Riparian management classification for Canterbury streams

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John M. Quinn

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National Institute of Water & Atmospheric Research Ltd
Gate 10, Silverdale Road, Hamilton
P O Box 11115, Hamilton, New Zealand
Phone +64-7-856 7026, Fax +64-7-856 0151
www.niwa.co.nz

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Reviewed by: *Approved for release by:*

Stephanie Parkyn Kevin Collier

Formatting checked

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Executive Summary

I. Riparian zone management provides opportunities to mitigate damage to the ecological health and human uses of streams, rivers and downstream aquatic ecosystems caused by intensive production land uses. However, the functions of riparian zones vary spatially within catchments, so their management requires a framework that matches actions with the functions occurring at a site, and with river management goals. This study aimed to develop ways of classifying riparian areas within relatively large catchments according to their functional roles in improving stream habitat, controlling contaminant inputs and enhancing aesthetics, biodiversity, and recreation. When linked with information about river goals, such classifications should be useful tools for planning and prioritising riparian management actions.

II. Rapid assessments were carried out over usually 100 m long reaches at 313 sites to evaluate site characteristics (physical, vegetation and management practices) and use a protocol developed as part of the study to rate the activity of 12 riparian functions (i.e., streambank stabilisation; filtering contaminants in overland flow; nutrient uptake from shallow groundwater; denitrification of shallow groundwater; shade for instream temperature and nuisance plant control; input of wood and leaf litter to the stream; fish habitat enhancement; control of downstream flooding; and enhancing recreation and stream aesthetics). Both current and potential (under best practicable riparian management) ratings were made. These sites covered a representative range of the areas of agriculture and forestry in Canterbury, during late spring 2000 and 2002 and early summer of 2001 and 2003. Sites ranged from small, 1st order, headwater streams to large, 7th order, braided rivers. Additional catchment and site data were obtained from the River Environment Classification (REC) and Land Environments of New Zealand (LENZ) databases.

III. The survey found a low level of stream fencing (only 12% fenced on both sides) and generally low ratings for most riparian functions. Grass was the most common dominant riparian vegetation type (48% of sites), followed by willows (26%), low shrubs (9%), and native trees (8%).

IV. The current activity of twelve riparian functions varied widely between the sites but was typically rated as very low for input of woody debris, enhancement of fish habitat and recreation, and denitrification of groundwater, and “low-moderate” for bank stabilisation, control of downstream flooding, leaf litter input, shade control of stream temperature and instream plant growth, and aesthetics. Applying best practicable riparian management was judged to be capable of improving most riparian functions substantially. The biggest improvements were predicted for the shading functions and the least for denitrification.

V. The sites were classified according to both their *current* and *potential* (RMC-P) riparian functions (e.g., streambank stabilisation, shading for temperature control, etc.) into current and potential Riparian Management Classes (RMC-C and RMC-P). Discriminant function models were developed that can be used to classify new sites (and hence infer their likely riparian function ratings), based on either GIS information alone or GIS and local information. These models provide a means for non-experts to rate riparian functions and to map the predicted riparian classes throughout catchments. Maps of predicted potential classifications to a coarse (3 class) and finer (12 class) level are provided as GIS layers on a CD. Maps showing the results at a scale that is readable in report form are presented as an example.

VI. Models were also developed to predict the activity ratings as assessed following a detailed protocol of the 12 individual riparian functions (e.g., bank stabilisation or provision of shade to control instream temperature) assessed in the field surveys. These will be useful when management is focused on particular instream issues related to a reduced number of riparian functions. For example, if high water temperatures in summer were identified as the critical factor limiting stream health, then the model that predicts where riparian management has the potential to provide shade to control temperature would be of particular relevance. GIS layers for the function “shade for stream temperature control” are provided on CD, and a map showing the results at a scale that is readable in report form are presented as an example.

VII. The statistical approach to site classification described above indicated that the key factors influencing *potential* riparian functions that could enhance stream habitat and water quality in the Canterbury area are related to channel width, adjacent land slope and whether the stream is ephemeral or perennial. For example, these factors control the ability of riparian vegetation to influence instream habitat (width, permanence of flow), control downstream flooding (adjacent land slope), and the importance of overland flow in transport of contaminants to the stream (adjacent land slope). This provided the basis for development of a geomorphic riparian management classification (RMC-G). Sites were classified into 12 classes based on combinations of valley-form (plain, U- and V-shaped) and 4 channel width classes in relation to the ability of different vegetation types to shade the channel. Models were also developed to predict the geomorphic classification of sites from GIS data.

VIII. A flow-chart is provided showing how the Riparian Management Classification (RMC) and microhabitat-based native plant recommendations can contribute to improved river management planning when combined with information on stream and land management goals at various spatial scales.

1. Introduction

Riparian zones are the three-dimensional zones of direct interaction between terrestrial and aquatic ecosystems (Gregory et al. 1991). A variety of biophysical functions of riparian areas can be managed to enhance stream habitat and water quality, including: stream bank stabilisation, filtering overland flow, shading for stream temperature and nuisance plant control, woody debris inputs, spawning habitat and cover for some fish species, and denitrification and nutrient uptake from shallow groundwater (e.g., Collier et al. 1995). Riparian areas are also heavily used for recreation, and play an important role in stream aesthetics. Their location, at the land-water interface, and the biophysical processes that occur within riparian zones, enable the management of the relatively small amount of land in riparian areas to have a disproportionately large role in controlling the effects of broader catchment activities on streams and downstream aquatic ecosystems (Collier et al. 1995, MFE 2001).

Riparian management is recognised as an important aspect of water management in the policy statements of all New Zealand's regional councils (Boothroyd and Langer, 1999). Most proposed regional plans include a range of methods for promoting riparian management, including funding part of the costs of riparian management activities undertaken by farmers. For example, Environment Waikato has recently funded a $10 M Clean Streams Fund that focuses on riparian management to improve stream health (http://www.ew.govt.nz/ourenvironment/water/cleanstreams.htm). However, the biophysical roles and human uses of riparian margins change from headwater streams to lowland floodplain rivers, and planners need a framework that accounts for these variations so that management actions at a site are matched with riparian functions.

Quinn (1999) developed a riparian zone management classification (RMC) for the Piako and Waihou River catchments in the Waikato region that provides such a framework. This recognised 10 riparian classes based on the physical characteristics of 30 sites. The relative importance of the main riparian functions in each area was assessed in each of these 10 classification groups, and this ranking was used to recommend different riparian management options for each class. This classification provided the basis for an analysis of the costs and benefits of applying "first step" and "best practicable" riparian management options to the pasture streams in the Piako Catchment (Brown and Mackay 2000, Quinn et al. 2001). This approach was developed further in a preliminary RMC of three areas of Canterbury: Banks Peninsula; Canterbury plains catchments near Christchurch (Cam, Eyre, Halswell and Cust); and the foothill catchments of the Ashley, Hurunui and Waipara (Quinn and Suren, 2001; Quinn et al. 2001).

In this report we develop riparian management classification further by: extending the RMC approaches used in the pilot study to cover most of the area of Canterbury that is used for pastoral agriculture and forestry.

2. Methods

2.1 Survey methods

Three hundred and thirteen sites that cover the range of riparian conditions present within areas Canterbury used for pastoral/forestry land use were surveyed to provide information for developing a Riparian Management Classification (RMC, see APPENDIX 1 for site location details). Sites that could be readily accessed from roads were selected to give a good coverage of the different areas within the region. Site characteristics that affect key riparian functions and human uses were assessed over a reach at each site (typically 100 m long), photographs were taken and representative site cross-sections were sketched. Data were also collected on the stream/riparian physical attributes at three different spatial scales: catchment scale, valley scale, and reach scale (Table 1). Some of this information (e.g., valley slope, stream channel slope, % banks undercut, local land use, streambed substrate material and water width) was assessed in the field. Other data were obtained from the River Environment Classification (REC) database that NIWA has developed (Snelder et al. 1999) (e.g., catchment area, stream source of flow, geology, dominant catchment landuse, channel slope, Strahler stream order, and stream morphology class) or the Environmental Domains database (land-slope, particle size class, drainage class) and converted into numeric indices for use in statistical analyses (Table 1).

On-site assessments were made of the current functions of riparian vegetation in terms of streambank stability, denitrification of groundwater inflows, shading of the channels for temperature and instream plant control, wood and leaf litter input, enhancement of fish spawning and general fish habitat, downstream flood control, recreational use and aesthetics. The potential roles of these functions, if best practicable riparian management was applied, were also assessed. Best practicable riparian management was assumed to involve fencing out stock from the stream/riparian area and managing the area for the development of long grasses, shrubs and/or trees within this protected area as appropriate for the location (e.g., in the MacKenzie Basin we expected tussock grasses and matagouri to dominate protected riparian areas rather than large trees). These current and potential riparian functions and human uses were ranked as: 0 (absent), 1 (very low activity), 2 (low-moderate activity), 3 (moderate activity), 4 (high activity) or 5 (very high activity).

These riparian function assessments formed the basis for the riparian management classification (RMC) of sites into classes with similarities in current and potential riparian functions, and hence riparian management options. The site biophysical data provide the basis for predictive modelling of RMC classes within catchments and the entire Canterbury Region. Whether or not the function/use is important for the stream depends on the goals of watershed management, and is a separate issue to whether the function/use is active at the site.

Table 1: Details of physical attributes that describe the stream at the catchment scale, valley segment scale, and stream reach scale. # = see Snelder et al. (1999).

Spatial scale	Physical attribute	Explanatory notes
Catchment	Source of flow (SOF) index	Lake and lowland = 1; Hill = 2; Mountain and glacial Mountain = 3
	Dominant catchment baserock geology index	Soft sedimentary =1; Alluvium & sand = 2; Miscellaneous = 3; Volcanic basic = 4; Hard sedimentary = 5
	Catchment spatial average slope (°)	
	Accumulated flow (m^3s^{-1})	Calculated upstream annual rainfall - evaporation
	Catchment area (km^2)	
	Catchment land cover index	Bare = 1; Urban = 2; Pasture = 3; Tussock = 4; Exotic forest = 5; Scrub = 6; Indigenous forest = 7
Valley Segment	Riparian land use	Cattle, Conservation, Crop, Dairy, Forestry, Horticulture, Sheep, Urban
	Channel shape category	1 = Channelised; 2 = Straight; 3 = Meandering; 4 = Sinuous
	Valley bottom width category	1 = < 20 m; 2 = 20 – 50 m; 3 = 50 – 200 m; 4 = 200 – 100 m; 5 = >1000 m; 6 = "plains"
	REC channel slope (cm/m)	Inter-node difference in elevation/reach length
	REC segment mean air temperature (°C)	Predicted local mean air temperature
	REC segment annual rainfall (mm)	Predicted local mean rainfall temperature
	REC average land slope of segment's local catchment segment (m/m)	Derived from REC digital elevation model for the land draining directly to the local stream segment
	REC reach elevation (m)	Above sea level
	Domain land drainage class	1 = Very poor; 2 = Poor; 3 = Impeded; 4 = Moderate; 5 = Good
	Domain soil age class	1 = Recent, 2 = Older
	Domain acid soluble P class	1 = Very low, 2 = Low, 3 = Moderate, 4 = High, 5 = Very high
	Domain exchangeable Calcium class	1 = Low, 2 = Moderate, 3 = High, 4 = Very high
	Domain induration (hardening)	1 = Non-indurated; 2 = Very weakly; 3 = Weakly; 4 = Strongly; 5 = Very strongly indurated
Reach	Water width	Estimate of the average wetted stream width at low flow
	Non-vegetated width	Estimate of channel width lacking terrestrial vegetation
	Bankfull width	Total width at bankfull discharge
	Wet/dry index	0 = Dry channel, 1 = Water present in channel
	Channel slope index	1 = < 0.2°; 2 = 0.2° – 0.5°; 3 = 0.5° – 1.0°; 4 = 1.0° – 2.0°; 5 = 2.0- 4.0°; 6 = > 4 °
	Local land-slope index	1 = <2°; 2 = 2.0° – 5.0°; 3 = 5.0° – 15.0°; 4 = 15.0° – 25.0°; 5 = 25 – 35°; 6 = >35°
	Local land slope length index	1 = plains and ≤10 m; 2 = >10 – 50 m; 3 = >50 – 200 m; 4 = >500 m
	Substrate composition	Bedrock, boulder, cobble, gravel, sand, silt, clay
	Shade ratio	Bank + vegetation height/ channel width

Spatial scale	Physical attribute	Explanatory notes
	Bank height (m)	Estimate of average bank height
	Periphyton categories:	0 = None; 1 = sSippery; 2 = Obvious; 3 = Abundant; 4 = Excessive (> 80% FGA)
	Macrophyte species and % cover	Species present, % total bed covers. Bryophyte cover noted separately.
	Woody debris index	0 = Absent; 1 = Sparse; 2 = Common; 3 = Abundant
	Stock access index	0 = No access; 1 = One bank; 2 = Access to both banks
	Stock bank damage index	0 = None; 1 = Minor; 2 = Moderate; 3 = Extensive
	Streambank stability	Assessment of the % of banks stable undercut or slumped
	Riparian veg. & bank cover	List of dominant riparian vegetation
	Dominant riparian vegetation index	0 = Bare ground, 1 = Grass, 2 = Wetland, 3 = Low shrub, 4 = High shrub, 5 = Deciduous, 6 = Willows, 7 = Coniferous, 8 = Eucalyptus; 9 = Native
	Riparian wetland index	0 = absent, 1 = present
	Stock fencing stream index	None = 0; One side fenced = 1; Both sides fenced = 2
	Stock damage classes	0 = None; 1 = Minor; 2 = Moderate; 3 = Extensive
	Riparian fencing	% of each bank fenced and bank to fence distance
	Fencing type index	0 = None; 1 = Electric 1 wire; 2 = Electric 2 wire; 3 = Post & batten, or 5-7 Wire electric, or Deer fence

2.2 Riparian function assessment protocols

This section summarises the rationale for assessing each riparian function. Our assessments did not include the riparian zone functions of enhancing terrestrial biodiversity, providing wildlife corridors, and habitat and landscape connectivity, which were beyond the scope of the available resources.

2.2.1 Bank stabilisation

The role of riparian vegetation in stabilising banks depends on the ability of vegetation to: (1) reinforce bank strength through root network strengthening (Rutherfurd et al. 1999; Lyons et al. 2000), (2) provide a well-developed turf or a dense root system that protects against surface soil erosion (Murgatroyd and Ternan, 1983; Dunaway et al. 1994), (3) pump out water from the soil, and provide macropores for drainage, lowering erosion potential owing to bank sloughing and slumping (Thorne, 1990), and/or (4) buttress the toe of the streambank protecting it from shear failure (Thorne 1990). Key factors influencing these stabilising functions are: the height of the streambanks relative to the depth of root penetration, bank angles, the erosive power of the stream under high flows (including local effects such as whether the reach is straight or meandering with many erosion-prone bends), and whether the banks are protected by other features (e.g., boulders, bedrock or large woody debris).

Grasses, herbs and forbs are expected to provide good stabilisation of small banks (< 0.5m) and those with low angles (< 45°), whereas shrubs and trees give better protection for higher and steeper banks (Burckhardt and Todd, 1998; Abernathy and Rutherfurd, 1999). The following notes provide guidance for assessing the height of streambank that can be effectively strengthened by vegetation roots (Abernathy and Rutherfurd, 1999).

- Groundcover (typically up to 1 m high including prostrate shrubs, grasses, sedges and forbs) provide reinforcement of banks to a depth < 0.3 m.

- Understorey trees (typically 1-5 m high) have roots down to about 1 m and extend laterally to about the dripline.

- Overstorey species have a central rootball or rootplate of dense roots that can usually be considered as half a sphere that has a diameter 5 times the diameter of the trunk. Root density declines rapidly beyond the root ball and for reinforcement purposes there are usually few roots beyond the canopy dripline or below about 2 m under bank surface. Watson et al. (1999) report maximum root depths of 1.8 - 3.1 m for 8 to 25 year old *Pinus radiata* and 1.3 - 1.6 m for 6 to 32 year old kanuka. The root stabilization function will be greatest where the bank height is less than the depth of root penetration.

