average proportional sediment coverage:

Predicted sediment cover, estimated by FENZ, measures mean sediment size, and varied between mud and fine gravel with some coarse gravel. A significant portion of the lower main channel showed increased substrate size; however, the mean sediment size appears variable between class one and three. Most of the main channel is estimated as mud (one) or sand (two) (Figure 14.).

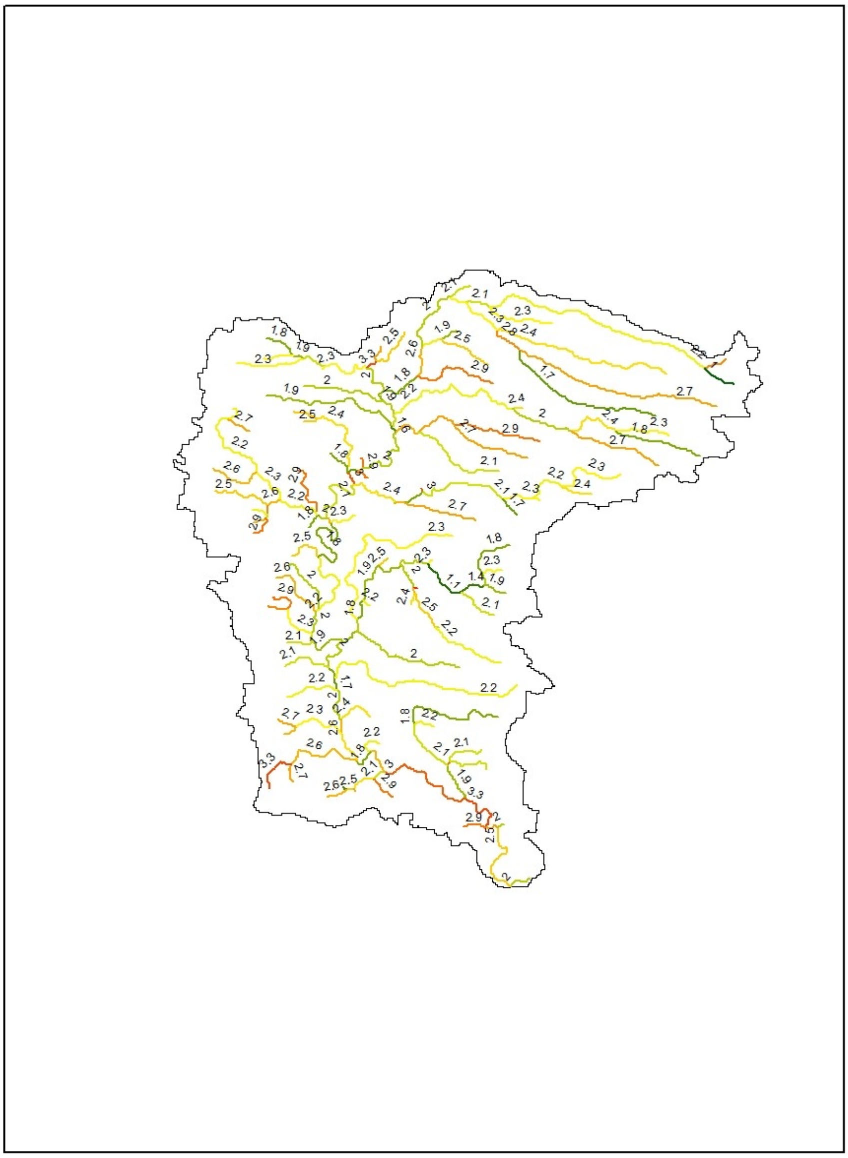

Figure 14. Weighted average of proportional cover of bed sediment. Categories: one = mud, two = sand, three = fine gravel, four = coarse gravel.

Average Habitat coverage:

FENZ estimates the mean stream habitat type in each segment, in the Mangaone west most of the habitats are estimated to be backwater or pool (Figure 15.). The colour coding shows the class of the segment, most of the main stream channel is coloured red-orange being classed as pool, some areas close to being closer to run than pool (>3.5). Most of the smaller tributaries are backwater with an exception to the upper catchment tributaries.

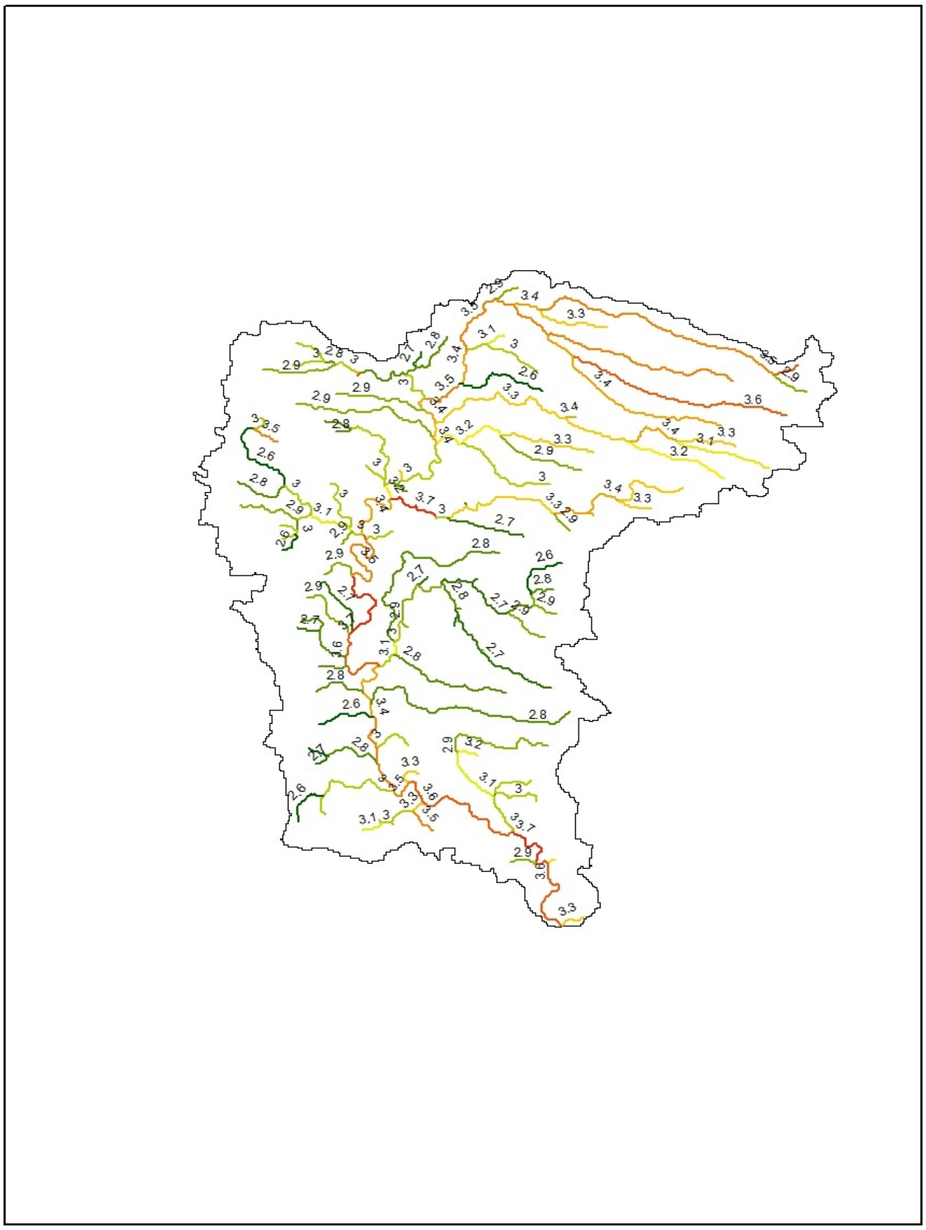

Figure 15. Weighted average of proportional cover of stream habitat.
Mean average habitat type by categories of: one = still; two = backwater; three = pool; four = run.

Flow

Flow, predicted from FENZ, increases with distance downstream as can be seen by the gradual colour change, from green (slowest) to red (fastest) (Figure 16.). Due to time constraints, actual flow was not modelled during sampling, there is no existing council data of flow in the Mangaone West, though it is monitored after its confluence with the Makino stream. The minimum flow occurs in smallest tributaries with the smallest contributing land, and the highest flow occurs toward the bottom of the catchment where the volume of water and contributing land area is the highest.

Figure 16. Predicted mean annual flow (m³/sec).

Modelled Nitrogen

Nitrogen concentration, predicted by FENZ, was expected to remain relatively low throughout the headwaters and main channel, only increasing slightly from around 0.002 g/m³ to ~0.004g/m³. Peaks in nitrogen were predicted in the smaller tributaries in the lower catchment (red, Figure 17.).

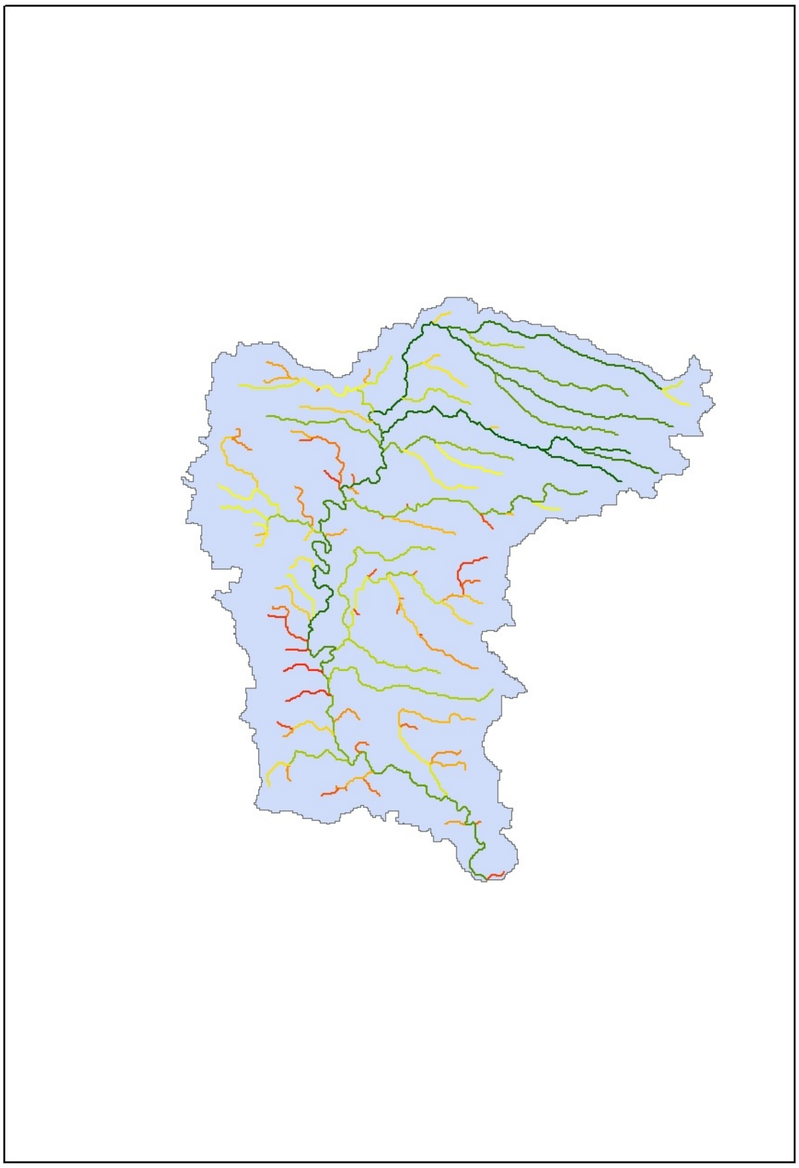

Figure 17. Nitrogen concentration estimation (ppb).
Estimated from CLUES, a leaching model combined with a regionally-based regression model, implemented within a catchment framework (Woods et al. 2006). The highest predicted nitrogen levels are expected where the catchment's dairy farm is located, due to associated land practices, and is 24ppb or 0.024g/m³ (lower left of map).

Riparian shade

Riparian shading (proportional), predicted by FENZ, using national, satellite image-based vegetation classification to identify riparian shading in each segment. The degree of shading is then estimated from river size and expected vegetation height. The shading varies from none to significant stream coverage, represented by the colour change from red to dark green (Figure 18.). Riparian shading is higher in the lower catchment along the main channel compared to everywhere else: this is inverse to what would naturally be expected due to stream width increase with distance downstream. It shows areas where there is minimal riparian shading in the tributaries, and the areas along the main channel which could be improved (mid upper).

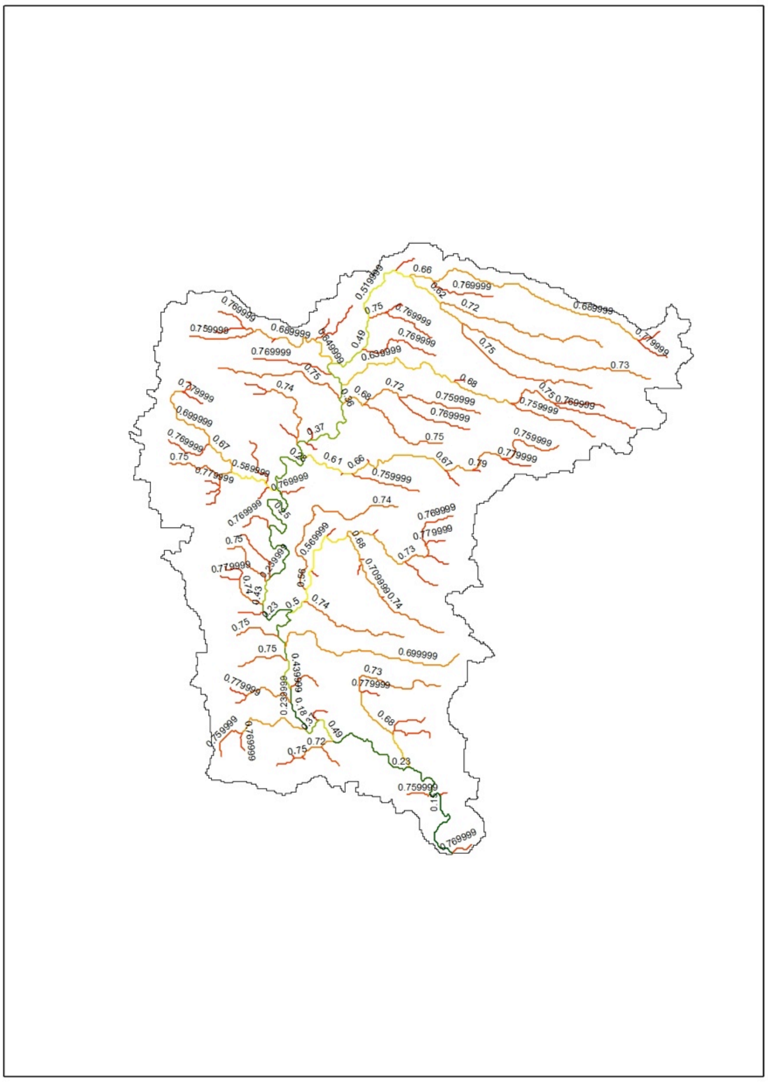

Figure 18. Map of proportional riparian shade.

Topography

Topographic map from LINZ (land information NZ) with the catchment area overlapped (approximately) in darker blue (Figure 19.). The hilltops of the upper catchment have the highest elevation, maximum 213masl (circled in red) and the minimum occurs at the very bottom of the catchment, as expected, where the Mangaone West joins the Makino stream (~60masl, circled in red).

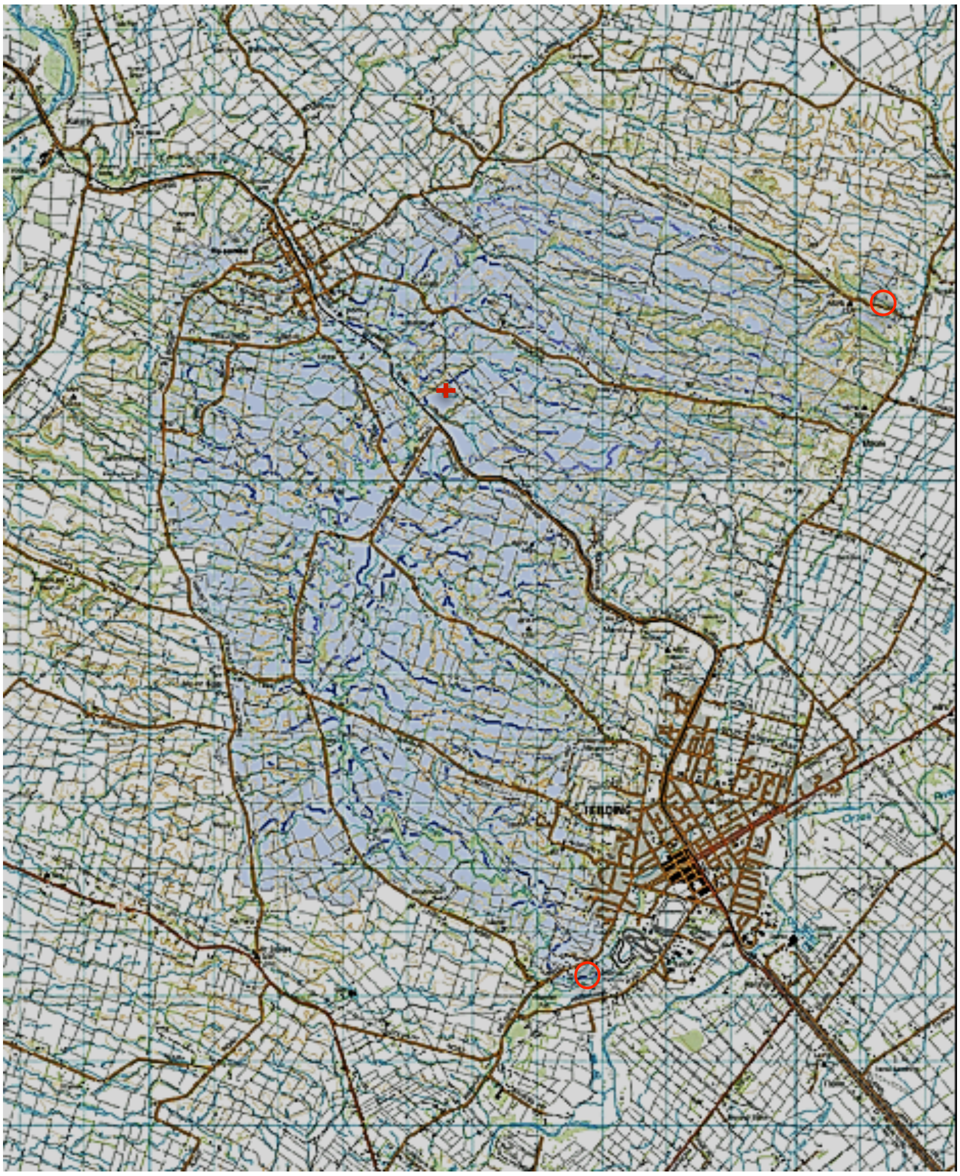

Figure 19. Topographic map.
Approximate catchment area in blue, and elevation maxima and minima circled in red (213masl and ~60masl). X depicts a wetland site.

Land cover

Under the LCBD, most all of the catchment is classed as high-producing exotic grassland; there are patches of indigenous forest in the lower catchment, particularly along the stream edge, and some small patches of exotic forest in the upper catchment (Figure 20.).

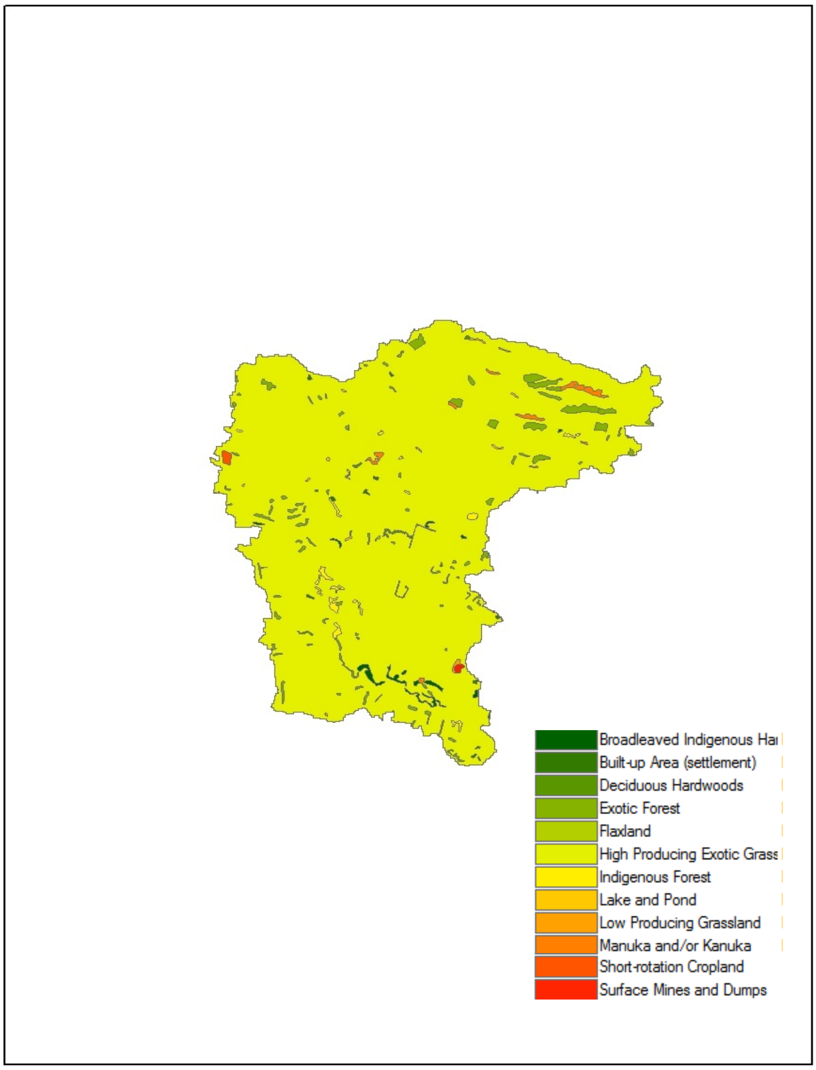

Figure 20. Land coverage.

Land Environments of New Zealand (LENZ)

Level four provides the most detailed categorization of land environments, similar environments being grouped together allows for more practical management of such areas. Aside from the headwater region in the upper catchment, the majority of the catchment is classed as environment C3.2a, with a significant portion adjacent to the main channel C3.2b. There is a lot more variation in environments in the upper catchment and headwaters, with seven of the eight catchment's environments present.

The different environments have some similar characteristics; environments A to F are widespread in the North Island, typically with warm temperatures, moderate to high solar radiation, low monthly water balance ratios, low to moderate water deficits and moderately high vapour pressure deficits. The environments of the catchment are described in detail below, information was provided by the LENZ user guide.

B1.3a: Dry hill-country and older alluvial soils at low elevation (160masl). The climate within this environment is dry, and warm, with high solar radiation, moderate to high vapour pressure deficits and low annual water deficits (severe in low rainfall years). Parent materials include sandstone (Wanganui), soils are imperfectly drained and of low natural fertility. Terrain is generally flat to moderately sloping (undulating), in this case on the top of slopes.

C2.1: This environment occurs in the upper catchment and occupies gently undulating inland plains (~200masl) in Manawatu. The climate is mild, with high solar radiation, moderate vapour pressure deficits and low annual water deficits, but may experience intense droughts. Loess is the predominant parent material, along with some fine-textured alluvium. Soils are of imperfect drainage and low natural fertility. C2.1a experiences high annual water deficits is poorly drained while C2.1b is typical of type C in water deficit but is also poorly drained.

C3.2 (a): This environment covers a lot of the catchment. It includes the dry, flat, low-lying (~65masl) plains of Manawatu. Warm temperatures, high solar radiation, moderate vapour pressure deficits and moderate annual water deficits typify the climate. Soils are of low fertility, from loess, old dune sands, and tephra. Slopes are very gentle, and soils are imperfectly drained.

Variations; C3.2b: lower annual water deficits (significant portion of catchment), C3.2d: gently undulating plains (small portion, very lower end of catchment).

F: Environment F occurs on low to mid-elevation hill. The climate is mild, with high levels of annual solar radiation and moderate winter solar radiation. It has a low monthly water balance ratio, low annual water deficits, and moderate vapour pressure deficits. The spread of rainfall throughout the year tends to be even, except for drought years.

F1.4a: Occurs on dissected tertiary hills of Manawatu, which are easy to strongly rolling (elevation ~305masl). Predominant parent materials are of tertiary sandstones, mudstones, greywacke and argillites with some volcanic material in the north. Soils are well-drained and of low natural fertility.

F4.1e: Generally consisting of the south-eastern coastal hills of Wairarapa, and Wellington. Hills are easy rolling with an elevation of around 175m. Soils are generally moderately to well-drained, formed from easily-weathered Tertiary mudstones with some argillite, limestone and sandstone with small amounts of older greywacke. This particular group is characterized with very low natural fertility.

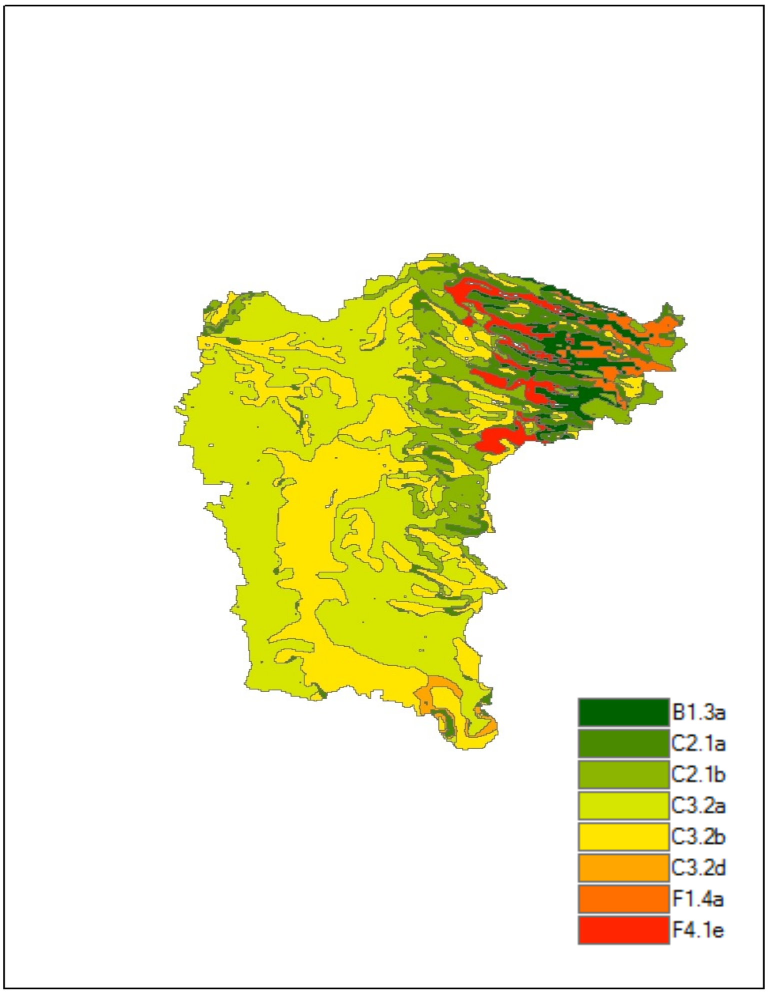

Figure 21. Land environments at level four.

