MANAGING RIPARIAN ZONES:

A contribution to protecting New Zealand's rivers and streams

Volume 2: Guidelines

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INTRODUCTION TO VOLUME 2

THE PURPOSE AND SCOPE OF THIS DOCUMENT

The purpose of this two-part document (*Volume 1: Concepts, Volume 2: Guidelines*) is to provide information on how to improve the management of riparian[1] zones along streams and rivers in modified and developed[2] landscapes, particularly in agricultural areas. It adds to a suite of documents already available on water management in New Zealand and complements a guidelines document on management of riparian zones in production forests currently being prepared by the Logging Industry Research Association.

Improving conditions in streams and rivers through riparian management is consistent with the aims of New Zealand's resource laws. The Resource Management Act (1991) promotes the sustainable use of resources while "avoiding, remedying, or mitigating any adverse effects on the environment". Riparian management is an important tool for resource users and managers to meet their obligations under the Act (see *Volume 1: Section 3: The legal framework*).

WHO THIS DOCUMENT IS FOR

We have tried to keep both documents non-technical but the application of some guidelines requires a high skill level (see next section). For this reason we consider the document will receive widest use by staff in local and regional councils and management agencies such as the Department of Conservation. Nevertheless, the success of the document will depend also on it being used widely in the community and we hope it will be read, understood (at least in part) and, most importantly, applied by a wide cross-section of people. To assist with this it is hoped to publish later a simplified booklet on riparian management techniques based on this document.

As our understanding of the interactions between terrestrial and aquatic ecosystems improves, the guidelines will be reviewed and further editions published.

HOW TO USE THIS DOCUMENT

- If you wish to improve your understanding of the environmental problems affecting rivers and streams in New Zealand and if you wish to know more about the natural processes which go on in rivers and streams, you should browse *Volume 1: Concepts*. This will help you to form judgements about the nature of the problems you may face, understand the interactions between different stream processes, and help you to select the guideline(s) most relevant to you.

- Some of the information in *Volume 1: Concepts* is repeated in *Volume 2: Guidelines* to reinforce important concepts. It is intended that each guideline can be used as a stand-alone sub-document; cross-references to other relevant guidelines are made in each. *Feel free to make photocopies of individual guidelines for your own particular purposes.*

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[1] Riparian – on or of the river bank. The Concise Oxford Dictionary.

[2] Those areas where the original vegetation, usually native forest, has been mostly removed and the land developed for agriculture, plantation forestry, horticulture, and urban and industrial use (see *Volume 1: Concepts: Section 1.5*).

- If you wish to find out more about the science behind the concepts you are strongly recommended to read Quinn *et al.* 1993 (see next section and References). This paper provides the scientific underpinning for *Volume 1: Concepts.*

- If you wish to build up a resource kit to add to this document, you are recommended to purchase or acquire the books listed in the section below. Sometimes you will be referred to these books for important information that is not covered in this volume.

- If you don't understand the techniques outlined in this volume, don't panic! Some techniques require a high level of skill in their interpretation and you will need to seek expert advice and input. In many cases, costly management decisions may be involved and considerable planning and investigation will be required before any management proposals are even drafted (see section on planning a riparian management scheme later in this volume). Names and addresses of the organisation(s) to contact for expert assistance are provided, where appropriate, in the guidelines.

- The guidelines are aimed particularly at land managers and it is assumed that they already know about aspects of land management such as fencing, grazing regimes and weed and pest control. Therefore, the guidelines make only general statements about these aspects and leave it up to the reader to develop the detail.

IMPORTANT READING KIT

Some of the guidelines are designed to be used in association with other publications. These publications contain detail that it would be impractical to include in this report. In particular, it is recommended that you obtain the Plant Materials Handbook for Soil Conservation: Vol. 1: Principles and practices, Vol. 2: Plant materials, Van Kraayenoord and Hathaway, 1986a,b; and Vol 3: Native plants, Pollock, 1986. These are available from *Publications Section, Landcare Research, Massey Campus, Private Bag 11-052, Palmerston North.* Cost is $155 for the set of 3. Guideline: **STABILITY** is intended to be used with these three volumes, but a number of other guidelines also refer to them.

Some of the guidelines require information such as stream flow. How to gauge stream flow and make other such measurements is described in Fenwick, 1991: Hydrologists Field Manual. NIWA Science and Technology series No. 5. This is available from *NIWA, PO Box 8602, Christchurch*, and costs $75.

At least two of the guidelines require you to assess river stability using the Pfankuch method. This is described in greater detail, with diagrams, in Collier, 1992: Assessing river stability: use of the Pfankuch method. DoC Internal Report No. 131. This report costs $9 and is available from *Publications Section, Science & Research Division, DoC, PO Box 10-420, Wellington.*

A more detailed account of the science underpinning the guidelines is provided in Quinn *et al.*, 1993: Riparian zones as buffer strips: a New Zealand perspective. Copies of this paper are available from *NIWA, PO Box 11-115, Hamilton.*

Another useful publication is Native Forest Restoration – A Practical Guide for Landowners, Porteus, 1993. This is available from *Queen Elizabeth the Second National Trust, PO Box 334, Wellington*, and costs $29.95 for non-members and $24.95 for members. As well as providing information on aspects such as native plant propagation, planting, maintenance etc., it also has very useful material on animal and weed control.

Similar broad-based advice is also provided in Buxton, 1991: New Zealand Wetlands – A Management Guide. This costs $20 and is available from *Publications Section, Science & Research Division, DoC, PO Box 10-420, Wellington.* This report contains guidelines on the management, restoration and construction of wetlands, and much of the information is very appropriate to riparian zones.

A recent publication from DoC – Weeds in New Zealand Protected Natural Areas Database by Timmins and Mackenzie, 1995, may also be useful. It contains information on the ecology and control of a number of environmental weeds. It can be obtained from *Publications Section, Science & Research Division, DoC, PO Box 10-420, Wellington*, and costs $45.

Similarly, West, 1994: Wild willows in New Zealand – proceedings of a Willow Control Workshop, provides information on the chemical (and other) control of willows, and the selection of non-weed willow and poplar species. This report costs $15 and is available from *Publications Section, Science & Research Division, DoC, PO Box 10-420, Wellington.*

Another recent DoC publication – Collier (Ed.), 1994: The Restoration of Aquatic Habitats – has a focus on riparian management. One chapter in particular, by Howard-Williams and Pickmere, documents the changes that occurred to a stream and its associated riparian zones over a number of years after stock were fenced out. It includes colour photographs. This report is available from *Publications Section, Science & Research Division, DoC, PO Box 10-420, Wellington*, and costs $17.

WHAT'S IN *VOLUME 1: CONCEPTS*

The main purpose of *Volume 1* is to provide a full account of the concepts that lie behind riparian management in the context of water management and conservation in New Zealand. It provides important background information to help the reader determine how best to use the guidelines presented in *Volume 2.*

In *Volume 1: Concepts* you can read about:

- The circumstances in New Zealand which make this document necessary. *(Volume 1: Section 1.5)*
- Why riparian zones are important. *(Volume 1: Section 1.6)*
- The vision behind this document. *(Volume 1: Section 1.7)*
- The limitations to riparian management. *(Volume 1: Section 1.8)*
- The concepts behind riparian management (*Volume 1*: *Section 2*)
- The legal framework relevant to riparian management. *(Volume 1: Section 3)*

IMPORTANT CONCEPTS FOR RIPARIAN MANAGEMENT SCHEMES

A number of general concepts discussed in *Volume 1: Concepts* are particularly important when designing suitable riparian management strategies. These concepts are summarised below.

- The influence of riparian zones is much larger than would be expected from their size relative to the rest of the catchment..

- Riparian management techniques for the restoration of instream ecological values and improvement of water quality depend primarily on effective management of riparian vegetation. By careful selection of the mix of species planted within a riparian community, it is possible to beneficially modify at the same time: light, temperature, nutrient and sediment regimes, channel and bank stability, carbon inputs, and habitat for terrestrial species. In some places (e.g., areas historically covered in tussock), it may not be desirable to plant trees if the management goal is to restore natural conditions.

- Changes to riparian management alongside small streams will generally exert a larger influence on stream functioning than they will alongside large lowland rivers. Lowland river management through riparian planting largely entails management of smaller streams further upstream. This concept is vital to the design of riparian management strategies for catchments.

- Temperature, river flows, streambed substrates, food resources, nutrient and sediment regimes are influenced by conditions both on-site and up-stream.

- Inputs of nutrients (nitrogen and phosphorus), suspended solids, pesticides and microbes occur unevenly along a river system and within a watercourse reach. Consequently, these inputs are more effectively managed by targeting remedial measures at important source areas within the catchment rather than by adopting catchment-wide control measures.

- Riparian wetlands are believed to play important roles in regulating runoff, removing nutrients, providing carbon and increasing habitat diversity. Most nitrate in groundwaters passing through wet, organic rich riparian seeps is removed by denitrification.

- Shading is widely recommended for aquatic plant control and can favour the development of "clean-water" invertebrate communities. Riparian vegetation reduces the amount of solar and atmospheric radiation which reaches the water surface. This will reduce light levels and maximum water temperatures, especially in small streams.

- Planting trees and shrubs alongside developed watercourses will increase supplies of terrestrial carbon to streams. Wood that is retained in river channels serves many important functions.

- Restoration of native riparian forest alongside developed streams should increase habitat diversity and the diversity of native plant and animal communities.

- The beneficial results of riparian zone management on streams are often not immediate and may take several years to become evident. Stream shape will probably take considerably longer to reach a new equilibrium.

HOW *VOLUME 2: GUIDELINES* IS STRUCTURED

Volume 2 is divided into three main parts: an introduction to help you navigate through the report, a section on planning a riparian management scheme and, thirdly, the guidelines.

Where appropriate, each of the guidelines contains information on:

- The nature of the problems addressed by the guideline (includes reiteration of important points from *Volume 1: Concepts*).
- Ways in which riparian management can help solve the problem.
- Objectives and targets for management.
- What data are required to help select the most appropriate management practice.
- Field investigations necessary to collect data and information.
- Predictive methods to help in assessment of what riparian management might achieve.
- Methods of implementation.
- Justifications and assumptions associated with each guideline.
- Potential side effects and limitations of the proposed management.
- Confidence limits associated with the proposed methods.
- Appendices of important information to assist in using the guidelines.

The following guidelines are provided:

- Increasing channel and bank stability (**STABILITY**).
  - Protecting streambanks by planting trees and shrubs (**STABILITY: TREES**).
  - Managing remnant vegetation on streambanks (**STABILITY: REMNANT**).
  - Managing stock grazing on damaged streambanks (**STABILITY: STOCK**).
- Reducing inputs to watercourses via overland flow (**CONTAMINANT**).
- Reducing inputs to watercourses in subsurface flow (**NITRATE**).
- Improving the light climate of streams (**LIGHT**).
- Improving watercourse temperature regimes (**TEMPERATURE**).
- Improving inputs of terrestrial carbon to watercourses (**CARBON**).
  - Improving the supply of terrestrial carbon to watercourses (**CARBON: SUPPLY**).
  - Improving the quality of terrestrial carbon in watercourses (**CARBON: QUALITY**).
  - Increasing the retention of terrestrial carbon inputs (**CARBON: RETENTION**).
- Attenuating floodflows (**FLOW**).
- Increasing terrestrial habitat diversity (**HABITAT**).

Each guideline has been given an abbreviated code (referred to in capitals above) to assist users in finding their way around *Volume 2: Guidelines*. We do not currently have enough information to develop a generalised guideline for managing dissolved phosphorus concentrations in drainage waters.

Note that in *Volume 2: Guidelines* figure and table numbering in each guideline applies only to that guideline, and is not consecutive through the report.

PLANNING A RIPARIAN MANAGEMENT SCHEME

IS THERE A PROBLEM?

All riparian management schemes begin with a problem of some sort. The scale, seriousness and location of the problem usually determine the amount of effort and resources that end up being applied to solve it. Restoration programmes will vary from tree planting or fencing of small areas on a single property, perhaps to improve scenic and property values, to catchment wide programmes aimed at protecting the quality of a major water resource.

The first step in any scheme, big or small, is recognising and reviewing the problem(s) causing concern and determining where they occur in the drainage system (see Figure 1).

MAKING AN INVENTORY

Making an inventory of problems provides a very useful framework for initial planning. The inventory should record the location of problems in the river or stream network, their severity, and their likely causes. Simple indices can be developed to help determine and prioritise actions (e.g., problems could be ranked on a three-point scale of severity). A sample of a possible blank inventory sheet is provided in Table 1.

The sort of problems faced in New Zealand are:

- Excess algal and aquatic plant growth which interfere with consumptive water uses and aesthetic appearance of water.
- Poor water quality for swimming and boating.
- Disturbance and destruction of aquatic life, e.g., through oxygen depletion and sediment deposition.
- Unnaturally low diversity of native wildlife in lowland rivers and streams.
- Poor fishery performance.
- Poor scenic quality leading to lowered recreational and land property values.

Table 1 Sample problem identification and planning sheet.

Problem[1]	**Severity (Scale:1-3)**[2]	**Cause**[3]	**Location of cause**	**Action required**	**Benefits**[4]	**Costs**[5]

1 Could include excess algal and aquatic plant growth, poor water quality, disturbance to aquatic life, high silt levels, poor fishery, poor scenic quality.
2 1 = low, 2 = moderate, 3 = high.
3 Could include nutrient enrichment, sediment run-off, bank instability, flooding, decrease of vegetation, inappropriate carbon supply, lack of shade, excessive water temperatures.
4 Could include increase in property value, reduced loss of nutrients, woodlot potential, shelter, emergency grazing, improved stock control, downstream water quality, erosion control, wildfowl habitat.
5 Could include high implementation costs, increased pest numbers, loss of current productive land, reduced access.

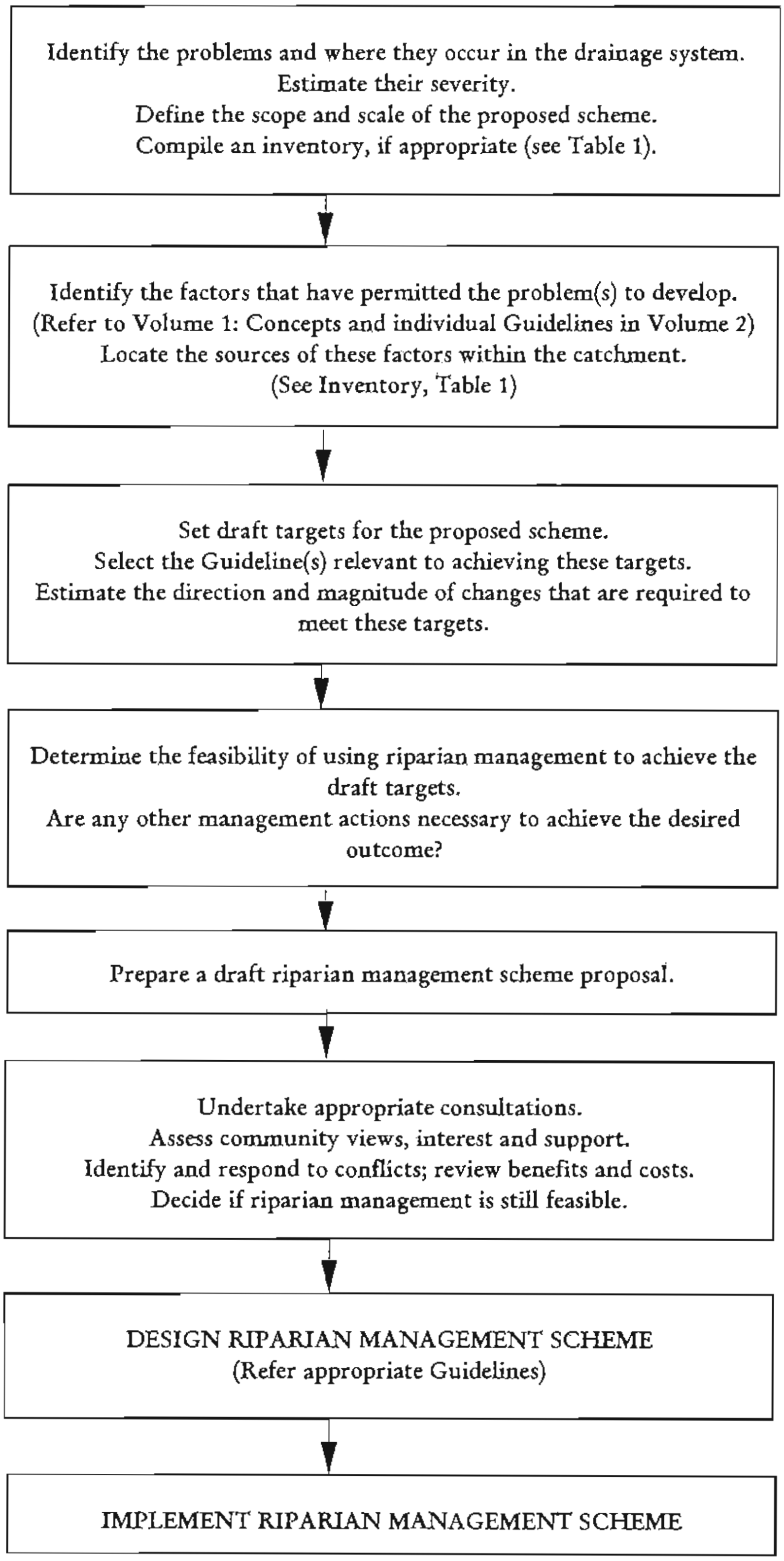

Figure 1 **Steps to be followed when designing a riparian management scheme.**

Riparian management schemes have the potential to help solve, at least in part, all of these problems.

Typical causal factors which might be recorded in the inventory are:

- Nutrient enrichment by surface run-off and sub-surface flows from productive land, and direct inputs from animals.
- Contamination by sediments and bank instability caused by animal trampling.
- Flooding caused by land clearance in headwater catchments.
- Clearance of vegetation from stream and river banks.
- Sediment deposition leading to unsuitable substrate on the stream or river bottom.
- Inadequate or inappropriate carbon supply to streams.
- Lack of shade and cover for fish and wildlife or excessive water temperatures.
- Loss of visual amenity afforded by rivers and streams in their natural state.

SETTING TARGETS AND DETERMINING FEASIBILITY

Once the scope and nature of the problems to be addressed have emerged, a number of draft targets will start to crystallise. This is the time to select and examine relevant guidelines, and to use them to help determine how these targets might be met. From this it should start to become evident whether it is feasible to use riparian management to achieve these targets.

Four commonly used riparian management actions are relevant to meeting the targets and they crop up in various combinations in each of the guidelines. Table 2 will assist readers to understand the scope of influence of each action and help them refer to the appropriate guidelines.

In some instances, other management actions may be necessary before the proposed targets can be achieved through riparian management. For example, a manager may wish to plant riparian trees to reduce troublesome aquatic plant proliferations, but this is likely to have little benefit for aquatic life if there is a point source input of contaminants upstream. Clearly, in such situations a combination of management actions will be needed to achieve the desired goal.

CONSIDERING THE BENEFITS AND THE COMMUNITY INTEREST

After the completion of an overview of the type outlined above, the scope and nature of the problems faced will be apparent. At this stage it is valuable to consider what costs and benefits might arise from future riparian management and who might share these. For many schemes a consultation process should begin at this stage and a political process should be established to run parallel with the technical process covered by these guidelines.

UNDERSTANDING COMMUNITY PERCEPTIONS

Only rarely will there be a consensus view on the benefits to be obtained from riparian management. Management agencies may promote water, soil and ecosystem conservation as their most important priority, whereas interest groups may promote recreation, fishing and wildlife priorities. By contrast, individual land-owners will quickly recognise the potential disadvantages of a scheme if it interferes with their land management procedures and their livelihood. They will require convincing that they will receive benefits also. O'Brien (1994) describes public attitudes to riparian protection and the importance of community involvement in riparian management schemes.

SOLVING CONFLICTS

Occasionally, conflicts arise between the desired outcomes of different guidelines. For example, there is a potential conflict between maintaining a healthy grass sward in order to prevent erosion and to filter contaminants, and providing shade in order to reduce temperatures and aquatic plant proliferations. It is clearly important that the manager decide which are the most important problems and focus on solving them. In many situations it may also be possible to overcome these apparent conflicts by implementing different guidelines in different parts of the riparian zone. In the example given above, sparse plantings of trees in areas where overland flow commonly occurs will help to maintain a healthy grass sward while denser tree plantings along other parts of the streambanks will shade the channel. This approach requires that managers have an understanding of the important mechanisms operating in the riparian zone so that they can adapt the guidelines to "design" a riparian management scheme which meets their objectives. *Volume 1: Concepts* is intended to assist with this understanding.

The final riparian zone design at a specific site will reflect many factors including the nature and cause of the problem(s), the resources available and social considerations.

CONFIDENCE LEVELS

Our knowledge of the functions of riparian zones and the best ways to manage them is still developing and we view this document as providing interim guidelines based on our current understanding. We have indicated the degree of confidence we believe is associated with each guideline based on our assessment of the knowledge base available.

Confidence has been expressed on a scale of low, moderate or high.

High – considerable scientific evidence of effectiveness available from studies in New Zealand or overseas, or is a widely used or well-proven management practice.

Moderate – some scientific evidence or informed observation that this is likely to be effective.