2.2.2 Filtering contaminants from overland flow

To be effective at filtering of contaminants from overland flow, the riparian zone needs to: (1) slow the flow of surface runoff, enhancing settling of particulates; and/or (2) increase infiltration into the soil, enhancing filtration of particulates (Phillips, 1989a,b; Smith, 1989; Cooper et al. 1995; Williamson et al. 1996; Lowrance et al. 1997). These filtering and settling functions are enhanced by the zone having flat topography, dense ground cover of grassy vegetation or litter under riparian forest that increase surface roughness, and soil characteristics that increase hydraulic conductivity (low compaction, high sand content, abundant macropores). Obviously, the zone must receive surface runoff from the adjacent landscape for this filtering role to operate. The function will be compromised if the surface runoff is channelised, so that runoff passes rapidly through the riparian area with little time for settling of particulates or infiltration into riparian soils. The likelihood of surface runoff occurring increases with rainfall intensity, slope length, slope angle and convergence of flows, and decreases with infiltration rate. Animal trampling typically reduces infiltration rate (Nguyen et al. 1998) and excluding stock from the riparian reverses this effect (Cooper et al. 1995). The quantity of sediment carried in surface runoff increases with the clay content of the soil. Guidelines are available to predict the optimal width of grass strip to filter suspended sediment from surface runoff in relation to slope length, slope angle, drainage and clay content (Collier et al. 1995).

2.2.3 Nutrient uptake by riparian plants

Nutrient uptake by riparian plants is an important function where infiltration surface runoff or shallow groundwater passes through the root zone before entering the stream (Fig. 1). In contrast, the function is unimportant where groundwater bypasses the root zone of riparian plants. This may occur in deeply incised streams, where tile drains deliver most of the shallow groundwater directly to the stream, or where deep groundwater emerges in the streambed as springs (Hill, 1996; Prosser et al. 1999).

Riparian vegetation type influences this function via vegetation rooting depth in relation to bank height and groundwater flows – larger trees and shrubs have deeper roots that can intercept deeper groundwater. Large plants also have a greater biomass and hence generally store more nutrient in plant tissue than small plants. Harvesting of these plants (e.g., by timber harvest or controlled animal grazing and subsequent removal of the animals) contributes to long-term removal of these stored nutrients from the riparian area. Plants nearest the stream are most likely to interact with groundwater, but nutrient uptake is expected to increase with the width of the zone of deep-rooting riparian plants.

The transpiration of riparian vegetation can also pump water from the riparian soils, leading to hydraulic gradients that draw river water into the riparian area where it is exposed to nutrient uptake and removal processes.

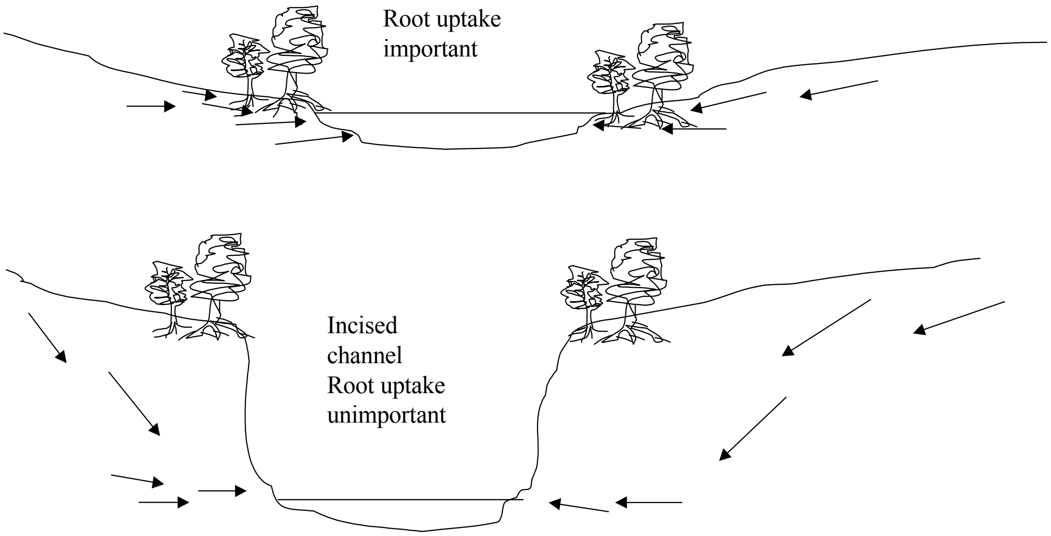


Figure 1: Schematic showing the influence on channel shape on the interaction between shallow groundwater and the root zone of riparian vegetation.

2.2.4 Denitrification

Denitrification is a process by which bacteria reduce nitrate to nitrous oxide and N_2 gases that are lost to the atmosphere, providing permanent N removal from the water (Hill, 1996; Willems et al. 1997). The process requires nitrate N, low oxygen conditions provided by waterlogged soils or hot spots of buried organic matter, and an available carbon source to drive the process (Knowles, 1982). Denitrification is most important in riparian areas where shallow groundwater passes through wetlands before emerging in the stream (Cooper, 1990; Prosser et al. 1999). Riparian plants enhance the process as their roots increase the supply of carbon at depth within the streamside soils.

2.2.5 Shading for instream temperature control

Cool groundwater entering shallow streams heats quickly under direct solar radiation in unshaded conditions (Quinn et al. 1992; Rutherford et al. 1997; Rutherford et al. 1999). The rate of heating decreases with stream depth, as the mass of water absorbing the incident radiation increases, and with shading vegetation, that absorbs and reflects much of the incident radiation. The ability of riparian vegetation to shade the channel decreases with stream width and the height of the vegetation (Davies-Colley and Quinn, 1998). Mature trees produce a closed canopy over channels narrower than about 6 m but the shade gap between the trees on either bank increases above this width (Davies-Colley and Quinn, 1998). Tussock grasses, sedges and flaxes only provide effective shade in very narrow channels (i.e., < c. 2m). Streams with poorly conductive beds (e.g., clay or bedrock) are expected to heat more rapidly than equivalently shaded streams with conductive beds (e.g., gravels), due to less conductive heat loss to the ground and less heat exchange with groundwater. Streambanks and hills can also provide topographic shade, independent of riparian vegetation, and are particularly important in incised streams (Rutherford et al. 1999).

2.2.6 Shading for instream plant control

Riparian shade can control stream lighting and thus control instream plant growth below nuisance levels, whilst maintaining the biodiversity benefits and desirable functions that plants provide (Biggs, 2000). Shading of 60-80% is expected to prevent proliferation of filamentous green algae (Quinn et al. 1997a; Davies-Colley and Quinn, 1998), but 90% shading is needed to prevent growth of some emergent macrophytes in low gradient streams (Wilcock et al. 1998).

Shade control of instream primary production also reduces the instream processing of nutrients (uptake of dissolved nutrients into plant biomass) (Quinn et al. 1997b), so that increased shade can result in increased export of dissolved nutrients and higher concentrations downstream (Howard-Williams and Pickmere, 1999). Decomposition of leaf litter from riparian trees also results in uptake of dissolved nutrients from the stream water, but this is not expected to compensate for the reduction in uptake by plants under highly shaded conditions (Quinn et al. 2000a). The overall effect of shade from riparian plantings on downstream nutrient concentrations depends on the balance of the increased riparian uptake versus decreased instream uptake. If nutrient concentrations in a downstream receiving water are judged more important than nuisance plants or high temperature in the reach (e.g., if the stream drains to a nutrient-sensitive lake or river reach of high recreational value), then riparian plantings need to be planned and managed to maintain open lighting conditions (>c. 50%) and to retain nutrient removal functions within the riparian zone (e.g., by managing for low-growing, or spaced, deciduous, riparian vegetation). Because of the site-specific, trade-off nature of shade control to enhance instream uptake of dissolved nutrients, this issue was not included in our riparian function assessments during this study. Modelling studies (Parkyn et al. 2001) indicate that riparian protection/planting that starts in the headwaters will result in lower instream dissolved nutrient concentrations, provided that the groundwater interacts with the riparian area, despite the effect of channel shading lowering instream uptake, because riparian uptake processes will dominate.

2.2.7 Input of large wood and leaf litter

Large wood and leaf litter can play important roles in streams as food resources and habitat (Collier and Halliday, 2000; Quinn et al. 2000b). The role of leaf litter and wood depends on the retentiveness of the stream, which decreases with stream size (Webster et al. 1994, 1999) and flooding frequency. Large wood is most stable in smaller streams, especially where the channel width is less than the typical wood piece length, and in low gradient streams that lack the power during floods to transport wood downstream. Large wood can be a key habitat-forming feature, increasing habitat diversity and cover for invertebrates and fish, and often forms the deepest pools (Quinn et al. 1997a). Wood is particularly important as invertebrate habitat in sandy and silty bedded streams (Collier and Halliday, 2000), and wood input generally increases with the wood density in the riparian area. Restoration of wood in streams, by natural recruitment from restored riparian forest, is a much longer term process (several decades to centuries) than restoration of shade (several years to decades, depending on stream size), because it requires time for tree growth and wood recruitment, via processes including bank undercutting, windthrow and fall of dead trees or branches. Wood recruitment increases with riparian buffer width out to about the maximum height of riparian trees (typically 20-30 m but up to 50 m for large podocarps), beyond which trees are only likely to contribute wood through land slides that enter the channel. However, trees growing closest to the channel contribute the most wood, because they are most likely to drop wood, or fall, into the channel.

2.2.8 Enhancing instream fish habitat and fish spawning areas

Riparian vegetation enhances fish habitat by providing cover and also encourages the input of terrestrial insect food items from overhanging vegetation (Main and Lyon, 1988; Jowett et al. 1996). Cover can take the form of overhanging plants, tree roots, wood and leaf accumulations. Higher over-storey vegetation is less effective fish cover than low-growing grasses and shrubs that grow just above stream level or hang into the stream (pers. comm. R Allibone).

Riparian zones also provide spawning areas for some galaxiid fish species, such as banded kokopu (Mitchell and Penlington, 1982), and short-jawed kokopu that spawn in leaf litter and woody debris during high flows (pers. comm. R Allibone), and inanga that spawn in riparian grasses in tidal lowland reaches (near the salt wedge) (Mitchell and Eldon, 1991). Removal of riparian vegetation in upland areas is expected to reduce the suitability for banded kokopu spawning by eliminating the moist microclimate and leaf litter found under forest, but details of spawning requirements are sketchy. Intensive stock grazing is expected to reduce inanga spawning success by removal of dense grassy vegetation, trampling of eggs and exposure of eggs to desiccation from sunlight and wind during their month-long incubation period.

2.2.9 Controlling downstream flooding

Riparian forest and wetlands are expected to attenuate the peak flow of runoff into the stream channel in small rainfall events (Smith, 1992). Furthermore, well-developed riparian vegetation has greater hydraulic roughness than short grass and hence retards the progress of flood flows as they spill out into the riparian area (Coon 1998, Darby 1999). This water retention may cause increased local flooding of the riparian area and adjacent land, but is expected to reduce the peak flow in downstream reaches. Factors expected to influence the ability of riparian management to control downstream flooding are: the likelihood of overbank flows (less in deeply incised channels); the size of the riparian area and floodplain; the extent of wetlands; and the roughness (stem height in relation to the flow depth, stem diameter, stem spacing, and resistance to flattening) of the riparian vegetation (Darby 1999).

2.2.10 Human recreation

Riparian management can influence human recreation of the riparian area and the stream by changing stream aesthetics, naturalness, access, and the fishability of the stream (Mosley, 1989). These effects are generally more important along medium-sized streams, with access to safe swimming and fishing spots, and in areas of high human access, such as urban streams and reserves.

Riparian management also influences boating and canoeing. Overhanging willows and large wood can be hazardous for boating, whereas native planting plays a particularly important role in enhancing recreational use. Walkways, picnicking facilities (tables and seating), weed control (especially blackberry and other invasives) and vehicle parking areas are all important for enhancing recreational use. Angling use requires particular attention to riparian planting design to provide both overhanging cover and low vegetation to allow fly casting.

2.2.11 Landscape and stream aesthetics

Riparian areas can enhance landscape aesthetics substantially by providing vegetation diversity with ribbons of green within developed pastoral and urban landscapes (Mosley, 1989). We have assumed that shrubs and trees have greater aesthetic appeal than grasses, and that native vegetation has more appeal than exotic vegetation.

3. Results

3.1 General characteristics of the Canterbury study sites

The 313 sites included in the survey covered a wide range of conditions from small, 1st order, headwater streams to large, 7th order, braided rivers (Table 2). The typical (median) stream had no riparian fencing, 80% of the 0.6 m high, stream banks were stable, and stock damage to the banks was judged to be minor. Woody debris was typically sparse and, despite low levels of stream shade (median shade ratio = 0.7), periphyton was only "slippery" and macrophytes were typically absent. One side of the stream was 100% fenced at 21% of sites and both sides at 12% of sites. Riparian wetlands were observed at only 10% of the sites, probably reflecting the low rainfall and permeable soils in the study area. The Land Environment of New Zealand (LENZ = Environmental Domains) database indicates the typically sandy soils of plains are usually slightly impeded to moderately well drained, and the sand-gravel soils of the uplands have moderate to good drainage. Tile drains were not observed at any site but 10% of sites had land drainage channels in their vicinity. Dry channels occurred at 15% of the sites.

Table 2: Summary of stream and riparian characteristics (*see Table 1 for index definitions).

Attribute	Mean	Median	SD	Min	Max
Catchment mean slope (°)	22.4	22.5	16.4	0.1	57.9
Local land slope (°)	11.9	5.3	12.8	0.1	52.7
Segment elevation (m a.s.l.)	190	123	184	8	906
Segment slope (cm/m)	1.9	1.0	3.2	-0.9	28.3
Stream order	3.2	3.0	1.2	1.0	7.0
Local rainfall (mm)	859	819	208	531	1520
Local evapo-transpiration (mm)	691	695	31	608	778
Local mean air temperature (°C)	10.9	11.0	1.0	7.5	12.8
Catchment area (km^2)	54	15	174	0.3	2520
Accumulated flow ($m^3 s^{-1}$)	0.81	0.08	3.50	-0.16	53.55
Water width (m)	3.4	2.0	4.8	0.0	40.0
Nonvegetated channel width (m)	10.1	3.5	21.0	0.3	225
Bankfull width (m)	14.4	6.0	26.7	0.5	225
Valley bottom width index	4.1	4.0	1.7	1.0	6.0
Channel slope index	4.1	4.0	1.7	1.0	6.0
Shade ratio	1.5	0.7	2.4	0.0	22.9
Bank height right bank (m)	0.9	0.7	0.9	0.1	10.0
Bank height left bank (m)	0.9	0.5	0.8	0.0	5.0
Mean bank height (m)	0.9	0.7	0.8	0.1	6.0
% macrophyte cover	12.2	0.0	23.6	0.0	100
Periphyton index	1.5	1.0	1.3	0.0	4.0
Wood index	1.0	1.0	0.9	0.0	3.0
%Stable bank	64.3	80.0	35.2	0.0	100

Attribute	Mean	Median	SD	Min	Max
Stock access left bank index	0.6	1.0	0.49	0.0	1.0
Stock access right bank index	0.6	1.0	0.49	0.0	1.0
Left and right banks stock access index	1.2	2.0	0.91	0.0	2.0
Stock bank damage index	0.8	1.0	0.87	0.0	3.0
Local slope length index	2.2	2.0	1.19	1.0	4.0
Local land slope (°)	9.7	3.5	9.4	1.0	30
Local land slope index	3.0	2.0	1.7	1.0	6.0
Tile drain index	0.0	0.0	0.0	0.0	0.0
Drainage channel index	0.1	0.0	0.29	0.0	1.0
Riparian wetland presence index	0.2	0.0	0.42	0.0	1.0
Waste discharge index	0.02	0.0	0.13	0.0	1.0
Fence type index	1.0	0.0	1.38	0.0	3.00
Fence to left bank stream (m)	12.9	5.0	20.6	0.0	100
Fence to right bank stream (m)	10.5	5.0	17.1	0.0	100
Both sides fenced (%)	11.5	10	0.0	0.0	100
One side fenced (%)	21.1	20	0.0	0.0	100

Most sites were classified by the REC as having pastoral catchments with cool dry climates, low elevation source of flow, alluvium geology, middle order (> low order) network position, and low gradient valley land form (Fig. 2). Annual local rainfall (median 819 mm) ranged from 531 to 1520 mm, but evapo-transpiration was high (median 695 mm) so that the accumulated flow of upstream reaches (calculated from rainfall and evapotranspiration) was negative at some sites (indicating ephemeral flow). The channel was dry at 14.5% of the sites during the surveys.

