Riparian management: investigating public perception and the effect of land-use, groundcover and rainfall on sediment retention

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Abstract

The physical and biological characteristics of a stream are strongly influenced by its surrounding catchment. The riparian zone acts as a buffer between land and water ecosystems and can play an essential role to retain contaminants (e.g. sediment) from entering and affecting the receiving waterway. When the riparian zone is not managed, the consequence can be high amounts of sediment entering the waterway that negatively affects in-stream communities with a decline in native invertebrate and fish populations.

I investigated three aspects of riparian management in the Canterbury region, South Island, New Zealand, by investigating the public perception using a questionnaire to determine what the public knows about riparian management and what practices are being done in the farming community. Results showed that riparian management varied across farm types, and there was some confusion about the roles of riparian management. Crop farmers were the least likely to do riparian management, in contrast to dairy farmers who were the most likely to do riparian management. A main concern is that the majority of respondents highlighted that filtering nutrients was the main goal for riparian management, and only 5% thought it was due to sediment, and 10% to decrease erosion.

I then conducted a field survey to investigate riparian zone sediment retention in different land-uses (dairy farming, production forestry and urbanisation) compared to native forest. Surprisingly, dairy farms produced the least amount of sediment, and urban areas produced the most, and there was a marginal effect of season. However, generally there was no difference between the amounts of sediment passing through the riparian zone. Therefore, I was unable to distinguish if there were any vegetation effects occurring within the riparian zone.

To complement the field survey, I tested sediment overflow by conducting multiple experiments using a rain simulator. The simulator controlled the intensity and amount of

rainfall over differing percentages of riparian groundcover. My results were consistent with other studies showing that as groundcover increases, sediment runoff decreases. However, there was no relationship between rainfall intensity and the amount of sediment in runoff.

My thesis indicated that riparian planting to reduce sediment flow into streams needs to focus on high amounts of groundcover (such as rank grass).

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Chapter 1: Introduction

Land-use change in New Zealand

There has been a marked change in land-use and land cover across New Zealand since European colonisation in the 1840s (Glade 2003), but this process began much earlier than this with the first Polynesian settlers arriving approximately 700 years ago (McGlone 1989). Before the arrival of European settlers, land cover in hilly regions was only slightly changed by human activity which occurred primarily on the coastal plains or near lakes and rivers. Following the arrival of Europeans, widespread land clearance started which transformed extensive hill areas of native forest and bush into open grasslands and pastures (Glade 1998). Foregoing these changes, streams throughout New Zealand were likely pristine waterways with high water quality, healthy ecosystem functioning and nutrient cycling, as well as high diversity of invertebrates and fish (Rowe et al. 1999).

The pressure to modify the land from native forests to agriculture and urban areas has increased as New Zealand's population has risen. Forest cover in New Zealand has declined from 82% to 24% since the arrival of humans (Ewers et al. 2006, New Zealand Forest Owners Association Inc. 2012). As a result, streams in these modified landscapes have changed markedly. For example, Davies-Colley (1997) showed that the channel width has become narrower in pastures than forested streams. Streams are some of the most threatened, degraded and fragile ecosystems due to the strong links between them and their adjacent terrestrial environments (Gillies et al. 2003). Changes in terrestrial land-uses usually affect the characteristics of adjacent streams. Frequently land-use changes result in altered flow regimes via channelisation, increases in water abstraction resulting in streams drying, declines in invertebrate and fish populations (Bunn and Arthington 2002), reduced vegetation health and reduced water quality (Kingsford 2000). These factors are critical to stream health.

The morphology, hydrology, and biological characteristics of a stream are strongly influenced by its catchment and adjacent land-use (Allan 2004). The area between the land and water is called the riparian zone. This is the interface between terrestrial and aquatic ecosystems which acts as a buffer between the stream and adjacent land, and is also the primary source of organic matter (Gregory et al. 1991). The riparian zone has the potential to provide important ecosystem services to improve water quality, provide flood mitigation, and improve hydrology (Hogan and Walbridge 2009). The idea of protecting riparian zones is relatively new (since the 1970s) and now most stream rehabilitation projects include setting aside riparian areas for water quality improvements (Cooper et al. 1995).

Erosion and sedimentation

Erosion and sedimentation are two very important processes that occur naturally, but these processes can be intensified and altered by human activities such as agricultural practices, earthmoving, and storm water systems in urban areas (Costa 1975, Wear et al. 2013). Soil erosion is a very complex process that depends on a variety of soil properties such as ground slope, vegetation, rainfall duration and intensity (Montgomery 2007). These processes have been active throughout geological time and have shaped the current landscapes, but erosion and sediment transport can cause significant engineering and environmental problems (Julien 2010). Sedimentation is a mechanism where particulate matter and their associated contaminants, such as phosphorous, are physically deposited on the soil surface or in waterways (Johnston 1991). Human activities can increase rates of erosion up to 100 times more than the erosion rate caused by normal geological processes (Julien 2010).

Soil erosion is considered to be a major threat to soil quality worldwide, and the chief sources are believed to be overgrazing (agriculture) and deforestation of both plantation and native forests (Erktan and Rey 2013). Over the last half century, nearly one third of the world's arable land has been lost to soil erosion and this rate continues to rise resulting in more than ten million hectares being lost per year (Pimentel et al. 1995). The clearance of natural vegetation and forests to make way for land to be used for pastoral agriculture and the introduction of livestock has become a common scenario. These changes have had a significant effect on stream ecosystems including higher loads of sediment entering waterways (Dolédec et al. 2006). Recent studies have pointed out that overland flow connectivity through artificial channelling, runoff and sediment trap effectiveness are currently the cutting edge solutions in soil erosion research (López-Vicente et al. 2013). Both agricultural and urbanisation are land-uses that can increase the transport of sediments to aquatic systems via erosion, leeching, and runoff which consequently has significant impacts on receiving biological systems such as wetlands and streams (Zedler 2003).

The ecological health of streams and rivers has become an increasingly important water management issue. Ecosystem level processes (e.g. gross primary production) are ideal measures of ecosystem health as they provide a response to disturbances occurring within the catchment (Bunn et al. 1999). These disturbances include increased levels of sedimentation entering waterways from adjacent land-uses, subsequently leading to a decline in water quality, invertebrate and fish populations.

Riparian Buffers

As previously mentioned, the riparian zone is the interface between aquatic and terrestrial ecosystems, and activities in the riparian zone directly influence stream health (Bren 1993). Riparian vegetation is recognised as a critical zone which can prevent nutrients and sediment entering the waterway. The riparian zone can act as a tool for mitigating nonpoint source pollution (Borin et al. 2010, García-Ruiz 2010, Knight et al. 2010). Buffer zones is defined by Bren (1998) as “an area of land along a stream, retained from the watershed land-use practice, to protect the stream from up-slope impacts”. An important role of buffers is to provide an undisturbed area of adjacent land next to streams to act as a filter for pollutants prior to coming in contact with the stream. Riparian zones are constantly under threat by many edge effects that involve the interaction of human related activities across the boundaries of riparian zones (Foxcroft et al. 2007). Due to changes of adjacent habitat characteristics, alterations to both in-stream environment and riparian zones have occurred (Gillies et al. 2003).

Dairy farming, production forestry, and urbanisation

Agriculture and forestry are economically important sectors of New Zealand’s economy. In 1991 they contributed NZ$2.7 billion per annum to the New Zealand economy and by 2007 this had increased to NZ$5 billion per annum (Ministry for the Environment 2010). However, there has been a growing realisation that production needs to occur sustainably within environmental limits.

MacLeod and Moller (2006) identified five major phases of agricultural development throughout New Zealand during the period between 1840 and 2002. Firstly, colonisation, when large areas of native land were burnt for grazing. Expansion, clearing land was intensified due to the introduction of refrigerated shipping which opened export markets. Early intensification occurred with the developments of soil science, fertilisers and improved animal and plant breeding systems. Diversification arrived when technology allowed farmers to fertilise and work on previously inaccessible areas. Later intensification has occurred up until the present time with the development of more intensive farming systems.

Historically, there was plenty of land to allow for the expansion of agricultural areas. However, more recently, available land is at a premium, which has led to intensification to increase production within a given area.

Forest coverage within New Zealand is approximately 20%, with plantation forests used for production forestry making up 7% (Ministry of Agriculture and Forestry 2009). The production forestry industry has increased from annual export earnings of NZ$4.2 billion in 1998 to NZ$4.7 billion in 2011/12, becoming New Zealand's third largest export (Death et al. 2003, New Zealand Forest Owners Association Inc. 2012). The New Zealand forest industry is based on rotating plantations of predominantly Monterey pine (*Pinus radiata*), a native to USA which was bought here in the 1860's. In New Zealand it is a fast growing tree which makes up 90% of total production tree plantings with approximately 22 million cubic metres harvested in 2011 (New Zealand Forest Owners Association Inc. 2012), and makes up one third of the world's radiata forests (Wu et al. 2007). Radiata forests were first planted for soil and water conservation purposes on erosion-prone hill country. Once the species has become established, it rapidly populates steep hillsides, protects soil and regulates water runoff (Dymond et al. 2012). The Code of Practice for plantation forestry enforces that all efforts are to be made to avoid riparian strips, by clear felling trees at least five metres from waterways and not allowing any machinery to come in contact with riparian zones (New Zealand Forest Owners Association Inc. 2007).

The recent expansion and intensification of dairy farming has led to widespread recognition that dairying needs to be conducted without depleting natural resources (i.e. water) that are paramount for the success of the industry. However, it has been challenging to maintain water quality standards due to on-going intensification of existing dairy farms and the expansion of dairying into new regions (Aarons and Gourley 2013).

Individual dairy companies (e.g. Fonterra Co-operative Group) must ensure that 100% of their dairy farms containing waterways will have a riparian management plan by 31st May 2020 (DairyNZ 2013). Promoting and facilitating riparian planting to enhance waterway ecosystem health is an on-going objective. It is important that councils and dairy companies work together to assist farmers and raise awareness of good practice and aid in implementing management programs.

As of 2002, 85.7% of New Zealand's population live in urban areas (Bayley and Goodyear 2007). Urban landscapes are dominated by impervious surfaces (e.g. roofs, roads and car parks) which can potentially cause changes in water chemistry, physical habitat and riparian conditions. Prior to urbanisation, runoff would have drained slowly into streams via vegetation buffers. Subsequently, urbanisation has altered drainage patterns as runoff flows over impervious surfaces, bypassing riparian vegetation and flow directly into waterways. Storm water and drainage networks collect runoff and greatly reduce the overland flow path as well as increasing the volume, velocity, frequency and timing of runoff following storms, and speed up the process of sediments and contaminants entering waterways (Konrad and Booth 2005, Bettez and Groffman 2012). The "first flush" theory suggests a disproportionately high delivery of either concentration, or mass, of a substance occurs during the beginning of a rainfall event (Deletic 1998, Sansalone and Cristina 2004). This first flush can contain a large amount of contaminants such as heavy metals (He et al. 2001), hydrocarbons, oils, and grease from roads (Stenstrom et al. 1984), nutrients from industry and garden surfaces, and particulate matter (Lee et al. 2002).

Due to these human activities (agriculture, production forestry and urbanisation) guidelines have been introduced to reduce environmental risks. Published reports support the benefits of Best Management Practices (BMP) (Liu et al. 2008, Anderson and Graeme Lockaby 2011). A BMP is "a practice or usually a combination of practices that are determined by a state or a designated planning agency to be the most effective and practicable means (including technological, economical, and institutional considerations) of controlling point and nonpoint source pollutants at levels compatible with environmental quality goals" (Helms 1998). These BMP's have been commonly seen within intensive industries with an aim to reduce the impacts that affect receiving environments.

Thesis Outline

There is an increasing amount of information distributed to the public regarding the benefits of riparian management. However this information may not be using robust science and is therefore misleading. In Chapter 2, I used a questionnaire to investigate the public perception of riparian management in Canterbury and how well the role of riparian management was understood.

In Chapter 3 I compared the sediment runoff in riparian zones of different land-uses (dairy farming, production forestry, urban areas and native forests). My aim was to determine whether different land-uses (and their riparian vegetation) influenced the quantity of sediment runoff. I also investigated other variables that may be affecting runoff (rainfall, slope, and groundcover).

In Chapter 3, I identified marked variations in vegetation groundcover between different land-uses and their riparian zones that strongly influenced sediment runoff. In Chapter 4, I experimentally tested this link between sediment and groundcover using a rain simulator. I was able to manipulate the amount of rainfall that fell on sites that varied only in groundcover, and then quantify the amount of sediment contained in the runoff. My aim was to determine the optimum percentage of vegetated groundcover required to efficiently filter sediment.

Chapter 2: Investigating public perceptions on the role of riparian management – a questionnaire

Introduction

The population of New Zealand is dependent on clean freshwater resources for their health and economic well-being; however, relatively little is known about how they perceive our waterways (Dutcher et al. 2004). The scientific community and local governments invest significant resources studying the ecological value of streams, but whether this is reflected in improving the public's knowledge of how to manage waterways and their riparian zones is unclear. It is important to understand the public's perception of freshwaters and riparian management so that progress can be made to improve the water quality of New Zealand's waterways.

Compared to international standards, the quality of New Zealand waterways, streams, rivers and lakes are considered healthy but since human colonisation, clearance of native bush and subsequent conversion into farmland, urban, and industrial areas, there has been a deterioration in stream health (Ministry for the Environment 2001, Decamps et al. 2009). Ballantine and Davies-Colley (2010) in a 19-year report (1989 – 2007) reported that water quality has deteriorated with an increase in pastoral land area across catchments. Hart and Calhoun (2010) identified that there are many ecologists providing evidence of environmental degradation, but this information is not being used by society.

Farmers have become increasingly aware of the impacts that certain land management practices are having on water quality and stream health (Ministry for the Environment 2001). This awareness has led many to change the way they manage their land to reduce negative impacts. However, to improve cooperation between management agencies and famers, better communication and education is necessary.

In recent years the dairy industry has undergone considerable expansion and intensification. This intensification has resulted in greater impacts on water, therefore the effort put into mitigation has increased. In 2001, Fish and Game New Zealand launched the 'Dirty Dairying' campaign which led to the 'Dairying and Clean Streams Accord' in 2003 (Edgar 2009). The 'Dirty Dairying' campaign was designed to raise public awareness on the adverse consequences that dairying was having on the nation's waterways. Another important initiative was the Land and Water Forum in 2009, which has enabled greater communication and consultation between farming interests and water management (Land and Water Forum 2012).

In the agricultural industry, there has been a strong focus on riparian management. This is particularly apparent in dairying due to the intensity of their farming practice, environmental impacts and economic importance to the nation. Regional Councils in intensive dairying regions (Canterbury, Southland, Otago and Waikato), have emphasised riparian fencing and planting as a way of reducing the amount of sediment and nutrients entering waterways.

Since the signing of the 'Dairying and Clean Streams Accord', there has been a greater focus on preventing sediment and nutrient runoff into adjacent waterways. However, the Dairying and Clean Streams Accord (Ministry for the Environment 2003) was voluntary for farmers and expired in 2012. It has since been replaced with the 'Sustainable Dairying: Water Accord' which came into effect from the 1st August 2013 and required compulsory contribution from dairy farmers (DairyNZ 2013). This document emphasised the need to improve management including riparian management. In 2006, Taranaki farmers were surveyed on how they decide on management practices. Results showed that dairy farmers considered riparian management as a low priority as the benefits from fencing and planting did not outweigh the costs (Collier 2006).