The level two classifications may be more useful as the upper catchment shows five rather than seven environments, and the majority of the catchment is one environment, simplifying the groups into more significant rather than slight differences (Table 1and Figure 22.).

The climates between the environments do not vary much; most of the catchment is warm with the upper catchment mostly mild. Solar radiation is high throughout the catchment, with low fertility and moderate vapour pressure all over. The drainage of environments F2 and F4 is moderate- well however the majority of the catchment is imperfectly drained. The annual water deficit is moderate in environment C3, and therefore in most of the catchment, but the upper catchment has a low water deficit. The slope varies from ~0.8˚ in C3, the majority of the catchment, and increases in the upper catchment up to ~13.6˚. It is noted that this is much lower than predicted by LRIS above.

Table 1 *The characteristics of the five environments predicted by LENZ*

Tabulated characteristics of the different environments in the Mangaone West					
	B1	C2	C3	F1	F4
Climate	Warm	Mild	Warm	Mild	Mild
Solar radiation	High	High	High	High	High
Fertility	Low	Low	Low	Low	Low
Drainage	Imperfect	Imperfect	Imperfect	Well	Moderate-well
Slope˚	6.9	2.9	0.8	13.6	7.9
Water deficit (annual)	Low	Low	Moderate	Low	Low
Vapour pressure	Moderate	Moderate	Moderate	Moderate	Moderate

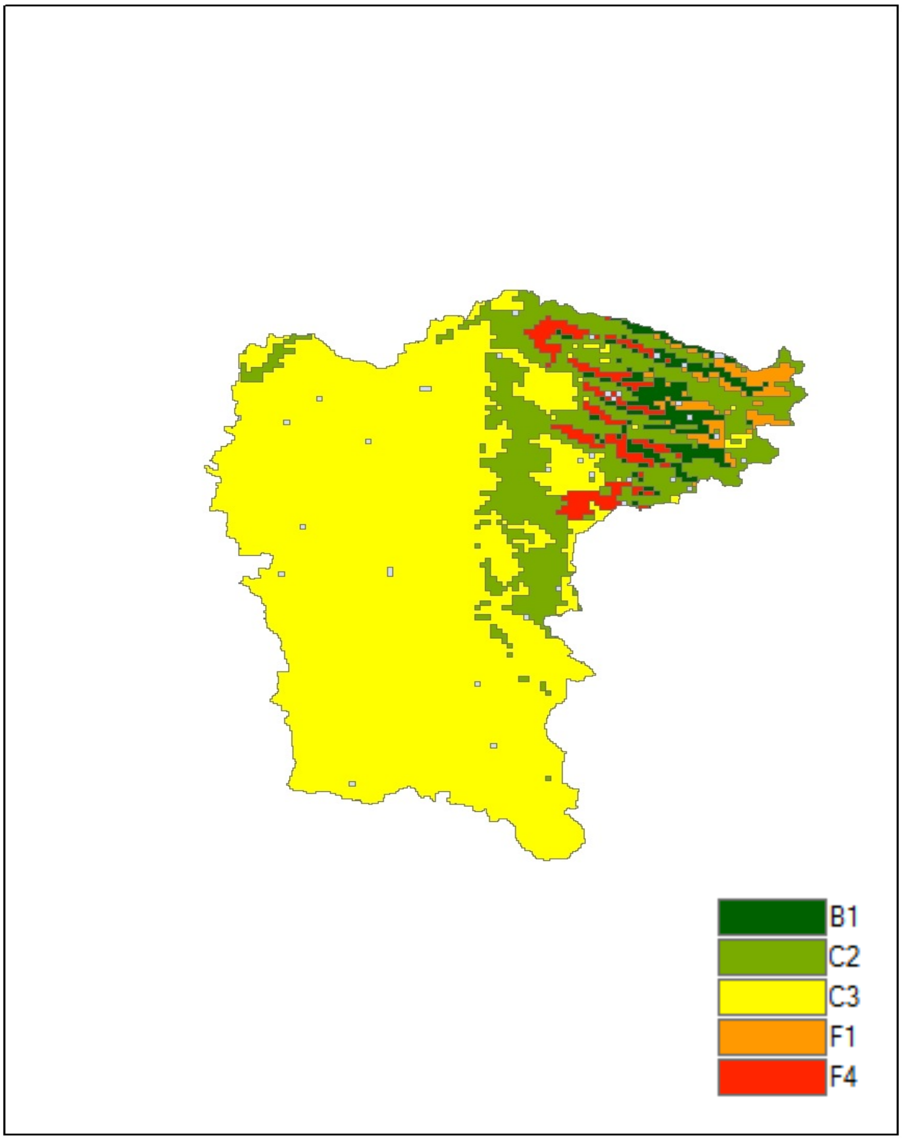

Figure 22. Land environments of level two.

Vegetation inventory

LRIS provides an indication of land cover and its homogeneity. The catchment is predominantly categorised as homogenously P1 in dark green (high producing, improved pasture), also including areas of high producing, improved pasture combined with L1 (cereal crops), or L3 (root & green fodder crops). The upper catchment is mostly P2, in orange, considered low producing unimproved pasture (Figure 23.).

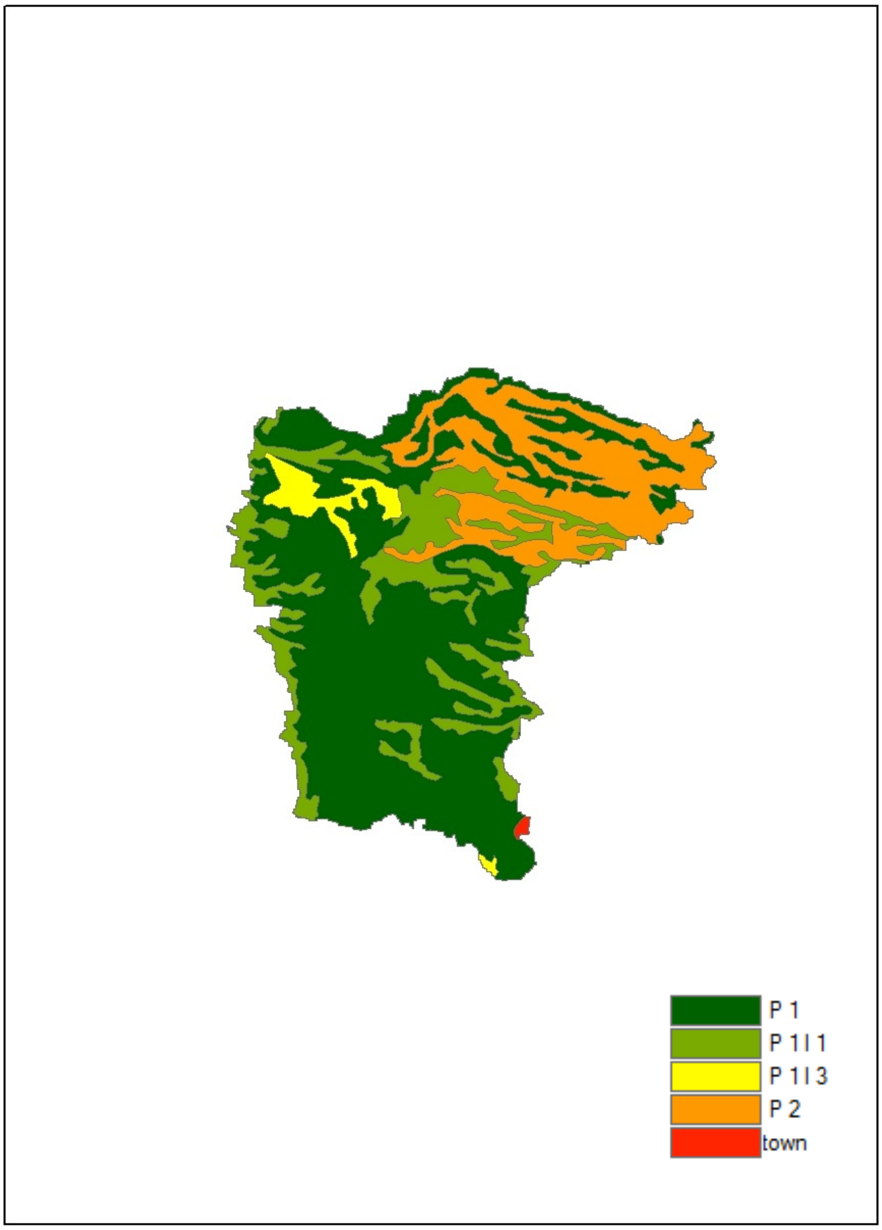

Figure 23. Land coverage and homogeneity.
P1= high producing improved pasture (dark green), P1L1= high producing improved pasture and cereal crops (light green), P1L3= high producing improved pasture

Human Pressure

Human pressure exerted on the area was estimated by FENZ, calculated using the MinimumSum method of Leathwick et al. (2007). The effect of human activities on the area is estimated with a minimum value of zero and a maximum of one. The highest human pressure is predicted to occur in the upper catchment (0.624), with much of the catchment showing slightly less pressure with an index of 0.593. This indicates the human pressure on the catchment is significant, but not extreme. The variation in human pressures through the catchment is low (Figure 24.).

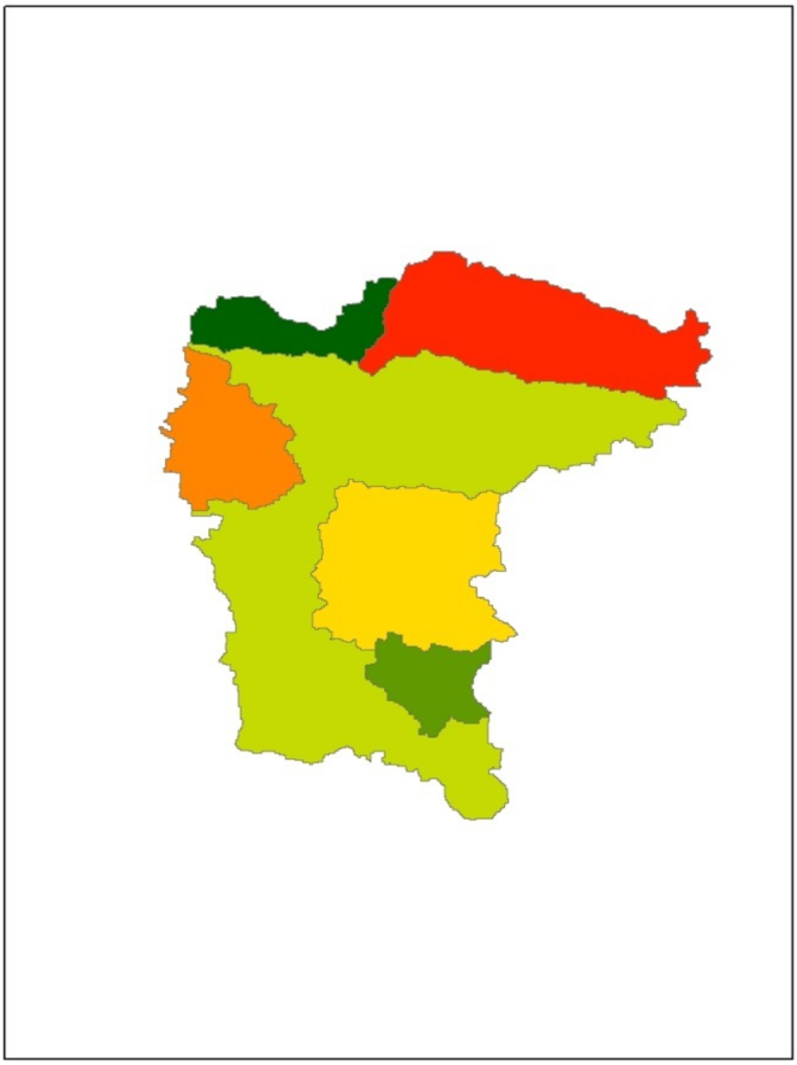

Figure 24. Average human pressure.
The pressure index increases with increasing brightness in colour, varying from dark green (0.567) to red (0.624), showing humans have the most impact in the upper catchment.

Lentic areas
Still-watered wetlands and lakes produced by FENZ; one wetland area depicted by an X on the topographic map has not been picked up here.

The one wetland area (small central body, Figure 25.) shown in FENZ, considered most likely a swamp (p=0.64), but may be a marsh (p=0.48) with a location of 1,814,016.858m by 5,548,272.827m according to ArcMap. There are three water bodies FENZ considers lakes in the catchment, the long, thin centre lake having a residence time of 35.6years, which may be useful in future monitoring, while the other lakes have too higher residence times.

Figure 25. Lake and wetland environments.

Google Earth

Erosion
The upper catchment was mapped and areas of rilling, gullying or landslides with little or no vegetative support were identified in red. This mapping provides an indication of where erosion control for hill slopes would be useful and shows which areas are worse affected and could be prioritized (Figure 26.).

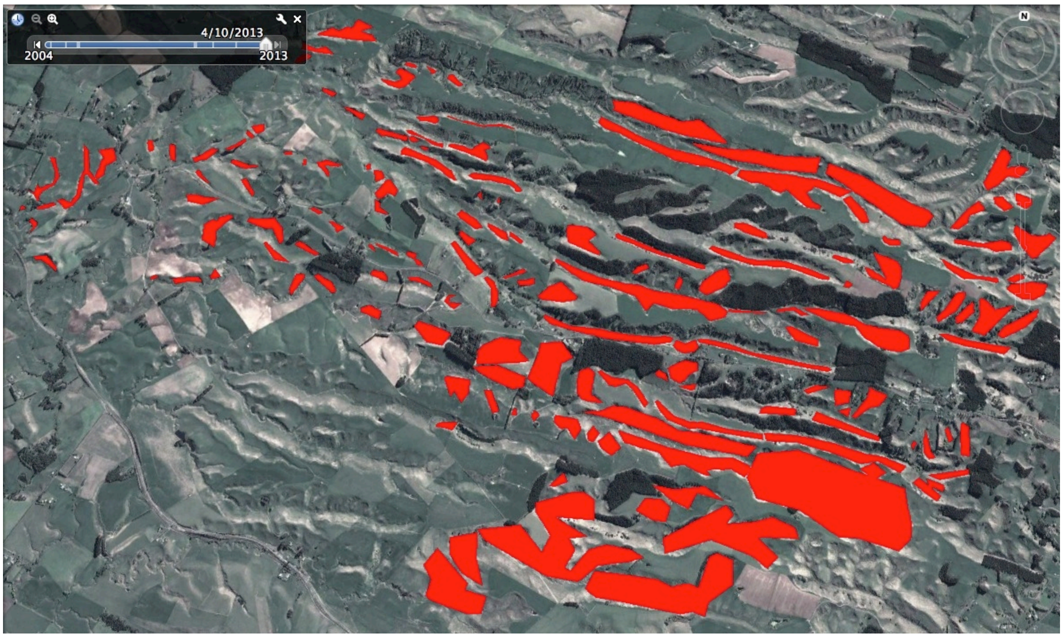

Figure 26. Google Earth with hillslope instability in red.

Riparian shade

Riparian shading was estimated at reach scale using Google Earth, with the main channel shading considered also during fieldwork for alignment. As with the riparian shading predicted by GIS, the shade at reach scale shows a general trend of increasing shade with distance downstream (for the main channel). This is observable from in the Google Earth images below (Figures 27. to 31.). The colour scheme of the waterways depicts the level of riparian shading; red indicates little to none, yellow indicates some to moderate, and blue indicates moderate to heavy shading. Both sides of the streams' riparian planting is taken into account, along with the change in shading with season (some plants provide little shade over winter, such as Willows). The map shows the shading of the upper catchment (Figure 27.) and tributaries is rather poor, this will be influencing water quality and erosion.

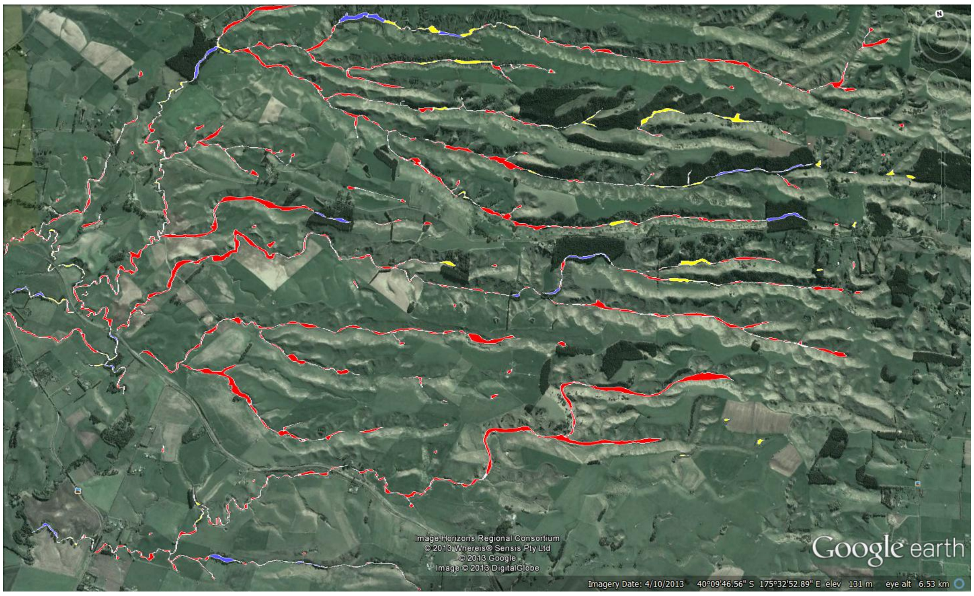

Figure 27. Upper catchment riparian shade.
Red= little to none (0-30%), yellow= some to moderate (31-60%, blue= moderate to complete (61-100%).

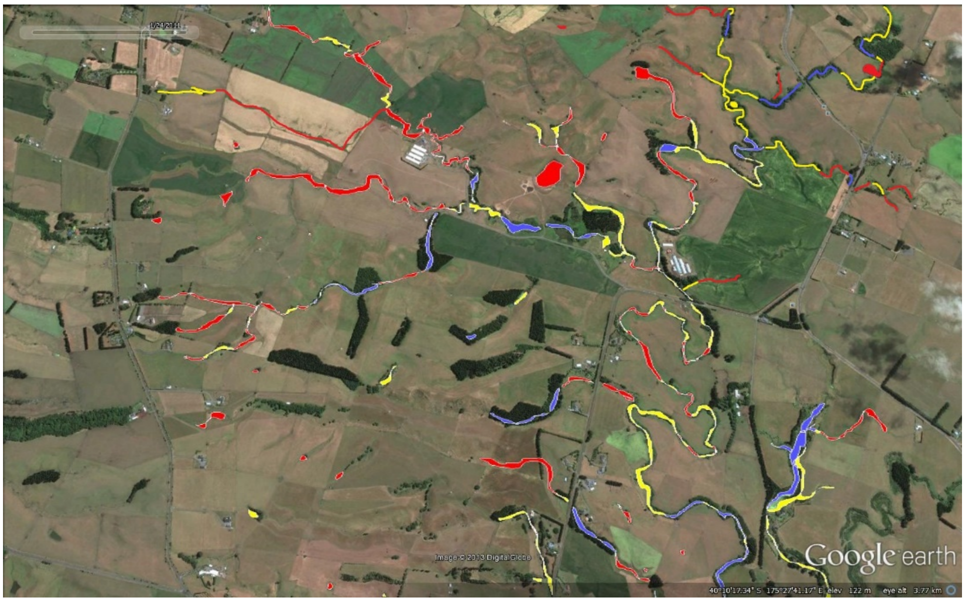

Figure 28. Mid catchment riparian shade.
Red= little to none (0-30%), yellow= some to moderate (31-60%, blue= moderate to complete (61-100%).

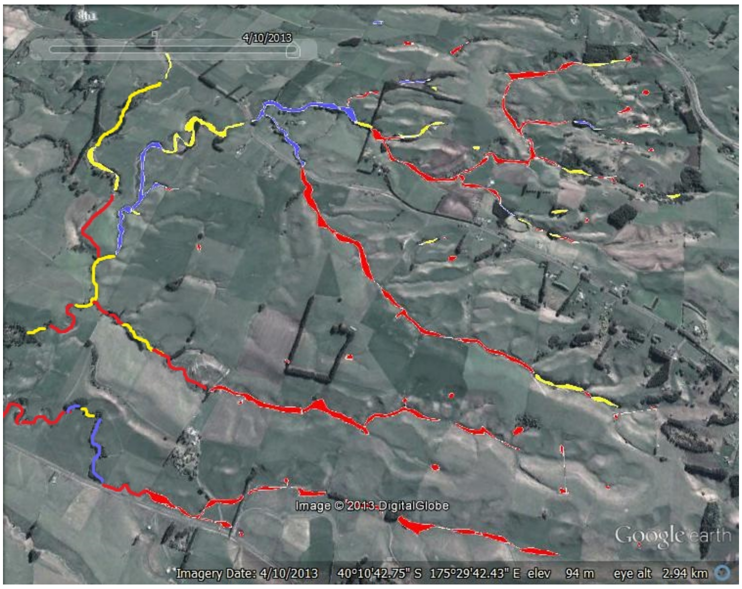

Figure 29. Mid-east catchment riparian shade.
Red= little to none (0-30%), yellow= some to moderate (31-60%, blue= moderate to complete (61-100%).

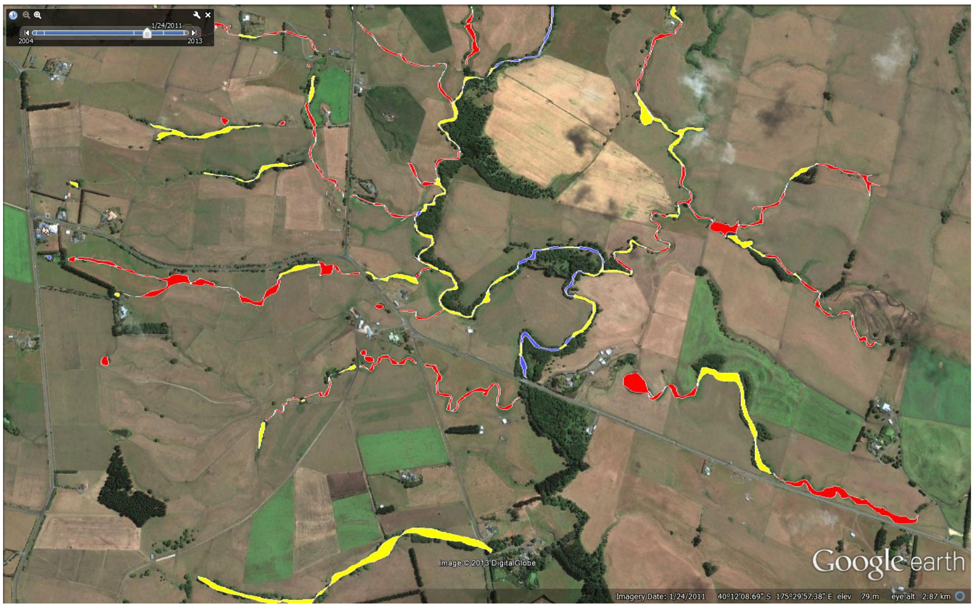

Figure 30. Mid-lower catchment riparian shade.
Red= little to none (0-30%), yellow= some to moderate (31-60%, blue= moderate to complete (61-100%).

Figure 31. Lower catchment riparian shade.
Red= little to none (0-30%), yellow= some to moderate (31-60%, blue= moderate to complete (61-100%).

Willows

Willows were mapped on Google Earth and represented in white patches (Figure 32.). These were then confirmed by sight during fieldwork sampling. Willows are an issue in the catchment as they are causing some change in channel morphology. The trees on the channel side often have limbs break off which end up causing some damming downstream, this leads to lateral erosion and stream widening, reducing farm owner land adjacent to the waterway. The build-up of debris can also interfere with flow dynamics, reducing flow in the area and increasing the vulnerability to flooding during high rainfall events. Willows growing from within the channel can also cause significant channel alteration as the water is forced around the tree or large debris causing eroding or scouring of the stream banks or streambed adjacent to the willow.

The majority of willows were growing excessively in the lower catchment, as well as a significant patch near the middle of the catchment, seen in the top of Figure 32. The occasional willow in the upper catchment was present along the streambank, however the scale of impact was far smaller. In the mid-upper catchment where the railway (Figure 19. red x) overpasses the main waterway also had willows which were impacting flow dynamics. The railway bridge meant the channel was confined, the willows immediately upstream of the bridge further slowed down and displaced water. The area immediately upstream was boggy and water extended far around the main channel path, causing loss of some productive land especially during wetter seasons, it however may act somewhat as a nutrient and sediment sink for the upper catchment.

Figure 32. Willow presence.
Willows marked in white.

Fieldwork

Geomorphologic aspect

The planform of the Mangaone West stream is meandering; this was clear during fieldwork from the winding path it follows. As one would expect there was more evidence of landslides in steeper terrain, mostly in the form of scars. Bank erosion was expected downstream of bends, however, in the more strongly meandering lower catchment this was less evident due to riparian planting and more cohesive banks. Little work has been done with regard to river engineering.

Bank erosion

Some incision was apparent in the upper most of the catchment, along the ephemeral waterway where site one was located. This was most likely due to the waterway's damming, which had been constructed using earth bunds. Small culvert outlets at the downstream end of the dammed area forced increased flow pressure and velocity. The increased stream power allowed the scouring of the waterway and erosion of banks immediately downstream of dammed areas. The waterway is very small, around a foot wide, and ephemeral, so the erosion is very localised.

Further downstream, beginning just before Mangaone road bank erosion becomes discernible at bends and where stock have trodden down to the waterway. As there is a higher volume of water and the gradient to allow higher stream power during higher flows, the bends become eroded on the outside edge late in the corner. This was apparent from freshly slipped banks showing exposed fresh soil. This continues downstream until near the railway crossing where a wetland area exists, slowing the flow down. Banks become more stable and cohesive, most likely due to increased riparian cover and fencing of the riparian area to exclude stock. Bank erosion is then much less observed.

Toward the stream's confluence with the Makino, cut-offs become apparent from abandoned and partially abandoned riverbeds as the main flow continues in a more straightforward direction. Stream power has increased significantly due to the higher volume of water and the lessened riparian cover on and around the banks. The bends have eroded to a point where the sinuosity of the waterway is so high that under heightened flow the stream power is high enough to cut off the old pathway as the bends meet.