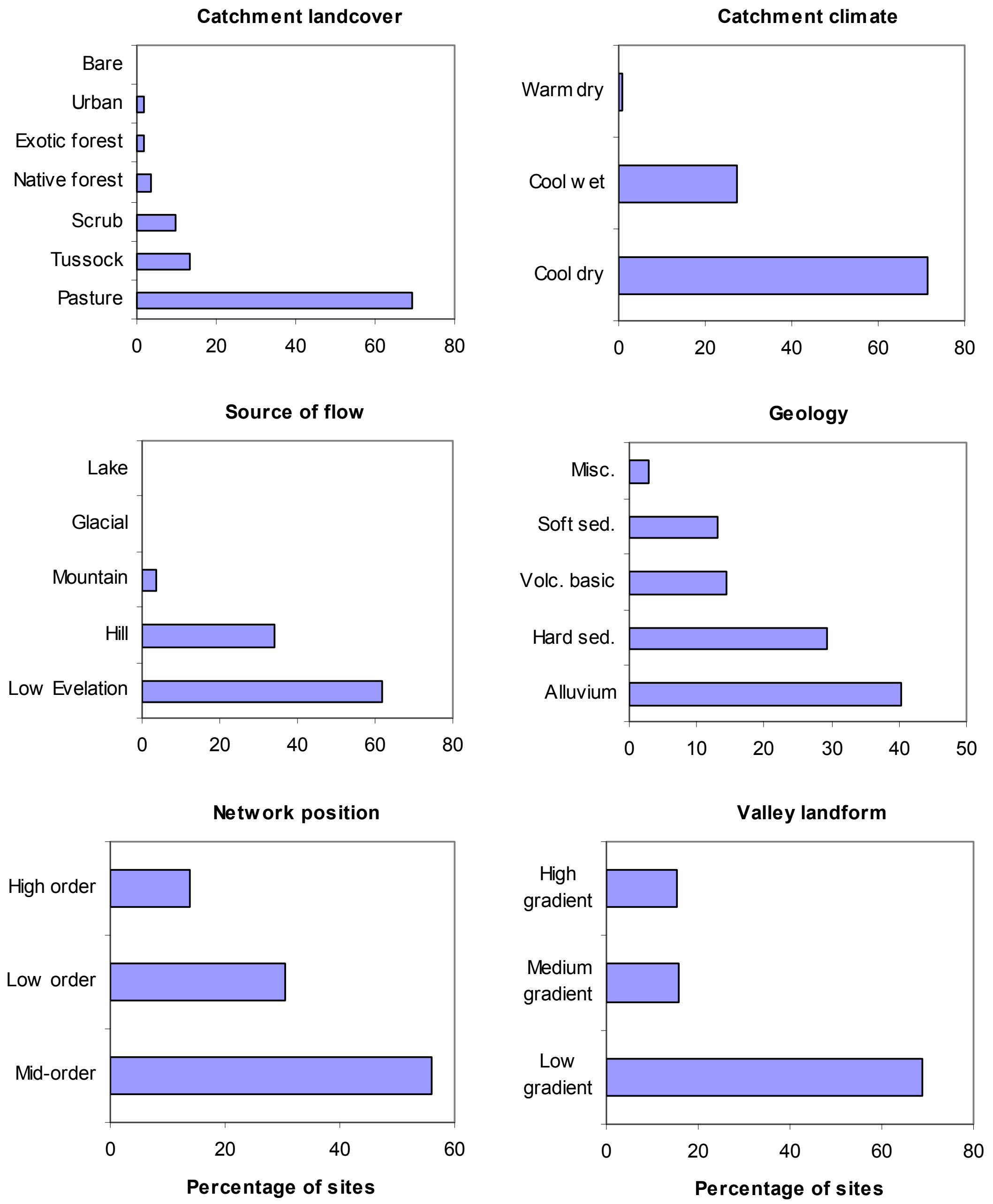


Figure 2: Summary of survey sites' REC characteristics.

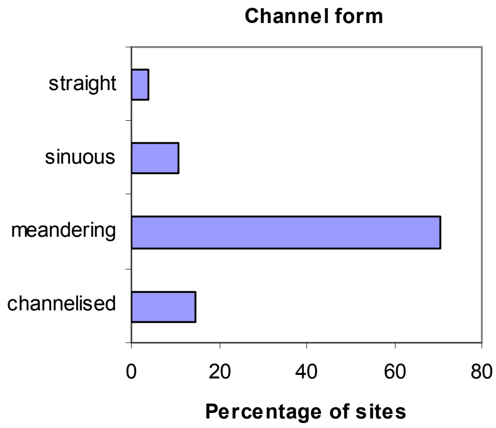


Figure 3: Channel form at study sites

Grass was the most common dominant riparian vegetation type (48% of sites), followed by willows (26%), low shrubs (9%), and native trees (8%) (Fig. 4). Conifers and deciduous trees (usually a mix of willow and poplar) were each dominant at 3% of sites. Wetland plants (flax, sedges, rushes) were dominant at only 2% of sites, and bare soil at 0.6%.

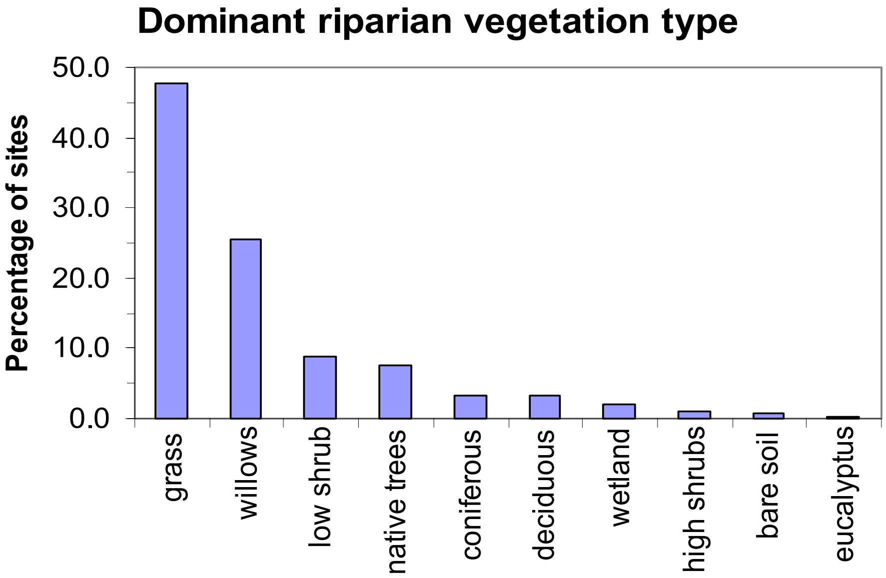


Figure 4: Dominant riparian vegetation at Canterbury stream sites.

3.2 Assessment of riparian functions

The field assessments of riparian functions are summarised in Table 3. The various functions differed in their average assessed current and potential activity and also varied widely in activity between the sites. Denitrification was assessed as currently the least active function, whereas bank stabilisation was judged the most active. Applying best practicable riparian management at the sites was judged to be capable of improving most riparian functions substantially (Table 3). The average improvement in function expected followed the order of shading > input of litter and wood, and bank stabilisation > fish habitat, overland flow, and down-stream flood control > recreation > denitrification.

Table 3: Summary of the assessed current (_C) and potential (_P) riparian functions at sites in 3 sub-regions of Canterbury. Functions scored from 0 (not active) to 5 (very highly active).

Function	Mean	median	SD	min	Max
Current functions					
Bank stability_C	2.2	2	1.3	0	5
Overland flow filtering_C	1.9	2	1.2	0	5
Nutrient uptake _C	2.1	2	1.2	0	5
Denitrification _C	0.7	0	0.9	0	4
Shade for temp_C	1.7	1	1.5	0	5
Shade for plant control_C	1.7	1	1.5	0	5
Wood input_C	1.5	1	1.3	0	5
Litter input _C	1.6	1	1.3	0	5
Fish habitat_C	1.2	1	1.2	0	5
Downstream flooding_C	1.7	2	1.2	0	5
Recreation_C	1.3	1	1.4	0	5
Aesthetics_C	2.0	2	1.4	0	5
Potential functions					
Bank stability_P	3.7	4	1.0	0	5
Overland flow_P	3.0	3	1.2	0	5
Nutrient uptake_P	3.4	3	1.1	1	5
Denitrification_P	1.3	1	1.3	0	5
Shade for plants_P	3.5	4	1.5	0	5
Shade for temperature_P	3.6	4	1.5	0	5
Wood input_P	3.2	3	1.1	0	5
Litter input_P	3.0	3	1.2	0	5
Fish habitat_P	2.2	2	1.5	0	5
Downstream flooding_P	2.8	3	1.0	0	5
Recreation_P	1.7	2	1.5	0	5
Aesthetics_P	3.3	3	1.0	0	5

3.3 Predicting riparian function activity

3.3.1 Predicting current riparian functions

The factors influencing the activity of the riparian functions were evaluated using multivariate statistics (MOPED programme developed by Ian Jowett of NIWA). First, the sites with similar current riparian function ratings were grouped together in a 3 x 4 Self Organising Map (SOM) using k-medoids (Kauffman and Rousseeuw 1990). The Silhouette Index indicated that these 12 RMC-C cells formed 2 main RMC-C groups between which each of the current riparian function ratings differed significantly (ANOVA, $P < 0.1$) (see APPENDIX 1 for site classification details). RMC-C group 1 sites had relatively low function ratings compared with group 2 (Fig. 5). Differences in environmental variables between the RMC-C groups 1 and 2 were tested by one-way ANOVA. Six variables assessed on site during the surveys differed most strongly between the groups (Table 4). These were related to dominant riparian vegetation type, shade ratio, stream water width, stock damage to the stream banks, % stable stream bank, and the length and angle of the local land slope and channel slope. Several variables derived from the River Environment Classification (REC) and LENZ databases also showed statistically significant differences between RMC-C groups 1 and 2 (see Table 4).

Table 4: Results of one way ANOVA of environmental variables amongst 2 groups of sites based on current riparian functions. * = variables were log transformed with averages reported as geometric means, other variables are arithmetic means. Results shown for variables with ANOVA $P < 0.1$ only.

RMC-C	ANOVA F	P	1	2
Number of sites			175	137
Dominant riparian veg type	199.9	<0.0001	1.93	5.21
Shade ratio*	58	<0.0001	0.41	1.26
stock Bank damage Index	34.2	<0.0001	1.01	0.46
%Stable bank	14.1	<0.0001	57.90	72.66
SLOPE_SECT	13.4	<0.0001	1.38	2.67
Local land slope length index	13.2	<0.0001	2.02	2.50
Loc Land Slope Class	9.2	0.003	2.71	3.31
CTCHSLOPE	8.9	0.003	10.00	14.31
Channel Slope Index	8.7	0.004	2.53	2.96
PSIZE	8.6	0.004	2.09	2.50
ACCSLOPE	7.3	0.007	20.09	25.08
Local Land Slope Metrics	7.1	0.008	8.47	11.29
Log nonvegetated width*	7	0.009	3.32	4.82
INDURATION	5.8	0.016	2.82	3.10
Water Width +1*	5.6	0.018	2.88	3.54
CTCHRAIN	4.7	0.03	836	888
Mean Bank Ht*	4.4	0.037	0.64	0.76
Geol index	4.2	0.041	2.91	3.26

RMC-C	ANOVA F	P	1	2
SOF Index	3.6	0.058	1.36	1.48
Bankfull width*	3.5	0.062	6.27	7.89
Land cover index	2.9	0.086	3.47	3.70

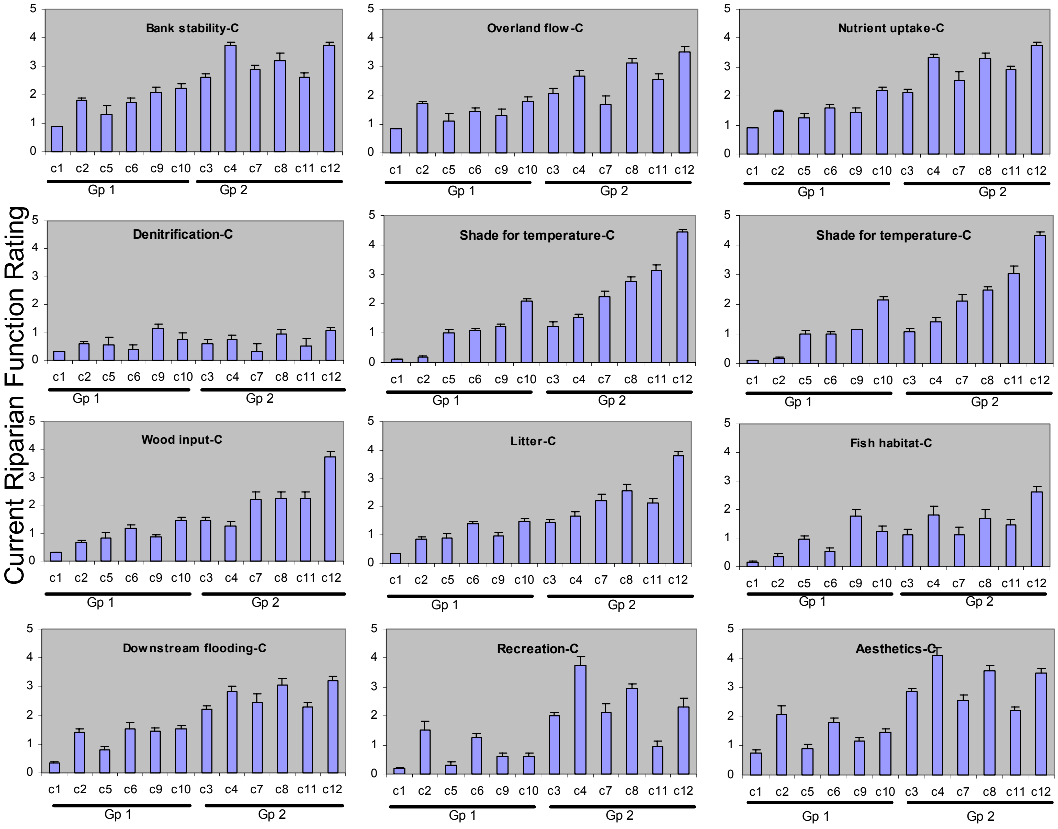


Figure 5: Comparison of mean (+SE) current function ratings amongst the individual Self Organising Map (SOM) cells (c 1 - c12) and the two major groups based on current riparian function ratings at 313 Canterbury stream sites. 0 = absent, 1 = very low activity, 2 = low-moderate activity, 3 = moderate activity, 4 = high activity and 5 = very high activity.

Group 1 sites (n = 175, SOM cells 1, 2, 5, 6, 9 and 10) had low riparian function ratings (mean ± S.D. of 12 functions = 0.9 ± 0.5, Fig. 5). These were typically unshaded streams, with grass as the dominant riparian vegetation, stock access to one or both banks, and low bank stability (Table 4). Group 2 sites (n = 137, SOM cells 3, 4, 7, 8, 11, and 12) had moderate to high current riparian function ratings (mean ± S.D. of 12 functions = 2.5 ± 0.7,

Fig. 5). These sites typically had trees as the dominant riparian vegetation, more stream shade, higher land and channel slopes and slightly wider channels. Variation in functions was greater at the 12 cell classification level (Fig. 5), with the mean rating of all 12 functions ranging from 0.4 ± 0.2 for cell 1 to 3.3 ± 0.5 for cell 12. Compared to cell 12 sites (n = 43; e.g., Photo 2), cell 1 sites (n = 64; e.g., Photo 1) were much wider (mean 13 m wide non-vegetated channel c.f. 3.5 m), poorly shaded (shade ratio = 0.4 c.f. 4.4), and more likely to be dry (31% c.f. 7% of sites).

Photos 1 and 2: Examples of RMC-C cell 1 (group 1) (upper photo) and cell 12 (group 2) sites.

The variables in Table 4 were used to develop a discriminant model to predict SOM cell and group affinities. The SOM group (1 and 2) model (see spreadsheet RMCmodelequations.xls on CD for models) assigned 83% of the sites to the correct group (c.f. 50% expected by chance).

The 83% correct prediction rate for site group classification indicates that this discriminant model could be used as a way for non-experts to assess likely riparian function ratings at a site, based on the mix of site and GIS information in Table 4. A similar model to predict membership amongst the 12 SOM cells based on available GIS and site data had a 57% success rate (c.f. 8% by chance), with an additional 23% of sites being “near misses”, classed in the next most probable cell. These models could be used by people who are not sufficiently trained to make direct onsite evaluations of riparian functions or as a check against individual site evaluation. The models would predict the group or cells affinity and attributes of the site could then be deduced from the typical riparian function ratings for that RMC-C group or cell.

Discriminant models were also developed, using only GIS variables in Table 4 that differed between the RMC-C classes at $P < 0.10$ information available from REC and LENZ databases. These models assigned 63% of the sites to the correct group (c.f. 50% by chance, see spreadsheet RMCmodelequations.xls for models) and 26% to the correct cell (c.f. 8% by chance). The low hit rate of these models indicates that the currently available GIS data are not suitable for predicting riparian classes and hence riparian functions. The results of these two modelling exercises indicate that reliable prediction of current riparian functions at the regional scale will require additional information on riparian vegetation/shade that is not currently included in the REC or LENZ databases, perhaps from remote sensing using aerial photography of satellite imagery data at levels of resolution appropriate for determining near-stream attributes.