Low – based on unsubstantiated intuition, or high degree of variability means general applicability to specific sites is questionable.

As our understanding of land-water interactions improves there will be a need to revise these guidelines.

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GUIDELINES FOR MANAGING CHANNEL AND BANK STABILITY

INTRODUCTION

As described in *Volume 1: Concepts: Section 2.2.3*, streams and rivers are dynamic systems and have the potential to alter their slope, length, width, shape or location by processes that generally occur over long time scales. (See also *Volume 1: Concepts: Section 2.1.5*). Here we discuss concerns for their short term stability (geologically speaking, decades to several hundred years) and resulting morphology (shape and form). This short term stability is affected by a variety of natural and human related factors, particularly land use changes.

The response of streams and rivers to land use change has been complex. Removal of native vegetation almost inevitably brings about changes to the morphology and stability of watercourses, because catchment hydrology is altered. However, where vegetation has been removed, the resulting changes may not necessarily have been significant or deleterious, and even if they were, the intervening period between development and the present time may have been sufficient to allow the stream to reach a new steady-state of relative stability.

Because of this, it is important to realise that the guidelines offered here are not a general panacea for all developed streams. They are specifically for the restoration of *degraded systems, primarily in the agricultural landscape*. It is important to have clearly identified the problem(s) and the cause(s) (see *Volume 2: Guidelines: Introduction: Figure 1* for a suggested approach to problem solving). Riparian management will not cure all instability, and may even accelerate it if the problem and its causes have been incorrectly identified. Any systematic problem-solving approach requires a good understanding of the processes affecting instability and morphology, some of which may have nothing to do with pastoral development (see *Volume 1: Concepts*). A brief summary of these processes is provided below.

PROBLEM IDENTIFICATION

Problems caused by changes in channel and bank stability include:

- Loss of farmland and equipment (e.g., fences).
- Undermining of roads and bridge supports.
- Downstream channel aggradation (build up of sediments), instability and flood damage.
- Decline in the food quantity and quality of periphyton in stream water because of fine sediment deposits and light reduction.
- Clogging of streambed interstices by fine sediments. This reduces flushing, dissolved oxygen concentrations, and available microhabitats for aquatic animals.
- Inputs of nutrients from bank erosion.
- Increased streambed width leading to increases in light and temperature in the stream.
- Reduced water clarity and aesthetic appeal because of fine suspended sediments.

IDENTIFYING CAUSATIVE OR CONTROLLING FACTORS

Problems associated with channel instability and morphological changes may be caused by the following:

Increased floodflows: Although streams in long-settled areas are expected to have reached some sort of steady-state equilibrium following development so that they are no longer widening or deepening, erosion rates may be higher and channel migration faster. Continual development (e.g., improving drainage) is expected to augment floodflows and exacerbate these problems.

Increased sediment supply from upstream: Excessive suspended solids supply from upstream as a consequence of erosion can lead to deposition of sediment with its attendant problems when the stream transport capacity decreases (e.g., with a change in slope).

Destabilisation of the channel bed: Destabilisation and erosion of the streambed can be caused by a sudden increase in stream slope. Such an increase can occur naturally or because of human activities, and causes include floodflow scouring of a blockage or the bed, removal of bed material for roads and farm tracks, lowering of the bed level due to human interference with morphology (e.g., channelisation, concentrating flow through bridge abutments), or removal of logs in the channel. Typically, the change of slope at one point may result in the streambed cutting back ("waterfalling") upriver.

Channelisation: Channelisation (straightening and deepening) may alter streambank and streambed erosion rates. The major factor causing this latter degradation appears to be the exposure of erodible material and/or increasing stream power. This is particularly important in streams on alluvial plains, where deepening exposes non-cohesive substrata which are more susceptible to being washed away than overlying cohesive soils (Williamson *et al.* 1992).

Removal of protective riparian vegetation and channel debris: This may contribute to or cause increased floodflows and destabilisation of the bed and banks.

Increased flow velocities or redirected flow: Obstacles in the stream such as bank debris, logs and bridge abutments may destabilise banks or beds by redirecting flow.

Stock-induced damage: Stock can induce slumping, pugging, accelerated collapse of undercut banks, and a consequent increase in bare ground in and adjacent to small-medium sized streams (see photos in Howard-Williams and Pickmere 1994). The effects can vary from minor to severe but are often quite localised. Cattle seem to be more problematic than sheep. Observations indicate that farmed deer (1.1 million in NZ; Pullar and McLeod 1992), particularly larger species such as red deer, cause severe damage because they wallow in small streams and ponds.

(Note: this guideline deals primarily with bank stability. Overall stream and river stability and its influence on in-stream carbon supply is dealt with in Guideline: CARBON. Appendix I of Guideline: CARBON describes the Pfankuch method of assessing river stability. Examination of the parameters discussed under the Pfankuch method will give useful pointers to assessment of bank stability under Guideline: STABILITY.

GENERAL GUIDANCE ON THE DESIGN OF PROTECTION MEASURES

The role of riparian vegetation

Vegetation is widely accepted as a key factor in bank stability. However, the interactions between vegetation, streambank erosion and morphology are complex. Vegetation can destabilise rather than stabilise banks if inappropriate vegetation types or planting densities are chosen.

Above-ground, vegetation increases channel roughness which slows floodflows and traps fine sediments (Smith 1976; Platts *et al.* 1985) when the channel expands into the riparian zone (see **FLOW**). A vegetation mat protects banks from scour. However, excessive riverbank shading by trees or shrubs will inhibit ground cover growth. This can lead to a loss of close ground cover, and result in greater sediment inputs (Smith 1992) and increased bank erosion (Murgatroyd and Ternan 1983).

Below ground, roots increase bank stability in two ways. Firstly, exposed roots armour soils against entrainment from floodflows. The root systems of tree, osier and shrub willows, in particular, form an extensive and deep root system that stabilises banks and streambeds (Hathaway 1973; Van Kraayenoord and Hathaway 1986a, 1986b). Secondly, root mass and density are important components of the shear strength of soils and hence offer protection against gravity collapse of undercut banks (Smith 1976; Kleinfelder *et al.* 1992). They may cross potential failure surfaces and vertically anchor the bank to a more stable substrate (Sidle 1991). Also, a dense network of medium to small roots can reinforce the upper soil so that it acts as a membrane of lateral strength (Figure 1) (Kleinfelder *et al.* 1992). Once overhangs have collapsed into streams, the slumped masses may be stabilised in position by the "hinge" of reinforcing roots. In streams with low banks (e.g., ≤0.5m) pasture and other ground cover can fulfil this role, thereby armouring the bank against further undercutting (Figure 1) (Imeson and Zon 1979; Murgatroyd and Ternan 1983).

There is a general perception that forested streams will have stable banks, and that large organic debris from fallen branches or trees are important in stabilising the channel and providing substrate. However this is not always the case in small streams. After afforestation of grassed catchments, channels may widen due to suppression of thick grass

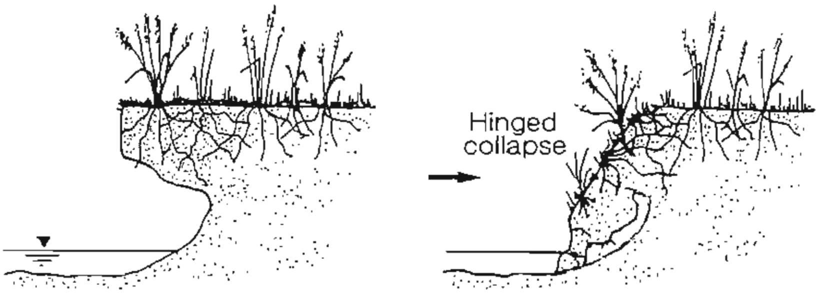

Figure 1 Hinged collapse.

turf and its associated network of fine roots (see above), or because the river attempts to by-pass log jams and debris dams (Zimmerman *et al.* 1967; Murgatroyd and Ternan 1983). Sudden increases of large organic debris (e.g., from plantation thinnings or following unusually heavy snow falls) in streams that had not received them in the recent past, may result in destabilisation of the channel. However, in the long term, natural inputs of large organic debris probably stabilise streambeds.

From the above, it can be seen that establishing the relative merits of grass and large shrubs and trees can be quite difficult. It does not always follow that trees offer a greater bank stability (as is commonly perceived) and in some areas (e.g., where tussock is the natural vegetation) they may be considered undesirable. The merits can be summarised as follows:

- Grass and other dense ground cover can protect soil from scour and, in shallowly-incised streams, stabilise overhangs (either in place or collapsed) through their root system (Figure 1). They may also colonise and stabilise collapsed or deposited sediments. However, the level of protection is poor in uncohesive or unstable soils unless cover is robust and continuous, which is unlikely when pasture is damaged under heavy grazing, tracking or shade. There is little protection where the stream incision depth is greater than the grass root depth and the streambanks beneath the rooting zone are steep.

- Large trees and shrubs have the potential to stabilise higher banks through their deep, robust rooting system. Some trees and shrubs form an extensive and deep root system that armours banks and streambeds, irrespective of grazing, tracking or shade. Other trees are unsuitable, offering little protection in rapidly migrating channels and even causing erosion if they collapse into the channel.

Plants suitable for bank protection

Badly-eroded or eroding streambanks in pasture require trees or shrubs with vigorous growth and extensive rooting systems, such as willows and poplars. The techniques are widely practised (Dixie 1982, Rowall 1983) and well described (Van Kraayenoord and Hathaway 1986a, 1986b, Pollock 1986). For heavy bank protection of rivers, tree willows and poplars, sometimes in conjunction with other bank protection methods, are recommended. In small streams, osier or shrub willows are recommended. In these cases, plantings of native trees can be included for diversity and long term stability, but so far, no native plant has been identified to match the vigour and protection of willows and poplars. Follet and Dunbar (1984) found that the native shrubs (*Hebe odora, Coprosma rugosa, Cassinia fulvida, Olearia avicenniaefolia, Griselinia littoralis, Cortaderia richardii*) which they examined, were not vigorous enough to stabilise rapidly-eroding streambanks in South Island mountain lands.

In more stable systems, where long term stability is of concern, there are a number of native species that may be suitable for small to medium sized streams. Pollock (1986) makes the general observation that few natives can be regarded as colonizers or pioneers but that there are a few that show a surprising tenacity and if not kept in check will revert pasture to scrub. He recommends flax (*Phormium tenax*) for the banks of small streams and drains because it is able to tolerate wet soils. However, it has neither a deep nor a wide-spreading root system. He also recommends kowhai (*Sophora microphylla, S. tetraptera*) for disturbed but stable streambanks where long term protection is required. The semi-deciduous habit of kowhai would also benefit ground cover in some areas (see also Table 1 of **CARBON**). There are a number of small trees and shrubs that are recommended for controlling gully erosion, which may be useful for streambank erosion control on small to medium streams, and these have been listed later. Some of these have been also recommended by van Slui (1991) and Taranaki Regional Council (1992) for streambank stabilisation or planting, but without any quantitative information on how effective they are with different degrees of streambank erosion.

Anecdotal evidence from surveys of rapidly-eroding streambanks in pine forests near Hamilton (Smith *et al.* 1993) suggest that tree ferns would be excellent for streambank protection. The older plants of both species have extensive fibrous root systems, but may not be as deeply rooting as willow and poplars. Kanuka and manuka are often found as remnant shrubs along streams and so seem able to withstand compaction from stock tracking and camping, as well as browsing. They are also the primary native colonising species, so appear to have the inherent characteristics for successful utilisation in streambank protection. However, this requires further study.

The importance of bank substrate type

Bank stability is determined by the properties of the bank materials. Both soil *cohesion* and *dispersivity* are important. Uncohesive soils and substrata (e.g., sandy or gravelly banks) are more susceptible to being washed away than cohesive soils or bedrock (Myers and Swanson 1992). An example where uncohesiveness has resulted in massive erosion is on the yellow-brown pumice soils and substrata around Taupo following pasture development.

Erosion rates are largely controlled by the removal of bank material at the toe slope of the bank (see section on understanding the erosion mechanism later). Bank material may either be collapsed material from further up the bank, or the soil horizon between the channel bed level and flood peak height. Streams that are not incised will be interacting mostly with the topsoil, and it is the properties of this topsoil that will influence erosion and morphology. In incised streams, it is the interaction with subsoils or basement materials that influences erosion and morphology.

An indication of bank cohesiveness can be obtained from soil type data and geology. Cohesion of streambank material is a function of aggregate size distribution and the degree of cementation or packing. For example, a loose fine sand is easier to displace than one which is tightly packed; and a clay soil composed of small, loosely-packed aggregates is less cohesive than one with large interlocking aggregates. Cohesion is strongly affected by vegetation (see previous section) and moisture content. Uncohesive soils can be located from soil maps using a preliminary index of stability based on the ease with which the unvegetated, *in situ* material is eroded by flowing water. Four cohesion classes have been identified in Table 1 for the major soil classes in New Zealand (Table 2). This classification is provided to help managers identify potential problem areas or reaches, and set management priorities.

In addition to soil cohesiveness, the related property of dispersivity may be used in identifying potential problem areas or reaches, and setting priorities (P. Singleton, Landcare, pers. comm.). Material entering the stream, either from erosion or subsequent collapse, may disperse in the water, reducing its clarity, reducing the food quality of periphyton, smothering aquatic life, or infilling sediment interstices. In some situations, however, cohesion and dispersivity are not necessarily related. For example, gravels may have low cohesion but on entering the water do not disperse into fine particles, whereas soil which has fallen into the stream may muddy the water for many meters, even though it has high cohesion *in situ*.

The degree to which the dislodged streambank material will disperse into fine particles is related to the proportion of unaggregated silt and clay-sized particles that it contains. Clay soil may be slowly dispersive in water because the clay may be bound together into larger aggregates. Silty material is likely to be dispersed more rapidly than clay because it lacks this bonding, even though it appears to be aggregated when in the soil.

From a water clarity perspective, clay particles are the most damaging because they absorb or scatter more light than silt-sized particles, and remain suspended for longer times. Management of those soils with high dispersibility may be most critical when considering streambank-derived sediment inputs to clear waters. Streambank material may be divided into 3 classes depending on its dispersibility in water (Table 3) and applied to the major soil classes in New Zealand (Table 4).

Understanding the erosion mechanism

Streams erode via the processes of fluvial entrainment (the washing away of bank material by water currents), and weakening and weathering (Thorne 1982). When these processes oversteepen the banks, subsequent failure depends on the structural properties of the bank. This, in turn, depends on the nature of the bank material, vegetation and bank height. The removal of failed material from the toe of the bank depends on the flow of the stream or river (Figure 2). The resulting morphology and rate of watercourse migration is determined by the balance between rates of supply and removal of failed material. The controlling step is the rate of removal of failed material at the bank toe (Carlson and Kirkby 1972; Thorne 1982).

This is termed the *rate limiting step* and is one of the most important concepts in understanding streambank erosion and its management. If the rate of removal of material at the bank toe increases (e.g., from an increase in floodflows, or removal of protective roots), then the bank will oversteepen more rapidly, and there will be an increase in sediment supply to the toe, which is quickly removed (Figure 2). The stream moves to a new state of more rapid erosion (Williamson *et al.* 1990, 1992). On the other hand, increasing the supply of material to the bank toe may not result in an increase in overall erosion rates if the stream does not have sufficient power to remove the sediment, as may be the case in small streams with low gradients. In this case, the build-up of failed material would be predicted to lead to a change in bank morphology, with a loss of undercut and a decrease in bank slope (Figure 2). These changes would subsequently decrease the supply of failed material to the bank toe.

The importance of watercourse size

Watercourse size affects:

- Accessibility to grazing stock.
- Degree of incision and hence the soil horizon exposed in the streambank and extent of protective riparian vegetation rooting system.
- Stream power.

Small headwater streams are very accessible and thus if other factors are conducive (e.g., uncohesive bank material), they are especially prone to grazing damage. Grazing animals, particularly cattle, can directly affect many of the erosion processes by trampling or browsing the bank tops, sides and base. As watercourse size increases, the channel becomes wider and typically more incised, and thus becomes less accessible to grazing animals and a barrier to animal movement. A point is reached where grazing animals only have access to the bank tops and they do not affect other erosion processes such as undercutting and fluvial entrainment. In particular, they cease to affect the rate limiting step, the removal of base material from the bank toe. Where this has happened, grazing may have little effect on overall bank stability or channel morphology, although there may be localised impacts (e.g., stock crossings, stock tracks, accelerated bank collapse). In even larger, deeply-incised streams, streambank grazing effects become relatively unimportant.

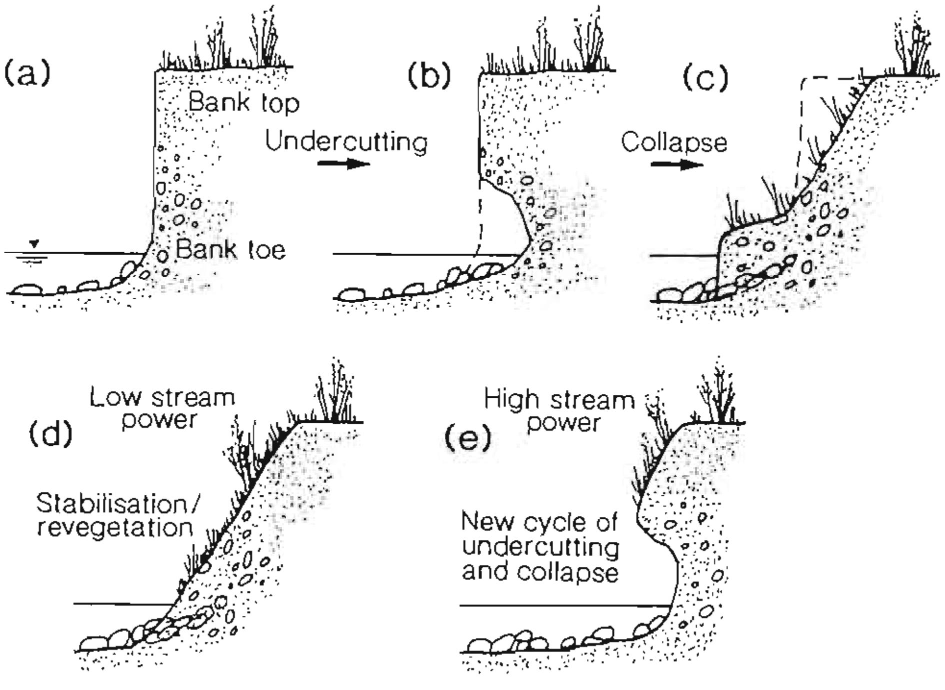

Figure 2 The sequence of undercutting and collapse (a – c). Under low stream power, the collapse stabilises (d), whereas under high stream power the collapse is removed and new undercutting commences.

Table 1 Cohesion classes of soils (P. Singleton, Landcare, pers. comm.).

CLASS	FEATURES
Low	Easily dislodged by spade; does not maintain a vertical face; often loosely packed, sandy, gravelly or pumice material.
Moderate	Easily dislodged by spade; maintains a vertical face; often tightly packed sands or gravels with some silt or clay. Loose soils with fine or very fine aggregates.
High	Difficult to dislodge except with a spade and by removing individual fragments; maintains a stable vertical face; most soil types, tightly packed gravel or sand often in a clayey matrix.
Extremely high	Very difficult to dislodge except by pick or levering; most rock and cemented material, boulders.

Table 2 Relationship between Cohesion classes and Soil groups (P. Singleton, Landcare, pers. comm.).

CLASS	SOIL GROUP
Low	Southern and central yellow-brown sands Yellow-brown pumice soils Central recent soils from alluvium Southern and central recent soils
Moderate	Northern yellow-brown sands Yellow-brown loams Central recent soils from volcanic ash
High	Yellow-grey earths Yellow-brown earths Podzols and associated soils Redzina and associated soils Brown granular loams, clays and associated soils Red and brown loams Organic soils Gley soils Saline gley recent soils and associated soils Brown grey earths
Extremely high	Bare rock

Table 3 Features and examples of Dispersivity classes of soils (P. Singleton, Landcare, pers. comm.).

CLASS	FEATURES	EXAMPLES
High	On agitation the water rapidly becomes turbid and stays turbid for some considerable time	Highly silty material Weathered mud and silt stones Dispersive clay soils
Moderate	On agitation the water becomes slightly turbid, or very turbid for some short time	Sands and gravels with a low silt content Most clay and loamy soils
Low	On agitation the water remains clear or slightly turbid	Sand and gravels Clay soils Loose unweathered rock Undecomposed peat

Table 4 Relationship between Dispersivity classes and Soil groups (P. Singleton, Landcare, pers. comm.).

CLASS	SOIL GROUP
High	Yellow-grey earths Brown grey earths Central recent soils from alluvium Southern and central recent soils Central recent soils from volcanic ash
Moderate	Central, Southern, High Country yellow-brown earths Northern yellow-brown sands Yellow-brown loams Gley soils Podzols and associated soils
Low	Northern yellow-brown earths Redzina and associated soils Southern and Central yellow-brown sands Yellow-brown pumice soils Brown granular loams, clays and associated soils Red and brown loams Organic soils Saline gley recent soils and associated soils Bare rock

In many small streams, bank collapses and trodden material will probably remain attached to the bank because stream power is too low to shift sediment. When bank heights become greater than grass depth, collapses are less likely to remain attached to the bank. In this situation, stream power also increases and grasses have little stabilising effect. Trees with rooting depths equivalent to at least the height of the collapsed bank are necessary for stabilisation. Alternatively, "hard" engineering techniques such as rock rip-rap can be used.