Willows were also a problem throughout much of the catchment (demonstrative photo in appendix E) causing erosion around areas where fallen branches and trees had become lodged. Scouring around such areas widened the waterway and probably affected flow velocity. Branches that hadn't become quickly lodged would travel downstream where some collection of branches would build up and have a similar effect. The stream is too small for willows to be appropriate as a riparian plant.

Hillslope erosion

Landslides were only apparent in the upper catchment where the slope was steep. The headwater area where site one was positioned had minor landslides and some significant scars from previous years, likely triggered by high rainfall events. Minor rilling and gullying was also evident in the headwaters, particularly where there was less vegetative hillslope coverage. The valley-floors' slopes were steep in the upper catchment, so rills occurring on the hillslopes perpendicular to water flow were therefore not exacerbated; this gave the upper catchment its different drainage pattern (trellis) to the rest of the typical dendritic patterned catchment. Sheet erosion, while difficult to see and examine in the field, was likely a prominent form of erosion in the headwaters as the steep slopes would allow the movement of much topsoil downhill into the valley floor and waterway.

Engineering in-stream

There are five bridges the Mangaone West main channel passes under. Directly upstream of site two is a bridge-like culvert, as the waterway is seasonally active here and little water is present in the channel, excluding flood events. The bridge causing the most noticeable change to flow dynamics is the railway bridge, in the mid-upper catchment. The waterway is confined between the bridge support beams and willows in stream cause flow to reduce, and pooling upstream of the bridge. The confinement between the bridge beams may be causing some local streambed scouring, however the main concern is the pooling and inundation immediately upstream. This could be improved by the removal of the willows adding to the congestion.

Immediately upstream of site three is a concrete weir, accompanied by a small culvert to let water through during normal flow. The concrete ramp remains above water level unless there is high flow, during which heightened water levels allow flow downstream. This is important, as during high flow the culvert would be insufficient to avoid flooding. The structure has been put in place to retain and slow water, forming a pond, likely to provide extra water resources during drier months. As it is not near a residence it is unlikely to be to provide aesthetic value, though it may attract some wetland fauna. The flow is definitely locally reduced from what would be its normal regime, but the flow remains relatively slow-moving for a long way downstream as well, where its effect would be negligible. This may be due to the meandering nature of the Mangaone West stream.

Water quality

Water quality parameters tested against distance downstream showed varied responses, some showed distinct patterns and responses (invertebrate sampling, sediment coverage, shading), while others appeared to have no association (nutrients). The averaged data is displayed below (Table 2).

Table 2 *Mangaone West sites and the biophysical parameters assessed.*

Site	Distance downstream (Km)	Mci	Qmci	% Sediment Adjusted	% Shade	Total Oxidised N03 (g/m)	DRP (g/m)
1	2.5	75	3.0	100	3.33	0.055	0.075
2	7.0	63.1	2.2	63	13.33	0.007	0.042
3	10.4	77.6	4.2	77	13.33	0.068	0.036
4	13.8	74.4	4.2	45	26.67	0.153	0.066
5	18.4	80	4.2	52	43.33	0.142	0.058
6	22.3	94	4.7	57	63.33	0.090	0.039
7	28.0	89.7	4.8	28	65	0.081	0.050

Invertebrate sampling

The MCI and QMCI indices increased in scores with distance downstream (Figures 33. & 34.). There was a significant relationship with distance downstream and MCI, as well as QMCI from the regression analyses. The R-squared value of MCI with distance downstream was 0.447, with a P-value of 0.001, when data was average prior to regression analysis the R-squared value was 0.648, P-value 0.029. The R-squared value of QMCI with distance was 0.575 and the P-value of less than 0.000, when sites were averaged prior to regression, the R- squared was 0.672 and the P-value 0.024. As the P-values are significant (<0.05), both MCI and QMCI are shown to have a relationship with the distance from the headwaters, however, as QMCI has the higher R-squared value QMCI scores appear to be better related to distance downstream.

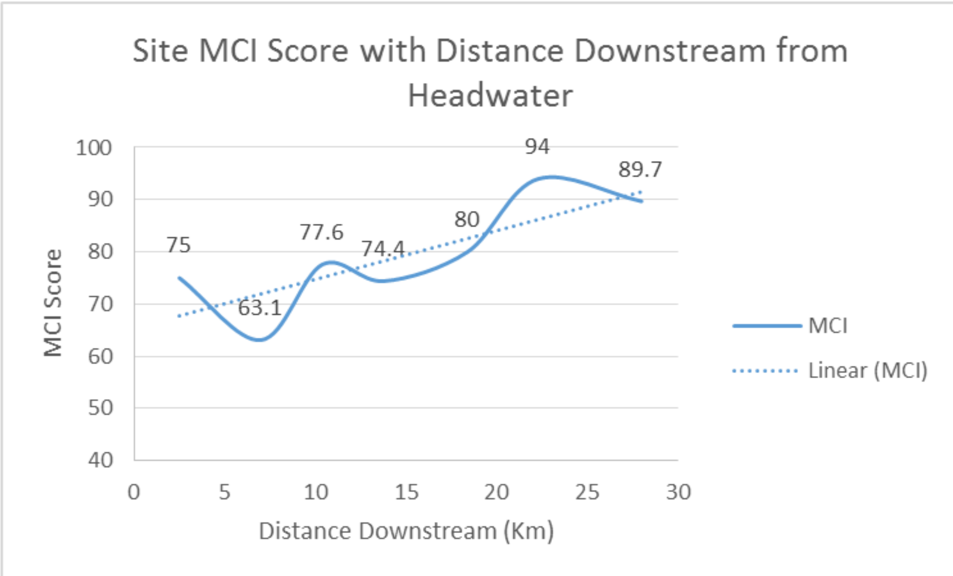

Figure 33. Average MCI index score.

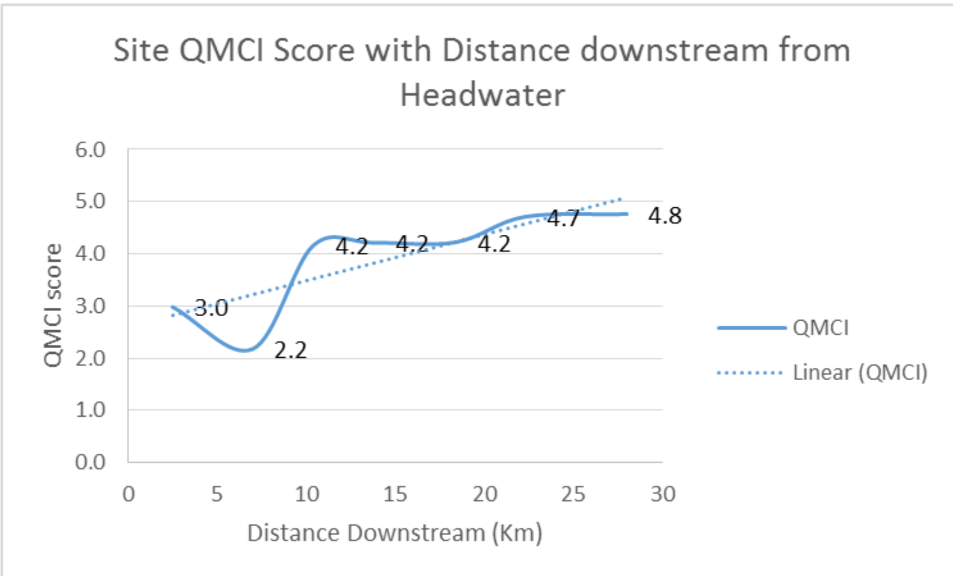

Figure 34. Average QMCI index score.

Chemical sampling

Nitrogen

Nitrogen levels (total oxidized $NO3^{-}$-N) were much higher than anticipated from the GIS nitrogen modelling (predicted ~0.002-~0.004g/m^3 throughout the entire main channel), however none of the sites exceeded the recommended drinking water concentration guideline of 11.3 g/m^3 ($NO3^{-}$-N) (Ministry of Health, 2008; Rosen, 1996), or recommended concentration levels to prevent algal growth 0.167g/m^3 (>150m), 0.444g/m^3 (Australian and New Zealand Environment and Conservation Council (ANZECC) & Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ), 2000). This implies agricultural practices may be having an impact, likely through stock presence and potentially nitrogen-based fertiliser use, but the effect on nitrogen concentration is not severe. There appears to be a loose relationship between the nitrates and distance downstream, with nitrates increasing slightly with distance downstream; the R-squared value for total oxidized nitrates was 0.191 with a significant P-value of 0.0475 (>0.05). When site values are averaged before the regression analysis no significant relationship is clear (R-squared value of 0.192, P-value >0.05). There was a peak in concentration at sites four and five (13.8 and 18.4Km downstream) of 0.153g/m^3 and 0.142g/m^3 (Table 3, Figure 37.). Nitrite concentrations were omitted as they were extremely low throughout the catchment, to the point where the lab could by in large not accurately report the concentration <0.005g/m^3.

Due to the unexpectedly low results in the top of the catchment, compared to the rest of the catchment a resample was taken; total nitrogen and ammonia were included, with no repeat samples taken at the site due to costs of lab analysis. These samples were taken with the intention of understanding better the low oxidized nitrogen levels. These samples were taken again at a time where there had been no excessive rainfall in the previous days, on 15/09/2014. These samples showed total nitrogen to be present in large quantities, particularly in the upper catchment, at concentrations which exceed Waikato Regional Council's (2014) eutrophication guideline (0.5g/m^3), and the ANZECC & ARMCANZ (2000) trigger value of 0.295g/m^3 (>150m), and 0.614g/m^3 (<150m) (2000), by up to an order of magnitude (table. Figure 35.).

Only the top two sites of the catchment are considered upland under ANZECC & ARMCANZ (2000), upland and lowland are assigned different trigger values, so both are included. Total nitrogen showed no relationship with distance downstream, the R-squared value was low and the associated p-value was insignificant at 0.222.

Ammonia, at almost all sites, also exceeds maximum guideline concentrations of $0.01 g/m^3$ and $0.021 g/m^3$, upland and lowland respectively (ANZECC & ARMCANZ, 2000). Ammonia peaks at site four, at an order of magnitude higher than previously. This is likely due to the wastewater inputs of the piggery directly upstream (Figure 36.). There was no trend in ammonia with distance downstream, the regression analysis gave a low R-squared value and an insignificant p-value of 0.800.

Table 3 *Mangaone West sites and associated nitrogen concentration.*

Site	Distance (Km)	NH4 (g/m^3)	Total N (g/m^3)
1	2.5	0.022	1.2
2	7	0.014	3.2
3	10.4	0.014	0.6
4	13.8	0.14	0.8
5	18.4	0.03	0.6
6	22.3	0.056	0.75
7	28	0.022	0.54

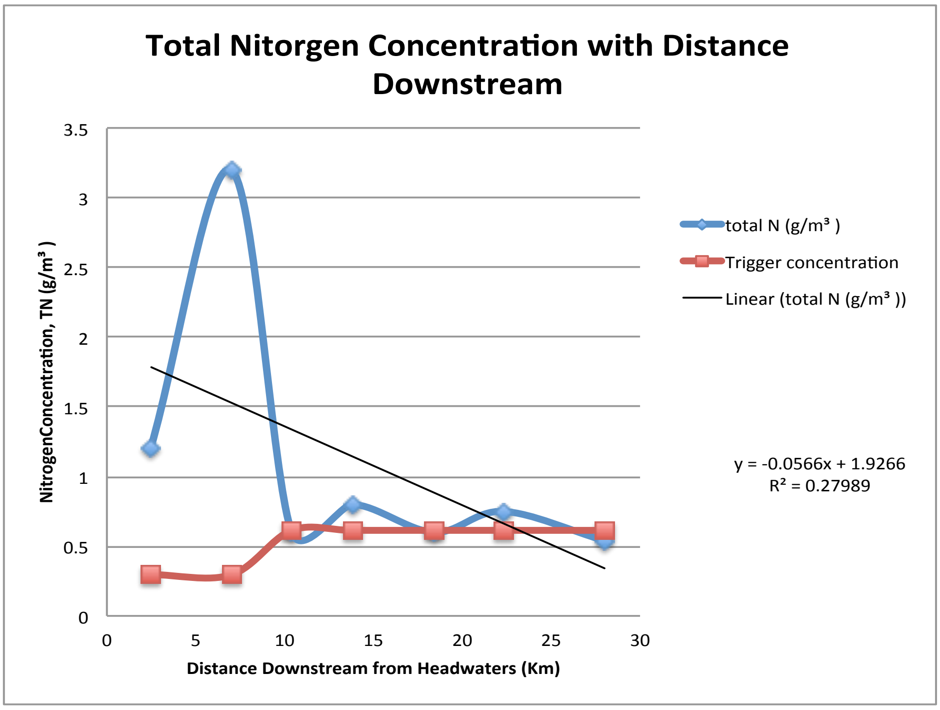

Figure 35. Total nitrogen concentration.
Trigger concentrations of nitrogen as stated in ANZECC & ARMCANZ (2000) for water quality (red).

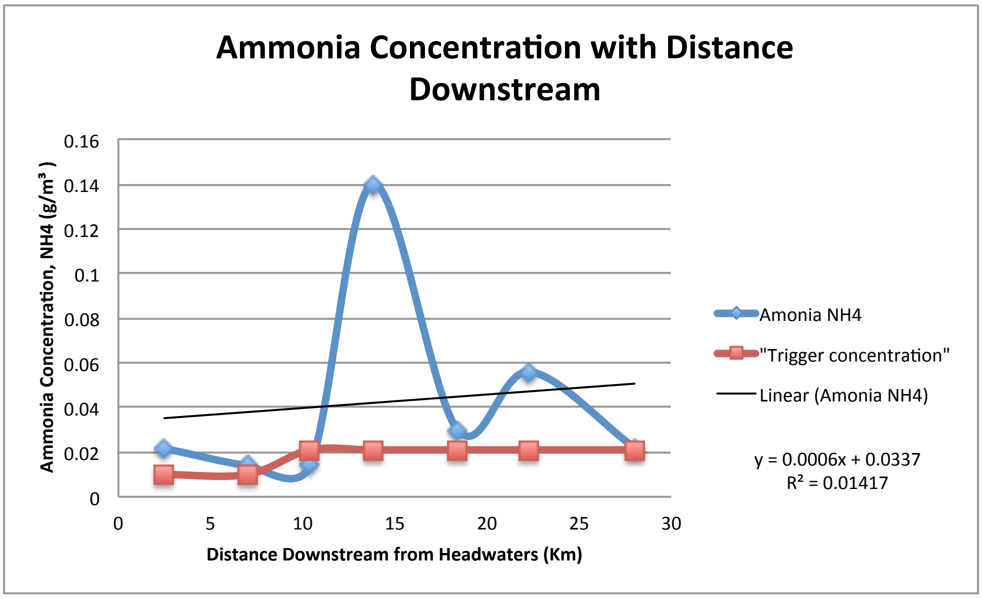

Figure 36. Ammonia concentration.
Trigger value for freshwater quality decline (red) (ANZECC & ARMCANZ, 2000).

Phosphorous

Dissolved reactive phosphorous (DRP or PO4) showed concentrations above 0.009g/m³ (upland, sites >150m) 0.01g/m³ (lowland, <150m) the recommended guideline concentration protection value (ANZECC & ARMCANZ 2000), and most concentrations were above 0.04 g/m³ which is considered undesirably nutrient-enriched (Waikato Regional Council, 2014). There was no relationship apparent with DRP concentration and distance downstream from the headwaters when raw data was analysed and when data was averaged before analysis (respective R-squared values of 0.068, and 0.102, P-values >0.05) (Figure 37.). As phosphorus is often soil-bound, high concentrations may indicate erosion in various forms, and run-off of fertilizer containing soluble phosphorus (Weiderholt, & Johnson 2005). Reactive phosphorous was omitted because concentrations were too low to be reported by the laboratory (<0.005g/m³).

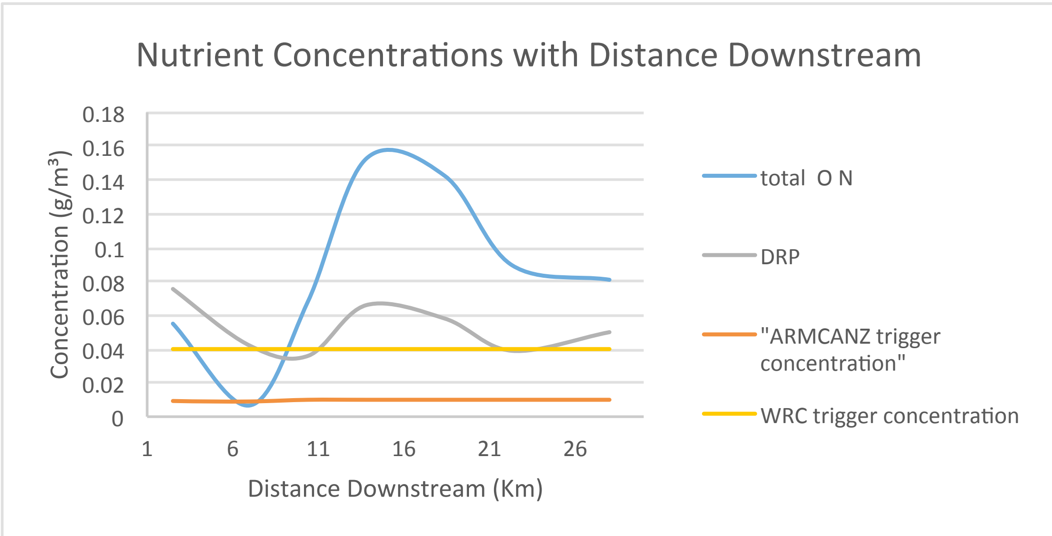

Figure 37. Averaged nutrient concentrations (ToN and DRP).
Trigger values for water quality impairment (ANZECC & ARMCANZ, 2000) and problem algal growth (Waikato Regional Council, 2014) are also included to highlight the unacceptable phosphorous concentrations (DRP). As total oxidised nitrogen levels are well below trigger values, the trigger values have not been included.

Physical sampling

Sediment coverage

Deposited sediment showed signs of decreasing downstream, however, site five, which had no riparian cover and no fencing for some considerable distance upstream, skewed the trend (Figure 38.). This outlier affected the results of the regression analysis; giving an R-squared value of 0.295 and a p-value of 0.011. With the outlier removed or modelled based on the rest of the data, the relationship between deposited sediment and distance downstream from headwaters was stronger, with R-squared values of 0.543 and 0.552 (respectively), and both with P-values <0.000. When site values were averaged before analysis, with the outlier included, the relationship is insignificant (R-squared 0.316, P-value >0.05). With the outlier data removed or modelled, the relationship is strong (R-squared values of 0.716 and 0.723, P-values 0.034, 0.015). It is unusual in a natural system for fine deposited sediment to decrease downstream; naturally sediment accumulates in the downstream direction due to increased sediment inputs with associated increased catchment size, and the reduced slope and thereby stream power to further transport large amounts of deposited sediment (Jowett & Milhous, 2002). It was expected that deposited sediment load would increase downstream, however, this was not the case and with the given outlier removed or modelled, sediment decreases significantly with distance downstream (P-value<0.05).

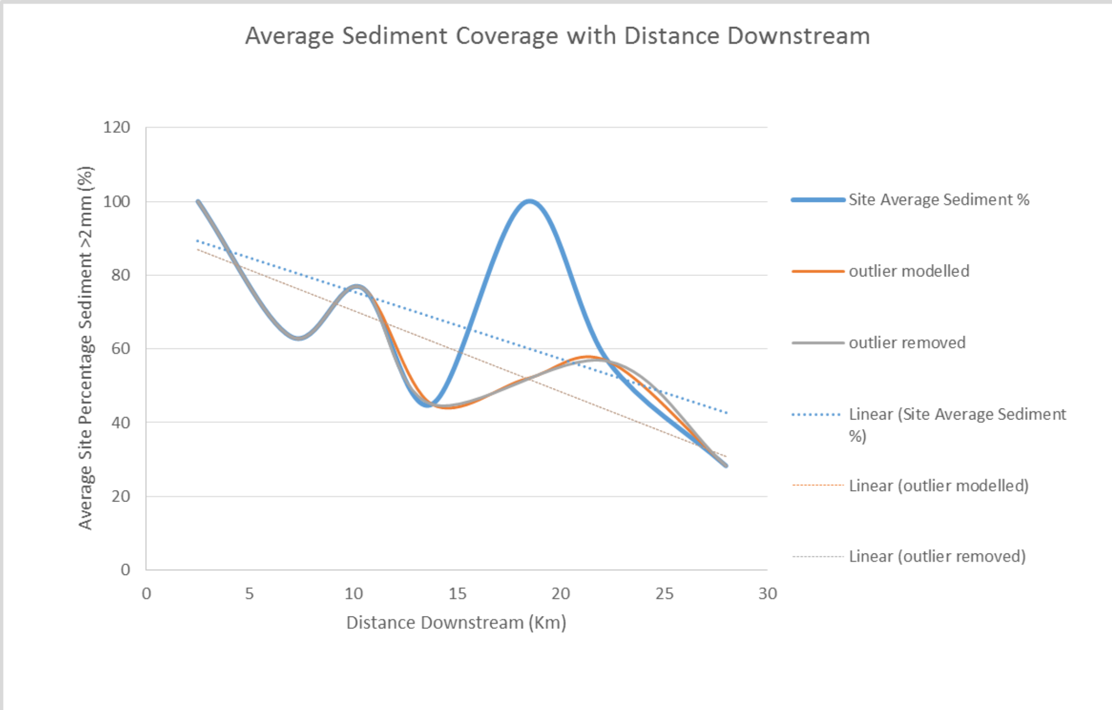

Figure 38. Average deposited sediment coverage.
Original data (blue), the outlier modelled by the trendline equation, (in red), and the outlier removed (green), along with their associated trendlines.

Habitat shading

Riparian shading of the sites increased with distance downstream, the regression analysis produced significant results with an R-squared value of 0.844 (0.946 when averaged before analysis) and a P-value >0.000 (averaged p-value the same) (Figure 39.). Until nearing site three, there was little to no riparian shading over the waterway; site one had only the shading from the grassy water bank and site two was much the same with a small amount of shading from trees directly upstream. While site three also had little shading immediately around it, riparian shading was becoming more common over the waterway. Site four was shaded partially from one side by willows and site five nearing 50% shading from willows growing out over the waterway. Site six was quite well-shaded with native riparian strips extending on both banks and site seven was again well-shaded from both banks, however with fewer native trees.

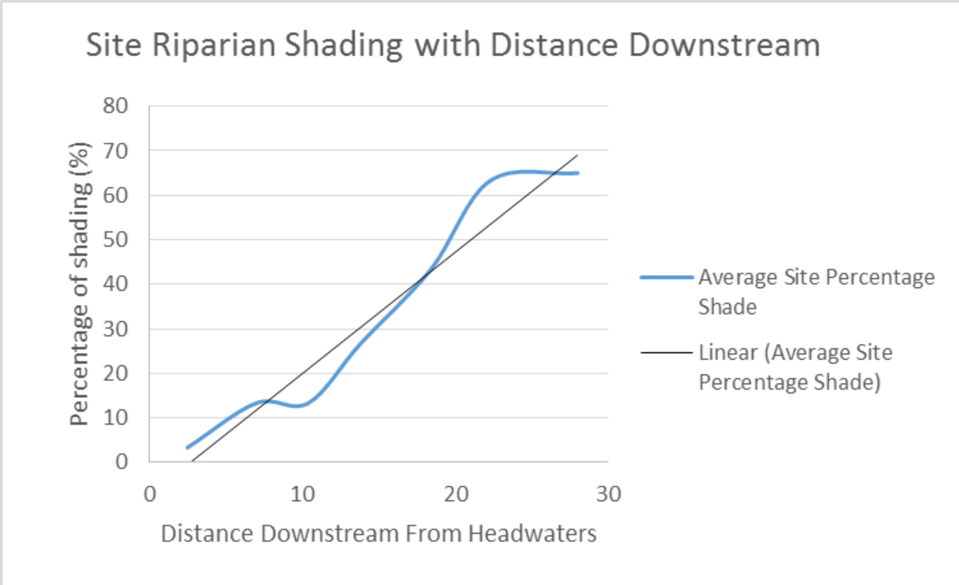

Figure 39. Average riparian shading.

Regression between sampled variables

MCI and QMCI both showed a significant relationship with shade (p-value<0.05), regression analysis of the site average values giving an R-squared value of 0.445 (p-value 0.001), and 0.406 (p-value 0.002) respectively. Both invertebrate indices shade increased with distance downstream, however, as the regression analysis assesses correlation not causation, it may be stipulated that increased shade coverage caused increased index scores, as more sensitive invertebrates inhabit cooler waters.

QMCI showed a relationship with total nitrogen, and total oxidized nitrogen (R-squared 0.792, p-value 0.007; R-squared .410, p-value 0.002 respectively), with increasing QMCI score associated with decreasing total nitrogen and total oxidized nitrogen. QMCI also increased with decreasing sediment (adjusted), with a low but significant R-squared value 0.258, p-value 0.019.

Adjusted sediment (adjusted to remove outlier) and habitat shading showed a significant relationship, with an R-squared value of 0.355 (p-value 0.004, <0.05). As sediment decreases downstream while shade increases, they exhibit an inverse correlation. The decrease in sediment is not due to the increase in shade, but is closely associated with it as the increase in shade is due to more extensive riparian plantings, which increase soil cohesion and filter out sediment, which would otherwise more likely reach the waterway, as it does in the upper catchment.

Weed and pest species

Weeds were mostly an issue in the lower catchment where there were more extensive non-pasture areas plants could proliferate, amongst, primarily, unmaintained native riparian vegetation. The significant weeds observed during fieldwork are important as a management issue. Photographs of the weeds found are available in appendix E.

Tradescantia

Wandering Jew was found through much of the lower catchment, and was proliferate and smothering areas of native forest on the left, downstream of site six. This invasive weed is the most extensively spread through the mid to lower catchment. Its tendency to blanket the ground means riparian seedlings have a lesser chance of surviving and growing to replace older generation trees (Dawson, Navie, James, Heenan, & Champion, 2010). Tradescantia is a priority weed to target for the benefit of the riparian margin, in particular the native areas and associated remnant bush.

Blackberry

Blackberry is another common weed amongst native bush, particularly in less dense and edges, it was found growing densely in a large retired streamside area in the lower catchment. This area could be turned into more native bush to aid the shading on that side of the stream; planting natives amongst the black berry could be a simple low effort option.

Banana Passionfruit

This is an aggressively fast growing vine that can smother plants and forest quickly (Dawson et al. 2010; Department of Conservation, 2014). A dense patch was found downstream, of site six, in an area of native forest. The hindrance on the stream edge to allow native regeneration may eventually cause bank stability reduction as older generation forest dies off.

Pondweed

Blunt

This is an endemic aquatic herb, common in shallow, turbid waters (National Institute of Water and Atmospheric Research, 2013). The thickness of one particular patch downstream of site six demonstrates the need for riparian shading, as the plant is densely clogging the waterway in an area of direct sunlight. As this is currently not an issue along much of the lower catchment some riparian planting may reduce its matted growth and congestion.

