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LAND-USE EFFECTS ON CHANNEL MORPHOLOGY
IN STREAMS IN THE MOUTERE GRAVELS,
NELSON, NEW ZEALAND

A thesis
submitted in partial fulfilment
of the requirements for the Degree of
Master of Applied Science
at
Lincoln University
by
B. R. Baillie

Lincoln University
2001
Abstract of a thesis submitted in partial fulfilment of the
Requirements for the Degree of Master of Applied Science

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Land-use can have significant effects on channel morphology, especially in smaller-sized catchments (< 5ha). Pasture streams in these small catchments are usually narrower than forested streams. It is hypothesized that the sediment trapping and retention ability of grass sod is responsible for the narrower channels in pasture streams. It is suggested that the coarser root structure in forested streams is less effective in armouring bank material against fluvial erosive processes. This, along with the influence of woody debris obstructions in diverting and channelising stream flow is thought to be the reason behind the wider and more variable stream widths in forested streams.

In the Hakarimata Ranges, Waikato New Zealand, it appears that streams in pine plantations that were planted onto pastureland 15 years previously are in the process of widening back to a forested channel morphology, releasing the sediment retained in the banks by the grass sod. As the majority of new plantings in pine plantations are occurring on pastureland or reverting pastureland the possibility of increased sedimentation in streams during the conversion process may be an issue in some areas.

The purpose of this thesis was to assess the influence of land-use on channel morphology in another area of New Zealand. The Moutere Gravels in Nelson provided an area of contrasting geology, hydrology and climate to that in the Hakarimata Ranges. The study compared channel morphology characteristics in 15 streams in small-sized catchments, 5 streams each in pasture, pine plantation and native forest. Channel morphology
measurements were made along a representative 100 m section of stream reach in each catchment. Woody debris was measured in each of the pine plantation and native streams to assess its influence on channel morphology.

There was no significant difference in bankfull and channel widths between the three land-uses in the Moutere Gravels. Width variability was less in the forested streams compared to the pasture streams. The presence of large woody debris (LWD) in the pine and native streams did not appear to be influencing channel width. There were no significant differences between the three land-uses in channel depth and cross-sectional area.

Width-to-depth ratios were significantly higher in the pasture streams in comparison to the forested streams. The higher number of bank undercuts and lower width-to depth ratios in the forested streams indicated that the tree roots were assisting in stabilising and retaining the channel bank material. Bank disturbance was low in all streams regardless of land-use ranging from 1-3%. There were more fines in the streambeds of the pasture sites but higher levels in one site influenced this. The median particle size was significantly lower in the pasture and pine sites in comparison to the native sites.

The presence of LWD in the pine and native streams increased the number and variety of pools and influenced sediment storage in the stream channel. The volume of LWD in these streams was low in comparison to streams in similar temperate forests in the Pacific Northwest of the USA.

The results of this study differ from similar studies in New Zealand and overseas. It is suggested that low sedimentation rates, low frequency of floods of sufficient magnitude to influence channel morphology and the cohesive structure of the channel bank material in the Moutere Gravels, may provide some explanation for the lack of land-use effects on channel morphology in these small catchments.

While the results of land-use effects on small streams in the Moutere Gravels are the exception when compared to other similar studies it does demonstrate that in some circumstances factors other than land-use can exert a dominant influence on channel morphology. When assessing the possible implications of converting pastureland to pine plantations, the influence of local hydrology, geology and climate need to be considered.
Keywords: channel morphology, land-use, Moutere Gravels, streams, Nelson, pine plantation, pasture, native forest, large woody debris, pools
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Introduction

Comparative land-use studies in small-sized catchments (up to 5 – 8 ha) both in New Zealand and overseas have found streams in pasture sites to be significantly narrower than forested streams (Zimmerman et al., 1967; Murgatroyd and Ternan, 1983; Clifton, 1989; Sweeney, 1993; Trimble, 1997; Quinn et al., 1997; Davies-Colley, 1997). The authors attributed the narrower stream channels in pasture to the ability of grass sod to trap and retain sediment and stabilise the channel banks. Wider channels in the forested streams were attributed to the lesser ability of tree roots to hold and retain sediment, and to localised channel widening from woody debris obstructions in the stream channel.

In the Hakarimata Ranges in New Zealand, streams in pine plantations recently converted from pastureland, were of intermediate width between the pasture and native streams, indicating they were widening to a forested channel morphology (Quinn et al., 1997). The authors suggested this channel widening process could result in increased stream bank erosion and sedimentation as sediment stored in channel banks by the retaining process of the grass sod was released.

As most of New Zealand’s new afforestation is likely to be on pasture or reverting pastureland (Maclaren, 1996; MAF, 2000), the possibility of increased sedimentation in streams during a channel widening process could have implications for the pine plantation industry. Increased sedimentation can potentially adversely impact on on-site and downstream values such as aquatic invertebrates, fish, estuaries and harbours.

Riparian vegetation is only one factor that can influence channel morphology in small-sized catchments, other factors such as geology, climate and hydrology can also have a strong influence on channel dimensions. The purpose of this thesis was to measure channel morphology characteristics in pine plantation, native and pasture streams in another region of New Zealand, with contrasting geology, climate and hydrology to that of the Hakarimata Ranges. The objective was to determine whether:

a) the occurrence of narrower stream channels in pasture and wider stream channels in forest extends to another region in New Zealand
b) the conversion of pastureland to pine plantations is likely to result in increased bank erosion and sedimentation in the stream channels in another region of New Zealand.

Chapter 1 gives a brief overview of the pine plantation industry in New Zealand. Chapter 2 expands on the concepts identified in this section, reviewing the factors that can influence channel morphology and summarising the results of other similar land-use studies. Chapter 3 outlines the reasons for selecting the Moutere Gravels in the Nelson region for the study and provides background information on the area. Chapters 4 and 5 explain the study design and methodology used and the results are presented and discussed in Chapter 6. Chapter 7 summarises the results of the study and the conclusions that were drawn from these results, and Chapter 8 provides recommendations for future work.
Chapter 1 - Forest industry as a land-use in New Zealand

1.1 Plantation forestry in New Zealand

The indigenous timber industry was first established in New Zealand in the mid to late 19th century following European settlement in the 1840's. The early spar trade was succeeded by the establishment of sawmilling industries and a timber export trade. Indigenous timber continued to be an important export commodity in New Zealand, particularly in regions such as Auckland and Westland, until the early 1940's (Roche, 1990).

The planting of exotic species started in the early 1900's and the Forest Service was established in 1919 (Roche, 1990). Prison labour was used initially in tree planting programmes from about 1900 to 1920. In the 1920's and 1930's an extensive State and private sector afforestation programme was undertaken in response to a perceived timber shortage. The results of a national inventory showed that the demand for forest products outweighed the ability of the indigenous resource base to provide them. Exotic afforestation, despite its uncertainties, offered the only real solution. Having dispensed with prison labour in the 1920's the Forest Service used cheap seasonal labour, mainly recruited from the ranks of the unemployed, to complete its planting programmes. By the 1930's, as the depression intensified, the need to engage as many unemployed workers as possible led to extended planting programmes. As a result, since 1945, the forest industry has become increasingly orientated towards exotic tree species, principally Pinus radiata.

By the late 1950's, Forest Service analysts suggested that a second larger afforestation programme was needed in order to meet projected domestic and export demands for forest products for the remainder of the century. This lead to a second planting boom which was initiated in the 1960's and continued through into the 1980's (Roche, 1990).

Today, pine plantations cover an estimated 1.731 million hectares, 6% of New Zealand's land area (total area of New Zealand, 27.0 million hectares). In comparison pasture and arable land is by far the predominant land-use in New Zealand (Figure 1.1), followed by natural forests and other non-forested land. Pinus radiata remains the dominant pine plantation species accounting for 90% of the planted area. Douglas Fir is the next most common species covering 5% of the planted area (NZFOA, 2000).
A third of New Zealand’s pine plantations are found in the Central North Island, 11.5% in Northland and 10% in both Nelson/Marlborough and Otago/Southland. Smaller areas are found in the Auckland, East Coast, Hawke’s Bay, Southern New Zealand, West Coast and Canterbury Regions. Pine plantations account for practically all the wood harvest in New Zealand, producing 15.7 million m³ of wood in 1998 compared with 0.1 million m³ of wood from indigenous forests (NZFOA, 2000). Forestry exports generate 12.6% of total exports from New Zealand and supply 1.1% of world and 8.8% of Asia Pacific’s forest products trade.

Most of the new afforestation is occurring on pastureland (Maclaren, 1996). An estimated 51,200 hectares of newly planted production forest was established in 1998 (MAF, 2000). Forty-four percent of this planting was on improved pasture, 47% on unimproved pasture and 9% on land where scrub was the previously predominant cover. Future plantings are expected to continue at a higher rate of 66,000 ha in the year 2000 and 65,000 ha/yr between 2001 and 2010. (Glass, 1997). It is estimated that 80% of the new plantings will be in Pinus radiata.

1.2 Environmental issues in New Zealand’s pine plantations

Increasing environmental awareness of the general public, legislative requirements, expectations of customers, and marketing of New Zealand’s ‘green’ image overseas has
focused attention on the environmental performance and sustainability of New Zealand’s pine plantations. The implications of increasing afforestation of pastureland have been well documented in Maclaren (1996) which covers a wide range of environmental issues such as water yield and quality, soil erosion and deterioration, greenhouse effects, aesthetics and biodiversity.

The main legislation affecting the pine plantation industry today is the Resource Management Act (RMA) of 1991 (NZ Government, 1994). Section 5 states that the purpose of this Act is to promote the sustainable management of natural and physical resources. Section 5(2) defines sustainable management as: ‘managing the use, development and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural well being and for their health and safety while –
(a) sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations; and
(b) safeguarding the life supporting capacity of air, water, soil and ecosystems; and
(c) avoiding, remedying or mitigating adverse effects on the environment.

Two other important documents pertaining to the sustainable management of pine plantations are The New Zealand Forest Accord (1991) and the Principles for Commercial Plantation Forest Management in New Zealand (1995). The New Zealand Forest Accord (1991) was signed by forest industry and environmental groups acknowledging the importance of natural indigenous forest and the need to maintain and enhance it. It also recognised the importance of commercial plantation forests as a source of perpetually renewable fibre, offering an alternative to the depletion of natural resources. The Principles for Commercial Plantation Forest Management in New Zealand (1995) complement the New Zealand Forest Accord (1991), and lay out in more detail guiding principles for the sustainable management of plantation forest and the protection, preservation, and sustainable management of natural forests.

Historically, research programmes in the pine plantation industry have focused primarily on improved technology and productivity with less emphasis on environmental issues. One outcome of the increasing environmental awareness and legislative changes, has been the development of a range of research programmes by various research organisations, government departments, forest companies and other agencies, addressing the issues of
environmental performance and sustainable management of pine plantations. Land-use studies are regularly used as a means of comparing pine plantations with other land-uses, especially pastureland. Indigenous (native) forests often provide a 'reference' or 'benchmark' for these types of studies.

A land-use study was used in this thesis to determine whether land-use was influencing channel morphology in the Moutere Gravels of Nelson, to compare these results with other similar studies and to discuss the implications of those results for the pine plantation industry in New Zealand.
Chapter 2 - Land-use effects on channel morphology (a literature review)

2.1 Factors affecting channel morphology

Channel morphology simply means channel shape. To quote Leopold et al. (1964, p.198), 'The shape of a cross-section of a river channel at any location is a function of flow, the quantity and character of sediment movement through the section, and the character or composition of the materials making up the bed and banks of the channel. In nature the last will probably include vegetation.'

Channel morphology is dynamic, changing both spatially and temporally in response to controlling factors such as changes in hydraulic discharge, sediment delivery, and stream bed and stream bank roughness (Beschta and Platts, 1986; Montgomery and Buffington, 1998). The channel can adjust to these changes in a number of ways including changes in channel width and depth, channel cross-section shape, channel gradient, bed material composition, channel sinuosity, and bedform composition (Figure 2.1). Therefore, channel morphology or channel shape is a reflection of the processes that formed it.

Figure 2.1: Factors Affecting Channel Morphology (Adapted from Montgomery and Buffington, 1998)
The morphology of a stream channel along with its hydrological characteristics will, in turn, influence the structure and functional characteristics of the stream’s biological communities (Vannote et al., 1980). These communities will respond to the dynamic physical conditions of the stream channel.

2.2 Influence of riparian vegetation and large woody debris (LWD) on channel morphology

Riparian vegetation and large woody debris (LWD) are two factors that can influence channel morphology (Montgomery and Buffington, 1998). Riparian vegetation contributes to bank stability by providing root reinforcement and increasing shear strength, particularly in non-cohesive alluvial bank materials. Riparian vegetation is also an important source of channel roughness (Keller and Swanson, 1979; Gray et al., 1989; Montgomery and Buffington, 1998; Abernethy and Rutherford, 1999).

LWD in the stream channel increases channel bed roughness and dissipates flow energy; provides sediment storage sites; and has a strong influence on pool formation (Keller and Swanson, 1979; Mosley, 1981; Smith, 1992b; Montgomery et al., 1995; Montgomery and Buffington, 1998). LWD can both protect the channel banks and bed from erosion and increase bank and bed erosion by deflecting flow toward the channel bank, increasing the variability in channel width and depth and contributing to habitat complexity. The influence of LWD on channel morphology characteristics is, in most cases, more strongly associated with smaller sized, low gradient streams (Bisson et al., 1987; Bilby and Ward, 1989; Bilby and Bisson, 1998).

Any land-use change that significantly changes the riparian vegetation and delivery of LWD to the stream channel can consequently affect channel morphology.

2.3 Land-use effects on channel morphology

Studies in New Zealand and overseas have found that land-uses which influence the composition of riparian vegetation along a stream edge can have a significant effect on channel morphology (Zimmerman et al., 1967; Murgatroyd and Ternan, 1983; Clifton, 1989; Sweeney, 1993; Trimble, 1997; Quinn et al., 1997; Davies-Colley, 1997). These
studies showed that riparian vegetation could override other factors such as hydrology, geology, and sediment regime in influencing channel morphology in streams.

2.3.1. Importance of catchment area

Catchment area was one of the most critical parameters in determining the degree to which streamside vegetation influenced channel morphology, particularly channel width. Influence of riparian vegetation on channel width was, in most cases, strongest in catchment areas up to 5-8 km² and less obvious in catchments greater than 10 km² (Zimmerman et al., 1967; Murgatroyd and Ternan, 1983; Clifton, 1989; Sweeney, 1993; Quinn et al., 1997; Davies-Colley, 1997).

For example, in the studies that Zimmerman et al. (1967) carried out in 5 streams in Vermont, U.S.A., the influence of vegetation on channel width was strongest in catchment areas 0.5 - 2.0 km² (0.2 - 0.8 square miles), extending up to approximately 8 km² (~ 3 square miles). In catchment areas greater than 10 - 16 km² (4 - 6 square miles), influence of vegetation on channel form became marginal. In the streams in the smaller catchment areas, channels were wider under forest and narrower under sod regardless of whether land-use transition was from forest to sod, or sod to forest. Similar relationships were found when comparing between catchments.

Sweeney (1993) found similar results in Pennsylvania, U.S.A, when measuring channel widths on streams of varying size (order) and discharge in the White Clay Creek catchment (158 km²). In the smaller catchments (1st and 2nd order) channel widths in the forested streams were about 2.5 times wider than deforested streams. Narrowing of the meadow streams was less pronounced in larger catchments (3rd and 4th order) but was still significant. Even 4th order streams were 35% wider in forested areas.

Davies-Colley’s (1997) results also showed that the effects of land-use on channel width diminished with increasing catchment area. He measured channel widths in paired native forest/pasture reaches in 20 streams of varying size, catchment area and geology in the Hakarimata Range, New Zealand. In small catchments (<1 km²) channel widths in pasture streams were half that of the forested streams (Figure 2.2). The difference between pasture and forest channel widths decreased with increasing catchment area and was minimal in catchment areas >30 km² (channel width in forest >10m). This trend did not seem to be
dependent on geology or order of land-use transition along the stream channel i.e. native to pasture or pasture to native.

Figure 2.2: Difference in channel widths in a pasture and native forest site along the same channel reach, Waikato New Zealand (Photos courtesy of R. Davies-Colley, NIWA, Hamilton).

2.3.1.1. Studies in smaller sized catchment areas

Murgatroyd and Ternan (1983) found that land-use influenced bankfull channel widths in the Narrator Brook, Dartmoor, United Kingdom. The total catchment area was 4.75 km², with the upper catchment in moorland and the lower catchment in a 50 year old coniferous plantation. A regression predicting downstream increases in bankfull channel width with increasing basin area was used to determine whether afforestation of the lower part of the catchment was affecting channel morphology. The results showed that bankfull channel widths in the forested channel reach were up to three times greater than that predicted from the regression and bankfull channel capacity was over two times greater. The authors attributed this to the more active bank erosion along the forested channel reach, resulting in increased streambed aggradation, wider and shallower channels and decreased channel sinuosity.

Clifton’s (1989) study in Wickiup Creek, in Oregon, (2nd order stream, catchment area 24 km²), measured channel morphology characteristics at 6 sites along the stream continuum; two forested, two meadow, one ungrazed meadow and one meadow/forest site. Channel
width, depth and cross-sectional area did not show any strong systematic trends with increasing distance downstream; instead, spatial variability in the stream channel was a reflection of the varying streamside vegetation and grazing intensity. Stream channels were widest in the forested sites and depths were greatest in the ungrazed meadow site. There had been a 94% decrease in channel cross-section area in the ungrazed site over the last 50 years. In the forested reaches, both channel shape and width were highly variable. Organic debris in the stream channel affected the channel form and fluvial processes, both reducing and enhancing bank erosion, dissipating stream energy, deflecting flow and controlling storage of sediment.

Dijkman (1997) followed up with additional channel measurements on 7 of the 20 sites in the Davies-Colley (1997) study. While the author confirmed the wider streams in the native sites compared with pasture found by Davies-Colley (1997), additional measurements showed no significant difference in channel depth between the 2 land-uses, but cross-sectional area was greater in the native streams. Water width and exposed bed area appeared to be greater in the native streams than the pasture streams at low flow.

In a land-use study in the Hakarimata Ranges New Zealand, which compared pasture, pine plantation and native forest streams, Quinn et al. (1997) found native forest streams to be 60% wider than pasture. In pine plantations approximately 15 years of age, which had been established on pastureland, streams were of intermediate width. Catchment area in these sites ranged from 0.4 to 2 km². In the pine streams, over 40% of bank length was unstable (either bare soil or actively slumping and eroding) compared with 20 –40% of the bank length in pasture streams. Coarse woody debris (CWD) was more abundant in pine plantation streams than native, and scarce in pasture streams. Woody debris played an increasing role in pool formation from pasture to pine to native. There was a significant correlation between submerged wood volume and percentage of pools formed by wood.