3.3.2 Predicting potential riparian functions

Similar clustering and modelling procedures to those carried out on current riparian functions were also carried out using the *potential* riparian function activity ratings. This resulted in 3 main RMC-P groups (Fig. 6, Photos 3-5), amongst which each of the riparian functions differed in potential activity ratings (ANOVA, $P < 0.05$, except for recreation enhancement that was marginally significant $P = 0.063$) (see APPENDIX 1 for site classification details). Group 2 (n=153, e.g., Photo 4) had the highest average rating for all potential functions (mean ± S.D. for all 12 functions = 3.5 ± 0.4). Typical streams in this group were third order with lowland source of flow and had the highest local land slope (Table 5). Group 3 sites (n = 90, e.g., Photo 5) had the lowest average potential ratings for shading, litter and wood input, denitrification, nutrient uptake and overland flow filtering (mean ± S.D. for all 12 functions = 2.1 ± 0.5). Typical sites in this group were fourth order, sourced from hill catchment, had large areas, high average catchment slope and high site elevation. Group 1 (n = 69, e.g., Photo 3) had high potential riparian function ratings for shading but low ratings for recreation and fish habitat enhancement. Typical sites in group 1 were third order, with small catchments, lowland source of flow, sand geology, and low catchment and stream channel slope. Thirty-six percent of the sites were dry.

Photos 3, 4 and 5: Examples of RMC-P Group 1 (Cell 1, site E91), Group 2 (Cell 8, site K6), and Group 3 (Cell 9, site K5).

The average potential rating for all 12 riparian functions within the RMC-P cells ranged from 1.8 ± 0.4 for cell 9 (that had the highest average width and 22% with dry channels) to 3.9 ± 0.3 for cell 12 (small streams with the greatest average local land slope). This level of classification is likely to be more useful for finer scale planning.

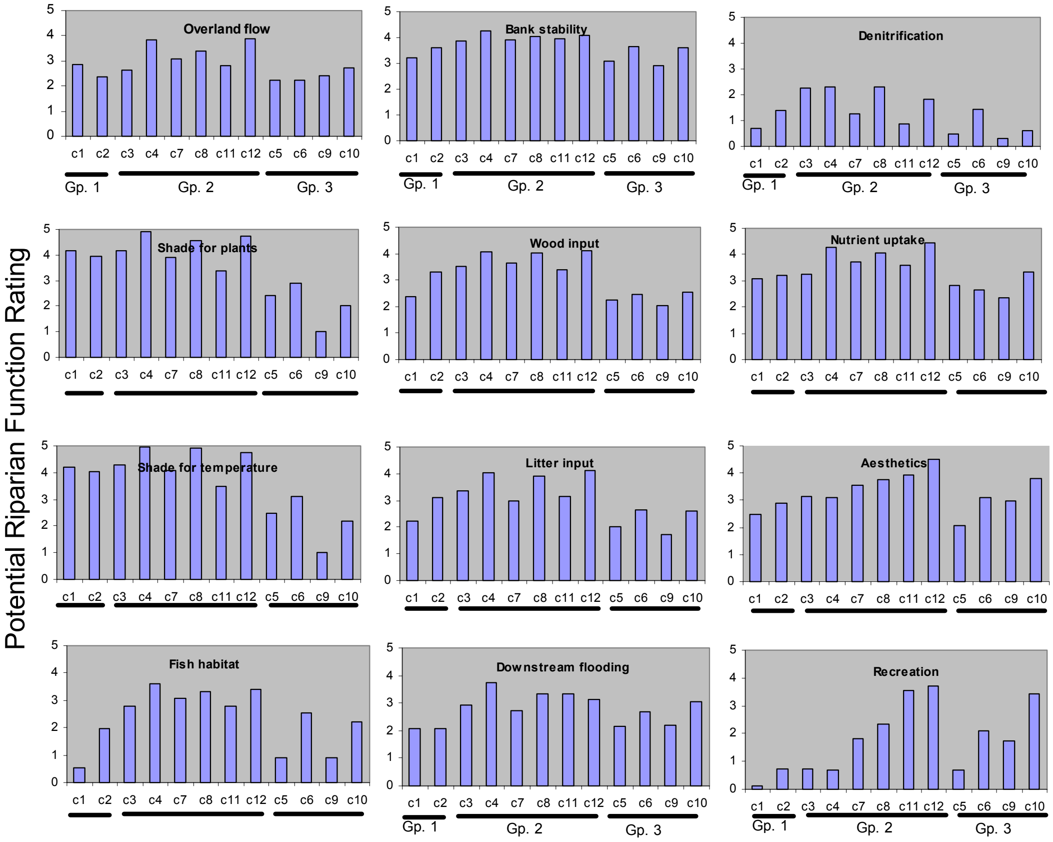


Figure 6: Comparison of mean potential function ratings (0 = not activity to 5 = very highly active) amongst the individual Self Organising Map (SOM) cells (c1 - c12) and the three major groups based on these ratings at 313 Canterbury stream sites.

Table 5: ANOVA results and mean values of GIS environmental variables in REC and LENZ databases amongst 3 clusters of sites based on potential riparian functions showing average values (*are geometric means).

	Anova results			**SOM Group**	
Variable	F	P	1	2	3
Acc Flow* (m^3s^{-1})	60.4	<0.001	0.07	0.12	0.75
SOF Index	38.8	<0.001	1.25	1.26	1.81
Average catchment slope (°)	31.4	<0.001	12.86	21.10	31.51
Catchment area* (km^2)	30.7	<0.001	8.55	11.02	41.21
REC land cover index	26.7	<0.001	3.20	3.33	4.27
Stream order	25.8	<0.001	2.70	2.97	3.84
Reach elevation (m)	16	<0.001	188	141	273
Domain particle size class	15.8	<0.001	1.94	2.07	2.87
Local average air temp (°C)	15	<0.001	10.64	11.17	10.57
Domain induration class	12.1	<0.001	2.78	2.77	3.38
DRAINAGE	11.2	<0.001	3.80	3.72	4.38
REC local land slope (°)	9	<0.001	6.32	13.90	12.74
Local evaporation (mm)	8.2	<0.001	678	695	694
Geology index	7.4	0.001	2.57	3.05	3.47
Local annual rainfall (mm)	6.8	0.001	785	865	905
Domain Ca class	3.9	0.022	2.01	1.94	1.83
REC reach slope (cm/m)	3.7	0.026	1.22	2.40	1.72
Local catchment flow ($m^3 s^{-1}$)	2.8	0.066	0.00	0.00	0.01
Domain soil age class	1.3	0.294	1.86	1.78	1.76
Chemical limitation on plants class	1.2	0.326	1.03	1.02	1.00
Domain acid P class	0.7	0.496	3.52	3.56	3.62
Sinuosity	0.7	0.505	1.17	1.19	1.18

A discriminant model (see supplied spreadsheet RMCmodelequations.xls on CD for model) that included all the GIS variables in Table 5 allocated 69% of sites to the correct SOM group (c.f., 33% expected by chance). Function 1 of the discriminant model accounted for 76% of the overall variance explained and was most strongly correlated (canonical structure coefficients) with the log of the calculated flow (Acc Flow; r = 0.67), SOF Index (r = 0.54) and log of catchment area (r = 0.48). Function 2 (24% of variance explained) was most strongly correlated with the local average air temperature (r = 0.46) and the slope of the land draining directly to the stream segment (r = 0.44).

A second discriminant model was developed to predict the SOM cell (n=12, see Fig. 6) affinity using the GIS variables in Table 5 (see supplied spreadsheet RMCmodelequations.xls for model and the GIS layer of predictions of SOM cell RMC-P predictions of each REC reach in Canterbury). This assigned 48% of sites to the correct cell (c.f. about 8% by chance) and 18% of classification were "near misses" (assigned to the next most probable cell), so that overall 66% of classifications were correct or near misses. Similarly to the model for the 3 SOM groups, function 1 of the SOM cell model (37% of variance explained) was most strongly correlated with log of the calculated flow ($r = 0.72$) and log of catchment area ($r = 0.53$), and function 2 (26% of variance explained) was most strongly correlated with the local average air temperature ($r = 0.46$) and the slope of the land draining directly to the stream segment ($r = 0.49$).

The better performance of the discriminant function models for predicting potential than current riparian management classes from GIS variables reflects the strong influence on the current function ratings of the current local land management, that is not currently dealt with in the available GIS databases.

These discriminant models provide a means for non-experts to assess the likely potential riparian functions at a site by inputting key information on the site characteristics into the model and examining the characteristics of the cluster to which the site is allocated. This should improve the basis for deciding: (1) whether riparian management is likely to improve functions that provide benefits to the local of downstream aquatic ecosystem; (2) what functions can be enhanced and hence the type of riparian management to put in place and (3) the relative priority of sites in a catchment or region for riparian management. The models can also be used to map the distribution of RMC-P classes using information in the River Environment Classification and LENZ GIS databases (Figure 7). Note however, that the classification error rates of the models (e.g., average 31% for potential function groups based solely on the GIS databases) mean that the predictions will only be indicative. Nevertheless, they are expected to be useful for broad-scale planning purposes.

LENZ data were not available for 4.7% of REC cells in Canterbury. The reaches affected were mainly on large braided rivers that generally have low potential riparian function ratings. Two options were considered for dealing with this missing data issue: (1) running with predictive models that used only the REC data or (2) using the models that incorporate both REC and LENZ data but not classifying the small percentage of reaches that lacked LENZ data. Option 1 was evaluated by comparing the percentage of correct RMC-P cell and group classifications with and without inclusion of the LENZ variables. Excluding these reduced the % correct group classification from 69% to 64% and correct cell classification from 48% to 39%. From this it was decided to use the models that included REC and LENZ data, because (1) the RMC-P cell prediction accuracy dropped significantly without the LENZ variables (2) a small proportion of reaches would be left unclassified (due to lack of LENZ data), and (3) the unclassified reaches were typically on large braided rivers where we would expect relatively low riparian function potential.

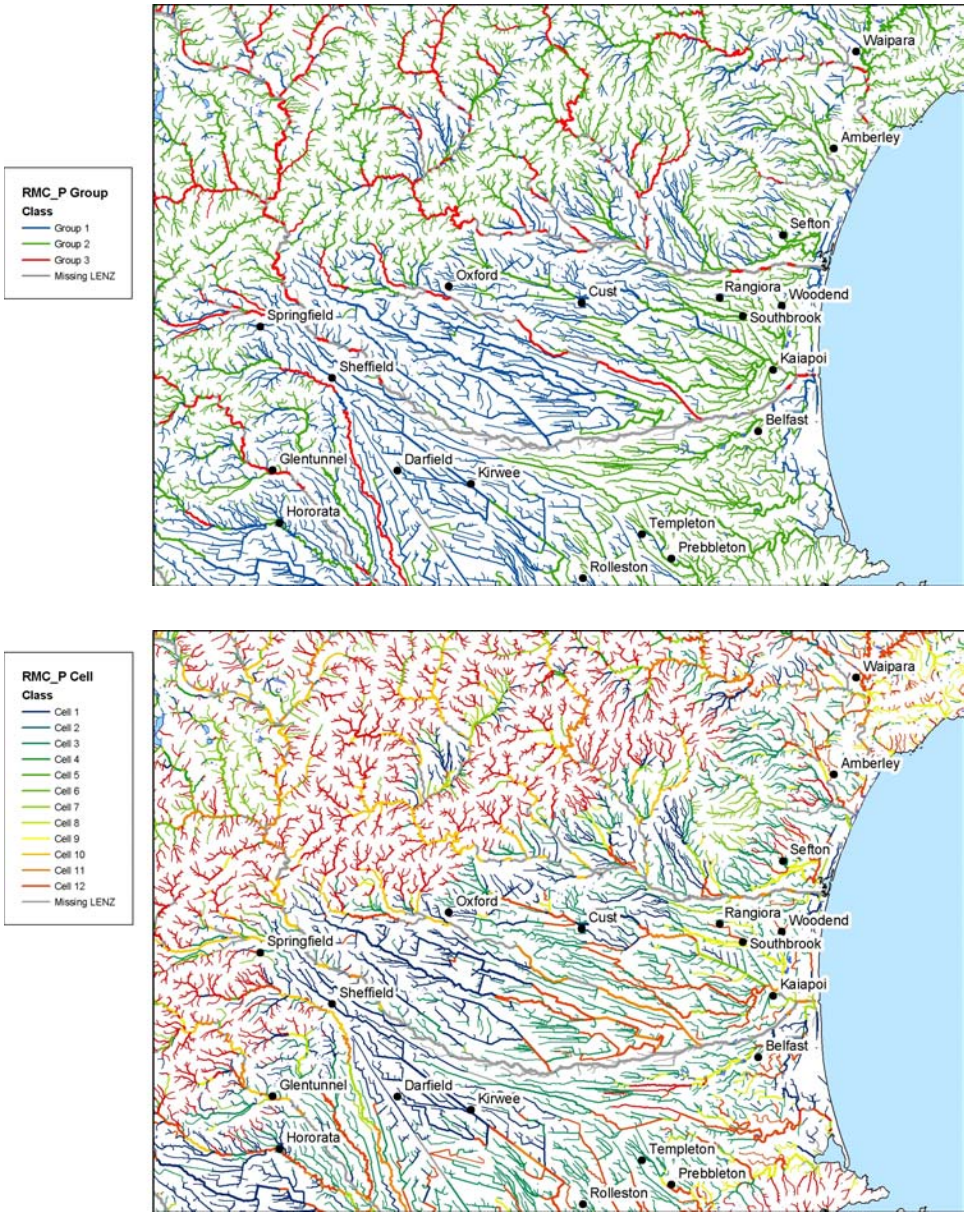


Figure 7: Map showing predicted potential riparian management classification (RMC-P) groups (1-3, upper map) and cells (1-12, lower map) for the coastal area north of Christchurch.

3.3.3 Predicting individual riparian functions

Discriminant function modelling was also used to predict the potential ratings of individual riparian functions (0 to 5) based on GIS variables (see supplied spreadsheet RMCmodelequations.xls for model and GIS layers showing the predictions for each REC reach in Canterbury). The predictive accuracy of the models and most important GIS environmental predictors (i.e., those with strongest correlations with first 2 functions) are summarised in Table 6. The models allocated 37 – 53% of sites to the correct class and 69-91% of the predictions were either correct or near misses (predicted an adjacent rating, i.e., 3 or 5 if the actual assessed rating was 4). This suggests that these models would be useful for predicting the potential roles of various individual riparian functions at particular locations or mapping variations in potential functions. An example of the mapped prediction for the potential shade for temperature function rating is shown in Figure 8.

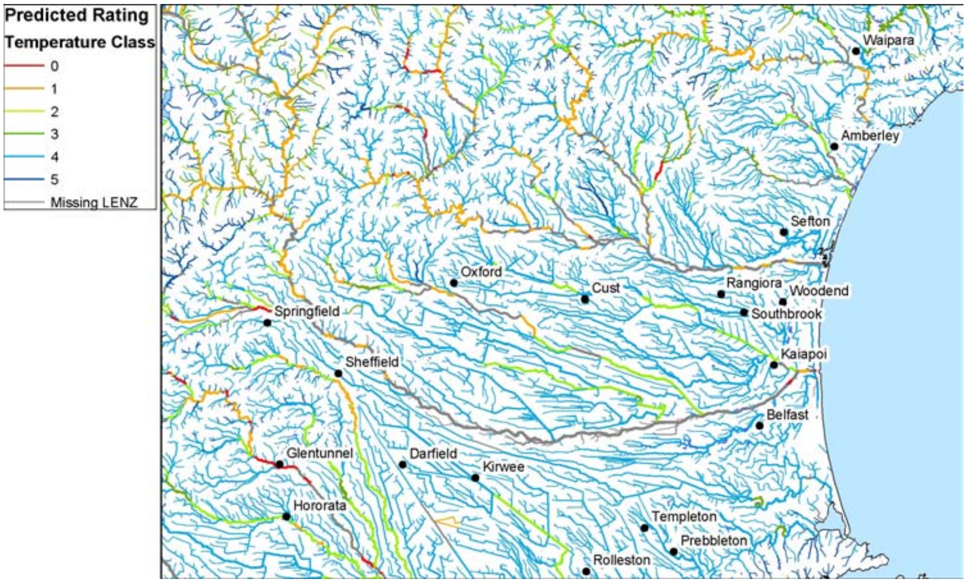


Figure 8: Map showing predicted potential riparian shading for instream temperature control function ratings for the coastal area north of Christchurch.