Besides dairying, there are few stream management rules for other farm types, with voluntary suggestions for farm management practices. Management suggestions for crop farmers include, avoid cultivating close to waterways and planting shelter belts to reduce wind erosion. For pastoral farmers, it is recommended to avoid overgrazing, and graze strategically in wet conditions to reduce pugging and soil damage (Environment Canterbury 2005). In the Canterbury region, all intensively farmed livestock (farmed pigs, dairy cattle, any stock on irrigated land and any stock fed via break feeding or strip grazing), are prohibited from entering waterways (Environment Canterbury 2012b).

A questionnaire from 2008, asked New Zealanders how they perceive the state of New Zealand's environment (Hughey et al. 2008). There was a perceived improvement in the management of 11 out of 13 components of the environment compared with surveys done in 2006, 2004, 2002 and 2000. However, farm effluent and runoff were identified as major problems, with 51.6% of respondents describing the current situation as 'bad' or 'very bad'. Examples of other concerns were pest and weed control, solid waste disposal, sewerage disposal, and industrial impacts. Furthermore, urban New Zealanders thought that the natural environment was improving, and they identified riparian management as an important part of this (Hughey et al. 2008). Although New Zealanders rated the state of New Zealand's environment to be either 'good' or 'adequate', rivers and lakes were considered poorly managed and in a declining condition since surveys began in 2000. From 1700 responses, 40% rated waterways as either 'bad' or 'very bad', however only 14% identified the most important environmental issue as 'water quality and / or water pollution' (Hughey et al. 2013).

A telephone survey by Environment Waikato to determine public environmental awareness, attitudes, and actions (Environment Waikato and Gravitas Research and Strategy Ltd 2007) showed that 61% felt water pollution was the most frequently mentioned current environmental concern. Rural residents were asked about specific issues regarding their local environment and 46% thought there was an increase in fencing of waterways, and 78% of residents expressed concerns of water pollution being a result from farms. However, there is a lack of understanding or misperceptions of the causes of environmental problems, as 25% of respondents said that livestock should be allowed to enter waterways on farms. Other results showed 75% of rural residents perceived either no change or deterioration in soils and land erosion, while 50% of rural residents thought there was an improvement in fencing waterways. These discrepancies in the public's awareness demonstrate that there is miscommunication between management agencies and the public that needs to be rectified.

Hughey et al. (2008) compared 2008 results with those from 2000 (Hughey et al. 2001), and concluded that negative perceptions about the environmental impacts of farming had increased from 22.7% in 2000 to 46.2% in 2008. People were asked to identify the main causes of damage to freshwater environments and 46% reported that farming was the main cause, followed by sewerage and storm water (44%) and industrial activities (31%) (people were able to identify three causes). This change in the perception of waterways could be a result of both continued environmental degradation, or increased awareness of environmental issues.

The aim of my study was to identify Cantabrian's perception and understanding of riparian management. I used a survey to determine which management strategies people are adopting to improve water quality through riparian management. This information would be important, as the success of riparian management schemes require significant community involvement. The results from the survey would be used to determine if the information provided by councils and water management agencies can be more clearly explained to the public.

Methods

The following report was based on questionnaires conducted on three occasions: the Canterbury Agricultural and Pastoral (A&P) Show in both November 2012 and November 2013, and Lincoln Field Days in March 2013. The Canterbury A&P Show went for three days with a total attendance of approximately 95,000 (2012) and 117,000 (2013), while the Lincoln Field days went for three days with a total attendance of approximately 19,900 with over 80% of attendees from the Canterbury region.

These events were chosen as they are the main agricultural events within Canterbury, and were therefore likely to attract a good representation of the Canterbury farming sector. It also maximised the chance of finding members of the public that are linked to the land-use practices targeted in this research. Even if the respondent didn't have a waterway through their property, they were still questioned if they were influenced by a waterway, such as for recreational or personal purposes. A total of 170 face-to-face interviews were conducted with willing members of the public.

The questionnaire was designed to be short and simple (i.e. to take <5 minutes), to encourage a large number of responses. I constrained a number of questions with closed answers to simplify analysis. However, several open questions were included to allow the participant to show an individual perspective and opinion.

A University of Canterbury human ethics permit was obtained prior to conducting the questionnaire (Reference HEC 2012/165).

Questionnaire Outline

The main objectives of the questionnaire were to identify the understanding, attitudes and perspective of the Canterbury public on riparian management, and to identify management practices being conducted by landowners. The questionnaire comprised of 17 questions (Appendix 1), but depending on the responses of the initial questions, the participant could answer as few as six questions. The average time to complete the survey was approximately between five and ten minutes, however the total amount of time depended on how enthusiastic and interested individuals were in the topic.

I also contacted companies and departments (Department of Conservation, Environment Canterbury and Christchurch City Council), to see if any similar research had been carried out on the public perception of riparian management. The Department of Conservation had conducted a survey in Marlborough in 1995, and the Christchurch City Council redirected me to the Taranaki District Council who had surveyed landholders within the Waiokura catchment in 2006 as part of their riparian management programme. Those surveys acted as a guide to the style and format of my questionnaire.

The questionnaire was conducted face-to-face. Respondents were approached and asked if they were willing to take part in a survey and were told that they remained anonymous. The questions were split into three sections.

The first questions were designed to determine the background of the participant and to identify if they had any personal connection to a waterway either on their own property or for other uses (such as recreation). Subsequent questions were designed to identify if the participant understood what a riparian buffer zone is, and if they actively manage any waterways through their property. If the participant was unsure or did not know what a riparian zone was, then an explanation was given that included the brief definition: "the interface between the land and a waterway acting as a filter from adjoining land practices". A more detailed definition was given if requested. This section also identified if the participants were farmers and what type of farming they practiced. This section questioned management issues faced by landowners.

Finally the participants were asked demographic questions as to whether they live in rural or urban areas, and their sex and age.

Data Analysis

Percentages were used to effectively show the results in a numerical form.

Two sets of questions were tested for independence using a chi-square test to ask whether the answer to a question was influenced by responses to a proceeding question. The response that a person gave to “What type of farming practice is performed on your farm?” was tested to see if it influenced the answer they were likely to give on the type of management they did. The categories were grouped to gain a large enough sample size to be statistically correct.

The response that a person gave to “Do you know what a riparian zone is?” was tested to see if it was independent of whether the respondent did or did not conduct riparian management. The categories were grouped to gain a large enough sample size to validate the assumptions of chi-square analysis.

Results

Of the 170 individuals that completed the questionnaire, 123 (72%) had streams running through their property. Overall, 160 people (94%) interviewed proceeded past the initial section which asked if they either had a stream through their property or had a stream of value to them. Of those, 97 (61%) knew what a riparian zone was. Interestingly, of those that had a stream in their property, only 81 (66%) knew what a riparian zone was.

The majority of respondents were males (153 or 90%), from a rural area (132 or 78%) and over the age of 50 (105 or 62%).

Farming Activity

A total of 97 responders either owned or part-owned a farm. The most common farms were mixed sheep and beef (30%), dairy farming (18%) and beef farming (11%). A small percentage were dairy support (5%); i.e., graze dairy cattle over the winter months while cows were calving in the “dry” period while they are not being milked. Other minor farm types included: sheep, crop, deer and forestry (Figure 2.1). The mixed farming category included farms that conducted more than three of the above practices.

All cropping farmers answered that they did not do any riparian management. A number commented that they saw no benefits for them in doing riparian management. Comments included; riparian management was a “waste of productive land”, and “plants next to streams invite rats and bird wildlife that destroy commercial crops”.

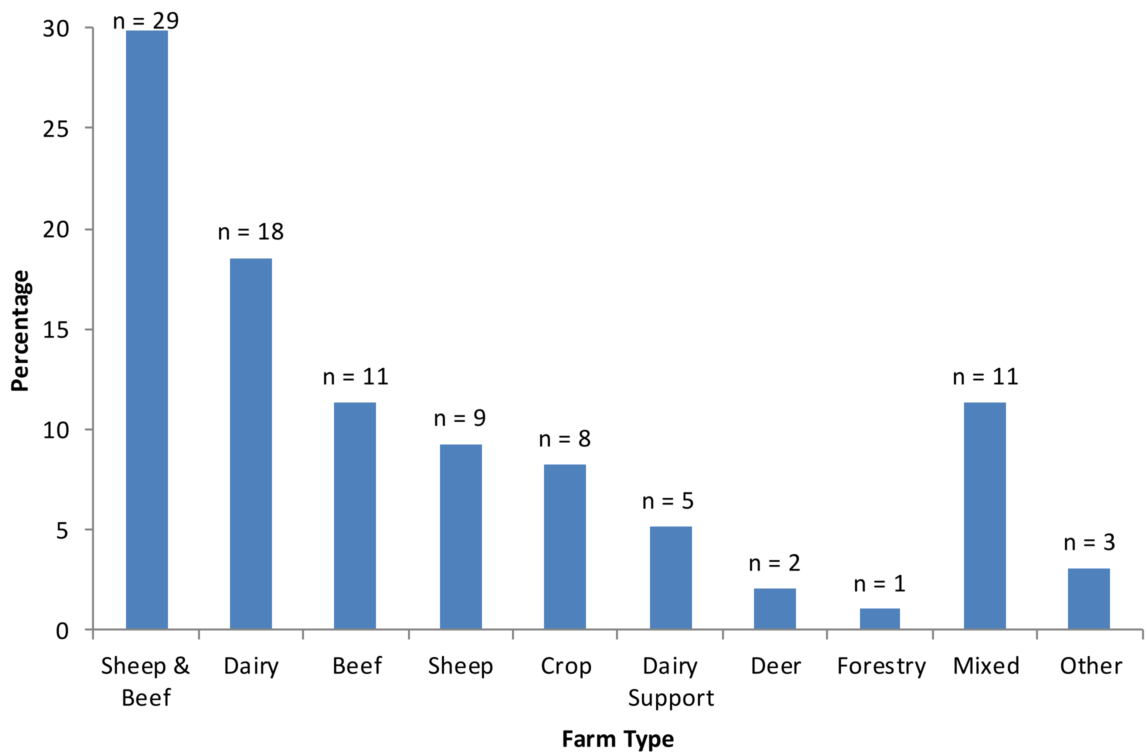

Figure 2.1: Farm types owned or managed by 97 respondents (n values = the number of farms per farm type).

Riparian Management

Of the 123 participants that had a stream running through their farm, a high number (51 or 43%) did not do any riparian management. Of the 72 (57%) participants that did riparian management, the most common management was fencing (to exclude stock). Of these 72 participants, 33% also plant native vegetation in this zone. Cleaning waterways using machinery, spraying and controlled grazing were minority responses (Figure 2.2). A single participant may have included more than one type of management.

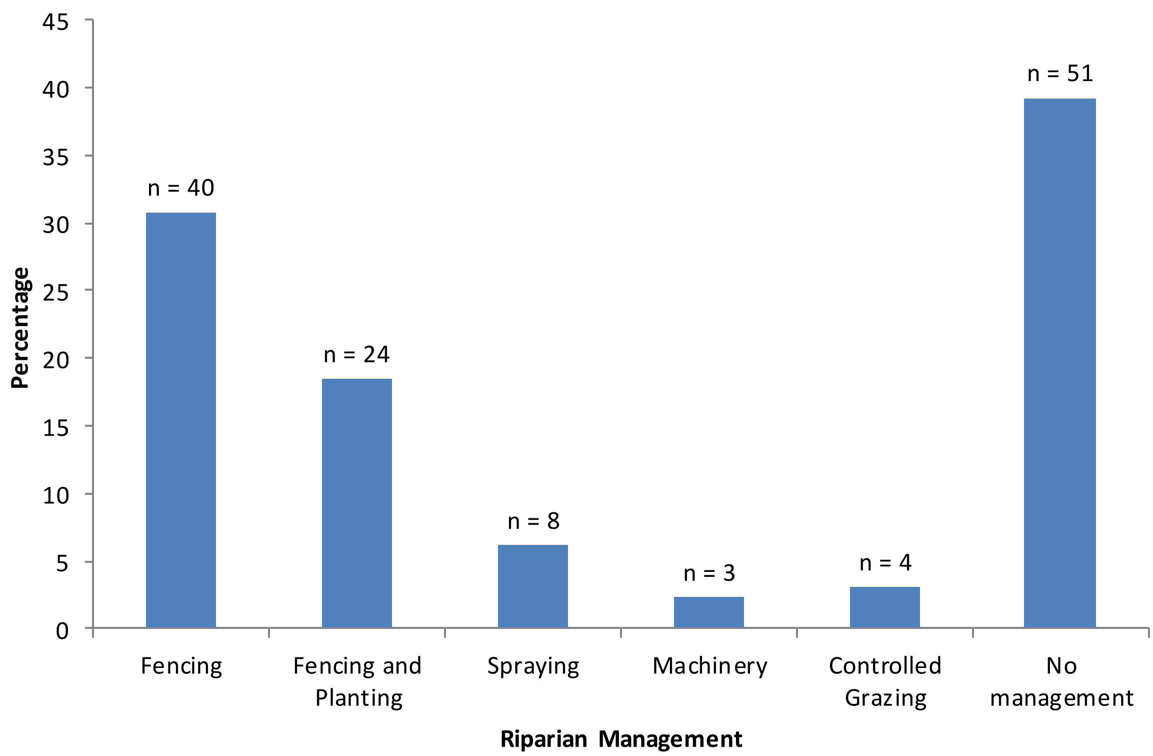

Figure 2.2: Types of riparian management conducted by 123 participants (n = responses per management type).

Value of planting

Of 160 responders, 76% said that waterways with riparian planting were more appealing. However, 29 people (18%) preferred no planting along waterways, and 10 (6%) had reasons both for and against planting. These people thought that planting was good for aesthetic and environmental reasons, but thought that flooding, weeds, and practicality for ease of access and maintenance could become an issue.

Of the participants that thought that riparian planting was appealing, most of these people valued the aesthetic benefits (90 responses). Other responses included: "planting is better for the environment", "increase in the amount of wildlife" and "more shelter for farm livestock" (Figure 2.3).