SUMMARY

The problems attributed to stream bank and channel instability include: bank erosion, smothering of plant and animal life, poor water clarity, streambed widening, lose of streambed permeability and bed siltation. Causes of these problems, and suggested remedies, are summarised in Table 5. Some of the remedies are beyond the scope of these guidelines and are only briefly commented on here. Some of the other causes of sediment enrichment, which may be incorrectly attributed to streambank and channel erosion, are also listed in Table 5. To reiterate, before using the guidelines it is essential to determine the problem and its cause, because not all of these are addressed by riparian management (see *Volume 2: Guidelines: Introduction: Figure 1*).

Table 5 Causes of, and suggested remedies for, problems attributed to channel and bank instability.

CAUSES	REMEDIES
Flow	See STABILITY: TREES, STABILITY: REMNANT, FLOW
Sediment supply	Land management, upslope erosion control (see Van Kraayenoord and Hathaway (1986a, 1986b) and Pollock (1986))
Destabilisation	Control stream and river works that create instability by removing sediment (e.g., shingle removal, channel deepening). Do not remove logs etc. which are integral part of bed or banks (see CARBON: RETENTION).
Channelisation	Avoid channelisation in unstable substrates. Research needed before restoration procedures can be recommended.
Removal of vegetation	See STABILITY: TREES, STABILITY: REMNANT.
Obstacles	Remove obstacles that are an unnatural addition to the channel, are mobile and which create major, visible instability (e.g., prunings, plantation thinnings). Do not remove logs etc. which are integral part of bed or banks (see CARBON: RETENTION).
Sediment from surface runoff	See CONTAMINANT
Stock grazing	See STABILITY: STOCK.

Guidelines for Protecting Streambanks by Planting Trees and Shrubs

OBJECTIVE(S)

- To protect unstable streambanks from fluvial erosion.
- To stabilise steep banks and undercuts against gravity failure.

GUIDELINE(S)

These guidelines are intended to be used in association with Volumes 1–3 of the Plant Materials Handbook for Soil Conservation by Van Kraayenoord and Hathaway (1986a, 1986b) and Pollock (1986). Porteus (1993), Native Forest Restoration – A Practical Guide for Landowners, is useful for methods of native forest propagation (see *Important reading kit* earlier in this volume for further details).

1. Assess by site inspection and from local knowledge whether the problem is caused by an increased flow and lack of protective vegetation and is capable of being addressed through planting trees or shrubs (Table 5). Identify intensity of erosion and the erosion mechanism(s). The intensity of erosion can be rated as "low", "moderate" or "extreme" based on a first-hand description of the problem. Some guidance is offered in Table 6, or stability can be assessed semi-quantitatively using parts of the Pfankuch index (see Appendix 1 of CARBON, and *Important reading kit* earlier in this volume). The lower bank component of the index (particularly "channel capacity", "obstruction, flow deflectors and sediment traps" and "cutting") are likely to be most useful for this. *Remember that these are relative terms; streams and rivers should be assessed from comparisons with other sites in the region.* Undercutting and collapse is amenable to control with this guideline.

2. Determine the size and species of tree or shrub required to stabilise the bank.

- In extreme cases, such as in some larger streams with high stream power or where large volumes of sediment are moving down the stream, recourse may need to be made to engineering solutions where the banks and beds are protected by rock rip-rap to stabilise

Table 6 Symptoms of erosion intensity.

EROSION INTENSITY	SYMPTOMS
Extreme	• Usually in larger streams and rivers (greater than third order) because of high stream power. Active undercutting of banks, lots of fresh soil or sub-soil exposed. Trees, shrubs fences undercut. • Evidence for large recent channel migrations (e.g., from aerial photographs, partially vegetated large point bars). • Significant quantities of soil and/or collapsed banks in stream.
Moderate	• Banks show signs of instability, as in extreme case above, but not as severe.
Low	• Banks well vegetated, most undercuts often vegetated or mossy. • Little recent channel migration. • Little soil and/or collapsed banks in stream.

the channel sufficiently so that plantings can be established (Acheson 1968). If rock is too expensive or not available, there are a number of engineering structures utilising willows, poplars or other trees (see Section 5 of the Plant Materials Handbook for Soil Conservation (Van Kraayenoord and Hathaway 1986a)). Alternatively, sufficient room should be left along actively migrating channels for movement of the stream until plantings have become established. Likely movement rates could be assessed from local knowledge or time series of aerial photographs.

- Badly-eroded or eroding streambanks require trees or shrubs with vigorous growth and extensive rooting systems, such as some tree willows (Table 7). Crack willow (*Salix fragilis*) invades channels and is easily spread, and is not recommended, except for severely eroding sites where ongoing and active management is feasible. In small streams, osier or shrub willows can be used. In all these cases, native trees can also be planted for diversity and to enhance long term stability (see below), but so far no native plant has been identified to match the vigour and protection of willows and poplars.

- In more stable systems, where long term stability is of concern, there are a number of native species that may be suitable for protecting streambanks from erosion (Table 8). Tree ferns may also be suitable as they are often found on streambanks and have extensive fibrous root systems. In addition to these, other native species can be planted further up the bank to increase habitat diversity and aesthetic appeal. See your local Department of Conservation office for recommended species and supply nurseries.

3. Plan planting density and architecture (composition and canopy height) and manage plantings (e.g., by pruning) to regulate light levels on the streambanks (see also **LIGHT**). Plantings should be planned to meet *one* of the following aspirations:

- Maintain adequate light levels on streambanks to encourage ground cover. Ground cover prevents entrainment of bank soils during overland flow, and will stabilise banks with low angles or sediment deposited at the bottom of eroding banks. Trees and shrubs need to be planted at a sufficient density (e.g., approximately 10 m intervals) to be effective against erosion; however, that would provide insufficient light at ground level in a forest situation. Therefore, plantings should form a narrow band parallel to the streambank to allow oblique light to support ground cover under the trees. Alternatively, wider plantings of deciduous trees could be supported because these allow light levels to maintain ground cover during autumn–spring (e.g., some *Salix* spp., poplar, kowhai, see Tables 7 and 8).

- Reduce light levels on streambanks to discourage weeds. This can be contemplated where there is little overland flow (either from surface runoff or over-the-bank flows). This could be achieved by dense plantings (e.g., 1200 stems ha^{-1} or stems at 3 m intervals), or by plantings of different species of different sizes to minimise light at ground level.

- Use a multi-tiered system which incorporates a grassed buffer strip. For example, the Taranaki Regional Council (1992) recommends a three-tier system of streambank protection: shade, habitat enhancement, and a grassed buffer strip arranged progressively from the streambank.

4. Establish plants and maintain plantings.

It is absolutely essential for success that planting and maintenance is carried out under proven procedures as described in Volumes 1–3 of the Plant Materials Handbook for Soil Conservation (Van Kraayenoord and Hathaway 1986a, 1986b, Pollock, 1986). This handbook gives extensive details on planting densities, thinning and pruning, weed, pest and disease control, and climatic limitations of recommended species. Porteus, 1993, could also be useful (see *Important reading kit* earlier in this volume).

Without appropriate establishment and maintenance, most plantings will fail.

5. Manage grazing (see also **STABILITY: STOCK**).

Most plantings will require permanent retirement from grazing, or light grazing once trees or shrubs are established (for establishment times see Plant Materials Handbook for Soil Conservation). Light grazing must be managed to maintain a good ground cover, as well as minimise trampling damage. Sheep are preferred over cattle, especially where stream margins are susceptible to hoof damage. Other useful information is provided in Buxton, 1991 (see *Important reading kit* earlier in this volume).

Grazing intensity will depend on climate and soil cohesiveness. We cannot recommend grazing densities with confidence, but as a rough guide 5–10 stock units/ha is probably sustainable on most cohesive soils (see Tables 1 and 2). Intensive grazing (10–20 s.u./ha) may lead to loss of ground cover, especially if the planted trees or shrubs provide the only protection for stock from sun or cold rains in the grazed paddock, when animals will tend to "camp" in these areas.

To balance loss of income, economically useful tree species can be interspersed with plantings (Table 7, Appendix 1). If grazing control is not part of the scheme, then it would be essential to provide other shade and shelter for stock, some distance away from the riparian zone. This shelter would have to be large enough to shelter all stock likely to be found in the paddock.

In the special case of spawning areas for the native fish, inanga, controlled grazing is recommended until trees or shrubs are of sufficient size to limit light and prevent the build-up of a dense bank cover which is impenetrable or unattractive to inanga (Mitchell 1993). Grazing regimes are currently under trial.

JUSTIFICATION AND ASSUMPTIONS

The root structure of large trees and shrubs is known to prevent bank soil being washed away as well as providing lateral and vertical strength to banks against gravity failure. Their main value has been shown to lie in situations where grass cover provides insufficient protection because of the following:

- Stream power is high.
- The stream is incised beyond the grass rooting depth, and subsoils are susceptible to entrainment under the flow regime of the stream.

- Grazing exposes uncohesive soils to being washed away.

Badly-eroded or eroding streambanks in pasture require trees or shrubs with vigorous growth and extensive rooting systems, such as willows and poplars. The techniques are established and well described in the Plant Materials Handbook for Soil Conservation. No native plant has been identified to match vigour and protection of willows and poplars for bank stabilisation.

Grazing management will reflect many other conservation aspirations besides streambank protection; for example: fisheries protection, maintenance of water quality and protection of riparian habitats. Some of the best maintained riparian areas have been those that were fenced off, planted and then lightly grazed.

SIDE EFFECTS AND LIMITATIONS

In stable pasture systems, trees and shrubs planted near the channel may result in bank instability and channel widening (see earlier section on the role of riparian vegetation). They will also alter the light climate in streams (see **LIGHT**), increase terrestrial carbon inputs, especially if the trees are deciduous (see **CARBON**), and may alter water temperature regimes downstream (see **TEMPERATURE**). Trees and shrubs will also re-introduce landscape and riparian diversity (see **HABITAT**), and slow large floodflows when floodwaters overflow into the riparian zone (see **FLOW**). However, planting of trees and shrubs may not be considered desirable where tussock is the natural ground cover.

There is a problem in establishing trees in the presence of grazing animals, especially if the species are palatable to stock. If banks are retired before planting, then there is the initially high cost of fencing (Appendix 2), and possibly the costs of providing alternative stock watering systems and land take. This will need to be weighed against the economic benefits of reducing the incremental loss of productive land due to erosion, and other benefits to water quality.

There may be problems with noxious weed infestations and the need to control these by herbicide applications. Methods for protecting plantings against grazing damage and procedures for noxious weed control have been laid down in Volumes 1 and 2 of The Plant Materials Handbook for Soil Conservation. Similar information is also available in Buxton, 1991, and Timmins and Mackenzie, 1995 (see *Important reading kit* earlier in this volume). Procedures for herbicide spraying are currently being developed by the Department of Conservation. Weed control in riparian areas has been a problem because of a reluctance to spray near streams or because adjacent land owners resent having to do this. The use of grazing to control weeds needs further trials. To this end, a better understanding of vegetation succession is needed for the different districts of New Zealand, as well as its interaction with various grazing intensities.

In strongly-eroding systems, it may not be possible to use native plants for rehabilitation, at least initially. Higher floodflows will persist where floodflows are regulated by upland hydrology, and stream migration may overwhelm less vigorous native plantings. Here, recourse may need to be made to engineering techniques to protect banks; these are described in Section 5 of Volume 1 of the Plant Materials Handbook.

Some tree species may be unsuitable in certain situations, because they provide inadequate protection (e.g., in highly mobile large streams) while creating instability after falling into the channel (e.g., *Pinus radiata*).

Riparian forest may harbour pests such as possums, rabbits and hares, and corridors of forest may enhance possum movement (Taranaki Regional Council 1992). People contemplating widespread plantings may need to consider pest management in the design and implementation of their plans.

CONFIDENCE

High. This soil conservation technique is widely practised throughout New Zealand. However, confidence in the success of weed control by controlled grazing or herbicide spraying is low.

Table 7 Summary of characteristics of introduced trees and shrubs for riverbank protection (summarised from Van Kraayenoord and Hathaway 1986a).

Species	Rating	Deciduous/ evergreen	Form	Maximum height (m)	Growth rate	Frost tolerance	Other uses
†*Alnus glutinosa* Black alder	*	D	S	15-20	M	HHH	Firewood
Casuarina cuninghamiana River sheoak	*	E	S	15-20	M	H	Fodder Firewood
Casuarina glauca Swamp sheoak	*	E	S	10-14	M	H	
Cornus baileyi Bailey's dogwood *Cornus stolonifera* Red osier dogwood	*	D	S	1.5-2.5	M	HH	Ornamental
Corylus avellana Hazelnut	*	D	S	3-5	S	HHH	Nut crop
Cupressus macrocarpa Macrocarpa	*	E	S	20-30	M	HH	Timber
†*Elaeagnus angustifolia* Russian olive	*	D	S	4-8	S	HHH	Bee fodder
†*Lupinus arboreus* Tree lupin	*	E	S	1-2	M	HH	
†*Populus alba* cv. 'Silver poplar'	*	D	S	15-25	F	HHH	
Populus alba cv. 'Pyramidalis' Upright silver poplar	*	D	N	20-30	F	HHH	Timber Amenity
Populus deltoides X maximowiczii cv. 'Eridano'	*	D	S	20-30	VF	HHH	
Populus X euramericana cv. 'Flevo'	*	D	S	20-30	VF	HHH	
Populus X euramericana cv. 'I 154'	*	D	S	20-30	VF	HHH	

Table 7 condt.

Species	Rating	Deciduous/ evergreen	Form	Maximum height (m)	Growth rate	Frost tolerance	Other uses
Populus X euramericana cv. 'I 214'	*	D	S	20-30	VF	HHH	
Populus X euramericana cv. 'Tasman'	**	D	N/S	10-30	VF	HHH	Timber Amenity
Populus alba X glandulosa cvs. 'Yeogi 1' and 'Yeogi 2'	*	D	S	10-30	F	HHH	
Populus nigra cv. 'Italica' Lombardy poplar	*	D	N	30-40	F	HHH	Amenity
Populus trichocarpa cv. 'PMC 471'	*	D	N	20-40	F	HHH	
Populus yunnanensis	*	D	S	20-25	F	HH	Amenity
Salix acutifolia	*	D	N	4-6	M	HHH	Ornamental Bee fodder
Salix alba White willow	**	D	N/S	15-25	M	HHH	Timber Amenity
Salix alba var. *britzensis*	*	D	N	10-15	M	HHH	Ornamental
Salix alba var. *vitellina* Golden willow	**	D	S	15-25	M	HHH	
Salix babylonica Sleeping willow	*	D	S	15-25	M	HH	Amenity
Salix daphnoides Violet willow	*	D	N	5-10	M	HHH	Ornamental
Salix elaeagnos Bitter willow	*	D	S	3-6	M	HHH	
Salix elaeagnos X daphnoides	***	D	S	4-8	M	HHH	

Table 7 condt.

Species	Rating	Deciduous/ evergreen	Form	Maximum height (m)	Growth rate	Frost tolerance	Other uses
Salix matsudana X alba c. 'Aokautere' (NZ 1002)	***	D	N	15-25	VF	HHH	Bee fodder
Salix matsudana X alba cv. 'Hiwinui' (NZ 1130)	***	D	S	15-25	VF	HHH	Bee fodder
Salix matsudana X alba cv. 'Adair' (NZ 1143)	**	D	N/S	15-20	F	HHH	Bee fodder
Salix matsudana X alba cv. 'Wairakei' (NZ 1149)	***	D	S	15-25	VF	HHH	Bee fodder
Salix matsudana X alba cv. 'Moutere' (NZ 1184)	***	D	N	15-25	VF	HHH	Bee fodder
Salix purpurea Purple osier	***	D	S	3-6	M	HHH	Bee fodder
Salix purpurea cv. 'Booth' Booth willow	***	D	S	7-8	M	HHH	Bee fodder
Salix purpurea cv. 'Holland'	***	D	S	6-7	M	HHH	Bee fodder
Salix purpurea cv. 'Irette'	***	D	N/S	7-8	M	HHH	Bee fodder
Salix purpurea cv. 'Pohangina'	***	D	S	7-8	M	HHH	Bee fodder
Salix reichardtii (formerly *S. discolor*) Pussy willow	*	D	N	6-10	M	HHH	Bee fodder
Salix repens X purpurea	*	D	S	2-3	S	HHH	
Salix X sepul-chralis	*	D	S	15-25	F	HHH	Amenity
Salix triandra	*	D	S	5-9	M	HHH	Basketry Bee fodder

Table 7 condt.

Species	Rating	Deciduous/ evergreen	Form	Maximum height (m)	Growth rate	Frost tolerance	Other uses
Salix viminalis Common osier	***	D	S	5-8	M	HHH	Bee fodder Basketry
Tamarix chinensis Tamarix	*	D	N	2-5	M	HHH	Ornamental

TABLE LEGEND:

Rating	Suitability listed as 3 '*' scale, the more asteriks the more suitable.
Deciduous/evergreen	D = deciduous; E = evergreen.
Form	N = narrow crown; S = spreading crown; N/S = intermediate; N S = narrow when young, becoming spreading when aged.
Growth rate	S = slow, 0.1 to 0.5 m/year; M = medium, 0.5 to 1.0 m/year; F = Fast, 1 to 1.5 m/year; VF - Very Fast, more than 1.5 m/year.
Frost tolerance	H = -2°C to -6°C; HH = -6°C to -10°C; HHH = lower than -10°C.

† May be a weed in some areas.

Table 8 **Native trees and shrubs recommended for streambank erosion and gully erosion control taken from Pollock (1986), Van Slui (1991), and Taranaki Regional Council (TRC) (1992).**

Species	Common name	Suitability (Pollock 1986)	Use (van Slui 1991, TRC 1992)	Comments
Aristotelia serrata[1,2]	makomako, wineberry	G	Bt	Palatable. Deciduous nature in some areas may benefit ground cover
Brachyglottis repanda[1]	rangiora	(Sb)		Flowers and leaves poisonous to stock
Cassina sp.[2]	tauhinu, cottonwood	(G)		
Coprosma sp.[2]			Bt	
Cortaderia toetoe	toetoe	Sb	Sb	
Cordyline australis	cabbage tree	(G)	Bt	Palatable
Coriaria arborea[1]	tutu	G		Poisonous to stock
Corynocarpus laevigatus[1]	karaka		Bt	
Dodonaea viscosa[1]	akeake	G		Dry soils
Fuchsia exorticata[1,2]	tree fuchsia, kotukutuku	G, Sb		Like willow, can stabilise erosion prone mountain streams and gullies. Deciduous nature may benefit ground cover. Palatable
Griselinia littoralis[1]	broadleaf		Bt	Palatable
Hebe salicifolia[1]	koromiko	G, Sb		Extensive fibrous root system
Kunzea ericoides	kanuka	G	Bt	Both kanuka and manuka are important pioneering native shrubs. Able to stand soil compaction, camping and browsing due to moderate-low palatability. Primary colonisers with extensive fibrous root systems, and may also be suitable for streambank erosion control on small-medium sized streams
Leptospermum scoparium	manuka	G	Bt	

Species	Common name	Suitability (Pollock 1986)	Use (van Slui 1991, TRC 1992)	Comments
Macropiper excelsa[1,2]	kawakawa		Sb	
Melicytus ramiflorus[1,2]	mahoe, whiteywood	G		Useful in wetter climates on uneroded soils
Metrosideros excelsa[2]	pohutukawa	G		Coastal soils
Oleria avicenniaefolia[1]	akeake	(G)	Bt	Dry climates, coastal soils
Phormium cookianum *P. tenax*	flax	Sb, G	Sb	Withstands inundation, but does not have deep or wide root system
Pittosporum crassifolium[1,2]	karo		Bt	
Schefflera digitata[1,2]	pate		Bt	
Sophora microphylla[2] *S. tetraptera*[2]	kowhia	(Sb)	Bt	Suitable for stable streambanks for long term protection. Semi-deciduous nature may also benefit ground cover

TABLE LEGEND

Suitability	Pollock assigned suitability categories to his recommendations: G = suitable for gully erosion, (G) = possibly suitable for gully erosion, Sb = suitable for streambank erosion, (Sb) = possibly suitable for streambank erosion.
Uses	Recommendations by Van Slui (1991), and Taranaki Regional Council (1992) have been assigned as Sb = suitable for streambank erosion, Bt = suitable for bank-top erosion protection, shade, habitat, and/or diversity.
[1]	also recommended for use in Table 3 of **CARBON**.
[2]	also recommended for use in Table 1 of **HABITAT**.

Guidelines for Managing Remnant Native Trees, Shrubs and Tussock on Streambanks

OBJECTIVE(S)

- To manage remnant native vegetation so as to maintain or improve bank stability, while retaining the benefits of shade, habitat diversity, carbonaceous inputs and flood water retention.

GUIDELINE(S)

This technique is applicable to catchments that still have significant stands of native trees, shrubs or tussock near stream channels.

1. Before any development, such as converting extensive to intensive grazing, identify floodplain from maps, aerial photographs, or ground surveys.