Table 6: Summary of multiple discriminant Analysis modelling to predict potential ratings of individual riparian functions from GIS variables.

Riparian functions	% pred. correct	% near misses	Top correlations: function 1	Top correlations: function 2
Bank stability	41	33	Land cover index; SOF index	Local rain, flow
Overland flow	46	33	Local land slope; channel slope	Chemical limitation on plants; local temperature
Nutrient uptake	45	43	Local land slope; channel slope	SOF index
Denitrification	40	27	Flow, SOF index, induration	Soil particle size
Shade for plants	53	28	Flow, upstream catchment area	Local rain, local land slope, local evaporation
Shade for temperature	53	27	Flow, upstream catchment area	Local rain, local land slope, local evaporation
Wood input	42	33	Local temp, site elevation	Chemical limitation on plants
Litter input	41	28	Local temp, channel slope	SOF index, flow
Fish habitat	42	28	Local temp, land drainage	Local land slope, local evaporation
Downstream flood control	40	28	Local temp, soil phosphorus	Land slope of whole catchment
Recreation	47	25	Catchment slope, order	Channel slope
Aesthetics	37	32	Local land slope, channel slope	SOF index, catchment slope

3.3.4 Geomorphic approach to riparian management classification

The results of the assessments of current and potential riparian functions amongst Canterbury streams highlight some key morphological factors influencing function ratings that need to be considered in management decisions. These were channel width, permanence of flow and the slope of land adjacent to the stream/riparian area.

3.3.4.1 Permanence of flow

The permanence of flow at a site has obvious influences on its values for recreation, and aesthetics. Although knowledge of the ecological roles and values of intermittent streams is rudimentary, I have assumed for the purposes of this exercise that riparian functions to protect local instream values are less important at sites that are usually dry, or dry up during summer. Our on-site assessments of potential riparian functions indicate that the 46 sites (15% of total) that were dry during our spring-summer surveys are similar (i.e., mean rating within 1 unit) to the perennial sites in their potential bank stabilisation, overland flow control, nutrient uptake from groundwater and downstream flood control functions, but were less active for all other functions. Nevertheless, the seasonal importance of ephemeral reaches for fish spawning (e.g., trout spawning during winter) may result in some ephemeral reaches warranting high priority for riparian management to enhance instream habitat even though the reach is dry during summer. Further research is required on the natural values and roles of ephemeral streams for maintaining the health of downstream ecosystems in order to provide a better basis for their management.

Riparian management planning should, therefore, consider the permanence of flow at sites. Unfortunately, attempts to predict whether sites were dry or not during our spring-summer surveys by discriminant function modelling using the GIS variables were not particularly successful. Stream order, catchment area and predicted flow were all significantly lower at the dry sites, but the discriminant model assigned only 71% of sites to the correct wet/dry class (c.f. 50% by chance). Further work to develop better predictions of flow permanence would improve the basis for riparian management decisions.

3.3.4.2 Channel width

Channel width has a strong influence on the interaction of riparian vegetation and instream habitat (i.e., shading, delivery and retention of wood and leaf litter from the riparian vegetation to the wetted channel, and influence on fish habitat). This suggests that classifying streams by channel width will improve the effectiveness of riparian management.

Our assessments of potential shading function for control of stream temperature and instream vegetation in relation to channel width indicate that the shading function decreases from “high activity” (rating 4-5) to “low-moderate activity” (rating 2) at a non-vegetated channel width of approximately 10-12 m (e.g., Fig. 9). (Note that some narrower channels have low potential shade ratings because only low growing plants are likely to grow as riparian vegetation (e.g., in tussock areas of the intermontane basins) or because the channels are typically dry, which reduced the shade function rating). This is consistent with changes in stream lighting measured with canopy analysers in relation to stream width and riparian vegetation (Davies-Colley and Quinn, 1998), and indicates that a non-vegetated channel width of 12 m is an appropriate cut-off for distinguishing sites above which the shading functions (temperature and algae control) of riparian trees are likely to be ineffective.

Some inland areas of Canterbury are expected to be unsuitable for growth of riparian trees due to climatic and soil constraints, and natural riparian vegetation is limited to tussock grasses and small shrubs (e.g., matagouri). This suggests that further subdivision of sites by channel width would be useful for guiding riparian planning. With this in mind, 4 channel width classes are suggested related to the types of riparian vegetation required to provide stream shade: <2 m (T = “tiny”), 2 to <6 m (S = “small”); 6 to <12 m (M = “medium”); and ≥12 m (L = “large). Long pasture grasses and tussocks are expected to shade tiny streams effectively, whereas high shrubs will shade tiny and small streams and trees will shade channels up to the medium size class.

Potential riparian function ratings varied between sites when grouped by these size classes (tested by ANOVA with post-hoc Scheffe multiple comparisons between groups). As expected, potential shade ratings for instream plant control and temperature were highest in the tiny and small channels > medium > large. The large class also has significantly lower potential function ratings for denitrification, nutrient uptake from groundwater, litter and wood input, fish habitat and downstream flooding. Tiny streams had significantly lower average ratings for aesthetics and recreation.

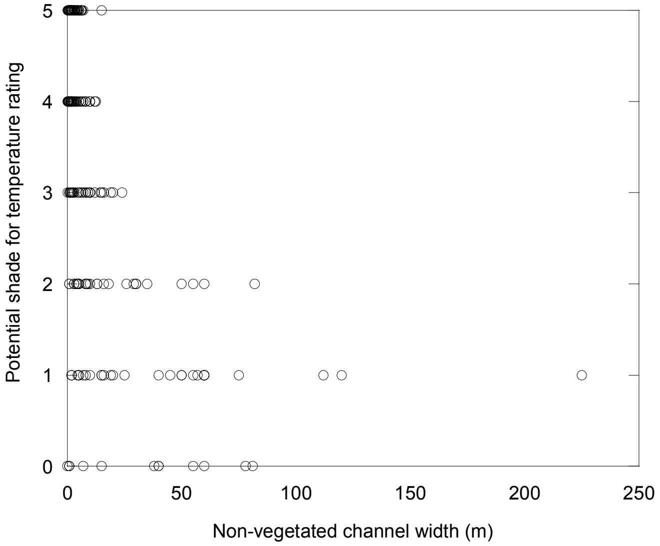


Figure 9: Effect of stream channel width on assessed potential riparian shading function for temperature control at sites in Canterbury. Function ratings range from 0 (no activity) to 5 (very high activity).

3.3.4.3 Local landform

Local landform is another key morphological influence on riparian functions and management, through its influence on surface runoff. This will generally increase (and buffer widths will need to widen to provide optimal efficiency) as the slope length, angle and clay content of the adjacent land increase and as soil drainage decreases. Collier et al. (1995) provide a method for determining how combinations of these factors influence the optimal width of a buffer strip for controlling sediment in surface runoff. The combination of slope length and angle is expected to increase the optimal width of riparian areas for contaminant filtering as the adjacent landform changes from plain to U-shaped to V-shaped. Our on-site assessments of potential riparian functions amongst sites classified as plain (P), U-shaped or V-shaped showed that riparian areas in V-shaped valleys had ≥1 unit higher average ratings than those in plain areas (Scheffe tests, $P < 0.05$) for control of overland flow (means 2.6, 3.5 and 4.2 for P, U- and V-shaped landforms, respectively) and recreation functions (means 1.5, 2.3, and 2.5, respectively). Landform also influenced potential ratings for nutrient uptake from shallow groundwater by riparian vegetation (means 3.2, 3.9 and 4 for plain, U and V morphologies), but potential ratings for the other riparian functions did not differ markedly by landform class.

3.3.4.1 Riparian/stream geomorphic classes

Based on the above, the sites were grouped into 12 geomorphic classes using combinations of channel width and valley shape (i.e., PT = Plain/Tiny; PS = Plain/Small; PM = Plain/Medium; PL = Plain/Large; UT = U-shaped/Tiny; US = U-shaped /Small; UM = U-shaped /Medium; UL = U-shaped /Large; VT = V-shaped/Tiny; VS = V-shaped /Small; VM = V-shaped /Medium; VL = V-shaped /Large) (see Photos 6-17 for site examples and Appendix 2 examples of cross-section sketches). Figure 10 shows that all 12 riparian functions showed statistically significant differences in their assessed potential activity amongst these classes. Riparian/stream geomorphology influences what riparian management can deliver to improve stream values and meet defined catchment or site goals. Differences in function ratings were strong (high F statistics) for shading functions (decreasing with size across shape types) > overland flow filtering (V>U>P) > recreation (very low at tiny plain and v-shaped sites) and weakest for downstream flood control. Bank stabilisation and aesthetic enhancement were rated as moderately to very highly active potential functions (mean ≥3) in all classes. Riparian denitrification potential was lowly rated in all classes, but particularly so around large channels. A discriminant function model, using 20 GIS variables that differed significantly between the groups (at $P < 0.1$; all except CHEMLIM and sinuosity), allocated 60% of sites to the correct class (c.f. 8% by chance) and another 17% were classified to an adjacent class. This indicates that the GIS-based model is useful for preliminary mapping riparian sites into these landform/size classes. An example of the mapped geomorphic classes for an area of Canterbury is shown in Figure 11 (see supplied spreadsheet RMCmodelequations.xls for model and GIS layers showing the predicted geomorphic classes for each REC reach in Canterbury).

Photos 6-9: Examples of Plains Tiny (PT), Small (PS), Medium (PM), and Large (PL) riparian/stream geomorphic classes.

19/2/2001 14:27

20/2/2001 15:22

Photos 10-13: Examples of U-shaped valley Tiny (UT), Small (US), Medium (UM), and Large (UL) riparian/stream geomorphic classes.

24/1/2001 18:13

24/1/2001 14:48

Photos 14-17: Examples of V-shaped Tiny (VT), Small (VS), Medium (VM) and Large (VL) geomorphic classes.

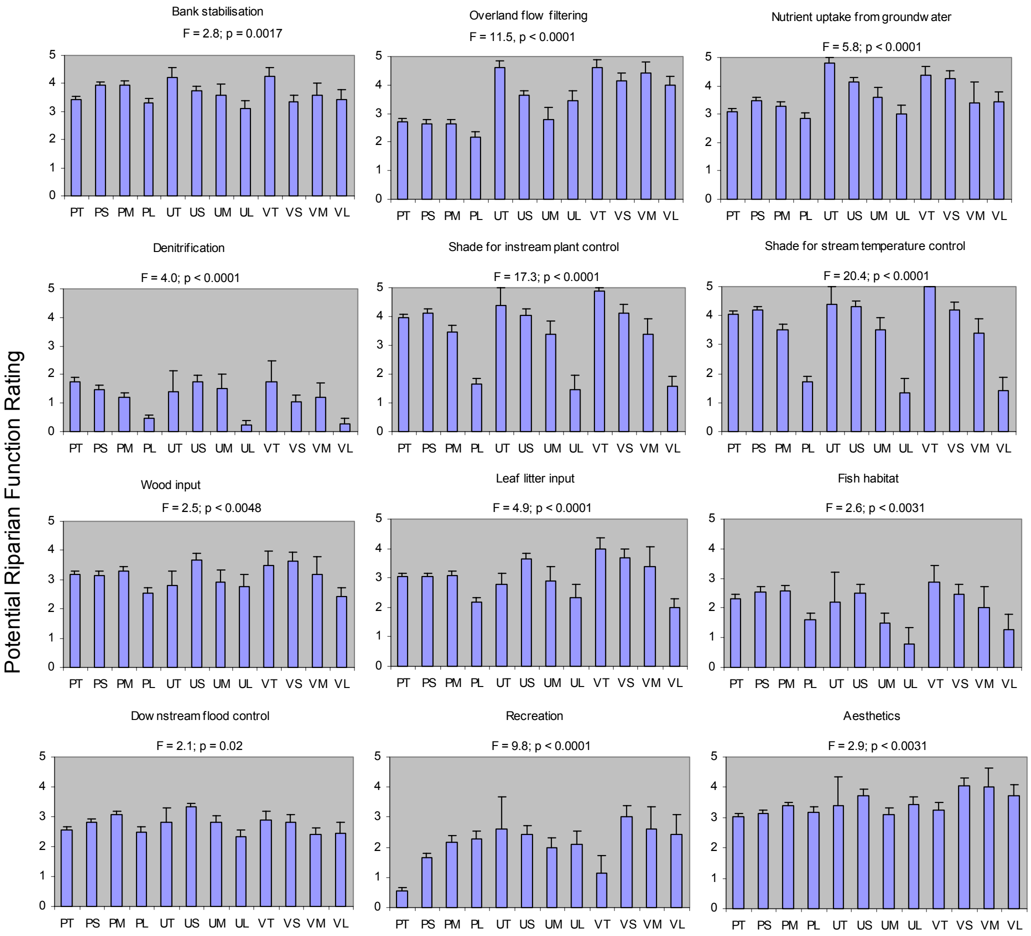


Figure 10: Average potential ratings (+ SE) for 12 riparian functions amongst twelve geomorphology based classes (RMC-G) at 313 Canterbury stream sites. Landform/width codes: P = plain/floodplain; U = U-shaped; V = V-shaped. Size codes: T = tiny (channel width < 2m); S = small (2 - <6m); M = Medium (6 - <12m); L = Large (≥12 m).

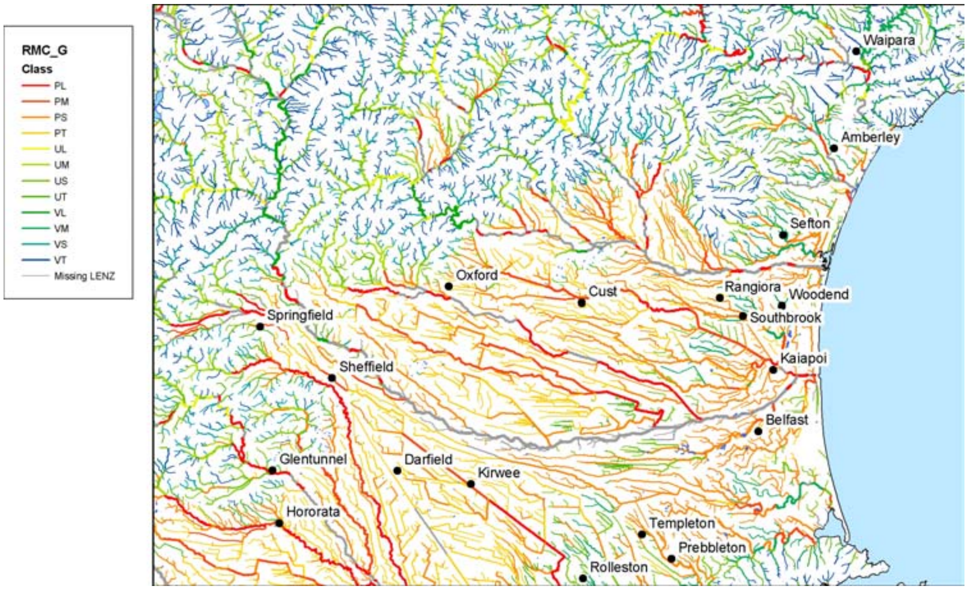


Figure 11: Map showing predicted geomorphology based classes (RMC-G) for the coastal area north of Christchurch. Landform/width codes: P = plain/floodplain; U = U-shaped; V = V-shaped. Size codes: T = tiny (channel width < 2m); S = small (2 - <6m); M = Medium (6 - <12m); L = Large (≥12 m).

3.3.4.2 Other potential classification attributes

High rates of riparian denitrification require groundwater flows through water-logged soils (anoxic conditions) with a source organic carbon (Barton et al. 1999). Recent research in the USA has used soil map data to identify area with wet soils as a planning tool for riparian management to enhance denitrification (Gold et al. 2001). In Canterbury, heavy, slow draining soils (where denitrification is expected to be operative in riparian zones) have been mapped (Main, 2003 (in prep.)) from data in Kear et al. (1967), and this map (Fig. 12) will be useful for identifying areas where riparian zones can probably be managed effectively for denitrifying inflows of shallow groundwater to streams. Free-draining soils, that cover approximately 77% of the Canterbury Plains (mostly Lismore series), are also unlikely to generate much surface runoff whereas the opposite is expected for heavy soils. Thus, overlaying the map of heavy, poorly drained soils should also identify the areas where riparian management is likely to be needed to deal with surface runoff in flatter areas and also where denitrification has potential to reduce nitrate inputs from shallow groundwater.