Curly

Introduced species with wide nutrient and flow tolerance range, exhibiting wavy leaf edges. Found in the mid and lower catchment in clumped areas (Champion, Rowe, Smith, Wells, Kilroy, & De Winton, 2012). This aquatic macrophyte can be of use filtering nutrients, but can also compete with native species and clog waterways through excessive growth (Guo, Haynes, Hellquist, & Kaplan, 2010). Again, once nutrient inputs and sediment (its preferred substrate) are reduced, and shade increased, the weed should not show excessive growth or alter flow dynamics.

Horsetail

Seen in mid-upper catchment around Halcombe Road, encroaching on pasture of the farm adjacent to the waterway. Also seen along roadside of Te Rakau and Lees road. This perennial weed spreads by rhizomatous roots and has proven difficult to control, therefore this should be proactively managed before becoming more of an issue in the catchment (Dawson et al. 2010; Department of Conservation, 2014).

Japanese Honeysuckle, and Periwinkle were also reported as present in the catchment, with localized effects of smothering likely where dense growth occurs (A. Cole, personal communication, July 5, 2014).

Existing information and data

Little information exists regarding the Mangaone West catchment environment and its waterways. One study conducted by a Massey University student cited references which cannot now be found, including a report by Horizons. During an overhaul of Horizons much of their older paper-based documents were lost. While this may have been useful information and reduced some efforts and time in research, the project is most likely not affected because a reference site has been used. However Horizons were able to provide some applicable flow and rainfall data.

Flow data
The flow exiting the Mangaone West as estimated by the Regional Council. There may be no actual flow monitoring of the Mangaone West; however, there is flow monitoring nearby upstream (Rata St) and gauging downstream (Boness Road) of its confluence with the Makino stream. As the Mangaone West is the only significant contributor of water between thes two points, the flow can be approximately estimated by deducting the downstream flow data from the pre-confluence upstream data. (raw data in appendix D).

From the 20 years of data (1992-2012) provided by the council, the mean annual flow (MAF) of the Mangaone West was estimated at 0.442m^3/s, roughly four times higher than predicted in GIS (0.144 m^3/s). MAF may be slightly overestimated as there is more land that contributes to the flow of the Makino at Boness Road than just the flow from the Mangaone West and the upstream Makino gauged flow, though the greater part of the difference may be attributed to the Magaone West stream.

Rainfall data
Raw rainfall data was provided by the council from their station along Halcombe Road. While the water collected drains into the Makino stream, the area is on the edge of the Mangaone West catchment. Complete data sets were used from the years 1999 through to 2012. Data was transformed for better visualisation: averages for both monthly and yearly, seasonal patterns are shown (Figure 40. & 41.). The average annual rainfall was 920mm/year; this provides some confidence in the GIS rainfall mapping by NIWA, as the station is near to the middle of catchment, and 920mm is well in between the maximum from the top of the catchment (965mm) and the minimum at the bottom (885mm). Over the years the average rainfall has not increased (R-squared 0.002, P-value 0.891), however it may vary widely from year to year as 2004 reported the highest rainfall of 1221mm and 2005 the lowest rainfall of 661mm. Seasonal variation in rainfall is significant; there is more rainfall in the winter and less in the summer (Figure 41.). The regression analysis of under a linear relationship was significant but not as strong as the relationship under polynomial fit (R-squared of 0.468 and 0.620).

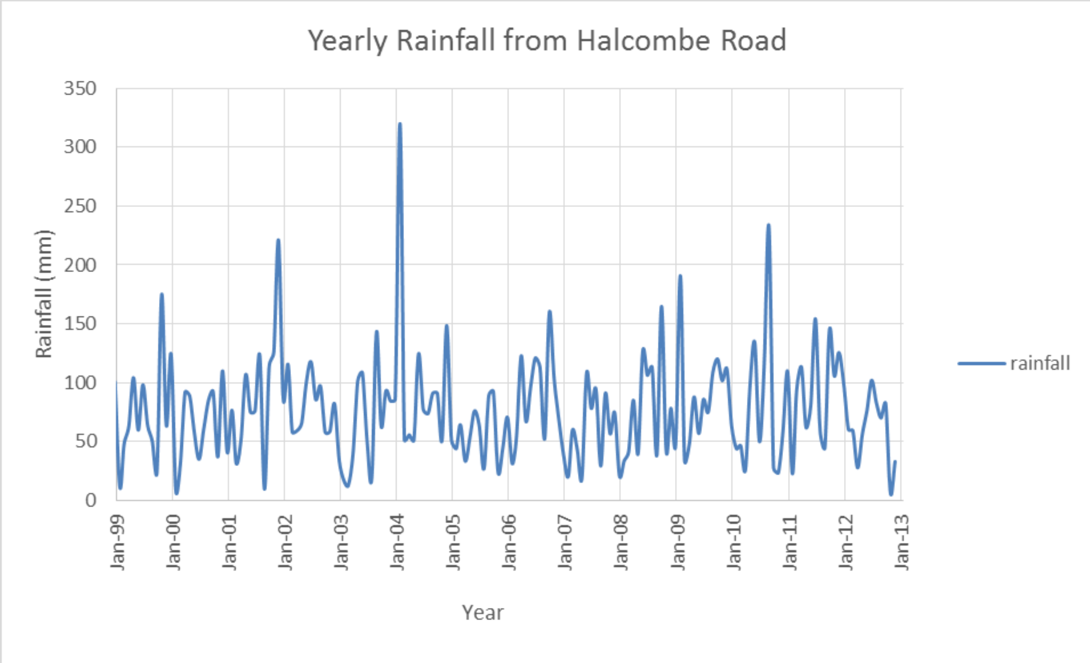

Figure 40. Average rainfall from 1999 to 2013.

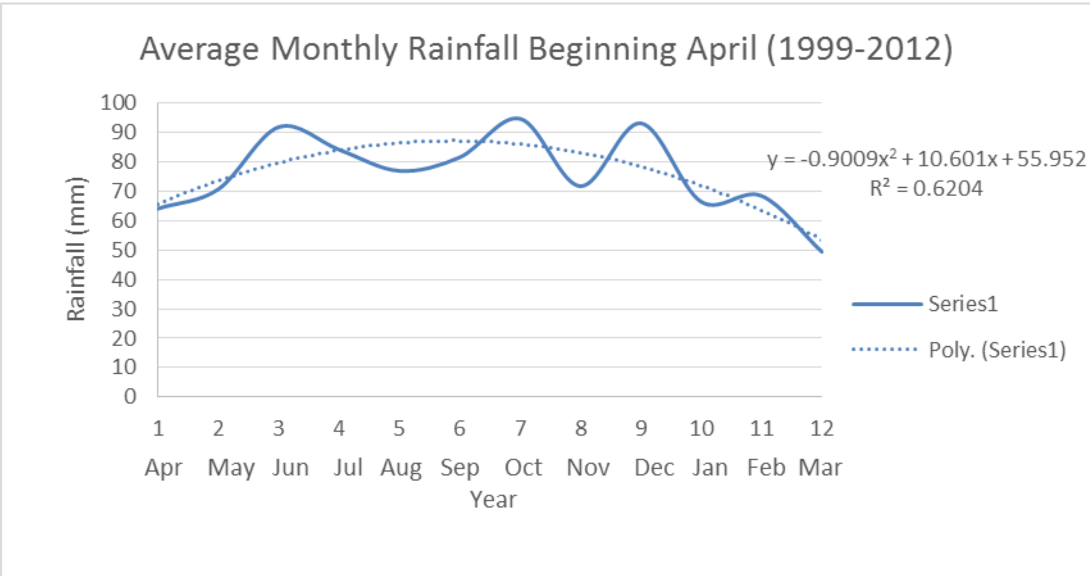

Figure 41. Average Monthly rainfall.

Reference stream

The upper Kahuterawa was selected as the undisturbed reference to comparison with the Mangaone West to assess degradation and make targets for improvements. This stream was selected due to its similarity to the Mangaone West's likely original state with much native forest and some forestry (Figure 42.). Although some of its geology is different, the altitude (~170masl); meandering stream; confinement-partial confinement-unconfined further down; the steep to rolling hills; small amount of human disturbance, forest coverage; and close proximity (under 40km), make the upper Kahuterawa a useful reference. The data for the Kahuterawa was provided by Horizons regional council, and is summarized below (Table 4).

Table 4 *Summarised water quality parameters for the upper Kahuterawa stream.*

Parameter	2013	2012	2011	2010	2009	**Average**
MCI	111	120	119	115	108	**115**
QMCI	5.6	6.6	7.3	7.1	5.4	**6.4**
Sediment (%)	3.7	16.5				**10.1**
TN (g/m3)	0.213	0.264	0.348	0.375	0.373	**0.315**
DRP (g/m3)	0.008	0.008	0.008	0.008	0.010	**0.008**
DO (%)	104	104	104	102	112	**105**

Figure 42. The upper Kahuterawa stream.

River styles assessment

River character and behaviour

Dominant land units mapped at catchment scale

Figure 43. is an estimate of land unit areas: borders or areas may overlap somewhat. The upper catchment is coloured yellow, including the plateaux (planar interfluves) and steep upland slopes. The lighter blue indicates foothills and rolling hill country with little valley floor. The aqua shows the area of valley floor and plain of the catchment and purple shows a lower floodplain, which fully develops near the base of the catchment.

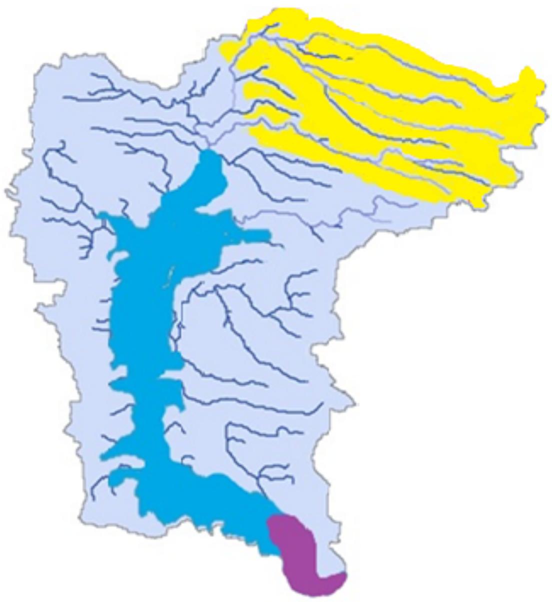

Figure 43. Mangaone West land units.
The steep headwaters = yellow, the foothills = light blue, the valley floor = aqua, and the lower floodplain = purple.

River styles tree

The river styles tree below (Figure 44.) visually depicts the process of assigning river styles; this too was carried out following the steps used in Brierley and Friyrs (2005). The end points show the river styles result. The characteristics of the different river styles are also presented below, providing further information about the different river style types occurring in the catchment (Table 5).

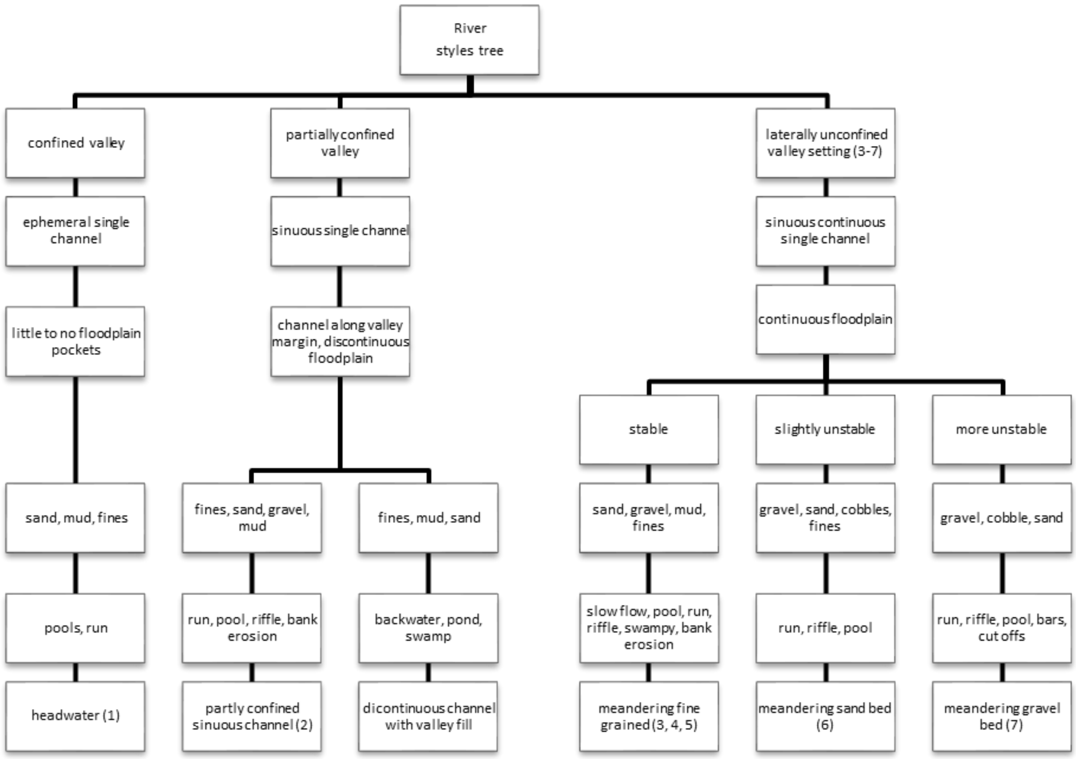

Figure 44. Mangaone West River styles tree.

Table 5 *River styles and description of character.*

River style (site)	Landscape unit/valley setting	Channel planform	Geomorphic units	Bed material/ texture	River behaviour
Headwater (1)	Confined/ uplands	Straight single channel	Run, pool	Fines, sand, mud	Narrow, young valley, ephemeral, straight due to setting, mostly slow flow with some pooling and swamps (due to earthbunds), stepped ponds. More sediment than naturally expected
Partly confined sinuous channel (2)	Uplands, rounded foothills, partially confined	Sinuous/ meandering single channel along valley margin	Discontinuous floodplain, pool riffle, run	Fines, sand, mud, gravel	Widening valley floor, channel butting valley margin with bank erosion occurring. Deposited sediment levels remain high, transport inefficient
Discontinu ous channel with valley fill	Alluvial fill, semi confined valley floor	Discontinuous sinuous, single channel	Pooling, backwater, run	Mud, fines, sand	Flow dissipates from headwaters, base of all upland tributaries, sediment deposition and sweeping channel partially present, reconfined at swamp end due to bridge
Meanderin g fine grained (3 4, 5)	Unconfined rounded foothills	Single highly sinuous channel meandering, relatively stable	Continuous plain, run, pool, riffle	Sand, gravel, mud, fines	Sinuosity increased, single meandering channel, no observed abandoned channels/cut offs, some likely to occur in future. Valley floor wider, flow remains slow in some areas, has flow year-round.
Meanderin g sand bed (6)	Unconfined valley, lowland plain	High sinuosity, slightly instable single channel	~90% Continuous plain, run, pool, riffle	Gravel, sand, fines, cobble	Transfer of sediment much more efficient, strong meandering with cut offs/abandoned beginning shortly downstream, wide valley with further lowland floodplain beginning.
Meanderin g gravel bed (7)	Unconfined valley, lowland floodplain, alluvial	Highly sinuous, loses more stability, single channel	Continuous floodplain, run, pool, riffle, bars, cut offs	Gravel, cobble, sand	Sediment transfer more efficient compared to uplands, more active meandering with many abandoned channels seen, more natural function occurring

River styles cross-sections

Cross sections of river styles for each type were creatd using a representative site (Figure 45.). The corresponding fieldwork site(s) in the catchment are noted. The cross sections provide a view that allows better understanding of characters such as planform constraints, and show visually the changes in style down stream.

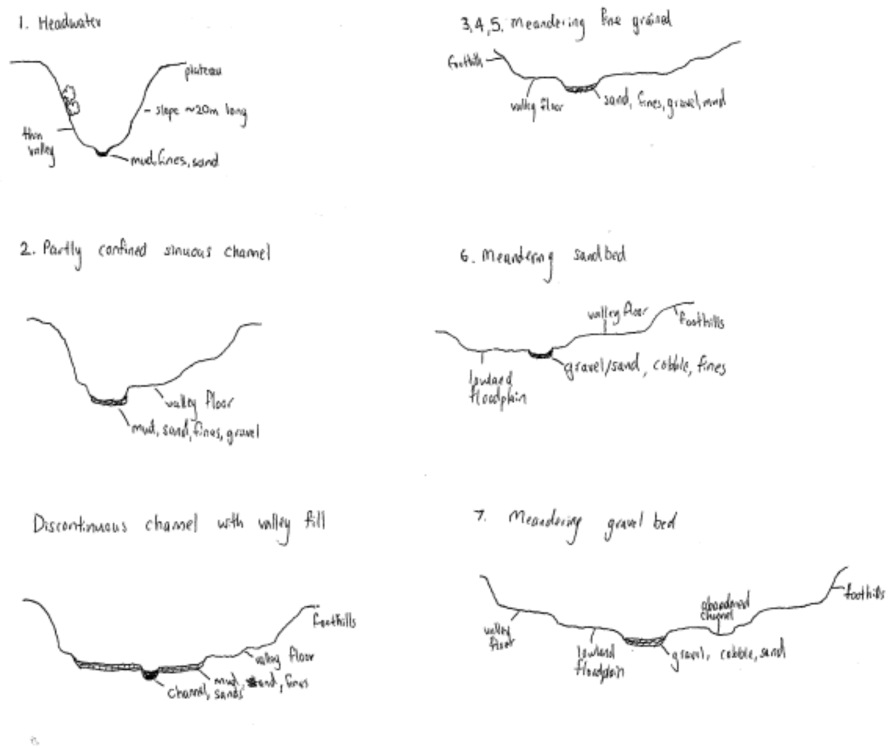

Figure 45. River style cross sections.

Downstream flow of river styles

The stages of river styles change downstream through the main channel. The six different styles from headwater reach to convergence with the Makino occur in a linear fashion (Figure 46.).

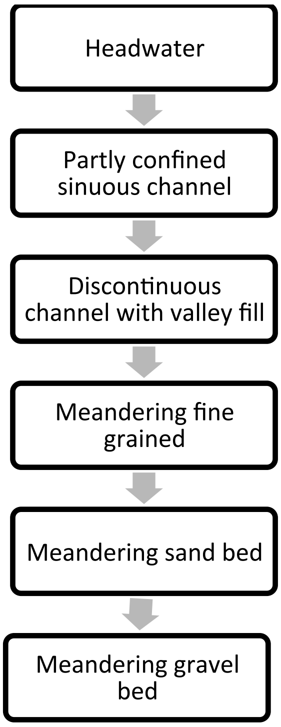

Figure 46. Linear progression of river style downstream.

Mapped river styles

The mapped river styles of the Mangaone West progressing downstream, with estimates of style change (Figure 47.). Each bold colour represents a different river style: blue represents headwater; yellow represents partially confined sinuous channel; orange represents the swamp (discontinuous channel with valley fill); green represents meandering fined grained; aqua represents meandering sand bed; lastly, purple represents meandering gravel bed. Alternate tributaries aren't mapped due to constraints of assessing all the waterways, which are mostly ephemeral. The upper catchment tributaries are visibly all straight and constrained, with mid-lower catchment tributaries being mostly sinuous and constrained, while a couple of the third to fourth order tributaries become sinuous and partially constrained.

Figure 47. River styles catchment context map.

Geomorphic condition

The lack of historical data pre-disturbance (clearance) means comparing the Mangaone West to its original character is more challenging, though the waterways are likely to have been the same in direction, according to Jackson, Dissen & Berryman (1998). The capacity for adjustment is determined by channel attributes, planform, and bed character (Table 6). Capacity for adjustment and sensitivity are important in identifying restoration plausibility.

Table 6 *The estimated capacity of Mangaone West river styles to adjust to change.*

	Ability to adjust			
Riverstyle	**Channel attributes**	**Planform**	**Bed character**	**Capacity for adjustment/sensitivity**
1. Headwater	Some (veg)	N/A (Natural)	Some (reduce sed load)	**Limited**
2. Partly confined sinuous	Some (veg)	Natural-little	"	**Moderate**
Discont channel valley fill	Some (veg)	Natural-little	None-little	**Low/Limited**
3. Meandering fine grain	Some (localized)	Some	Some	**Moderate**
4. Meandering fine grain	Significant	Some	Significant	**Moderate-high**
5. Meandering fine grain	Significant	Significant-some	Some	**Moderate-high**
6. Meandering sand bed	Some	Significant-some	Some-significant	**Moderate-high**
7. Meandering gravel bed	None-little	Some	"	**Low-moderate**

River evolution

In this step the original geomorphic condition is compared to the current condition in an attempt to identify if irreversible change has occurred. It also allows the formation of a geomorphic reference condition to be later used for restoration. As the Mangaone West has little historical information, ergodic reasoning, or location for time subsidy, is used. A comparable stream (Kahuterawa upstream) and downstream in the Mangaone West system were used to best evaluate the evolution and changes. This meant the results were a limited predictor and mostly provided indication rather exact knowledge of change. The removal of riparian vegetation and intensified land use means the most likely changes are increased sediment loads, resulting in general aggradation of previous wetted channel, and wetted channel width decreases along with depth increases. Notes of more detailed likely changes are contained below within Figure 48. The timeframe from one cross-section to the next is roughly 100 years.

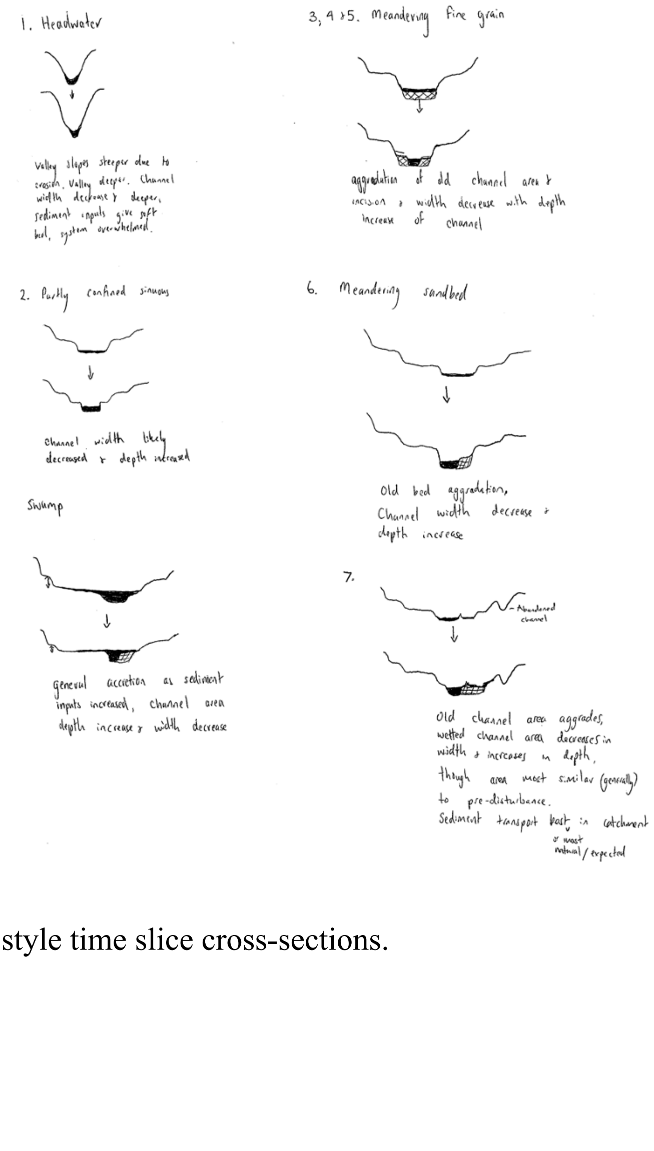

Figure 48. River style time slice cross-sections.

Geomorphic change

The changes that have occurred over the timescale since disturbance have potentially altered some river styles present. The headwaters are overloaded with sediment and lost riparian and aquatic vegetation. The sediment load has led to a more soft bed (fines) than would have been typically natural; deduced from ergodic reasoning of expected headwater characteristics. This is supported by the lower deposited sediment coverage in the Kahuterawa; 10%. The sediment load increase has had a significant impact on most of the catchment, with more natural transport function occurring in the lower end of the catchment where there have been fewer other geomorphic changes; particularly riparian and bank morphology have been less altered. It is generally expected that sediment accumulates in the downstream reaches of a naturally functioning system (Knighton, 1980). The meandering fine grained and sand bed river styles may have been expected to have rougher beds and be transporting sediment more efficiently, more similar to the meandering gravel bed downstream. It is uncertain whether the change is irreversible but the occurrence of a system in a more original state downstream suggests changes may be reversible with correct management.

Desirable geomorphic river character or reference condition

1. Headwater: sediment source, gravel-cobble bed, efficient sediment transport downstream, straight, confined, heterogenic bed, woody debris, heterogenic geomorphic units including run; riffle, pool and cascade, intact riparian margin, in-stream native macrophytes.
2. Partly confined sinuous: efficient sediment transport, heterogenic gravel bed, intact riparian margin, sinuous, in-stream macrophytes, woody debris, heterogenic geomorphic units; run, pool, riffle.

   Swamp: intact riparian, sediment accumulation-sink, sinuous channel, macrophytes, woody debris, grain sorting.

3, 4, &5. Meandering (currently fine grained): larger bed constituents; gravel, heterogenic bed, efficient sediment transport zones, intact riparian margin, in-stream macrophytes (more native), appropriate woody debris, heterogenic geomorphic units; run, pool, riffle, bars

6. Meandering (sand bed): larger particle, more heterogenic bed, efficient sediment transport zone, intact riparian margin, appropriate woody debris, in-stream macrophytes, diverse and sequential geomorphic units including; run, riffle, pool, bars, old cut offs, chutes.

7. Meandering gravel bed: rough gravel bed, efficient sediment transport zone, native macrophytes, intact riparian margin, woody debris, geomorphic unit diversity and heterogeneity maintained with run, chute, bars, cut offs and sequential riffle-pool units.

Assessment of current condition

The assessment of current geomorphic condition was carried out following the approach taken in Brierley and Fryirs, 2005 (Table 7). Relevant geoindicators were used as suggested and overall condition based on scoring of the three degrees of freedom (channel attributes, planform and bed character). To score ‘poor’ none of the requirements are met; scoring less than 4/5, 4/5 and 3/4 respectively. To score ‘moderate’ one to two of the requirements are met (any 4/5 or 3/4). To score ‘good’ all three sections must score more than 4/5, 4/5 and 3/4. Y= condition appropriate, scoring 1; N= condition not appropriate, scoring a 0; and S= somewhat appropriate, scoring 0.5

Currently, the headwater (1), partly confined sinuous (2) and meandering fine grained (5) are considered in poor condition. The swamp, meandering fine grained (3), and meandering sand bed (6) are currently considered to be in moderate geomorphic condition. The meandering gravel bed (7) and the meandering fine grained (4) are considered to be in good geomorphic condition.