2.3.1.2. Study in a large catchment area

Trimble’s (1997) study was one example where riparian vegetation was still influencing channel width in a larger catchment area (360 km²). The study compared four reaches; each with paired subreaches of grass and forested stream channel in Coon Creek, Wisconsin. One grass subreach had been grazed. In every reach, forested bankfull cross-sectional area was larger than grassed and grassed channels were storing an estimated
2,100 to 8,800 m³/km more sediment than the forested channels. In every reach, base-flow width and base-flow cross-sectional area were greater in the forested subreaches. Maximum depths were greater in the forest but not significantly so. Grassed subreaches averaged width-depth ratios that were 67% – 72% of their forested counterparts, with the exception of the grazed subreach which was 90%. The grazed subreach was also wider than the other 3 grassy subreaches. LWD in the forested reaches restricted flow, created highly variable velocities, and the net result created a greater local flux of sediment. The author suggested that conversion of forested reaches to pasture might be one method of decreasing downstream sedimentation.

2.4 Effects of land-use on in-stream habitat

Sweeney (1993), in studies in White Clay Creek, Pennsylvania, USA, not only looked at the physical differences in channel morphology between pasture and forested streams as discussed in 2.4.1, but also looked at the effect this had on in-stream habitat and macroinvertebrate communities. The study showed that the presence of heavy shade, woody debris and root structures in forested streams resulted in significantly more physical habitat for macroinvertebrates than deforested channels. To quote Sweeney (1993, p. 292) ‘The main point of this paper is that the presence or absence of trees adjacent to stream channels may be the single most important factor altered by humans that affects the structure and function of stream macroinvertebrate communities, especially in the streams like White Clay Creek of the Piedmont Physiographic region of eastern North America.’

Tree roots bordering the stream channel and extending into the water column have a very high surface area to volume ratio (Sweeney, 1993). They can persist for a long time and provide habitat for a variety of aquatic biota. Woody debris in the stream channel provides additional surface area for macroinvertebrates. Woody debris accumulations increase local habitat variety and retain organic material in the channel for in-stream processing. Roots of grasses along channel banks are much finer and shorter lived and do not provide suitable aquatic invertebrate habitat. This results in significantly higher macroinvertebrate densities in the forested streams, compared with pasture streams.

Sweeney’s (1993) findings are also supported by New Zealand studies that show marked differences in the composition and abundance of aquatic invertebrates both in larger rivers and in smaller streams between different land-uses (Quinn, 2000). Differences were
strongest between native and pasture streams showing that pastoral land-use had a profound effect on the composition and abundance of the more common invertebrates in New Zealand's streams. In particular, pasture sites had lower species richness in the enrichment-sensitive *Ephemeroptera* (mayfly), *Plecoptera* (stonefly) and *Tricoptera* (caddisfly) groups and smaller proportions of shredders. Where Quinn's (2000) results differed from Sweeney (1993) was in macroinvertebrate density, which was often higher in the pasture streams of New Zealand. A common species of snail (*Potamopyrgus antipodarum*) accounted for much of the invertebrate density in the pasture streams. There were fewer differences in aquatic invertebrate richness and composition between plantation and native forests, although some differences in relative taxa have been observed between forest types (Harding et al., 2000). Similarly to Sweeney (1993), Quinn (2000) stated that the New Zealand studies supported the hypothesis that riparian vegetation exerts a strong influence on stream invertebrate communities.

Land-use also influences pool formation in the stream channel. Quinn et al. (1997) found that pool numbers were higher in pine plantation and native forest streams compared with pasture streams due to the higher volumes of LWD in the forested streams. The contributing influence of LWD to pool formation in forested streams has been well documented particularly in Pacific Northwest (Andrus et al. 1988; Carlson et al. 1990; Evans et al., 1993; Montgomery and Buffington, 1998).

### 2.5 Key findings from the land-use studies

- All papers showed that riparian vegetation could override other factors such as hydrology, sediment regime, and geology in influencing channel morphology in streams in small catchments.
- Influence was strongest in catchment areas up to 5-8 km² and less obvious in catchments greater than 10 km².
- Riparian vegetation influence over-.rode the stream continuum concept i.e. streams tend to be wider and deeper as stream flow and catchment area increases.
- Streams tended to be wider under forest and narrower under pasture regardless of the transition order along the stream reach, i.e. whether pasture to forest or forest to pasture. Widths were more variable in the forested streams due in part to the presence of woody debris.
• Cross-sectional area was usually larger and channel banks less stable in the forested reaches.
• There was usually no significant difference in stream depth between pasture and forest.
• The narrower streams associated with pasture provided limited surface area and less suitable habitat for aquatic invertebrates. In the forested streams, wider channels and the presence of tree roots and woody debris in the stream channel, extended the surface area and habitat diversity for aquatic invertebrates and increased the number of pools in the stream channel.

2.6 Reasons for land-use effects on channel morphology

Two main reasons have been put forward by various authors to explain the differences in channel morphology between forest and pasture streams (Zimmerman et al., 1967; Murgatroyd and Ternan, 1983; Quinn et al., 1997; Davies-Colley, 1997). Firstly, the narrower widths in pasture streams were attributed to the stability of grass sods and their ability to trap and retain sediment. The sediment trapping and storage capacity of grass buffer strips has been demonstrated in flume trials by Karssies and Prosser (1999). Although channel banks in pasture are subject to some under cutting and slumping, slumps were often stabilized by the grass cover and fine root systems, making them highly resistant to erosion. Zimmerman et al. (1967) noted that the width-to-depth ratios indicated that the sod was behaving more like a cohesive sediment than bank material consolidated by tree roots. Smith (1976) also found that grass roots assisted in the reinforcement of channel banks; stream bank sediment with a 5-cm root mat of dense grass and scrub willow had 20,000 times the resistance to fluvial erosion than comparable bank sediment with no vegetation.

Secondly, in forested streams, root density is lower along the stream edge, and there is little protective cover on the stream banks to maintain channel bank stability. Material weakly held by tree roots is easily removed by lateral stream erosion, resulting in channel widening. The presence of LWD in the stream channel also contributes to channel widening and increased variability in channel width when flow is diverted around these obstructions.

A working hypothesis put forward by Davies-Colley (1997) is that the clearance of native forests and subsequent establishment of land in pasture has led to a period of channel
narrowing. Pasture grasses on exposed channel bars and stream banks have trapped and stored sediment deposited during high flow events, consolidating and building up the channel banks and bars over time. It has been suggested that the active bank erosion in the pine plantation streams in Quinn et al.'s (1997) study indicate that these streams are in the process of widening back to a forested stream morphology. This is reflected in the intermediate channel widths between pasture and native forest streams. These changes are in response to increasing shade levels as the pine plantations mature, causing the die-off of pasture grasses, leaving the channel banks more vulnerable to lateral stream erosion.

2.7 Implications for the forest industry

There are implications for the forest industry in New Zealand, particularly when converting pasture or tussock land into pine plantations. The hypothesis discussed by Quinn et al. (1997) and Davies-Colley (1997), suggests that this type of land-use change could result in a period of stream bank erosion, high turbidity and sediment yield during the channel adjustment phase as the channel widens from a narrow pasture morphology to a wider forest channel. Although riparian vegetation can have a strong influence on channel morphology in small-sized catchments, geology and climate are also key factors influencing the morphological response of the stream channel (Figure 2.1). Whether a channel adjustment phase during land conversion from pasture to pine is likely to occur in other regions of New Zealand with differing geology and climatic conditions to the Hakarimata Ranges is unknown.
3.1 Introduction

Nelson was chosen for the study as the area contains extensive pine plantations (172,000 ha) with much of it located on the Moutere Gravels. Along with Otago/Southland the Nelson region has the third largest area of pine plantation in New Zealand (NZFOA, 2000). Suitable native forest benchmark streams were located in Big Bush and in various reserves throughout the Moutere Gravels (Wall, 1985). Surrounding farmland provided the pasture sites. The Moutere Gravels provide contrasting geology and hydrology to those of the Hakarimata Ranges in the North Island.

3.2 Geology and soils

The Moutere Gravels lie in the Moutere Depression which formed in the Pliocene-Pleistocene during the uplift of the Tasman Mountains to the west and the Nelson Ranges to the east (Rattenbury et al., 1998). The Moutere Depression is fault-bounded to the east by the northeast trending Waimea-Flaxmore Fault System (Figure 3.1); it averages about 30 km across, and reaches depths of up to 2,500 m. The eastern margin of the Depression lies within the most tectonically active zone of New Zealand, comprising central New Zealand, the east coast of the North Island, and the west coast of the South Island (Thomas, 1989).

The Moutere Gravels infilled the Moutere Depression in the late Pliocene-early Pleistocene (about 2-3 million years ago) as a result of rapid uplift of the Southern Alps and Spenser Mountains (Wall, 1985; Rattenbury et al., 1998). Subsequent erosion by advancing glaciers and transportation by river systems from the mountains deposited large volumes of gravel out beyond the present coastline of Tasman Bay.
The Moutere Gravels cover approximately 134,000 ha and the gravel surface descends in altitude from about 1,000 m a.s.l. in the south to about 60 m a.s.l. at the coast, a distance of about 70 km (Wall, 1985). In places the gravel deposits are up to 500 m thick (Wall, 1985; Johnstone, 1979). The Moutere Gravels consist of uniform yellow-brown, silty, clay-bound gravel with deeply weathered subrounded to well-rounded clasts consisting mainly of sandstone and semi-schist (Johnstone, 1979; Rattenbury et al., 1998). The clasts are rarely more than 200 mm across but can be up to 0.5 m in diameter. Deep weathering suggests a long period of a warm humid climate following the initial period of glaciation which eroded the gravels from the Spenser Mountains (Wall, 1985).

The main river systems that divide the Moutere Gravels are the Motueka, Wai-iti, Motupiko, Tadmore and Moutere. The floors of these valley systems have been infilled with alluvial material, much of which is derived from reworked Moutere Gravels (Wall, 1985).
Linear valleys and ridges, lying in a predominantly E-W and SE-NW direction, with regular spaced tributaries are a typical geomorphic expression of the Moutere Gravels. The hillslopes show distinct asymmetry with steep southern sides and a more gently sloping northern side. (Wall, 1985; Thomas, 1989; Rattenbury et al., 1998). Hillslopes range from strongly rolling to moderately steep and steep (16 - 35°) (Ministry of Works and Development, 1975a&b and 1978). Current erosion is rated as slight to moderate sheet, gully and soil slip, with the potential for moderate sheet, gully and soil slip, increasing in severity on the steeper slopes, particularly under a grassland regime.

The soils in these gravels are predominantly Hill soils transitional between yellow-grey (Pallic Soils) and yellow-brown earths (Brown Soils) at the seaward end of the Moutere Gravel formation, with yellow-brown earths (Brown Soils) covering the remainder of the area (Chittenden et al., 1966). Soils at all the sites in this study are classed as yellow-brown earths (Rosedale silt loam, Rosedale hill, Stanley hill, Spooner hill, Korere hill and Hope hill series). These soils are shallow, acidic, low in fertility and particularly lacking in phosphorus, calcium and potassium.

3.3 Climate

New Zealand is a maritime country; it is surrounded by oceans and lies in a zone of westerly winds for most of the year (Mosley and Pearson, 1997). The typical weather pattern in New Zealand consists of a series of anticyclones moving eastward across the country separated by troughs of low pressure with associated frontal systems from the south. Anticyclones tend to track to the north in winter and spring and to the south during summer and autumn. This pattern is often affected by low-pressure systems that form in the northwest Tasman Sea and by the occasional tropical cyclone. These weather systems are highly variable and can take anywhere from 3 – 10 days to pass over the country (de Lisle and Kerr, 1965; Beatson, 1985; Mosley and Pearson, 1997).

New Zealand's mountainous landscape has a strong influence on the weather systems (Beatson, 1985). The mountain ranges of the South Island intercept the prevailing westerly winds producing a sharp contrast in weather between the western and eastern sides of the island. This topographical influence produces distinct local weather patterns in New Zealand as is the case in the Nelson District.
The Nelson district is sheltered to the west, east and south by mountain ranges and is one of the sunniest places in New Zealand. Nelson and Marlborough average around 2,400 hours of sunshine a year (Beatson, 1985). Average temperatures at sea level in NZ range from 15°C (59°F) in Northland to 9.4°C (49°F) in Invercargill. Mean temperature in the Nelson area is 12°C (53-54°F). The warmest months are January and February and July is the coldest. Because of the high number of clear days, temperature fluctuations are quite large (de Lisle and Kerr, 1965).

The topography of the Nelson district causes many local variations in wind direction. The most frequent wind directions are from the north-east and south-west, influenced by the orientation and funneling effect of the Waimea Plains (de Lisle and Kerr, 1965).

Mountain ranges to the west shelter the Nelson District from the prevailing westerly weather patterns (de Lisle and Kerr, 1965). As a result, rainfall is highest in these western mountain areas. Because the district is exposed to the north, widespread cloud and heavy
rainfall sometimes occur with the passage of a depression across central New Zealand. Rainfall is lowest near the coast, increasing inland to the south with higher rainfall in the east and western ranges (Figure 3.2) and is fairly evenly spread between the seasons.

In the Moutere Gravels, annual rainfall averages 900mm at the seaward end of the formation, increasing toward 1500 – 1750 mm at the southern end (Wall, 1985). At Golden Downs a central location in the Moutere Gravel study area, annual rainfall averaged 1347mm (New Zealand Meteorological Service, date unknown). Mean monthly rainfall distribution at this site is illustrated in Figure 3.3. Although rainfall tends to be evenly distributed throughout the year, like much of New Zealand, Nelson experiences dry periods in the summer and the Moutere Gravels are prone to drought during these periods (Shirley et al., 1979; de Lisle and Kerr, 1965; Beatson, 1985).

Figure 3.3: Mean monthly rainfall at Golden Downs Forest 1951-1980 (New Zealand Meteorological Service, date unknown).
3.4 Vegetation past and present

3.4.1 Vegetation prior to 1840

Past vegetation cover on the Moutere Gravels has been reconstructed using information from recent vegetation surveys, maps, old photographs and descriptions from early settlers (Wall, 1985; Ward and Cooper, 1997). Prior to 1840 the lower plains contained large swamps along the shoreline while grasslands and grass and herb meadows extended up the Waiti, Motueka, Motupiko and Buller Rivers. Much of the lower hill country was covered with kanuka, manuka, bracken and scrub. While some of these areas are likely to be natural, fires from early Maori settlement probably accounted for some of this vegetation distribution (Wall, 1985; Ward and Cooper, 1997). However forests covered most of the land prior to 1840 and most of the hill country was covered with extensive beech forests with some podocarps. Podocarp forests along with some swamps covered the valley floors and plains.

3.4.2 Land development 1840 to early 1930's

Over the next 100 years European settlers and their descendants cleared about four-fifths of the forests and replaced most of the original scrub, flax, grasslands, and swamp with sown pasture, pine plantations and cultivated crops (Wall, 1985; Ward and Cooper, 1997). Fire was the main land-clearing tool used by early European settlers and several large runs were developed on the Moutere Gravels (Ward and Cooper, 1997). Smaller farming units were established after World War One when land was purchased for the soldiers' settlement scheme.

At first most soils grew good pasture but as their fertility diminished, along with world wars, economic depression and political change, it became increasingly difficult to maintain agriculture on the Moutere Gravels (Wall, 1985; Ward and Cooper, 1997). The scrubby weed infested nature of the hill country, small property size, limited resources and knowledge to develop the land, infertile soils, falling stock prices and the onset of the 1930's Great Depression, resulted in many farmers selling their land or walking off it. At this time the government had committed to a policy of large-scale forestry, in response to a prediction that indigenous forest resources would be exhausted by 1965-70 (Ward and Cooper, 1997). The government was also looking for jobs for the increasing number of
unemployed. The Forest Service was able to purchase large blocks of reverting farmland on the Moutere Gravels at a lower price. The climate and soils suited forestry, the gravels provided a cheap source of roading material, and labour was also plentiful and cheap. As a result, extensive areas of the Moutere Gravels were planted in pines in the late 1920’s and early 1930’s.

3.4.3. Present day land cover

A survey by Wall (1985) found 298 indigenous forest remnants on the Moutere Gravels, a total of 15.6% of the land area (20850 ha) and representing a loss, judging by accounts of the first Europeans and the findings of this survey, of about 80% of the original native forest cover. The proportion of native forest in the landscape increases inland from the coast, reflecting the increasing altitude and rainfall, lower temperatures and soil fertility, which would have determined the value for agriculture and proneness to fire. Most of the area of the Moutere Gravels and the Nelson lowlands is now covered in either native or exotic forests or pasture grazed by sheep and cattle (Wall, 1985) (Figure 3.4). Much smaller areas, mainly towards the coast, are used for the production of various crops.

![Pie chart of land use in the Nelson Region](image)

Figure 3.4 Land-use in the Nelson Region (MAF, 1996/97).
3.5 Hydrology

Both the Moutere Gravels and the underlying in situ rocks have a limited capacity to store water. The gravels are more permeable than the underlying rocks so effective storage of water in the Moutere Gravels is limited to the gravels. Water is stored close to the surface and streams tend to dry up in summer (Shirley et al., 1979; Johnstone et al., 1979).

Compared with other geologies in the Nelson area, base flow discharges in the Moutere Gravels are very low. For example, specific discharges (l/sec/km²) for February 1979 (12 year drought frequency) were Moutere Gravels 0.22, Separation Point Granites 4.72, Maitai Group (sandstone variously bedded with siltstone/mudstone/limestone) 12.25, and Mt Arthur Marble 24.81 (Shirley et al., 1979).

It is thought that the lower base flows in the Moutere Gravels may be a reflection of the lower permeability of the Moutere formation (Shirley et al., 1979). This would confine the major part of the storage to shallow depths where a significant proportion could be located within the plant root zone although there are no quantitative data available on this. The greater the proportion of this water storage area occupied by roots, the greater the effect on base flow yield. Vegetation can have a pronounced effect on water discharges in the Moutere Gravels (Johnstone et al., 1979) and much of the research on the Moutere Gravels has focused on the hydrological implications of land-use change.

Conversion of pasture or gorse land into pines has been found to affect the hydrology of streams in small catchments. Although there were no measurable changes in hydrology from catchments in 3-4 year old pines (McKerchar, 1979), reduced flows were noted in one study in 5-6 year old pines, and there were measurable differences in hydrology when pines reached 8-10 years in age (Duncan, 1979; Hewitt and Robinson, 1983). By this age, run-off was lower, the number of days with zero flow increased and flood peaks and volumes were lower in comparison to similar streams in pasture catchments (Duncan, 1979). Two native catchments that were harvested and replanted in pines took 8 years for water yields to reduce to pre-harvest levels and 10 years for storm peak flows, quick flows and low flows to reach pre-harvest levels (Fahey and Jackson, 1997). At Kikiwa at the southern end of the Moutere Gravels, a pasture and fern catchment prior to establishment in pines had similar summer flows to a nearby native forest catchment. By the time the pines had reached 8-9 years of age, increased interception and evaporation from the trees.
had reduced summer flows to 50% of that of the native catchment (Hewitt and Robinson, 1983).