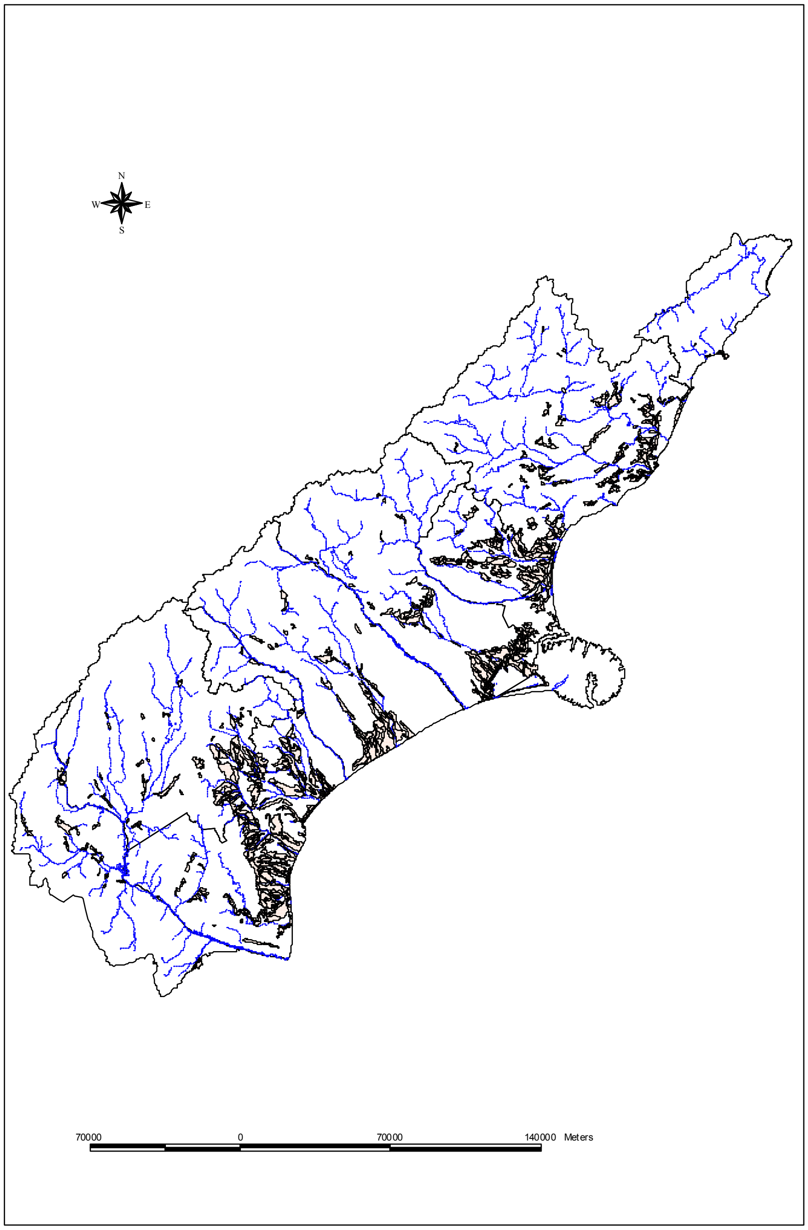


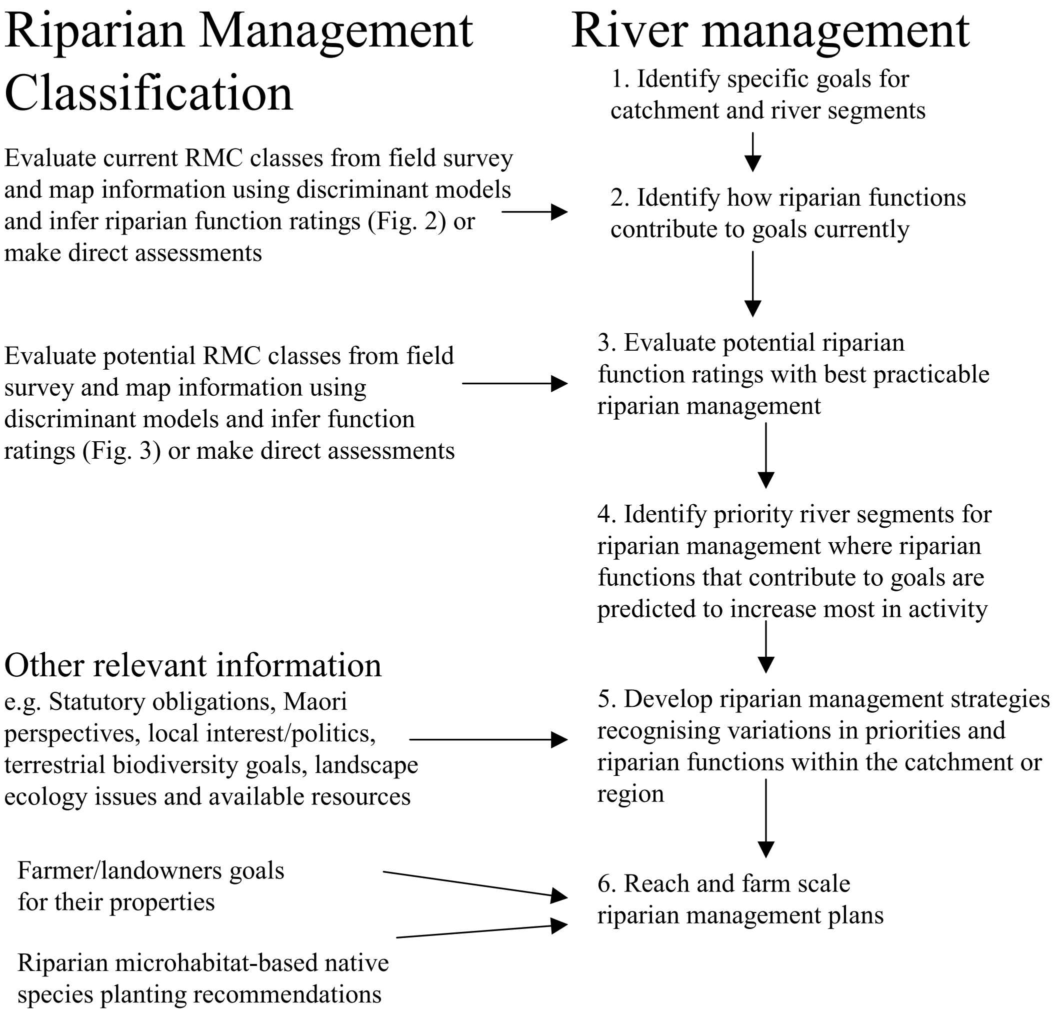
Figure 12: Extent of heavy, slow draining soils on the Canterbury plains as listed by Kear et al. (1967).

3.4 Application of riparian management classification in river management

The preceding sections outline the development of approaches to riparian management classification for Canterbury streams. Figure 13 provides a proposed framework for using RMC in catchment management.

Once specific goals are established for a river at the catchment and/or segment scale (step 1), predictions of current (RMC-C) and potential RMC classes (RMC-P and/or geomorphic classes), or potential ratings of specific riparian attributes, can be made using the discriminant function models. These classes indicate the riparian functions that currently contribute to the river management goals (from RMC-C class and mean function activity ratings in Fig. 5) and the potential functions that can be enhanced by riparian management (predicted RMC-P class and mean function ratings in Figs. 6 and/or geomorphic class and mean potential functions in Fig. 10) (steps 2 and 3 in Fig. 13).

Because of the need for field data for reasonably reliable predictions of RMC-C classes, this step will involve surveys of a representative sample of site and extrapolation to similar sites. The information in Sections 2.2 and 2.3 provides a basis for direct on-site evaluation of current and potential riparian functions that can be checked against the predictions of discriminant function models. The riparian function information from the RMC-C, RMC-P and geomorphic classifications provides an improved basis for prioritising areas for riparian management to meet the river goals (step 4). This feeds into riparian management strategies, which also recognise other goals, pressures, and the available resources (Step 5), and provide the context for reach or farm scale riparian management plans by/with farmers and other land-owners (step 6). Finally, the riparian microhabitat-based native plant recommendations (see Fig. 7 and Table 9 in Quinn et al. 2001) feed into this step by providing the detail needed to improve the success of native plantings.



Riparian Management Classification

River management

1. Identify specific goals for catchment and river segments

Evaluate current RMC classes from field survey and map information using discriminant models and infer riparian function ratings (Fig. 2) or make direct assessments

2. Identify how riparian functions contribute to goals currently

Evaluate potential RMC classes from field survey and map information using discriminant models and infer function ratings (Fig. 3) or make direct assessments

3. Evaluate potential riparian function ratings with best practicable riparian management

4. Identify priority river segments for riparian management where riparian functions that contribute to goals are predicted to increase most in activity

Other relevant information

e.g. Statutory obligations, Maori perspectives, local interest/politics, terrestrial biodiversity goals, landscape ecology issues and available resources

5. Develop riparian management strategies recognising variations in priorities and riparian functions within the catchment or region

Farmer/landowners goals for their properties

Riparian microhabitat-based native species planting recommendations

6. Reach and farm scale riparian management plans

Figure 13: Flow chart showing how Riparian Management Classification (RMC) and microhabitat based native plant recommendations can contribute to river management planning.

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7. Appendix 1:

List of study site names, locations and riparian management classifications. Classifications are presented according to their current (RMC-C) and potential riparian functions determined statistically (RMC-P) and inferred from knowledge (Geomorphic class: PT = Plain/Tiny; PS = Plain/Small; PM = Plain/Medium; PL = Plain/Large; UT = U-shaped/Tiny; US = U-shaped /Small; UM = U-shaped /Medium; UL = U-shaped /Large; VT = V-shaped/Tiny; VS = V-shaped /Small; VM = V-shaped /Medium; VL = V-shaped /Large).

Site No	Location	Map No.	Grid Ref.	RMC-C Cell	RMC-C Group	RMC-P Cell	RMC-P Group	Geomorphic Class
1	Halswell River @ Motukarara	M36	772198	9	1	8	2	PM
2	Drain on Whithells Rd	M36	785208	2	1	1	1	PS
3	McQueens Ck @ SH75	M36	787196	9	1	2	1	PS
4	Halswell River @ Seabridge Rd	M36	776172	1	1	3	2	PM
5	Halswell @ Seabridge Rd, Upper	M36	782173	9	1	6	3	PM
6	small stream near Ataahua	M36	803164	5	1	2	1	PT
7	Kaituna Rv @ SH75 (Ataahua)	M36	852147	9	1	7	2	PM
8	Okana Stream	M36	847174	1	1	3	2	PS
9	Kaituna Rv @ Parkinsons Rd	M36	854194	1	1	12	2	PM
10	small trib into Kaituna Rv on Parkinsons Rd	M36	853195	8	2	12	2	PS
11	trib into Kaituna Rv (upper near road end)	M36	900210	12	2	8	2	US
12	Upper Kaituna Valley	M36	895212	12	2	12	2	US
13	Mid Prices Stream	M36	864153	1	1	8	2	PS
14	Upper Prices Stream	M36	876161	3	2	8	2	US
15	Prices Stream near Willesden	M36	859143	1	1	8	2	US
16	Prices Stream @ SH75	M36	845126	4	2	4	2	PS
17	Garry Rv on Birch Hill Road	M34	570756	7	2	10	3	PL
18	Wooded Gully	M34	561793	12	2	12	2	UM
19	Maori Stream	M34	533786	4	2	11	2	PL
20	Washpool Stream on Birch Hill Rd	M34	535754	10	1	4	2	PS
21	Glentui Rv on Ashley Gorge Rd	M34	524756	12	2	3	2	PM
22	Glentui Rv @ DOC picnic site	L34	492783	12	2	12	2	VS
23	Ashley Rv @ Road bridge	L34	475752	4	2	9	3	VL
24	Ashley Rv @ lower bridge	L34	426757	2	1	9	3	VL
25	Trib into Ashley off Ladbrooks Hill	L34	417774	12	2	12	2	VS
26	Townsend Stream near Ashley Rv	L34	400793	1	1	9	3	UL
27	Ashley Rv above gorge	L34	410798	1	1	9	3	UL
28	Five Gully Stream, Mt Pember Station	L34	405818	1	1	1	1	PS
29	Whistler Stream	L34	412827	1	1	9	3	PL

Site No	Location	Map No.	Grid Ref.	RMC-C Cell	RMC-C Group	RMC-P Cell	RMC-P Group	Geomorphic Class
30	Broom Stream	L34	435845	1	1	1	1	PS
31	Ashley, Upper road bridge	L34	466867	1	1	9	3	PL
32	Duck Creek, on road to Island Hill	L34	466876	11	2	7	2	PS
33	Stream draining Ashley (Hill?)	L34	478888	1	1	5	3	UM
34	Stream past Okuku Falls	M34	525934	10	1	4	2	VT
35	trib into Okuku Downs Stream	M34	548938	3	2	3	2	VS
36	Okuku Rv @ upper Ford	M34	570948	1	1	5	3	PL
40	Trib into Cam on Church Bush Rd	M35	821623	5	1	4	2	PS
41	Cam Rv @ Revells Rd	M35	817617	7	2	12	2	PM
42	Cam @ Youngs Rd	M35	802634	11	2	8	2	PM
43	Stream on North Brook Rd	M35	792663	12	2	4	2	PT
44	Cam Rv @ Camside Rd	M35	796660	12	2	4	2	PT
45	Cam @ Coldstream	M35	788874	12	2	4	2	PT
46	Southbrook @ Lineside Rd	M35	776646	9	1	12	2	PS
47	Stream beside Rangiora/PLaxton Rd	M35	776635	12	2	4	2	PT
48	Stream on Todds Rd/Fernside Rd	M35	768638	10	1	4	2	PT
49	Stream on North Todd Rd	M35	772643	9	1	4	2	PT
50	Southbrook on Townsend Rd	M35	763651	12	2	4	2	PS
51	Small Drain Into Townsend Rd	M35	764644	1	1	4	2	PT
52	Small stream on No.5 Drain Rd	M35	760643	1	1	4	2	PT
53	Small stream on No.5 Drain Rd at Elarish	M35	760638	10	1	4	2	PS
54	Stream on Fawcetts Rd (upstream of road)	M34	765703	10	1	1	1	PT
55	Stream on Fawcetts Rd (downstream)	M34	765703	5	1	1	1	PM
56	Stream on Dixons Rd	M34	749711	11	2	1	1	PS
57	Stream on Mowatts Rd	M34	743719	11	2	1	1	PS
58	Stream on Carrs Rd near Mowatts	M34	745726	11	2	1	1	PS
59	Trib into Makerikeri Rv, Barkers Rd	M34	728711	10	1	1	1	PT
60	Stream on Barkers Rd corner	M34	687712	11	2	4	2	PT
61	Stream on Barkers Rd near Swamp rd	M34	697712	1	1	1	1	PT
62	Waipara Rv @ Stringers Rd	M34	830938	4	2	10	3	PL
63	Waipara @ Ladmores Rd	M34	766941	4	2	10	3	PL
64	Small trib on Ram Paddock Rd	M34	730935	11	2	1	1	VS
65	Forestors Culvert on Ram Paddock Rd	M34	728938	12	2	4	2	US
66	Waipara Rv south branch	M34	727958	3	2	9	3	PL
67	Dry Creek in Forestry Block	M34	725960	1	1	1	1	UT
68	Waipara Rv, North Branch	M34	732990	3	2	10	3	UL
69	Reservation gully, Mid Waipara branch	M34	685988	11	2	7	2	VS
70	Mid Waipara @ McDonald Downs Rd	M34	729990	7	2	11	2	UM