Table 7 *The current river styles geomorphic condition assessment with explanations.*

	1.Headwater	2. Partly confined sinuous	Discontin channel valley fill	3. Meander fine grain	4. Meander fine grain	5. Meander fine grain	6. Meander sand bed	7. Meander gravel bed
- Channel attributes	**1.5/5**	**2.5/5**	**3.5/5**	**4/5**	**4/5**	**3.5/5**	**4/5**	**4/5**
Size appropriate	Y (natural)	Y (close to natural)	Y (close to natural)	Y (close to natural)	N (smaller)	Y (close to natural)	S (semi-natural)	S (semi-natural)
Shape appropriate	S (slightly thinner/ deeper)	S (slightly thinner/ deeper)	Y (natural)	Y (close to natural)	Y (close to natural)	Y (close to natural)	Y (close to natural)	Y (natural)
Bank morphology appropriate	N (erosion in unnatural areas)	Y (ero natural areas)	Y (close to natural)	Y (close to natural)	Y (close to natural)	S (some extra ero)	Y (natural)	Y(natural)
In-stream veg appropriate	N (lacking)	N (lacking)	S (some as expected)	N (lacking)	Y (natural)	N (lacking)	S (some natural)	S (some natural)
Enough woody debris	N (lacking)	N (lacking)	N (lacking)	Y (natural)	Y (from willow)	Y (from willow)	S (less than expected)	Y (natural)
- Channel planform	**2/5**	**3/5**	**4/5**	**4.5/5**	**4/5**	**2.5/5**	**3.5/5**	**5/5**
No. of channels appropriate	Y (1-natural)	Y (1-natural)	Y (1-natural)	Y (1-natural)	Y (1-natural)	Y (1-natural)	Y (1-natural)	Y (1-natural)
Lateral stability appropriate	Y (naturally confined)	S (could be more natural)	Y (natural)	S (some straightened)	Y (natural)	S (some straightened)	S (slightly too stable)	Y (natural cut-offs etc)
Assemblage of geo units appropriate	N (lacking)	S (some riffle/pool as expected)	Y (backwater & pool)	S (some as expected, riffle/pool)	Y (natural, riffle/pool, run sequence)	N (lacking riffle/pool sequence)	N (lacking riffle/pool, sequence bars)	Y (natural, cut-offs, bars, riffle/pool sequence, run)
Rip veg near natural	N (removed)	N (removed)	N (removed)	S (removed)	N (unnatural/ removed)	N (unnatural/ removed)	Y (mostly natural)	Y (intact, natural)
Sinuosity appropriate	Y (confined setting)	Y (natural)	Y (natural)	Y (natural)	Y (natural)	Y (natural)	Y (natural)	Y (natural)
- Bed character	**0/4**	**2.5/4**	**3/4**	**0.5/4**	**3/4**	**0/4**	**4/4**	**4/4**
Grain size appropriate	N (fine)	S (some variation)	Y (expected fines)	N (fines dominate)	Y (close to natural)	N	Y	Y
Stability appropriate	N (unnatural)	Y (close to natural variability)	Y (natural, stable)	S (slightly too stable)	Y (close to natural variability)	N (too stable)	Y (close to natural variability)	Y (natural)
Hydraulic diversity appropriate	N (roughness and pattern altered)	S (somewhat less diverse than natural)	Y (as natural/ expected low)	N (low-inappropriate)	S (some expected variability)	N (low, unnatural)	Y (natural variability)	Y (natural variability)
Sediment regime appropriate	N (source completely overwhelmed)	S (some transport, overwhelmed)	Y (sink, accumulation expected)	N (transport inefficient, overwhelmed)	S (some transport, not enough)	N (inefficient transport, accumulation)	Y (almost at necessary efficiency)	Y (transport efficient)
Overall condition	**(0/3) Poor**	**(0/3) Poor**	**(2/3) Moderate**	**(2/3) Moderate**	**(3/3) Good**	**(0/3) Poor**	**(2/3) Moderate**	**(3/3) Good**

Recovery potential, future condition and trajectory

Trajectory

Trajectory for each river style and the tactic appropriate were assessed with recovery-limiting factors considered. Headwater (1) less certain to recover due to the intense constraints, therefore its trajectory has been dotted toward both recovery and creation (Figure 49.). The tactic for improvement was assessed below (Table 8).

Recovery limiting factors

- Continued land use pressure
- Vegetation removal may have caused irreversible changes in places
- Hydrological regime has changed with loss of vegetative cover. This can change back but permanent erosion has already occurred.
- Artificial water storage and damming
- Land Management practices
- Economic pressures
- Climate change (variable and more unpredictable weather)
- High sediment loading

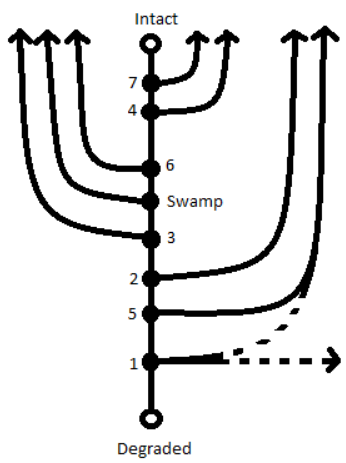

Figure 49. River style trajectory.

Table 8 *River styles tactic for geomorphic improvement.*

River Style	Will it naturally recover?	Is restoration possible?	Tactic
1. Headwater	No	maybe	Restore/ create
2. Partly confined sinuous	No	Yes	Restore
Swamp	No	Yes	Restore
3, 4, 5 Meandering fine grained	No	Yes	Restore
6. Meandering sand bed	No	Yes	Restore
7. Meandering gravel bed	No	Yes	Restore

Recovery potential

The recovery potential was then estimated by following the process set out in Brierley and Fryirs (2005). The decision-making protocol uses a tree which is shown below, whereby the potential of each river style is found by answering the tree questions (Figure 50.). The recovery potential varied within the catchment, and river style catchment position was of little indication. As expected, the good geomorphic condition river styles, meandering fine grained (four) and meandering gravel bed (seven) show high recovery potential. The other river styles show moderate recovery potential, even those in current poor geomorphic condition such as the headwaters (site 1). This gives optimism for catchment rehabilitation and restoration. The recovery potential of the river styles is framed by catchment position as suggested in Brierley and Fryirs (2005) (Figure 51.).

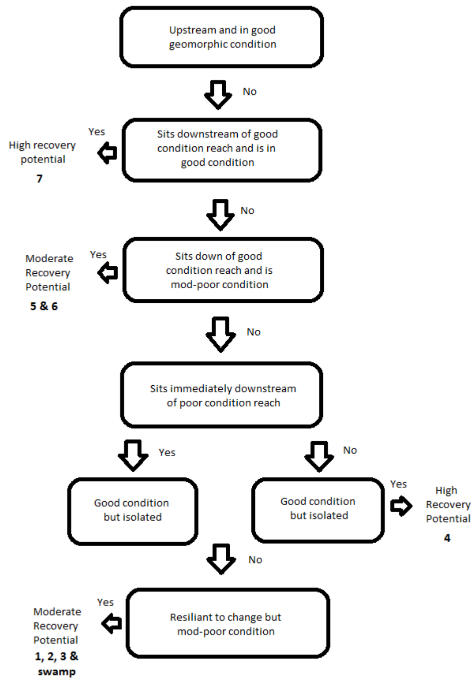

Figure 50. Recovery potential decision making tree.

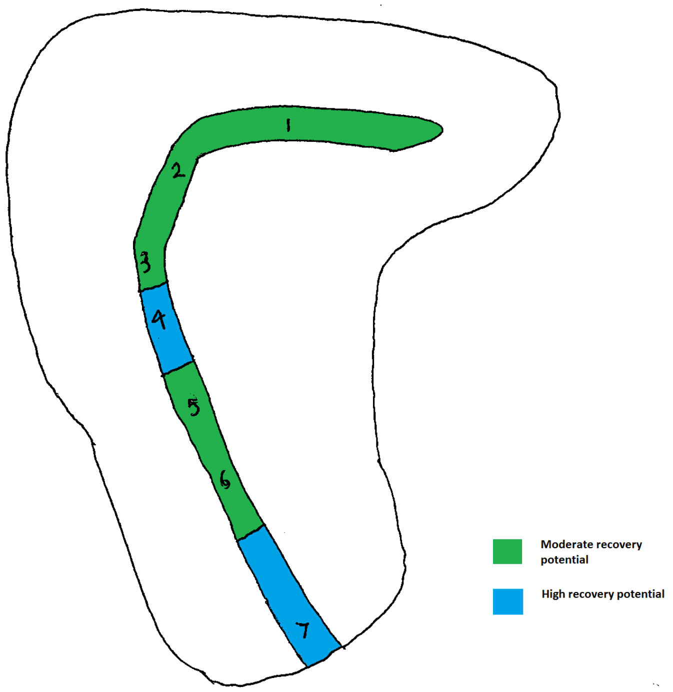

Figure 51. Mapped recovery potential of river styles by catchment context

Resulting river management application

Catchment vision

The scenario of working with natural processes in a realistic way with invasive improvement only where necessary was the approach suited to this catchment. The catchment framed vision was created with stakeholders as described in the following section. The locals do not tend to swim in the river but desire it to be healthy for activities such as fishing, and want an aesthetically pleasing catchment with abundant native birdlife returning. Therefore the aim is to manage the catchment in a way that allows the system to adjust as naturally as possible while making significant environmental improvements. This will be carried out through using soft engineering techniques rather than hard.

Target geomorphic conditions

The target conditions are based on what was considered desirable conditions from step two (geomorphic condition), and the potential for recovery found in step three. All targets include lowering sediment load and improving riparian margin intactness.

The level of intervention required and associated recovery timeframe vary and depend on current geomorphic condition and recovery potential (Table 9).

Table 9 *River style recovery expectancies.*

River style	Current (year 0)	Years 5-15	Final (~ 20years)	Intervention	Recovery time
(1)Headwater	Poor	Poor-Moderate	Moderate-Good	Significant	Long
(2) Partly confined sinuous	Poor	Poor-Moderate	Moderate-Good	Significant	Long
Swamp	Moderate	Moderate-Good	Good	Some	Medium
(3) Meandering fine grained	Moderate	Moderate-Good	Good	Some	Medium
(4) Meandering fine grained	Good	Maintained	Maintained	Little	Short
(5) Meandering fine grained	Poor	Moderate-Good	Good	Some	Medium
(6) Meandering sand bed	Moderate	Moderate-Good	Good	Some	Medium
(7) Meandering Gravel bed	Good	Maintained	Maintained	Minimal	Short

Intervention required and manipulation strategies

The intervention required to improve most of the catchment includes soft engineering approaches. While some areas require less intervention than others, to improve geomorphic condition downstream, intervention will occur catchment wide. There is the least intervention required at the bottom of the catchment (seven), and the most required up the top (one and two). As improvements upstream will lead to subsequent improvements downstream, due to flow, it is appropriate that the upper catchment has the most intervention. In particular, the sediment loads will be influenced by upstream intervention.

Manipulation strategies that are necessary to improve geomorphic condition include hillslope stabilisation, riparian planting and stock exclusion. These strategies would also improve the ecological condition.

Management Prioritisation

The river styles approach suggests priority management of areas based on the geomorphic condition and recovery potentials examined above. The descending prioritisation framework is shown below (Figure 52.). Under this framework the upper catchment (styles one and two) is prioritised first as a strategic restoration due to the threats of sediment loading caused. The mid catchment (styles three, four and the swamp), and some of the lower end of the catchment (style five and six) could also be said to be strategic reaches as their upstream degradation puts the lower end (style seven) at risk. The next prioritised area would be the lower end, river style seven, as it is connected to the conservation area of Kitchener Park, which is immediately after the conjunction of the Mangaone West with the Makino stream, and it has high recovery potential. If the styles three to six are not considered strategic, the area in river style four is the next prioritised area for management. After that, the remaining upper mid- lower reaches, areas of styles three, five, six, and the swamp would be targeted.

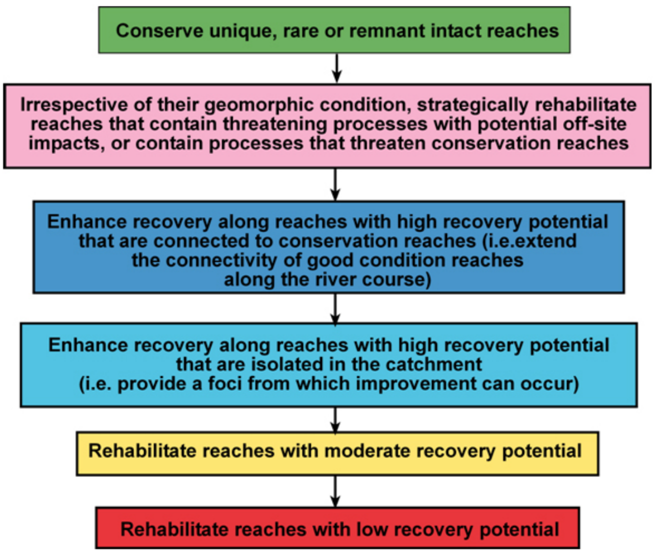

Figure 52. Prioritisation management framework (Brierley and Fryirs, 2005, pg. 353).

ICMP development

From the open invitation meeting with stakeholders and the local community many issues and goals were put forward, including pest species invasion, nutrient losses being retained to land, and improving management practices. These ideas lead to the objective of achieving more sustainable farming in the Mangaone West catchment. Self-identification participation was used for this particular process as only interested individuals were involved, making consensus-forming easier, and reducing conflict which can arise from uninterested parties' required attendance

To achieve this objective, a plan strategy had to be carefully considered. Shortlisting was not necessary as there were not numerous plan options to begin with, as there would be in large projects. Weighting was included in the score for each criterion, but extensive weighting evaluation was not needed due to the small-scaled nature of the plan to be developed. Standardised scaling was used to evaluate the plan options. The lowest scoring, and thereby best plan option, was the combination approach with a total of 29, followed by the riparian rehabilitation option (31) (Table 10). The two lowest scoring options only differ by 1 point so the overall positive benefits were the looked at confirm the most appropriate plan option. As higher scores were for a worse fit, the combination approach is indicated as the best course of action. This will involve using techniques such as riparian planting, hillslope planting, and management practices in particular areas where they will be likely to have the most positive effects for the costs involved.

Table 10 *Plan option constraint and criteria assessment.*

Plan option	Cost	Difficulty	Time	Waterway improvement	Geomorphic improvement	Land compromised	Biodiversity improvement	Total	Sum of benefits
Inactive	1	1	1	10	10	4	10	37	
Complete restoration	10	10	10	1	1	10	1	43	
Riparian	5	5	5	4	5	5	2	31	10
Hillslope planting	4	4	4	6	5	5	7	34	
Steep hillslope retirement	4	5	3	7	4	4	6	33	
BMPs	2	8	6	6	6	5	7	35	
Riparian and hillslope planting	6	5	5	4	4	5	3	32	
Combination	7	6	6	2	2	4	2	29	6

Plan option descriptions

Inactive: Do nothing.

Complete restoration: remove all unnatural activity and restore catchment to natural land cover.

Riparian: Full riparian margin restoration of 10m from waterway throughout entire catchment, with fencing (full stock exclusion), and pest and weed control. Includes willow removal.

Hillslope planting: spaced stability plant of all erosion risk areas identified in results

Steep hillslope retirement: retirement of all slopes over 21 degrees; much of the upper catchment (considered steep in Lynn et al., 2009).

BMPs: implementation catchment wide of BMPs for all agricultural land use and management practices.

Riparian and hillslope planting: extensive riparian margin throughout catchment, with fencing (six meter minimum and full stock exclusion), pest and weed control, as well as spaced stability planting of all erosion risk areas identified in results, and willow removal (riparian)

Combination: a combination of all rational approaches; BMPs implemented as best as possible, hillslope planting on erosion risk areas, riparian margin restoration (six meter minimum, shading focus in ephemeral upper catchment), with fencing (full stock exclusion), and pest and weed control, and willow removal (riparian).

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Discussion

Results findings

GIS

From the GIS work it is clear that there are some significant characteristics and constraints acting on the catchment, which need to be taken into account for management.

From the LUC assessment, most land is found to be unsuitable for cropping (class six land of upper and scattered through the sides of the catchment). Land owners need to be aware of their catchment positioning in relation to this to ensure they are cropping in suitable areas, with suitable conservation practices.

There are highly notable increased erosion risks in the upper catchment and along the western flank. Soil conservation efforts in these areas need to be of focus.

The carrying capacity varies within the catchment, with the central areas near the main channel capable of carrying much higher stocking rates than the sides and upper catchment. Individual property positioning and associated carrying capacities need to be learned by landowners to reduce pugging and erosion and maintain the lands productivity for years to come.

Most of the catchment is imperfectly to poorly drained, those in the central catchment from mid upper to the very catchment end need to be made aware that their drainage in winter will make faster stock rotations and hold offs from some areas necessary to minimise and avoid pugging. They will also need to stick to the carrying capacity more rigidly, especially during times of soil saturation.

While the catchment is loam, mostly silt loam, the soils can be quite shallow, and the largely loess bedrock means water loss can be an issue during low rainfall periods, which will be increased under climate change, so drought resistant plants may become more necessary.

The considerable higher waterway slope in the upper catchment results in higher gravitational energy and movement of water when the ephemeral waterways are active. Coupled with the steep slopes of the upper catchment there is the potential for higher erosion rates as indicated previously. These waterways have the ability to carry much sediment at times; indicating sediment and soil management in this area must be focused on.

Most of the catchments waterways, aside from the upper catchment and a few sporadic exceptions of the main channel, are very similar in character and the vast majority of the catchments waterways should thereby react similarly to management (FENZ). Apart from one lower catchment section, all of the lower end waterways are classed the same, and thereby similar management of the entire catchment is plausible as it will likely have a similar impact on all waterways.

The sediment coverage predicted differs to the sediment coverage found during sampling as the substrate varied more than the model predicted, containing coarse gravel and cobble which was not expected to be to present in significant amounts. The amount of pooling and backwaters was also over predicted in the main channel, particularly in the mid and lower catchment, where there was mostly run occurring with some pool and riffle areas.

Modelled total nitrogen was much lower than the actual total nitrogen levels, apart from in the very upper catchment. Total nitrogen levels were up to 3 order of magnitudes higher than predicted, indicating human activities are having a higher impact than expected in the catchment, verifying further the need for the catchment management plan.

The LENZ level 2 map was the most useful level of environment categorisation at the catchment scale, showing the vast majority of the catchment to be of one class, with the upper catchment and a small area in the east extending down from the upper catchment to be quite different. This supports the idea of managing the upper catchment differently to the rest of the catchment, which is implied by; the FENZ river classification results; erosion risk; and the soil depth results. Human pressure is also predicted to be highest in the upper catchment, which further supports differing management in the headwaters.

Google Earth Mapping

Willows are of significance in that where they are most abundant in the mid and lower catchment, they will be significantly altering flow and channel dynamics due to fallen branches collecting and damming, as well as new growth within the channel. Hindered and slowed flow, resulting in built up sediment and poorer flushing capabilities causes observable significant changes in stream habitat, flora and fauna. This is seen clearly at site five, amongst willows with deep sediment coverage of 100% of the area and poor species richness with a high proportion of snails, and little to no native macrophytes present.

Riparian shading of the waterways is, as a whole, poor, with little to none throughout the upper to mid-upper catchment. The importance of riparian shading for freshwater quality, fauna, flora, and ecosystem functioning is critical, and so must be of priority; this is founded by the relationship between shade and MCI/QMCI, and supported in much literature (Poole & Berman, 2001; Pusey & Arthington, 2003). Bunn, Davies and Mosisch (1999) found a significant decrease in environmental state where riparian planting had been removed, with algal growth, water quality and food webs altered. Riparian buffers also filter sediments and some nutrients, so management of the riparian area is of utmost importance for the plan to succeed in improving the catchments environmental state, by reducing eutrophication (Bunn, Davies & Mosisch, 1999). The shading of riparian plants reduces algal growth which traps sediment, it was found from sampling that sediment and shade had an inverse relationship, potentially supporting this theory, and its action as a filter (Bunn, Davies & Mosisch, 1999). Sufficient riparian shading thereby will likely enhance the freshwater ecosystem in many ways.

Field sampling

The high reactive dissolved phosphorous, total nitrogen, and ammonia concentrations are of concern as some are much higher than trigger values which suggest environmental degradation and eutrophication an issue. As Smith, Tilman and Nekola (1999) describe, the impact increased nutrients can have on freshwater systems is undesirable as it can alter entire food webs and disrupt natural ecosystem processing and amenities. A review goes further, (Carpenter, Caraco, Correll, Howarth, Sharpley & Smith, 1998) with nutrient inputs, if high enough, causing oxygen depletion (hypoxic zones), toxicity, undrinkable water, and cumulatively adding to ocean acidification. As discussed in Carpenter et al (1998), nutrient usage needs to be modified and better administered and cycled on land, with reduced inputs to waterways a necessity. This is to be targeted in the management plan through behavioural change in nutrient management, and soft engineering through riparian management to filter nutrients.

Sedimentation was also identified as a significant issue, GIS underestimated deposited sediment levels, which were 100% in some areas. While sediment inputs in agricultural areas tend to be high, this is undesirable for freshwater ecosystems and farmers as the sediment entering the water is the topsoil needed for production. The impact of deposited sediment mostly causes habitat loss, through infilling and aggradation, and leads to ecosystem breakdown through removal of many sediment sensitive species, both flora and fauna (Clapcott et al., 2011). With high amounts of deposited sediment, there is clearly much sediment entering the waterway, not all of which is settled out; suspended sediment is likely having an impact as well, causing higher turbidity, lower light penetration, and therefore macrophyte growth and gill clogging fauna (Berry, Rubinstein, Melzian & Hill, 2003). To reduce the rate of sediment input, and loss of soil from hillslopes, slopes must be better stabilised, erosion reduced, and riparian vegetation is needed for filtering.

River styles

The river styles assessment showed six different styles occurring through the main trunk of the catchment. A large portion was meandering fine grained. Untypically, the most intact, best geomorphic condition occurs in the lower catchment, around site seven. The meandering gravel bed is more as one would expect in the majority of the mid to lower catchment under natural conditions. However, as the system is overwhelmed by sediment inputs, only toward to exit of the catchment is the channel able to efficiently transport smaller particles and sediment. The headwaters and subsequent downstream reaches have been completely overwhelmed by sediment, having a large impact on the in-stream habitat. The main cause of this was the land cover change, as well as riparian removal and intensified land use (a large on-going disturbance in the catchment).

Some areas, in particular, the headwaters, may or may not be able to be effectively restored due to the limitation of continued pressures of land use. The highest likelihood for restoration occurs in the meandering gravel bed style, and there is moderate to high chance of restoration for most of the mid to lower catchment.

The most significant improvement to aid geomorphic structure and function would be by reducing sediment inputs, which is done by improving hillslope stability, and restoring riparian margins to filter sediment in overland before entering the waterways.

By the river styles approach, if all areas upstream of the meandering gravel bed are considered strategic (due to threatening the good condition site, and conservation area at the catchment exit), this approach is fairly appropriate. If some of the upstream sites such as meandering sand bed aren't considered strategic (as they aren't in as dire situation as the upper catchment), this approach would make less sense due to downstream flow and cumulation.

It is recommended all upstream reaches of the gravel bed are considered strategic and made priority. This means all reaches are close in priority levels. Financial involvement of landowners means intensive implementation in small areas would not be feasible; individuals are only able to contribute so much when there is only partial subsidy occurring. Due to the constraints of financial aspects on landowners, work would be best to take place throughout the catchment, to better disperse the costs over time. This approach focuses as much as possible on getting the most improvement for action efficiency, while minimising economic hardship to landowners. This allows work to be carried out in strategic areas simultaneously to restoration work in the gravel bed area in the lower of the catchment, fitting well with the result of a combined approach from the traditional management approach.

Combined plan option

From the results findings, it is apparent that the most useful management plan option is a combined approach, with the backup option focused on riparian management. The combined approach prescribes the incorporation of multiple plan options, with consideration to where such approaches are appropriate. The combined plan scored the best in the plan option assessments, and provided significantly more likely positive impacts than the close second best option. The plan approach requires certain aspects of different plan options to be used at smaller scale areas within the catchment to maximise the effect of management. With the goal of improving agricultural sustainability in the catchment, by reducing topsoil loss and erosion, therefore improving waterway health, this option proved to be most viable. The implementation guide of the plan was constructed with consideration to the complexity of the plan option chosen.

Plan Approach

A mixed approach of traditional style and river styles framework was used to attempt to provide a well-formulated plan. As the catchment is a dynamic system, it was divided into areas based on areas' characteristics, in order to allow the plan to more effectively manage and improve environmental health at the local and catchment scale. The river styles method identified areas to be prioritised based on their recovery potential. However, the highest potential were meandering gravel bed (site seven) and meandering fine grained bed (site four), which require upstream work in order to improve due to the downstream flow of sediment, nutrients, and plant matter. Even though the headwaters according to the river styles have the lowest recovery potential, they need to be a management priority due to the downstream transmission of its issues (sediment in particular).

Catchment sections and issues

For the sake of ease for discussing the catchments issues in particular areas, the catchment is divided roughly into sections based on characteristics derived from GIS mapping and visual observations during fieldwork (Figure 53.). The changes in sections based on land versus waterways are slightly different, so both were considered during section division. No one tactic based plan option would effectively manage these issues, so a combined approach is required, as selected from rationality processing shown in the results section.

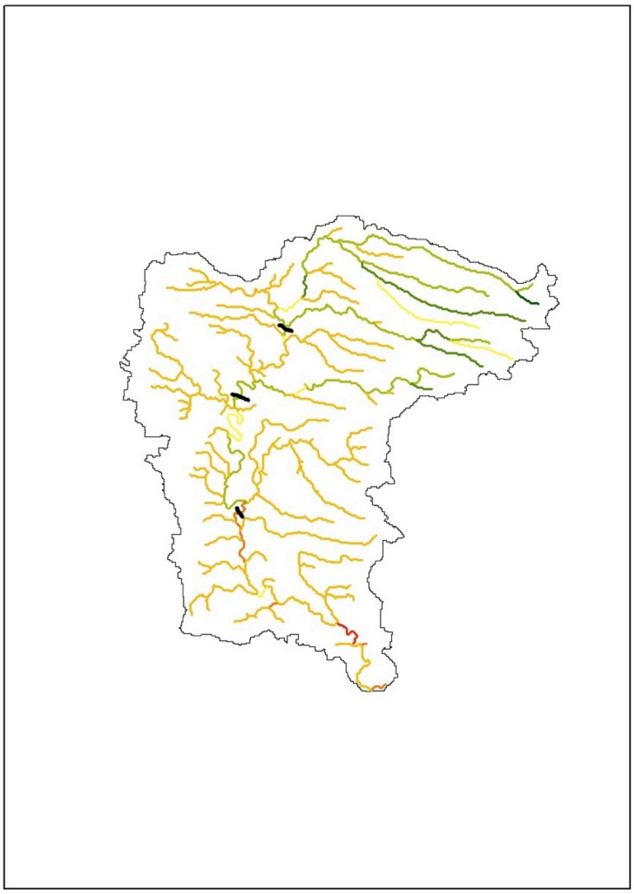

Figure 53. Catchment section divisions.