Hydrological monitoring in native forest catchments in the Moutere Gravels indicates that the development of channel morphology characteristics will be more strongly influenced by high flows and flood events (O’Loughlin et al., 1978). There was very little sediment transport during low flows and flows were clear with negligible sediment for 99.7% of the time over an eighteen-month monitoring period. Only one event with an estimated return period of 1-2 years transported significant quantities of sediment. The authors propose that the sculpturing of the Moutere Gravels has depended closely on infrequent high intensity storms, occurring perhaps every 10 years or less. However, similar-sized catchments in pasture and young pines will be carrying comparatively higher annual flows and more importantly for channel morphology processes, higher flood peaks and volumes. It is likely that channel forming events in small pasture and young pine catchments will occur more frequently than that suggested by O’Loughlin et al. (1978) for small native catchments.

3.6 Stream fauna

Although the smaller steams in the Moutere Gravels frequently dry up in summer, they still provide habitat for aquatic invertebrates, native crayfish (koura), native fish and trout.

3.6.1. Aquatic invertebrates

Small streams in pine forests in the Moutere Gravels tend to be dominated by true flies (Diptera) followed by caddisflies (Tricoptera) and mayflies (Ephemeroptera) (Graynoth, 1979; Stark, 1990; unpublished data N. Deans, Fish and Game New Zealand Nelson & A. Karalus, Weyerhaeuser New Zealand Limited Nelson). Stoneflies (Plecoptera) and dobsonflies (Megaloptera) were the next most abundant groups. Graynoth (1979) noted the seasonal variation in aquatic invertebrate abundance, in particular, the increase in true flies during the summer months. This pattern was also evident at other pine sites (unpublished data N. Deans, Fish and Game New Zealand Nelson & A. Karalus, Weyerhaeuser New Zealand Limited Nelson) where mayflies and caddisflies were more abundant than true flies during the winter months. This distribution pattern of aquatic invertebrates was common in both harvested and unharvested sites. One exception was a
harvested stream where worms (Oligochaetes) were most abundant, followed by midges (Chironomids) and mayflies (Graynoth, 1979).

In one pine stream, which had a riparian buffer along the edge, mayflies were most abundant, followed by stoneflies, true flies, caddisflies, and beetles (Coleoptera) (Graynoth (1979). This pattern of abundance is similar to that of native streams (Graynoth, 1979; Stark, 1990). In two small native streams, mayflies were the most abundant group. Either caddisflies or stoneflies were the next most common groups followed by the beetles and true flies.

No information was found on the variety and abundance of aquatic invertebrates in small pasture streams in the Moutere Gravels.

3.6.2. Native fish, trout and koura (native crayfish)

Surveys of both pine and native streams have recorded the presence of koura, brown trout and a variety of native fish (Graynoth, 1979; Graynoth, 1990; New Zealand freshwater fish database, 2000; unpublished data, N. Deans, Fish and Game, NZ, Nelson). The most common species of native fish present in both the pine and native streams were the dwarf galaxiids. Other native fish species included the longfinned eel and upland bully. Koura were present in some of the native and pine streams and brown trout were recorded in some of the pine streams although they tended to be present in the lower reaches of the catchments rather than in the small headwater streams. Graynoth (1979 and 1990) noted that the density and variety of both native fish and brown trout varied between a native stream and three pine streams. A number of factors contributed to this including variation in habitat conditions, barriers to fish movement and the effect of logging operations.

Information on fish and koura populations in small pasture streams in the Moutere Gravels is less extensive. One survey of a pasture stream in 1998 found long-finned eels were most abundant, followed by upland bully, dwarf galaxias and koura. No brown trout were recorded (unpublished data, N. Deans, Fish and Game New Zealand, Nelson).
3.7. Comparison with the Hakarimata Ranges, Waikato, New Zealand.

The geology of the Hakarimata Ranges is predominantly sedimentary sandstones, siltstones, mudstones and greywacke with some areas of overlying airfall tephra (Ministry of Works and Development, 1979a&b; Quinn et al., 1997). Hillslopes are moderately steep to steep (21-35°), and gully, soil slip and sheet erosion are the main erosion types; the degree of erosion is mainly slight to moderate. The potential for soil slip, sheet and gully erosion ranges from slight to severe (Ministry of Works and Development, 1979a&b).

Soils are predominantly yellow-brown earths (Kaawa hill soil and Waingaro steepland soil) (Brown Soils) with smaller areas of yellow-brown loams (Allophanic Soils) (Ministry of Works and Development, 1979a&b; Quinn et al., 1997).

Rainfall at Whatawhata in the Hakarimata Ranges averages 1627mm per annum, about 20% higher than at Golden Downs Forest (New Zealand Meteorological Service, date unknown). The rainfall distribution also differs with most of the rainfall occurring in Whatawhata during the winter months (Figure 3.5). Average rainfall intensities and durations in the Waikato area are comparable to other areas of New Zealand, with the notable exception of rainfall intensities in the late summer and early autumn, which are amongst the highest in the New Zealand. Extreme hourly and daily rainfall intensities are also high when compared with other stations in New Zealand (Maunder, 1974).

Thompson’s (1987) report noted that Nelson has twice the number of events per year for a rainfall duration of 24 hours (50 events per year) compared to Whatawhata but the amount of rainfall per event is less averaging 15mm/event for Nelson and 20mm/event for Whatawhata.

Streams in the smaller catchments of the Hakarimata Ranges are usually perennial and stream flows are quite variable in both pasture and forested streams (Boulton et al., 1997). Baseflow in 14 streams of varying land-use (pasture, pine and native) ranged from 11 to 19 litres s\(^{-1}\) km\(^2\) (Boulton et al., 1997; Hicks and McCaughan, 1997).

The geology, hydrology and climate of the Moutere Gravels with their shallow stony soils and intermittent stream flow provide a contrasting study area to the Hakarimata Ranges in the North Island where similar channel morphology studies to this one have been carried out.
Figure 3.5: Comparison of mean monthly rainfall distribution 1951-1980 between Golden Downs Forest in the Moutere Gravels of Nelson and the Hakarimata Ranges in the Waikato (New Zealand Meteorological Service, date unknown).
Chapter 4 – Study Design

4.1 Hypotheses

The following hypotheses will be tested:

• that streams in the pine plantations and native forests are wider and have more variable widths than the streams in pasture

• there is more channel bank disturbance (eroding banks) in the pine plantation and native forest streams, compared with pasture streams

• the presence of LWD in the pine plantation and native streams increases the number and variety of pools in the stream channel in comparison with pasture streams.

4.2 Study design selection

Initially this study was going to be based on paired land-use comparisons along the same stream channel as used by Sweeney (1993) and Davies-Colley (1997). As long as the paired reaches are close together, of similar gradient and have no major tributaries along their length, they experience the same geological, hydrological and climatic conditions, reducing the amount of background variation within the paired sites. Although there appeared to be sufficient sites for paired pine/pasture comparisons, there were insufficient sites for paired native/pine and native/pasture comparison. Many of the transition points for native/pasture sites occurred at the junction of major tributaries or at major slope changes (i.e. native forest on the hills, pasture on the flats).

Instead, a catchment comparison design was used, similar to that used by Quinn et al. (1997). Five catchments were selected for each land-use (pasture, pine, native). Their locations were interspersed throughout the study area to ensure true replication of each land-use (Figure 4.1).
Hydrology, geology, morphology and climate are major factors controlling stream pattern, shaping landform, influencing drainage patterns, and bed materials (Gordon et al., 1992). The site and reach selection criteria detailed below identify the steps taken to minimise the background variation caused by these factors when using between-catchment comparisons.

4.3 Site selection

To reduce the background variation between the 15 catchments (5 in each land-use; pasture, pine plantation and native forest) sites were selected for:

- same geology (Moutere Gravels)
- same hydrology
- similar gradient (Table 4.1)
- similar catchment area (Table 4.1)
- similar climate
- same land-use in all of the catchment.
The exception was one pasture site with 4-year-old pines covering the top 30% of the catchment (Pa2).

<table>
<thead>
<tr>
<th>Land-use</th>
<th>Location</th>
<th>Grid Ref (NZMS 260)</th>
<th>Area (ha)</th>
<th>Altitude (m)</th>
<th>Gradient (m m⁻¹)</th>
<th>Stream Order*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pasture</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Pa1</td>
<td>Kikiwa</td>
<td>N29 976 491</td>
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<td>500</td>
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<td>Tadmore</td>
<td>N28 902 722</td>
<td>124</td>
<td>280</td>
<td>2.63 (0.046)</td>
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<td>Eban Valley</td>
<td>N27 045 912</td>
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<td>200</td>
<td>2.13 (0.037)</td>
<td>2nd</td>
</tr>
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<td>Wakefield</td>
<td>N28 139 767</td>
<td>94</td>
<td>100</td>
<td>1.01 (0.018)</td>
<td>2nd</td>
</tr>
<tr>
<td>Pa5</td>
<td>88 Valley</td>
<td>N28 107 749</td>
<td>124</td>
<td>140</td>
<td>1.01 (0.018)</td>
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</tr>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Pi1</td>
<td>Ben Gully</td>
<td>N28 911 534</td>
<td>129</td>
<td>400</td>
<td>1.47 (0.026)</td>
<td>1st</td>
</tr>
<tr>
<td>Pi2</td>
<td>Stade Road</td>
<td>N28 030 641</td>
<td>60</td>
<td>340</td>
<td>2.28 (0.040)</td>
<td>2nd</td>
</tr>
<tr>
<td>Pi3</td>
<td>Buster Creek</td>
<td>N28 978 585</td>
<td>128</td>
<td>440</td>
<td>2.63 (0.046)</td>
<td>1st</td>
</tr>
<tr>
<td>Pi4</td>
<td>Thorn Road</td>
<td>N27 036 833</td>
<td>85</td>
<td>300</td>
<td>2.36 (0.041)</td>
<td>2nd</td>
</tr>
<tr>
<td>Pi5</td>
<td>Pigeon Valley</td>
<td>N27 085 811</td>
<td>69</td>
<td>180</td>
<td>2.61 (0.046)</td>
<td>2nd</td>
</tr>
<tr>
<td>Native</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na1</td>
<td>Melville Gully</td>
<td>N29 917 482</td>
<td>137</td>
<td>480</td>
<td>2.36 (0.041)</td>
<td>2nd</td>
</tr>
<tr>
<td>Na2</td>
<td>Donald Creek</td>
<td>M28 877 558</td>
<td>94</td>
<td>520</td>
<td>1.84 (0.032)</td>
<td>2nd</td>
</tr>
<tr>
<td>Na3</td>
<td>Scuffe Creek</td>
<td>N28 024 757</td>
<td>127</td>
<td>280</td>
<td>2.24 (0.039)</td>
<td>2nd</td>
</tr>
<tr>
<td>Na4</td>
<td>Spooners Reserve</td>
<td>N28 032 705</td>
<td>84</td>
<td>300</td>
<td>3.28 (0.057)</td>
<td>2nd</td>
</tr>
<tr>
<td>Na5</td>
<td>Long Gully</td>
<td>N28 968 608</td>
<td>101</td>
<td>420</td>
<td>1.81 (0.032)</td>
<td>1st</td>
</tr>
</tbody>
</table>

Table 4.1: Site characteristics
*(Strahler, 1957) based on NZMS 260 1:50,000 maps

Catchment area was calculated from NZMS 260 maps, scale 1:50,000. Catchment areas were kept to 2km² (200 ha) or less as other studies had indicated that riparian influences on channel morphology were more pronounced in smaller catchments (Zimmerman et al., 1967; Quinn et al., 1997, Davies-Colley, 1997). The ranges of catchment areas were kept as similar as possible between the 3 land-uses. A one-way ANOVA found no significant differences in catchment area between the three land-uses at the 95% confidence level.

Pasture sites were selected with all or most of the catchment in pasture and where LWD was absent from the stream channel to provide a ‘no wood’ comparison with the pine and native sites. Lack of residual native woody debris in the pasture streams indicating minimal residual influence from previous land-use (native forest). These sites had been in pasture for varying amounts of time. The longest was site Pa3 that was established in native grass (danthonia and browntop) in the late 1800's and developed into English pasture, predominantly rye grass and white clover with some coxfoot, in the 1960's. Pa1 was established in native pasture during the 1930s’ depression, with some reversion to fern
and scrub and has been in English pasture for the last 15 years. Pa2 had been in pasture for about 50-60 years. The head of this catchment (about 30% of the catchment area) was converted from scrub to *Pinus radiata* in 1995. The 4-year-old pines would have been too small to influence hydrological flow. Pa4 has been in pasture with patches of gorse for at least 40 years. Site history prior to 1969 is unknown for Pa5, but the site was in half gorse, half pasture in 1969 and all in pasture since 1982. Deer were farmed on the lower catchment and sheep and cattle on the upper catchment at this site. The remaining four pasture catchments were running a mix of sheep and cattle.

Pine sites were selected in the more mature stands of *Pinus radiata* when streams are at their most stable in the harvest cycle and the effect of harvesting on channel bank disturbance and hydrological flow is minimised. Channel banks usually stabilise within 3-4 years after harvest and hydrological flows return to pre-harvest levels 8-9 years after harvest. If possible, sites were selected in a second rotation crop of trees to minimise previous land-use effects on channel morphology. Of the 5 pine plantation catchments, one site (Pi1) was a 1st rotation crop of 31 year old *Pinus radiata* on reverting farmland. Three sites were in second rotation crops of *Pinus radiata* (Pi2, Pi4 and Pi5) aged 23 years, 24 - 26 years and 19 years respectively. Site Pi5 had 3-year-old pines at the head of the catchment. One site (Pi3) was in its 3rd rotation of 27 year-old *Pinus radiata*. Pi1 had been in pine plantation forest for 31 years, the 2nd rotation sites had been in pine plantation forest for 46 – 55 years and the 3rd rotation site had been in pine plantation forest for at least 60 years (the date of establishment of the 1st rotation crop is unknown). Residual native woody debris was present at Pi1 and absent or minimal in the 2nd and 3rd rotation sites indicating that the influence of previous land-use (native forest) in pine plantation streams was minimal by the 2nd rotation.

Riparian vegetation in the pine plantation sites (apart from *Pinus radiata*) consisted of a mix of exotic and native shrubs, ferns and sedges. Common exotic species included; blackberry, foxglove, buttercup, gorse, old mans beard, and himalayan honey suckle. Common native species included; marble leaf, fuchsia, wineberry, *Coprosma sp.*, pate, tutu, whitey wood, five-finger, bracken, *Blechnum sp.*, *Asplenium bulbiferum* (hen and chicken fern), and various sedges.

Native forest catchments were selected to provide a ‘pristine’ benchmark to compare with the pine plantation and pasture streams. However, as most of the unmodified (unlogged)
native forest was in Big Bush (located in the southern and western corners of the Moutere Gravels), a compromise was made between selecting unmodified native catchments and ensuring that the native sites were spread throughout the study area. One native site has been described by Wall (1985) as being modified with some logging (Site Na3); another site has been lightly logged (Site Na5). All the sites are in varying types of beech forest. Riparian vegetation apart from beech trees consisted mainly of native shrubs, ferns and sedges including, pepper tree, *Coprosma sp.*, marble leaf, juvenile lancewood, fuchsia, *Griselinia sp.*, punga, crown fern, *Blechnum sp.*, *Asplenium bulbiferum* (hen and chicken fern), hook grass and other sedges.

More details on the history and characteristics of each site and contact personnel that supplied the information are provided in Appendix 1. Descriptions of the riparian vegetation in the pine and native streams were recorded at the time of field measurements and these are also detailed in Appendix 1.

4.4 Stream Reach Selection

Hauer and Lamberti (1996) define a stream (channel) reach as a relatively homogenous association of topographic features and geomorphic units, which distinguishes it in certain aspects from adjoining reaches. Gordon *et al.* (1992) suggested that a reach should be long enough to include a full meander amplitude with two sets of pools and riffles. Generally this requires a reach length 12-15 times that of bankfull width. For sinuosity measurements, reach length needs to be at least 20 times the average width of the channel. The initial survey of stream sites for this study indicated that bankfull widths averaged 4-5 m.

A reach length of 100 m was used in this study as it met the guidelines of Gordon *et al.* (1992) in ensuring adequate sampling of sinuosity and channel bed units. The reach length chosen was also comparable to the reach length used in similar studies (Quinn *et al.*, 1997; Davies-Colley, 1997). At each of the fifteen sites, stream reach was visually assessed in the field to select a representative 100 m section (i.e. similar channel pattern, channel confinement, streambed and bank materials). Sites were selected where there were no major tributaries or significant changes in gradient and away from any boundary influences i.e. fences across streams.
Chapter 5 details the field measurements that were taken along the 100 m section of stream reach at each of the 5 sites in pasture pine plantation and native forest.
Chapter 5 – Methodology

5.1 Field Measurements – Introduction

There are a variety of field measurements that can be used to assess and describe channel morphology characteristics. The purpose of this study was to determine whether land-use was influencing channel morphology in the Moutere Gravels. To achieve that purpose, measurement criteria were selected that would characterise the channel morphology of small streams, provide information for statistical analysis and allow comparison between the three land-uses and with other similar studies.

Geomorphically based stream reach and channel unit classification schemes are relatively new and undergoing refinement. So far there is no universal acceptance of any one classification system (Hawkins et al., 1993; Hauer and Lamberti, 1996). The lack of consistent terminology and classification systems highlights the importance of giving detailed definitions and descriptions of the terminology being used. The next two sections define and describe the channel morphology characteristics measured in this study.

5.1.1 Cross-section measurements

![Figure 5.1: Transect location along the stream reach](image)
Cross-section measurements were taken along transects located at 5m intervals along the 100 m section of stream reach (21 transects in total). The reference point for each transect was the middle of the channel. The transect line ran either side of this point to the right and left banks, perpendicular to main stream flow. Distance to the next transect line was measured from the mid-channel reference point (Figure 5.1).

<table>
<thead>
<tr>
<th>Cross-section measurements</th>
<th>Measurements along the 100 m reach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bankfull width</td>
<td>Sinuosity</td>
</tr>
<tr>
<td>Channel width</td>
<td>Channel gradient</td>
</tr>
<tr>
<td>Channel depth</td>
<td>Channel bank disturbance</td>
</tr>
<tr>
<td>Maximum depth (thalweg)</td>
<td>Channel units (pool/riffle/run)</td>
</tr>
<tr>
<td>True left and true right channel bank height and slope</td>
<td>Pool classification</td>
</tr>
<tr>
<td>Substrate</td>
<td><em>In pine plantation and native streams only</em></td>
</tr>
<tr>
<td></td>
<td>LWD length and diameter</td>
</tr>
<tr>
<td></td>
<td>LWD orientation</td>
</tr>
<tr>
<td></td>
<td>LWD position in the channel</td>
</tr>
<tr>
<td></td>
<td>LWD morphological influence</td>
</tr>
</tbody>
</table>

Table 5.1: Field Measurements

Using this method for transect location allows for repeat measurements, should that be the purpose of the study, while meeting the statistical requirement for randomness in site selection (Platts et al., 1983). The first column in Table 5.1 lists the cross-section measurements taken at each transect. These measurements are illustrated in Figure 5.2.