2. Delineate the buffer zone that is not to be developed; in most cases, the retention of a zone 2–5 m wide is all that is necessary. Sometimes (e.g., as in tussock-lands), floodplains provide a natural indication of appropriate buffer width.

3. Avoid developing these areas, e.g., by burning, scrub cutting, forest harvesting, or discing.

4. Grazing management:

- *In preference, trees and shrubs should be permanently retired from grazing to allow regeneration*, or lightly grazed. Light grazing must be managed to maintain a good ground cover, as well as to minimise trampling damage. Sheep are preferred over cattle, especially where stream margins are susceptible to hoof damage, but they may be less effective in dealing with rank vegetation. Grazing intensity will depend on climate and soil cohesiveness. We cannot recommend grazing densities with confidence, but as a rough guide, 5–10 s.u./ha is probably sustainable on most cohesive soils (see Tables 1 and 2). Intensive grazing (10–20 s.u./ha) may lead to loss of ground cover, especially if the planted trees or shrubs provide the only protection for stock from sun or cold rains in the grazed paddock; animals will tend to "camp" in these areas. If grazing control is not part of the scheme, then it would be essential to provide other shade and shelter for stock some distance away from the riparian zone. This shelter would have to be large enough to shelter all stock likely to be found in the paddock.

- Tussock grassland, by contrast, may not need to be permanently fenced. However, intensive grazing will result in an increase of introduced grasses at the expense of tussocks and other native grasses. Further research is needed to investigate the succession of tussock to introduced grasses under intensive grazing.

JUSTIFICATION AND ASSUMPTIONS

Removal of remnant trees, shrubs and tussock may lead to stream instability if introduced grasses provide insufficient protection. This will occur if the remnant plants had been armouring banks that would otherwise be susceptible to fluvial entrainment or weathering erosion. Remnant natives may offer more protection because of their woody roots (all trees and shrubs), dense protective roots (e.g., tree fern) and/or because they are deeper rooting than introduced grasses. The latter applies especially where remnant vegetation root depth is greater than streambank height or grass root depth. In more deeply-incised banks, remnant natives may stabilise overhangs against gravity failure.

The question of streambank stability is quite complex in hilly or mountainous regions, because bank stability may be dictated by mass wasting processes upslope, which deliver the soil mantle and other material to the stream. For example, in V-shaped valleys, remnant trees and shrubs may also stabilise the hillslopes against mass movement (e.g., soil creep, earthslips). These cases are not addressed here, and the reader is referred to The Plant Materials Handbook, Volumes 1–3, Van Kraayenoord and Hathaway (1986a, 1986b), and Pollock (1986).

SIDE EFFECTS AND LIMITATIONS

Tussock, sedges etc. may stabilise large blocks of collapsed material in streams. This provides instream cover, but may also create localised scour by redirecting flows.

The remnant natives will maintain landscape and riparian diversity (see **HABITAT**), provide shade (see **LIGHT**), continue to regulate temperatures (see **TEMPERATURE**), and provide organic inputs to the watercourse (see **CARBON**). They will also retard large floodflows when floodwaters overflow into the riparian zone (see **FLOW**).

Native vegetation may not protect banks sufficiently when flows are increased by catchment development. Anecdotal evidence in northern Southland shows that tussock left on the floodplains of small streams did not prevent serious streambank erosion after the surrounding land was developed to intensive pasture, which coincided with an increase in high intensity rainfalls. Dense native vegetation may also shade banks and discourage protective ground cover (e.g., fast growing introduced pasture plants) from establishing on laid-back banks or on sediment that has been deposited at the bottom of eroding banks.

Nutrient stripping from overland flow by plants may be quite poor if ground cover is shaded out (see **CONTAMINANT**). Multi-tier schemes that involve grass buffer strips may be needed (see Guideline Planting and Stripping in Taranaki Regional Council 1992).

CONFIDENCE

Moderately confident based on observation. Further research is needed, however.

Guidelines for Managing Stock Grazing on Damaged Streambanks

OBJECTIVE(S)

To protect "sensitive" streambanks that have been broken down, trampled or badly pugged for one of the following reasons:

- The soils are naturally uncohesive under intensive grazing.
- The soils are permanently or seasonally saturated and intensively grazed.
- Streambanks are accessible to farmed red deer.
- Streambanks (regardless of soil cohesiveness) are included in high density rotational stocking systems, including mob or strip grazing.

GUIDELINE(S)

1. Identify sensitive streambanks listed above that have been severely damaged under traditional management. Permanently or seasonally saturated streamside soils are best located by field inspection. Obtain maps (1:50,000) of soil type for the catchment of interest. Maps may already be in existence or they can be obtained from the computer-based Land Resource Inventory (LRI). Inquiries for such information should be directed to your nearest Landcare Research NZ Ltd office. Uncohesive soils can be located from soil maps using the preliminary index of stability based on the ease with which the unvegetated *in situ* material is eroded by flowing water (Tables 1 and 2). Soils which also show high dispersivity (Tables 3 and 4) may be of particular concern for downstream water clarity.

2. Once sensitive areas have been identified, they can be managed in one of the following ways:

Option 1: Permanently fence streambanks: Fence distance from the stream depends on flood height, and anticipated migration of the stream channel. Typically, fences will be strung along the floodplain edge with a suitable buffer zone to filter surface runoff (see CONTAMINANT). Fence type reflects that needed to exclude animals being grazed in adjacent pastures.

Manage exclosures taking into account other objectives (see section on side effects and limitations later). Management practices could include:

- Selective grazing to maintain a good grass sward.
- Agro-forestry with sufficient spacing between trees to allow growth of protective and sediment-trapping ground cover (see Appendix 1).
- Haymaking.
- Permanent retirement with conservation plantings or natural regeneration.

Option 2: Temporarily exclude animals from streambank: Install or extend electric fences to exclude animals from streambanks during set stocking in order to maintain an adequate buffer strip width for treating surface runoff (see CONTAMINANT). This strip should remain ungrazed until a good sward (e.g., 10 cm) has re-established on the rotationally-grazed land upslope.

Option 3: Create barriers to animal access to wet streamside soils: Sometimes animals walk along the stream edge through wet soils formed from seeps or drains because of the shorter distance or because of floodplain morphology or fence lines. In some of these cases, it may be expedient to close off this route, rather than permanently exclude animals. Possibilities include:

- Tree planting (see STABILITY: TREES) (Figure 3).
- Installing a short section of fence at an appropriate angle to the stream (Figure 3).
- For wetland exclosures that are fenced along but not over the stream channel, create a barrier to animals walking along the stream edge with a "spur" fence (Figure 3).

JUSTIFICATION AND ASSUMPTIONS

Improper grazing has caused serious long term damage in riparian areas in the rangelands of the western USA (Kauffman and Krueger 1984; Skovlin 1984; Platts 1991) because of widening, shallowing, loss of overhang and decreasing bank angles ("laying back"). Insignificant damage is found when range management ensures uniform cattle distribution. Surveys of set-stocked streambanks in Southland found little evidence of significant morphological changes to stream channels except when stock density was high (i.e., 15–20 s.u./ha), where wet streamside soils attracted grazing cattle, and at major stock crossings. Elsewhere, most streambanks showed evidence of minor bank damage only (hoof prints, small pieces of broken bank and bare soil from stock tracking). This can be seen on any recently-grazed streambank, and largely disappears or is obscured by grass growth after a rest period. It therefore seems intuitively sensible that conditions that impose *relatively* high stoc-

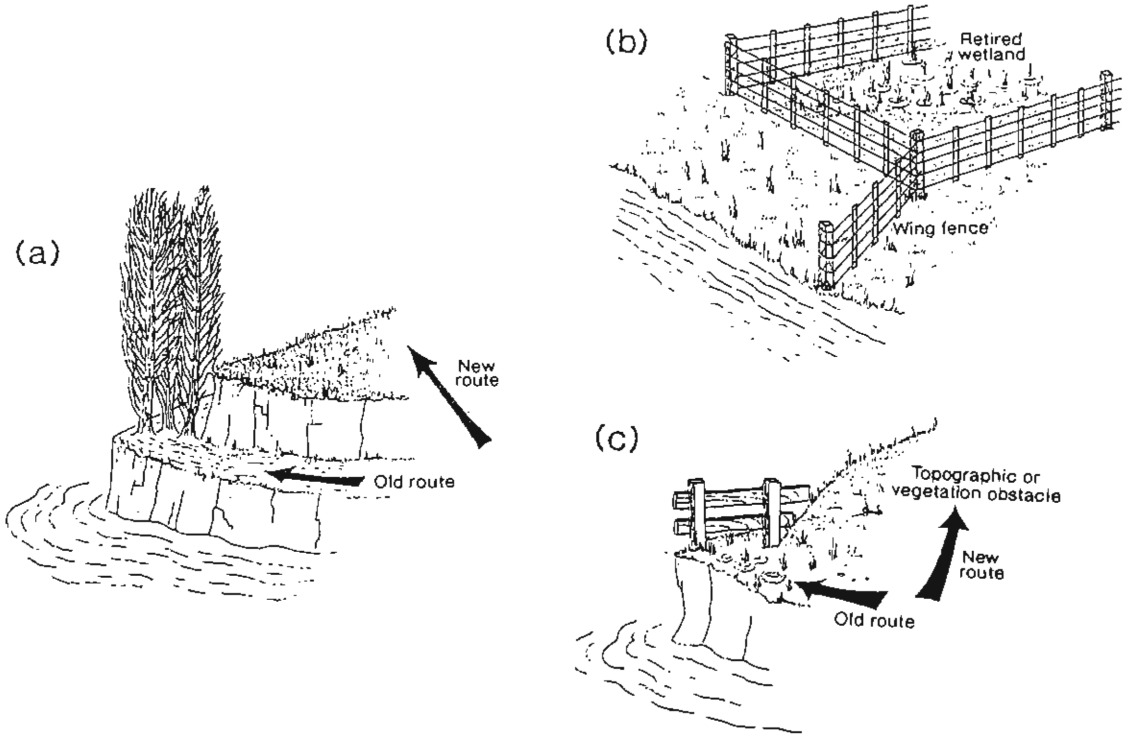

Figure 3 Creating barriers to animal access to wet streamside soils, by (a) tree planting, (b) and (c) fencing.

king rates on streambanks will produce serious damage to them, and in the case of cattle and large deer, to streambeds.

For the specific situations described in the guideline objective, the following rationale also applies, and justifies retirement:

- Uncohesive soils are expected to be sensitive to hoof damage and/or fluvial damage under intensive grazing. An example is the yellow-brown pumice soils around Lake Taupo.

- The shear strength of cohesive soils is lessened when wetted, and perennially wet soils on streambanks can be subjected to continual breakdown by trampling. Cattle are attracted to water and the wet meadow systems sometimes found beside water, and do not avoid wet soils as do sheep (Skovlin 1984, Kauffman and Kreuger 1984). For example, surveys of grazed and retired streambanks in Southland found severe morphological changes to stream channels in areas of wet streamside soils under intensive grazing.

- Red deer exhibit strong wallowing behaviour: males and females wallow in summer and males in middle and latter periods of the rut. Animals urinate in wallows and cake themselves with mud. Wallows are used repeatedly over years and appear to be an important part of habitat. Wallowing will have a drastic effect on streams: effectively changing them into mud hollows. In addition, red deer congregate on slopes and pace the fencelines, and these tracks can be a source of sediment and animal excreta to the stream. Fallow deer are not a problem.

- Very high stocking densities sometimes found under rotational strip and mob grazing practices (Table 9) are expected to damage streambanks, even if the soils are cohesive.

Table 9 Grazing densities (number of animals per hectare) used in New Zealand.

SYSTEM	CATTLE	SHEEP
Continuous ("set-stocking") extensive grazing	0.5–1	5–10
Continuous ("set-stocking") intensive grazing	2–3	10–20
Rotational (~24 hrs)	30–90	150–450
Strip (≤ 12 hrs)	120–400	500–1200
Mob (2 hrs – 2 weeks)	Variable, can be high density e.g., 50 s.u./ha	

SIDE EFFECTS AND LIMITATIONS

The smaller the watercourse, the more useful the techniques. There is not much benefit for large streams (> 6 m width). Maintenance of a narrow, overhung stream channels will enhance shade in smaller streams (particularly widths < 2 m). Depending on the length of channel protected, this may significantly decrease instream plant production, and temperature extremes and fluctuations (see **TEMPERATURE** and **LIGHT**).

In *open* streams with sufficiently low power and which are accessible to grazing animals, retirement will encourage aquatic plant growth. This may, in turn, change the aquatic habitat and increase nutrient processing in the stream. If growths are excessive, plants may effectively block the stream to migrating fish. Riparian shading from trees and shrubs can be used to limit aquatic plant growth (see **LIGHT**). Salmonid spawning redds may be enhanced in some streams because fine sediment inputs decline and the streambed is not trampled. Temporary exclusion of grazing animals at appropriate sites during inanga spawning has been recommended (Mitchell and Eldon 1991).

Retirement will result in an increase in vegetation in the riparian zone, which will help slow over-the-bank flows (see **FLOW**). Retirement of streamside wetland soils will also reduce nitrate groundwater inputs (see **NITRATE**) and improve habitat for terrestrial species (see **HABITAT**).

For permanent exclosures, there is the initially high cost of fencing (Appendix 2), providing alternative stock water, and land take. There are also potential problems with noxious weed infestations and the possible need to control these with herbicides. Methods for noxious weed control have been laid down in volumes 1 and 2 of The Plant Materials Handbook for Soil Conservation. Other information is available in Buxton, 1991, and Timmins and Mackenzie, 1995 (see *Important reading kit* earlier). Procedures for herbicide spraying are currently being developed by the Department of Conservation. Weed control in riparian areas has been a problem because of a reluctance to spray near streams or because adjacent land owners resent having to do this. West, 1994, provides information on willow control and the selection of non-weed willow and poplar species (see *Important reading kit* earlier in this volume).

CONFIDENCE

Moderate-high

APPENDIX 1 Farm forestry

A number of tree species are being evaluated by the Forest Research Institute (Rotorua), AgResearch (Whatawhata, Hamilton) and various tree farming associations and private individuals. Latest information can be obtained from Forest Research Institute, Rotorua, or your local branch of the Tree Crops Association or Farm Forestry Association.

Forest Research Institute see *Acacia melanoxylon* (Tasmanian blackwood), eucalypts (*E.regnans, E.nitens*), *Juglans nigra* (black walnut), poplars and cypresses as potentially the most useful for timber (I.D. Nicholas, FRI, pers. comm.).

The Upper Kaituna Catchment Control Scheme retired and planted 80% of streambanks in the Rotorua and Rotoiti catchments mostly with natives, but also used *Acacia melanoxylon, A. dealbata, Cupressus lusitanica* (douglas fir), oak and black walnut as high quality timber species to provide a financial return.

APPENDIX 2 Fencing costs (Taranaki Regional Council 1992)

Estimated costs for fencing range from $3.50/m for a 5 wire electric fence to $7.00 for a 8 wire conventional fence. Establishing a riparian buffer (which incorporates bank protection, shade trees and grass buffer), including fencing, trees, planting costs, spray for preplant and "releasing" after one year, range from $6.64/m (for a 3 m strip with a 5 wire electric fence) to $11.71/m (for a 5 m strip with a 8 wire conventional fence).

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GUIDELINES FOR MANAGING CONTAMINANT INPUTS TO WATERCOURSES VIA OVERLAND FLOW

INTRODUCTION

The effects of contaminant inputs on stream ecosystems and the influence of pastoral development on these is described in *Volume 1: Concepts: Section 2.2.5.* Water flowing across the soil surface during rainfall events (i.e, overland flow or surface runoff) transports sediment and associated nutrients (e.g., nitrates and phosphorus[1]) and pesticides as well as bacteria and other pathogens from developed land to surface waters. The entrainment of pollutants into overland flow, their movement downslope, and removal within riparian filter strips has been extensively studied, although the long term implications of contaminant build up are not known. Experimental results show that filter strips vary widely in their ability to remove pollutants, reflecting variation in such factors as slope, soil porosity, and vegetative cover upslope and within the filter strip. This variability prevents any general statement being made on filter strip performance and optimal width for controlling contaminant inputs to watercourses. Riparian filter strips are not a substitute for wise land management such as conservation planting and grazing control.

Development of models

Research over the past 15 years has focused on developing computer simulation models of the hillslope processes that regulate overland flow and pollutant transport within it. These physically-based models combine site information on climate, soil properties, vegetation, land management practices and topography to predict volumes of overland flow and the quantity of soil particles and soluble components entrained into this flow (see Figure 1). The mathematical relationships used in the models have been derived from considerable theoretical and experimental research and so represent an amalgam of current scientific wisdom.

Typically, a water balance for the hillslope for each time interval (a day or less) is performed first. If overland flow is predicted to occur, then soil loss equations and stream power theory are used to predict particle detachment and downslope transport of this detached material. Extraction of soluble components from the soil into overland flow are usually dealt with by semi-empirical relationships that assume a certain extraction efficiency and depth of soil that interacts with the flow.

The influence of riparian filter strips can be incorporated by segmenting the hillslope and changing the value of key parameters within the strip to reflect the altered conditions (e.g., increased vegetative cover). These models have found particular favour in the United States where they have been used to predict the effects of various land management alternatives on pollutant transfer to waterways, including the effects of installing riparian filter strips.

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[1] This refers to sediment bound phosphorus. Sufficient information is not currently available to develop general guidelines for managing dissolved phosphorus concentrations using riparian vegetation. Nitrates are treated separately in Guideline: **NITRATE**.

Factors affecting filter strip performance

The models and experimental studies have shown the following factors to be critical in influencing the performance of riparian filter strips:

Spatial distribution of incoming overland flow: Filter strips perform best when overland flow arrives at the upslope edge as a spatially diffuse sheet flow. When overland flow becomes concentrated into small rivulets, both its velocity and depth increase and the performance of the filter strip declines.

Particle size distribution of incoming sediment: Filter strips are best able to remove coarse particles from overland flow, with a larger reduction in transport energy being required to deposit clay-sized particles within the strip. This sieving effect has two important consequences. Firstly, for any particular situation the installation of a filter strip will decrease the amount but increase the proportion of fine sediment (and conversely lower the proportion of coarse sediment) reaching the stream channel. Because other pollutants (e.g., phosphorus, pesticides) are preferentially bound to these fine particles, the performance of a filter strip with respect to sediment bound materials may be less than that observed for the sediment itself. Secondly, with all other factors being equal, filter strips will be less effective in catchments containing high clay contents in their topsoils.

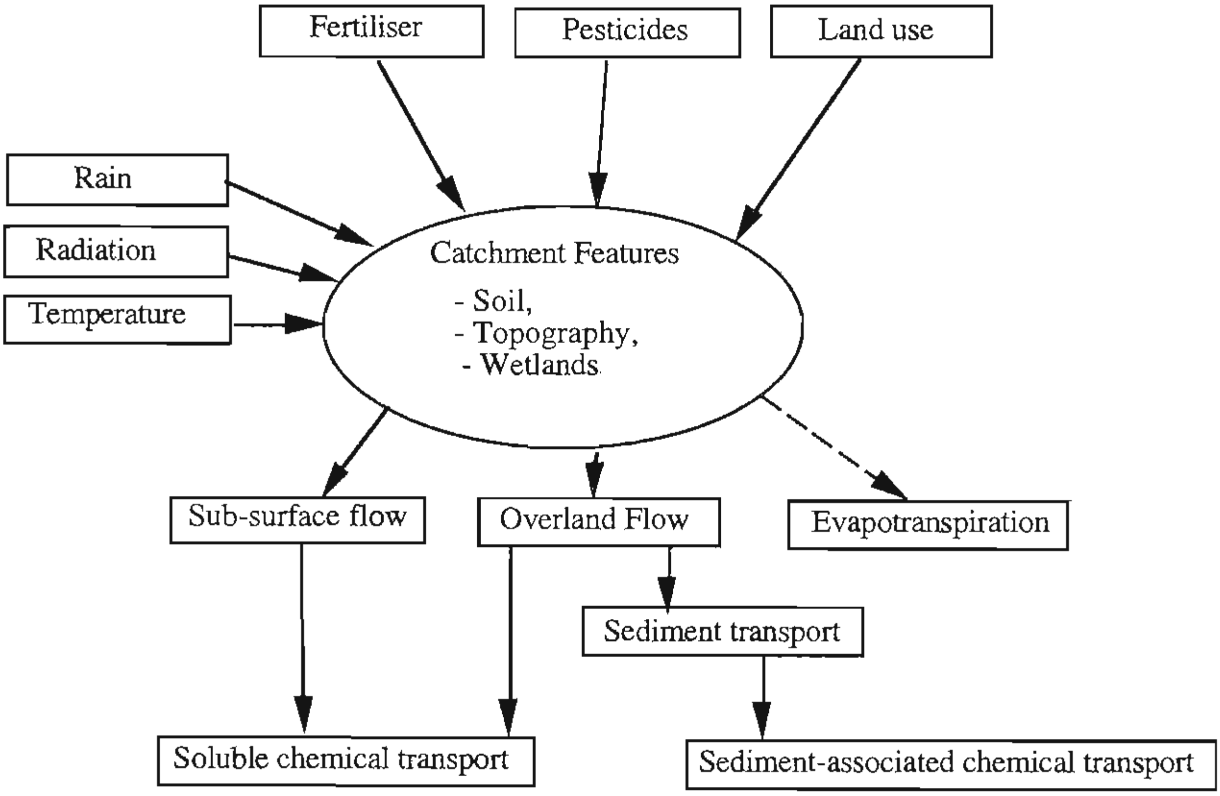

Figure 1 Conceptual flow diagram showing inputs and outputs of catchment water quality models, such as the modified Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model used to develop the guideline.