Upper catchment

The upper catchment has unique characteristics different to the rest of the catchment; this was deduced from observations in field and based on GIS: for example, it is far steeper, and exhibits a different drainage pattern (trellis). This area includes the headwaters and ephemeral main channel until around where site two is positioned. The river styles present are headwaters, (corresponding to sampling site one), transitioning to partially confined sinuous and includes the swamp area. The primary issues this area faces include hillslope topsoil erosion, a lacking riparian margin, sediment overwhelmed streambeds, and agricultural practices its differences to the rest of the catchment make it necessary to consider it as a different unit for management.

Mid-upper catchment

This area begins to become more perennial as flow increases enough from contributing tributaries. While it is difficult to define where the transition occurs from one section to another, the mid-upper characteristics are present after site two, around the railway crossing of the main channel. The slope of the Mangaone west main channel is lessened significantly, it becomes more sinuous, and the planform changes from parallel/trellis, to the more typical dendritic planform (Mejia &Niemann, 2008). The river style present is meandering fine grained. The issues in this area are more based on riparian loss (filtering and shading function), the inefficient transport of sediment, and agricultural practices.

Middle

The central area trunk of the catchment and main channel has flatter surrounding adjacent land again. Meandering becomes more intense and the waterway is significantly deeper with higher nutrient concentrations. The river style present remains meandering fine grained. The main issues are inefficient sediment transport, nutrient loadings, and incomplete riparian margin (fencing is still required in many areas and gaps in riparian plantings require filling, willows and weeds become a more significant issue).

Lower

The lower end of the catchment has much a more intact riparian margin and banks of the main channel are steeper, which improves stock exclusion when there is a breach of the riparian margin. The waterway becomes more efficient at sediment transport, and the river styles of meandering sand bed and meandering gravel bed occur sequentially as a result. There are some gaps in riparian margin that require attention, as well as weeds such as Tradescantia and willows which need to be addressed.

Catchment wide strategic methods

Best Management Practices

BMP adoption is a catchment wide strategy that is completely necessary to improve the environment. Agriculture influences environmental health significantly, potentially the most important aspect of change needed in the catchment will be all practitioners following the best management strategies possible. Adopting the best possible agricultural management practices would allow for the best possible improvement in the catchment's environmental health. Behavioural adaptations to efficient, sustainable farming can improve all of the most problematic issues the catchment faces. Nutrient enrichment, sedimentation, and loss of productivity could significantly improve, if the practices of the farmers are adapted to the specific requirements of the catchment.

In order for both sustainable and productive farming to co-exist in the catchment the following procedures ought to be adhered to as closely as possible by all of those in the catchment. Most of the BMP's are common and already suggested in farming communities all over New Zealand, however, following them more closely with awareness and reasoning for the management practices is necessary, as it is known that many farmers do not follow BMP's. A BMP resource needs to be made available to all by the production of a smaller document sent out physically and electronically, and made available online, to catchment inhabitants.

Farm Management Plans

Farm management plans need to be developed with experts for optimal management promote farm success and sustainability. Whole farm plans indicate how to maximise efficiency of resources while minimising environmental impacts (Landcare Trust, 2013). Landcare Trust provides consultation advice and development of tailored, effective farm management plans, with achievable targets and economically viable environmental progress for individual estates.

Implementation

BMPs

The entire catchment would benefit from all inhabitants using best practice management techniques, so the practices above ought to be distributed and expressed to all, in farmer friendly form, and reiterated often. Extensive integration will be required to get all landowners using appropriate BMPs. Farm plans will likely go over applicable BMPs for each farm, a non-exhaustive list of relevant BMPs is provided in appendix F. A meeting to go over the information and advice, as well as questioning, to assess understanding, is needed. Those who do not attend a communal meeting should be followed up personally as the importance of following the BMP is crucial to the plan success and environmental improvement, both terrestrial and aquatic. Periodical review of BMP's advice and a meeting with a follow-up questionnaire survey is advised, with any significant changes in BMPs communicated to landowners in between review periods. Changing the behaviour of Individuals so that human activities have less impact may likely be one of the most important aspects of improving the Mangaone West's environmental state and sustainability.

Slope stability planting

In the upper catchment the steep hillslopes are at risk of erosion through landslides, rilling and gullying, and there is very little shading of the perianal waterways. Improving hillslope stability and establishing some form of riparian management is a priority due to the erosion risk and high levels of sedimentation. The deposited sediment and phosphorous from fieldwork results for Site One give an indication of the processes occurring in the upper catchment area and show accelerated sedimentation, as is common in agricultural catchments (Wood & Armitage, 1997).

Reduction of sediment inputs into the small, perennial streams of the upper catchment, advantaged by also reducing loss of the more productive topsoil, can be carried out by using methods that include stabilising steep slopes and developing a riparian buffer.

The GIS results for slope show the steeper areas of the catchment, and the upper headwaters stand out. The land owners know their land best, and will be aware of areas of hillslopes currently experiencing the most erosion. The map obtained using Google Earth showed the areas which exhibit erosion through sheet, rilling, gullying and landslides or slumping. The tributaries with the most erosion-prone areas, (largest areas in red) could be prioritised for hillslope plantings, with the most significant areas (input from landowner) along the tributary covered first.

Spaced Planting

Spaced planting of trees varies with plant species and slope steepness. Steeper slopes require closer plantings and sturdier, tensile rooted trees. Generally, on steep hills like some of the Mangaone West, spacing of up to eight meters is suitable (National Poplar and Willow Users Group, 2007). While sometimes there is some adversity to spaced planting, the advantages of shelter for stock and shading to reduce soil moisture loss, compensating for its water usage (Environment Waikato, 2002).

Poplar poles are common practice for spaced hillslope planting as they are fast growing and easy to establish using pole or post rammers (Horizons, 2001). Maintenance topping when poplars become a liability to wind would be needed eventually. As willows are problematic in their build-up of debris, and many need to be removed in the lower catchment, their use for hill stabilisation is less desirable. Pines could also be planted, harvested and replaced, however stock consumption has been associated with abortion in pregnant stock, so caution is needed (Greg, 2012; Myles & Beckett, 2001).

Natives have generally been excluded from hillslope stabilisation as there is the stigma of growtn inefficiency compared to exotics (Nautilis Contracting, 2011). While there is little research to confirm their usefulness relative to exotics, some natives show potential, such as Kanuka and Pohutakawa (GBIT, 2005; Nautilis Contracting, 2011).

Kanuka grows strong interlocking roots, meaning it stands at 16 years old or more as effective at erosion control compared to close-planted pines of eight or more years old. With kanuka the stability can maintained for centuries due to its long lifespan. Kanuka won't stop an existing gully eroding out, but it will stop initiation on a slope that in pasture is vulnerable and is therefore useful in many areas of the upper catchment (Great Barrier Island Trust, 2005).

Pohutakawa in low branching form may be the most successful native for soft engineering of hillslopes (Nautilis Contracting, 2011). Its structural attributes and ability to establish itself in harsh environmental conditions allow it to flourish almost anywhere, as it can tolerate wind, infertility, wet and dry soils. Once germinated, its survival rate is high and growth rate is good. Pohutukawa trees have a mosaic of thick, deep and broad anchoring roots, and fine, fibrous roots as well as descending aerial roots. Anchoring roots of mature trees measure five to eight metres below the ground surface and about 35m beyond the trunk horizontally. The low-spreading branched Pohutakawa form retain a relatively low, oval canopy; reducing wind effects, thereby reducing trunk movement at ground level (resistant to uprooting) and wind damage to branches (Nautilis Contracting, 2011).

Vetiver Grass, an exotic, shows some potential due to its fast and deep rooting system which makes it very suitable for steep slope stabilisation. It can tolerate extreme climatic variability once established, but, can take 3-6 months to become established fully, and is heavily affected by shading and may require watering during establishment.

New growth and young shoots are edible to stock. It needs to be grazed or cut down to 15-20cm regularly, and once long is inedible. It can easily be destroyed by roundup. Vetiver first reduces erosion, stabilizes the erodible ground, especially well on steep slopes, then improves its micro-environment so that can work as a nurse plant for other plants to be established later (Nautilis Contracting, 2011).

Pair and gully planting

Where more extreme erosion such as gullying is occurring, pair planting and planting up the gully with closer spaced trees is needed to reduce erosion. Pair planting involves two trees being planted on each side of the gullying ground, 2-3m apart as suitable, continued up the gully (Greg, 2012). The surrounding hillslope of the gullies needs closer panting than the average spaced hillslope planting, again every two to three meters may be suitable, and the top of the gully ought to be planted too, to slow the process and protect the topsoil and land adjacent. The same plants suggested for the spaced planting are well suited in this role as well due to the similar function of reducing and inhibiting erosion. Native flaxes (such as Harakeke) however, may be useful as well at the lower gully ends as it is tolerant but provides less steep slope stabilisation due to reduced root growth (Nautilis Contracting, 2011).

Stream bank and riparian planting

While the streams in the upper catchment are ephemeral some streamside plantings would be hugely beneficial to shade waterways and dammed areas during the warmer months while there is water present. The planting here may again be spaced three to five meters depending on plant type. This would reduce stream bank erosion some upper catchment farmers had mentioned, reduce sediment entering the waterways and reduce water temperature, thereby reducing algal blooms and undesirable plant and insect species (Environment Waikato, 2002; Rutherford, Davies-Colley, Quinn, Stroud & Cooper, 1997).

Timing of stability implementation

The most significant contributors to erosion and most risk-prone erosion areas would be ideal to focus on. However, implementing this strategy would be impractical owing to serious constraints: time to identify all areas and rank them, along with lack of farmer willingness, and costs, as large areas may have one owner. The mapped erosion risk areas (Figure 26.) provide focus on areas that would be most appropriate, but surveying during the planting would allow for adjustments. Asking the land user which areas they notice eroding worst would also add extra basis for priority areas, as their knowledge of the land is more long-term. The areas mapped out from the heads of tributaries are a good starting point for a top down approach, with priority areas also considered. Beginning planning with the farmer for planting as soon as weather and finances allow is advisable, with multiple tributaries being planted simultaneously. The risk areas should be planted progressively downstream from the headwaters, the aims for progress under five years review are mapped in Figures 54. to 57.). The first round of hillslope stability plantings ought to be completed within five years in order to allow efficient progress and spread out costs of the work to individual farmers. The suggested aim for percentage of work completed in each stage increases from ~20% to 60% to 90% to all completed.

Streamside plantings are more advantageous where water is running more periodically. Therefore, spaced planting is advised, to shade waterways as a start to setting up a riparian buffer, and reducing some environmental effects, while not overwhelming upper catchment farmers. This should begin from the lower end of the upper catchment. This boundary is roughly pinpointed in Figure 53. Consulting with land owners on the process for their opinion for which plant species they would like to see present ought to be taken into account. Many individuals stated they wanted the native birdlife returned, so consideration to trees which attract native birds should be given. The presence of natives and non-natives ought to be discussed with each landowner to allow for diversity and functionality. Progressive streamside planting upstream in each tributary should allow an efficient method for improving shading over waterways and initiate riparian management, to be followed up at a later stage. Starting streamside planting at the opposite end to the hillslope planting is also advantageous in spacing out the costs and workload of the landowners. The actual progress could be mapped against expected progress to the landowners as part of integration to retain their interest and enthusiasm.

Riparian management

Riparian management is necessary throughout the catchment, however the approach to riparian areas ought to focus on priority areas that will have the most positive impact. There is some resistance to riparian planting and fencing off due to perceived associated loss of productive land; this is not necessarily the case, as the land unprotected from stream bank erosion results in land loss, and the movement of the meandering stream will occur faster, cutting away land where bank cohesion is lowered. An effective riparian strip allows the land use of adjacent productive land to be more intensive with less impact as it filters eroding topsoil and runoff before it is lost to the waterways (Parkyn, 2004).

Fencing

The lower catchment is well-fenced and the banks drop off before reaching the stream; the mid catchment has some fencing but is lacking in large areas, and the mid upper and above are by in large completely unfenced. The fencing of riparian areas is needed to protect the stream banks and riparian plants from stock damage. It allows the filtering strip the best chance of filtering out nutrients and sediments before entering the stream, as well as providing shading of the stream to reduce algal growth and reduce water temperatures, which rise with sun exposure, particularly over summer months.

Ideally a riparian strip needs to be a minimum of 10m on flat ground (Parkyn, 2004), however understanding land-use economic feasibility constraints, an absolute minimum distance of six meters from the water's edge ought to be fenced off in the mid-upper to lower catchment where new fencing is to be erected. Associated streamside areas that are swampy and thereby not useful, as productive land ought to be fenced off. In many cases this will mean the width of the riparian strip exceeds 10m.

Google earth allowed measuring of the six meters from the stream bank, and showed how much land famers would lose for productive use. Interestingly, particularly in the lower to upper-mid, it was clear that many unfenced streamside areas are not utilised by the farmers, and the distance from the stream bank to cultivated or actively used land often well exceeded the proposed six meters.

The upper catchment is more difficult to address as while steeper areas require a wider riparian strip to effectively filter, the waterways only run in the wetter season and so the accumulation of sediments and nutrients which run off the hillslopes are most likely utilised by the valley floor rather than entering the waterway. This being said, to reduce bank erosion the waterways do need to be fenced off to exclude stock. A minimum fencing distance of three meters from the stream bank may be more appropriate to account for the need of flatter land on the valley floor and the seasonal flow of the waterways.

Appropriate areas for stock crossings need to be made and discussed with the landowner, as bridges will be necessary when fencing is put in place.

Planting

The upper catchment tributaries, while lacking in riparian planting, are only active some of the year, and as hillslope planting is initially taking place and streamside planting is progressing upstream for shade, this area could be of less focus in the early stages. In the lower catchment, the gaps and areas where willows are present need to be planted up, especially a long straight closely upstream of site six, where riparian plants were removed a few years ago. This straight is also unfenced, though most of the farm has one stream bank fenced off with native riparian trees. The very lower end above Awahuri Feilding road also has more significant lapses in riparian plants along the streamside.

The areas lacking throughout the mid catchment tend to be significant lengths on one or both sides of the stream. A lot of the lower and mid catchment has riparian willows which provide stream shade for part of the year.

The entire riparian margin width needs be planted up with trees, shrubs and flaxes. Because of the protection needed for young plants from stock, planting up already fenced sections is faster and easier. The width of the riparian strip ought to remain constant at a minimum of six meters for new areas up until the upper catchment (above the swamp at the railway crossing). Above this point the spaced planting for shading is initially a priority, with more extensive planting suggested later in the project. If planting happens to precede fencing in any areas, there is a need for temporary fencing until the area is permanently fenced.

Willows

Willows were identified as a serious hydrological issue in the mid and lower catchment. The different options for willow removal were discussed by landowners, council members, an engineer, the Landcare Trust representative and myself. The most cost-effective and ecologically sensible strategy was decided on; the riparian areas with willows are to be planted with natives such as ferns, suited to the conditions willows created (shady), and integrated with exotics if landowners request, such as fruit trees. Over time the willows are to be removed through poisoning, and branch removal when appropriate. This approach was considered best practice by Waitakere City Council (n.d.) as the remnant dead willows continue to provide shade and bank stability from their roots after death. The hard-engineered options to remove willows using diggers was going to cost an estimated minimum of $8,000 for 250m and result in much sediment inputs and bank instability, so it was decided against after inspection. Herbicide glyphosate (round up) at full concentration can be injected into the willow after drilling for effective uptake. It can also be sprayed on a ringbark wound, however drill-injection is preferable as it is more effective. Both techniques must be carried out correctly to successfully kill the tree. Sapwood must be reached by the glyphosate as this is where it is actively taken up; inject-drilling tends to use less poison and have reduced run off (Waitakere City Council, n.d.).

Weeds

The mid and lower catchment have weed issues, particularly Tradescantia, in the native forest remnants and riparian strips. These require attention in both the short and long term to reduce the impact on native plant reproduction and growth. The weeds in the native riparian strips smother the younger trees and the forest floor, some smothering canopy too, and they compete for resources (water, space, light and nutrients) (Baars & Kelly, 1996; Standish, Robertson & Williams). Weed removal will require spraying and pull out weeds inappropriate to spray.

Most of the weeds (banana passionfruit vine, blackberry) will require cutting at the stump and removal of live stems or spraying, followed by gel herbicide at the stump. For vine stump applications, glyphosate (Roundup) or picloram gels are recommended, Grazon is more effective against blackberry but needs to be used with caution as it is a harsh chemical (Cole, 2014; Waikato Regional Council, 2012a). If spraying the vines is necessary glufosinate (Buster) or diluted glyphosate with an organosilicone penetrant.

Tradescantia in particular requires spraying repeats, (on a still, dry day), due to its ability to regenerate from any stem or leaf (DOC, 2014). Terbuthylazine (Gardoprim) is suggested for Tradescantia as it is highly effective and impacts native non-target plants less (A. Cole, personal communication August 5, 2014). The concentrations used for Grazon and Roundup need to be as low as possible to reduce impacts on non-target species while still being effective. The herbicides need to be used with precision and focused away from waterways and native or desirable plants.

Pests

While pest populations were not assessed in the catchment, rural areas with some forest commonly have significant pest predator populations such as possums, rats and stoats (Craig, Anderson, Clout, Creese, Mitchell, Ogden, Roberts & Ussher, 2000). With the issues they present of predating and competing with native fauna and their impact on native flora, particularly after this year’s mast season, pest fauna populations may increase in lag effect from widespread population booms from other areas (Department of Conservation, 2014; Moorhouse, Greene, Dilks, Powlesland, Moran, Taylor, & August, 2003). With increased planted areas, pest populations can be expected to increase as more favourable resources become available; therefore some form of control is necessary to reduce their impact on the fauna and flora of the Mangaone West catchment, and improve riparian success. Inhabitants also indicated they would like to see increased biodiversity and native birds returning to the catchment. For this to succeed, low-maintenance but effective pest management such as baiting is necessary. Benefits of toxin use for the ecosystem outweigh the negative associated effects (Innes & Barker, 1999). Anticoagulant bait stations are effective control for possum and rats, however mustalids do not generally eat the cereal and grain based bait and require trapping (Richardson, 1995). Anticoagulant leads to no bait aversion, as the effects take a few days to take place, and so is a good long-term form of control (Brodifacoum). While it allows secondary poisoning, there are few predatory birds in the catchment that would be impacted, and secondary pest poisoning is likely (Murphy, Clapperton, Bradfield, & Speed, 1998) Mustelids require trapping as they are not as easily attracted to the bait. A DOC 250 trap or similar is suggested, using rotten eggs as bait

(Department of Conservation, 2011). The trapping success rate should be recorded and analysed for trends in pest populations while bait and traps are being monitored quarterly. Extra bait should be included during spring and summer months to allow for the breeding season of native birds, thereby increasing survival rates (Innes & Barker, 1999).

Riparian implementation timing

Ideally, fencing will occur prior to riparian planting in all areas. This may not always be the case; in such circumstances temporary or guarding would be needed. The fencing would be most beneficial beginning in the mid-upper section and progressing downstream, as this area has more constant year-round flow and little to no fencing at present, meaning stock can erode the banks and significantly increase sediment and nutrient inputs. The gaps in fencing in the lower catchment should also be closed early in the project, as many of these gaps have native riparian plants which require protection from stock to allow regeneration. Breaking down the areas for fencing into smaller yearly portions for each zone covered by five years in the timetable should make attainable goals achievable.

Riparian planting is needed in areas under willows to allow bank protection, filtering, and added stability as willows are removed. Allowing some time for the establishment of these areas before significant willow poisoning will reduce the impact of shade, and instream resource losses (habitat heterogeneity, food sources). Filling the gaps in the mid and lower catchment where there is no riparian buffer is likely to significantly improve stream ecosystem conditions as the shade and filtering provided by the riparian system will reduce algal growth and sediment inputs (Parkyn, 2004). The mid-upper catchment planting would be the next useful stage to add the riparian buffer to as there is currently little present and, with fencing, complete riparian planting would likely improve the catchment stream health in this area and downstream due to reduced accumulation of nutrients and sediments. Again breaking the area into smaller segments to accomplish achievable portions per year is advisable; by roughly dividing the mid-upper into five sections, completing one each year. The original colour coordinated maps could be used for comparison showing the progress of riparian planting.

The willow removal process would best begin in the upper affected area of the mid catchment, near Te Raku Road, to reduce the accumulated downstream impacts faster.

Ideally the inplanting of natives and replacement trees would be carried out at least 6 months before willow poisoning to allow establishment and strengthening in the root zone so, as the willow roots die off, the bank remains supported (Waitakere City Council, n.d). Breaking the work down into achievable lengths such as 300m/year may aid in maintaining the progress and pace.

The presence of weeds such as Tradescantia, blackberry and banana passionfruit is having the most impact in the lower catchment, but weeds can easily spread downstream, therefore the mid catchment should be targeted first, from the top, with progression downstream. The second phase would progress from the top of the lower catchment downstream again. Seedlings likely to be killed by spraying should be removed first when possible, as they can be reused and replanted in another area or after residues are gone.

Progress and evaluation analysis

The progress of work in the catchment needs to be regularly assessed, as this was shown in the literature review to be an important component of ICMPs. Regular review and evaluation of BMPs and uptake has already been stated, but is reiterated due to importance. Water quality testing in the sites tested for fieldwork would be useful to analyse what changes occur and where (e.g sediment analysis shows how erosion control is progressing in the upper catchment). Mapping out the areas which have been planted (red-yellow colour change) would also be useful to assess how quickly riparian work (fencing and planting) and hillslope stability and shading (spaced planting in the upper catchment) are occurring. This could be transformed into percentage completed and can provide an assessment of progress and adapt the plan for future work.

If progress analysis is carried out every five years the plan will be more likely to succeed according to literature, and catchment inhabitants more likely to adhere to guidance (Feeney, Allen, Lees & Drury, 2010). If targets are met and exceeded the timing for progress can be sped up; if targets are not being met and there is a lag in progress, this can be looked into and resolved, with the potential to swap focus from one excelling aspect to a lagging strategy.

For water quality monitoring, invertebrate sampling and MCI and QMCI should be carried out at least at each five year review, as well as nitrogen, phosphorous, sediment, dissolved oxygen, conductivity and shade analysis in each of the seven sites assessed for this project. Monitoring way be useful to carry on after the 20 year point. This data should be tabulated and analysed for trends. Improved conditions would be expected in sites downstream of work, such as lowered deposited sediment levels after hillslope stability planting. The observed changes can be compared to the projected changes below, again to assess strengths and weaknesses of the plan and allow for adaptations to improve effectiveness. During the project, the nutrient limits and other regional regulations may come into practice, or be altered; these changes should be adhered to as efficiently as possible. Communication of the plan, and progress, with integration of any local government requirements included ought to be shared with the regional and district councils.

Projected Improvements

In order to assess how well plan implementation is going, targets for improvements to water quality have been formed based on typical trends and lags from other studies (Dosskey et al, 2010). However, with the variation between studies used and differences in the management plans, the improvements in this situation may be slower due to the staggered implementation of work, compared to complete immediate implementation. Initial improvements may be due, by and large, to practice alterations and work completed by the time of the first review, which would likely show improvements in specific areas downstream of work, rather than whole catchment improvements.

The lag in ecological improvement after work carried out may mean little change initially in invertebrate communities, with more significant improvements later in the project. Once work is completed in all aspects upstream of a site, more rapid improvement can be expected, as downstream flow will no longer contribute such levels of pollutants. The projections are estimates and observed improvements may vary. But, it is important to have targets, as discussed in the literature review, to show implementation success and areas or aspects which need more focus during review points. In areas with less deterioration, improvements may be more rapid than those more severely impacted, as less damaged ecosystems tend to be more resilient (Dosskey et al., 2010). This indicates some areas in the catchment will improve more rapidly than others. The timeframe from land-use change and initial degradation to restoration also has an effect; those with shorter impacted timeframes tend to improve more rapidly and are more likely to return to previous condition (Dosskey et al., 2010). As it has been roughly 100 years since disturbance occurred, this may indicate a slower recovery.

Targets or estimated predictions for improvements in DRP, Sediment, MCI, QMCI and TN are given to compare to observed changes (Tables 11 to 15 and Figures 58. to 62.). Improvements in water quality will vary during the different stages of succession while riparian plants become properly established: while there is less shade, more nutrients can be filtered by sunlight-efficient aquatic plants; this will be reduced when the shading of the stream becomes more intense, which may cause the reduction in nutrients to slow; however it will also promote the native, rather than problematic aquatic plants to grow (Williams & Pickmere, 1993). Observed changes may vary, however the trends should roughly follow predictions, with any serious deviations noted and assessed, plan adaptions may be necessary in this case.

The aim for DRP is to reduce it to levels considered ecologically sustainable by putting the aquatic ecosystems at lower risk of degradation: this is therefore a suitable, optimistic target (ARMCANS, 2000). The target may take a while to be achieved, due to its association with erosion and thereby riparian filtering capabilities (Table 10).

Sediment coverage is much higher in the upper catchment, indicating an inability of the stream to transport the large amounts at the high rate of their input in the upper catchment. The upper catchment may always have more erosion due to steepness of terrain, and thereby susceptibility; however riparian work, hill slope planting, and altered land management practices can be expected to significantly reduce the loads entering the waterway. The mid and lower should also improve with better riparian management, and significant improvements can be expected overall once riparian and management practices are effectively in place (Table 11). The sediment targets are in line with the Cawthron SAM guide (2011), which predicts reference sites to have sediment coverage of 16% (FENZ group A), which the lower catchment may get nearer to, as it is already lower than sites with over 80% catchment vegetated,. The upper catchment with the most sediment currently aims to be reduced to below contemporary predicted values of 67% coverage (FENZ group A).

The invertebrate community will take longer to recover as it relies on all aspects of the aquatic environment improving to improve in MCI and QMCI score itself (Hamilton, 2012). Therefore there is more of a lag predicted, and improvements may continue past the project works' completion, which should have continued monitoring; a base minimum target of 95 for the MCI, correlating to around 4.5 in the QMCI score, is expected by the end of plan implementation. While Clapcott et al. (2011) assessed MCI score with sediment coverage and didn't find the relationship strong (2011), a sediment coverage of 65% would support an MCI score of 95 (y=113.19-0.29x65, y=95). The upper catchment may not be able to improve as much or at the rates of the mid and lower due to its harsher conditions and more extreme loss of riparian margin, but the mid and lower sections should be able to improve to 110, or roughly 5.4, by the end of the project, based on the Clapcott et al. (2011) equation above and moderation from the Kahuterawa (Tables 12 and 13).