Figure 5.2: Cross-section measurements at each transect
• **Bankfull width**

Bankfull width is defined as the horizontal distance between the tops of the channel bank on opposite sides of the stream and at right angles to the general orientation of the stream channel, measured to the nearest centimetre using a fibre tape. If the tops of the banks were at differing heights, horizontal distance was taken from the top of the lower bank (Figure 5.2), as this is the point at which overbank flow would occur (Murgatroyd and Ternan, 1983). Criteria to determine the top of the bank included: a change in slope from bank to floodplain or a change in general slope of the land, change to terrestrial vegetation or a change in the composition of substrate material (Platts *et al.*, 1983). Bankfull width and depth (described later) provide a standardised description of channel dimensions.

Width/depth ratios can be used as a relative index of channel shape to compare between catchments and land-uses (Beschta and Platts, 1986; Gordon *et al.*, 1992). For the purposes of characterising channel morphology, bankfull width is considered more important than the width currently occupied by stream flow, as bankfull flow (where the flow is just large enough to completely fill the channel) is the dominant flow that shapes stream channels (Williams, 1978; Platts *et al.*, 1983).

• **Channel width**

Channel width is defined as the width across the bottom of channel, and is the relatively level substrate plane over which the water column moves (Platts *et al.*, 1983). Channel width edges are defined by a change in slope usually indicating the boundary between the channel bottom and the stream banks or a gravel bar (Figure 5.2). Channel width was measured to the nearest centimetre using a fibre tape. Channel width, along with channel bank height and slope (described below) provided cross-sectional profiles of the stream channel.

• **Average and maximum (thalweg) channel depth**

Channel depth was assessed by measuring the vertical distance from the channel bottom to bankfull height, using a 2 m pole marked in 1 cm graduations. Channel depth measurements were taken at 25%, 50% and 75% of bankfull width (Platts *et al.*, 1983). Maximum depth (thalweg) was measured to the nearest centimetre (Figure 5.2).
• Channel bank height & slope
True left and true right channel bank heights were measured from the bottom of the bank (usually a distinct break in slope from the channel bottom) to the top of the bank, (see definition of bankfull width) to the nearest centimetre. Bank slope was determined to the nearest 5° using a clinometer placed on top of a rod (Platts et al., 1983). Usually more than one measurement was taken, as there were often changes in the slope of the bank profile (Figure 5.2).

Channel bank characteristics, and in particular channel bank slope, can reflect land uses that may change the morphology and location of the stream bank (Platts et al., 1983). Channel bank condition and form have also been closely linked to the quality of fish habitat (Beschta and Platts, 1986).

• Substrate
Substrate usually refers to particles on the streambed, both organic and inorganic. (Gordon et al. (1992). Because substrate composition varies both longitudinally and in cross-section along the channel profile, sufficient samples needed to be taken systematically along the 100 m reach to ensure adequate sampling of the substrate distribution. To achieve this, substrate was measured using Leopold’s (1970) modification of Wolman’s (1954) pebble count procedure method. Samples were taken across the channel at evenly spaced intervals along the 21 transect lines until 150 pebbles had been measured. Each pebble was measured along its breadth to determine its substrate class. The substrate classification is described in Table 5.2.

<table>
<thead>
<tr>
<th>Class</th>
<th>Size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand/silt/clay (SA, SI, CL)</td>
<td>&lt;2 mm</td>
</tr>
<tr>
<td>Small gravel (SG)</td>
<td>2-8 mm</td>
</tr>
<tr>
<td>Medium gravel (MG)</td>
<td>8-16 mm</td>
</tr>
<tr>
<td>Medium/large gravel (MLG)</td>
<td>16-32 mm</td>
</tr>
<tr>
<td>Large gravel (LG)</td>
<td>32-64 mm</td>
</tr>
<tr>
<td>Small cobble (SC)</td>
<td>64-128 mm</td>
</tr>
<tr>
<td>Large cobble (LC)</td>
<td>128-256 mm</td>
</tr>
<tr>
<td>Boulder (B)</td>
<td>&gt;256 mm</td>
</tr>
<tr>
<td>Bedrock (BR)</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 5.2: Substrate classification based on the Wentworth scale (Gordon et al., 1992)
Substrate is a major factor affecting the occurrence of benthic invertebrates and fish requirements for shelter and spawning. Alterations to catchments, riparian areas and stream channels frequently result in substrate changes consequently, information on substrate composition is often used to assess the effects of human disturbance (Gordon et al., 1992; Hauer and Lamberti, 1996).

5.1.2. Measurements along the 100 m section of stream reach

The measurements taken along the 100 m section of stream reach are summarised in the second column of Table 5.1.

- Sinuosity

Sinuosity is a measure of the ‘wiggliness’ of a stream and is expressed mathematically as the sinuosity index (SI) where:

\[ SI = \frac{\text{channel (thalweg) distance between two points}}{\text{straight line distance between the same two points}} \]

Although sinuosity is normally computed from maps or aerial photos (Gordon et al., 1992), distances were measured in the field to the nearest 10 cm by measuring a straight line between the start and end point of the 100 m section of stream channel. Measurement error is conservatively estimated at 2%. Sinuosity is used to describe channel pattern (Gordon et al., 1992) and is useful for providing gross comparisons of aquatic habitat conditions between streams (Platts et al., 1983).

- Channel slope/gradient

Channel gradient is the amount of vertical drop per unit of horizontal distance along the water surface (Gordon et al., 1992). A surveyor’s automatic level was used to measure channel gradient. Rod height and distance along the channel was measured to the nearest centimetre. Sightings were taken along the longest possible length of uniform gradient. However, vision was often restricted in these small streams making it necessary to take several readings along varying lengths along the 100 m reach at each site. It was often not possible to measure the gradient along all of the 100 metres at each site. Measurement error is estimated at 1%.
A gradient for each reading was calculated using the formula;
Tangent of gradient = (difference in rod height (m) from datum height (m)/distance (m).

An average gradient was calculated for each site, weighted by distance.

Channel gradient is an important morphological parameter to measure. Coupled with stream discharge, it gives an indication of stream power, which is a measure of the erosive capacity of the stream, and with other factors such as sediment regime influences channel morphology (Beschta and Platts, 1986; Gordon et al., 1992, Hauer and Lamberti, 1996). Because of its influence on channel morphology, channel gradient was measured to ensure sites had similar gradients and to reduce the effect of background variation between catchments.

- Channel bank disturbance
Channel bank disturbances were assessed along the true right and true left channel banks to provide a one-off 'point in time' assessment of channel bank disturbance between the three land-uses. Disturbances were identified as those that were obviously recent, with a freshly eroded surface and lacked vegetation growth or a weathered surface. Disturbance types were classified using a modified version of Baillie et al. (1999b) and are described in Table 5.3.

<table>
<thead>
<tr>
<th>Code</th>
<th>Channel bank disturbance description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LS</td>
<td>Lateral scour - bank disturbance from fluvial scour, includes bank undercutting</td>
</tr>
<tr>
<td>SL</td>
<td>Bank slump, no discrete volume loss, bank material still intact</td>
</tr>
<tr>
<td>BC</td>
<td>Bank collapse, discrete volume loss</td>
</tr>
<tr>
<td>BS</td>
<td>Bank scuff, usually caused by animal disturbance/animal tracks</td>
</tr>
</tbody>
</table>

Table 5.3: Classification of channel bank disturbances

The length and height of each disturbance were recorded and where there had been a loss of bank material, depth measurements were also taken to estimate volume. Like channel bank slope, channel bank disturbance can be used to compare land-use effects on the morphology and location of the stream bank (Platts et al., 1983).
Figure 5.3: Hawkins et al., (1993) hierarchical classification of channel units

- Channel units

The three-level hierarchical classification system of Hawkins et al. (1993) was used to define the channel units in this study (Figure 5.3). The three levels allow the user a choice in the level of habitat resolution, and data sets can be collapsed or split for comparison across studies. Terms and definitions have based on the nomenclature used by Bisson et al. (1982) and the Habitat Inventory Committee Western Division, American Fisheries Society (1985). A channel unit was defined by Hawkins et al. (1993) as a quasi-discrete area of relatively homogenous depth and flow that is bounded by sharp physical gradients.

The following definition of "turbulence" has been used to differentiate between the turbulent and non-turbulent channel units in Level III of Hawkins classification system: 'the motion of water where local velocities fluctuate and the direction of flow changes abruptly at any particular location, resulting in disruption of laminar flow. It causes surface disturbance and uneven surface level, and often masks subsurface areas because air bubbles are entrained in the water'. Not all the channel units described in Hawkins et al. (1993) were applicable to this study. Pools, riffles and runs were the main channel units identified in the field, and are typical of channel units associated with small to mid-sized streams, particularly in alluvial valleys of low to moderate gradient (Hauer and Lamberti, 1996).
Following the definitions in Platts et al. (1983), the Habitat Inventory Committee Western Division, American Fisheries Society (1985) and Hawkins et al., (1993), a pool was defined as an area of the water column with slow water velocity, usually deeper than a riffle or run and having a gradient near zero. Pools are low points in the channel profile, they usually contain the finer substrates and are often concave in shape. They often have large eddies and widely varying directions of flow. Riffles are topographic high points in the bed profile and are composed of coarser sediments. The water surface gradient in a riffle is relatively steep, the water velocity is fast and stream depths are relatively shallow. A run is an area of swiftly flowing water, without surface agitation or waves, which approximates uniform flow and in which the slope of the water is roughly parallel to the overall gradient of the stream reach. It can be difficult to determine the boundary between these units in the field (Platts et al., 1983; Montgomery and Buffington, 1998).

Measurements of pool, riffles and run length were measured to the nearest 10 cm, directly along the 100 m reach using a fibre tape.

Pool/riffle/run ratios give a measure of habitat variability for comparison between land-uses. Variations in both the structure and dynamics of the physical stream environment are primary factors affecting production and diversity of stream biota (Hawkins et al., 1993). Fish distinguish between riffles, pools and types of pools and the composition and abundance of aquatic invertebrates varies between channel units.

- Pool classification

Pools were classified by Hawkins et al. (1993) into two groups; those formed by scouring processes and those formed by damming processes (Figure 5.3). These two groups were further divided into pool type, depending on their location within the flood or active channel, longitudinal and cross-sectional depth profiles, characteristics of surficial substrates, and the constraining feature that helped form them. This is the finest level of resolution that the authors believed could be visually distinguished in the field.

Not all the pool categories in Hawkins et al. (1993) have been used in this study as some were not pertinent or weren’t encountered in the field e.g. landslide pools, pools formed at the confluence of two tributaries or pools formed by beavers. Appendix 2 gives a more detailed description of the pool types identified in this study. Each pool was measured for length, width and depth, and the pool forming features were noted.
The abundance and geometry of pools has important implications for fish habitat (Harmon et al., 1986; Platts et al., 1983). Dammed pools tend to accumulate and retain more sediment and organic debris and provide greater amounts of cover than scour pools. These are important factors affecting stream ecosystem dynamics and the presence and abundance of fish.

- Large woody debris (LWD)

LWD was defined as all woody debris ≥ 10 cm in diameter and included all pieces in the 100 m section of stream reach. LWD assessments were based on low flow conditions in the stream channel. The purpose of including LWD measurements in this study was to provide information on whether the loading, size and spatial arrangement of the LWD in the stream was influencing channel morphology characteristics in the pine and native streams.

Factors that contribute to the stability and longevity of LWD and its influence on channel morphology include abundance, piece size, length of piece submerged in the water column (usually based on low flow conditions), orientation, degree of burial and how well the piece is anchored (Harmon et al., 1986; Bisson et al., 1987).

To calculate LWD volume of the *Pinus radiata* pieces (Ellis, 1982), LWD was measured for large end diameter (LED), small end diameter (SED) and length. The native LWD was more irregular in shape than the *Pinus radiata* LWD and major errors in volume can result if inadequate measurements are taken (Harmon and Sexton, 1996). To account for irregular shapes, in addition to measuring LED, SED and length, a diameter measurement was taken along the midpoint of the stem of the native pieces. To calculate the volume of hollow logs, the diameter and length of hollows were also recorded (Harmon and Sexton 1996). All LWD was classified as either submerged or above the water column and was based on low flow conditions. If a piece was partly submerged the length of the piece submerged and the length above the water column were recorded.

Orientation of LWD was recorded into four categories relative to stream flow (based on Bilby and Ward, 1989; Robison and Beschta, 1990):

1. parallel to stream flow
2. 90° to stream flow
3. 45/225° to stream flow
4. 135/315° to stream flow (see Figure 5.4).
LWD position in the stream channel was classified as either:

a) suspended across the stream channel,
b) partly suspended across the stream channel,
c) resting on the channel floor or
d) buried/partly buried in the substrate.

Each piece was also assessed as to whether a root wad anchored it.

LWD influence on channel morphology was determined by assessing each piece for:

a) contribution to pool formation,
b) sediment storage,
c) stream flow deflection,
d) formation of a step profile in the stream channel,
e) bank armouring,
f) debris collection
g) or having no obvious influence at all (Figure 5.5).

These are the key geomorphic influences of LWD on channel morphology that have been found in other studies (Keller and Swanson, 1979; Mosley, 1981; Bisson et al., 1987; Smith, 1992b).
Figure 5.5: Categories used to classify influence of LWD on channel morphology.
Chapter 6 – Results and Discussion

Methods used to analyse the data, the results, and discussion of the results are presented in this chapter. Because of the variability of terms and definitions used and the way results have been presented in similar studies for both channel morphology and LWD characteristics, comparisons have been limited to studies using similar terms and descriptions to this one.

6.1 Channel morphology characteristics

6.1.1. Bankfull and channel width

The 21 bankfull and channel widths for each site have been averaged and presented in Table 6.1, along with some descriptive statistics to indicate the precision and variability of the data sets. Mean bankfull widths were greatest in the pasture sites 4.57 ± 1.67m (95%CI), the pine sites averaged 3.72 ± 1.71m and the native sites 4.0 ± 1.06m. Mean channel widths were 2.11 ± 0.55m, 2.2 ± 0.44m and 2.54 ± 0.31m for the pasture, pine and native sites respectively. A one-way ANOVA (analysis of variance) showed no significant difference in either bankfull widths or channel widths for the three land-uses.

The three land-uses all showed more variability in bankfull widths in comparison to channel widths. The variation in bankfull and channel widths was significantly less in the pine sites when compared with the pasture sites (one-way ANOVA on standard deviations, followed by LSD (least significant difference) tests). There was no significant difference in the variation in bankfull and channel widths between the pine and native, and pasture and native sites.
Table 6.1: Bankfull and channel widths.

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Bankfull width (m) ± 95%CI (n=21)</th>
<th>SD</th>
<th>Range (m)</th>
<th>Channel width (m) ± 95%CI (n=21)</th>
<th>SD</th>
<th>Range (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pasture</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pa1</td>
<td>5.80±1.00</td>
<td>2.19</td>
<td>2.6-9.75</td>
<td>2.45±0.78</td>
<td>1.72</td>
<td>1.3-7.1</td>
</tr>
<tr>
<td>Pa2</td>
<td>2.99±0.56</td>
<td>1.23</td>
<td>1.3-5.6</td>
<td>1.62±0.43</td>
<td>0.94</td>
<td>0.8-4.2</td>
</tr>
<tr>
<td>Pa3</td>
<td>6.10±0.68</td>
<td>1.49</td>
<td>3.35-8.75</td>
<td>2.52±0.57</td>
<td>1.24</td>
<td>0.8-4.9</td>
</tr>
<tr>
<td>Pa4</td>
<td>4.30±0.91</td>
<td>2.01</td>
<td>2.15-8.9</td>
<td>1.65±0.28</td>
<td>0.62</td>
<td>0.9-3.4</td>
</tr>
<tr>
<td>Pa5</td>
<td>3.65±0.42</td>
<td>0.94</td>
<td>2.05-5.2</td>
<td>2.33±0.42</td>
<td>0.92</td>
<td>1.1-4.65</td>
</tr>
<tr>
<td>Mean</td>
<td>4.57±1.67</td>
<td>1.57</td>
<td></td>
<td>2.11±0.55</td>
<td>1.01</td>
<td></td>
</tr>
<tr>
<td>Pine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pi1</td>
<td>2.58±0.50</td>
<td>1.01</td>
<td>1.4-5.2</td>
<td>1.93±0.33</td>
<td>0.75</td>
<td>1.1-4.12</td>
</tr>
<tr>
<td>Pi2</td>
<td>1.98±0.16</td>
<td>0.17</td>
<td>1.4-2.6</td>
<td>1.72±0.17</td>
<td>0.37</td>
<td>0.8-2.4</td>
</tr>
<tr>
<td>Pi3</td>
<td>4.66±0.66</td>
<td>0.18</td>
<td>2.2-6.8</td>
<td>2.50±0.29</td>
<td>0.64</td>
<td>1.5-7.1</td>
</tr>
<tr>
<td>Pi4</td>
<td>4.20±0.34</td>
<td>0.75</td>
<td>3.15-6.3</td>
<td>2.36±0.31</td>
<td>0.68</td>
<td>1.4-2.17</td>
</tr>
<tr>
<td>Pi5</td>
<td>5.19±0.47</td>
<td>1.02</td>
<td>3.7-8.1</td>
<td>2.48±0.23</td>
<td>0.51</td>
<td>1.6-3.35</td>
</tr>
<tr>
<td>Mean</td>
<td>3.72±1.71</td>
<td>0.63</td>
<td></td>
<td>2.20±0.44</td>
<td>0.59</td>
<td></td>
</tr>
<tr>
<td>Native</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na1</td>
<td>3.64±0.63</td>
<td>1.37</td>
<td>1.85-6.4</td>
<td>2.49±0.23</td>
<td>0.50</td>
<td>1.25-3.55</td>
</tr>
<tr>
<td>Na2</td>
<td>2.99±0.43</td>
<td>0.95</td>
<td>1.8-5.55</td>
<td>2.27±0.25</td>
<td>0.55</td>
<td>1.5-4.0</td>
</tr>
<tr>
<td>Na3</td>
<td>5.27±0.70</td>
<td>1.54</td>
<td>2.4-8.4</td>
<td>2.51±0.37</td>
<td>0.81</td>
<td>1.4-4.2</td>
</tr>
<tr>
<td>Na4</td>
<td>4.30±0.45</td>
<td>1.00</td>
<td>2.15-6.6</td>
<td>2.95±0.49</td>
<td>1.07</td>
<td>1.2-6.0</td>
</tr>
<tr>
<td>Na5</td>
<td>3.80±0.45</td>
<td>0.98</td>
<td>2.4-5.6</td>
<td>2.49±0.22</td>
<td>0.49</td>
<td>1.7-3.4</td>
</tr>
<tr>
<td>Mean</td>
<td>4.00±1.06</td>
<td>1.17</td>
<td></td>
<td>2.54±0.31</td>
<td>0.68</td>
<td></td>
</tr>
</tbody>
</table>

The lack of significant differences in bankfull and channel widths between land-uses in the Moutere Gravels is in contrast to the results of similar studies. Other authors have found significant differences in bankfull widths and channel widths between pasture and forested sites in spite of the wide variation within the data sets (Murgatroyd and Ternan, 1983; Clifton, 1989; Sweeney, 1993; Trimble, 1997; Davies-Colley, 1997; Quinn et al., 1997). In streams with similar bankfull or channel widths, catchment area or stream order to this study, widths in forested streams were anything from 1.6 to 3 times wider than pasture streams (Murgatroyd and Ternan, 1983; Sweeney, 1997; Davies-Colley, 1997; Quinn et al., 1997). Some of these studies also noted that variation in width was greater in the forested reaches (Zimmerman et al., 1967; Murgatroyd and Ternan 1983; Clifton, 1989; Dijkman, 1997). Zimmerman et al. (1967) attributed the wider channel widths and greater...
variation in channel widths in forest streams to the woody debris in the channel and the tree root mats in the stream bank diverting channel flow. In the Moutere Gravels it was the pine and native sites which showed the least variation in both bankfull and channel widths. Woody debris did not appear to be significantly influencing bankfull and channel widths or the variability of widths in the forested streams.