Soil drainage: The drainage properties of the hillslope exerts their influence on filter performance in several ways. The better the drainage, the less often overland flow occurs and the lower the volume generated. Under such conditions filter strip performance may be high, but it is questionable whether such infrequent overland flow events need to be treated.

Where the creation of a filter strip improves the drainage properties of the soil within it, filter performance can be improved by allowing incoming overland flow to infiltrate into the ground. Dissolved pollutants and fine particles move into the soil matrix with the infiltrating water and can then be trapped by physical sieving, chemical sorption and biological uptake. In small events this mechanism might be important but in large events the filter strip will become saturated and incoming overland flow will not be able to infiltrate.

Hillslope and near-stream topography: Filter strip performance depends upon the gradient within the strip itself and the topography (both gradient and shape) above it. Performance is best on gentle slopes because a strip's ability to reduce the transport capacity of incoming overland flow increases as slope decreases.

Vegetation: Filter strips perform best when they comprise a dense vegetative cover of sufficient height and stiffness to avoid inundation during large runoff events. Vegetation acts to increase the tortuosity of the flow path, thereby reducing flow velocity and hence the capacity to transport particles. Vegetation can also act to bind dissolved pollutants and provide root channels for improving the infiltration of water.

A method has been developed for estimating the effectiveness and optimal width of a filter strip based upon three readily-obtained site parameters; slope, drainage class and clay content. It uses as its basis a large number of catchment model simulations of the various conditions commonly found in the New Zealand landscape. More details on the development of the guideline are given in Appendix 1. A worked example of the procedure is provided in Appendix 2.

Guidelines for Reducing Contaminants in Overland Flow

OBJECTIVE(S)

To limit the quantity of contaminants reaching watercourses by overland flow from pastures.

GUIDELINE(S)

Establish very dense grass filter strips in the riparian zone (e.g., by fencing off from stock; see **STABILITY: STOCK** for details of fencing and management). The following procedure assists in this assessment by providing estimates of the likely reduction in suspended sediment input to watercourses and the width of filter strip required. Reduction in inputs of particulate forms of nitrogen, phosphorus and pesticides may be similar to that presented for suspended sediments in coarse-textured soils, but less (not quantified) if the soils are fine-textured. Some reduction in dissolved nutrients might also be expected but cannot be quantified.

The procedure is:

1. Obtain maps (1:50,000) of slope class and soil type for the catchment of interest. Maps may already be in existence or they can be obtained from the computer-based Land Resource Inventory (LRI). Inquiries for such information should be directed to your nearest Landcare Research NZ Ltd office.

2. Place areas of the catchment into one of 3 slope categories (low, medium, high) according to the definitions in Table 1. Slope maps usually contain 7 classes and these need to be placed into the three broad categories used in Table 1.

3. Classify each of the significant soil types found in the catchment according to drainage class (Table 2) and clay content, where topsoil clay content categories are low (L=<20%), moderate (M=20–40%), and high (H=>40%). Information on these soil properties (at least at the level required here) is likely to be available in reports or databases or can be estimated by a soil expert (contact your nearest Landcare Research NZ Ltd office or other agricultural advisors).

4. Using a topographic map (1:50,000), divide the visible stream network up into reaches (say 0.2–1.5 kilometres in length, depending on desired detail) and sketch the "catchment" boundary for the right and left banks of these reaches. With this as the base map, overlay each of the slope, drainage, and clay content maps and record dominant categories for each streambank (left and right) for each reach. Use Table 3 to determine the optimal filter width (as % hillslope length) and estimated filter performance for both sides of each reach. From the topographic maps, estimate average hillslope length (ridge-to-stream) and convert filter width as a % of hillslope length to a filter width[2] in metres. Repeat this procedure for all stream reaches within the catchment. As a general rule, one measurement of ridge-to-stream length per kilometre of stream channel should be sufficient to estimate average hillslope

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[2] Filter width is a measure of the distance as a % of hillslope length run-off water will travel through the filter on its way to the stream.

length where the topography is reasonably constant, but more frequent measurements may be required where stream segments are short or the topography is variable.

5. Estimate the overall effectiveness of installing filter strips along the complete drainage network of the catchment, and the are a of land that would need to be given over to filter strips, by combining all the individual reach estimates using the relationships:

$$\textbf{Effectiveness} = \frac{\Sigma(L_i P_i)}{\Sigma L_i} \quad \text{..................}\textbf{Equation 1}$$

where L_i = stream edge length classified in composite slope/drainage/clay category i, from Table 3;
and P_i = performance of composite slope/drainage/clay category i, from Table 3.

$$\textbf{Land area required} = \Sigma(l_x w_x) \quad \text{..................}\textbf{Equation 2}$$

where l_x = stream edge length in unit reach, x (metres);
and w_x = width of filter strip in unit reach, x (metres).

These values represent an estimate of the maximum benefit that can be achieved through the use of filter strips within the catchment and the maximum amount of land that would need to be used. The effects of partial implementation of a filter strip policy on these two estimates can then be determined.

Table 1 Slope category definitions for use with Table 3.

SLOPE CLASS (per LRI)	SLOPE ANGLE (degrees)	DESCRIPTION	SLOPE CATEGORY (for use in Table 3)
A	0–30	Flat-gentle	L (low)
B	4–7	Undulating	L (low)
C	8–15	Rolling	M (moderate)
D	16–20	Strongly-rolling	M (moderate)
E	21–25	Moderately-steep	H (high)
F	26–35	Steep	H (high)
G	>35	Very steep	H (high)

Table 2 Soil drainage category as derived from three commonly used drainage measures or indices as used by Griffiths (1985). One or more indices can be used to determine drainage category.

PERMEABILITY CLASS	DESCRIPTION	INFILTRATION RATE (mm/h)	DRAINAGE CATEGORY (for use in Table 3)
1	Very slow	<1	L (low)
2	Slow	1–4	L (low)
3	Moderately slow	5–19	M (moderate)
4	Moderate	20–64	M (moderate)
5	Moderately rapid	65–129	H (high)
6	Rapid	130–250	H (high)
7	Very rapid	>250	H (high)

Table 3 Estimates of optimal width and performance for riparian filter strips. For definitions of slope categories see Tables 1 and 2 and the text.

SITE CHARACTERISTICS			FILTER WIDTH (% hillslope length)	FILTER PERFORMANCE (% reduction)
SLOPE CATEGORY	**DRAINAGE CATEGORY**	**CLAY CATEGORY**		
L	L	L	1	95
		M	5	90
		H	9	80
	M	L	1	95
		M	2	90
		H	4	80
	H	L	1	95
		M	1	95
		H	3	85
M	L	L	2	90
		M	7	70
		H	15	50
	M	L	1	95
		M	4	80
		H	11	55
	H	L	1	95
		M	2	85
		H	4	60
H	L	L	5	45
		M	15	30
		H	30	20
	M	L	3	60
		M	7	50
		H	13	35
	H	L	3	75
		M	4	70
		H	11	50

JUSTIFICATION AND ASSUMPTIONS

Filter strips have been shown to be an effective tool for removing particulates from overland flow draining agricultural land (see review by Muscutt *et al.* 1993). In New Zealand, riparian filter strips have been shown to significantly reduce sediment loadings from pastures in the Waikato (Smith 1989) and near Rotorua (Cooper *et al.* 1991). In both cases, subsequent work has shown that the effects observed could be predicted quite well by the modified CREAMS catchment model used to develop this guideline (Cooper *et al.* 1992, Cooper and Bottcher 1993).

SIDE EFFECTS AND LIMITATIONS

The establishment of riparian filter strips for control of contaminant input from overland flow may have the following side effects:

- Reduce streambank erosion by denying stock access to the stream edge and by allowing stabilising vegetation to develop (see STABILITY).
- Increase shading of small, incised streams due to growth of bankside vegetation (see LIGHT)
- Increase costs due to the possible need to control weed infestation within the strip and supply alternative water for stock denied access to the stream

The guideline has been developed by synthesis and simplification of information derived from the CREAMS model (see appendix 1). This approach is necessary to develop broad, useable guidelines but a consequence of such an approach is that the prediction error can be large. Research on filter strips has usually been of short duration, and questions remain as to their performance and management in the long term. For example, riparian filter strips are usually managed as total stock exclusion zones but is this necessary or indeed desirable?

Current scientific understandings are insufficient to allow general filter strip performance guidelines to be developed for removal of dissolved phosphorus and pesticides. In catchments with severe hillslope erosion this guideline cannot be used in isolation, but can be applied in conjunction with conservation plantings and careful grazing management.

CONFIDENCE

High for ability of riparian filter strips to remove contaminants but low for defining optimum width and quantifying performance at specific locations.

APPENDIX 1 Development of a guideline for riparian filter strips of overland flow

The best means of predicting the width and performance of a proposed filter strip is to run catchment model simulations for the site concerned. In this way, the specific properties of the site and local climate are included in the prediction. However, the complexity of the models and the expertise required to run them may make modelling an unattractive tool for initial feasibility studies. The guideline presented here provides a compromise between detailed site-specific modelling and the intuitive methods commonly used in New Zealand. It utilises the predictive power of the CREAMS catchment model but summarises its outputs in a single, easy-to-use table (Table 3).

The steps involved in producing the guideline were:

1. The modified CREAMS model of Cooper *et al.* (1992) was run for each of the major soil groups in New Zealand assuming pastoral land use and a grass filter strip. Input data for these soils was obtained from existing site descriptions and databases.

2. Model simulations were run using climate data (minimum 10 years) taken from a site located within the geographic area where the soil group was dominant. These simulations therefore provided predictions of the long term average effectiveness of filter strips within the appropriate climate zone for each of the soil groups.

3. For each soil group, a suite of model simulations were run that covered all of the possible combinations of the following:

• slope angle	2, 5, 10, 15, 20, 30 and 40 degrees
• hillslope length	50, 100, and 200 metres
• filter width	2, 5, 10, 15, 20, 30 and 50 metres

The filter was assumed to have a "very dense" vegetative cover.

A total of 2,200 model runs were performed. This modelling revealed, more or less, the generalised relationship presented in Figure 2.

The first inflexion point represents the filter strip width beyond which benefits diminish for land given over to the filter strip. The second inflexion point occurs at high filter width/hillslope length ratios and results from the decrease in sediment entrainment into overland flow within the filter strip rather than from an effect of the filter strip on treatment of upslope runoff. The first inflexion point can therefore be regarded as defining the optimal filter width/hillslope length ratio (i.e., giving the best return for the amount of land given over to the riparian filter).

The filter strip performance and filter width ratio at this optimal point were taken from each simulation run, and these data were grouped according to key soil and landscape properties. The median value for each group is the value presented in Table 3. Table 3 predicts that narrow filter strips can be expected to perform well in gentle to strongly rolling land, especially where clay content is below 40%. In steeper land, performance can still be reasonable where drainage is moderate to high but wider strips are required.

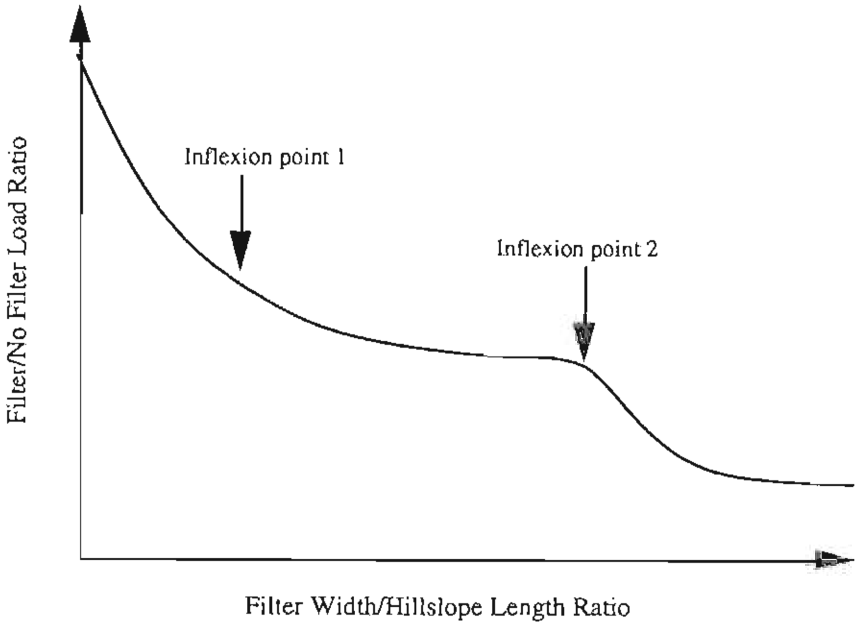

Figure 2 Generalised curve showing the relationship between filter strip effectiveness and the proportion of the hillslope given over to a filter strip. "Filter/No filter load ratio" refers to the ratio of the contaminant load with a filter strip over the load without a filter strip.

APPENDIX 2 Worked example of the guideline for riparian filter strips of overland flow

For this example, part of a stream network located in pastoral land in North Auckland was randomly selected. Using the guideline, the following steps were carried out:

1. Defined the catchment boundary of the entire stream network of interest using a 1:50,000 topographic map.

2. Requested Landcare Research NZ Ltd to produce 1:50,000 slope and soil maps for the area from information held on the Land Resource Inventory. The resultant maps are presented in Figure 3.

3. Obtained information on clay content and drainage rate for the soil types in the area from existing soil survey reports.

4. Used the topographic map to divide the stream network up into numbered reaches of varying length. The length of the reaches was largely determined by either stream confluences or changing hillslope lengths, bearing in mind the suggested length in the guideline of 0.2 to 1.5 km (see Figure 3, top left). It was found useful to outline ridge tops within the catchment before deciding on stream divisions as this gave an idea of how hillslope length varied along the stream network.

5. Determined the catchment boundary of each reach.

6. Measured the average hillslope length (ridge-stream) for the left and right banks of each reach length from the topographic map.

7. Made a transparency of the reach map and overlaid it on the slope map and then the soil map to determine the dominant slope, drainage rate, and clay content category for the left and right banks of each reach.

8. Entered the results of 6 and 7 on a computer spreadsheet (Table 4) and added optimal filter width (as a percentage) and buffer performance using Table 3. The spreadsheet was used to calculate optimal filter width in metres for each side of each stream length, and to rapidly calculate the overall effectiveness of installing riparian filters along the complete stream network (63%), and to estimate the land area that this would require (130 ha or 11.4% of the total area of the catchment).

The outputs from this procedure can be displayed in different ways. A histogram showing the length of stream edge that would need to be given over to different filter widths is presented in Figure 4, while the spatial distribution of these data are shown in Figure 5. These figures are useful aids to future action. For example, Figure 4 shows that there are nearly 7 km of stream edge that would require filter widths in excess of 50 metres and the dark blue in Figure 5 shows where these are located. By use of the spreadsheet, it can be can shown that if the width of these filters were reduced to, say, 10 metres, then the land area required would drop to 90 ha and, assuming a worse case of 0% performance for these narrower buffers, overall effectiveness would fall to 56%. The spreadsheet can be used to rapidly sort reaches by performance and by filter width so that if partial implementation were to be carried out the most effective locations can be targeted.

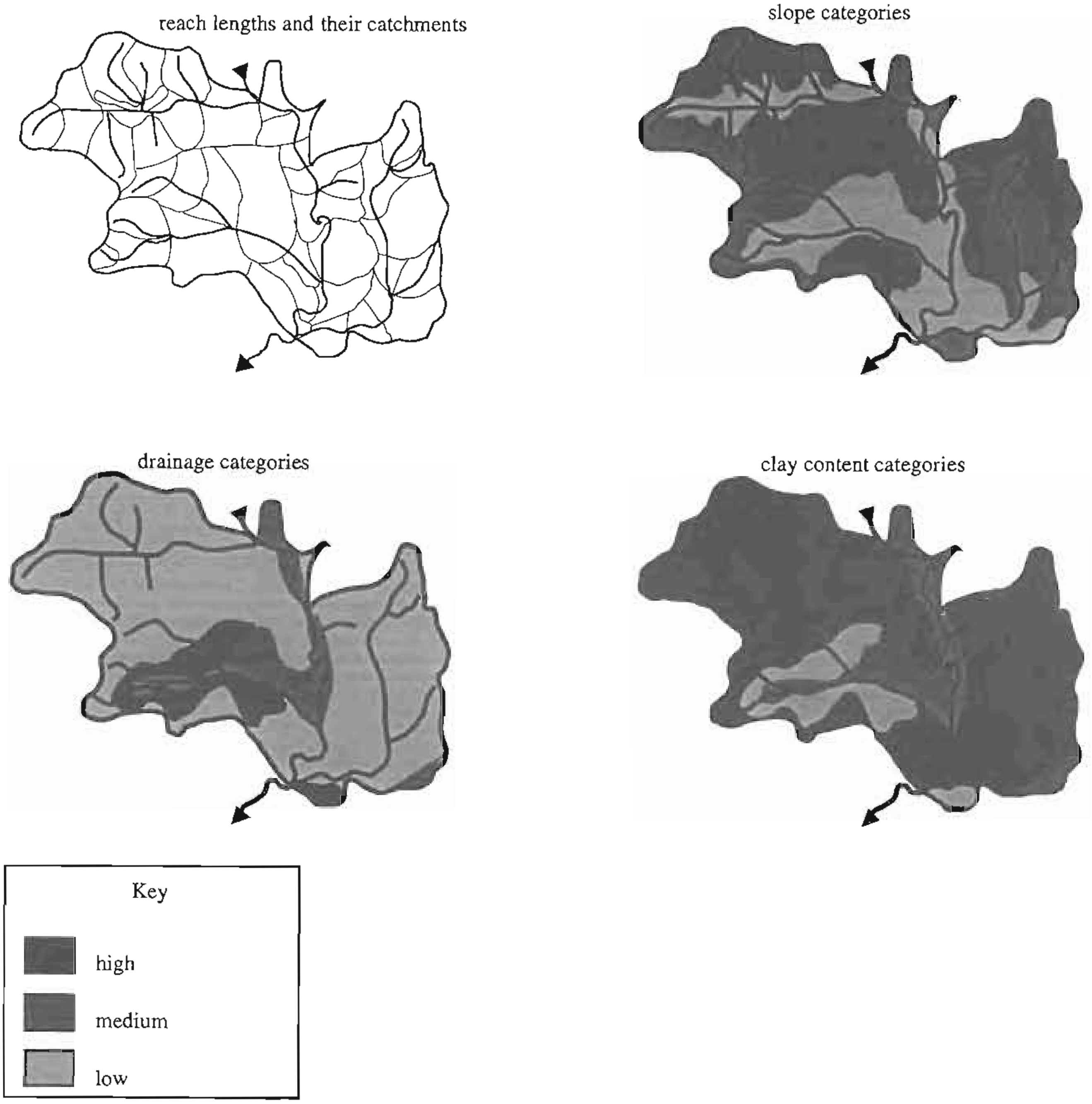

Figure 3 Test catchment maps used to derive the optimal filter strip widths and performance estimates given in Table 4.

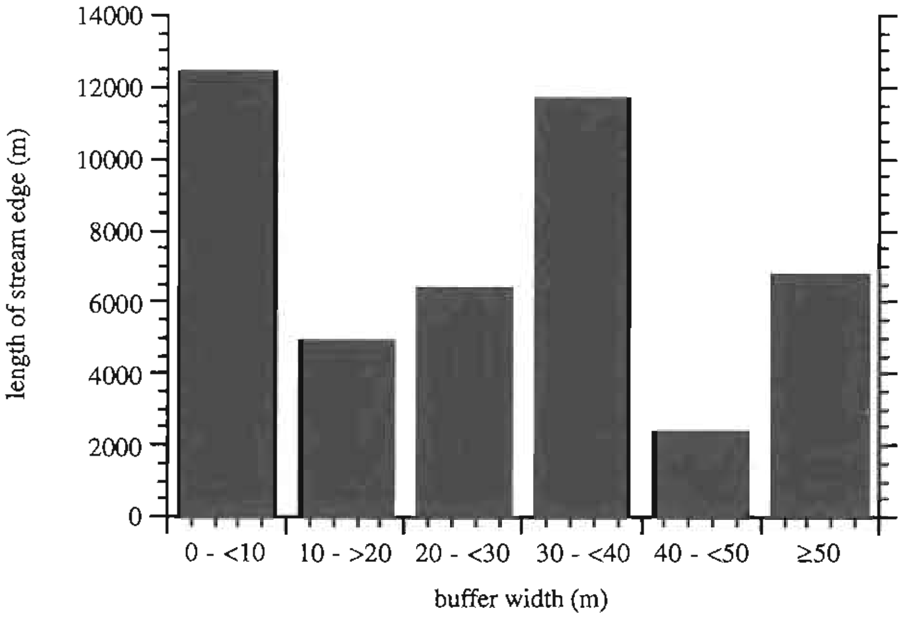

Figure 4 Distribution of optimal buffer widths derived for the test catchment.