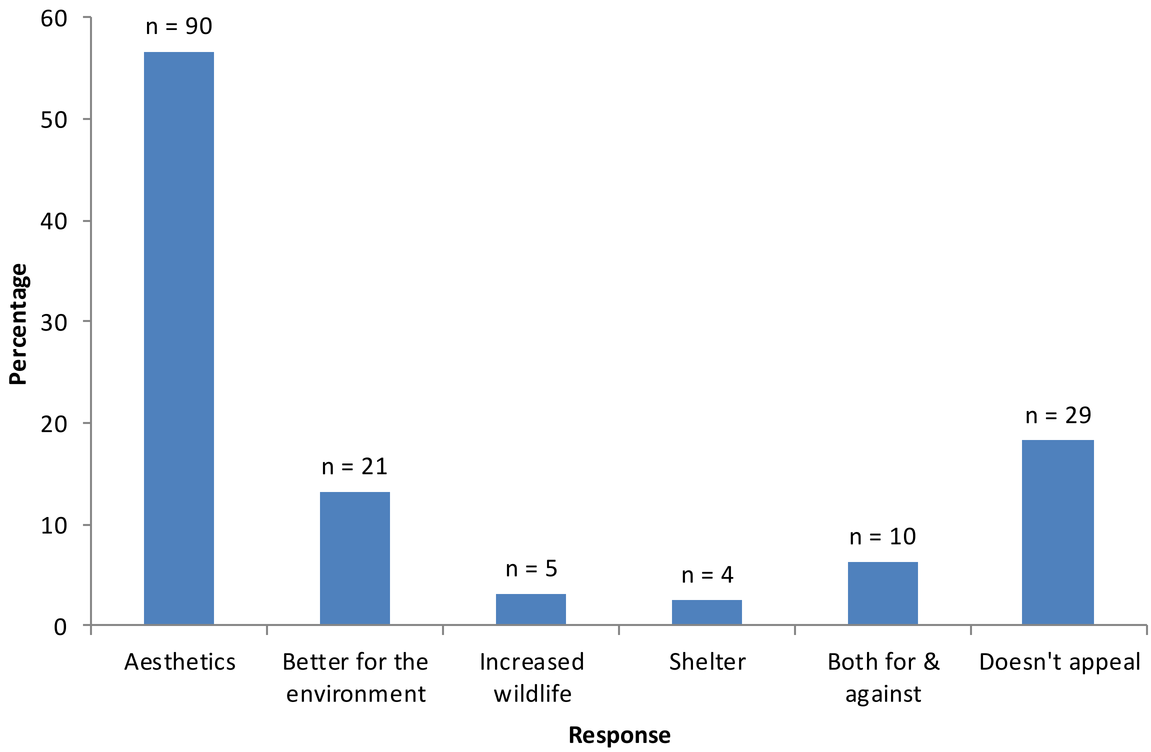

Figure 2.3: Values of planting from 160 participants (n = number of responses regarding value of planting).

Perception of the benefits of riparian management

There was a wide range of responses concerning the benefits of riparian planting and fencing (Figure 2.4). The most common response was that riparian management filtered nutrients (49 or 22% of responses). Other benefits most commonly mentioned included: increase water quality (38 or 17% of responses), livestock protection and shelter (35 or 16% of responses), increase wildlife and biodiversity (34 or 15% of responses), and decreasing erosion and increasing bank stability (23 or 10% of responses). Filtering sediment was a minor response, with only 12 respondents (5%) mentioning this aspect. A minority of 15 (7%) participants were not aware of any benefits of riparian management, and 12 (5%) said that there was no benefit at all. Thus, 27 participants (12%) had no idea or did not think that riparian management was of any benefit to streams. A single participant may have included more than one benefit.

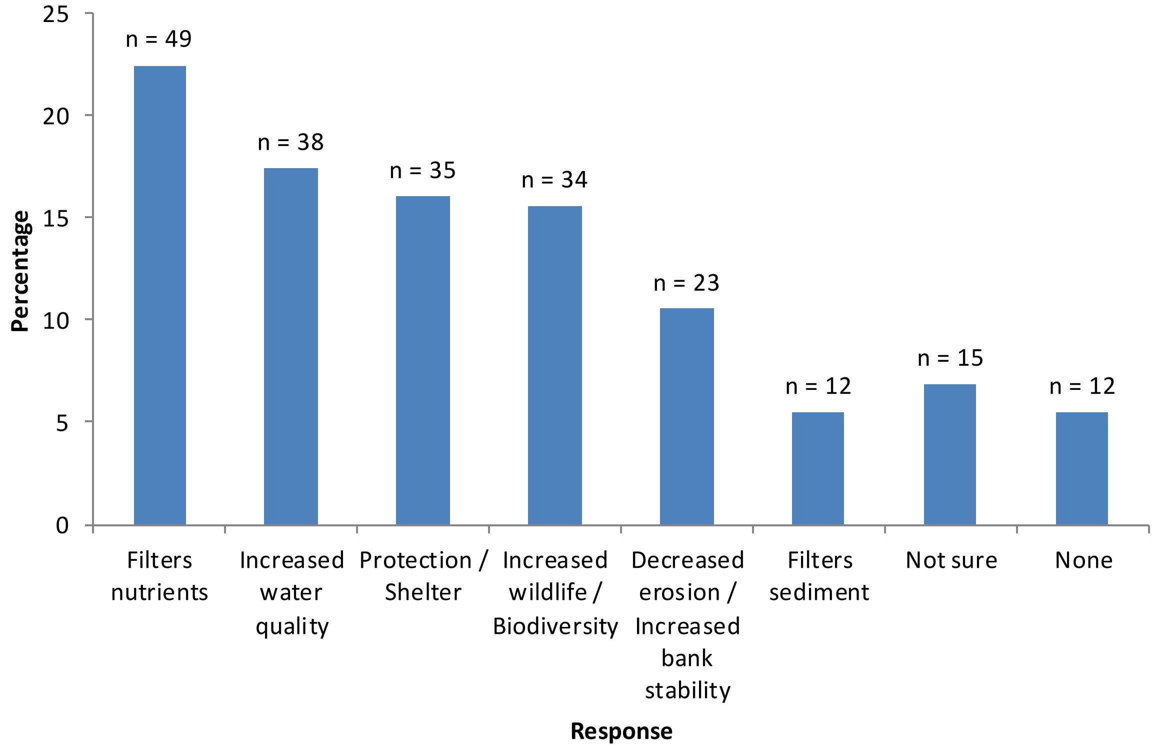

Figure 2.4: The benefits of riparian management from 160 responses (n = number of responses per benefit).

Perceived barriers to riparian management

Participants with waterways in their property (123 respondents) were asked if there were any barriers to conducting riparian management (Figure 2.5). The majority (73 or 59% of respondents) did not feel that there were any barriers to riparian management. Of the issues identified, the largest was the cost of management programs (14 or 10% of responses), and the areas that streams covered needing management was perceived as impractical by landowners to manage and maintain (8 or 6% responses). Other responses were issues with flooding, indicating that fencing is destroyed with each heavy rainfall and flooding event, which makes conducting riparian management both time wasting and costly.

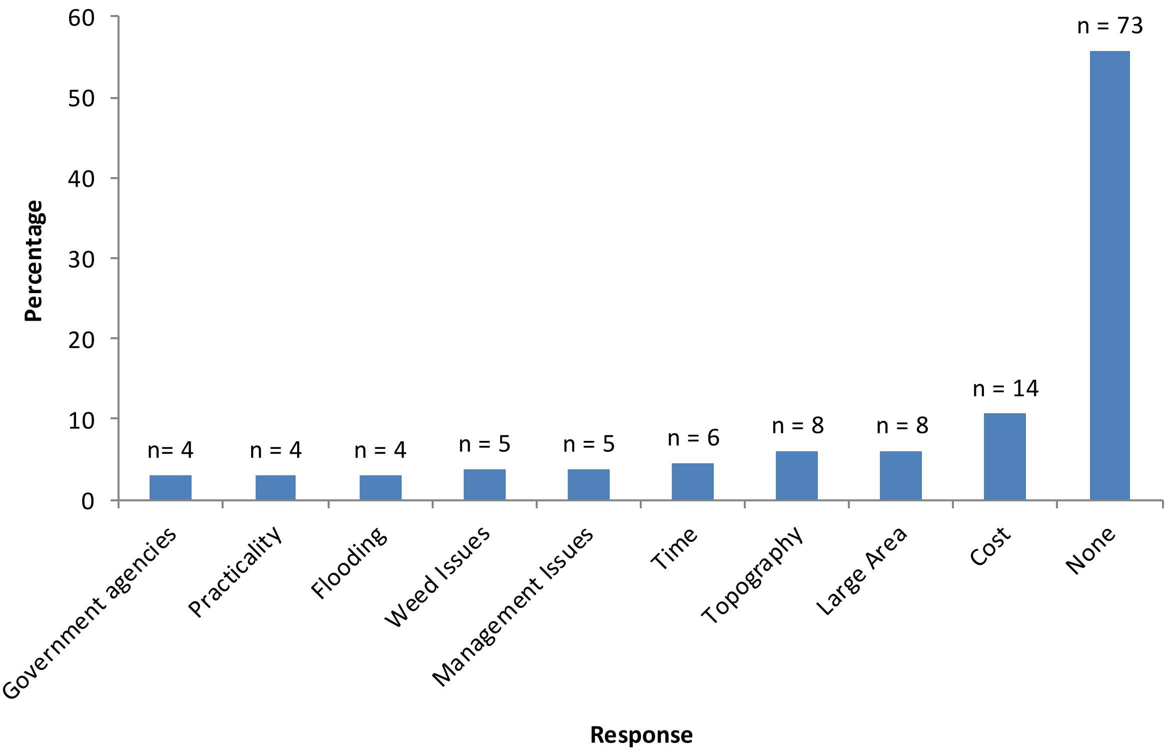

Figure 2.5: Barriers that landowners have with riparian management from 123 responses (n = number of responses for each difficulty).

Statistical Analysis – Chi Square

Analysis of responses to the question "What type of farming practice is performed on your farm?" indicated that farm type is significantly correlated with the management program performed on the farm (X^2 = 17.0084, df = 3, p = <0.005). Therefore each farm type is more likely to perform a certain type of management program. Sheep and beef farmers, dairy, and dairy support farmers were more likely to conduct management than crop farmers and other farm types (Table 2.1).

Table 2.1: Contingency table on the presence/absence of riparian management on different farm types.

	Fencing with or without planting	*No Management*	**Total**
Sheep & Beef	17	7	**24**
Dairy & Dairy Support	16	4	**20**
Other farm types with animals	10	20	**30**
Other farm types with no animals	2	7	**9**
Total	**45**	**38**	**83**

Analysis of responses to the question "Do you know what a riparian zone is?" showed that a person's knowledge of a riparian zone is not independent of presence or absence of management (X^2 = 10.9798, df = 3, p = <0.005). Therefore the knowledge that a person has of riparian zones is correlated with if any riparian management was conducted. Respondents that knew what a riparian zone was were more likely to conduct riparian management (Table 2.2).

Table 2.2: Contingency table on the presence/absence of riparian management on knowledge of riparian zones.

	Management	*No Management*	**Total**
Knew what a riparian zone was	56	25	**81**
Did not know what a riparian zone was	16	26	**42**
Total	72	51	**123**

Discussion

Results show that there are issues associated with the public understanding about improving farm waterway water quality by riparian management. Of the 170 people questioned, most responses were from rural landowners over the age of 50. While most participants who managed riparian zones reported no difficulties, over half of the respondents who have a stream through their property do no riparian management.

Most of the riparian management strategies mentioned by respondents in my survey involved fencing-off waterways. Fencing has been proposed as an effective tool to prevent stock from trampling stream banks, and should reduce the amount of sediment entering waterways (Parliamentary Commissioner for the Environment 2012).

Within the wide range of land owners I surveyed, riparian management varied between farm types. Crop farmers were the least likely to manage riparian zones, in contrast to dairy and other farm types, which were more likely to fence and plant along their waterways. Over half of sheep and beef farmers (collaborative), and three quarters of dairy farmers had riparian fencing. The majority of sheep farmers and beef farmers chose to do no riparian management.

Information presented by Regional Councils and management agencies to farmers needs to be practical, straightforward and yet relatively comprehensive to ensure understanding by everyone. My survey results indicate confusion among farmers about the benefits of riparian management. Although, the majority of participants thought that filtering nutrients was the main goal, this seemed to focus on nitrogen with little mention of phosphorous. Only 5% of respondents knew riparian management targeted sediment, and only 10% suggested that it also decreases erosion. Much publicity has focussed on reducing nitrogen at the expense of discussing other farm contaminants, and so many rural residents are only involved in discussions about reducing nitrogen in waterways. Furthermore, one in ten respondents surveyed were either unsure or unaware of any benefits of riparian management. Hughey et al. (2013) found that 2.3% of the total responses did not know the current state of environment when asked about the improvement of rivers, and 6.1% of the total responses did not know about the management strategies to deal with farm effluent and runoff. This disconnection between farmers and water management agencies may be due to miscommunication and misunderstanding about riparian management benefits.

Several important programs such as the Dairying and Clean Streams Accord, the Land and Water Forum, and Canterbury Water Zone Committees have increased the effort towards the mitigation of detrimental effects via environmental education (Parliamentary Commissioner for the Environment 2013). Collier (2006) found 19% of landowners were unsure of the benefits of the Dairying and Clean Streams Accord, and 12% believed that fencing and planting along waterways would not work. If programs incorporate public views and are targeted at the right audience, then public acceptance and support for riparian management programs will improve (Nassauer et al. 2001). For example, my results show that riparian planting was most valued for its aesthetics. Using this information, riparian management projects can enhance community involvement and acceptance by advertising an increase in aesthetics of the waterway. Similarly, in the Waiokura catchment, Taranaki, 85% of landowners were more likely to do riparian management to attain aesthetics (Collier 2006).

Management agencies should consider both the beneficial and detrimental effects to all relevant parties when recommending riparian management schemes. For example, to improve a waterway (beneficial) there may be a large cost e.g. time and money (detrimental) to implement. My survey revealed that this was one of the major barriers highlighted by farmers in their ability to conduct riparian management. To resolve this issue, agencies could offer financial aid such as grants and funding to help landowners offset costs. Furthermore, a report by the Department of Conservation (1995) in Marlborough found that if there were plans to make changes (i.e. planting and fencing) on private land, it was essential that the decisions were made primarily by landowners. This ensured that they felt in ‘control’ of the situation while still working in partnership with the authorities. Otherwise, management decisions and regulations appear threatening to individuals, and community participation is lost (O'Brien 1995).

Landowner concerns need to be addressed before riparian management plans can successfully improve water quality on private land (Dutcher et al. 2004). Landowners may have doubts regarding riparian management, particularly with financial issues, flooding, and weed control, all of which will create reluctance and potentially result in abandonment of riparian management. Agencies need to simultaneously target the problems faced when riparian management is absent (erosion, sediment, pugged areas), as well as promote the benefits of management (increased biodiversity and farm productivity) (Parminter et al. 1998).

My questionnaire could be extended to identify landowner’s specific riparian practices, i.e. ‘whether or not they are planting natives’. Another key question would be to find out where landowners get information about riparian management. Recognising why a farmer is doing a certain type of practice would indicate if they understand the benefits of riparian management. It would be useful to know if landowners were getting information from council and agency recommendations or simply through word of mouth. Information from within the farming community may create issues with the wrong messages being communicated.

To promote riparian management, there needs to be a strong relationship with the target audience. The information given to landowners needs to be clear and straightforward. Putting scientific terminology into documents aimed at an audience with no scientific background will not promote participation of management projects. This could be a reason as to why there was a high level of misunderstanding of riparian management in my results. Organisations need to work with landowners to discover the best way of presenting their information in a positive way and gain the most amount of support. Different education methods need to be considered; as technology evolves it may be an option to start using the internet as a new method of communication with farmers. Presentations and power-points could be uploaded onto council webpages, or simply through e-mail.