Site No	Location	Map No.	Grid Ref.	RMC-C Cell	RMC-C Group	RMC-P Cell	RMC-P Group	Geomorphic Class
71	Tommy's Stream	M33	712019	12	2	4	2	PS
72	North Branch Waipara Rv	M33	734042	12	2	11	2	PM
73	Waipara Rv Nth Branch @ Heathstock rd	M33	726084	1	1	1	1	PM
74	Dyfryn? Stream on Virginia Rd	M33	695108	10	1	2	1	VT
75	North Branch Waipara Rv @ Virginia Rd	M33	668093	12	2	12	2	VM
76	North Branch Waipara Rv @ Pannetts Bridge	M33	635096	9	1	4	2	US
77	Pig Gully	M33	615094	5	1	4	2	VT
78	Washpen Stream @ Murrays Rd	M33	742128	5	1	4	2	PT
79	Waitohi Rv @ Powers Rd	M33	740173	8	2	10	3	PL
80	Washpen Stream @ Horsley Down Rd	M33	800120	12	2	8	2	PS
81	Cust River on Swannonoa Rd	M35	715652	1	1	9	3	PL
82	Dockey's Stream at McIntoshs Rd	M35	690673	1	1	1	1	PS
83	Cust River on Oxford-Rangiora Rd	M35	661661	11	2	12	2	PM
84	Hunters Stream on Boundary Rd	M35	669652	9	1	3	2	PT
85	Hunters Stream on Springbank Rd	M35	650638	9	1	4	2	PS
86	Drainage ditch on Boundary Rd	M35	628639	5	1	4	2	PT
87	Drain on Gartery's Rd	M35	632645	1	1	2	1	PT
88	Trib into Cust River on Patersons Rd	M35	629675	1	1	1	1	PS
89	Cust River on Patersons Rd	M35	628670	6	1	8	2	PM
90	Cust River at Swamp Rd, near Cust	M35	603664	8	2	8	2	PM
91	Cust River on Tippings Rd	M35	576671	12	2	12	2	PS
92	Cust River on Bennetts Rd	M35	535678	8	2	8	2	PM
93	Cust River at Carleton Rd	M35	503692	9	1	1	1	PM
94	Eyre River at Steffens Rd	M35	507637	1	1	9	3	PL
37	Okuti River - top bridge on Okuti Valley Rd	N36	977137	12	2	12	2	VS
38	Tributary into Okuti River	N36	973136	12	2	12	2	VS
39	Tributary into Mid-Okuti River	N36	958134	6	1	12	2	VM
95	Okuti River at Ushers Rd	N36	945134	6	1	12	2	PM
96	Te Oka Stream near beach	N37	927066	1	1	8	2	UM
97	Stream at Tumbledown Bay	N37	917063	3	2	12	2	UT
98	Okuti River at Kinloch Rd	N36	935134	11	2	12	2	PS
99	Hukahuka Turoa Stream at waterlevel recorder	N36	937175	8	2	12	2	PM
100	Hukahuka Turoa Stream at Montgomeries Rd	N36	933188	3	2	12	2	US
101	Hikuika Stream at end of Whites Rd	N36	968208	12	2	12	2	VS
102	Hikuika Stream on Puaha Rd	N36	965181	9	1	12	2	PS
103	Opuahou Stream on Puaha Rd	N36	967184	10	1	12	2	PS
104	Pigeon Bay Stream at Kukupu	N36	018208	11	2	12	2	VS
105	Pigeon Bay Stream at Pigeon Bay Rd	N36	018212	6	1	8	2	US

Site No	Location	Map No.	Grid Ref.	RMC-C Cell	RMC-C Group	RMC-P Cell	RMC-P Group	Geomorphic Class
106	Pigeon Bay Stream at Wilsons Rd	N36	018225	2	1	12	2	US
107	Totara Stream, trib into Pigeon Bay Stream	N36	016233	9	1	8	2	PS
108	Holmes Stream at Port-Levy Pigeon Bay Rd	N36	002258	5	1	12	2	UM
109	Te Kawa Stream at Port Levy	N36	952273	2	1	12	2	PM
110	Te Kawa Stream on Port-Levy Little River Rd	N36	940262	5	1	8	2	US
111	Tributary into Te Kawa Stream	N36	923235	12	2	12	2	VS
JQ1	Heathcote River at Pioneer Park	M36	787375	4	2	12	2	PS
JQ2	Heathcote River at Warren Crescent, Curtletts Reserve	M36	761390	12	2	12	2	PS
JQ3	Nottingham Stream at Nichols Rd	M36	747363	8	2	7	2	PS
JQ4	Small tributary into Halswell River	M36	779315	12	2	4	2	VT
JQ5	Tributary into Halswell River, Early Valley Rd	M36	768322	12	2	3	2	US
JQ6	Lower tributary into Halswell River, Early Valley Rd	M36	755319	5	1	7	2	PT
JQ7	Halswell River at Osterholts Rd	M36	747312	1	1	7	2	PS
JQ8	Halswell River at Tai Tapu bridge	M36	735274	11	2	12	2	PM
JQ9	Cam River at SH 1 bridge	M35	824614	10	1	8	2	PM
JQ10	Cam River off Tuahiwi Rd	M35	814623	3	2	11	2	PM
JQ11	Cam River at Bramlegs Rd	M35	805625	10	1	11	2	PM
JQ12	Cam River at Waikorara Rd	M35	801650	10	1	3	2	PS
JQ13	North Brook River at Boys Rd	M35	788657	5	1	8	2	PS
JQ14	Ashley River at Cones Rd Bridge	M35	764696	1	1	9	3	PL
JQ15	Makerikeri River on Dixon's Rd bridge	M34	735709	5	1	9	3	PL
JQ16	Makerikeri River on Station Rd	M34	708760	10	1	11	2	PS
JQ17	Marerikeru River at Ford	M34	721785	6	1	10	3	US
JQ18	Trib into Marerikeru River on Terrace Rd	M34	703776	5	1	4	2	PS
JQ19	Grey River at Mt Grey Rd ford	M34	685817	3	2	9	3	PM
JQ20	West branch of Grey River at Mt Grey ford	M34	684817	3	2	10	3	UM
JQ21	Grey River at White Rock Rd	M34	668785	6	1	9	3	PL
JQ23	Tracey River, tributary of Grey	M34	668796	12	2	3	2	PS
JQ24	Keretu River at Loburn-Whiterock Rd bridge	M34	651809	3	2	10	3	PM
JQ25	West branch of Karetu River on Taffes Glen Rd	M34	646817	9	1	8	2	PT
JQ26	Kowhai Stream at Taffes Glen Rd	M34	626835	6	1	2	1	PS
JQ27	Fox Creek on Taffes Glen Rd	M34	605845	8	2	11	2	US
JQ28	Okuku River at Whiterock Downs station	M34	607845	1	1	9	3	UL
E1	Heathcote River @ Pioneer Park	M36	787375	4	2	11	2	PS
E2	Halswell River at Osterholts Rd	M36	747312	2	1	8	2	PS
E3	Okana Stream	M36	847174	1	1	3	2	PT
E4	Saltwater at SH1 (tidal)	J39	700417	2	1	11	2	PL

Site No	Location	Map No.	Grid Ref.	RMC-C Cell	RMC-C Group	RMC-P Cell	RMC-P Group	Geomorphic Class
E5	Saltwater Creek @ Fairview Rd	J39	684428	10	1	12	2	PL
E6	Otipua @ Brushfield Rd	J38	677643	12	2	4	2	VS
E7	Saltwater @ Brockley Rd	J39	625429	11	2	4	2	VT
E8	Waikakahi @ Te Maihoroa Rd	J41	595861	10	1	7	2	PS
E9	Waikakahi @ Glenavy Tawai Rd (Upstream only)	J41	579868	4	2	8	2	PS
E10	Waikakahi @ Cock and Hen	J40	491909	10	1	3	2	PT
E11	Awakino @ ford on Awakino Rd	I40	059048	6	1	5	3	UM
E12	Little Awakino River @ Ford Awakino Rd	I40	038057	1	1	4	2	UT
E13	Awakino East branch	I40	040018	1	1	9	3	VM
E14	West Branch of Awakino	I40	040019	1	1	9	3	VS
E15	Spring Creek SH8 (non willow stretch)	H39	726478	3	2	10	3	PT
E16	Twizel SH8	H38	793573	4	2	10	3	PL
E17	Frasers Stream d/s ford	H38	751605	3	2	10	3	PM
E18	Dry Stream @ Canal Rd (downstream)	H38	762618	1	1	9	3	PS
E19	Bullock Creek Culvert Upstream	I38	168769	4	2	9	3	PT
E20	Bains Crossing @ SH8 downstream of culvert	J38	346782	1	1	2	1	PS
E21	LI @ Lincoln	M36	685297	12	2	12	2	PT
E22	LII @ McDonalds Rd bridge (upstream)	M36	681257	2	1	6	3	PM
E23	LII @ McDonalds Rd bridge (downstream)	M36	681257	1	1	11	2	PM
E24	Selwyn @ Coes Ford	M36	625232	4	2	11	2	PL
E25	Irwell @ ChCh Leeston Rd (upstream)	M36	575205	11	2	3	2	PT
E26	Hanmer Rd Drain	M36	567189	5	1	1	1	PS
E27	Harts @ Leeston and Lake Rd	M36	558118	7	2	12	2	PM
E28	Drain on Heslerton Rd (downstream)	L36	400228	10	1	1	1	PT
E29	Drain on Heslerton Rd (upstream)	L36	400228	10	1	3	2	PT
E30	Drain on Herleston Rd (downstm only)	L36	441203	9	1	1	1	PT
E31	Drain on Herleston Rd (upstm only)	L36	441203	1	1	1	1	PT
E32	Hororata on Derretts Rd (upstm only)	L36	281376	3	2	11	2	PM
E33	Drain on Cordy's Rd (downstm only)	L36	244399	1	1	2	1	PT
E34	Selwyn @ Bealey Rd (downstm only)	L36	314390	1	1	9	3	PL
E35	Hawkins @ SH72 (upstm only)	L35	317542	10	1	2	1	PM
E36	Selwyn @ SH72 (upstm only)	L35	230467	8	2	11	2	PL
E37	Acheron @ Lake Coleridge Rd	K35	955555	3	2	6	3	PS
E38	Trib of Camp Gully Stm on Coleridge Rd (upstm only)	K35	020455	1	1	1	1	PL
E39	Camp Gully Stm @ SH72	K35	027414	6	1	9	3	PM
E40	Unnamed trib of Ashburton River @ SH72 (upstm only)	K36	917326	1	1	2	1	PT
E41	Ashburton @ SH72 North Branch (downstm only)	K36	915324	3	2	9	3	PL

Site No	Location	Map No.	Grid Ref.	RMC-C Cell	RMC-C Group	RMC-P Cell	RMC-P Group	Geomorphic Class
E42	Staverly Stm @ SH72 (downstm only)	K36	853277	10	1	2	1	PT
E43	Bowyers Stm @ SH72 (downstm only)	K36	846236	8	2	10	3	PM
E44	Drain/Race on Tramway Rd	K36	894188	1	1	1	1	PL
E45	Drain on Thompson Track Rd	K36	075174	5	1	1	1	PT
E46	Harding Creek @ Lyndhurst Culvert	K36	016135	6	1	7	2	PT
E47	Stm on Thompson Track Rd (downstm only)	K36	939183	10	1	3	2	PT
E48	Stm on Thompson Track Rd (upstm only)	K36	939183	1	1	3	2	PT
E49	Ashburton River South Branch at Buicks Bridge Hakatere Heron Rd (upstream only).	J36	615344	6	1	9	3	PL
E50	Puddle Hill Creek at Hakatere Heron Rd (downstream only)	J36	623319	10	1	6	3	PS
E51	Potts River at Hakatere Potts Rd	J36	446348	1	1	9	3	PL
E52	Whiskey Creek at Hakatere Potts Rd (upstream only)	J36	493320	3	2	6	3	PS
E53	Lambies Stream at Hakatere Potts Rd	J36	576308	9	1	6	3	PS
E54	Woolshed Creek at Ashburton Gorge Rd (downstream only)	K36	762240	11	2	2	1	PM
E55	Woolshed Creek at Ashburton Gorge Rd (upstream only)	K36	762240	2	1	5	3	PL
E56	Drain on Montatts Rd (dry)	K36	709141	11	2	1	1	PT
E57	Hinds at SH72 below bridge (downstream only)	K37	836097	4	2	9	3	PM
E58	Drain on Mill Rd (upstream only)	K37	019043	5	1	1	1	PT
E59	Drain on Rules Rd (downstream only)	L37	276041	1	1	1	1	PT
E60	Wakanui on Corbetts RD (downstream only)	L37	189883	5	1	2	1	PT
E61	Hinds at SH7	K37	961982	8	2	10	3	PL
E62	Drain on Surveyors Rd (upstream only)	K37	017849	5	1	11	2	PT
E63	Drain on Surveyors Rd (downstream only)	K37	017849	9	1	2	1	PT
E64	Drain on Boltons Rd (downstream only)	K37	822953	1	1	2	1	PT
E65	Coopers Creek at SH72 (downstream only)	K37	719865	10	1	7	2	PS
E66	Coopers Creek at SH72 (upstream only)	K37	719865	3	2	10	3	PS
E67	Black Creek SH 79 (upstream only)	J38	659749	10	1	2	1	PT
E68	Black Creek SH79 (downstream only)	J38	659749	5	1	1	1	PT
E69	Trib of Kakahu on Pletcher Rd	J38	618698	5	1	3	2	PT
E70	Rangitira at Seven Sisters Rd above bridge (upstream only)	J38	662667	12	2	3	2	PT
E71	Raupo Creek on Walker Rd	J38	664625	9	1	2	1	PS
E72	Kohika at Twinstock Rd (partly dried up)	J39	579253	9	1	2	1	PT
E73	Sir Charles Creek at Lindsays Pass Road, below road	J40	633033	11	2	7	2	PT
E74	Trib of Waihao at Gum Tree Plat Rd	J40	528995	5	1	2	1	PT
E75	Papaka Stream at Washdyke Rd (downstream only and almost stagnant)	J39	687487	5	1	9	3	PS
E76	Unnamed trib of Waihao River at Mt Harris Rd (partly dried up)	J40	478995	12	2	2	1	PT

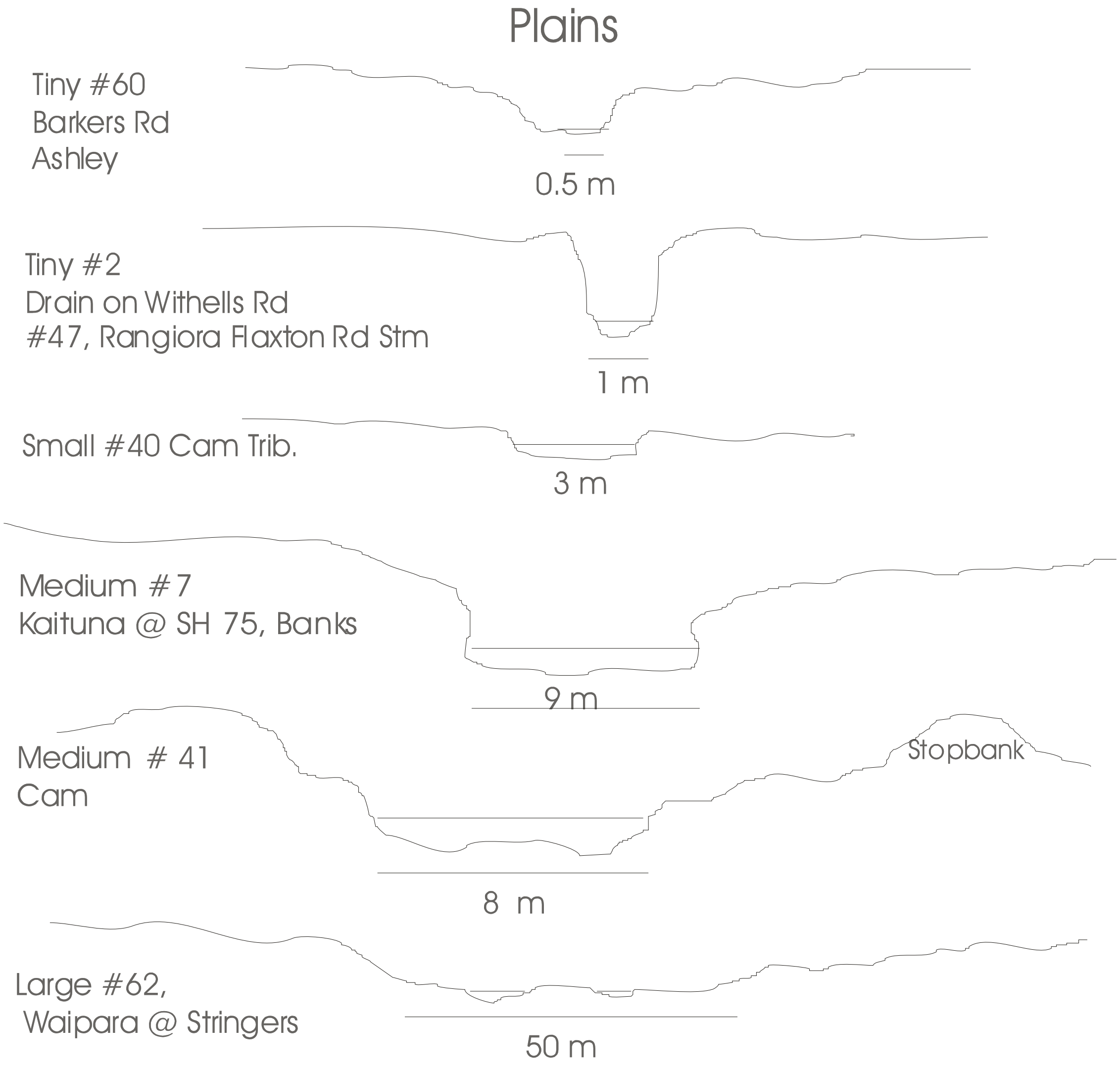
Site No	Location	Map No.	Grid Ref.	RMC-C Cell	RMC-C Group	RMC-P Cell	RMC-P Group	Geomorphic Class
E77	Trib of South Branch Waihao River at Waihaorunga Rd	J40	373049	9	1	6	3	PT
E78	Sth branch Waihao River at Kaiwarua Rd (downstream only)	J40	350148	5	1	1	1	VS
E79	Stony Creek on Stony Creek Rd (downstream only)	J40	437047	10	1	2	1	PT
E80	Waikokopara at SH82 (downstream of bridge)	J40	534036	9	1	2	1	PS
E81	Waimate Creek at Mill Rd	J40	532070	6	1	5	3	PS
E82	Hook Stream at Waimate Hunter Rd (downstream only)	J40	543113	10	1	3	2	PT
E83	Hook River at Waimate Hunter Rd	J40	531152	7	2	9	3	PM
E84	Makikihi on Pakihi Rd	J40	535192	10	1	5	3	PS
E85	Teschemaker at Back line Rd (dried up. Below bridge only)	J39	505237	11	2	5	3	PL
E86	Otaio River at School Crossing RD (partly dry, almost all)	J39	490312	7	2	9	3	PT
E87	Unnamed trib of Paeora River at Paeora River Rd (dry)	J39	598370	1	1	9	3	PT
E88	Trib of Washdyke on Kings Rd (almost dry)	J39	669484	11	2	1	1	PT
E89	Oaklands Stream on Kelands Hill Rd (partly dry, stagnant)	J39	670481	9	1	1	1	PT
E90	Rosewill Stream at Rosewill Valley Rd (partly dry, stagnant)	J39	665499	9	1	3	2	PT
E91	Papaka at Levels Store Rd (dried up)	J38	666515	1	1	1	1	PT
E92	Papaka at Connells Rd	J38	626543	11	2	2	1	PT
E93	Trib of Papaka stream on Marshall Rd (downstream only, dry)	J38	581536	1	1	1	1	PT
E94	Rosewill at Bassett Rd (partly dried up)	J38	620514	10	1	3	2	PT
E95	Oakwood at Brockley Rd(downstream only, stagnant, partly dry)	J39	613482	5	1	1	1	PT
E96	Taiko at Paeora Ford Rd (partly dry)	J39	549480	11	2	2	1	PT
E97	Trib of Pig Hunting Creek at Briens Rd (dry)	J39	585437	12	2	2	1	PT
E98	Trib of Pig Hunting Creek at Holme Station Rd (upstream only)	J39	593410	1	1	9	3	PT
E99	Pig Hunting Creek at George Ward Rd (upstream only)	J39	627404	11	2	3	2	PT
E100	Pig Hunting Creek at SH8	J39	688368	9	1	2	1	PS
E101	Unnamed stream (semi dry, stagnant)	J39	657409	9	1	1	1	PT
E102	Otipua Creek North Branch at Claremont Rd Reserve (only just moving)	J39	660451	12	2	11	2	PT
E103	Sutherlands Creek SH8 (dry)	J38	544570	1	1	5	3	PT
E104	Burnetts stream at Cannington Rd (partly dried up, downstream only)	J38	460524	12	2	3	2	PT
E105	Unnamed trib of Tengawai at Cricklewood Rd (upstream only)	J38	345669	1	1	1	1	PT
E106	Unnamed trib of Tengawai River at Cricklewood Rd (downstream only)	J38	347670	12	2	3	2	PT
E107	Coal Stream SH8 (downstream only)	J38	371724	11	2	2	1	PS
E108	Station Creek on Plantation Rd	J40	366927	7	2	5	3	PS
E109	Deep Creek at Plantation Rd	J40	381952	11	2	2	1	PS