6.1.2. Channel depth and thalweg (maximum depth)

<table>
<thead>
<tr>
<th>Pasture</th>
<th>Channel depth (D) (m) ± 95%Cl (n=21)</th>
<th>SD</th>
<th>Range (m)</th>
<th>Thalweg (m) ± 95%Cl (n=21)</th>
<th>SD</th>
<th>Range (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pa1</td>
<td>0.54±0.07</td>
<td>0.16</td>
<td>0.34-0.93</td>
<td>1.00±0.16</td>
<td>0.35</td>
<td>0.50-1.80</td>
</tr>
<tr>
<td>Pa2</td>
<td>0.25±0.03</td>
<td>0.01</td>
<td>0.11-0.35</td>
<td>0.46±0.04</td>
<td>0.02</td>
<td>0.30-0.64</td>
</tr>
<tr>
<td>Pa3</td>
<td>0.48±0.09</td>
<td>0.04</td>
<td>0.19-0.89</td>
<td>0.91±0.12</td>
<td>0.06</td>
<td>0.54-1.53</td>
</tr>
<tr>
<td>Pa4</td>
<td>0.33±0.09</td>
<td>0.19</td>
<td>0.08-0.73</td>
<td>0.68±0.20</td>
<td>0.43</td>
<td>0.18-1.90</td>
</tr>
<tr>
<td>Pa5</td>
<td>0.79±0.06</td>
<td>0.03</td>
<td>0.59-1.15</td>
<td>1.22±0.08</td>
<td>0.04</td>
<td>1.00-1.74</td>
</tr>
<tr>
<td>Mean</td>
<td>0.48±0.26</td>
<td>0.09</td>
<td></td>
<td>0.86±0.36</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>Pine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pi1</td>
<td>0.42±0.06</td>
<td>0.03</td>
<td>0.20-0.74</td>
<td>0.52±0.06</td>
<td>0.03</td>
<td>0.26-0.88</td>
</tr>
<tr>
<td>Pi2</td>
<td>0.64±0.08</td>
<td>0.04</td>
<td>0.29-0.89</td>
<td>0.73±0.08</td>
<td>0.04</td>
<td>0.34-1.14</td>
</tr>
<tr>
<td>Pi3</td>
<td>0.83±0.08</td>
<td>0.04</td>
<td>0.51-1.11</td>
<td>1.03±0.11</td>
<td>0.05</td>
<td>0.59-1.47</td>
</tr>
<tr>
<td>Pi4</td>
<td>1.05±0.34</td>
<td>0.16</td>
<td>3.15-6.30</td>
<td>1.32±0.14</td>
<td>0.07</td>
<td>0.61-1.87</td>
</tr>
<tr>
<td>Pi5</td>
<td>0.71±0.08</td>
<td>0.04</td>
<td>0.45-1.10</td>
<td>0.94±0.10</td>
<td>0.05</td>
<td>0.62-1.39</td>
</tr>
<tr>
<td>Mean</td>
<td>0.73±0.29</td>
<td>0.06</td>
<td></td>
<td>0.91±0.38</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>Native</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na1</td>
<td>0.70±0.11</td>
<td>0.05</td>
<td>0.34-1.15</td>
<td>0.90±0.12</td>
<td>0.06</td>
<td>0.43-1.33</td>
</tr>
<tr>
<td>Na2</td>
<td>0.48±0.03</td>
<td>0.02</td>
<td>0.27-0.64</td>
<td>0.58±0.06</td>
<td>0.03</td>
<td>0.40-0.94</td>
</tr>
<tr>
<td>Na3</td>
<td>0.96±0.15</td>
<td>0.34</td>
<td>0.36-1.57</td>
<td>1.18±0.16</td>
<td>0.36</td>
<td>0.49-1.87</td>
</tr>
<tr>
<td>Na4</td>
<td>0.57±0.07</td>
<td>0.03</td>
<td>0.26-0.56</td>
<td>0.71±0.08</td>
<td>0.04</td>
<td>0.34-0.99</td>
</tr>
<tr>
<td>Na5</td>
<td>0.48±0.06</td>
<td>0.03</td>
<td>0.29-0.75</td>
<td>0.60±0.07</td>
<td>0.04</td>
<td>0.40-0.97</td>
</tr>
<tr>
<td>Mean</td>
<td>0.64±0.25</td>
<td>0.09</td>
<td></td>
<td>0.79±0.31</td>
<td>0.11</td>
<td></td>
</tr>
</tbody>
</table>

Table 6.2: Mean channel depth and thalweg.
Mean channel depth was calculated for each cross-section using the formula:

$$\text{Mean depth} (D) = \frac{(D_2 + D_3 + D_4)}{4}$$

where $D_2 =$ depth at 25% of bankfull width, $D_3 =$ depth at 50% of bankfull width and $D_4 =$ depth at 75% of bankfull width (Platts et al., 1983). See Appendix 3 for the derivation of this formula.

Mean channel depth and thalweg (maximum depth) have been summarised in Table 6.2 along with descriptive statistics of precision and variability. Mean channel depth was shallowest in the pasture sites averaging $0.48\pm0.26$ m, deepest in the pine sites averaging $0.73\pm0.29$ m, and of intermediate depth in the native streams averaging $0.64\pm0.25$ m. Thalweg was also deepest in the pine sites followed by the pasture and native sites $0.91\pm0.38$ m, $0.86\pm0.36$ m, and $0.79\pm0.31$ m respectively. As with the width measurements, results of a one-way ANOVA showed no significant differences between land-uses for both depth measurements.

Likewise, Murgatroyd and Ternan (1983), Trimble (1977) and Quinn et al., (1997) and Dijkman (1997) found no significant differences in depths between moorland or pasture and forest streams. However Clifton (1989) found that land-use did have an effect on depth in some instances. Both bankfull mean and maximum depths were much greater in the ungrazed exclosure site and one forested reach was significantly shallower than other sites.

6.1.3. Cross-sectional area

Bankfull width and average channel depth for each transect were multiplied to give an estimate of cross-sectional area. The cross-sectional areas for each site (average of 21 transects) are listed below in Table 6.3.

There is a high degree of variability in cross-sectional area within each land-use and although cross-sectional area was smaller in the pasture sites compared with the pine and native sites, a one-way ANOVA found no significant differences in cross-sectional areas for the three land-uses.
This contrasts with most other studies where cross-sectional areas in forested streams were greater than those in pasture streams (Murgatroyd and Ternan, 1983; Trimble, 1997; Dijkman, 1997). In the case of Murgatroyd and Ternan (1983), cross-sectional area was over two times greater than that predicted from the basin area. However the influence of land-use on channel cross-sectional area was not so obvious in Clifton’s (1989) study.

<table>
<thead>
<tr>
<th>Pasture</th>
<th>Channel cross-sectional area (m²)</th>
<th>SD</th>
<th>Range (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pa1</td>
<td>3.32±0.90</td>
<td>1.98</td>
<td>0.88-8.25</td>
</tr>
<tr>
<td>Pa</td>
<td>0.73±0.13</td>
<td>0.29</td>
<td>0.2-1.3</td>
</tr>
<tr>
<td>Pa3</td>
<td>2.86±0.54</td>
<td>1.19</td>
<td>0.89-6.1</td>
</tr>
<tr>
<td>Pa4</td>
<td>1.65±0.76</td>
<td>1.67</td>
<td>0.30-5.55</td>
</tr>
<tr>
<td>Pa5</td>
<td>2.82±0.31</td>
<td>0.68</td>
<td>1.65-4.26</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td><strong>2.28±1.32</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Pine</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pi1</td>
<td>1.11±0.34</td>
<td>0.75</td>
<td>0.41-3.83</td>
</tr>
<tr>
<td>Pi2</td>
<td>1.26±0.19</td>
<td>0.41</td>
<td>0.43-2.24</td>
</tr>
<tr>
<td>Pi3</td>
<td>4.05±0.85</td>
<td>1.86</td>
<td>1.33-7.55</td>
</tr>
<tr>
<td>Pi4</td>
<td>4.43±0.73</td>
<td>0.35</td>
<td>1.93-9.07</td>
</tr>
<tr>
<td>Pi5</td>
<td>3.73±0.69</td>
<td>1.51</td>
<td>2.32-8.91</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td><strong>2.91±2.00</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Native</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na1</td>
<td>2.52±0.51</td>
<td>0.24</td>
<td>0.64-4.62</td>
</tr>
<tr>
<td>Na2</td>
<td>1.47±0.27</td>
<td>0.59</td>
<td>0.57-2.96</td>
</tr>
<tr>
<td>Na3</td>
<td>5.3±1.21</td>
<td>2.66</td>
<td>0.97-11.46</td>
</tr>
<tr>
<td>Na4</td>
<td>2.47±0.44</td>
<td>0.96</td>
<td>1.12-4.63</td>
</tr>
<tr>
<td>Na5</td>
<td>1.82±0.35</td>
<td>0.77</td>
<td>0.77-3.96</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td><strong>2.72±1.89</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6.3: Cross-sectional areas (± 95%CI).
6.1.4. Width/depth ratios

The width-to-depth ratio (W/D) is a dimensionless index of cross-sectional shape and has been calculated using bankfull width and average channel depth measurements from each transect. The results in Table 6.4 show that width-to-depth ratios are significantly higher in the pasture stream in comparison with the pine and native streams (one-way ANOVA followed by a LSD test). There was no significant difference in width-to-depth ratios between the pine and native streams.

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Pasture width:depth ratio</th>
<th>Pine width:depth ratio</th>
<th>Native width:depth ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>13</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>17</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Mean</td>
<td>12a</td>
<td>5b</td>
<td>7b</td>
</tr>
</tbody>
</table>

Table 6.4: Width-to-depth ratios for the 3 land-uses. Mean width-to-depth ratios with different letters are significantly different (p<0.05).

The low width-to-depth ratios in the pine and native streams indicate that these streams were more trench shaped in their cross-sectional profiles than the pasture sites. Figures 6.1 – 6.3 give examples of a typical channel profile for each land-use.
Figure 6.1 Typical channel profile for a pasture stream

Figure 6.2: Typical channel profile for a pine stream

Figure 6.3: Typical channel profile for a native stream
In other similar studies, width-to-depth ratios were usually lower in the pasture sites and higher in the forest sites (Zimmerman et al., 1967; Clifton, 1989; Trimble, 1997).

Zimmerman et al. (1967) commented that the width-depth ratios indicated that the grass behaved more like cohesive sediment than the bank material consolidated by tree roots. These results are opposite to the trends in width-to-depth ratios in the Moutere Gravels where width-to-depth ratios were higher in the pasture sites and lower in the forested sites.

6.1.5 Channel banks

6.1.5.1. Channel bank disturbance

<table>
<thead>
<tr>
<th>Pasture</th>
<th>Channel bank disturbed (%)</th>
<th>Material lost (m³)</th>
<th>Type of channel bank disturbance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>BC</td>
</tr>
<tr>
<td>Pa1</td>
<td>9</td>
<td>3.3</td>
<td>4</td>
</tr>
<tr>
<td>Pa2</td>
<td>4</td>
<td>0.1</td>
<td>2</td>
</tr>
<tr>
<td>Pa3</td>
<td>11</td>
<td>0.9</td>
<td>6</td>
</tr>
<tr>
<td>Pa4</td>
<td>0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Pa5</td>
<td>3</td>
<td>0.3</td>
<td>1</td>
</tr>
<tr>
<td>Mean (total)</td>
<td>5</td>
<td>0.9</td>
<td>(5)</td>
</tr>
<tr>
<td>Pine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pi1</td>
<td>9</td>
<td>7.4</td>
<td>3</td>
</tr>
<tr>
<td>Pi2</td>
<td>1</td>
<td>0.0</td>
<td>2</td>
</tr>
<tr>
<td>Pi3</td>
<td>2</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>Pi4</td>
<td>5</td>
<td>2.1</td>
<td>6</td>
</tr>
<tr>
<td>Pi5</td>
<td>0.3</td>
<td>0.04</td>
<td>1</td>
</tr>
<tr>
<td>Mean (total)</td>
<td>3</td>
<td>2.0</td>
<td>(8)</td>
</tr>
<tr>
<td>Native</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na1</td>
<td>2</td>
<td>1.0</td>
<td>1</td>
</tr>
<tr>
<td>Na2</td>
<td>3</td>
<td>0.1</td>
<td>4</td>
</tr>
<tr>
<td>Na3</td>
<td>2</td>
<td>1.4</td>
<td>1</td>
</tr>
<tr>
<td>Na4</td>
<td>3</td>
<td>1.6</td>
<td>2</td>
</tr>
<tr>
<td>Na5</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Mean (total)</td>
<td>2</td>
<td>0.8</td>
<td>(3)</td>
</tr>
</tbody>
</table>

Table 6.5: Amount and types of channel bank disturbance. BC = bank collapse, SL = slump, LS = lateral scour, BS = bank scuff.
The percentage of channel bank length disturbed was similar for the 3 land-uses, ranging from 3-5% (Table 6.5). The average amount of bank material lost from channel bank disturbances in the pine sites, was twice that of the other two land-uses although a one-way ANOVA did not rate this as significant at the 95% confidence level. The high amount of bank material lost at Pi1 had a strong influence on the average amount of bank material lost in the pine sites. Lateral scouring undercutting the channel banks accounted for most of this. The remaining 4 pine sites had similar bank material losses to the pasture and native sites.

In the pasture sites, slumps and bank scuffs were the predominant types of bank disturbance. Neither of these disturbance types resulted in any significant loss of channel bank material. Although only fresh disturbances were recorded, it was noted that at two of the pasture sites there were a lot of older, stable slumps along the channel reach.

Bank scuffs were absent from the pine sites. Bank collapses were the main type of channel bank disturbances in the pine sites followed closely by slumps and lateral scour. Similarly to the pasture sites, bank scuffs were the main source of channel bank disturbances in the native sites. Most of this was due to pig rooting in one site (Na2).

The results from the Moutere Gravels study indicated that the channel banks were quite stable and there was very little active erosion along the bank margins regardless of the land-use. In contrast, Murgatroyd and Ternan (1983) found more active bank erosion along the forested channel reach in a coniferous plantation 50 years old. The forested section was less than 30% of the total channel measured, but accounted for over 80% of the eroding banks.

The low levels of bank disturbance in the mature pine plantation streams in the Moutere Gravels are similar to a New Zealand-wide survey of 17 1st to 3rd order streams in mature pine plantations (crop age 22-34 years). Channel bank disturbance ranged from 0-36% of bank length, averaging 5% (Baillie et al., 1999b). Channel bank disturbance levels were higher in a first rotation crop of 15-year-old pines planted on pastureland in the Hakarimata Ranges (Quinn et al., 1997). Over 40% of the bank length in the pine streams were unstable, compared with 20-40% in the pasture streams. The authors attributed the large amount of actively eroding channel in these pine streams to the widening of these streams from a narrower pasture to a wider forested channel morphology.
It appears that while a 1st rotation crop of young *Pinus radiata* on land converted from pasture is undergoing active bank erosion in the Hakarimata Ranges (Quinn *et al.*, 1997), channel bank disturbance is much lower and channel banks are more stable in mature *Pinus radiata* stands throughout New Zealand. Similarities in channel widths between pine and pasture streams in the Moutere Gravels suggest that the pine streams have not significantly widened during the land conversion process from pasture to pine, and it is unlikely that bank erosion during the 1st rotation would have been as extensive as that observed in the Hakarimata Ranges.

### 6.1.5.2 Bank undercuts

To compare bank undercuts between the three land-uses, the number of bank profiles that were undercut were expressed as a percentage of the total number of bank profiles for each site. The results are in Table 6.6. While four of the native and all of the pine sites had some degree of bank undercutting, bank undercuts were absent from three of the pasture sites. Bank undercuts tended to be quite stable and particularly in the native sites, the roots of the streamside vegetation were holding the bank material in place. Although the percentage of undercut banks was higher in the pine and native streams when compared with the pasture streams, this difference was not significant at the 95% confidence interval (one-way ANOVA, $P = 0.08$). However, a 5% LSD test found the amount of undercuts in the pine streams to be significantly higher than in the pasture streams. There were no significant differences between the pasture and native and the pine and native sites.

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Pasture (%)</th>
<th>Pine (%)</th>
<th>Native (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>26</td>
<td>24</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>21</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td><strong>3</strong></td>
<td><strong>16</strong></td>
<td><strong>10</strong></td>
</tr>
</tbody>
</table>

Table 6.6: Percentage of bank profiles that were undercut
There is contrasting information available in the literature regarding the influence of tree roots and grass sod on channel bank stability in small streams. Keller and Swanson (1979) noted that living vegetation rooted in stream banks is particularly effective in increasing bank stability. In Mallard Creek, North Carolina, USA, which flowed through a hardwood forest, tree roots protected 73% of the length of stream bank along the study reach. Tree root systems exposed along the stream banks extend along and into banks, therefore trees may be undermined considerably by bank erosion before they fall into the stream channel. Thus undercut stream banks are commonly found in association with tree root protected stream banks. The results of this study support that finding.

This is in contrast to other studies that propose that grass is a more effective retainer of sediment, stabilising and narrowing the channel banks (Zimmerman et al., 1967; Murgatroyd and Ternan, 1983; Trimble, 1997; Davies-Colley, 1997; Quinn et al., 1997). While grass sod has the ability to trap and retain sediment, its ability to stabilise channel banks will depend on the amount of cover on the tops and slopes of the channel banks. If grass sod is confined to the bank tops, its stabilising capacity is restricted to the depth of the grass roots. Beschta and Platts (1986) suggested that while sod-forming grasses may adequately protect banks of low-gradient or ephemeral streams, for many small streams this type of vegetation alone is inadequate to resist the erosional forces of flowing water. Often vegetation with woody root systems provides a physical barrier to high velocities and turbulence, increasing surface roughness and relative bank stability. Abernethy and Rutherford (1999) also found that roots from riparian trees reinforced the river bank increasing the apparent cohesion of the river bank material and increasing the stability of the channel bank slope.