Total nitrogen was the other component of concern, which is easily monitored, and aimed to improve under the management plan. The area with the most change likely is the upper catchment, which is well over guideline levels for eutrophication. The lag of improvement will also occur the most in the upper catchment as the riparian work will not be fully completed in the area for years. The riparian filtering should kick in rapidly when implemented. The targets from ARMCANZ, WRC and the nutrient levels of the Kahuterawa were used rationally to create the targets. Owing to the considerably higher TN concentration in the upper catchment, the highest value from the suggested concentration data was selected as the target concentration upon completion, as this was the most realistic and achievable concentration. The mid catchment is expected to improve as the upper catchment improves, aiming to be reduced to 0.4g/m^3, in between the Kahuterawa and the WRC guideline, and safely below the ARMCANZ trigger value (0.315, 0.5, 0.614 g/m^3 respectively). The lower catchment has the target of reaching the average TN concentration for the Kahuterawa as the effects of the upper catchment's higher concentrations are lower and plan implementation should take effect as well (table 14).

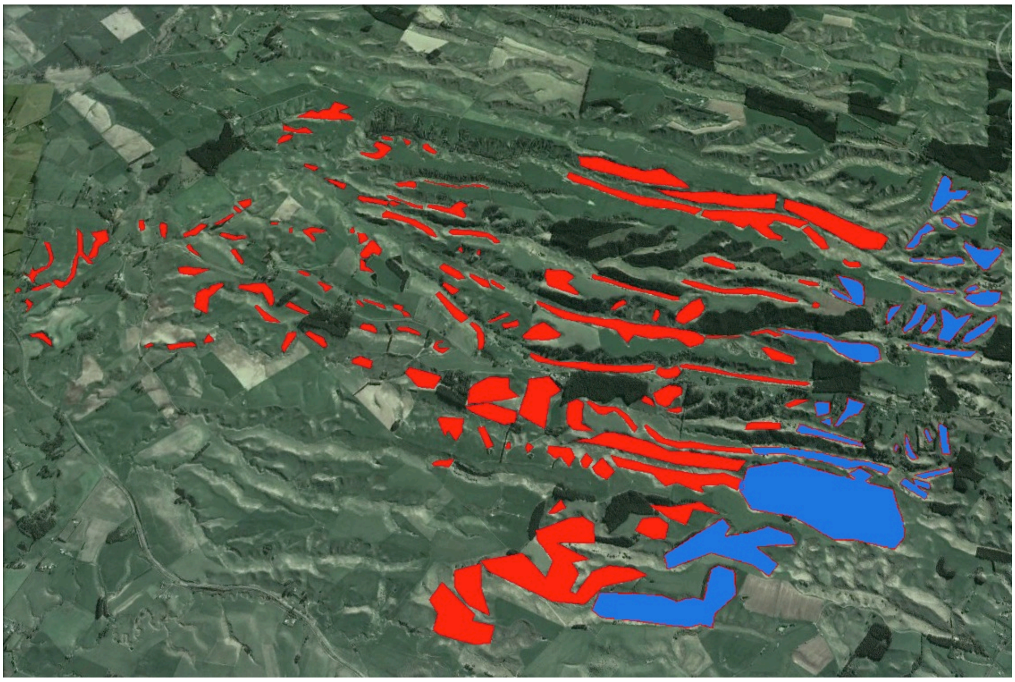

Figure 54. Hillslope stability progress at five years.

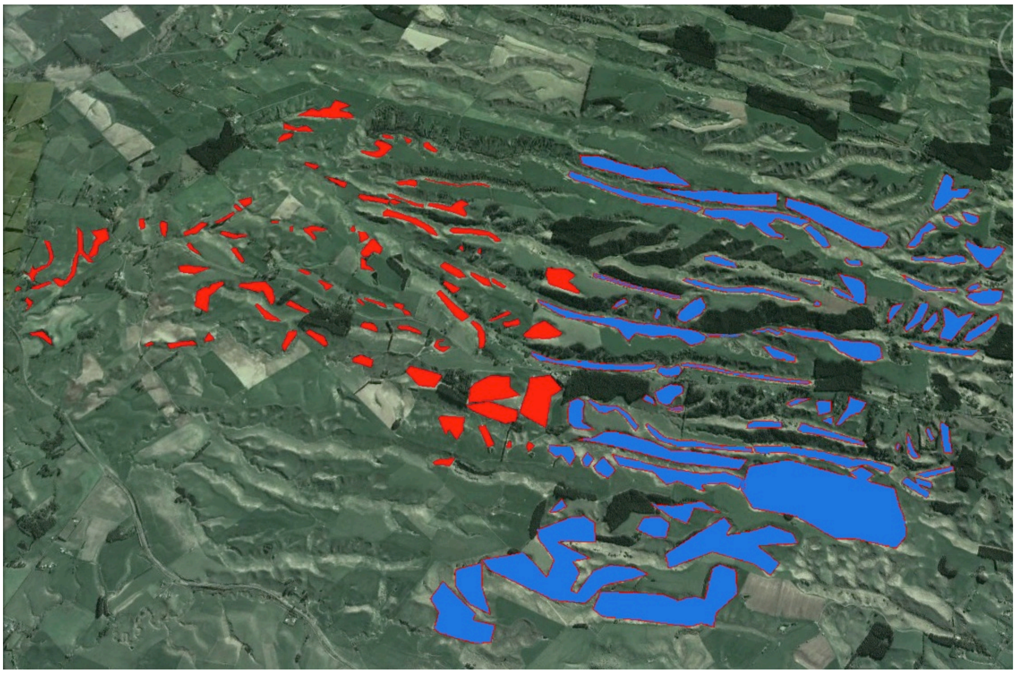

Figure 55. Hillslope stability progress at 10 years.

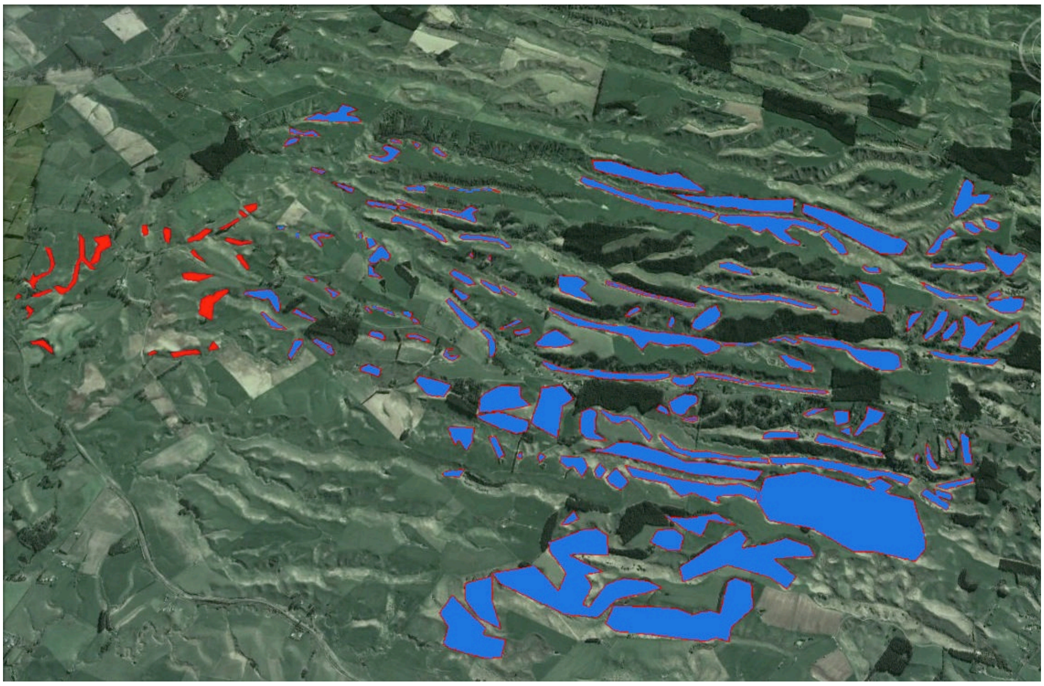

Figure 56. Hillslope stability progress at 15 years.

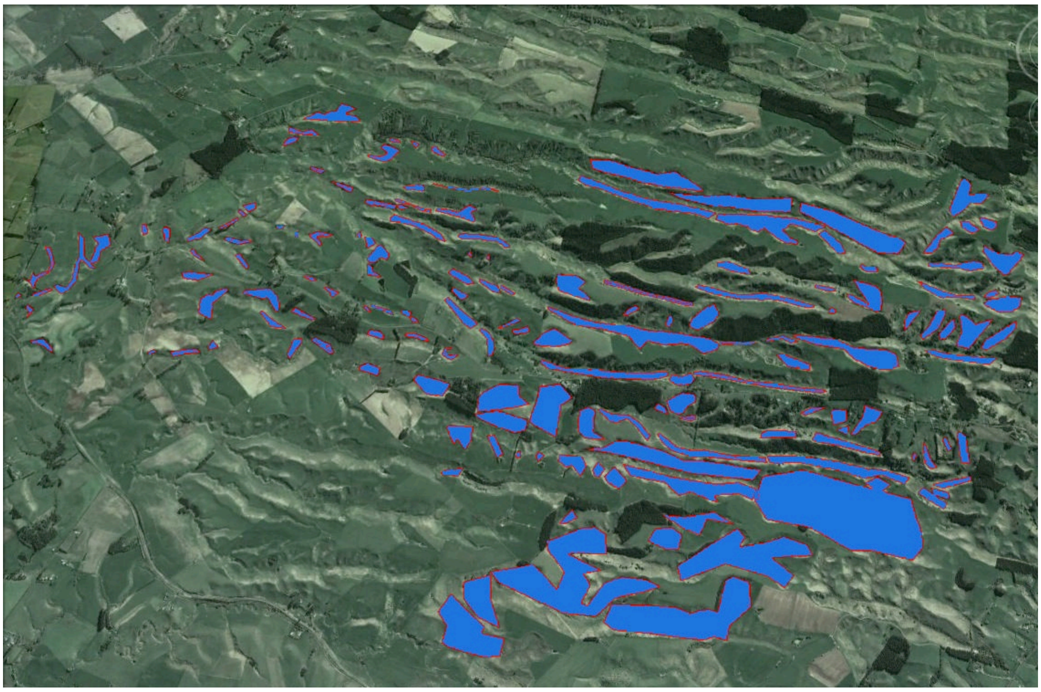

Figure 57. Hillslope stability progress at 20 years.

Table 11 *Dissolved reactive phosphorous decreases expected over the project period.*

Target/predicted DRP concentration (g/m3) by five yearly review					
	0	5	10	15	20
Upper	0.058	0.055	0.045	0.03	0.009
Mid	0.053	0.05	0.04	0.02	0.009
Lower	0.045	0.043	0.035	0.02	0.01

Table 12 *Sediment coverage decrease expected over the project period.*

Target deposited sediment coverage (%) by five yearly review					
	0	5	10	15	20
Upper	82	80	75	70	65
Mid	74	70	60	50	40
Lower	42	40	35	28	20

Table 13 *MCI expected increases over the project period.*

Target MCI score by five yearly review					
	0	5	10	15	20
Upper	69	69	72	85	95
Mid	77	77	85	95	105
Lower	92	95	100	107	110

Table 14 *QMCI score expected increases over the project period.*

Target QMCI score by five yearly review					
	0	5	10	15	20
Upper	2.6	2.7	3.1	4	4.8
Mid	4.2	4.2	4.4	4.8	5.2
Lower	4.7	4.8	5	5.3	5.4

Table 15 *Total nitrogen targets concentration decreases over the project period.*

Target total nitrogen concentration (g/m3) by five yearly review					
	0 years	5 years	10 years	15 years	20 years
Upper	2.2	2.0	1.5	1.0	0.6
Mid	0.7	0.7	0.6	0.5	0.4
Lower	0.7	0.6	0.5	0.4	0.3

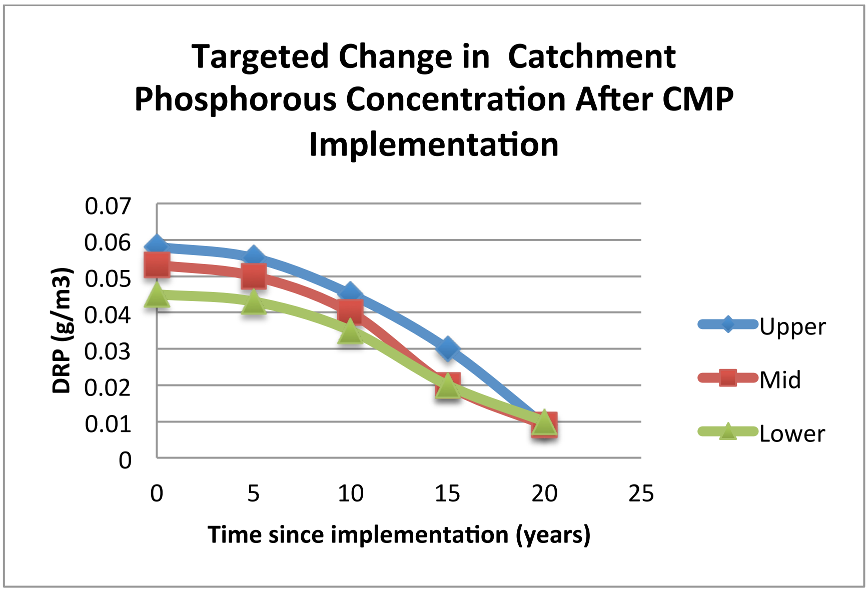

Figure 58. Targets for DRP improvement over the period of the project.

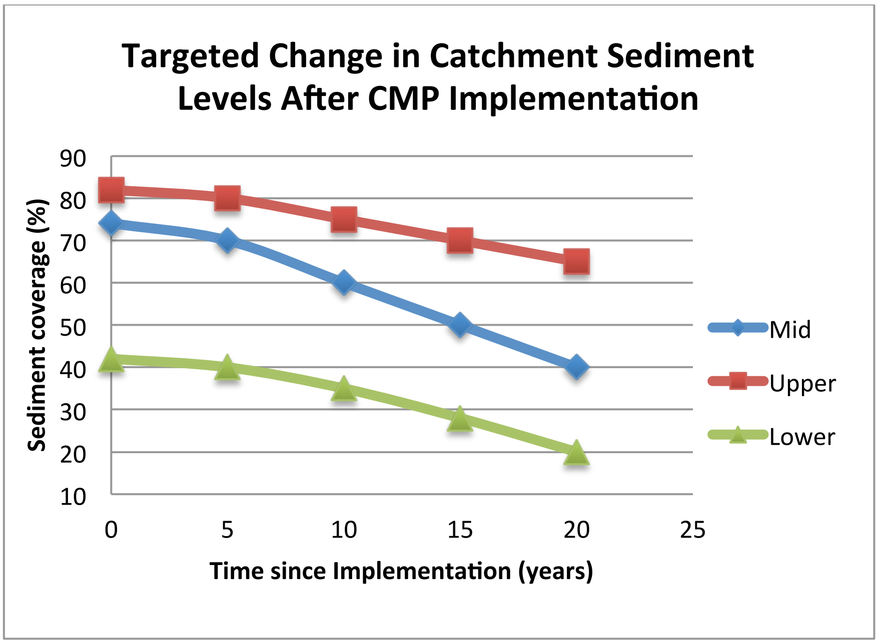

Figure 59. Targets for sediment coverage reduction over the project period.

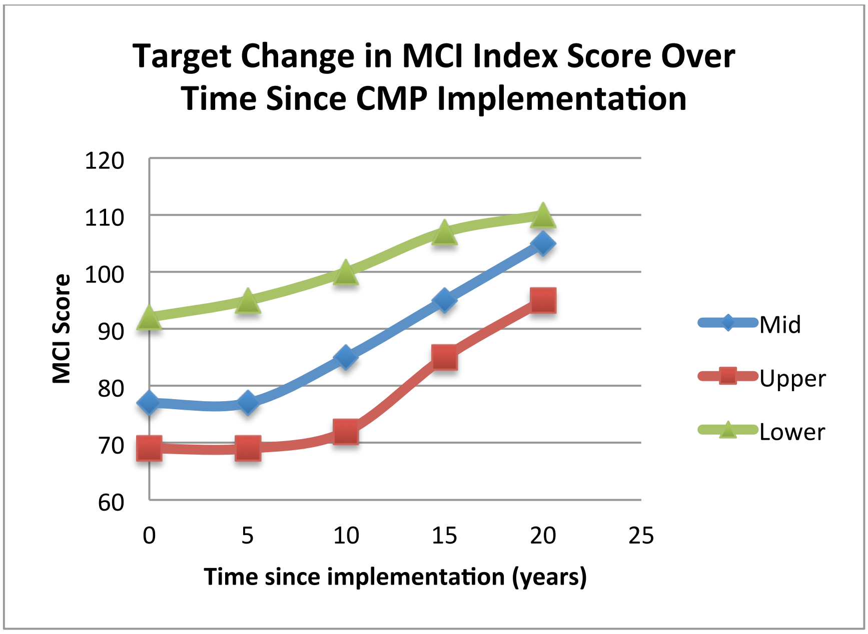

Figure 60. Target change in MCI score over the project period.

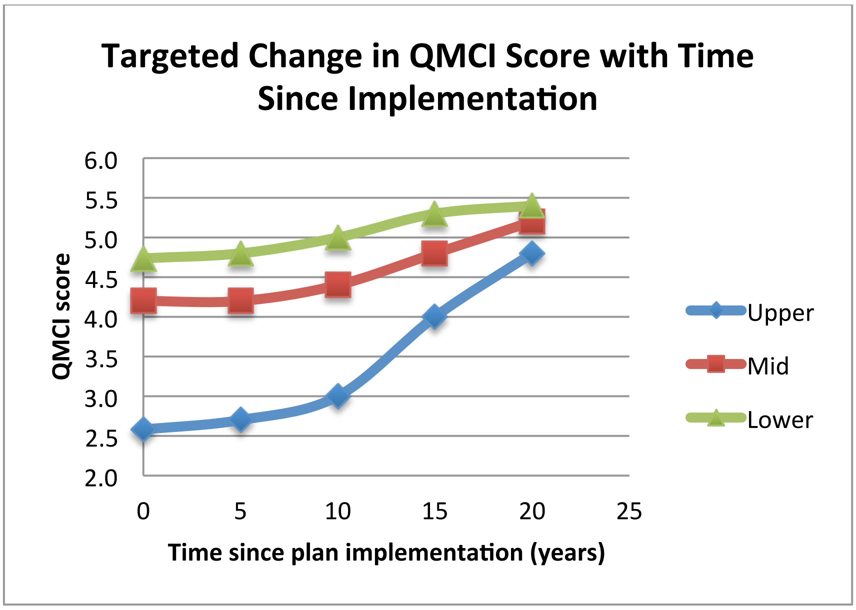

Figure 61. Target changes in QMCI score over the project period.

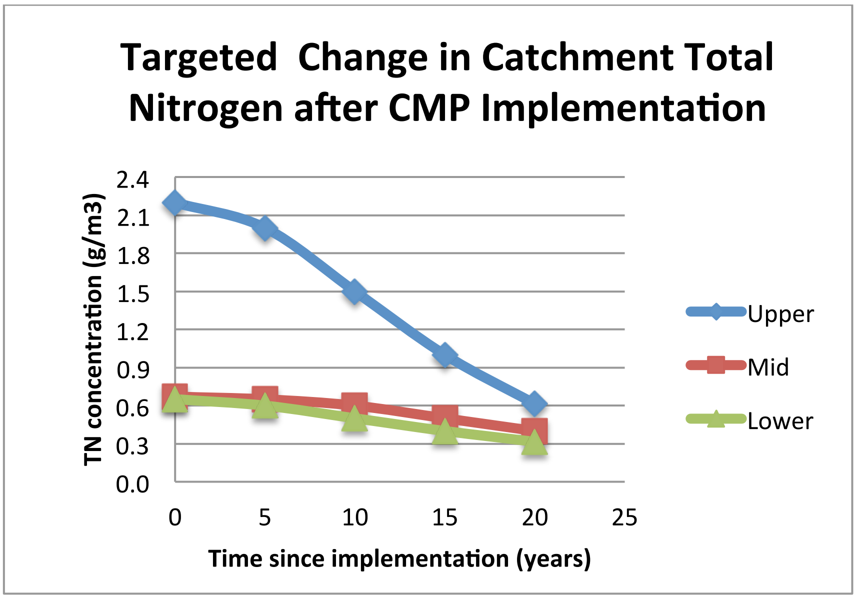

Figure 62. Target reductions in TN over the project period.

Reference site use

The forested area upstream of the Kahuterawa would have been relatively similar to the Mangaone pre-clearance. The MCI scores provide an ultimate target for the Mangaone West. The TN concentrations are much higher everywhere in the Mangaone West (min 0.54g/m3) compared to the reference catchment (average 0.315g/m3). The DRP is low, significantly lower than in the Mangaone West and is just below the trigger value for

DRP of 0.009g/m3; the aim for the Mangaone West with DRP is to be reduced to trigger values. The sediment values are far lower than the project catchment; however there is only two years of data. DO is within expected range, but as it has been taken during the day when maximums are reached, it is less informative; finding minimums which occur over night can show if oxygen depletion is occurring, indicating excessive algal growth and pollution (Dean & Richardson, 1999; Wilcock, McBride, Nagels, & Northcott, 1995).

Timeline

Project timeline by five year intervals, breaks represent expected progress analysis monitoring, review and adaptations. A total time of 20 years is estimated for implementation, due to the high environmental expectation sought. Adaptations such as adhering to nitrogen limits required by law may come into effect during the restoration process. If expectations are exceeded, speed up the timeline accordingly.

0-5 years	6-10 years	11-15 years	16-20 years
BMP advised information distributed and briefed to all in catchment	BMP revision session and new reviewed info sent out (new tech & practices).	Repeat	Repeat
Hillslope plantings in top quarter of all red sectioned headwaters and any identified urgent areas	Second section of hillslope plantings any new/reviewed priority areas included	Third section and review priority areas	Remaining completed
Spaced stream side plantings in bottom quarter of upper catchment	Streamside planting complete for opposing half to hillslope work	All streamside planting complete	maintenance check
Riparian fencing in gaps of lower catchment and mid-upper fenced	Fencing of mid catchment	Fencing of upper catchment	Ensure all fenced
Riparian planting in gaps in mid and lower sections, all areas under willows	Mid-upper catchment riparian planted	Streamside stability planting enhanced in upper catchment from bottom up	Inspect all riparian areas establishment and fill any gaps
Willows poisoned from beginning of mid section down, after riparian planting	All of mid catchment willows treated, accessible branches removed	All willows in lower catchment treated	Any new riparian willow growth
Weeds in mid section sprayed/ removed in downstream	Lower section removed/sprayed, progression downstream	Reassess weed areas for removal action	Reassess weed areas for removal action
Bait stations placed out in lower catchment riparian area	Bait stations placed out in mid catchment riparian area	Bait stations in mid-upper riparian area	Bait stations in non-riparian forested areas

Alternative Catchment Management Plan

The alternative, back-up plan focuses solely on riparian management. In this plan the implementation is altered from the approach taken in the suggested plan. This difference is due to the priority in this plan being solely on limiting inputs from entering the waterway. The suggested plan has the advantage of aiding in the reduction of losses from the land as well as their input into the waterways. The current riparian characteristics and deductions for riparian management previously remain the same, but the approach is different as the plan's priorities are different. The progress analysis would be much the same excluding the hillslope work aspect.

Plan Approach

The riparian strip is the sole functioning mechanism in reducing the connectivity between land and water, limiting the land-uses' effects on the aquatic ecosystem's functioning. The riparian filter must therefore be well established and maintained in all areas, and wider than prescribed in the combined plan, as there is a higher level of filtering required to compensate for erosion and runoff.

Fencing

The fencing is needed a minimum of 10m out from stream banks everywhere in the catchment. The upper catchment is a priority as this is where the worst erosion and run off typically occurs in a catchment, due to coupling (Gomi, Sidle, & Richardson, 2002). This area should therefore be targeted first and fenced off before planting to allow protection for riparian plants from stock. This will also protect the banks sooner from bank erosion (phosphorous and sediment inputs) caused by stock trampling. Working from the top of the catchment downstream to implement a riparian buffer where none is currently present is logical to reduce the cumulative effects of nutrients, sediment and bacteria downstream Sidle & Hornbeck, 1991). The fencing should continue downstream and finally fill the gaps in the lower catchment.

Planting

First areas for planting include the gaps in the lower and underneath willows. Newly established riparian planting should take place after the fencing to improve survival rates. The full 10m from fence line to stream banks should be well planted with natives and some desired exotics, if wanted by the residents, again from the top of the headwaters in a downstream direction. The planting on stream bank edge ought to be trees which will provide shade through height, and bank stability through extensive interlocking root growth. The upper catchment, as with the fencing, ought to be the starting point for new riparian planting, with downstream progression.

Willows

Willows need to be initially planted up underneath and around as previously suggested before removal. Again removal should be done through drill inject poisoning. The middle section would suit planting first as the upper catchment is being planted, because after the upper catchment is done riparian work will begin covering gaps in the mid-section. The lower catchment willows would be planted under after the mid catchment, and again followed through with poisoning after the undergrowth has had some time to establish.

Weeds and pests

The weeds need to be approached in the same manner as described in the combined plan. The approach is suggested from the mid catchment where they begin to become an issue downstream, in order to reduce regrowth which could occur due to downstream spread if the bottom of the catchment was targeted first. The weed growth would then need to be checked seasonally for growth for any repeats in future. Later, after riparian planting in the upper catchment is completed, that area will need to be included in the process.

The same pest control management scheme as previously described is suitable again, with no progression to management of non-riparian forests. To even out the workload in the catchment, as well as begin pest control where effective, the pest management could begin in the bottom end of the catchment and proceed upstream.

Implementation timeline

1-5 years	6-10 years	11-15 years	16-20 years
Fence off upper catchment	Fence mid catchment	Fence gaps lower catchment	Recheck fence failings
Plant gaps in lower catchment riparian and under all willows	Plant up upper catchment riparian	Plant mid catchment riparian	Check establishment and fill any gaps
Poisoning of mid catchment willows	Poisoning of lower catchment willows	Any new or missed growth killed off	Any new growth removed
Mid catchment weeds removed	Lower catchment weeds removed	Yearly weed control where needed	Yearly weed control where needed
Pest control carried out in lower and mid catchment	Pest control carried out in upper catchment	Continued control and effectiveness evaluation	Repeat

As this plan option does not include any change in behaviour or reduce hillslope erosion, it is less beneficial than the primary plan option and will have less of a positive impact on the terrestrial and aquatic ecosystems, and the community. As the community indicated they wanted improved waterways, improvement in topsoil retention, sustainability, and more native biodiversity, particularly avian, the primary suggested plan is far more appropriate as it is more able to meet these objectives than riparian management alone. While this plan may be cheaper, the overall change will be less, and so ‘value for money’ or ‘ecological and economic improvement for money’ is higher with the combined plan approach.