On-farm best management practices such as nutrient budgeting and effluent management, must accompany riparian management to achieve enhanced water quality. Councils throughout Canterbury have already been introducing this through the Canterbury Land and Water Regional Plan (Environment Canterbury 2012a). However, to reach this goal, landowners must be made aware that riparian management will not be an immediate solution, and that there will likely be a time lag before they see any progress (Meals et al. 2010). Improving communication between agencies and farmers will strengthen relationships and in turn increase understanding of the participation in riparian management by landowners.

In conclusion, the public perception on riparian management is mixed. Some people fully understand the aims of conducting management along their waterways, although there are a large number of people that are unsure of the benefits of doing so. My results have shown a disconnection between our understanding of the benefits of riparian management, and landowner perception. With the help of Regional Councils and other organisations, the methods of communication can be made simpler and easier in order to get information broadcasted and understood by all members of the public that it concerns.

Chapter 3: Does the amount of sediment in runoff through riparian zones vary between different land-uses?

Introduction

New Zealand has gone through major shifts in land-use since its settlement by humans over 700 years ago. In particular, many streams have been highly modified by these land-use changes (Glade 2003). Many streams that were once in native forest are now surrounded by human modified landscapes such as forestry, agricultural and urbanisation. Along with a variety of adjacent land-uses are differences in riparian management. A number of those land-uses have their own rules and regulations on how riparian zones should be managed.

Production Forestry

Because of the intensive disturbance of forestry harvesting, these activities have been subject to scrutiny by local authorities and the public. As a result, guidelines and regulations have been created within the forestry sector. The New Zealand Climate Change Accord (2007) aims to achieve minimal environmental impact due to forestry operations (New Zealand Forest Owners Association Inc. 2012). Furthermore, the New Zealand Environmental Code of Practice for Plantation Forestry focusses on meeting minimum environmental standards and ensuring that environmental standards are met or exceeded to maintain healthy forests (New Zealand Forest Owners Association Inc. 2007). There is recognition that planted forests that are correctly managed can positively contribute towards environmental services such as soil and water protection, erosion control, rehabilitation of degraded lands, restoration of landscapes, and carbon sequestration (Jackson et al. 2005). The Code of Practice requires that environmental risks and values are identified prior to harvesting to ensure values are protected and adverse effects are avoided or mitigated through good operations and planning (New Zealand Forest Owners Association Inc. 2007).

Logging contractors are issued harvesting prescriptions and environmental standards to reduce the negative effects of harvesting on important environmental values and keep adverse effects to a minimum (New Zealand Forest Owners Association Inc. 2007). These documents are a summary of the area to be harvested, with highlighted areas that require extra care, or need to be avoided (i.e. waterways and native forest).

The guidelines include processes on how to avoid areas of special environmental importance. For example, trees are felled away from significant water sources, disturbance to roads, water tables and culverts are minimised, riparian and native vegetation areas are avoided, setbacks of at least five metres each side of all permanently flowing streams, and machinery is to be kept out of water bodies and riparian margins. Soil disturbance is common and unavoidable in harvesting operations, especially along new logging roads and landing areas, therefore there is a requirement to capture sediment prior to entering waterways (Croke et al. 1999, Gomi et al. 2005, Merten et al. 2010). Water and sediment control structures are required to maintain effective and sustainable operating conditions (New Zealand Forest Owners Association Inc. 2007).

Previous studies have demonstrated the negative impacts of sediment and debris deposition due to forestry operations on steams (Campbell and Doeg 1989, Merten et al. 2010). In forested catchments, vegetated riparian zones act as a filter for sediment produced from areas where there is high soil disturbance (Bren 1998, Gomi et al. 2005). In Australia, it has been suggested that streamside management zones not be harvested as they decrease the delivery of sediment into adjacent streams. These zones have been proven to be an effective tool for reducing nonpoint source pollution from landscapes such as forest harvesting (Neary et al. 2010).

Production trees, such as *Pinus radiata* take up water and therefore act to regulate runoff. However, once the trees are harvested, runoff usually increases. In Viti Levu, Fiji, following the harvesting of a mature plantation catchment water yield increased markedly (Waterloo et al. 2007).

Dairy Farming

Improved environmental management and better riparian practices has become a necessary and important component of the dairy industry. Unfortunately, poor riparian condition and in-stream water quality, including little or no native riparian biodiversity is a common feature on many grazed dairy farms (Department of Primary Industries 2006). The consequences of poor farm management are well known and can include overgrazing and trampling, damage to soil structure and increased soil erosion and runoff (Atapattu and Kodituwakku 2009, Cournane et al. 2010).

The Dairying and Clean Streams Accord (Ministry for the Environment 2003) was the first real unified attempt to improve the environmental performance and promote sustainable dairy farming in New Zealand. The Accord included a number of priorities including; to exclude dairy cattle from streams, rivers and their banks, regulate farm races requiring bridges or culverts where stock regularly cross a watercourse, and ensure dairy farm effluent is appropriately treated and discharged.

The "Sustainable Dairy: Water Accord" replaced the Dairying and Clean Streams Accord in 2013. This new Accord identifies and emphasises where efforts should be concentrated (DairyNZ 2013). The main purpose is to enhance the overall performance of dairy farming by creating good management practices to improve freshwater quality. The latest Accord aims to reduce the impact of existing dairy farms where freshwater values have already been compromised, and ensure that new dairy farms implement good practice in environmental management from the time of conversion.

The focus on water has sharpened with the new Accord as more organisations have become involved. For example, the government has developed the National Policy Statement on Freshwater Management (Ministry for the Environment 2011), many regional councils have tightened regional plans relating to waterways, and the Land and Water Forum has been established to help focus on related issues (Land and Water Forum 2012). The success of these initiatives still need individual dairy companies and DairyNZ to adopt sustainability strategies and programmes that work in conjunction with the Accord.

Riparian management has become an important component of the Accord, with expectations that all dairy farms will exclude cattle from 90% of significant waterways by 31st May 2014, and 100% by 31st May 2017, and from wetlands by 31st May 2014 (DairyNZ 2013). Furthermore, riparian plantings will be encouraged where they are beneficial to water quality, and waterway crossings used by dairy cows will not be allowed to degrade waterways. The management requirements have been accepted nationally in order to offset the deleterious effects of intensive agriculture (Greenwood et al. 2012).

Overseas studies on intensive farming have recommended farmers improve their riparian management. Aarons and Gourley (2013) looked at the need of farmers to enhance both their riparian zone and upland areas to attenuate sediment losses from fields. They found this is particularly relevant for dairy farms that have a large density of cattle using farm tracks, which are a large sediment source, at least twice daily for milking. In the United States, livestock grazing has damaged approximately 80% of streams and riparian ecosystems (Belsky et al. 1999). While another U.S. study showed that the sediment load into streams within agricultural systems was four times greater than in forested areas (Costa 1975). It is essential that New Zealand learns from overseas mistakes about the impacts of dairy farming.

The amount of suspended sediments coming from farm soils have been shown to increase as grazing intensifies (McDowell et al. 2003). However, other factors such as soil moisture, grazing duration, vegetative cover and soil physical properties influence the amount of sediment runoff from farmland (Cournane et al. 2010). Fencing along streams has been shown to rapidly decrease sediment export. This rapid response suggests stream-bank erosion and livestock access are key causes of erosion (Dodd et al. 2008).

Urban Areas

Due to the differences in relief and topography across Canterbury, land managers and developers are faced with many challenges with erosion and sediment control particularly within urban areas. The large number of sediment sources in urban areas (e.g. wash off from buildings and roads), and less opportunity for sediments to be filtered by plants before they reach waterways (Bettez and Groffman 2012) makes it particularly difficult to reduce sediment input to urban streams. Environment Canterbury has an Erosion and Sediment Control Guideline (Environment Canterbury 2007) that provides information on how to minimise adverse environmental effects on waterways due to surface erosion and resulting discharge of sediment. In Canterbury's lowland streams, rainfall events create runoff from recently disturbed sites that contain considerably higher concentrations of suspended solids than from vegetated or impervious land (Environment Canterbury 2007). Within urban areas, waterways have a slow velocity which results in sediment settling on the stream bed which can take a long time to move downstream and out of the stream system.

Within urban areas, an Assessment of Environmental Effects (AEE) is conducted to analyse areas potentially affected by a disturbance. AEE's quantify climate type, as well as the slope, land type, vegetation, soils and surrounding water bodies. As an outcome of AEE's, urban developers and councils often develop storm-water systems for direct sediment discharge prior to being released into a permanent water source such as a lake, lagoon or estuary.

Previous studies conducted in urban areas found that waterways with little to no riparian vegetation are in a degraded physical state due to the high rates of sediment transport (da Silva et al. 2007). It is widely accepted that vegetation adjacent to waterways can mitigate nonpoint source pollution, however much of the sediment runoff enters urban waterways via the storm water system (Hutchinson 2004). The hydrologic effects of urbanisation (e.g. storm water systems) have changed the natural course of runoff that would previously have been intercepted by vegetation (Konrad and Booth 2005). Modified drainage networks are also common in urban areas which allow runoff to quickly enter the receiving waterway, greatly reducing the length of the overland flow path. Urban water quality can be improved by forested riparian zones and aiding with the retention of sediments (Meyer et al. 2005).

Native forest

Approximately 24% of New Zealand is native forest, covering about 6.5 million hectares (New Zealand Forest Owners Association Inc. 2012). However prior to human arrival, New Zealand was 82% native forest (Ewers et al. 2006). Many of our forests are either southern beech, or upland and conifer broadleaved forests that thrive under wet, cool climates (McGlone 1989). There has been little research quantifying the input of sediment through riparian zones of native forest.

In this chapter I investigated the influence of human land-use activities (e.g. urbanisation, pine forestry operations, and dairy farming) on sediment runoff through riparian zones in each of these land-uses.

I predicted that: (1) different land-uses would result in different amounts of sediment runoff; (2) the presence of a riparian zone would reduce the amount of sediment entering adjacent waterways; and (3) there would be a correlation between the amount of rainfall and the amount of sediment runoff.

Methods

A total of 50 waterways were sampled in the Canterbury region: twenty sites on intensive dairy farms, ten in pine plantation forestry, ten in native forest and ten in urban areas (Appendix 2). Sites were located between the Waitaki and Ashley rivers (Figure 3.1a and b). The waterways vary in their physical structure from natural to artificial, commonly found within agricultural practices (Figure 3.2).

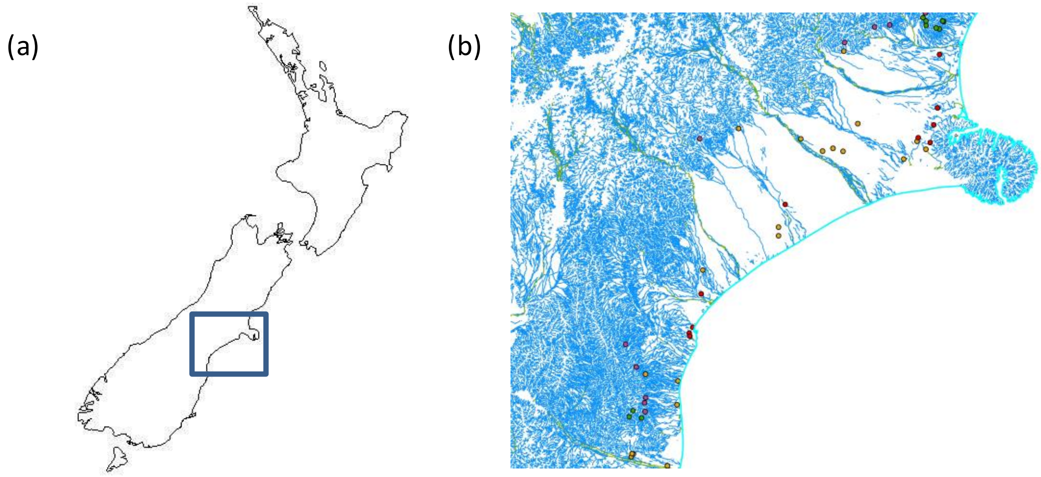

Figure 3.1: (a) New Zealand map with survey area (b) 50 sampling sites.

Figure 3.2: Examples of riparian zones from each land-use. (From Left to Right: Dairy farm, Pine forest, Native forest and Urban area).

There was a variety of riparian margins along the surveyed streams, consisting of either bare ground, extensive grass cover, recently cleared areas with native plantings, established native planting areas, pine trees, weedy species (gorse and blackberry), and native forest (Appendix 3).

All sites were sampled during three seasons in 2013: summer (February-March), autumn (April-May) and spring (October-November). Winter was not sampled due to a predicted change in weather conditions and a large increase in rainfall, which flooded riparian zones in the majority of streams.

The physical habitat of over 70 streams throughout Canterbury was initially analysed by conducting a field assessment using Harding et al. (2009) protocol 'p2d Field Assessment'. This protocol measures a number of different characteristics of a stream: shading, buffer width and intactness, vegetation composition of the buffer and adjacent land, bank stability, livestock access, slope and groundcover. The slope of each riparian zone was measured with an Abney level at each location where the pottles were deployed. I then selected the best 50 streams to use for the survey.

At each of these 50 sites, sediment runoff was estimated by deploying six 200 mL pottles as sediment pitfall traps. Each pottle was dug into the ground, flush with ground level. Three pottles were placed at the top of the riparian zone and three pottles were placed on the lower bank, close to the stream but above the obvious flood zone. In dairy farms, the pottles were placed within fenced riparian zones to avoid disturbance by cattle. In some cases, if the riparian zone was too narrow, only three pottles were deployed (two of the twenty dairy farms). In urban areas, the pottles were placed in inconspicuous areas to avoid disturbance by the public.

The pottles were deployed for at least 28 days, and then recovered. The material collected in each pottle was transferred to a labelled plastic-zip locked bags and the pottle was then replaced in its original position.

Sediment samples were oven dried at 60^{o}C for 48 hours to remove any moisture. The dry sample was then transferred into a pre-weighed tin weigh boat and weighed to give a total weight of organic matter and inorganic matter.

In many cases, the sediment deposits could not be washed from the leaves which could result in errors in final dry mass. This problem was solved by ashing samples. Organic matter samples were ashed for at least one hour at 550^{o}C. The remaining material was then re-weighed. This weight of mineral ash was subtracted from the initial dry mass, and recorded as ash-free dry mass (Hauer and Lamberti 2007). The following equation was used to calculate ash-free dry mass (AFDM):

$$\text{AFDM} = \text{dry mass (g)} – \text{ash mass (g)}.$$

In addition to the site characteristics estimated be the p2d Field Assessment, daily rainfall data was recorded from a total of 24 weather stations belonging to Environment Canterbury, NIWA (National Institute of Water and Atmospheric Research), and farmers.

Data analysis

The influence of groundcover from adjacent land-uses and season on sediment runoff was tested by analysis of variance (ANOVA) where land-use was included as a categorical variable, season as a factor and sediment as the response variable.

The effect of time (season), land-use (dairy, pine, native or urban) and treatment (top or bottom sample) on response variables (organic matter, percentage groundcover and vegetation composition) was analysed with a linear mixed-effects model. Season, land-use, treatment, slope, percentage groundcover and vegetation composition were set as fixed factors while stream and replicate within stream were included as random factors. I nested replicates within stream because some replicates had differing slopes. Land-use and treatment were fixed factors as they were the main predictors of my hypotheses. All response variables were ln-transformed to meet the assumptions of statistical tests.