In the case of the Moutere Gravels it appears that the tree roots are more effective in retaining the bank material in these streams than grass. The tree and shrub roots were better able to bind around the cobble and boulders of the channel banks and were able to penetrate to a deeper level. The shallower rooting system of the grass was mainly confined to the top soil and did not have the same capacity to penetrate the channel bank material. The ability of the tree and shrub roots to stabilise the channel banks of the Moutere Gravels is reflected in the higher degree of bank undercuts and the more trench like channel shapes (lower width-to-depth ratios) in the pine and native streams.
Channel bank condition and form are closely linked to the quality of fish habitat (Beschta and Platts, 1986). Well vegetated banks are usually stable regardless of bank undercutting which provides excellent cover for fish, (Platts et al., 1983). Bank and channel profiles can affect water temperature, water velocity, sediment input, hiding cover and suitable living space for fish (Bohn, 1986).

6.1.6 Substrate analysis

![Substrate distribution of total substrate (organic and inorganic).](image)

The substrate distribution of the three land-uses has been plotted in Figure 6.4. The graph indicates that pasture sites have a higher percentage of fines compared to the pine and native sites (30, 14 and 10% respectively). While a one-way ANOVA showed no significant differences at the 5% level (P=0.09), a 5% LSD test showed the amount of fines in the pasture sites to be significantly higher than the native sites. However, the high fine sediment levels in one site (Pa3, 74%) influenced the average amount of fines in the pasture streams. Similar analysis of the cumulative frequencies for each substrate group found the amount of MLG (medium large gravel) to be significantly higher in the pasture sites when compared to the pine and native sites.
The median particle size for each land-use is graphed in Figure 6.5. Median substrate size was significantly smaller in the pasture and pine sites compared with the native site (One-way ANOVA; P = 0.007).

While the results on the effects of land-use on sedimentation levels in streams can be conflicting (Maclaren, 1996), overall sediment levels tend to be higher in pasture streams because of the higher erosion rates within the catchment and higher levels of stream bank erosion (Quinn, 2000; Wood and Armitage, 1997). The sediment often contains high proportions of fine material, increasing the amount of fine material on the channel bed and decreasing median particle size. While the Moutere Gravel results also showed a higher percentage of fines in the pasture streams, median particle size was lower in both the pasture and pine streams, a similar result to Quinn et al. (1997) in the Hakarimata Ranges. Quinn et al. (1997) also recorded higher levels of fines in both the pine and pasture streams compared to the native streams, a reflection of the high levels of bank erosion in the pine streams.

The composition of the surface substrate in stream beds and changes in substrate composition can have significant biological implications (Beschta and Platt, 1986). Increases in the amount of fine material in the stream bed can alter both the surface substrate and the hyporheic zone (saturated interstitial subsurface), decreasing the availability of suitable stream habitat. This in turn can affect primary production and the
composition and diversity of aquatic invertebrates and fish living in the stream (Hanchet, 1990; Ryan, 1991; Wood and Armitage, 1997).

6.1.7. Gradient

The gradients for each site have been listed in Table 4.1 as part of the description of site characteristics. As part of reducing the background variation between sites, gradients were kept as similar as possible. These streams are of low to medium gradient (Hildebrand et al., 1997) and range in gradient from 1-3%. A one-way ANOVA detected no significant differences in gradient between land-uses.

6.1.8. Sinuosity

Sinuosity was calculated by dividing the 100 m of channel reach by the straight-line distance between the start and finish of the 100 m reach. The more sinuous the stream the greater the sinuosity index (SI). The sinuosity indexes were similar between the three land-uses in this study (Table 6.7) and a one-way ANOVA found no significant variation. Murgatroyd and Ternan (1983) found less sinuosity in the forested reach compared to the pasture reach.

Sinuosity is often used as a descriptor of channel pattern, which is the planimetric form of streams (Gordon et al., 1992). A straight stream will have a SI = 1, whereas meandering streams are somewhat arbitrarily defined by Gordon et al. (1992) as those with a SI value greater than 1.5. Most of the streams in the Moutere Gravels have SI values of less than 1.5 (Table 6.7).

<table>
<thead>
<tr>
<th>Site No</th>
<th>Pasture SI</th>
<th>Pine SI</th>
<th>Native SI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.14</td>
<td>1.12</td>
<td>1.31</td>
</tr>
<tr>
<td>2</td>
<td>1.30</td>
<td>1.04</td>
<td>1.13</td>
</tr>
<tr>
<td>3</td>
<td>1.44</td>
<td>1.07</td>
<td>1.20</td>
</tr>
<tr>
<td>4</td>
<td>1.28</td>
<td>1.07</td>
<td>1.27</td>
</tr>
<tr>
<td>5</td>
<td>1.34</td>
<td>1.65</td>
<td>1.13</td>
</tr>
<tr>
<td>Mean</td>
<td>1.30</td>
<td>1.19</td>
<td>1.21</td>
</tr>
</tbody>
</table>

Table 6.7 Sinuosity index (SI) for the three land-uses
Under Gordon et al.'s, (1992) classification of channel patterns, the Moutere Gravel streams are characterised as having a single channel with a meandering thalweg, width-to-depth ratios <40 (which these streams do, see Table 6.4), high stream power, well-defined banks, typically stable channels, sediment and/or bedload load is suspended and load is usually small in comparison to transport capacity.

6.1.9. Channel units

6.1.9.1 Pool/riffle/run ratios

The three channel units measured in the field were pools, riffles and runs. Pool/riffle/run units were not measured at one of the pasture sites (Pa5), as most of the channel was dry. Water flow was present upstream and downstream of the site indicating that the flow in this particular section was underground. The percentage of channel reach in pools, riffles and runs has been calculated for each of the 15 sites and the mean percentage for each land-use has been graphed in Figure 6.6.

Riffles dominated the streams in all three land-uses. The pool percentage in the pasture sites has been dominated by a high percentage of pool length in one site Pa4, 13% of channel length compared with 0.0, and 5% at the other three sites. A one-way ANOVA found no significant differences in the percentage of channel units between the pasture, pine and native streams indicating that land-use was not having a significant impact on the proportions of stream channel units.

Figure 6.6: Percentage of channel length in pools, riffles and runs for the three land-uses.
6.1.9.2 Pool characteristics

Although the % length of the channel reach in pools was similar between the 3 land-uses (Figure 6.6) there were differences in the number of pools and pool volume (Table 6.8). The total number of pools increased from pasture to pine to native, even when taking into account that pools were assessed at only 4 pasture sites compared with 5 pine and native sites.

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Eddy</th>
<th>Mid-channel</th>
<th>Lateral</th>
<th>Plunge</th>
<th>Debris</th>
<th>Back water</th>
<th>Total/100 m</th>
<th>Mean pool vol(m3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pa1</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>0.47</td>
<td></td>
</tr>
<tr>
<td>Pa2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Pa3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Pa4</td>
<td>-</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>-</td>
<td>4</td>
<td>1.67</td>
<td></td>
</tr>
<tr>
<td>Pa5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>ND</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>Total (%)</td>
<td>0</td>
<td>1 (20)</td>
<td>2 (40)</td>
<td>2 (40)</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Pi1</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>0.48</td>
</tr>
<tr>
<td>Pi2</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>Pi3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Pi4</td>
<td>-</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>-</td>
<td>4</td>
<td>0.23</td>
<td></td>
</tr>
<tr>
<td>Pi5</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>3</td>
<td>0.65</td>
<td></td>
</tr>
<tr>
<td>Total (%)</td>
<td>0</td>
<td>3 (27)</td>
<td>3 (27)</td>
<td>3 (27)</td>
<td>1 (9)</td>
<td>1 (9)</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Na1</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>4</td>
<td>0.60</td>
</tr>
<tr>
<td>Na2</td>
<td>-</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>0.22</td>
</tr>
<tr>
<td>Na3</td>
<td>-</td>
<td>3</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>7</td>
<td>0.36</td>
</tr>
<tr>
<td>Na4</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>3</td>
<td>0.25</td>
</tr>
<tr>
<td>Na5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1 (5)</td>
<td>4 (19)</td>
<td>6 (29)</td>
<td>3 (14)</td>
<td>1 (5)</td>
<td>6 (29)</td>
<td>21</td>
<td></td>
</tr>
</tbody>
</table>

Table 6.8: Pool characteristics of the three land-uses. Due to rounding conventions percentages do not always add up to 100.
Pool spacing could only be calculated at some sites as one stream (Pa5) was not flowing and some sites recorded no pools along the 100 m stream reach (Table 6.8). The 100 m length was divided by the number of pools to give average pool spacing for each site. Average bankfull width for each site was used to calculate the number of channel widths per site and hence the number of pools per channel width. Pool spacing averaged 63 m in the pasture sites (n=2), 48 m in the pine sites (n=4), and 22 m in the native sites (n=22). Pool-to-pool spacing averaged 12 channel widths in the pasture sites, 19 channel widths in the pine sites and 6 channel widths in the native sites. Given that 2 pasture, 1 pine and 1 native site recorded no pools at all, actual average pool spacing and number of channel widths per pool will be higher than the figures quoted here.

Pool volume was estimated from length, width and depth measurements taken in the field in low flow conditions and averaged for each site (Table 6.8). One pasture site had a high mean pool volume of 1.67 m$^3$, otherwise mean pool volume for the remaining sites ranged from 0.08 to 0.65 m$^3$. Mean pool volume for all pasture sites was 1.43 m$^3$, 3.5 – 4 times greater than the average pine and native pool volumes (0.4 m$^3$ and 0.34 m$^3$) respectively.

As was expected, with the absence of woody debris in the pasture streams, pool types were all scour pools, with lateral and plunge pools being the most common (Table 6.8). The substrate was the main pool-forming factor in all the pasture streams. The pine and native sites had a wider variety of pool types, a mixture of both scour and dammed pools. Mid-channel, lateral and plunge pools were most common in the pine sites and backwater, lateral, mid-channel and plunge pools were most common in the native sites.

When comparing pool characteristics in the Moutere Gravel streams with other studies, Quinn et al. (1997) provided some information on both pasture and forested streams; comparisons were only available for forested streams in the remaining studies.

In both the Moutere Gravels and the Hakarimata Ranges (Quinn et al., 1997) woody debris had the least influence on pool formation in the pasture streams. Woody debris had more influence in pool formation in the pine streams compared with native in Quinn et al.'s (1997) sites, while it was the reverse in the Moutere Gravels. Evans et al.'s (1993) older native streams had similar numbers of pools per 100 m to this study. These numbers were low in comparison to those recorded by Carlson et al., (1990) in northeastern Oregon streams (range 8 – 36 pools/100 m).
The frequency with which pools occur along a stream is a fundamental aspect of channel morphology. Pool-to-pool spacing generally averages 5-7 channel widths in free-formed pool-riffle reaches (Leopold et al., 1964). Pool spacings along pool-riffle reaches in Washington and southeast Alaska forested streams varied widely depending on factors such as LWD loading channel types, slope and width, averaging 2-4 channel widths (Montgomery et al., 1995). The lower pool spacings when compared to Leopold et al. (1964) are attributed to the influence of LWD. While pool spacing was lower in the pine and native streams in the Moutere Gravels, overall pool spacing is much higher than that recorded by both Leopold et al. (1964) and Montgomery et al. (1995).

Pool size also varies markedly between studies. Pool size in the pine and native streams of the Moutere Gravels was similar to that of Carlson et al. (1990) in northeastern Oregon streams where pool size ranged from 0.3 to 2.0 m$^3$. Pool volume was very high in the native streams of Evans et al. (1993) ranging from 2.8 – 4.0 m$^3$, much higher than the average pool size recorded in the Moutere Gravel native sites.

Similarly to the Moutere Gravel streams, Bilby and Ward (1989) found scour type pools to be most common in their forested streams, especially plunge pools. Dammed pools such as debris and backwater pools only accounted for a small percentage of pool types. Montgomery et al. (1995) also found scour around LWD was the dominant pool-forming mechanism in forested streams.

6.2 Large woody debris (LWD)

LWD was defined in this study as all wood debris ≥10cm in diameter and was measured in the pine and native sites only. LWD was not present in the pasture sites. There is no world-wide standard definition of LWD. This makes comparison with other studies difficult. Comparisons have been made with other studies using similar definitions to this study. Variations in definitions used by other authors have been noted in the text.
6.2.1. LWD dimensions

The volume of each piece of pine LWD was calculated using the three-dimensional formula of Ellis (1982);

\[ V_{\text{piece}} = (\exp \left[ 1.944157 \ln l + 0.029931 (d) + 0.884711 \ln (D-d)/l - 0.0038675 \right] + 0.078540 (d^2 l))/10,000 \]

where

- \( V_{\text{piece}} \) = volume of piece (m\(^3\))
- \( D \) = large end diameter (cm)
- \( d \) = small end diameter (cm)
- \( l \) = length of piece (m)
- \( \exp \) = exponential
- \( \ln \) = natural logarithm.

The volume of the native LWD was calculated using Newton's formula (Harmon and Sexton, 1996);

\[ V_{\text{piece}} = (L(A_b + 4A_m + A_t)/6)/10,000 \]

where

- \( V_{\text{piece}} \) = volume of piece (m\(^3\))
- \( L \) = length of piece (m)
- \( A_b \) = area at the base of the stem (cm\(^2\))
- \( A_m \) = area at the mid-point of the stem (cm\(^2\))
- \( A_t \) = area at the top of the stem (cm\(^2\)).

The LWD piece volumes for the pine and native sites were converted to m\(^3\) ha\(^{-1}\) using the stream channel floor area, which was calculated using the channel widths along the 100 m section of stream reach.
The LWD volumes in the mature pine sites in the Moutere Gravels are higher than those in a New Zealand-wide survey of 24 mature pine plantation streams which averaged 97 m$^3$ ha$^{-1}$ (Baillie et al., 1999a). The LWD volumes in the Moutere Gravel native streams were similar to those recorded by Evans et al. (1993) in an ancient native forest stream (101 m$^3$ ha$^{-1}$) and were higher than the wood volumes recorded in 120-year-old and 10-year-old native streams 17 and 2.7 m$^3$ ha$^{-1}$ respectively. However Evans et al. (1993) defined LWD as all material with a diameter greater than 2.5 cm so volumes will be comparatively higher than the LWD volumes recorded in the Moutere Gravels.

When compared with similar-sized streams in the temperate forests of North America, the range of LWD volumes in New Zealand’s mature pine plantation streams are similar to those in North America’s Pinus and Picea mixed forests (Baillie et al., 1999a) and are at the lower end of the range in the Fir (Pseudotsuga) and Redwood (Sequoia/Sequoiadendron) forest streams. LWD volumes in New Zealand’s native streams are generally lower than their North American counterparts.

The numbers of LWD pieces in the channel averaged 33 pieces per 100 m in the pine sites compared with 20 pieces per 100 m in the native sites (Table 6.9). Although average diameter was similar between the native and pine sites, stem length was longer on average in the pine sites. This along with the higher number of pieces in the pine sites resulted in a higher volume of LWD (average 127 m$^3$ ha$^{-1}$) compared to the native streams (94 m$^3$ ha$^{-1}$).

The number of LWD pieces per 100 m of channel in the Moutere Gravel pine and native streams were at the lower end of the range recorded by Bilby and Ward (1989) in similar sized streams in western Washington (25-80 stems/100 m). LWD diameter and length were also higher in the western Washington streams of similar width when compared to the Moutere Gravel streams; diameters ranged from 25-45 cm and LWD length ranged from 2-5 m in these streams. However while all LWD was measured, regardless of length, in the Moutere Gravels streams, only LWD pieces $\geq$ 2.0 m in length were measured by Bilby and Ward (1989). The lower number of LWD pieces in the stream channel and the smaller piece size (diameter and length) in the Moutere Gravel streams are the most likely reasons for the lower wood volumes when compared to similar streams in North America.
<table>
<thead>
<tr>
<th>Site No</th>
<th>No of stems/100 m</th>
<th>Mean stem diameter (cm)</th>
<th>Mean stem length (m)</th>
<th>Mean vol/stem (m³) ± 95%CI</th>
<th>Total volume (m³)/100 m</th>
<th>Total volume m³/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pi1</td>
<td>19*</td>
<td>30</td>
<td>2.7</td>
<td>0.21±0.1</td>
<td>3.9</td>
<td>165</td>
</tr>
<tr>
<td>Pi2</td>
<td>20</td>
<td>22</td>
<td>1.6</td>
<td>0.08±0.04</td>
<td>1.5</td>
<td>77</td>
</tr>
<tr>
<td>Pi3</td>
<td>57</td>
<td>19</td>
<td>3.3</td>
<td>0.13±0.04</td>
<td>7.5</td>
<td>200</td>
</tr>
<tr>
<td>Pi4</td>
<td>25</td>
<td>21</td>
<td>2.8</td>
<td>0.09±0.06</td>
<td>3.1</td>
<td>91</td>
</tr>
<tr>
<td>Pi5</td>
<td>42</td>
<td>22</td>
<td>2.1</td>
<td>0.14±0.05</td>
<td>4.1</td>
<td>102</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>33</td>
<td>23</td>
<td>2.5</td>
<td>0.13</td>
<td>4.0</td>
</tr>
<tr>
<td>Na1</td>
<td>19</td>
<td>26</td>
<td>1.8</td>
<td>0.22±0.04</td>
<td>4.1</td>
<td>134</td>
</tr>
<tr>
<td>Na2</td>
<td>23</td>
<td>20</td>
<td>1.6</td>
<td>0.08±0.06</td>
<td>1.8</td>
<td>64</td>
</tr>
<tr>
<td>Na3</td>
<td>16</td>
<td>20</td>
<td>2.3</td>
<td>0.11±0.09</td>
<td>1.8</td>
<td>44</td>
</tr>
<tr>
<td>Na4</td>
<td>8</td>
<td>15</td>
<td>1.5</td>
<td>0.03±0.02</td>
<td>0.2</td>
<td>6</td>
</tr>
<tr>
<td>Na5</td>
<td>32</td>
<td>27</td>
<td>2.2</td>
<td>0.23±0.18</td>
<td>7.4</td>
<td>224</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>20</td>
<td>22</td>
<td>1.9</td>
<td>0.13</td>
<td>3.1</td>
</tr>
</tbody>
</table>

Table 6.9: Large woody debris dimensions. *50% of the stems were native.

### 6.2.2. LWD orientation and position

![Figure 6.7: Orientation of the LWD in the stream channel. 1 = parallel to stream flow, 2 = 90° to stream flow, 3 = 45/225° to stream flow, 4 = 35/315° to stream flow.](image-url)

Figure 6.7: Orientation of the LWD in the stream channel. 1 = parallel to stream flow, 2 = 90° to stream flow, 3 = 45/225° to stream flow, 4 = 35/315° to stream flow.
If the LWD had been randomly orientated in the stream channel 25% of the wood would have been in each of the 4 orientation classes. In the pine sites there was very little wood aligned parallel to stream flow (8%), most of the LWD lay across the channel at 90° to the water flow (40%) (Figure 6.7). In the native sites most of the wood was also at 90° to the water flow (31%) with very little difference in the distribution of wood in the other three orientation categories.