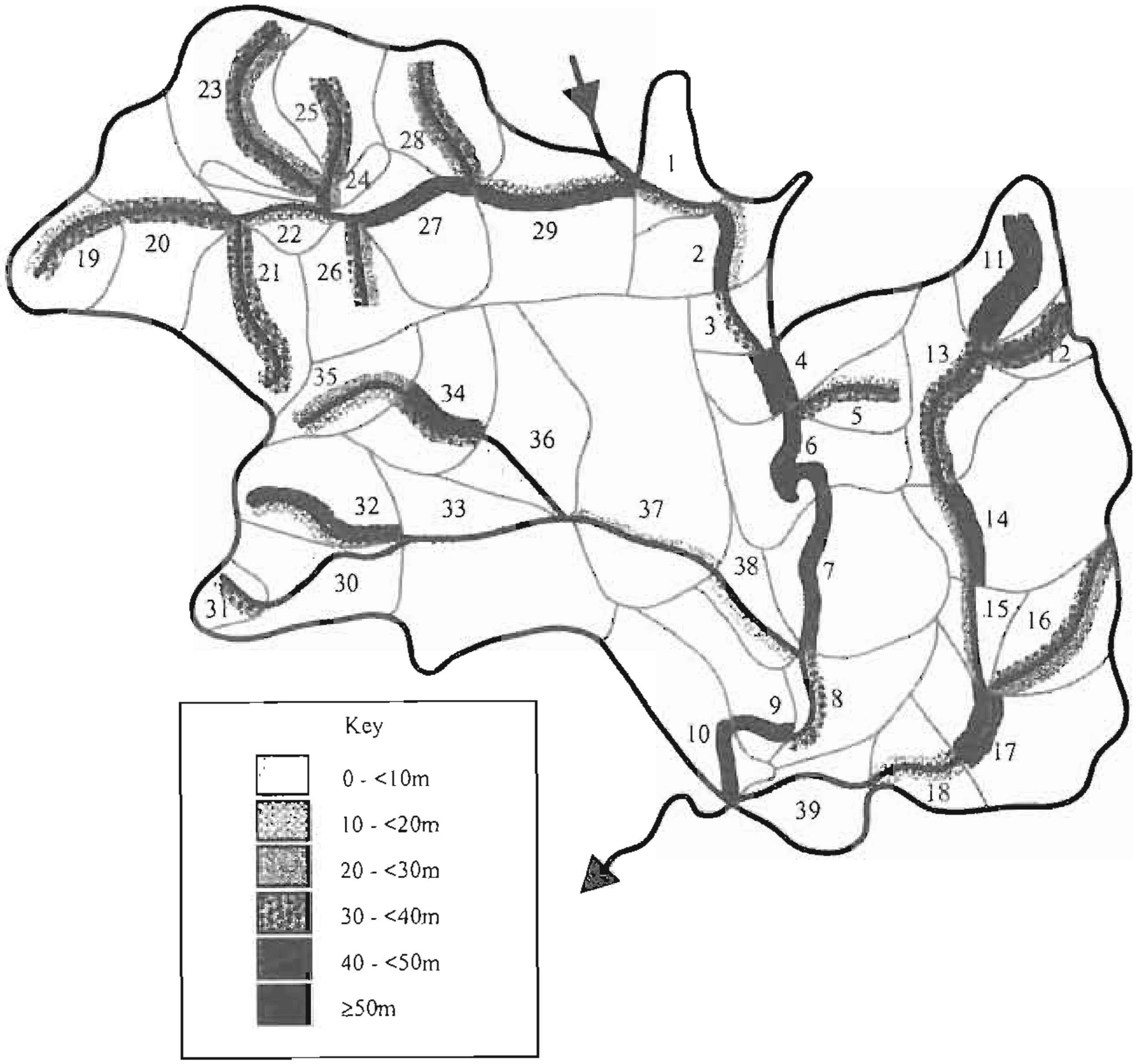

Figure 5 Test catchment maps used to derive the optimal filter strip widths and performance estimates given in Table 4.

Table 4 Spreadsheet showing data and results for each stream reach of test catchment. For stream reach, "lb" and "rb" = left and right bank, respectively.

Stream reach	L_i distance to hill (m)	l_x reach length (m)	Slope category	Drainage category	Clay category	Buffer width (% of hill slope length)	w_x Buffer width (m)	P_i Buffer performance (% reduction)	L_xP_i	l_xw_x
1 lb	200	500	m	m	m	4	8	80	40000	4000
1 rb	150	500	m	l	h	15	22.5	50	25000	11250
2 lb	150	400	m	l	h	15	22.5	50	20000	9000
2 rb	450	400	m	l	h	15	67.5	50	20000	27000
3 lb	125	350	l	m	m	2	2.5	90	31500	875
3 rb	250	350	m	l	h	15	37.5	50	17500	13125
4 lb	650	300	m	l	h	15	97.5	50	15000	29250
4 rb	350	300	m	l	h	15	52.5	50	15000	15750
5 lb	200	500	m	l	h	15	30	50	25000	15000
5 rb	100	500	m	l	h	15	15	50	25000	7500
6 lb	450	700	m	l	h	15	67.5	50	35000	47250
6 rb	300	700	l	m	m	2	6	90	63000	4200
7 lb	600	900	m	l	h	15	90	50	45000	81000
7 rb	150	900	l	m	m	2	3	90	81000	2700
8 lb	400	500	l	l	h	9	36	80	40000	18000
8 rb	100	500	l	l	h	9	9	80	40000	4500
9 lb	75	350	l	l	h	9	6.75	80	28000	2362
9 rb	800	350	l	l	h	9	72	80	28000	25200
10 lb	100	350	l	l	h	9	9	80	28000	3150
10 rb	850	350	l	l	h	9	76.5	80	28000	26775
11 lb	150	700	h	l	h	30	45	20	14000	31500
11 rb	250	700	h	l	h	30	75	20	14000	52500
12 lb	150	500	h	l	h	30	45	20	10000	22500
12 rb	100	500	h	l	h	30	30	20	10000	15000
13 lb	250	700	m	l	h	15	37.5	50	35000	26250
13 rb	250	700	m	l	h	15	37.5	50	35000	26250
14 lb	600	500	m	l	h	15	90	50	25000	45000
14 rb	150	500	m	l	h	15	22.5	50	25000	11250
15 lb	100	600	l	l	h	9	9	80	48000	5400
15 rb	150	600	m	l	h	15	22.5	50	30000	13500

Stream reach	L_i distance to hill (m)	l_x reach length (m)	Slope category	Drainage category	Clay category	Buffer width (% of hill slope length)	w_x Buffer width (m)	P_i Buffer performance (% reduction)	L_xP_i	l_xw_x
16 lb	150	1050	m	l	h	15	22.5	50	52500	23625
16 rb	200	1050	m	l	h	15	30	50	52500	31500
17 lb	450	350	l	l	h	9	40.5	80	28000	14175
17 rb	350	350	m	l	h	15	52.5	50	17500	18375
18 lb	150	400	l	l	h	9	13.5	80	32000	5400
18 rb	150	400	l	l	h	9	13.5	80	32000	5400
19 lb	100	500	m	l	h	15	15	50	25000	7500
19 rb	250	500	m	l	h	15	37.5	50	25000	18750
29 lb	250	600	m	l	h	15	37.5	50	30000	22500
20 rb	250	600	m	l	h	15	37.5	50	30000	22500
21 lb	200	800	m	l	h	15	30	50	40000	24000
21 rb	250	800	m	l	h	15	37.5	50	40000	30000
22 lb	100	550	l	l	h	9	9	80	44000	4950
22 rb	150	550	l	l	h	9	13.5	80	44000	7425
23 lb	150	1000	m	l	h	15	22.5	50	50000	22500
23 rb	250	1000	m	l	h	15	37.5	50	50000	37500
24 lb	250	150	l	l	h	9	22.5	80	12000	3375
24 rb	550	150	l	l	h	9	49.5	80	12000	7425
25 lb	200	600	m	l	h	15	30	50	30000	18000
25 rb	200	600	m	l	h	15	30	50	30000	18000
26 lb	250	450	m	l	h	15	37.5	50	22500	16875
26 rb	150	450	m	l	h	15	22.5	50	22500	10125
27 lb	100	650	l	l	h	9	9	80	52000	5850
27 rb	500	650	m	l	h	15	75	50	32500	48750
28 lb	250	650	m	l	h	15	37.5	50	32500	24375
28 rb	150	650	m	l	h	15	22.5	50	32500	14625
29 lb	200	750	l	l	h	9	18	80	60000	13500
29 rb	450	750	m	l	h	15	67.5	50	37500	50625
30 lb	350	700	m	h	l	1	3.5	95	66500	2450
30 rb	250	700	l	h	l	1	2.5	95	66500	1750

Stream reach	L_i distance to hill (m)	l_x reach length (m)	Slope category	Drainage category	Clay category	Buffer width (% of hill slope length)	w_x Buffer width (m)	P_i Buffer performance (% reduction)	L_xP_i	l_xw_x
31 lb	50	250	m	l	h	15	7.5	50	12500	1875
31 rb	200	250	m	l	h	15	30	50	12500	7500
32 lb	300	700	m	l	h	15	45	50	35000	31500
32 rb	100	700	m	l	h	15	15	50	35000	10500
33 lb	200	850	l	h	l	1	2	95	80750	1700
33 rb	500	850	m	h	l	1	5	95	80750	4250
34 lb	500	550	m	l	h	15	75	50	27500	41250
34 rb	250	550	m	l	h	15	37.5	50	27500	20625
35 lb	150	550	m	l	h	15	22.5	50	27500	12375
35 rb	100	550	m	l	h	15	15	50	27500	8250
36 lb	500	600	l	h	l	1	5	95	57000	3000
36 rb	200	600	l	h	l	1	2	95	57000	1200
37 lb	1100	550	l	m	m	2	22	90	49500	12100
37 rb	250	550	m	h	l	1	2.5	95	52250	1375
38 lb	100	600	l	m	m	2	2	90	54000	1200
38 rb	150	600	l	l	h	9	13.5	80	48000	8100
39 lb	250	650	m	h	l	1	2.5	95	61750	1625
39 rb	100	650	l	l	h	9	9	80	52000	5850
Sum		44700							2795500	1303137

GUIDELINES FOR MANAGING NITRATE INPUTS TO WATERCOURSES IN SUB-SURFACE FLOW

INTRODUCTION

During stable flow conditions, the major transfer of nitrogen from land to streams occurs as groundwater nitrate. Riparian removal of this sub-surface nitrate is now a widely-accepted phenomenon, and is described in more detail in *Volume 1: Concepts: Section 2.2.5.* The important removal process is microbial denitrification, whereby bacteria within the riparian zone convert nitrate to gaseous forms of nitrogen which are then vented to the atmosphere. These bacteria are only able to carry out denitrification in the absence of oxygen and in the presence of organic matter. The position that riparian zones occupy in the landscape favours the development of these conditions and riparian environments variously described as floodplains, bottomlands, wetlands, swamps, seeps and muck soils have all been shown to have a high capacity for denitrification compared to their terrestrial and aquatic neighbours on either side. Nitrate removal efficiencies in these riparian environments can exceed 90%, providing that the incoming nitrate has sufficient residence time within the riparian zone. Such high removal efficiencies can result in low nitrate concentrations (typically around 30 mg NO_3-N m^{-3}) leaving the riparian zone and entering adjacent watercourses. Drainage of riparian wetlands, which has been a common practice in New Zealand, drastically reduces their nitrate removal efficiencies and, from a water quality perspective, should be avoided.

Removal of incoming groundwater nitrate by riparian wetlands typically occurs within the first 5 – 10 metres, with the remaining wetland being "unused". This finding indicates that, on a catchment-scale, the relative importance of a riparian wetland to act as a nitrate sink *is not necessarily related to its size but rather to the nitrate load arriving at its upslope edge.* Within any particular catchment, the long term average nitrate load arriving in groundwater will be related to the contributing area and to the land use within that area. Horticultural land receiving high inputs of N fertiliser may be expected to leach the greatest amounts of nitrate to groundwater. Intensive dairying, where nitrate is leached from beneath urine spots, can also show high leaching losses.

Guidelines for Managing Nitrate Inputs in Sub-surface Flow

OBJECTIVES(S)

To limit the quantity of nitrate reaching surface waters by sub-surface flow from agricultural areas.

GUIDELINE(S)

1. Map riparian wetlands[1] by using aerial photographs (1:2000 or less) and field surveys. Field surveys are best conducted in summer when the lush vegetation of these wet areas contrasts most with vegetation on the surrounding dry land. Mapping needs to include first order streams (see *Volume 1: Concepts: Section 2.1.3* for explanation of stream order) and, in particular, the "swampy" ephemeral channels in the headwaters of such streams.

2. From the topography, estimate the catchment area delivering runoff to each riparian wetland. Rank these areas and group them into 4 categories (category 1 being the 25% of wetlands with the largest catchment areas, category 2 being the 25% of wetlands with the next largest catchment areas, and so on). Also, assign an upslope land use intensity ranking to each wetland as described below:

RANKING	LAND USE
1.	Cropping, horticulture, with N fertiliser
2.	Intensive dairying, with or without N fertiliser
3.	Cropping, horticulture, no N fertiliser
4.	Dry stock; sheep, beef, deer, goats

   Multiply the area category by the land use intensity ranking to estimate an index of the relative nitrate loading to each riparian wetland (see worked example in Appendix 1).

3) Fence off riparian wetlands, protect them from drainage, and encourage the development of native wetland plant species. Priority should be given to those wetlands with the lowest index value. Buxton, 1991, gives useful information on the management, restoration and making of wetlands (see *Important reading kit* earlier in this volume).

JUSTIFICATION AND ASSUMPTIONS

Removal of groundwater nitrate within riparian zones has been observed in a diversity of landscapes throughout the world. New Zealand research on riparian nitrate removal is extensive and clearly shows the importance of this process in buffering surface waters from the effects of land use (Howard-Williams 1991, Cooke and Cooper 1988, Cooper 1990, 1993, Schipper *et al.* 1991, 1993). For example, the median nitrate concentration entering the

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[1] The term "wetland" is used loosely and encompasses all wet and organic-rich streamside areas.

riparian organic seeps in Cooper's (1990) study was 361 mg N m-3 whereas the median concentration leaving the seeps was 23 mg N m^{-3}, well below the 40 – 100 mg m^{-3} range regarded as restricting plant growth in streams (Stockner and Shortreed 1978, Grimm and Fisher 1986, Lohman *et al.* 1991). Riparian wetlands are therefore capable of reducing nitrate concentrations to below an important threshold in stream ecosystems. Additionally, such reductions may have beneficial consequences for downstream ecosystems (lakes and estuaries).

SIDE EFFECTS AND LIMITATIONS

Protection of riparian wetlands may have the following side effects:

- Helps sustain summer lowflows, which is important for both stream biota and out-of-stream uses (e.g., stock watering, irrigation).
- If riparian zones are fenced, prevents stock getting "bogged" in the wetland.
- Provides riparian habitat for certain life stages of aquatic plants, animals and birds (see **HABITAT**).

Although there is ample evidence to show that riparian zone denitrification can lower nitrate inputs to streams, questions remain about the long-term sustainability of the process in the face of continued (and, sometimes, increasing) loadings of nitrate-enriched groundwaters (Quinn *et al.* 1993). Studies to determine the long-term sustainable rate of denitrification are currently underway at NIWA.

The guideline presented here is largely a preservation or preventative one (i.e., maintaining the existing level of nitrate removal). General guidelines for enhancing the nitrate removal capacity of existing riparian wetlands, restoring the capacity in drained wetlands or creating that capacity within riparian zones are not able to be given at this stage. These are topics of current research; if guidance for specific sites is required to enhance, restore, or create riparian nitrate removal then expert advice should be sought.

A potential conflict exists between this guideline and other guidelines that use riparian tree planting. There is some evidence to suggest that dense tree planting in riparian zones can dry out riparian wetlands, thereby reducing their nitrate removal capacity (Smith 1992).

CONFIDENCE

Moderate. Nitrate removal in riparian wetlands is a well-demonstrated and well understood phenomenon. The method described in the guideline for targeting those riparian wetlands of most importance has not been scientifically tested but observation indicates that it is likely to be effective.

APPENDIX 1 Worked example of Guideline: NITRATE

Figure 1 shows a map of riparian wetlands, their catchments, and dominant land use in these catchments. Using the guideline, we can construct Table 1 from this map.

Table 1 Estimation of relative importance of riparian wetlands shown in Figure 1 for removal of nitrate.

WETLAND	CATCHMENT AREA (rank)	LAND USE (RANK)	COMBINED INDEX (product of ranks)
A	4	4	16
B	3	2	6
C	1	4	4
D	2	2	4

Following the guideline procedures, we therefore identify wetlands C and D as priority wetlands for nitrate removal; i.e., wetland C is important in nitrate control because of its large relative size and wetland D because of its combination of size and intensity of land use.

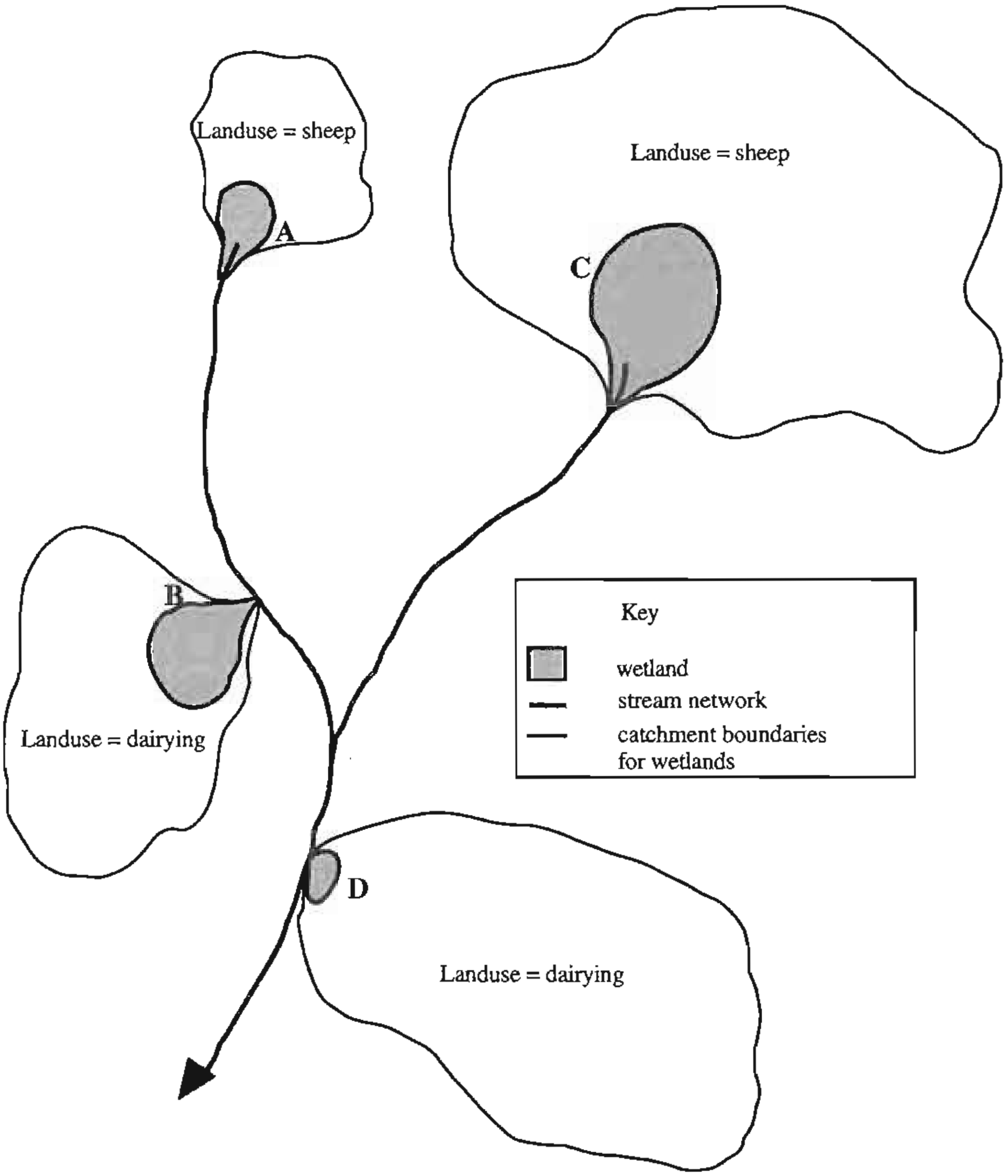

Figure 1 **Map of riparian wetlands and their catchments in a small drainage network.**

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GUIDELINES FOR MANAGING THE LIGHT CLIMATE OF STREAMS

INTRODUCTION

Heavy shade is typical of the natural situation in forested New Zealand streams, and plant communities are typically dominated by bryophytes (native mosses and liverworts) or thin diatom films. Manipulation of the amount of light reaching streams will strongly influence the structure and function of stream ecosystems (see *Volume 1: Concepts: Section 2.2.6* for further discussion). In particular, the planting of tall woody riparian vegetation along stream channels in cleared catchments will reduce direct sunlight influx and restrict the growth of aquatic macrophytes (plants) and periphyton (algae) (Hill and Harvey 1990). Indirect energy sources based primarily on terrestrial organic carbon inputs then become important.