The influence of the amount of rainfall and land-use on sediment capture was tested with an analysis of covariance (ANCOVA), where land-use was included as a categorical variable and rainfall as a continuous variable. Sediment was the response variable and was ln-transformed to meet assumptions of normality and equal variance.

All analyses were conducted using the nlme package (Pinheiro et al. 2007) in R (R-Development-Core-Team 2011).

Results

Runoff from adjacent land-uses

Urban riparian zones had the lowest amount of groundcover (~50%) with sparse native plant species, whereas in native forest there were higher amounts of groundcover (~60%). In pine forest there was ~80% groundcover of mixed exotic species and dairy farms had the highest levels of groundcover (~90%), predominantly due to dense, un-grazed rank grass. Differences in percent groundcover across land-uses were significantly different (One-way ANOVA; $F_{3,46} = 5.59$, $p = <0.005$) (Figure 3.3).

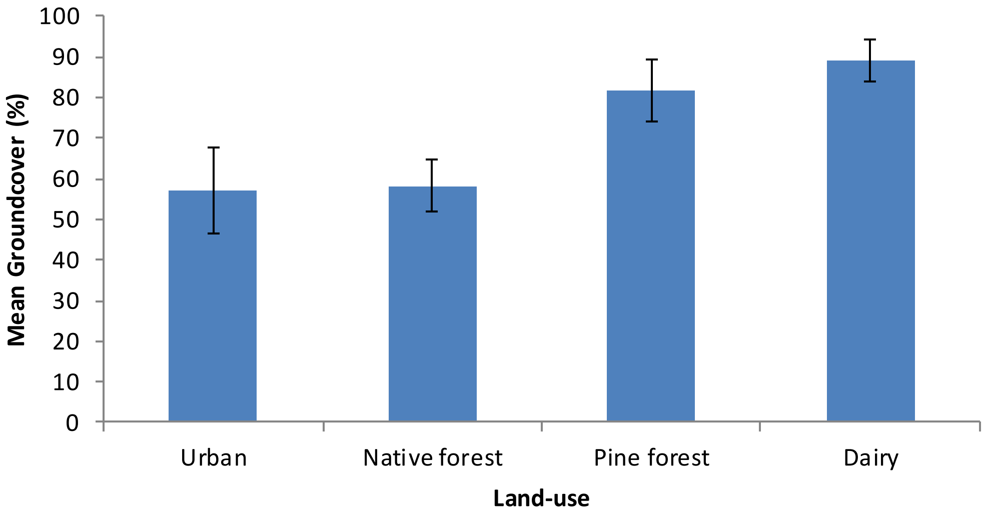

Figure 3.3: Mean groundcover (± SE) across each land-use (Urban, n = 10; Native, n = 10; Pine, n = 10; Dairy, n = 20).

Sediment runoff was significantly different between adjacent land-uses (Figure 3.4, Table 3.1). The highest sediment runoff occurred in urban riparian zones, and lowest in native, pine forests and dairy farms. This pattern was consistent across all three seasons. Although there was a marginally significant effect of season (Table 3.1) due to lower sediment runoff during the summer, there was no significant interaction between season and land-use. Sediment runoff entering the riparian zone was greater in streams where the adjacent land-use had less groundcover despite the presence or absence of livestock (Figure 3.4).

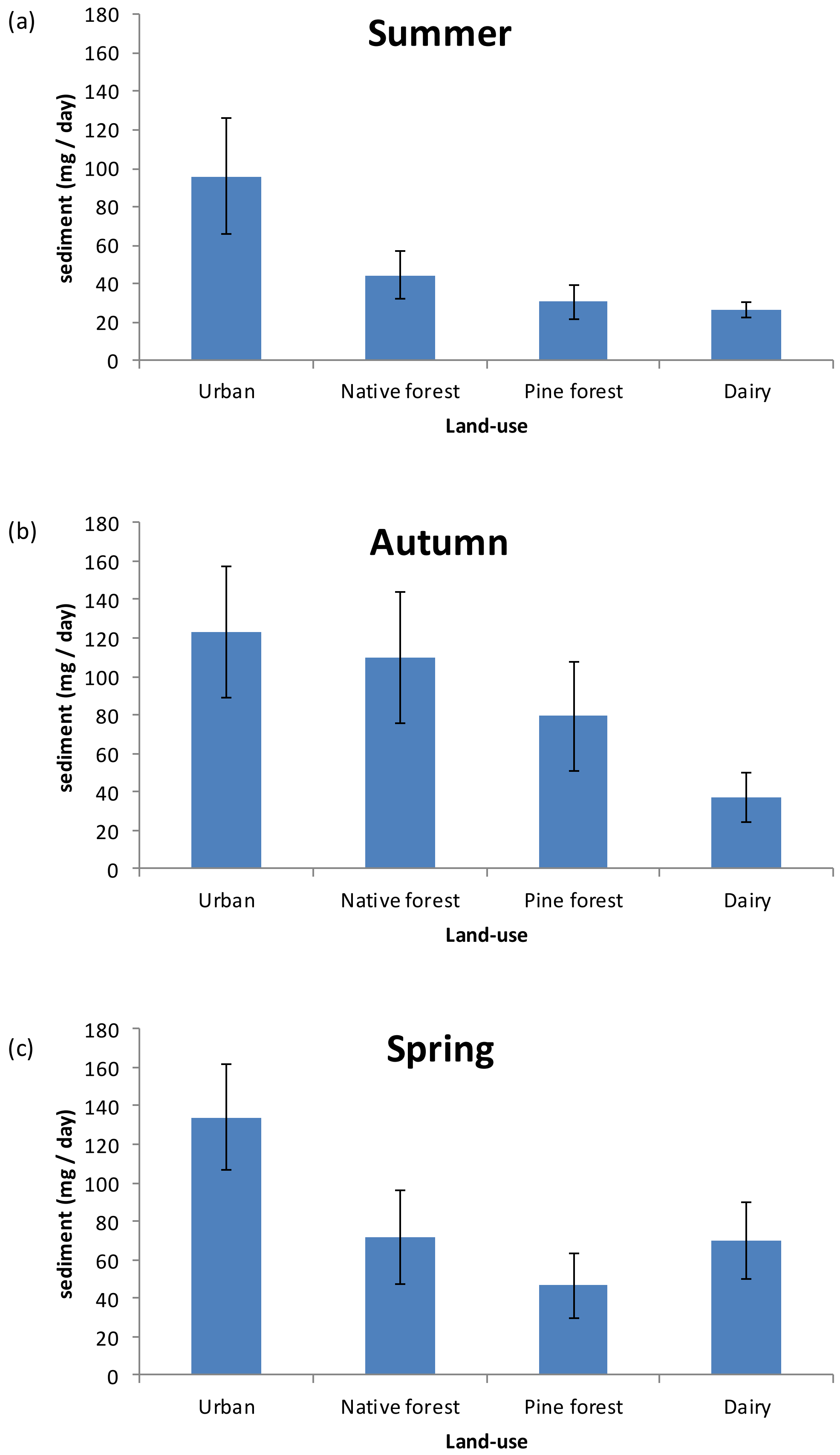

Figure 3.4: Mean sediment runoff (± SE) from adjacent land-uses in three seasons (Urban, n = 10; Native, n = 10; Pine, n = 10; Dairy, n = 20).

Table 3.1: Results of an Analysis of Variance investigating the effect of land-use and an interaction of season on sediment values.

Effect	**d.f.**	**F value**	**p value**
Land-use	3	7.85	<0.001***
Season	2	2.39	0.096 .
Land-use:Season	6	0.744	0.62
Residuals	135		

Sediment intercepted in the riparian zone

Surprisingly, I found no significant difference between samples taken from the top of the riparian zone and the lower banks of the riparian zone (Figure 3.5, Table 3.2). This pattern was consistent across different land-uses (no significant Land-use x Treatment interaction, Table 3.2). However, the native forest treatment in autumn between the top and the bottom of the riparian zone seemed to have an effect.

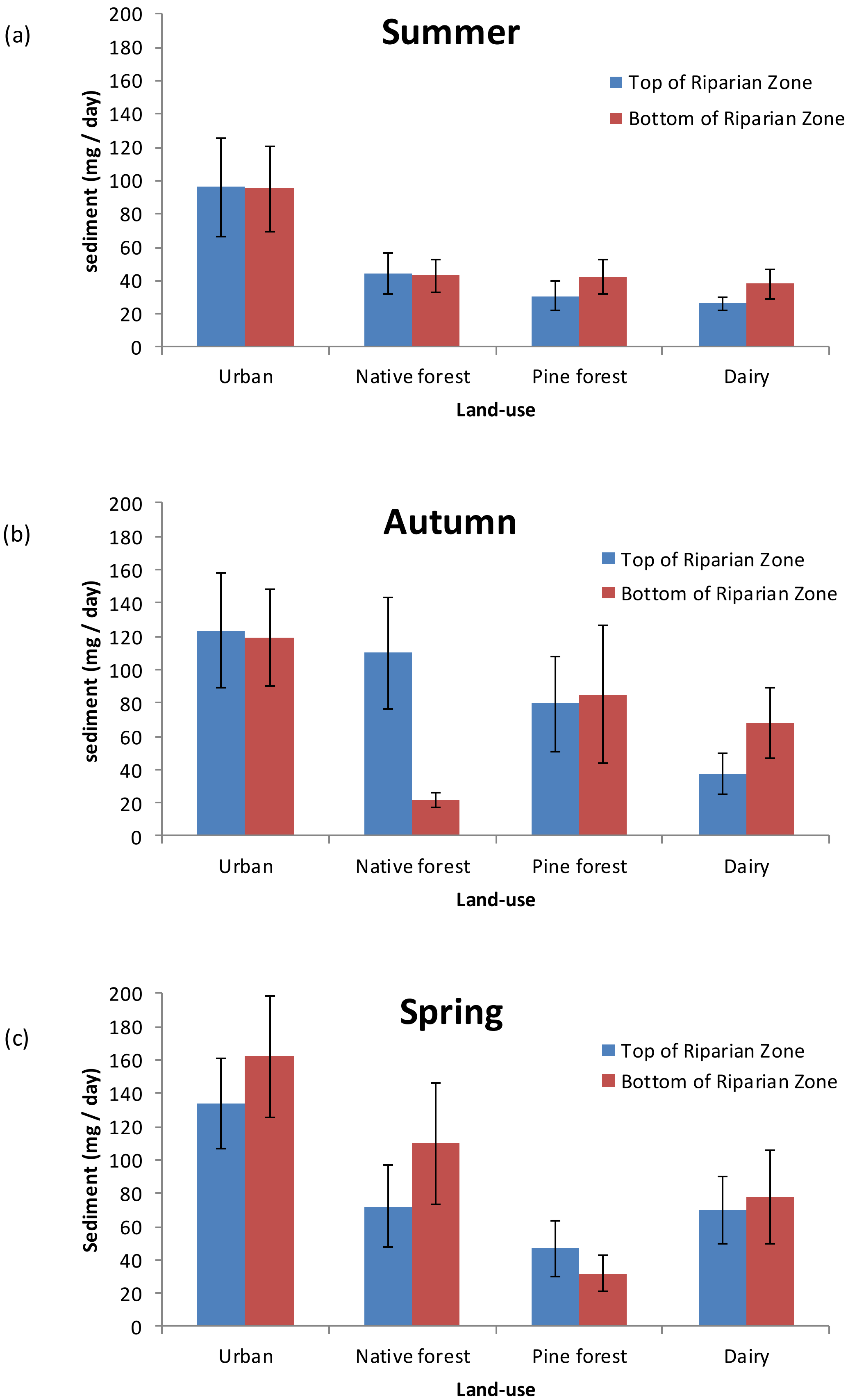

Figure 3.5: Mean sediment runoff (± SE) from within riparian zones of four different land-uses over three seasons (Urban, n = 10; Native, n = 10; Pine, n = 10; Dairy, n = 20).

Land-use type and groundcover had significant effects on sediment runoff across all three seasons, with groundcover the strongest of these predictors (Table 3.2). Other site descriptors, including slope and vegetation composition within the riparian zone had no significant influence on sediment runoff.

Table 3.2: Linear Mixed Effects Model testing the influence of land-use, riparian zone (treatment), groundcover, slope, and vegetation composition on sediment values. Stream identity was included as a random factor to account for multiple sampling sites within a given stream.

Season	**Effect**	**d.f.**	**F value**	**p value**
Summer	Land-use	3	3.36	0.027*
	Treatment	1	3.23	0.074 .
	Groundcover	1	7.09	0.0085**
	Slope	1	2.55	0.11
	Veg.comp	1	1.29	0.26
	Land-use:Treatment	3	0.554	0.65
Autumn	Land-use	3	2.77	0.053*
	Treatment	1	0.0676	0.80
	Groundcover	1	4.36	0.038*
	Slope	1	2.71	0.10
	Veg.Comp	1	0.165	0.69
	Land-use:Treatment	3	2.07	0.11
Spring	Land-use	3	5.41	0.0032**
	Treatment	1	1.61	0.21
	Groundcover	1	40.43	<0.0001***
	Slope	1	1.39	0.24
	Veg.Comp	1	0.0652	0.80
	Land-use:Treatment	3	0.527	0.66

The effect of rainfall on sediment

Rainfall significantly influenced sediment runoff across all land-uses and corresponding levels of groundcover (Figure 3.6, Table 3.3). The more rainfall that fell, the more sediment occurred in the runoff. While the sediment load differed across land-use, and was greatest in urban systems, the effect of rainfall was consistent across different land-uses (no land-use x rainfall interaction, Table 3.3). When land-use was tested individually using a regression analysis, native forest had a significant effect showing that sediment increased in higher rainfall events (R^2 = 0.15, p = 0.035). The other three land-use types did not show a significant relationship between sediment and rainfall (urban (R^2 = 0.0108, p = 0.58), pine forest (R^2 = 0.08, p = 0.15) and dairy farms (R^2 = 0.0007, p = 0.84)).