Site No	Location	Map No.	Grid Ref.	RMC-C Cell	RMC-C Group	RMC-P Cell	RMC-P Group	Geomorphic Class
E110	Ross Stream at Clayton bridge on Lochaber Rd	J40	404983	10	1	2	1	PT
E111	Three Springs Creek at Three Springs Rd.	I38	298799	2	1	3	2	PS
E112	Halls Stream at Nixons Rd (dry)	J38	339768	12	2	2	1	PS
E113	Raincliff Stream at Elliots Bridge (very slow moving)	J38	456793	7	2	2	1	PS
K1	Unnamed AS1	N33	183108	1	1	7	2	VM
K2	Hurunui R @ SH1 bridge	N33	179121	4	2	10	3	VL
K3	Unnamed AS2	N33	286168	9	1	5	3	PT
K4	Leader River @SH1	O32	348354	8	2	9	3	PL
K5	Conway River	O32	372428	3	2	9	3	PL
K6	Waingaro Stream	O32	353430	8	2	8	2	VS
K7	Limestone Stream	O32	475442	5	1	4	2	PM
K8	Conway River lower	O32	463442	4	2	10	3	PL
K9	Ploughman Creek at Conway Plat Rd	O32	462389	9	1	4	2	VT
K10	left branch, Big Bush Gulley Stm	O32	456381	4	2	10	3	VS
K11	right branch, Big Bush Gulley Stm	O32	456380	4	2	10	3	UT
K12	below confluence of left and right branches	O32	458379	4	2	12	2	US
K13	Silvery Crk @ Conway Plat Rd	O32	473410	1	1	6	3	PS
K14	Hundalee Stm @ SH1	O32	452476	12	2	12	2	VS
K15	Limestone Stm @SH1	O32	461486	8	2	12	2	VS
K16	Okarahia Stm	O32	464510	4	2	11	2	VL
K17	T Moto ?moki Stm @ Laidlaws Rd	O32	498540	11	2	8	2	US
K18	stm before Paraititahi tunnel	O31	576620	12	2	12	2	VT
K19	Kahutara River@ SH1	O31	584635	6	1	10	3	PL
K20	Flags Crk @SH1	P30	5197	9	1	4	2	PT
K21	Wordside Crk @ SH1	P30	999191	10	1	5	3	VL
K22	Kekerengu R @ lower rd bridge	P30	927113	8	2	10	3	PL
K23	trib into Kekerengu R	P30	926112	1	1	4	2	VT
K24	Valhalla Stm	P30	919104	1	1	9	3	VS
K25	Shingle Fan Bridge No.2 @ SH1	P30	865989	1	1	9	3	PM
K26	McLean Stm above pine plantation	P30	78723	1	1	6	3	US
K27	lower site of McLean Stm	P30	78920	3	2	9	3	UL
K28	Ohau Stm @ SH1	P31	783844	12	2	12	2	VS
K29	Kowhai River @ ford	O31	610686	3	2	9	3	PL
K30	Kahutara River@ dairy farm	O31	545665	2	1	9	3	PM
K31	Cribb Crk @ SH70	O31	521691	3	2	9	3	PL
K32	Katutara River @ SH70	O31	470690	3	2	9	3	UL
K33	Trib into Katutara R	O31	465696	4	2	9	3	US
K34	Great Burn @ Scott's Rd bridge	O31	474669	12	2	8	2	US

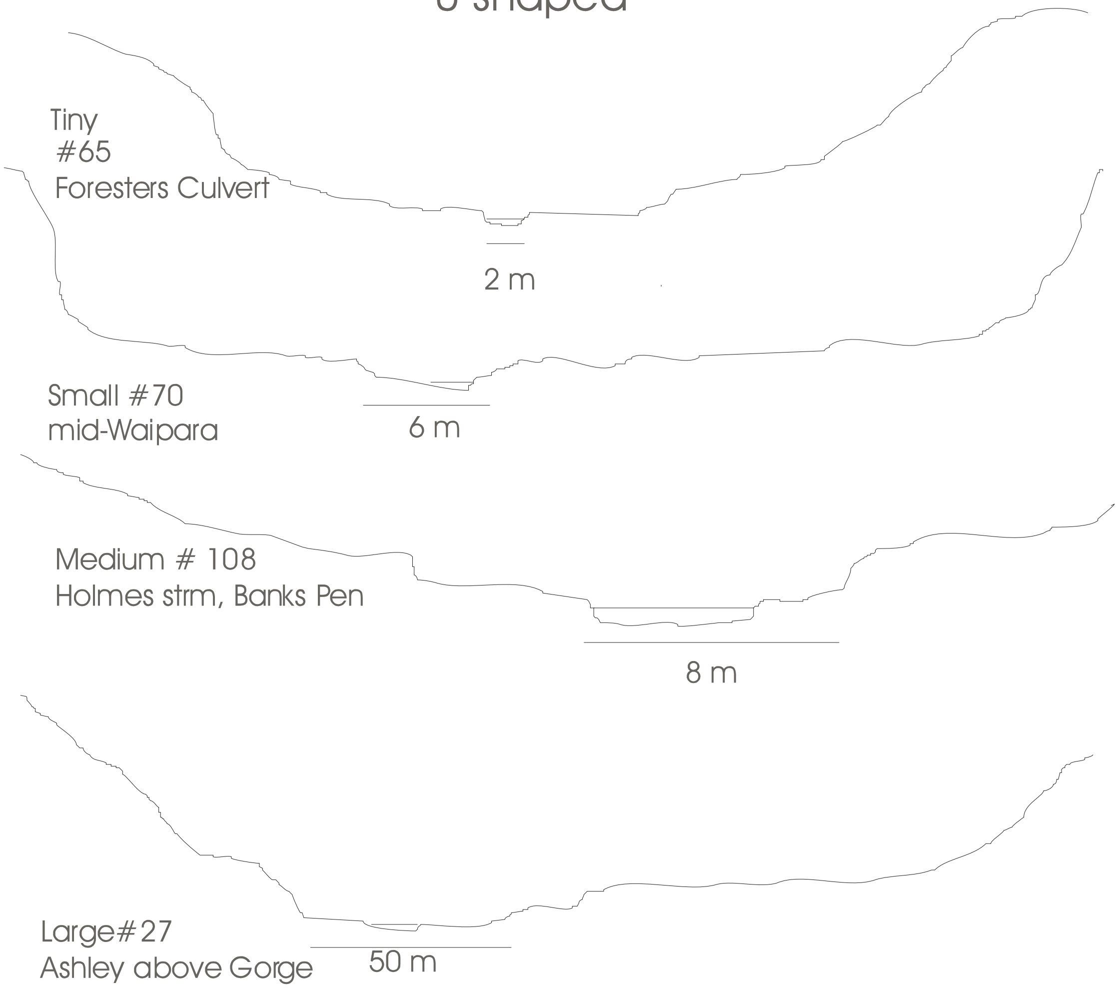
Site No	Location	Map No.	Grid Ref.	RMC-C Cell	RMC-C Group	RMC-P Cell	RMC-P Group	Geomorphic Class
K35	Green Burn @ SH70	O31	431680	3	2	4	2	UM
K36	Charwell River @ SH70 bridge	O31	399651	1	1	9	3	UL
K37	Stag Stm	O32	391565	7	2	12	2	US
K38	Conway R @ Cloudy Range Rd bridge	O31	325622	2	1	9	3	VL
K39	Conway R @ SH70 bridge	O31	325607	2	1	9	3	VL
K40	Mason River	N32	241561	12	2	11	2	US
K41	Mason River @ road bridge	N32	236558	3	2	9	3	UL
K42	Wandel R @ SH70	N32	182468	1	1	9	3	PL
K43	Lottery R @SH70	N32	170442	1	1	9	3	PM
K44	Dog brook	N32	126405	5	1	4	2	PM
K45	Blind Stm on Leslie Hills Rd	N32	47414	1	1	3	2	PM
K46	Stm on Jack's Pass	N32	958594	8	2	12	2	UT
K47	Peter's Valley Stm	N31	933627	6	1	5	3	UM
K48	Timm's Stm @ bridge	N31	925717	2	1	9	3	US
K49	Hornble Stm @ Tophouse Rd	N31	931665	3	2	2	1	PS
K50	Pass Stm	N31	9602	1	1	9	3	UM
K51	Dog Stm on Jollies Rd	N32	966543	12	2	12	2	US
K52	Hamner River off Hossack Rd	N32	998489	6	1	9	3	PM
K53	Brown's Stm	N32	907380	2	1	10	3	VS
K54	Countess Stm @ SH7	N32	984327	1	1	1	1	PS
K55	Stanton Stm by Leader-Waiau Rd	N32	209410	1	1	1	1	US
K56	Stanton Stm by road bridge	N32	216419	12	2	4	2	US
K57	Stanton Stm near sheep yard	N32	234427	1	1	3	2	US
K58	Leader River @ Mendip Hills Stm	O32	326404	3	2	10	3	PL
K59	Motanau R @ Buchanans Rd	N34	158959	12	2	8	2	UL
K60	Motanau R in gorge	N34	132970	8	2	11	2	VM
K61	Motanau R @ Sudbury	N34	106980	12	2	8	2	US
K62	Cave Crk @ Motanau Beach Rd	N33	105008	2	1	1	1	US

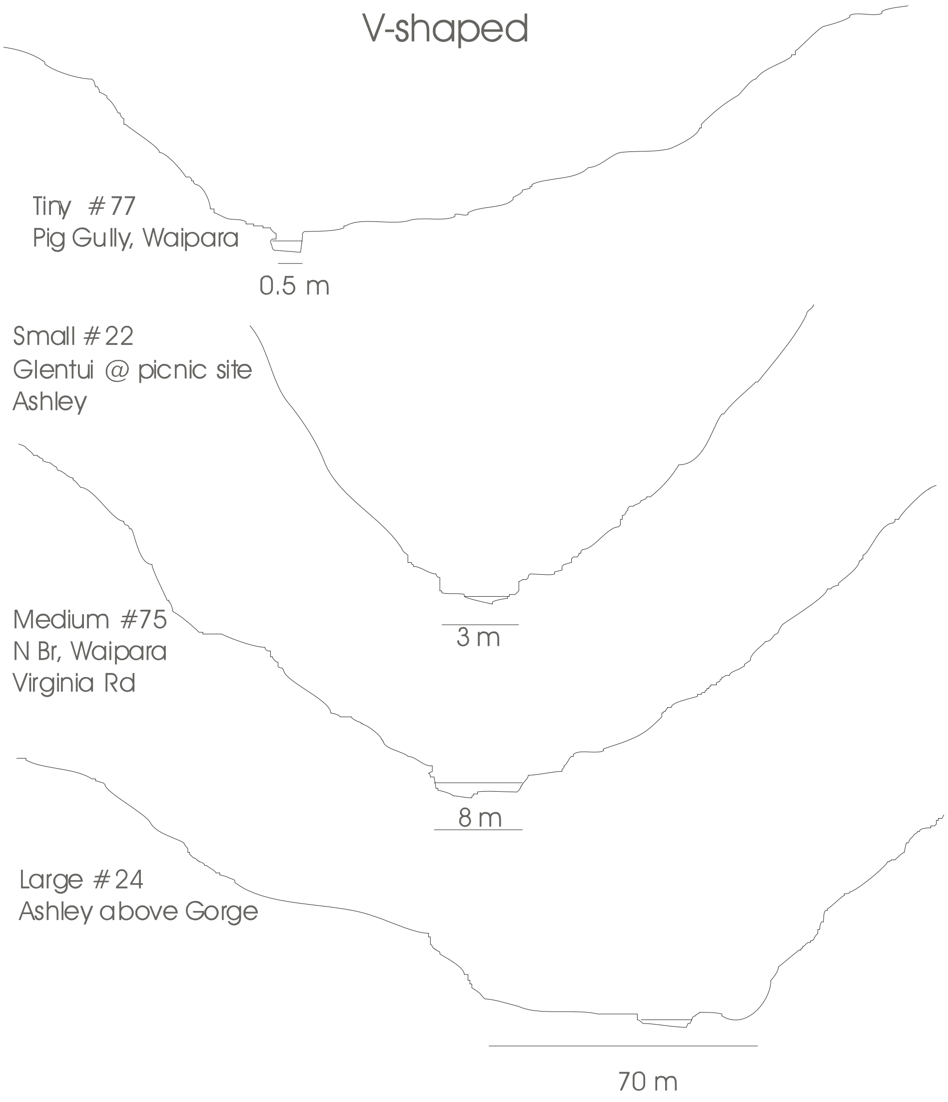
8. Appendix 2:

Representative cross-section sketches of geomorphic riparian management classes.



U shaped


Tiny
#65
Foresters Culvert
2 m
Small #70
mid-Waipara
6 m
Medium # 108
Holmes strm, Banks Pen
8 m
Large#27
Ashley above Gorge
50 m


V-shaped
Tiny #77
Pig Gully, Waipara
0.5 m
Small #22
Glentui @ picnic site
Ashley
3 m
Medium #75
N Br, Waipara
Virginia Rd
8 m
Large #24
Ashley above Gorge
70 m