Light reaching the bed of streams is reduced (or attenuated) through interception by the canopy of riparian plants, by banks and hills ("topographic shade"), and by absorption and scattering within the water column (Westlake 1966). The relative importance of water column "shade" compared with terrestrial shade increases with stream size (Davies-Colley *et al.* 1993), and the influence of riparian shade elements generally declines as channel size increases. A useful index of average shading of the stream channel (or, conversely, average light received) is the ratio of height of riparian vegetation (and banks) to stream channel width.

When managing the light climate of a stream, it is often important to distinguish between the *direct solar beam* (only present when the sun is not covered by cloud and not obstructed by topography) and *diffuse skylight* which comes from the whole sky whether cloud-covered or clear (blue) (see *Volume 1: Concepts: Figure 7*). Generally, streambanks and hills only shade out skylight and the direct solar beam at relatively low angles, although some areas of stream water located directly under high or overhanging banks may be shaded from the direct solar beam for most of the day. Near noon, the direct solar beam may reach most of the water surface, or it would do so were it not blocked by vegetation.

Shading by topography is absolute in the sense that no direct light is transmitted, whereas vegetation shade is only partial. This is because there are small gaps in even the most dense vegetation canopy through which direct sunlight can penetrate as *sunflecks* (Chazdon 1988), and some light will also penetrate the canopy by transmission through foliage or reflection off foliage (Gates *et al.* 1980). Vegetation shade also differs from topographic shade in that it acts as a colour filter. The light that has penetrated through a canopy is richer in green than other colours owing to absorption primarily of blue and red light by the leaves. Thus, light under vegetation is typically a dim green (e.g., Federer and Tanner 1966, Smith 1982).

In very small (low order) streams where the forest canopy is completely closed over the channel, the shading in the centre of the channel is almost as great as in areas adjacent to the edge. Breaks in the forest canopy occur only with larger streams (perhaps fourth order and above) depending on the stream channel width and the height and nature (or architecture; e.g., spreading broadleaf compared to erect conifer) of the riparian vegetation. Under canopy breaks, the streamwater surface may experience open site light levels for at least part of the time on sunny days, but the average light exposure over time is still appreciably lower than at open sites.

Light climate and instream plant growth

The long term average production of plant communities correlates with long term average light exposure (Chazdon 1988). This concept applies broadly to aquatic as well as terrestrial plants (e.g., Canfield and Hoyer 1988, Dawson and Haslam 1983) so that a reduction in stream lighting produces a near-proportional reduction in aquatic plant production. Sometimes, loss processes affecting plants in streams, such as grazing by invertebrates and sloughing, may produce a greater-than-proportional reduction (Davies-Colley *et al.* 1992).

A major concern with open stream reaches, especially those with nutrient-enriched waters, is that periphyton or macrophytes may grow to nuisance proportions (MfE 1992). Because these plant associations are present at high biomass, they are usually severely "self-shading" so that plant tissue at the top of the "canopy" shades the tissue lower down. It follows that a self-shaded association of plants is light-limited, and is more prone to a reduction in available light by riparian planting than associations that are not self-shaded. This means that shading will severely impact on nuisance growths, reducing if not eliminating these plants. For example, nutrient-rich streams which are severely affected by abundant growths in open reaches, generally lack such growths in reaches shaded by riparian vegetation.

At least 30% of the light at an open site seems to be required to maintain macrophyte stands (Haslam 1978). Thus, shading by 70% or more (i.e., <30% average light transmission) can be expected to eliminate growth of these plants. This level of average shade is easily achieved with continuous tree plantings along small streams (e.g., Dawson and Haslam 1983). However, it must be remembered that macrophytes greatly increase habitat diversity and can be the main substrate for invertebrate (such as insects) colonisation in open streams with sandy/silty bottoms and little woody debris. Dawson (1989) recommended half shading (50% average light) of the channel to achieve a "desirable" level of macrophyte growth for British streams, and this rule-of-thumb may also be applicable to New Zealand streams where maintaining low biomass (non-nuisance) macrophyte stands is considered desirable.

Periphyton nuisances (aesthetically unsightly filamentous growths or mats of algae) are also likely to be eliminated by 70% reductions in average light exposure. Filamentous green algae appear to have a higher light requirement than diatoms (Raven 1992), so reduction in lighting, even by a small factor, may shift the balance towards the latter organisms.

Limitations of existing knowledge

Our knowledge is not yet sufficient to be able to "design" optimal stream shade by riparian plantings. Deciduous riparian tree species may be appropriate shade elements for streams as the shade they provide is very seasonally-dependent; introduced deciduous species lose all their leaves in autumn, whereas native deciduous species lose leaves year-round but have peaks of leaf-fall in spring and sometimes in late autumn (see **CARBON**). Typically, about 60% of incident light is transmitted through bare deciduous canopies in winter compared with <10% in summer (e.g., Anderson 1964). Since the most critical time of the year for shading of streams is in summer (to prevent both high temperatures and nuisance plant growths), deciduous trees may be just as good from a shading perspective as evergreen species. More research is required before we can make specific recommendations on the planting of deciduous trees to manage light climate, however.

There are considerable difficulties associated with measuring average shade conditions beneath canopies, and resolving conflicting needs for light levels that will inhibit nuisance plant growths but allow ground cover on stream banks to grow, as well as some macrophytes in sandy/silty-bottomed streams. There does not seem to be a practical means of reliably measuring average light without expensive scientific equipment, although research is currently underway on this topic. The only certain thing is that planting trees and allowing them to achieve canopy closure will decrease lighting to <10% of that at open sites, and that this will limit plant growth in small streams. Due to the limitations of existing knowledge, only one general guideline has been provided for managing the light climate in streams.

Guidelines for Managing Watercourse Light Levels

OBJECTIVE(S)

To reduce light inputs to streams so that:

- Nuisance growths of aquatic plants are prevented.
- Growth of bryophytes and thin diatom films is encouraged in stony streams.

GUIDELINE(S)

1. Judge whether the banks are shading the channel sufficiently to prevent nuisance plant growths (>70% shade), or if the substrate is stony, to encourage growth of bryophytes and thin periphyton (algal) films. An assessment of the biomass of the different plant types following a period of summer low flow should permit this judgement. Bear in mind that stream stability can also affect the success of bryophytes in streams. A method of assessing stability is given in Appendix 1 of **CARBON**. Plants may also be nutrient limited (their growth restricted by low levels of nutrients in the water), but this is probably rare in the agricultural landscape. If macrophyte or periphyton growths are not a problem, then managing light levels may not be an issue, although the manager may still wish to provide shade to encourage bryophyte development.

2. If macrophytes or periphyton growths are causing a problem, establish plants along streambanks, as appropriate to local conditions of microclimate and soil suitable for the plant (see **STABILITY: TREES**). Trees are generally more effective than herbs, but some taller herbs, including native flax and tussock, may be appropriate shade plants for small (first to second order) streams. Once the canopy has closed over the stream channel, the average light exposure will be <10% of that in the open. Canopy closure may not occur over larger stream channels, in which case eventual average lighting may be higher than 10%. As noted above, the effects of riparian shade are generally most acute in small streams while shade will minimally affect large rivers.

   The shading by plants closest to the streambank will be most effective in reducing lighting, and the contribution of plants to stream shade declines with their distance from the channel. Depending on species, roughly 80% of the total achievable vegetative shade may be realised by planting a single line of plants on each bank which eventually achieve canopy closure over the stream channel. However, for a variety of reasons, including mutual wind sheltering and the maintenance of microclimate, riparian shade plants should be planted in "buffer strips", say three times wider than the eventual crown height (see *Volume 1: Concepts: Section 2.2.4* and *Figure 3b*).

   Obviously, plant species differ in foliage density and growth habit (e.g., spreading broadleaf cf. erect conifer), but apart from the potential advantages of deciduous species (see *Limitations of existing knowledge* earlier in this Guideline) *there is little to choose between different species for the purpose of shade alone*. Choice could be made on the basis of other considerations such as timber value (see Appendix 1 in **STABILITY**), aesthetics, food for stream invertebrates (see **CARBON**), microclimate requirements (see **HABITAT**), bank stabilisation (see **STABILITY**) and "naturalness". Where the aim is to restore natural conditions at sites with a history of forest cover, a variety of native species characteristic of the area should be used. For timber production, mixed woodlots are preferable to single age class, single species tree crops since, as well as the aesthetic advantage compared with monocultures, the inevitable staggered timing of harvest should avoid "sun exposure shock" to the stream.

3. Monitor the extent of instream plant and algal growth during summer as the riparian plantings develop. To maintain any light regime other than deep shade in a small stream under a tree canopy, active management is required to counteract the natural tendency of vegetation to close canopy gaps and achieve high foliage density. Consider pruning branches from selected trees or thinning trees to increase light penetration if the following occur:

   - Macrophytes appear to be dying off completely in sandy/silty-bottomed streams.
   - Shading of ground cover plants is leading to bank erosion.

   Timber production woodlots might be the only economically viable means of maintaining balanced shade levels, say around the 50% average shade recommended to maintain macrophytes at non-nuisance levels. If active management is not carried out, conditions will probably stabilise over a period of years to decades following a phase of increased erosion and sediment yields.

JUSTIFICATION AND ASSUMPTIONS

We can probably safely assume that most New Zealand streams originally developed under heavily shaded conditions. Light levels necessary to limit plant growth have been recommended overseas and are probably also applicable in New Zealand.

SIDE EFFECTS AND LIMITATIONS

There is a need to proceed with great caution with riparian plantings in cleared catchments because shading of formerly open areas along streams can lead to loss of the ground cover, with consequent loss of its nutrient "filtration" function (see **CONTAMINANT**), and increased streambank erosion, channel instability, high sediment yields, and poor water clarity (see **STABILITY**). For example, Smith (1992) reported that water quality was poorer in a catchment with riparian pine plantings than in neighbouring pasture catchments.

Observations on New Zealand streams flowing from forest to pasture or *vice versa*, suggest that shading of the streambanks causes marked changes in stream channel morphology. The mechanism apparently centres around the high level of protection against streambank erosion afforded by pasture plants. Typically, stream channels in pasture reaches are much narrower (by a factor of two) than in shaded reaches of the *same* streams, because of the cohesive character of streambanks covered with pasture species (Zimmerman *et al.* 1967, Sweeney 1993, Davies-Colley, NIWA, unpubl. data). When these pasture species are eliminated by light reduction, their solids filtering action is obviously lost (e.g., Smith 1992) (see **CONTAMINANT**), and so too is their protecting action against streambank erosion (see **STABILITY**). Consequently, the stream widens towards a "forest" stream morphology and a temporary (several years to decades) but intense phase of low channel stability and high sediment yields/low water clarity may ensue.

Another possible negative effect of riparian shading of formerly pasture streams is an alteration in the character of riparian wetlands. This may affect their high nutrient removal capacity (see **NITRATE**) and decrease habitat diversity in the riparian zone (see **HABITAT**). Dense shading over sandy/silty-bottomed streams may eliminate macrophytes, reducing diversity and invertebrate habitat.

Restoration of dense riparian shade in small streams will assist in restoring the natural condition. Increased shade levels will also reduce stream temperatures (see **TEMPERATURE**), and will lead to a shift in the energy base from primarily plant-based to one based primarily on inputs of terrestrial organic carbon (see **CARBON**). Trees and shrubs will slow large floodflows when flood waters overflow into the riparian zone (see **FLOW**), but may harbour animal and plant pests such as possums. (Corridors of forest may enhance wildlife movement generally, including pests.)

CONFIDENCE

High for controlling nuisance growths. Moderate for re-establishing conditions similar to those expected to occur in unmodified streams.

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GUIDELINES FOR MANAGING WATERCOURSE TEMPERATURES

INTRODUCTION

Water temperature can affect the distributions of aquatic animals directly by exceeding preferences or tolerances of various invertebrate and fish species, and indirectly by controlling saturated dissolved oxygen levels and microbial processes. A list of known preferences or tolerances of native fish, introduced salmonid fish (trout and salmon), and invertebrates (such as insects and freshwater crayfish) is presented in Appendix 1. The effects of diurnally (24 hourly) varying water temperatures are not known. A description of heat inputs to and losses from streams, the effects of high water temperature on the aquatic environment, and the influence of catchment clearance on temperature is presented in *Volume 1: Concepts: Section 2.2.7.*

Effects of riparian vegetation on water temperature

Riparian vegetation reduces the amount of solar radiation which reaches the water surface and hence plays an important role in determining stream water temperature. The stream channel is also shaded by hillsides and by the streambanks (collectively termed *topographic shading*). It is possible to control the amount of riparian shading by vegetation and hence to influence water temperature, especially in small streams. Riparian vegetation also influences wind speed, air temperature and humidity at the water surface, and these exert second order controls on water temperature (see *Volume 1: Concepts: Figure 9*).

If there is no riparian vegetation along the streambank then, when the solar elevation exceeds the topographic shade angle, the stream is fully exposed to direct solar radiation. The topographic shade angle is not constant. For instance, it may be high when the sun rises because of hills to the east of the stream, but low when it sets because of a wide plane to the west of the stream. The topographic shade angle may change with season because the sun rises and sets further south in the summer than in winter. The shade angle is also affected by orientation of the stream channel: for example, a stream in a canyon running east-west is less well shaded at sunrise and sunset than the same stream running north-south.

Near infra-red radiation (NIR) comprises about 50% of solar radiation; it affects water temperature but is unimportant in photosynthesis. NIR is *not* absorbed efficiently by vegetation foliage (Gates *et al.* 1965) and so penetrates vegetation canopies to a much greater extent than visible light. Appropriate measurements appear not to have been made in New Zealand, but relative values are probably similar to those in a rainforest in Sumatra where 6% of the total radiation reached the ground at a site receiving only 0.8% of the Photosynthetically available radiation (PAR) (Torquebiau 1987). Native rainforest in New Zealand has a high canopy density, and PAR under the canopy is typically only about 1% of that above the canopy (e.g., McDonald and Norton 1992). Szeicz (1974) and Baldocchi *et al.* (1984) have shown that the ratio of PAR (essentially visible radiation) to total solar radiation (NIR + PAR) under canopies decreases steadily but not linearly as canopy density increases. It follows, therefore, that *measurements of visible light cannot be used to estimate the transmission of total solar radiation to a stream.*

Use of temperature modelling

Several questions arise when considering the use of riparian shade to manage stream water temperature:

- What temperature decrease is likely to occur as a result of establishing riparian shade?
- Over what length of channel are these temperature changes likely to occur?
- Are water temperatures more sensitive to changes of riparian shading in small, shallow streams than large, deep streams?
- If so, then in a catchment are stream temperatures best managed by managing riparian shading in low order streams?

A number of publications furnish qualitative information on these questions. It is clear, for example, that in shallow streams the temperature changes more rapidly (over time and with distance) than in deep streams under similar conditions. Shallow streams have a smaller thermal inertia (i.e., exhibit larger diurnal and seasonal temperature changes than deep streams). There is, however, insufficient published data to give quantitative answers to the questions posed above in a form which is useful to managers.

To address this shortfall in information, a number of *predictions* of likely riparian shade scenarios have been made using a mathematical stream temperature model (SEGMENT, Blackett 1993). The SEGMENT model has been tested and found to predict stream water temperatures well in a number of first and second order streams at Whatawhata near Hamilton, and in the fifth order Mangatangi Stream near Auckland (for explanation of stream order see *Volume 1: Concepts: Section 2.1.3*).

Shortwave solar radiation flux can be measured at a point adjacent to the stream using a pyranometer (e.g., LiCor Model LI-200SB) or estimated using semi-empirical formulae (TVA 1972). The SEGMENT model described in Appendix 2 can be used to predict stream temperatures using either solar radiation measurements or formulae. Instruments are also available to measure longwave atmospheric radiation flux, or this can be estimated using empirical formulae (TVA 1972).

The model predictions are used to provide *semi-quantitative* guidelines to assist the manager assess the likely impact on stream temperature of planting or removing riparian vegetation. Important predictions from the modelling exercise are:

- For a very long, uniform channel and for regular diurnal solar radiation and air temperature cycles, stream temperatures will eventually follow a regular diurnal pattern (dynamic equilibrium).
- Stream temperatures increase with distance from a bush-pasture boundary and eventually reach a new dynamic equilibrium.
- Daily maximum equilibrium temperatures decrease markedly as the degree of shading increases.
- Daily maximum equilibrium temperatures decrease with increasing stream depth (e.g., with increasing stream size).
- Small, shallow streams are much more susceptible to cooling as a result of the planting of riparian shade than are large, deep streams. Reductions in the daily maximum

temperature of the order 5°C are feasible over distances of about 1 km provided moderate (75%) shade can be restored. By comparison, 5 and 12 km of dense shade are required to reduce temperatures by 5°C in third and fifth order streams, respectively (refer to Table 1 in Appendix 2 for a description of the streams to which this applies).

- It follows that, if low stream temperatures need to be maintained throughout a stream network, then it is probably more important to maintain dense shade along the small (first and second order) than along the larger (third, fourth and fifth order) streams). This point is illustrated in more detail in Appendix 3.

Microclimate effects

The most important effect of planting/removing riparian vegetation is to decrease/increase the amount of solar radiation which reaches the stream water surface. However, the presence of riparian vegetation also creates a microclimate near the stream with characteristic wind speed, humidity and air temperature. Any changes which are made to the riparian vegetation have the potential to alter the microclimate (especially air temperature) near the stream and this in turn can affect stream temperatures.

The planting of a narrow strip of riparian vegetation is unlikely to cause a significant change in air temperature from that measured at an open site nearby. It is only when considering the effects of restoring or removing dense vegetation from an extensive area of the catchment (e.g., clear felling a forest or replanting an entire sub-catchment) that changes in air temperature need to be considered. Humidity also influences stream temperature because it affects the rates of evaporation and sensible heat transfer but, as with air temperature, this is less important than shading. Large changes in humidity in the vicinity of the stream are only likely with clear-felling or re-forestation of extensive areas. Further research work is planned to quantify more precisely the effects of changes in microclimate on stream water temperature. These studies will be conducted in such a way that they will help identify the effects on stream temperature of restoring certain types of riparian vegetation.

Guidelines for Regulating Summer Maximum Stream Water Temperatures

OBJECTIVE(S)

To manage summer maximum water temperatures within a stream or stream network by:

- Planting riverbank vegetation, or
- Controlling riverbank vegetation clearance operations.

GUIDELINE(S)

1. Field Investigations

- Measure typical summer daily maximum temperatures at several points in each stream of the network.

- Measure channel morphology (depth, width and flow) in representative reaches of each stream. "Typical" channel widths should be measured in ≥20 homogenous reaches, and the average taken to obtain average width (m). Also measure average water velocity ($m.s^{-1}$). Measurements at several points across the channel are desirable. The velocity at 0.6 of the depth approximates the depth-average velocity. In the absence of a current meter, the mean velocity can be estimated by measuring the time it takes for a surface float (e.g. an orange) to travel a fixed distance. Measure the discharge ($m^3.s^{-1}$) by gauging (details of gauging stream flow are provided in Fenwick, 1991. See *Important reading kit* in introductory section of this volume) and then calculate mean depth (H) by the following equation:

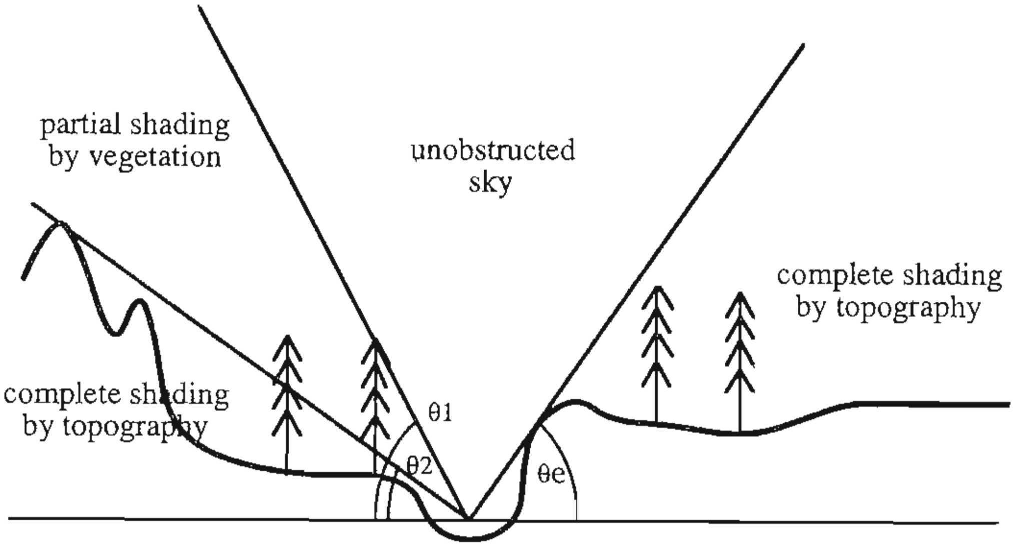
  H (m) = Q / BU.....................................Equation 1
  where B=average width, U=average velocity and Q=discharge

- Estimate the percent shade for representative reaches in each stream. Stand in mid-stream and, from the water surface, measure the shade angles with an *inclinometer* above the horizon on both sides of the channel looking east and west (see Figure 1). The percent shade is then calculated as:

  Shade (%) = $100(\theta_e+\theta_w)/180$.......................Equation 2
  where θ_e and θ_w are the shade angles on the east and west banks of the stream.