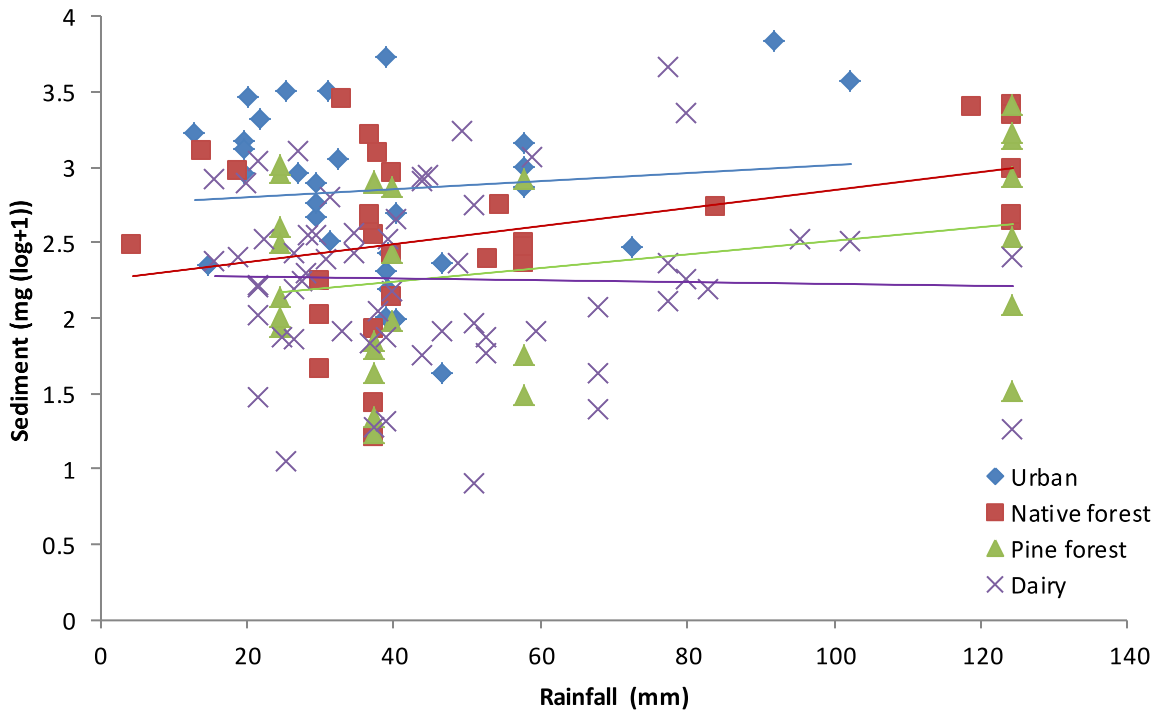

Figure 3.6: Sediment runoff compared with rainfall from 147 sampling occasions between different land-uses and associated groundcovers.

However, when land-use was combined over all three seasons, there was a significant effect showing that both land-use and rainfall influenced the amount of sediment in runoff (Table 3.3).

Table 3.3: Results of an Analysis of Covariance investigating the effect of rainfall and land-use (groundcover) on sediment values.

Effect	d.f.	F value	p value
Land-use	3	7.9512	<0.001***
Rainfall	1	4.3774	0.0382*
Land-use:Rainfall	3	0.9229	0.4316
Residuals	139		

Discussion

This study was conducted across 50 Canterbury waterways within four different land-uses. My objectives were to identify: (1) the amount of sediment entering riparian zones from adjacent land-uses; (2) the effectiveness of riparian zones in each land-use; and (3) if there were any confounding factors affecting runoff through these riparian zones.

Land-use had a highly significant effect on the amount of sediment entering the riparian zone and there was a marginally significant effect of season. A number of studies have shown land-use effects on sediment runoff and transport rates (Allan et al. 1997, Kosmas et al. 1997, Dolédec et al. 2006). Somewhat surprisingly the lowest sediment runoff was recorded in my dairy farm riparian zones, while the highest runoff occurred in urban areas. Thus, what I expected to be the most intensive land-use had the least runoff. These findings indicate that the amount of vegetation in the riparian zone plays an important role in controlling sediment runoff.

Further analyses of these riparian zones indicated that the amount of groundcover was a key factor in reducing sediment runoff. In this study, the land-uses varied substantially in the amount of groundcover vegetation adjacent to the riparian zone. My results indicate that groundcover was consistently the most important variable in influencing the amount of sediment contained in runoff. Urban areas had the least amount of groundcover and dairy farms had the highest percentage of groundcover across the four different land-uses. This suggests that the adjacent land-use is highly important as it can increase the amount of sediment coming into the riparian zone. For land-uses with significantly less groundcover (i.e. urban areas), it is essential for the design of riparian management to be efficient to filter sediment and prevent it from flowing into the waterway.

When I investigated how much sediment was intercepted within the riparian zone, I found no significant difference between sediment at the top of the riparian zone compared to the bottom. This may be because types of vegetation found within riparian zones may not be efficient at filtering out sediment, although the lack of difference between the bottom and top of the riparian zone was consistent across all land-uses (no interaction between land-use and treatment). However the amount of sediment was significantly different between land-uses and was highly significant between different levels of groundcover within the riparian zone. Slope and vegetation composition (plant types within the riparian zone) were two variables found not statistically significant at effecting sediment runoff. There have been similar published results that agree with my findings that groundcover is an important factor in limiting runoff. Nunes et al. (2011) suggested that runoff and sediment yield decreased with an increase in vegetation that covered soil. Glade (2003) investigated forest clearance, and found that increased landslide activity further contributed to sediment accumulation downstream. While Rogers and Schumm (1991) found that groundcover below 15% coverage was ineffective at preventing erosion.

To investigate if rainfall influenced sediment runoff in my riparian zones, the sediment sample at the top of the riparian zone was used to test for an effect between rainfall and the amount of suspended sediment in runoff. Rainfall had a highly significant effect on the amount of sediment going into streams, with greater sediment yields following periods of high rainfall. Similarly, land-use type had a strong effect on sediment runoff. However, there was no significant interaction between rainfall and runoff, indicating that heavier rainfall consistently increased sediment runoff across all land-uses types.

My comparison of upper bank and lower bank sediment traps produced surprising results. For further research looking at the effects of land-use on sediment runoff I would recommend using a different methodology to look at the effect of sediment transport within the riparian zone to distinguish what is occurring. This may be achieved by isolating areas into plots to ensure there is no additional sediment being captured in either the top or bottom riparian sample, therefore gaining a more accurate reading. In addition, investigating differences in nutrient concentrations between the top and bottom of the riparian zone (nitrogen and phosphorous), and investigating differences in soil types may also be useful for designing the best possible riparian management program.

For intensive industries such as production harvesting and dairy farming, there needs to be a dense riparian buffer zone between the adjacent land-use and the waterway. In urban areas, riparian zones are currently areas that have perhaps been poorly designed, with the removal of groundcover and replacement of sparse native plants.

Prior to designing and planning riparian management, research from other studies needs to be considered to ensure that the most efficient riparian management design is produced. For example, Collier et al. (2009) investigated habitat quality and fish and community composition within streams. They found that the presence of riparian vegetation can help enhance in-stream community structure, and assist with filtering pollutants from urban catchments. Borin et al. (2010) compared riparian zones composed of alternating trees (*Platanus hybrida* Brot.) and shrubs (*Viburnum opulus* L.) of different ages. The riparian zones of three to five years have been shown to reduce total runoff by 33% and once matured can reduce it by almost 100% in farms. These studies show that riparian management can have an important role in sediment interception into waterways, resulting in an increase in in-stream community composition and effective runoff capture. Thus, considering riparian cover as a series of tiers of vegetation could be beneficial, with larger trees providing shade and litter inputs and groundcover playing a role in attenuating pollutants and sediment.

Results from this chapter indicate groundcover and rainfall are important in sediment interception, so I investigated this further in Chapter 4 by using a rain simulator experiment to look at the effects of rainfall volume and intensity and groundcover on sediment runoff.

Chapter 4: Investigating the effectiveness of groundcover: a rain simulator experiment

Introduction

In Chapter 3 I found that differing land-uses produced significantly different levels of sediment runoff. These differences appeared to be driven by the amount of groundcover in different riparian zones. Maintaining a high amount of groundcover within riparian buffers would seem to be an important factor in reducing sediment runoff to receiving waterways. Consequently, the effects of groundcover on sediment transport have been an increasing research focus (Blinn and Kilgore 2001). For example, an American study looked at four groundcover levels (0, 45, 70 and 95% cover), and found that the mean runoff volume from the bare ground was approximately twice that of the other three levels of groundcover (Butler et al. 2006).

Several studies have shown that other variables such as rainfall intensity and the amount of rainfall influence the efficiency of groundcover. Nearing et al. (2005) investigated the response of seven different erosion models to different factors such as precipitation and differences in amount of vegetative canopy and groundcover. They found that as rainfall and rain intensity increased, erosion and runoff increased in direct response.

In Spain, Quinton et al. (1997) conducted a rain simulated study looking at five different riparian plant species and bare ground soil over eight months. The study measured the effect of different groundcovers, species composition and plant properties on runoff. Their results showed that although there was a decrease in soil runoff in vegetated plots compared to the bare soil, there was little variation between different vegetation treatments. An Australian field study used rainfall events that compared bare ground with plentiful grass cover on hill slopes. They found that the bare ground had between six and nine times more water runoff, and up to 60 times more sediment loss than similar sites with no bare ground (Bartley et al. 2006). Thus groundcover appears to be an important factor, but the effect can vary among locations.

There have been several studies within New Zealand which have investigated factors influencing the efficiency of groundcover in filtering sediment runoff. In Waikato, field experiments showed sheep grazing increased concentrations of sediment in runoff with increasing bare ground (Elliott and Carlson 2004). Infiltration rate (the soils ability to hold water prior to runoff) decreased with grazing which resulted in an increase in rain runoff. Furthermore, Galbraith and Burns (2007) showed that the conversion of pastoral land to native tussock groundcover, decreased sediment load into streams. For riparian buffers to be successful, it is necessary to identify the ideal amount of groundcover which can efficiently filter sediment.

One method to experimentally investigate the influence of groundcover on runoff is to manipulate rainfall across a range of vegetation types. Rain simulators have been used by several researchers to test the effect of rainfall, duration and intensity on sediment runoff. Adams and Elliott (2006) used a simulator to assess the effect of suspended sediment due to grazing sheep and cattle. They found that as the amount of bare ground increased, suspended sediment runoff increased. Grazing also had an effect, as post-grazing tests generated up to 30 times more sediment than pre-grazing tests. This result was consistent with results found in similar New Zealand studies. For example, Elliott et al. (2002) found that treading by stock increased bare ground, which resulted in an increase in the concentration of sediment within runoff. Also, Adams et al. (2005) used a rain simulator and found that infiltration is the most important mechanism to produce runoff. Cournane et al. (2011) used a rain simulated study and found that a dairy farm had increased surface runoff and suspended sediment losses when cattle treading intensity was increased.

Numerous vegetation and planting guides have been produced by local authorities to advise landowners about specific plant species to grow in riparian zones. Some guides provide information on species tolerances and preferred habitats. For example, the Christchurch City Council Planting Guide (Christchurch City Council 2005) is a simple and easy to read guide incorporating a stream profile diagram specifying where plants should be planted and highlights the areas of the bank that may become submerged during different rainfall events. A more detailed Christchurch City Council (2003) document for riparian planting provides site planning and design, how to prepare a planting site, what seasons are best to plant, as well as how to control weeds. Environment Canterbury's pamphlet 'Caring for streams in the Canterbury Plains' explains why people should care for our streams, and the value streams add to the community (Environment Canterbury 2001). The pamphlet gives clear instruction of what and where to plant and relays simple and easy to understand information to the public. Although these guides are a positive step towards promoting planning and designing riparian zones, they are not necessarily based on robust science. These planting recommendations may not focus on reducing contaminants into streams or improving stream health.

To investigate the relative importance of groundcover in decreasing runoff, I conducted a series of rain simulator experiments in riparian zones with similar morphological characteristics (i.e. slope, species composition), but differing extents of groundcover. I predicted that as groundcover increased, the sediment yield in the runoff would decrease. Furthermore, I expected that as rainfall intensity and duration increased, sediment yield would also increase.

Methods

Study area and site selection

A total of 17 sites were selected within riparian zones on the University of Canterbury campus. All sites consisted of short, mown, grass vegetation that ranged in groundcover from 10% to 100% (Figure 4.1). Each experimental site covered approximately 4m^2 with slopes between 12^o and 16^o of similar grass and soil type. Generally, sites were adjacent to streams so that results were comparable to sediment runoff processes occurring in riparian buffer zones.

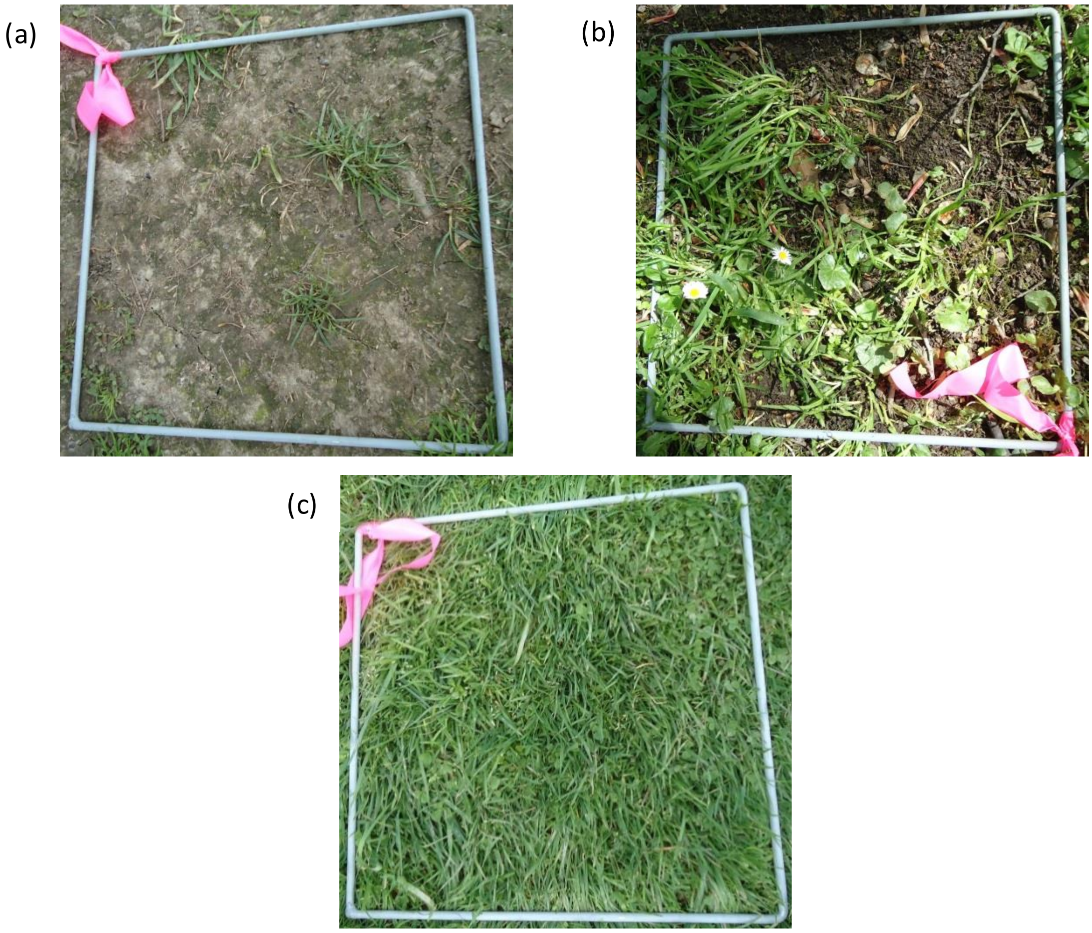

Figure 4.1: Examples of different amounts of groundcover of short grass. (a) 10% (b) 50% (c) 100% groundcover

A Norton Rainfall Simulator (two-head module system) from the University of Canterbury Fluid Mechanics Department (Figure 4.2) was used to create artificial rain on a known area of the riparian zone. Rainfall rate and raindrop size was controlled by water pressure and nozzle size. To ensure that the simulator realistically mimicked natural rainfall, the pressure was carefully monitored to maintain 6psi.