The amount of LWD lying above the water column in the pine streams was significantly higher than the amount in the native streams (two-sample t-test, \( P = 0.07 \)) (Figure 6.8) and significantly more of the native LWD was submerged in the water column compared with the pine LWD (two-sample t-test, \( P = 0.07 \)).

![Figure 6.8: Proportion of LWD volume submerged or above the water table](image)

Both the native and pine sites had a similar percentage of LWD sitting in the stream channel and partly suspended across the stream channel (Table 6.10). More of the native LWD was either buried or partly buried in the stream channel compared with the pine LWD, whereas a greater percentage of the pine LWD was suspended across the stream channel. The pine sites also had higher amounts of LWD anchored by a rootwad.
The predominance of LWD pieces orientated perpendicular to stream flow in the Moutere Gravel pine and native streams is similar to results in other streams, regardless of stream size (Hogan, 1987; Bilby and Ward, 1989; Robinson and Beschta, 1990). The most likely explanation for this is the phototrophic response of trees to lean toward the higher light levels over the stream channel and bank undercutting during high flows. Tree blowdown was a major influence on woody debris distribution along smaller stream reaches in Robinson and Beschta’s (1990) study. Likewise in the Moutere Gravel pine streams, windthrown stems were a major contributor to LWD volumes in the stream channel.

Only a small proportion of the wood was submerged in the Moutere Gravel streams and this result was similar to other studies. In other mature pine sites, the percentage submerged was 10% in Baillie et al.’s (1999a) study and 17% in Collier et al.’s (1998) sites. Eighteen percent and 6% of LWD respectively was submerged in the ancient native and 120-year-old native sites of Evans et al. (1993). Robinson and Beschta (1990) found 20% of the wood was submerged in 1st and 2nd order streams. The amount of wood lying in-stream is important for in-stream processing and providing habitat and cover for stream organisms.

### 6.2.3. LWD influence on channel morphology

While LWD influence on channel width and depth was not obvious, it has some influence on habitat complexity. The type of influence of LWD on channel morphology varied between the pine and the native sites (Table 6.11). LWD in the pine streams mainly influenced sediment storage and few pieces contributed to pool formation, flow deflection, bank armouring, debris collection and forming steps in the channel profile. Nearly 80% of the LWD in the pine streams had no influence on channel morphology.

<table>
<thead>
<tr>
<th>Position in the stream channel (%)</th>
<th>Sitting</th>
<th>Buried/part buried</th>
<th>Suspended</th>
<th>Partly suspended</th>
<th>% anchored by rootwad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pine</td>
<td>34</td>
<td>7</td>
<td>48</td>
<td>11</td>
<td>28</td>
</tr>
<tr>
<td>Native</td>
<td>38</td>
<td>24</td>
<td>26</td>
<td>12</td>
<td>11</td>
</tr>
</tbody>
</table>

Table 6.10: Position of the LWD in the stream channel
LWD in the native streams mainly influenced flow deflection, debris collection and sediment storage. LWD had a greater influence on pool formation in the native streams and like the pine streams LWD had little influence on forming steps in the channel profile and bank armouring. About half the LWD in the native streams had no influence on channel morphology.

| Influence of LWD on channel morphology (% of LWD pieces): |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Storing sediment                 | Pool formation  | Flow deflection | Step            | Bank armour      | Debris collection| None            |
| Pine                            | 15              | 5               | 4               | 4               | 2               | 0               | 78              |
| Native                          | 12              | 9               | 16              | 3               | 3               | 15              | 54              |

Table 6.11: Influence of LWD on the channel morphology. Figures do not add up to 100% because some LWD pieces were influencing more than one aspect of channel morphology.

| Mean stem diameter (cm)       | 35              | 22              | 22              | 24              |
| Mean stem length (m)          | 2.0             | 2.8             | 1.8             | 2.0             |
| Orientation (%):              |                 |                 |                 |                 |
| 1. parallel to stream flow    | 17              | 9               | 26              | 22              |
| 2. 90° to stream flow         | 23              | 43              | 23              | 41              |
| 3. 45/225° to stream flow     | 40              | 21              | 18              | 20              |
| 4. 135/315° to stream flow    | 20              | 27              | 33              | 17              |
| Position (%):                 |                 |                 |                 |                 |
| Sitting                       | 69              | 32              | 43              | 36              |
| Buried/partly buried          | 20              | 2               | 43              | 10              |
| Suspended                     | 0               | 55              | 3               | 41              |
| Partly suspended              | 11              | 11              | 13              | 13              |

Table 6.12: Comparison of characteristics of LWD pieces influencing channel morphology, with pieces that have no influence, in the pine and native streams.
The LWD pieces in the pine and native streams sites were divided into those stems which were influencing channel morphology and those which were not, to determine if there were any LWD spatial configurations peculiar to each group (Table 6.12).

Although there were many more pieces of LWD present in the pine streams compared with the native streams, nearly 80% of the pine LWD pieces were having no influence at all on the channel morphology. The total number of LWD pieces influencing channel morphology in both the pine and the native streams, was very similar.

There was little difference in the mean diameter and length of the LWD pieces in the native streams, regardless of influence on channel morphology. In the pine streams, LWD pieces influencing the channel morphology were about 30% shorter and had larger diameters than the pieces having no influence at all.

In the pine streams, the majority of LWD pieces influencing the channel were orientated in position 3, with similar amounts in the remaining three categories. Most of the pieces were sitting on the channel floor (69%), 20% of the pieces were buried/partly buried in the substrate and 11% were partly suspended across the stream channel (Table 6.12). Thirty-one percent of the pieces were aligned in position 3 (obliquely to the channel) and sitting on the channel floor. This configuration had the most influence on channel morphology in the pine streams.

In the native streams, a third of the LWD pieces influencing channel morphology were aligned at 135/315° to the stream channel (Orientation 4) with slightly lesser amounts in positions 1 and 2 and with the least pieces in position 3. Most of the pieces were either sitting on the channel floor or buried or partly buried in the substrate (41% each), with similar amounts either suspended or partly suspended across the stream channel. There were three main configurations of orientation and position influencing channel morphology; pieces aligned obliquely to channel flow (Orientation 4) and sitting on the channel floor (18%), pieces aligned with the direction of flow (Orientation 1) and sitting on the channel floor (15%), and those pieces positioned across the channel (Orientation 2) and buried in the substrate (15%).

In both the pine and native streams LWD pieces having no influence on channel morphology tended to be positioned at 90° to the stream flow (Orientation 2) and most
pieces were suspended across the stream channel. This was influenced by the presence of windthrown stems in the pine streams, which accounted for 25% of the stems suspended across the stream channel. While native streams also had a high percentage of pieces suspended across the stream channel (42%) they also had a slightly lesser amount sitting on the channel floor (36%). Pieces lying at 90° to flow and suspended across the channel were the most common configuration in both pine and native streams for pieces having no influencing channel morphology (43% and 41% respectively).

<table>
<thead>
<tr>
<th>Pools formed by:</th>
<th>LWD</th>
<th>LWD + substrate</th>
<th>Substrate</th>
<th>Substrate + channel bank</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pine</td>
<td>4 (36%)</td>
<td>2 (18%)</td>
<td>5 (45%)</td>
<td>-</td>
<td>11</td>
</tr>
<tr>
<td>Native</td>
<td>6 (29%)</td>
<td>3 (14%)</td>
<td>8 (38%)</td>
<td>4 (19%)</td>
<td>21</td>
</tr>
</tbody>
</table>

Table 6.13 Influence of LWD on pool formation.

While Table 6.13 shows that the about half the pools in the pine and native streams were formed by LWD or LWD in conjunction with the substrate, the total number of pools in the pine sites is only half that of the native.

The contributing influence of LWD to pool formation in the Moutere Gravels is similar to one other New Zealand study (Evans et al., 1993) but is less than that recorded in the Pacific Northwest streams (Andrus et al., 1988; Carlson et al., 1990; Montgomery and Buffington, 1998). Woody debris contributed to 50% and 33% of pool formation in 2 older New Zealand native streams (Evans et al., 1993). In the Pacific North-west woody debris influenced 50% of pool formation in Carlson et al.'s (1990) study, 70% of pool formation in Andrus et al.'s (1988) site and 73% of pool formation in Montgomery et al.'s (1995) streams. The comparatively lower influence of LWD on pool formation in the Moutere Gravel streams is probably due to the lower LWD volumes and frequency and smaller piece size, compared to similar sized streams in the Pacific Northwest.
There appears to be a lack of comparative information in New Zealand streams on other influences of LWD on channel morphology characteristics such as sediment storage, flow deflection and flow dissipation. Bilby and Ward (1989) found that nearly 40% of woody debris pieces in smaller streams were associated with sediment accumulation. This is a lot higher than that recorded in the Moutere Gravel streams. Carlson et al. (1990) recorded 1% of pieces were creating falls, 17% restricted stream width, 4% diverted flow against the channel bank, and 28% had no effect at all. The percentage of pieces having no influence on channel morphology in the Moutere Gravel streams is higher than this especially in the pine streams. While most of the LWD stems in the pine streams are suspended across the stream channel and are not influencing channel morphology, they have the potential to do so if they remain in the stream after harvest.

6.3 Differences in the Moutere Gravel channel morphology characteristics, possible reasons.

6.3.1. Introduction

In the Moutere Gravels it is possible that land-use differences have been obscured by the inherent variability within the data sets when using between catchment comparisons. If this is the case, then the land-use influence is significantly less than that found in other catchment studies. Both Zimmerman et al. (1967) and Quinn et al. (1997) still found significant differences in widths between pasture and forested sites in spite of the background variation that exists when using between catchment comparisons. Quinn et al. 's (1997) catchment study was similar to this study, comparing 5 catchments each in pasture pine plantation and native forest and found native forest streams to be up to 60% wider than the pasture streams (Quinn et al., 1997). Pine streams were of intermediate width. The results from the Moutere Gravels indicate that either land-use is having no effect at all on channel morphology or that the influence is insufficient to overcome the natural variation in channel morphology characteristics, particularly when comparing between catchments. Other factors then, must be exerting a greater influence on channel morphology.
6.3.2 Hydrology and sedimentation rates

Some of the other factors influencing channel morphology that were discussed in Chapter 2 and illustrated in Figure 2.1 include hydrological regime, sedimentation regime, channel bed material and the channel bank material, all of which are influenced by local climate and geology. Some of the hydrological studies in the small catchments of the Moutere Gravels indicate that sediment yields, particularly in forested catchments, are very low. Sediment yields averaged 5 m\(^3\) km\(^{-2}\) in 4 small native forest streams over a 20 month period and 90% of the sediment yield occurred in one storm event (O’Loughlin et al., 1978). These sediment yields were low in comparison to other sites in the USA and one site in Westland, New Zealand. In a paired basin comparison of sediment yields in pine and pasture sites around New Zealand, sediment yields from pine catchments in the Moutere Gravels and the central North Island were significantly lower compared to other sites around New Zealand, although higher sediment yields were recorded in the Moutere Gravel pasture catchment (Hicks, 1990). This is the opposite result to Smith (1992a) who recorded higher sediment yields in two pasture catchments with 9-year-old Pinus radiata riparian areas when compared with a similar catchment that was entirely in pasture. High sediment yields have also been recorded during high flows in recently harvested pine streams (Graynoth, 1979). O’Loughlin et al., (1978) attributed the low sediment yields in small native catchments in the Moutere Gravels partly to the lack of storms during the study period and partly to the high degree of slope stability which limits sediment supply to the stream. They suggest it would require infrequent high intensity storm events occurring approximately every 10 years to produce flow and sediment in sufficient quantities to affect channel-forming processes in forested streams. Channel forming flows in the pasture steams are likely to be more frequent than this as pasture streams convey higher annual and flood peak flows than equivalent forested streams. Lack of significant differences in channel width, depth, cross-sectional area, sinuosity and ratio of pools, riffles and runs between land-uses indicates that if pasture streams are experiencing more frequent high flow they are of insufficient power, or are carrying insufficient sediment loads to generate major differences in channel morphology dimensions.

It is possible then, that the low sedimentation rates in the Moutere Gravels together with the infrequency of storm events of sufficient size to deliver significant amounts of sediment to the stream and to affect channel morphology, are two factors influencing the lack of land-use effects on stream morphology. Pasture catchments in the Moutere Gravels
have been in some form of pasture for at least 40-50 years, a similar time period to the Hakarimata Ranges (Quinn et al., 1997), yet the channel narrowing processes observed in the Hakarimata Ranges are not evident in these streams. The processes hypothesised by Quinn et al. (1997) and Davies-Colley (1997), of sediment storage and build-up in the channel banks by pasture grasses, may be occurring in the Moutere Gravels, but at a much slower rate due to the low sediment yields and infrequency of flood events of sufficient magnitude to influence channel morphology. A possible explanation for the channel narrowing in pasture streams in the Hakarimata Ranges, is that the yellow-brown earth soils (Kaawa hill soil in association with Waingaro steepland soil) that dominate Quinn et al.’s (1997) study sites, are subject to moderate to severe sheet and soil slip erosion if vegetation is cleared (Hanchet, 1990). These soils may be supplying far greater quantities of sediment to the streams compared to the sedimentation rates associated with the Moutere Gravels.

6.3.3. Channel bank materials

Another factor that may be influencing channel morphology in the Moutere Gravels is the composition of the bank materials. Composition of stream banks can have a strong influence on channel shape and width-to-depth ratios (Leopold et al., 1964; Gordon et al., 1992). Channels in noncohesive sands and silts are usually wider and shallower and have higher width-to-depth ratios than channels in bedrock or more cohesive bank materials. Also aggrading streams tend to be wider and shallower and degrading streams deeper and narrower. Channels with high bank cohesion tend to deepen with increasing discharge whereas channels with noncohesive bank materials tend to widen.

The low width-to-depth ratios in the Moutere Gravel streams indicate that these bank materials are cohesive in their structure. The low levels of bank disturbance in these streams also tend to support this. That the width-to-depth ratios are significantly lower in the pine and native sites could be attributed to the ability of the tree roots and other vegetation to retain and stabilise this type of channel bank material more effectively than grass roots, contributing to the incision of these streams during high flow events.
6.3.4. Grazing effects

There is also the possibility that grazing effects are influencing the channel shape and larger width-to-depth ratios in the pasture streams. While papers give a variety of results on the effects of grazing on channel morphology there are several conclusions that can be drawn from the literature. The degree of grazing impact is related to type of animals (cattle are more destructive than sheep), grazing intensity, and the cohesiveness and moisture content of the bank materials (Hackley, 1989; Williamson et al., 1992; Trimble and Mendel, 1995; Myers and Swanson, 1992; Platts, 1979). Livestock impacts have decreased bank stability, increased the amount of fine material in the stream, and caused channel widening although widening is often confined to animal crossings.

A mix of sheep and cattle grazed most of the pasture sites in the Moutere Gravels (Appendix 1). While animal presence has influenced the type of channel bank disturbance in the pasture streams of the Moutere Gravels, animal tracks have not resulted in significant destabilization of the channel banks or significant losses of channel bank material. However this does not discount the possibility that over time livestock presence in the stream area has influenced the channel shape and reduced the amount of overhanging banks.

Although one of Trimbles’ (1997) grazed sites had width-to-depth ratios within 90% of the forested sites, other pasture sites still show obvious narrowing in channel morphology even when they have been grazed (Clifton, 1989; Quinn et al., 1997; Davies-Colley et al., 1997). Similar to the Moutere Gravels, sheep and cattle were run on the pasture sites in the Hakarimata Ranges (Quinn et al., 1997).

6.3.5. Biological significance

The lack of variation in widths and channel cross-sectional area between land-uses in the Moutere Gravels means there will be little difference in inorganic substrate area available for colonization by stream organisms. This is contrary to Sweeney (1993) who found that the forested streams with their greater widths provided more suitable habitat particularly for aquatic invertebrates. However, the presence of LWD in the pine and native streams and tree roots along the stream banks provides additional surface area for invertebrate colonisation and an alternate food source, as well as increased habitat diversity in the
stream channel (Anderson, 1982; Collier and Halliday, 2000; Sweeney, 1993). The LWD contribution to pool formation in the pine and native streams increases the number and variety of pools types. The presence of LWD in the pine and native streams increases the ability of the stream channel to trap and retain fine particulate matter. LWD also plays an important role in retaining fine particulate matter in the stream ecosystem for in-stream processing (Bilby and Likens, 1980; Bilby and Bisson, 1998).
Chapter 7 – Summary and Conclusions

7.1 Summary

The hypotheses tested in this study were:

• that streams in the pine plantations and native forests are wider and have more variable widths than the streams in pasture
• there is more channel bank disturbance in the pine plantation and native forest streams, compared with pasture streams
• the presence of LWD in the pine plantation and native streams increases the number and variety of pools in the stream channel in comparison with pasture streams.

The channel morphology characteristics in the Moutere Gravels indicate that these streams are not showing any significant response to land-use effects. This is in contrast to the results from other studies and did not support the first hypothesis.

In particular, the lack of significant difference in bankfull and channel widths and cross-sectional area between the three land-uses in the Moutere Gravels differs from the greater widths and larger cross-sectional areas found by other authors in forested streams when compared with pasture streams. The lower width-to-depth ratios in the pine and native streams in comparison to the pasture sites is contrary to other studies which have found the opposite; pasture streams are usually narrower, more trench shaped and have lower width-to-depth ratios. One of the contributing factors to the greater widths and increased variability of widths in forested streams found by other authors was the influence of LWD in the stream channel. While LWD was present in both the pine and native streams in the Moutere Gravels it did not have any significant effect on both bankfull and channel width and width variability. Instead width variability was greater in the pasture streams and this difference was significant between the pine and pasture streams.

The channel narrowing processes observed in the pasture streams of the Hakarimata Ranges in the North Island either aren’t occurring in the Moutere Gravels or are occurring at a much slower rate. It is suggested that other factors are exerting a greater influence on stream channel morphology in the Moutere Gravels. It is possible that the relatively stable hillslopes and low sedimentation rates in the Moutere Gravels are not supplying sufficient
quantities of sediment to these streams for any significant narrowing of pasture streams to have occurred since the forest was cleared. This, combined with the probably low frequency of floods of sufficient size to affect the channel morphology of the streams may offer a partial explanation for the similar channel morphology between the three land-uses.

The second hypothesis that channel bank disturbance would be higher in the pine and native streams was not proven in this study either. The amount of channel bank disturbance was similar across all three land-uses and was low (3-5% of the channel bank length). The amount of bank material lost in the pine sites was twice that in the pasture and native streams but was influenced by the high amount of bank material lost from one site. The shape of the channel profiles, and lack of significant channel bank disturbance, indicates that the channel bank materials in these streams are reasonably cohesive and quite stable.