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Conclusion

The Mangaone West is valued by its community and has the potential for significant environmental improvements to be made. The catchment has undergone much change since it was more intensely colonised and developed from the 19th century. The clearance of much of the native forest and scrub that dominated the land, and the riparian margins alongside the waterways has had a profound effect on the catchment. The degradation of land and waterways through erosion and sedimentation has been significant; the comparison to a similar, more natural-reference catchment highlights this.

The proposed plan gives direction to change the environmental state of the catchment's land and waterways, which would improve the ecological, economic, social and aesthetic values of the catchment. A traditional CMP framework was combined with the river styles framework to aid in producing a well-rounded approach. The proposed plan has been created in a manner to maintain integration, and relies on a combined approach to address the main issues continuing to degrade the catchment.

The main issues to address

- Hillslope erosion and slope and waterway connectivity (upper-mid).
- Sedimentation of waterways, sediment regime.
- Nitrogen and phosphorous loss from land to waterways (exceeding guidelines), and potentially groundwater.
- Riparian degradation; incomplete, lack of waterway shade (upper-mid catchment), weeds and pests, willows present.

Main Strategies

The plan addresses the issues through management strategies:

- Hillslope plantings of erosion risk areas.
- Riparian restoration (planting, fencing, and weeding).
- Fencing of waterways (stock exclusion).
- BMPs by landowners and inhabitants.

Integration and success components

- Consensus catchment view plan object.
- Retain stakeholder engagement through entire project- consult, involve (planting, and monitoring), and inform (progress).
- Monitor.
- Evaluate and adapt.
- Outcomes- measurable (biophysical parameters, and social evaluation).

Environmental progress improvement limitations

Some shifts in regime such as flow and sediment have changed significantly within the catchment, but the extent of change can be reduced. The lower catchment has high potential to be restored more closely to the reference catchment, but in order to do this, areas upstream must be managed effectively. The mid catchment is also likely to improve significantly under management, and the upper catchment will also benefit from reduced erosion and sedimentation, though sediment levels may be expected to remain slightly higher than the rest of the catchment. Changes in some environmental aspects will occur faster than others; the physical changes in the environment once implementation has been carried out should occur relatively quickly with consideration to upstream influences. Biological changes will likely occur more slowly, potentially more so in the decades following project completion (Meals, Dressing, & Davenport, 2011). Limitations to improvement could occur if integration isn't successful at gaining community approval and participation and implementation of BMPs, though the Mangaone West has promising signs in this regard. Climate change may also be factor, but the better the plan is implemented, the less its effects will be (The Society for Ecological Restoration International, 2007).

Recommendations

The recommendations are largely a reiteration of plan strategies.

- Use the combined approach plan to address environmental issues occurring within the catchment from all areas, at the same time.
- Have all catchment landowners carry out BMPs on their properties, and use whole-farm plans.

- Spaced hillslope plantings of steeper slopes and headwater slopes in upper catchment.
- Riparian plantings of: gaps in lower catchment, spaces under willows throughout the catchment, and the entire upper catchment (at least six meters wide for the main channel except headwaters and small ephemeral streams (three meters).
- Fence off riparian margins (before plantings), at least six meters wide for the main channel (except headwaters and small, ephemeral, first order streams - three meters).
- Remove willows through staggered poisoning once native riparian plants have been established.
- Weed management through riparian assessment followed by poisoning or physical removal where appropriate.
- Pest management through bait stations every 50 by 50m within remnant forest and riparian margins.
- Monitoring of water quality (nitrogen and phosphorous), invertebrate community assessments (MCI/QMCI), deposited sediment assessment, during project and for 10 years after completion.
- Use targets provided in the discussion for evaluation and progress assessment. These may also be useful for gaining support and adoption by landowners and other stakeholders.
- Evaluation of progress of implementation and effects of strategies implemented by five yearly review.
- Allow community involvement through plantings; weed control, and progress report-back.

Recommendations to reduce limitations of catchment knowledge:

While flow has been estimated, through ArcGIS and from council meter reading above and below the Makino and Mangaone West confluence, a more detailed assessment of flow may be valuable to monitor seasonal variation, and potential changes during and after the project due to climate change. This would provide a better understanding of the flow regime, dynamics, and the catchment's hydrological response to afforestation.

The E-coli concentration in the waterway was not assessed; it may also be valuable to assess and monitor the E-coli concentrations of the project period. This would show the impact of excluding stock from waterways to landowners, and ensure that the waterway meets recreation contact requirements.

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Appendices

Appendix A

Tabulated raw chemical data

site	site	total O N (g/m³)	NO2 (g/m³)	NO3 (g/m³)	DRP (g/m³)	RP (g/m³)
Top (1)	1	0.057	<0.005	0.053	0.049	<0.005
	2	0.05	<0.005	0.046	0.093	<0.005
	3	0.057	<0.005	0.053	0.082	<0.005
Bushlands (2)	1	0.007	<0.005	<0.005	0.046	<0.005
	2	0.006	< 0.005	<0.005	0.039	<0.005
	3	0.007	<0.005	<0.005	0.04	<0.005
Managhs up	1	0.074	<0.005	0.07	0.033	<0.005
(3)	2	0.063	<0.005	0.059	0.04	<0.005
	3	0.068	<0.005	0.064	0.034	<0.005
Te R (4)	1	0.152	<0.005	0.148	0.067	<0.005
	2	0.153	<0.005	0.149	0.068	<0.005
	3	0.153	<0.005	0.149	0.063	<0.005
Strandon (5)	1	0.141	<0.005	0.137	0.057	<0.005
	2	0.142	<0.005	0.138	0.061	<0.005
	3	0.144	<0.005	0.14	0.057	<0.005
Lees (6)	1	0.092	<0.005	0.088	0.047	<0.005
	2	0.088	<0.005	0.084	0.036	<0.005
	3	0.089	<0.005	0.085	0.034	<0.005
End (7)	1	0.081	<0.005	0.077	0.044	<0.005
	2	0.081	<0.005	0.077	0.053	<0.005
	3	0.081	<0.005	0.077	0.054	<0.005

Tabulated average water quality data of the Mangaone West.

Site	Distance (Km)	NH4 (g/m³)	total N (g/m³)	nitrite (g/m³)	nitrate(g/m³)	DRP (g/m³)	TP (g/m³)
1	2.5	0.022	1.2	0.002	0.001	0.041	0.1
2	7	0.014	3.2	0.002	0.001	0.106	0.58
3	10.4	0.014	0.6	0.004	0.098	0.023	0.07
4	13.8	0.14	0.8	0.01	0.186	0.031	0.11
5	18.4	0.03	0.6	0.005	0.2	0.038	0.09
6	22.3	0.056	0.75	0.006	0.297	0.029	0.12
7	28	0.022	0.54	0.004	0.212	0.034	0.08

Appendix B

Raw Invertebrate data, and MCI and QMCI scores

Site	Invertebrate	N	Invert MCI	Species r	Proportion abundance	MCI	Ave MCI	QMCI working	QMCI	Ave QMCI
1.top	physa	17.00	3.00	8.00	0.10	77.50		0.30	3.50	
	oligochaete	40.00	1.00		0.24			0.24		
	austrolestes	3.00	6.00		0.02			0.11		
	rhantus	1.00	5.00		0.01			0.03		
	antiporus	11.00	5.00		0.06			0.32		
	anisops	2.00	5.00		0.01			0.06		
	daphnia	80.00	5.00		0.47			2.35		
	chironomus	16.00	1.00		0.09			0.09		
		170.00								
	chironomus	15.00	1.00	8.00	0.13	72.50	75.00	0.13	2.67	2.98
	austrolestes	1.00	6.00		0.01			0.05		
	oligochaete	32.00	1.00		0.27			0.27		
	physa	42.00	3.00		0.36			1.08		
	rhantus	2.00	5.00		0.02			0.09		
	culicidae	1.00	3.00		0.01			0.03		
	antiporus	23.00	5.00		0.20			0.98		
	staphylinidae	1.00	5.00		0.01			0.04		
		117.00								
	austrolestes	1.00	6.00	8.00	0.01	75.00		0.08	2.78	
	physa	16.00	3.00		0.22			0.65		
	chironomus	32.00	1.00		0.43			0.43		
	culicidae	1.00	3.00		0.01			0.04		
	paradixa	2.00	4.00		0.03			0.11		
	antiporus	19.00	5.00		0.26			1.28		
	oxyethira	1.00	2.00		0.01			0.03		
	elmidae	2.00	6.00		0.03			0.16		
		74.00		8.00						
2. bushlands										
	rhantus	1.00	5.00	5.00	0.02	76.00		0.09	2.00	
	oligochaetes	40.00	1.00		0.74			0.74		
	physa	1.00	3.00		0.02			0.06		
	hydrophilid	1.00	5.00		0.02			0.09		
	cyclopoids	11.00	5.00		0.20			1.02		
		54.00								
	Oligochaetes	32.00	1.00	8.00	0.35	60.00	63.11	0.35	3.16	2.18
	Gyraulus	4.00	3.00		0.04			0.13		
	Sigara	1.00	5.00		0.01			0.05		
	austrosimulium	1.00	3.00		0.01			0.03		
	staphylinidae	4.00	3.00		0.04			0.13		
	muscidae	5.00	2.00		0.05			0.11		
	oxyethira	2.00	2.00		0.02			0.04		
	cyclopoids	42.00	5.00		0.46			2.31		
		91.00								
	oligochaetes	48.00	1.00	6.00	0.76	53.33		0.76	1.37	
	physa	1.00	3.00		0.02			0.05		
	gyraulus	1.00	3.00		0.02			0.05		
	laccobius	2.00	5.00		0.03			0.16		
	muscidae	10.00	2.00		0.16			0.32		
	oxyethira	1.00	2.00		0.02			0.03		
		63.00		6.33						

3. up managhs										
	paracalliope	32.00	5.00	8.00	0.44	90.00		2.19	4.63	
	physa	1.00	3.00		0.01			0.04		
	gyraulus	4.00	3.00		0.05			0.16		
	potamopyrgus	24.00	4.00		0.33			1.32		
	diaprepocris	2.00	5.00		0.03			0.14		
	sigara	2.00	5.00		0.03			0.14		
	antiporous	1.00	5.00		0.01			0.07		
	austrolestes	7.00	6.00		0.10			0.58		
		73.00								
	potamopyrgus	7.00	4.00	5.00	0.58	72.00	77.64	2.33	3.75	4.16
	sigara	1.00	5.00		0.08			0.42		
	anisops	1.00	5.00		0.08			0.42		
	gyraulus	2.00	3.00		0.17			0.50		
	oligochaetes	1.00	1.00		0.08			0.08		
		12.00								
	physa	10.00	3.00	11.00	0.03	70.91		0.10	4.10	
	diaprepocoris	3.00	5.00		0.01			0.05		
	potamopyrgus	200.00	4.00		0.69			2.78		
	gyraulus	15.00	3.00		0.05			0.16		
	oligochaetes	1.00	1.00		0.00			0.00		
	sphaeridae	1.00	3.00		0.00			0.01		
	paracalliope	42.00	5.00		0.15			0.73		
	maoridiamesa	4.00	3.00		0.01			0.04		
	chrinomus	1.00	1.00		0.00			0.00		
	ischaura	9.00	6.00		0.03			0.19		
	xanthocnemis	2.00	5.00		0.01			0.03		
		288.00		8.00						
4. te r										
	sphaeridae	4.00	3.00	8.00	0.02	75.00		0.05	4.08	
	paracalliope	40.00	5.00		0.18			0.88		
	potamopyrgus	160.00	4.00		0.71			2.83		
	gyraulus	15.00	3.00		0.07			0.20		
	plectrocnemia	1.00	8.00		0.00			0.04		
	austrosimulium	3.00	3.00		0.01			0.04		
	oligochaetes	1.00	1.00		0.00			0.00		
	maoridiamesa	2.00	3.00		0.01			0.03		
		226.00								
	potamopyrgus	95.00	4.00	4.00	0.50	75.00	74.44	2.00	4.44	4.21
	paracalliope	90.00	5.00		0.47			2.37		
	hydrobiosis	2.00	5.00		0.01			0.05		
	oligochaetes	3.00	1.00		0.02			0.02		
		190.00								
	potamopyrgus	96.00	4.00	6.00	0.64	73.33		2.56	4.13	
	gyraulus	3.00	3.00		0.02			0.06		
	paracalliope	42.00	5.00		0.28			1.40		
	oligochaetes	7.00	1.00		0.05			0.05		
	alboglossiphonia	1.00	3.00		0.01			0.02		
	elmidae	1.00	6.00		0.01			0.04		
		150.00		6.00						

5. strandon										
	potamopyrgus	80.00	4.00	3.00	0.90	80.00		3.60	4.08	4.22
	muscidae	1.00	3.00		0.01			0.03		
	paracalliope	8.00	5.00		0.09			0.45		
		89.00								
	potamopyrgus	6.00	4.00	6.00	0.27	80.00	80.00	1.09	4.59	
	orthoclad	2.00	2.00		0.09			0.18		
	paracalliope	12.00	5.00		0.55			2.73		
	xanthocnemis	1.00	5.00		0.05			0.23		
	plectrocnemia	1.00	8.00		0.05			0.36		
		22.00								
	potamypyrgus	64.00	4.00	1.00	1.00	80.00		4.00	4.00	
		64.00		3.33						
6. lees										
	paracalliope	64.00	5.00	5.00	0.64	100.00		3.20	4.69	
	potamopyrgus	32.00	4.00		0.32			1.28		
	physa	1.00	3.00		0.01			0.03		
	xanthocnemis	2.00	5.00		0.02			0.10		
	zelandoptila	1.00	8.00		0.01			0.08		
		100.00								
	potamopyrgus	13.00	4.00	6.00	0.21	93.33	94.44	0.84	4.82	4.71
	physa	1.00	3.00		0.02			0.05		
	paracalliope	40.00	5.00		0.65			3.23		
	maoridiamesa	1.00	3.00		0.02			0.05		
	plectrocnemia	2.00	8.00		0.03			0.26		
	anisops	5.00	5.00		0.08			0.40		
		62.00								
	potomopyrgus	3.00	4.00	2.00	0.38	90.00		1.50	4.63	
	paracalliope	5.00	5.00		0.63			3.13		
		8.00		4.33						
7. end	paracalliope	64.00	5.00	4.00	0.75	95.00		3.76	4.80	
	potamopyrgus	14.00	4.00		0.16			0.66		
	orthoclad	4.00	2.00		0.05			0.09		
	psilochorema	3.00	8.00		0.04			0.28		
		85.00								
	potamopyrgus	4.00	4.00	10.00	0.01	98.00	89.67	0.03	4.88	4.76
	berosus	2.00	5.00		0.00			0.02		
	paracalliope	464.00	5.00		0.93			4.65		
	oligochaetes	12.00	1.00		0.02			0.02		
	orthoclad	7.00	2.00		0.01			0.03		
	elmidae	1.00	6.00		0.00			0.01		
	aoteapsyche	1.00	4.00		0.00			0.01		
	plectrocnemia	4.00	8.00		0.01			0.06		
	culicidae	1.00	3.00		0.00			0.01		
	neppia	1.00	3.00		0.00			0.01		
	psilochorema	2.00	8.00		0.00			0.03		
		499.00								
	berosus	1.00	5.00	5.00	0.00	76.00		0.01	4.61	
	elmidae	1.00	6.00		0.00			0.01		
	oligochaetes	32.00	1.00		0.08			0.08		
	paracalliope	368.00	5.00		0.89			4.44		
	orthoclad	12.00	2.00		0.03			0.06		
		414		6.333333						

Appendix C

Physical sampling data from the Mangaone West

Raw data of estimated sediment

Site	% Sediment	% Ave Coverage
1. top	100	100
	100	
	100	
2. bushland	60	63
	50	
	80	
3. managhs	70	77
	60	
	100	
4. te r	45	45
	40	
	50	
5. strandon	100	100
	100	
	100	
6. lees	40	57
	50	
	80	
7. end	20	28
	50	
	15	

Raw data of estimated stream shading from riparian cover

Site	% Shade	Ave % shade
1. top	0	3.3333333
	5	
	5	
2. bushland	5	13.333333
	5	
	30	
3. managhs	20	13.333333
	10	
	10	
4. te r	40	26.666667
	30	
	10	
5. strandon	40	43.333333
	50	
	40	
6. lees	70	63.333333
	50	
	70	
7. end	65	65
	70	
	60	

Appendix D

Flow data of Makino Stream from 1992 until 2012. Provided by Horizons Regional Council.

Year	Makino at Boness (L/s)	Makino at Rata (L/s)	Difference
1992	1122	607	515
1993	396	220	176
1994	1084	603	481
1995	1088	539	549
1996	1227	565	662
1997	404	234	170
1998	1207	375	832
1999	608	325	283
2000	625	268	357
2001	1066	607	459
2002	1155	817	338
2003	605	453	152
2004	1686	1339	347
2005	673	628	45
2006	1308	832	476
2007	580	409	171
2008	1089	626	463
2009	946	461	485
2010	1242	388	854
2011	1014	189	825
2012	726	87	639

Average difference (L/s)	Mangaone West flow (m3/s)
441.8571429	0.441857143

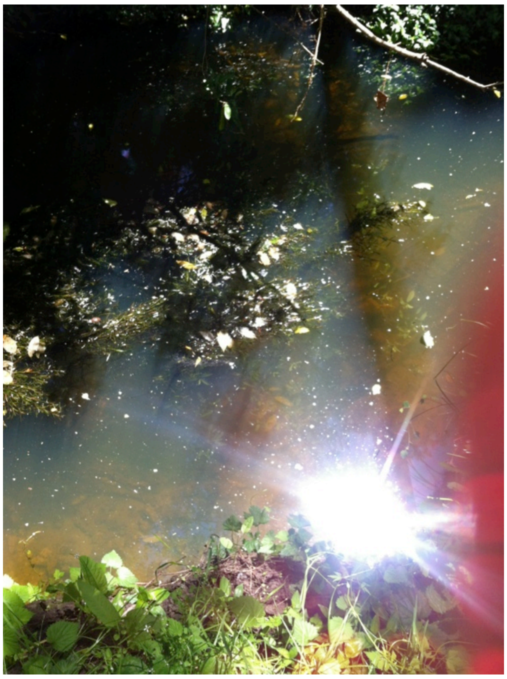
Appendix E

Photographs of weeds in the Mangaone West, taken during fieldwork (2013).

Tradescantia smothering banks and forest floor through remant riparian margins in the lower catchment. Note regeneration on close bankside where Tradescantia is not present (top right)

Damned blocked area, caused mostly to left by willow, tradescantia in background, clog from willows can cause bridge for tradescantia and allow proliferation to spread on other side.

Japenese honeysucke vine (rear right).



Blackberry and blunt pondweed, curly pondweed, respectively.

Both banana passionfruit vine.

Muehlenbeckia australis (Pohuehue). Blackberry

Appendix F

BMPs of relevance to the Mangaone West.

Nutrient Management

With nutrient efficiencies converted into animal growth or milk at only 30% for both phosphorous and nitrogen, it is important they are well managed within the catchment. While phosphorous is retained well in the soil (65%), nitrogen is not (13%) with leaching rates varying, averaging 30-40% (Ritchie, 2006). Although sheep and beef farming tends to use less fertiliser than dairying, management needs to be highly effective to allow for the best productivity and environmental outcomes (Davies, 2012).

Fertiliser

- Fertiliser/nutrient management plans and budget should be required for those using nitrogen, phosphorous or urea so vegetative/pastoral needs are met, but excess is not wasted (FAO/ECE, 1991). An individualised plan could suggest appropriate fertiliser needed to aid plant growth and replace nutrients lost from the system to animal growth. The capital cost of the plan if not subsidised or covered by LCT is off set by the gains in productivity by applying the correct amounts of fertiliser and the reduced costs of fertiliser when excess is added without the plan (Davies, 2012).
- Smaller amounts more frequently is more effective and efficient (plant uptake), and results in less loss to the environment. This is more cost-effective, and, while slightly more time consuming, the benefits for plant growth and reduced nutrient losses outweigh the extra time for application. From many literary studies, the range for acceptable and optimised fertiliser amounts per year ranges up to 120kg/ha/y with upper limits of 150kg/ha/y (Fertiliser Association, 2013; Waikato Regional Council, 2007/2012). This is lower than the once supported range of around 200 to 400kg/ha/y, due to the diminishing rate of return by applying more fertiliser, as the more applied, the higher the rates of loss from the area to the external environment (waterways, leaching). The total amount added in a single application should never exceed 60kg/ha as the amount vegetation is able to utilise is exceeded and lost from the land. More appropriate single application rates are around 25kgN/ha (Ritchie, 2006).
- Keep soil vegetated, as it reduces leaching and soluble nitrogen build up (Ignazi, 1993). Also reduces splash erosion and run off over winter. Grazing down excessively is not advisable in most circumstances as it leaves the area prone to erosion, leaching, runoff and pugging. Fertiliser should only be applied to land with over 25mm of pasture growth or 80% vegetative coverage, normally around a week after grazing (Fertiliser Association, 2013; Ritchie, 2006).
- The timing of fertiliser with regard to weather can make a significant difference in the amount wasted and lost, and the amount taken up by vegetation and kept within the soil. Fertilisers ought to be applied only when little to no rain is falling or predicted for the following day, and when little to no wind is present (<15km/h) or forecast for the following few hours, and especially avoided when wind is blowing toward water bodies.
- The seasonal variation in weather and plant growth provides indicators to when to apply fertiliser as well. Spring peaks pasture growth, and is associated with a net export of nutrient use, so fertiliser is often useful to allow further pasture

growth and nutrient maintenance of the land. Earlier autumn allows again for a more suitable climate, allowing quick pasture growth (Fertiliser Association, 2013). High rain and cooler temperatures closer to winter make fertiliser application inefficient and wasteful; it can be so during summer time as well, especially in this particular catchment where seasonality characteristics can be highly varied (Davies, 2012). Applying during periods of low growth and soil saturation wastes fertiliser as it is likely to be lost from the area before the plants uptake it for growth (Davies, 2012; Fertiliser Association, 2013, Ritchie, 2006)).

- When using multiple fertilisers, users need to ensure compatibility with an expert; this would be provided for in a farm plan.
- Excess fertiliser should not be dumped as it is a useful and costly resource: applying it to other suitable land or trading with a neighbour is a beneficial option.
- Application methods needs to be suited for the terrain Eg.: in the hill country of the Mangaone West, the calibration of equipment must be accurate for slopes to avoid under-fertilising or wasting product and polluting.
- Apply 4-6 weeks before grazing, never to fallow land, nor compacted/pugged or saturated soils, and never in a drought until after it's broken (Fertiliser Association, 2013).
- Distances of 10m from waterway for closest application, higher distances with increasing slope, as fertiliser will travel downhill with water over time (Fertiliser Association, 2013).
- Fertiliser limited further to slopes over 25°, as most will run downhill during rainfall events and be lost (Fertiliser Association, 2013).
- Fertilisers with as little cadmium as possible used, maximum of industry limit (280mg/kgP) (Fertiliser Association, 2013).
- Even distribution ensured, operating up and down slopes for safety if manually applying, along slopes if computerised. GPS used in any aerial application.
- Rational use, depth of not more than 8-10mm for effluent, to reduce leaching and nutrient/resource loss, as this is the suggested optimal amount to apply to gain maximum efficiency.
- Use of slow-release phosphate fertilisers.
- Nitrification inhibitors to reduce the leaching and loss of nitrogen (30-80%) meaning more fertiliser and urea can be put back into animal growth (increases the recycling of nitrogen within the area) (Ritchie, 2006).
- Correct soil acidification with lime, however ensure correct concentrations and evenness of spread using soil tests and appropriate application methods, again in smaller more frequent amounts (Ritchie, 2006).

Vegetation

- Where cropping is suitable or has some limitations, as proposed by GIS, erosion conservation practices should still be carried out, retaining more productive topsoil for future vegetation (Ongley, 1996).
- In regards to cropping, reduced/conservative tillage is highly advised, to reduce top soil loss during seedling stages. Contour farming, by shaping the crop to suit the slope of the terrain; plant adjacent to slope direction where possible to reduce downhill momentum of runoff (Ongley, 1996). Crop overlap with pasture reduces the period of bare soil exposure and thereby also erosion. Crop stubble

should be retained or clover sown after harvest to maintain nitrogen uptake and soil coverage (Ritchie, 2006). Drilling rather than cultivating may also reduce erosion and retain more nutrients (Ritchie, 2006).

Due to the climate and soil types present in the Mangaone West, some grasses may be better suited than traditional rye grass. The winter wet, summer dry character of the

- Catchment will likely become more extreme over the years with climate change. Pasture that can withstand poor drainage and droughts may allow better year-round growth. It was requested that potential grasses suited for the catchment were suggested. Cocksfoot is an example of a drought resistant grass that could be mixed in with present pasture to increase food availability during summer periods.
- The use of clover was traditionally high, to naturally provide more nitrogen for other grass growth. Fertilisers have replaced clover in most agricultural areas, however the merits of clover are high… Clover naturally fixes nitrogen from the atmosphere and soil, making a sustainable, readily up-taken nitrogen source for other vegetation, thereby reducing the amount of fertiliser needed. White clover is commonly used but can be affected by parasites. There is also red clover, a more resilient option. The planting of clover amongst pasture and crops is an investment which can return the capital costs many times over, and environmentally benefit the catchment.
- PKE (Palm Kernel Extract) should be avoided as it is a highly unsustainable resource and, while a short-term option, it is causing worldwide environmental issues.
- Growing supplementary crops may be viable in suitable areas during feed deceits, reducing feed import needs.
- Low nitrogen content supplements (e.g maize (Ritchie, 2006)).

Stock management

- Reduce stocking rate pressure over winter.
- Run lighter stock over winter, especially on saturated, wet, and steeper land (sheep to hillslopes, cattle to flats, hilltops where appropriate in the upper catchment).
- Ensure rotational grazing is efficient; move before pugging and compaction occurs, and before pasture is depleted, to reduce recovery time of the paddock and therefore erosion and rotation efficiency (Davies, 2012).
- Avoid leaving stock in paddocks and crop for any extended periods of time, to reduce pugging, compaction and productivity losses and extended recovery time.

Water

- Keeping stock away from open water bodies to reduce erosion of banks, sediment input into water bodies, waterbody widening, nutrient loss through excrement and urea directly entering water, nutrient loss from top soil which acts as a fertiliser, and the input of phosphorous in waterways through erosion. A temporary reeled polywire fence could be used while the paddock is in use before more permanent fencing is possible.

- Allowing a strip of ungrazed grass to filter run-off before it enters the waterbody, and removing stock access to the waterbody could improve land nutrient retention and creeping of the waterway banks, and also improve water quality..
- A few pumps from the stream were noticed during fieldwork; only one surface water take consent was noted by Horizons from within the catchment, so those without consent ought to contact Horizons in order to ensure the stream can withstand the water-takes without losing ecological integrity.
- Any discharges ought to be made well away from the open water bodies of the catchment. While the water is able to dilute pollutants, accumulation occurs also.