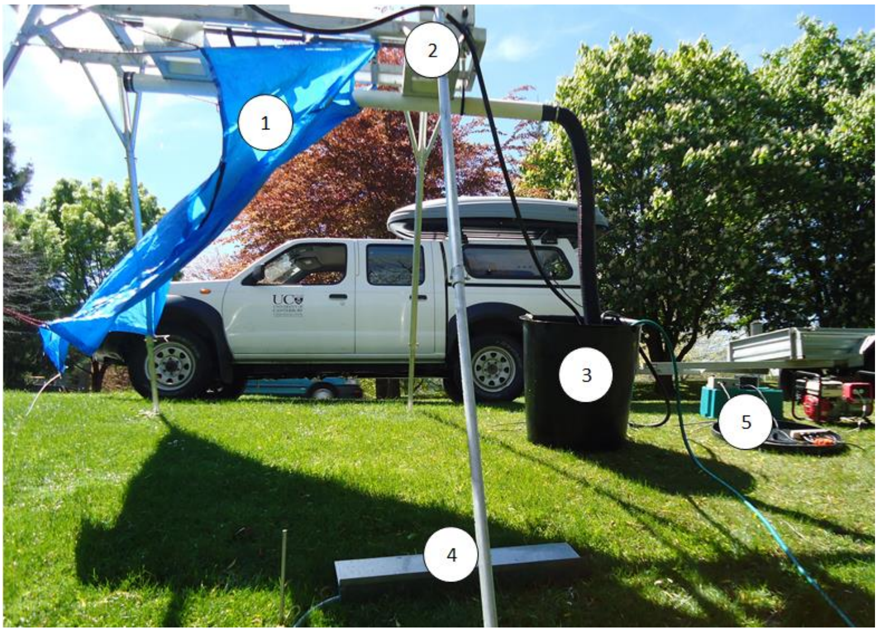

Figure 4.2: Norton Rainfall Simulator. (1) Tarpaulin used as a curtain shade to block one head module. (2) Single head module. (3) Reservoir tank used for water storage. (4) Runoff and sediment catch tray. (5) Control unit to set rain rate and intensity.

The rainfall rate was set at 8.65 mm per hour from the single module head. A runoff sediment catch tray was used to capture the runoff two metres downslope. The catch tray was 90 cm wide, and had a pipe leading to a water and sediment collection bucket positioned downslope (Figure 4.3).

Figure 4.3: Norton Rainfall Simulator. (1) Sample bucket. (2) Water and sediment catch tray.

Experimental design and sampling

A total of 17 trials were conducted. Percent groundcover at each site was visually estimated in a 30 cm x 30 cm quadrat placed in the middle of the simulator and slope was measured in the same location with an Abney level. Initially, the rain simulator was activated on the lowest intensity and the time from the start of rainfall to the first runoff into the collection tray was recorded. The distribution of rainfall and the amount of rainfall at each of the three intensities were recorded (Appendix 4 and 5). The simulation was then run for a further 15 minutes. The trial was repeated at three different rainfall intensities (8.65 mm per hour, 13.57 mm per hour and 17.98 mm per hour). Each of the three rainfall intensity trials were run on the same site and run consecutively, with 15 minutes of no runoff recorded between each trial.

All experiments were conducted under fine weather conditions and after it had not rained for the preceding 48 hours.

Laboratory Analysis

In the laboratory, the total volume of runoff from each trial was measured, and the amount of sediment contained within the water was quantified. Samples which had high levels of sediment were subsampled by mixing thoroughly to suspend sediment and split into 100 mL sub-samples. These sub-samples were filtered through Glass Microfibre Whatman Filters (GF/C 47 mm Ø circles). If the total sample was less than 100 mL, the entire sample was filtered. Filters were then dried at 60°C for 24 hours in a drying oven, then samples were weighed then ashed in a muffle furnace for at least one hour at 550°C and then reweighed. Plain filters were weighed and ashed to determine the weight of an individual filter.

Data Analysis

The effect of groundcover and rainfall intensity on the amount of sediment runoff was analysed with a general linear model. Sediment quantity (mg/100mL) was the response variable and ln-transformed to meet the assumptions of normality and equal variance. Analyses were conducted using the nlme package (Pinheiro et al. 2007) in R (R-Development-Core-Team 2011).

The influence of the amount of rainfall prior to runoff and groundcover on sediment capture was tested using a multiple regression. Again, sediment data was the response variable and ln-transformed to meet assumptions of normality and equal variance.

Results

Effect of groundcover on sediment runoff

The amount of sediment varied from 0 mg per 100 mL to 289 mg per 100 mL of runoff across all treatments. As the proportion of groundcover increased, the quantity of sediment within runoff significantly decreased across all three rainfall intensities (Figure 4.4(a) R^2 = 0.31, p = <0.05 (b) R^2 = 0.62, p = <0.005 (c) R^2 = 0.72, p = 0.0005).

As rainfall intensity increased the efficiency of groundcover in intercepting sediment also improved. At lower intensity, there was a weak, but significant negative relationship between groundcover and sediment. As rainfall intensity increased the relationship became stronger and more significant (Figure 4.4).

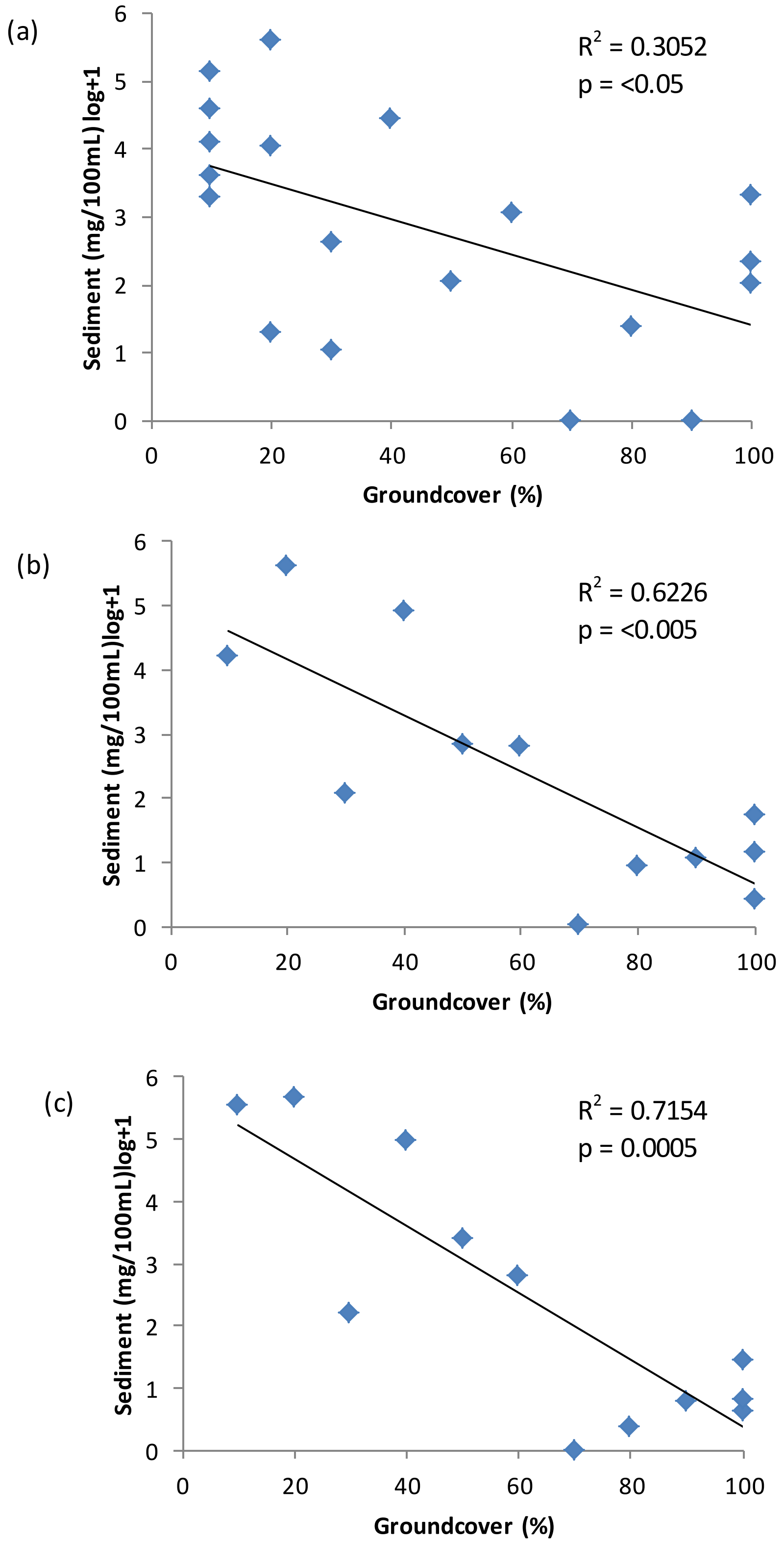

Figure 4.4: Sediment runoff for differing degrees of grass groundcover at three different rainfall intensities (a) 8.65mm/hr (b) 13.57mm/hr (c) 17.98mm/hr at increasing grass groundcover. p-values calculated from F-ratios in regression analysis.

Groundcover – rain intensity interaction

Groundcover had a significant influence on sediment runoff across all three levels of rainfall intensity ($p = <0.0001$, $\alpha = 0.05$), however rainfall intensity had a non-significant effect on groundcover effects on sediment (Groundcover x Intensity interaction, Table 4.1).

Table 4.1: Analysis of covariance results table showing the effect of Groundcover and an interaction of intensity.

Effect	**d.f.**	**F value**	**p value**
Groundcover	1	40.805	<0.0001***
Intensity	2	0.0914	0.9129
Groundcover:Intensity	2	1.9774	0.1528
Residuals	37		

Although the groundcover x intensity interaction was not significant, there was a slight trend towards a strengthening effect of groundcover on sediment at higher rainfalls (i.e. steeper slope), and at higher intensity there was a greater amount of sediment overflow at lesser groundcover (Figure 4.5).

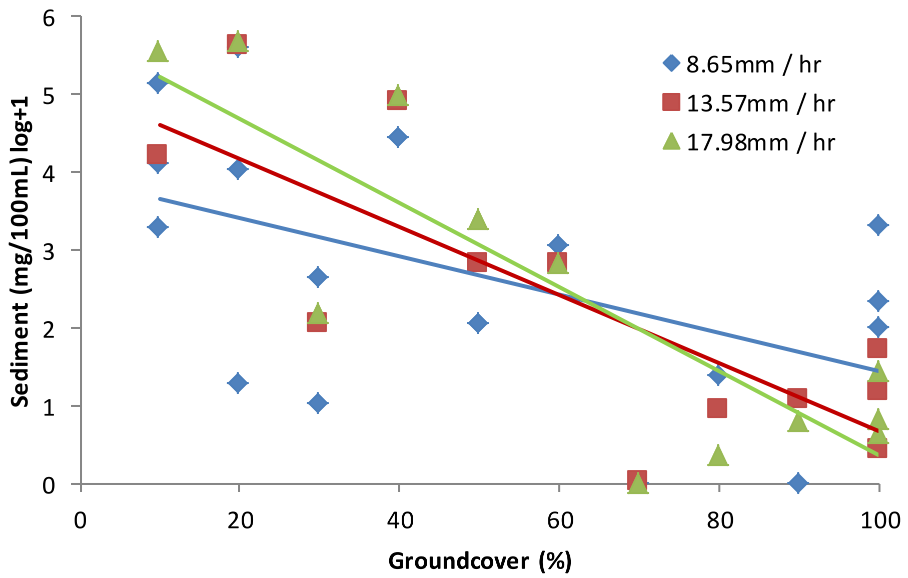

Figure 4.5: Amount of sediment runoff (mg/100mL) over different percentages of grass groundcover at three different rainfall rates.

Amount of rainfall before runoff occurs at different groundcovers

I measured the amount of rainfall that was required to cause overland flow to occur. A linear regression showed that there was no significant relationship between groundcover and total amount of rainfall that fell prior to runoff occurring ($F_{1, 15} = 2.95$, $p = 0.11$).

However, a multiple regression indicated that the amount of rainfall that fell prior to overland flow occurring changed the effect of groundcover on sediment runoff (Groundcover x Rainfall interaction, Table 4.2). While increasing groundcover decreased sediment runoff (negative effect, Table 4.2), more intensive rainfall prior to runoff occurring appeared to reduce sediment runoff for a given groundcover (Table 4.2); as shown by the positive effect of the interaction term.

Table 4.2: The effect of differing amounts of rainfall occurring prior to runoff at different groundcovers on the amount of sediment contained in runoff (Multiple regression). Direction effects were taken from coefficients of the regression.

Effect	**d.f.**	**F value**	**p value**	**Direction of effect**
Groundcover	1	7.016	0.02006*	-
Rainfall	1	2.5628	0.13342	-
Groundcover:Rainfall	1	4.5092	0.05348 .	+
Residuals	13			

Discussion

Results from my rain simulator experiments showed that sediment runoff was significantly correlated with the amount of groundcover. More specifically, values of groundcover ranging from 60% to 100% grass cover were increasingly efficient at reducing sediment. This result is consistent with studies that have shown overland flow and sediment yields decrease with increasing groundcover (Quinton et al. 1997, Galbraith and Burns 2007). Puigdefabregas (2005) found that in areas of scattered vegetation and bare ground, runoff is noticeably increased compared to areas with total vegetation coverage.

The experiments in this study were conducted in Christchurch which has a low mean annual rainfall (614mm / year) (Christchurch City Council 2010), compared to other New Zealand cities. However, when easterly airstreams occur there can be significant amounts of rainfall (McGann 1983). Short periods of heavy downpours occur rarely, but when they do rainfall intensity can reach 30 mm per hour. Between these severe storms, Canterbury has long dry spells occurring in the summer which dry out soils resulting in not enough moisture for plant growth, potentially reducing vegetative groundcover. The influence of groundcover may vary among regions depending on the rainfall conditions, as soils may retain moisture all year round compared to other areas that have dry soils for a longer period of time.

Runoff occurs when the amount of rainfall is greater than the storage capacity of the soil (McGann 1983). Sediment runoff is a result of the interaction between raindrop erosion and surface flow. The raindrop causes soil disturbance when sediment particles are dislodged by the raindrop impact. With greater groundcover, raindrops are intercepted before reaching the soil surface, which subsequently decreases the amount of sediment dislodged, and interrupts sediment runoff as sediment is captured as water runs downslope (Wainwright et al. 2000).

In my research, three different rainfall intensities were tested but there was no significant relationship between the intensity of rainfall and the amount of sediment in the runoff. Furthermore, when measuring the volume of rain which fell prior to runoff, there was no correlation between the volume of rain and amount of suspended sediment, although there was a marginally significant interaction between groundcover and rainfall volume. The positive interaction between groundcover and volume of rain implies that the effect of groundcover reducing runoff may be weakened under higher rainfall conditions. Therefore, the amount of rainfall can overwhelm the ability of groundcover to intercept raindrops and overland flow.