The only indication that land-use is affecting the channel morphology of these streams is in the width-to-depth ratios and the amount of bank undercuts. The narrower channel profiles in the pine and native streams and the higher number of stable bank undercuts, suggests that the roots of trees are more effectively retaining the streambank material than the pasture grasses. This is in contrast to other studies, which have found grasses to be more effective at retaining streambank material. It also appears that channel banks are more stable in mature 2nd rotation pine plantations, than in stream channels in young 1st rotation pines which were actively eroding along much of their channel banks in the Hakarimata Ranges.

While LWD has not had the effect of increasing width and variability in the forested streams as has occurred in other studies, it has influenced channel morphology in other ways. In agreement with the third hypothesis, the presence of LWD in the pine and native streams increased the number and variety of pool types. Scour pools were the only types of pool found in the pasture streams. Although scour pools still dominated the pine and native streams there was a mix of scour and debris pools in the stream channels. LWD also influenced the stream channels in other way, mainly contributing to sediment storage with minor influence on flow deflection and forming step in the channel profile. The LWD most influential on channel morphology lay obliquely to the stream channel and was either lying on the channel floor or buried or partly buried in the substrate.
The number of pools present in the Moutere Gravel streams was low compared with similar temperate forests in the Pacific Northwest, and pool spacing was much greater. This is probably a reflection of the lower woody debris volumes present in these streams in comparison to the Pacific Northwest. There was also a high percentage of wood (especially in the pine streams) suspended across the stream channel and not contributing at all to the channel morphology. This wood could provide a potential future source of wood to the stream channel. The presence of LWD in the streams also increases the surface area available for stream biota, especially aquatic invertebrates.

The greater number of pools and pool variety and the higher amount of undercut banks in the pine and native streams indicated a higher quality and greater diversity of stream habitat in these streams. Whether this translates into differences in the abundance and diversity of stream biota between the pine and native and pasture streams is unknown. There is a lack of information on aquatic fauna in small pasture streams in the Moutere Gravels.

7.2 Conclusions

1. The trend of wider streams in forests and narrower streams in pastureland in small catchment areas does not necessarily apply to all areas of New Zealand. The results in the Moutere Gravels are an example of this. Factors other than land-use may have a stronger influence on channel morphology.

2. Conversion of pastureland to pine plantations may not necessarily result in the channel widening processes observed in the Hakarimata Ranges.

3. Landowners and managers considering conversion of land from pasture to pine plantations need to assess local geological, climatic and hydrological conditions to determine whether channel widening is likely to occur in their area. Field assessments of widths in forested and pasture streams would assist with this assessment.

4. The trend of wider streams under forest and narrower streams under pasture has been observed in New Zealand and in a number of other studies around the world indicating that the situation in the Moutere Gravels is likely to be the exception rather than the rule.
5. Although LWD volumes in the Moutere Gravel forested streams may be lower than in the temperate forests of the Pacific Northwest; LWD still has an important morphological role to play in these small streams. It has made a significant contribution to increasing the number and type pools in the stream channels.
Chapter 8 – Recommendations for Further Work

There is very little information on sediment regimes in the Moutere Gravels. Most of the research in the Moutere Gravels has focused on the hydrological implications of converting pastureland to pine plantations. Information on hillslope processes, erosion rates and sediment budgets in the Moutere Gravels may provide some explanation for the different channel morphology results in this area.

There are other gravel deposits in New Zealand similar to the Moutere Gravels which have plantation forests on them. Examples include the Old Man Gravels in Westland, the Kowhai Gravels in Canterbury and the Maniototo Conglomerate within the Hawkdin Group in Southland/Otago. A similar channel morphology study to this one would show whether these channel morphology characteristics are peculiar to the Moutere Gravels or common to other similar gravel deposits.

Biological surveys in these small Moutere Gravel streams would assist in determining whether some of the differences in stream habitat found in this study are affecting the stream ecology. In particular there is a lack of biological information on small pasture streams.

New Zealand studies to date on channel morphology and effects of land-use on channel morphology in small streams have all focused on one small geographical area of New Zealand, the Waikato Basin of the North Island. The different results from the Moutere Gravels in Nelson, highlights the variability that exists within New Zealand’s range of geological and climatic conditions and the risks inherent in extrapolating results to other areas.

Not only do we need to extend this area of research in small New Zealand streams into other geographical areas, this study also shows that we are a long way from understanding the complex geological and hydrological processes that occur at the catchment level, how land-use practices influence these processes, and the impact this has on channel morphology and stream ecosystems.
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References:


* Neither of these agreements have any authorship or publishing details.
Appendix 1: Background information on the study sites.

Pasture sites

Pa1 (Kikiwa)
This farm was initially developed in the 1930’s depression and some areas had started reverting back into fern and scrub although the catchment was mainly in native pasture (mainly rye grass and clover). This catchment has been in English pasture (mainly rye grass and white clover) sown after discing for the last 15 years. Sheep and cattle are farmed on the land (pers. comm. October 2000. Mr Rudolf Aberlene, landowner, ph 03 521 1803 (since deceased) and Wayne Stafford ph 03 5211099).
Mr Aberlene commented that by discing and developing the land with a good grass cover, the hillslopes were stable, grass absorbed the run-off and the creek didn’t flood as frequently.

Pa2 (Tadmore)
The head of this catchment was in scrub and gorse; it was planted in Pinus radiata in 1995. The rest of the catchment has been in pasture for about 50-60 years (as at November 1999). There are some scrub patches on the hillsides. Sheep, with some cattle are farmed on the property (pers. comm. October 2000. Mr Brent Hodgkinson, landowner, ph 03 522 4381).

Pa3 (Eban)
This catchment was originally in native forest. In the late 1800’s it was hand-sown with native grass (danthonia and browntop), and burnt every 4-5 years to rejuvenate the pasture. In the 1960’s the catchment was developed into English pasture, predominantly rye grass and white clover, with some coxfoot. Sheep and cattle are run on the upper catchment area where the study took place (pers. comm. October 2000. Mr Fred Silcock, landowner, ph. 03 543 3891).
Mr Silcock commented that since the property was reworked into English pasture, it has softened the ground, absorbing moisture and reducing run-off.
Pa4 (Wakefield)
This catchment has been in pasture with patches of gorse for at least the last 40 years. There is a mixture of sheep and cattle on the property (pers. comm. October 2000. Mr Rex Waddington, landowner, ph 03 541 8351).

Pa5 (88Valley)
History prior to 1969 is unknown. In 1969 the catchment was half in gorse, half in pasture. All the catchment has been in pasture since 1982 (as at November 2000). Deer have been farmed for the last 10 years in the study area; sheep and cattle are run at the top of the catchment (pers. comm. October 2000. Mr Colin Ladley, landowner, ph 03 541 8265).

Pine plantation sites

Pi1 (Ben Gully)
Cpt 216, Golden Downs
The lower end of this catchment was converted from reverting farmland into Pinus radiata in 1968 and was 31 years old at the time of measurement in November 1999. Residual native wood was present in the stream. In 1981, part of the upper catchment was planted in Eucalyptus nitens, Acacia melanoxylon, Douglas Fir (Pseudotsuga menziesii) and Pinus sylvestra. The rest of the upper catchment remains in native forest (pers comm, Mark Smith, Weyerhaeuser, Nelson).

Riparian vegetation:
Trees - Pinus radiata,
Shrubs - marble leaf (Carpodetus serratus), fuchsia (Fuchsia excorticata), wineberry (Aristotelia serrata), Coprosma ‘taylorae’, pate (Schefflera digitata),
Ferns – bracken (Pteridium esculentum), Cyathea colensoi, Blechnum discolor, B. fluitatile, B. novae-zelandiae, Pnuematopteris pennigera,
Sedges – Carex sp.,
Weeds - native orchid, blackberry, buttercup (Ranunculus repens), foxglove, wall lettuce (Mycelis muralis), self-heal (Prunella vulgaris),
Other – native orchid, Viola lyallii.
Pi2 (Stade Road)
Golden Downs
The 1st rotation was in Pinus radiata; the establishment date is unknown. Most of the catchments 2nd rotation of Pinus radiata was established in 1976 and was 23 years of age at the time of measurement in November 1999. Some smaller areas were established in Pinus radiata in 1978 (3.7ha) and 1979 (8.9ha). (pers comm, Mark Smith Weyerhaeuser, Nelson). It is estimated that this catchment has been in pine plantation for 55 years.

Riparian vegetation:
Trees - Pinus radiata,
Shrubs – wineberry (Aristotelia serrata), fuchsia (Fuchsia excorticata), pate (Schefflera digitata), Coprosma grandifolia, C. robusta, whitey wood (Melicytus ramiflorus)
Ferns – bracken (Pteridium esculentum), hen and chicken fern (Asplenium bulbiferum), Hypolepis ambigu,
Sedges – Carex sp.,
Weeds – blackberry, gorse, foxglove, Haloragis erecta, barberry (Berberis glaucocarpa).

Pi3 (Buster Creek)
Golden Downs
The 1st rotation details on this catchment are unknown. In the early 1930’s the catchment was planted in a 2nd rotation of Pinus radiata, Pinus ponderosa, Pinus contorta and Chamaecyparis lawsoniana. A 3rd rotation crop of Pinus radiata was planted in 1972 and was 27 years old at time of measurement, November 1999 (pers comm, Mark Smith Weyerhaeuser, Nelson). This catchment has been in plantation forest for at least 60 years.

Riparian vegetation:
Trees – Pinus radiata, Douglas fir (wildings), willow (Salix sp.),
Shrubs – tutu, wineberry (Aristotelia serrata), Coprosma robusta, fuchsia (Fuchsia excorticata),
Ferns – crown fern, Blechnum novae-zelandiae, Pneumatopteris pennigera,
Sedges – hook grass (Unicina sp.),
Weeds – blackberry.
Pi4 (Thorn Road)
This catchment was planted in about 1944, and the previous land-use is unknown. The first rotation was harvested at approximately 28 years of age in 1972 using both hauler and ground-based systems. It naturally regenerated in *Pinus radiata* in 1973. However, natural regeneration was unsuccessful at the top of the catchment so it was replanted in *Pinus radiata* in 1975 (pers. comm. October, 2000. Mr Rodney Ryder, Ryder Planning Resources, ph. 025 201 3178).

As at November 1999 the current crop of trees was 24 – 26 years of age and this catchment has been in pine plantation for 55 years.

Riparian vegetation:
Trees – *Pinus radiata*,
Shrubs – wineberry (*Aristotelia serrata*), tutu (*Coriaria arborea*), marble leaf (*Carpodetus serratus*), pate (*Schefflera digitata*), *Pemantia corymbosa*,
Ferns – bracken (*Pteridium esculentum*), hen and chicken fern (*Asplenium bulbiferum*), *Paesia scaberula*, *Histiopteris incisa*, *Pneumatopteris pennigera*,
Weeds – foxglove.

Pi5 (Pigeon Valley)
This catchment was originally in reverted farmland and was planted in *Pinus radiata* in about 1953. The lower and eastern side of the catchment was harvested in 1979 using skidders on the flatter areas and a highlead hauler on the steeper slopes. The area naturally regenerated in *Pinus radiata* in 1980 and was thinned approximately 5 years later. A small area of the catchment suffered some wind damage and was logged using ground-based systems in 1982; it naturally regenerated in *Pinus radiata* in 1983 and was thinned in 1988.


As at November 2000, most of the lower catchment was in trees 19 years of age. The upper part of the catchment was 3-year-old pine. This site has been in pine plantation for 46 years.

Riparian vegetation:
Trees – *Pinus radiata*,

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Weeds – blackberry, himalayan honeysuckle, old man’s beard.

**Native forest sites**

Wall (1985) developed a Conservation Value Index (CVI) to rate each native forest remnant on the Moutere Gravels. Seven major criteria were used for conservation evaluation: size, representativeness, diversity of plant communities, distribution limits of plant species, rarity of plant communities, naturalness within landscape and modification. Within each criteria a score was given, and the sum of the scores expressed as a percentage of the maximum score. Most sites have a very low CVI, few exceed 50%.

**Na1 (Melville Gully, Big Bush)**

Melville Gully in Big Bush rates extremely highly (94%) in the Conservation Value Index. Most of the catchment is in forest dominated by hard beech (other associated species are silver beech, red beech, black beech and rimu), in some areas red beech dominates (Wall, G. 1985).

Riparian vegetation:

**Trees** – red beech (*Nothofagus fusca*),

**Shrubs** – pepper tree (*Pseudowintera colorata*), *Coprosma rhamnoides*, *C. ‘taylorae’*, marble leaf (*Carpodetus serratus*), juvenile lancewood (*Pseudopanax crassifolius*), *Neomyrtus pedunculata*,

**Ferns** – crown fern, punga (*Cyathea colensoi*), *Blechnum discolor*,

**Grass** – *Microlena sp.*

**Na2 (Donald Creek)**

Also located in Big Bush, Donald Creek has a CVI of 94%. There is mixed beech forest throughout the catchment with an area of red beech forest with associated silver and black beech and some rimu along the valley floor.
Riparian vegetation:

Trees – red beech (*Nothofagus fusca*), silver beech (*N. menziesii*),

Shrubs – Lancewood (*Pseudopanax crassifolius*), *Griselinia littoralis*, marble leaf (*Carpodetus serratus*), *Coprosma foetidissima*, *C. ‘taylorae’*, *C. propinqua* x *C. robusta*,

Fuchsias (*Fuchsia excorticata*),

Ferns – crown fern, *Blechnum sp.*, *B. fluviatile*,

Sedges – hook grass and other sedges

Weeds – buttercup (*Ranunculus sp.*)

**Na3 (Scaiffe Creek)**

Scaiffe Creek rates 38% in the CVI; it has been modified by some logging as well as burning around the margins of the catchment. Scaiffe Creek is in beech forest with hard beech dominating the forest through out with red beech along the valley floor.

Riparian vegetation:

Trees – silver beech (*Nothofagus menziesii*), black beech (*N. solandri var solandri*), red beech (*N. fusca*), kahikatea (*Dacrycarpus dacrydiodes*),

Shrubs – wineberry (*Aristotelia serrata*), *Coprosma grandifolia*, *C. rotundifolia*, *Griselinia littoralis*, marble leaf (*Carpodetus serratus*), pate (*Schefflera digitata*), pigeonwood (*Hedycarya arborea*),

Ferns – *Asplenium bulbiferum*, *Blechnum chambersii*, *B. colensoi*, *B. discolor*, *Pneumatopteris pennigera*, *punga* (*Cythathea dealbata*), *Leptopteris hymenophylloides*,

Sedges – various species.

**Na4 (Spooners Reserve)**

Spooners reserve rated 50% in the CVI; it is structurally intact with beech forest dominated by hard beech.

Riparian vegetation:

Trees – silver beech (*Nothofagus menziesii*), black beech (*Nothofagus solandri var solandri*),

Shrubs – *Coprosma grandifolia*, fuchsia (*Fuchsia excorticata*), *punga* sp., *Oleria rani*,

Ferns – hen and chicken fern (*Asplenium bulbiferum*), crown fern, houndstooth, *Blechnum chambersii*, *B. fluviatile*, *Pneumatopteris pennigera*,

Other – supplejack (*Ripogonum scandens*).
Na5 (Long Gully)

Long Gully rated 31% in the CVI. The forest has been subjected to light logging and some burning around the margins. The catchment is in red beech forest; hard beech is dominant on the ridges.

Riparian vegetation:

Trees – red beech (*Nothofagus fusca*), black beech (*N. solandri var solandri*), silver beech (*Nothofagus menziesii*), juvenile lancewood (*Pseudopanax crassifolius*),

Shrubs – fuchsia (*Fuchsia excorticata*), punga sp., pepper tree (*Pseudowintera colorata*), wineberry (*Aristotelia serrata*), *Griselinia littoralis*, pate (*Schefflera digitata*), *Coprosma grandifolia*, C. ‘taylorae’,

Ferns – *Blechnum fluviatile*. 
Appendix 2: Pool classification.

Pool classification has been based on Hawkins et al. (1993) who referred to both Bisson et al. (1982) and Habitat Inventory Committee Western Division, American Fisheries Society (1985) in developing these classifications. All three references have been used to provide the definitions and diagrams below. Only those pool types found in the study are included.

A: Pools formed by scour:

Eddy – A circular current of water, diverging from and initially flowing contrary to the main current. They are usually located along the banks usually formed by an obstruction or on the inside of river bends, fine substrates. Deepest point is in the middle of the pool.

Midchannel pool – located in the main channel, deepest point in the middle of the pool (Hawkins et al., 1993).
Lateral – formed by the scouring action of the flow as it is directed laterally or obliquely to one side of the stream by partial channel obstruction i.e. LWD, rootwad or bedrock. Longitudinal profile - deepest point at either the upper end or middle of the pool; cross-section profile – deepest point on one side of the pool. Undercut banks are often associated with this pool type (Bisson et al., 1982; Habitat Inventory Committee Western Division, American Fisheries Society, 1985).

Plunge – these pools are formed where the stream passes over a complete or nearly complete channel obstruction, drops vertically into the streambed below, scouring out a depression often large and deep. Flow radiates out from the point of water entry and flow patterns are complex, deepest point at the upper end of the pool. The substrate particle size is highly variable (Bisson et al., 1982; Habitat Inventory Committee Western Division, American Fisheries Society, 1985).
B: Pools formed by damming:

Debris – Water is impounded upstream from a complete or near complete channel blockage caused by debris in the stream. Depending on the size of the blockage, these pools can be quite large, water velocity is characteristically low and substrates tend toward smaller gravels and sand (Bisson et al., 1982; Habitat Inventory Committee Western Division, American Fisheries Society, 1985).

Backwater – located along channel margins and causing eddies behind large downstream obstructions such as rootwads and boulders or from back-flooding upstream from an obstructional blockage (Bisson et al. 1982; Habitat Inventory Committee Western Division, American Fisheries Society, 1985). These pools are often shallow, current velocities are low and tend to be dominated by fine substrates.
Appendix 3: Mathematical Explanation of the Stream Depth Measurements (Platts et al., 1983).

Given a channel cross-section underneath the transect, with water depths measured at 25%, 50% and 75% of the bankfull width, what is the average depth? The three depth measurements define four parts to the cross-section (see below).

Depth at 25, 50 and 75% of bankfull width

\[ D_1, D_2, D_3, D_4, D_5 \]

Bankfull width

4 cross-sections

Mean depth \( D \) = \( \frac{(D_1 + D_2)}{2} + \frac{(D_2 + D_3)}{2} + \frac{(D_3 + D_4)}{2} + \frac{(D_4 + D_5)}{2} \)

\[ = \frac{D_1 + 2D_2 + 2D_3 + 2D_4 + D_5}{8} \]

but \( D_1 \) and \( D_5 = 0 \); therefore

\[ D = \frac{2D_2 + 2D_3 + 2D_4}{8} \]

\[ = \frac{D_2 + D_3 + D_4}{4} \]