Infiltration rates (the rate at which water is absorbed by the soil) is an important process in determining the amount of rainfall required to produce runoff. During high-intensity events, rainfall can exceed the infiltration rate which therefore results in runoff across the entire surface. In contrast, during low-intensity storms, if maximum rainfall rate is lower than the infiltration rate there is no runoff (Puigdefabregas 2005). High amounts of groundcover aid infiltration by impeding overland flow, increasing frequency and depth of ponding, and protecting the soil surface from compaction that can inhibit infiltration (Johansen et al. 2001). Therefore, as groundcover decreased, the rate of water infiltration also decreased, resulting in increased sediment runoff (Mwendera and Saleem 1997).

My trials were conducted in riparian zones that may be influenced by trampling and compaction from people and vehicles (e.g. lawnmowers). This may have caused differences in the soil structure and vegetation cover as trampling decreases groundcover. This scenario is an issue for activities that have compact surfaces such as livestock tracks and roads. For example, within forestry harvesting areas, roadways are likely sources of sediment, however as these zones are usually localised, there are opportunities for sediment capture before contact with waterways (Croke et al. 1999).

Results from my experiments indicate a significant effect of groundcover in all analyses. Therefore, I can conclude that groundcover is an important variable to consider when planning riparian management projects (Quinton et al. 1997, Bartley et al. 2006, Galbraith and Burns 2007). Another study showed that after a fire event, the amount of groundcover remaining was far more important at determining amount of sediment runoff than surface roughness or slope (Johansen et al. 2001). This result is similar to results that I found in Chapter 3, showing that slope had no effect but groundcover had a significant effect on sediment runoff.

A further extension of my research would be an experiment using the rain simulator on planted beds to test the effect of different plant species on sediment runoff. This would provide more information on appropriate plant species that should be used within riparian zones to most effectively filter sediment.

Modelling the effects of groundcover, runoff and rainfall is essential for land-use planning in vulnerable environments, particularly those around freshwater areas to recognise which variables are determining the amount of sediment contained in runoff. Understanding the effectiveness of vegetation on protecting the ground surface to prevent erosion from occurring has great practical value for land management projects and agriculture (Rogers and Schumm 1991). More research is required to test the relative effectiveness of different types of riparian vegetation.

Chapter 5: Discussion

Synthesis

In New Zealand, there has been major agricultural intensification (in particular dairy farming) over the last two decades. This land-use intensification has been steadily replacing land covered in forest, scrub and wetlands (Cooper et al. 1995). As a result there is a risk of increased soil erosion due to these changes in land-use (Mahmoudzadeh et al. 2002).

In Chapter 2, I surveyed the public perception of riparian management. My results showed that there was some confusion about the roles of riparian management in maintaining water quality. A majority of people perceive riparian zones as a way to reduce the amount of nutrients in waterways, with little mention of their role in filtering sediment. Of even more concern was that over half of the people that have a stream through their property choose to do no form of management even though there are few or no barriers to do so.

Once I investigated what people from the farming community knew about riparian management, I then conducted a field survey of sediment transport in four different types of land-use. I had three main aims: (1) comparing sediment runoff between land-use, (2) measuring the effects a riparian zone has on sediment runoff, and (3) the effect of rainfall on sediment runoff. Land-uses had markedly different riparian vegetation, with dairy farms being dominated by grass which provided dense groundcover, while urban areas had mixed vegetation with abundant bare ground. This led to a somewhat surprising result that dairy farms produced the least amount of sediment runoff into riparian zones, compared to urban areas which produced the most. My original hypothesis was that the intensive land-use of dairy farms and production forestry would cause the most sediment runoff. Another surprising result was that generally, there was no difference between the amounts of sediment passing through riparian zones which implies that I was not able to measure vegetation effects on sediment attenuation within the riparian zone. This suggests that sediment that enters the top of the riparian zone is not intercepted by vegetation. However, my results might be affected by the periodic loss of streamside pottles leading to low replication and reduced power to detect significant differences. The methods used may not have been robust enough to detect the difference in sediment between the top and bottom of the riparian zone; to rectify this, more samples could be gathered at each site to increase statistical power. An alternative method would be to isolate sample plots to ensure there is no contamination within the sample from other sources of sediment and to determine an accurate result of sediment flow within a known area.

The field survey indicated that vegetation type, especially the percentage groundcover, was an important variable to consider when thinking about riparian management (Bartley et al. 2006, Galbraith and Burns 2007). Sites with higher levels of groundcover had consistently lower sediment input into the sediment traps, regardless of season or land-use type. I then followed this survey with a rain simulator experiment which enabled me to control and directly manipulate two variables: rainfall intensity and percentage of groundcover. I found that sites with 60% to 100% grass groundcover were the most efficient at filtering sediment. Therefore, when planning riparian management projects I recommend that a target value of at least 60% groundcover to have a positive effect of filtering sediment, even if only consisting of rank grass. My results are consistent with other studies that show as groundcover increases, sediment runoff decreases (Quinton et al. 1997, Bartley et al. 2006).

Limitations

There are some limitations that I encountered during my study that may influence my conclusions. The field survey could be broadened by using complete seasonal data including winter. High soil moisture levels in winter can produce more sediment runoff than drier seasons (Kosmas et al. 1997), indicating that I may have underestimated sediment runoff in my survey. It was forecasted in Autumn 2013 that there would be a large increase in the amount of rainfall in the Canterbury Region, and it was suspected that flooding would occur at the majority of my riparian zones over this time, so no data set was collected for the winter season. There were also several potentially confounding weather events during other seasons. For example, a major storm in September 2013 caused a large amount of wind throw in both the Ashley and Waimate forests which may have impacted my pine forest sites in Spring. Such weather extremes may influence the ability of riparian zones in attenuating sediment, which would be an interesting avenue for future research.

There may have been confounding factors in the rain simulator experiments that would not normally be found in fenced riparian zones. For example, my study was conducted on the University of Canterbury campus, so foot traffic may have caused compaction of the soils that may have influenced runoff. The efficiency of my testing of riparian zones to capture sediment was likely to be influenced by the degree of trampling by people or machinery. Whether the positive influence of grass cover on sediment capture highlighted in my experiment occurs in trampled areas is unknown, and would be a fruitful research direction.

Gaps in the research

Very little research has investigated what the perceptions of farmers have on riparian management. Collier (2006) questioned dairy farming communities, but I extended this by asking specific questions of the entire farming community investigating if there were differences between farm types. My research identified farmers' knowledge about riparian management and what riparian management they carry out, and this information might inform Regional Council communication strategies.

There have been few studies in New Zealand that have investigated the effect of land-use on sediment runoff into waterways. My results showed that there were significant differences on the amount of sediment runoff between land-uses in Canterbury. It was interesting to discover that urban riparian zones seemed to be allowing more sediment into waterways compared to intensive agricultural and forestry practices. Therefore, more emphasis should be placed on better riparian planting within urban areas. My results imply that the efforts that have been made to reduce the amount of sediment in dairy and pine harvest forest areas may have had a positive effect by decreasing the potential for sediment entering waterways.

Further Research

I focussed on dairying because of the number of rules, regulations and high profile on this activity, and that there has been so much attention towards dairy farms being highly detrimental to the environment (Aarons and Gourley 2013). It would be interesting to investigate other intensive agricultural practices, i.e. cropping farms and sheep and beef farms. These farm types don't have the same degree of centralised rules and guidelines that are compulsory for dairy farms (perhaps more in Canterbury than elsewhere), so it would be interesting to see if non-dairy farms choose to do riparian management on their own accord, or whether there is little riparian management occurring.

With more time, the experiments could be strengthened by comparing other groundcover vegetation types. This could be broadened to compare native and exotic species within riparian zones, heights, root structure and groundcover to find the best suited species at sediment attenuation in riparian zones.

Final conclusion

I have concluded that there is a need for better education by councils and government agencies in order to increase the public's understanding and knowledge about riparian management.

My results show that modifications of land-use by humans have had a large influence on the processes of sediment runoff. There needs to be a change in the design of riparian zones within urban areas as low groundcover in these areas can produce large amounts of sediment runoff. Finally, my study provides evidence from both experiments and surveys that one of the most important variables to consider when planning riparian zones is groundcover.

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Appendix 1: Public Questionnaire

UC Riparian Management Questionnaire

1. Do you have a stream or other waterway running through your property? Y/N
2. If “yes”, how long is the length of the waterway?
3. If “not”, is there a stream or waterway nearby that is of value to you? Y/N
4. Are there other waterways that are of value to you? e.g., Avon, Heathcote, Lake Ellesmere, Rakaia River.

IF “No” to the above questions end questionnaire. Thank you for your time.

5. Do you know what a riparian zone is? N/Y
6. Do you actively manage the riparian zone along your stream? N/Y
7. If “yes” to question 6. What types of management have been done on this stream?
8. Do you belong to a stream or water care group? N/Y
9. Do you own / partly own a farm?
10. If “yes” to question 9, what type of farming practice is performed on this farm?
11. Does a waterway with riparian planting appeal to you more than one without?
12. If more, then why does it appeal?
13. What benefits (if any) do you think riparian planting and or fencing might have for a stream or waterway?
14. Are there any difficulties that are stopping you from having or doing riparian management?

General questions

15. Do you live in an urban area or rural area?
16. Are you male/female
17. Aged between;

16-29 30-49 50+

Thank you for your time.

Appendix 2: GPS of survey sites

Appendix 2: GPS locations of each of the 50 sample sites in my field survey (New Zealand Map Grid).

	Easting	Northing
Urban		
Ashburton	2410307	5700725
Halswell	2475254	5735499
Jellie	2476977	5743012
Lincoln	2468497	5729923
Rangiora	2477781	5766331
Tai Tapu	2473777	5727854
Timaru 1	2368276	5644381
Timaru 2	2368547	5643153
Timaru 3	2369834	5646972

Native forest		
Coopers Creek	2436270	5771539
Glentui	2449382	5778337
Gunns Bush	2348760	5613942
Hook Bush	2349186	5616221
Waimate	2348958	5610119
Mt Grey	2471650	5784501
Mt Thomas	2456090	5779302
Nimrod	2340484	5639563
Otaio	2345102	5629614
Woolshed	2372926	5729562

Pine forest		
Ashley 1	2477789	5777581
Ashley 2	2476340	5777945
Ashley 3	2479654	5780831
Ashley 4	2479196	5780962
Ashley 5	2471911	5780983
Ashley 6	2471056	5782916
Ashley 7	2470538	5782444
Waimate 1	2347443	5607358
Waimate 2	2343689	5610547
Waimate 3	2342019	5607799

	Easting	Northing
Dairy farm		
Farm 1	2362908	5613093
Farm 2	2358727	5586379
Farm 3	2343851	5591557
Farm 4	2342860	5590295
Farm 5	2343238	5591682
Farm 6	2349097	5626454
Farm 7	2363284	5623499
Farm 8	2417143	5729449
Farm 9	2431119	5725282
Farm 10	2426582	5724127
Farm 11	2435591	5724030
Farm 12	2442003	5736067
Farm 13	2435940	5767797
Farm 14	2462114	5720588
Farm 15	2467995	5728291
Farm 16	2471847	5724889
Farm 17	2407412	5690827
Farm 18	2407351	5687004
Farm 19	2374196	5671981
Farm 20	2389911	5733932

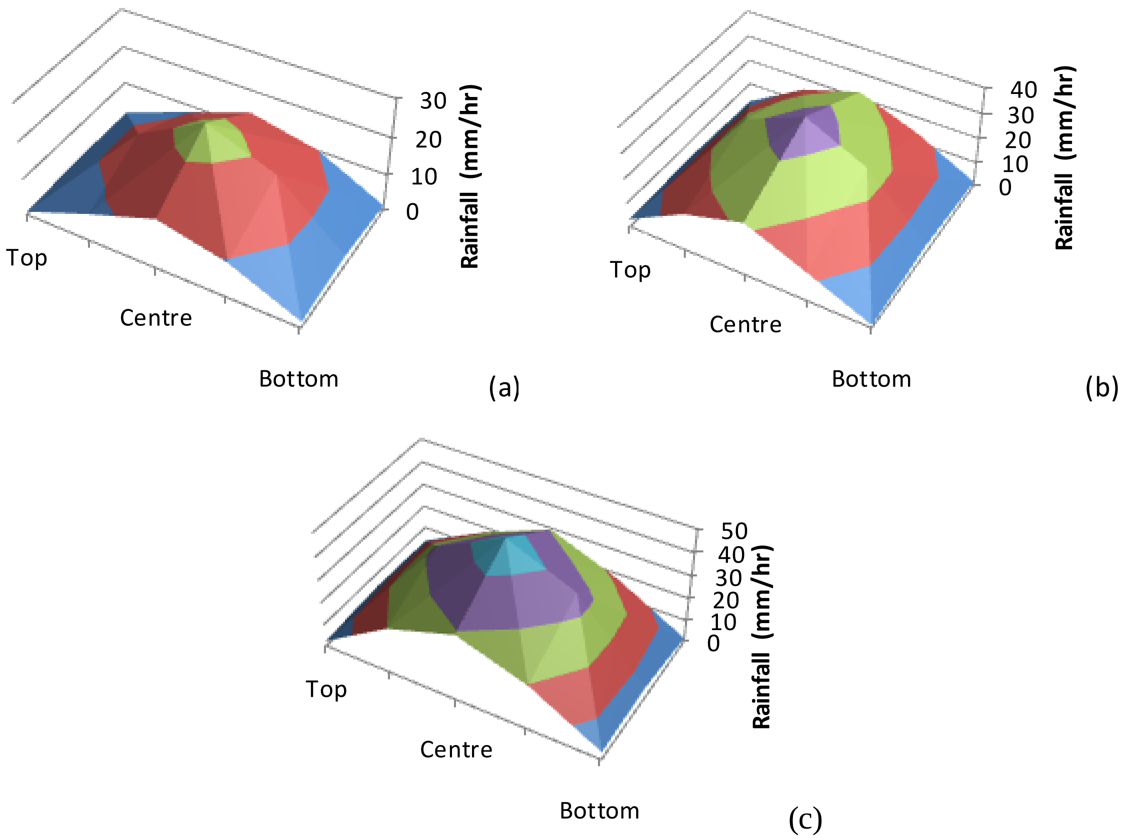
Appendix 3: Mean characteristics of each land-use

Appendix 3: Mean characteristics for each of the land-uses used in the field survey using data from the 50 sample sites.

	Urban		Native forest	
	x	**SE**	***x***	**SE**
Buffer width	6.13m	1.59	>30m	
Slope	15.58^o	1.82	21.36^o	2.4
Groundcover	61.4%	10.25	58.2%	6.47
Vegetation of riparian zone	Willow trees, low native shrubs		Mature native forest with large canopy cover	

	Pine forest		Dairy	
	x	**SE**	***x***	**SE**
Buffer width	>30m		5.68m	1.32
Slope	15.66^o	2.5	18.84^o	2.47
Groundcover	87.95%	4.49	89.5%	4.7
Vegetation of riparian zone	Pine trees, exotic weedy shrubs, gorse, blackberry and broom		High rank grasses with some farms including low native shrubs	

Appendix 4: Distribution of rainfall from rain simulator



Appendix 4: Distribution of water from the Norton Rainfall Simulator in mm per hour. (a) Intensity 1 (b) Intensity 2 (c) Intensity 3.

Appendix 5: Volume of rainfall from rain simulator

Appendix 5: Total volume of water distributed from the rain simulator for a period of 15 minutes at three different intensities.

Intensity	V (mL)
1	8734
2	13494
3	18728