  The shade angle is normally the canopy angle (i.e., the angle above the horizon at which the dense riparian canopy stops and clear sky commences). If there is no riparian vegetation, then the shade angle is the topography angle (i.e., the angle at which the hills or the banks stop and clear sky commences). For partial shade (e.g., intermittent fern, sedges etc.) the shade angle can be taken as the average of the topography angle and the canopy angle (see Figure 1).

  If the maximum daily water temperatures are measured at several points along a stream, then it may be possible to infer the percent shade from the observed changes in water temperature along the stream using Figures 3–5 in Appendix 2.



$$\theta w = (\theta 1 + \theta 2)/2$$

Figure 1 Sketch showing how to make an initial estimate of the percent shading.

2. Temperature Objectives

- Select the desirable daily maximum summer water temperatures in various parts of the stream network. This is likely to be dictated by the temperature tolerances of the most sensitive biota. Appendix 1 provides information on the temperature preferences or tolerances for a variety of fish and invertebrates. For many species, a variety of indices are specified; we recommend the use of preference data where these are available.

3. Shade Calculations

- Decide from the channel morphology data whether the stream segments being studied most closely match the first, third or fifth order channels in Table 1 (Appendix 2). *Mean depth is the most important variable.*

- Select the point on each stream where management is to start (the initial point).

- Decide on the distance at which the initial point lies on Figures 3–5 in Appendix 2. If the percent shade is uniform for a considerable distance above the initial point (e.g., if the entire catchment is covered in dense bush), then water temperatures at the initial point can be assumed to be at equilibrium and the distance of the initial point can be taken as 0.1 km. If, however, shading changes a short distance upstream from the initial point, then water temperatures will not be at equilibrium and the distance of the initial point must be estimated.

For example, assume that the initial point is located in open pasture in a first order stream with 50% shade for total solar radiation, 1 km downstream from the edge of dense bush with 95% shade. We want to use Figure 5 to investigate the effectiveness of planting dense riparian vegetation (95% shade) below the initial point, but not in the 1 km between the bush and the initial point. It is inappropriate to assume that the initial point is at a distance of 0.1 km in Figure 5 because water temperatures at the initial point are unlikely to have reached equilibrium for 50% shade. Figure 3 indicates that 1 km below the bushline in a first order stream going from 95% to 50% shade we can expect the daily maximum temperature to be 19°C. In Figure 5, a temperature of 19°C occurs at 600 m in a first order stream under 95% shade, and this is the appropriate distance for the initial point for these particular calculations.

- Decide on the best combination of percent shade and length of channel managed to achieve the desired water temperature objective(s). This may require performing several sets of calculations using Figures 3–5 in Appendix 2. Two worked examples are provided in Appendix 3.

  Generally, protecting or planting small headwater streams achieves the greatest temperature reductions per unit length of riparian shade.

  When controlling riverbank clearance operations, select the best streams to preserve and/or the allowable level of vegetation clearance that will not adversely affect water temperatures throughout the network.

- If these calculations are carried out on a stream network, then it may be necessary to perform some of the calculations using the graphs in Appendix 2 for a first order stream and some using the graphs for a third or fifth order stream. The distance of the initial point for the latter calculations must be selected carefully using the method outlined above and in Example 1 of Appendix 3.

4. Implementation

- The shade requirements to meet the desired temperature objectives have been selected in **3**. above. The programme which is actually implemented may be affected by other factors besides those discussed above, such as community aspirations, land ownership and other riparian management objectives (e.g., light levels)(see *Volume 2: Introduction: Figure 1*).

- 50% shade can be achieved in small, narrow (1–2 m wide) pasture streams simply by fencing out stock and encouraging grass, fern and sedges to grow. In wide streams (>5 m), tall riparian shade (e.g., sparse plantings of trees) is required to achieve 50% shade. To achieve moderate shade (75%) in third and fifth order streams (up to 5 m wide) fairly dense plantings of trees are required. Dense shade (95%) requires complete canopy closure over the stream and heavy plantings of tall trees in streams greater than 5 m in width. Further information on shading is given in **LIGHT**.

JUSTIFICATION AND ASSUMPTIONS

Based on modelling exercise using the temperature model SEGMENT (see Appendix 2).

SIDE EFFECTS AND LIMITATIONS

In different parts of the country the absolute temperatures observed and predicted in small streams may differ from those shown in Figures 3–5 of Appendix 2 (e.g., Northland v Southland). However, it is likely that these graphs give a fairly reliable prediction of the *changes* in temperature which are likely to occur as a result of altering riparian shading provided the channels are similar to those in Table 1 of Appendix 2.

Tall trees may take many years to grow and to shade wide streams significantly, although shading by grass, ferns and sedges can be achieved quickly in small, narrow streams. Shade inhibits ground cover (e.g., grass) in the riparian buffer zone (see **STABILITY** and **FLOW**). If surface runoff is a major contributor to floodflows (e.g., in a pasture catchment) then the loss of ground cover may result in sediments and nutrients entering the stream which would otherwise be retained by the ground cover (see **CONTAMINANT**). Where the banks are unstable it may be necessary to plant trees well back from the stream, thus reducing their shading efficiency.

Shade is also likely to inhibit instream vegetation which may help protect the bed against erosion and provide habitat for aquatic life in sandy/silty-bottomed streams (see **LIGHT**). As a result, shading may cause streams to become wider and shallower. The final stream width needs to be estimated (e.g., by surveying bush streams in the same locality) before deciding where to plant trees in the riparian zone. An increase in channel width also affects the efficiency with which trees shade the channel and may need to be considered when doing the shade calculations outlined above.

Riparian vegetation will increase the drag on floodwaters and is likely to retard floods which overtop the banks (see **FLOW**).

Riparian vegetation will increase the supplies of terrestrial carbon and woody debris to the stream which may have a beneficial effect on certain invertebrate species (see **CARBON**). Trees and shrubs will also re-introduce landscape and riparian diversity (see **HABITAT**) but may harbour animal and plant pests. Corridors of riparian forest may enhance wildlife movement generally.

CONFIDENCE

Moderate. Planting or removing riparian vegetation will undoubtedly change stream water temperatures. However, these guidelines are at present tentative because:

- So far we have studied only a sub-set of possible streams.
- The shade characteristics of riparian vegetation are difficult to quantify.
- The microclimate effects of riparian vegetation are not well defined.
- The mathematical model SEGMENT is still being tested and refined.

The predicted temperature changes shown in Figures 3–5 are fairly reliable for the South Auckland pastoral streams described (see Table 1 in Appendix 2). Elsewhere in the country and in other types of stream, the predicted temperatures and temperature changes may be slightly different.

APPENDIX 1 Various measures of the temperature preference and tolerance for some fish and invertebrates. From Richardson *et al.* (1994), Quinn *et al.* (1994), and other sources.

Abbreviations used in the table to describe the test measures are defined in footnotes. All temperatures are °C. ND = no data.

Species	Life stage/ size (mm)	Acclimated temp. (°C)	Upper lethal temp. (°C) and method		Preferred temp. and quartiles (°C)	Source
Shortfinned eel (*Anguilla australis*)	Glass eel	15	28.0	LT$_{50}$	-	Jellyman 1974
	Elver	12	33.4	CTM	-	Simons 1986
		15	35.7	LT$_{50}$	26.9 (25.6-28.5)	Richardson *et al.* 1994
		20	35.9	CTM	-	Simons 1986
		21.5	36.0	CTM	-	Simons 1986
		22	36.3	CTM	-	Simons 1986
		25	37.3	CTM	-	Simons 1986
		28	38.1	CTM	-	Simons 1986
		30	30.5	CTM	-	Simons 1986
	Adult	15	39.7	LT$_{50}$	-	Richardson *et al.* 1994
Longfinned eel (*A. dieffenbachii*)	Glass eel	15	25.0	LT$_{50}$	-	Jellyman 1974
	Elver	15	34.8	LT$_{50}$	24.4 (22.6-26.2)	Richardson *et al.* 1994
	Adult	15	37.3	LT$_{50}$	-	Richardson *et al.* 1994
Cran's bully (*Gobiomorphus basalis*)	mixture	12	32.3	CTM	-	Simons 1984
		15	30.9	LT$_{50}$	21.0 (19.6-22.1)	Richardson *et al.* 1994
		20	33.9	CTM	-	Simons 1984
Common bully (*G. cotidianus*)	mixture	12	32.7	CTM	-	Simons 1984
		15	30.9	LT$_{50}$	20.2 (18.7-21.8)	Richardson *et al.* 1994
		20	34.0	CTM	-	Simons 1984
Upland bully (*G. breviceps*)	Juvenile	15	32.8	CTM	-	Teale 1986
Torrentfish (*Cheimarrichthys fosteri*)	Adult	15	30.0	LT$_{50}$	21.8 (20.1-22.9)	Richardson *et al.* 1994
Inanga (*Galaxias maculatus*)	Whitebait	15	-	-	18.8 (18.0-19.8)	Richardson *et al.* 1994
		20	33.1	CTM	-	Simons 1986
	Juvenile	12	30.5	CTM	-	Simons 1986
		15	-	-	18.7 (17.3-20.0)	Richardson *et al.* 1994
		16	31.7	CTM		Simons 1986
		20	32.9	CTM	-	Simons 1986
		22	33.8	CTM	-	Simons 1986
		26.5	35.4	CTM	-	Simons 1986
	Adult	15	30.8	LT$_{50}$	18.1 (17.2-19.1)	Richardson *et al.* 1994
Giant kokopu (*G. argenteus*)	Whitebait	16	30.0	CTM	-	Main 1988
		16	29.0	LT$_{50}$	-	Main 1988
Shortjawed kokopu (*G. postvectis*)	Juvenile	16	30.0	CTM	-	Main 1988
		16	29.0	LT$_{50}$	-	Main 1988
Banded kokopu (*G. fasciatus*)	Whitebait	14	30.6	CTM	-	Simons 1986
		15	-	-	16.1 (14.8-17.7)	Richardson *et al.* 1994
		16	30.0	CTM	-	Main 1988
		16	29.0	LT$_{50}$	-	Main 1988
		20	32.5	CTM	-	Simons 1986
		22	31.2	CTM	-	Simons 1986
		24	34.0	CTM	-	Simons 1986
		26	31.1	CTM	-	Simons 1986
	Adult	15	28.5	LT$_{50}$	17.3 (16.3-18.3)	Richardson *et al.* 1994
Koaro (*G. brevipinnis*)	Juvenile	16	28.0	CTM	-	Main 1988
		16	27.0	LT$_{50}$	-	Main 1988
Common smelt (*Retropinna retropinna*)	Adult	15	28.3	LT$_{50}$	16.1 (15.1-17.4)	Richardson *et al.* 1994
		20	31.9	LT$_{50}$	-	Richardson *et al.* 1994
		20	31.8	CTM	-	Simons 1984
		20.5	33.4	CTM	-	Simons 1984
Grey mullet (*Mugil cephalus*)	78-122	21	27-29	CTM	-	Sylvester *et al.* 1974
	j	20	34.3	CTM	-	Davenport & Simons 1985

Species	Life stage/ size (mm)	Acclimated temp. 0(°C)	Upper lethal temp. (°C) and method		Preferred temp. and quartiles (°C)	Source
Brown trout[1]	Adult	-	14-16(1)	FP	-	Boubee (pers. comm.)
(*Salmo salar*)	j	-	17.4-17.6(2)	-	-	Boubee (pers. comm.)
Rainbow trout[1]	Adult	-	13-21(7)	FP	-	Boubee (pers. comm.)
(*Oncorhynchus mykiss*)	j	-	15-22(4)	-	-	
INVERTEBRATES						
Freshwater shrimp	4.5-6.5	12	28.9	CTM	-	Simons 1984
(*Paratya curvirostris*)	4.5-6.5	20	32.6	CTM	-	Simons 1984
	Adult	15	-	TP	(ND-23.1)	Boubee (pers. comm.)
	-	20	26-27	LT_{50}^{1}	-	Davenport & Simons 1985
	Adult	15	25.7-27.4		-	Quinn *et al.* 1994
Freshwater crayfish	12-23	12	28.8	CTM	-	Simons 1984
(*Paranephrops planifrons*)	6-22	20	31.9	CTM	-	Simons 1984
Paracalliope fluviatilis	mid-late instar	15	24.1-27.5	LT_{50}^{2}	-	Quinn *et al.* 1994
Deleotidium spp.	mid-late instar	15	22.6-26.8	LT_{50}^{2}	-	Quinn *et al.* 1994
Zephlebia dentata	mid-late instar	15	23.6-26.9	LT_{50}^{2}	-	Quinn *et al.* 1994
Zelandobius furcillatus	mid-late instar	15	ND-c.28	LT_{50}^{2}	-	Quinn *et al.* 1994
Aoteapsyche colonica	mid-late instar	15	25.9-27.8	LT_{10}^{2}	-	Quinn *et al.* 1994
Pycnocentrodes aureola	mid-late instar	15	32.4-32.4	LT_{50}^{2}	-	Quinn *et al.* 1994
Pyconocentria evecta	mid-late instar	15	25.0-30.4	LT_{50}^{2}	-	Quinn *et al.* 1994
Hydora sp.	mid-late instar	15	32.6>34	LT_{50}^{2}	-	Quinn *et al.* 1994
Potamopyrgus antipadarum	medium-large	15	32.4-32.4	LT_{50}^{2}	-	Quinn *et al.* 1994
Sphaerium novaezelandiae	medium-large	15	30.5-32.8	LT_{50}^{2}	-	Quinn *et al.* 1994
Lumbriculus variegatus	ND	15	26.7-30.1	LT_{50}^{2}	-	Quinn *et al.* 1994

[1] The values presented are for final preferenda only and are derived from a literature review conducted by J.A.T. Boubee, NIWA, in 1989. The number of studies included is given in parentheses following the temperature.

[2] 96 hour - 24 hour LT_{50} values.

CTM	Critical Thermal Maxima; i.e., the thermal point at which locomotory activity becomes disorganised and the animal loses its ability to escape from conditions that will promptly lead to its death. The animal is exposed to water heated at a continuous and rapid rate in this test.
LT_{50}	That constant temperature at which half of the test animals die within the test period.
TP	Temperature preference.
FP	Final preferendum. That is, the long-term preferred temperature.
AT	Avoidance temperature is the temperature avoided by fish when acclimated to their final preferendum.
LTS	Upper tolerable constant temperature for long-term survival following acclimation.
w	whitebait
j	juvenile

APPENDIX 2 The stream temperature model SEGMENT

Parameters of the model

NIWA is currently testing and refining a mathematical model (SEGMENT) for predicting stream temperatures (Blackett 1993). The model has been developed in-house based on the work of Theurer *et al.* (1984) and Beschta and Weatherred (1984). It is designed to address problems of water abstraction and changes to riparian vegetation in which the principal concern is with predicting changes in cross-sectional averaged natural temperature. For such problems, one-dimensional (longitudinal) models are adequate. The SEGMENT model handles advection by identifying individual water parcels, tracking each one down through the stream network (knowing the velocity and reach length), and calculating the heat gains and losses of each water parcel separately. The channel can be sub-divided into a number of sub-reaches each of which has characteristic hydraulic and shade parameters. The model requires input of:

- Hydraulic parameters (mean depth, velocity and width).
- Shade parameters (discussed below).
- Meteorological parameters.

The structure of the model is described in Blackett (1993). SEGMENT calculates heat transfer to and from streams using the semi-empirical formulae referenced above with allowances made for the effects of topographic shade and various effects of riparian vegetation. The model quantifies shade using shade angles as suggested by Beschta and Weatherred (1984). Shading includes topographic shading (i.e., that provided by channels, banks and the surrounding hills) and shading by vegetation (see Figure 2). When the solar elevation (the angle of the sun above the horizontal) is lower than the topographic shade angle (θ in Figure 2), no direct solar radiation reaches the water. SEGMENT selects an appropriate shade angle at regular intervals along a channel.

Diffuse solar radiation is higher directly overhead than at the horizon, but in the current version of SEGMENT it is assumed to originate uniformly from the entire hemisphere. When the solar elevation lies between the topographic (θ) and vegetation (α) shade angles, sunlight must pass through trees, bushes or grasses growing on the banks before it reaches the water (Figure 2).

In the SEGMENT model, the effects of vegetation are quantified by the shade factor (SF) defined as the proportion of the total incoming radiation (measured at an open site) which is intercepted by the vegetation. SF is zero at a completely open site ($\theta = \alpha = 0$) but can reach 95% under a closed bush canopy. When computing direct solar, diffuse solar and atmospheric radiation reaching the water surface, SF is zero when the solar elevation exceeds α, is unity when the solar elevation is less than θ, and is *assumed* constant between zero and one for all solar elevations between θ and α. In fact, the shade factor is not constant between θ and α. The shade factor is likely to be lower near midday than in the morning or afternoon because the path length through the vegetation is shortest at midday, and a greater proportion of the solar radiation is likely to penetrate the canopy.

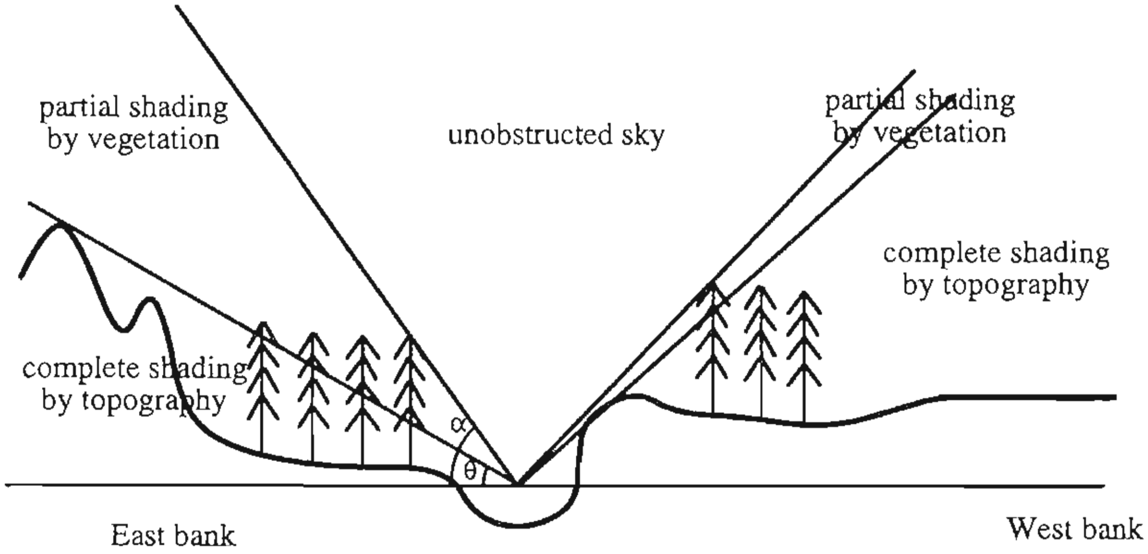


Figure 2 Sketch showing topographic (θ) and vegetation (α) shade angles for a stream flowing north–south. Note that for the west bank topographic shading is by the riverbank rather than the hills. This method for quantifying shading was developed by Beschta and Weatherred (1984).

Vegetation absorbs some of the incoming solar radiation and also some of the outgoing back-radiation from the stream and the surrounding soil. Vegetation also emits longwave radiation some of which travels downwards to the stream surface. The SEGMENT model assumes that vegetation acts like a black-body radiator emitting long-wave radiation at a rate proportional to the fourth power (Stefan-Boltzmann's law) of the local air temperature (Beschta and Weatherred 1984). SEGMENT makes no allowance for microclimate effects because it is very difficult to predict with confidence the effects of tree planting on parameters such as air temperature, humidity and wind speed.

SEGMENT model testing

The SEGMENT model has been tested using data from the fifth order Mangatangi Stream (near Auckland) and from 12 first and second order streams at Whatawhata (near Hamilton). For the Mangatangi Stream, *in situ* measurements were available of meteorological, shade and hydraulic parameters together with stream temperatures at a range of flows (Cooke *et al.* 1992). The model was able to match the observed maximum stream temperature, the time and the location at which this temperature occurred over a range of flow and meteorological conditions (Cooke *et al.* 1993, Blackett 1993). The model did, however, tend to underestimate daytime cooling (by about 1–2°C) in a 1 km reach which was heavily shaded by banks and pine trees. Cooke *et al.* (1993) used an earlier stream temperature model (THERMOS) to show that by planting riparian shading along 5 km of the channel summer temperatures could be reduced by about 5°C.

At Whatawhata, 12 first and second order streams were surveyed during November–December 1992. Stream temperatures were monitored at 15 minute intervals at a single site on each stream. Channel and shade parameters were measured on 10 streams in the vicinity of the recording sites. Long term average meteorological data for November–December from the adjacent Whatawhata Research Station were used in the model. Predictions were made of the (dynamic) equilibrium water temperature at the downstream end of a very long uniform channel exposed to constant meteorological conditions. These predicted temperatures were found to match within a few degrees the observed daily means and diurnal amplitudes.

Model predictions

The effect of shading on stream temperatures

Figures 3–5 show the temperature changes predicted to occur during clear summer days in first, third and fifth order streams typical of the South Auckland region (see Table 1). In these predictions the amount of shading is expressed as the difference between the daily total solar radiation measured at an unshaded site and the daily total which reaches the water surface, as a percentage. In the model, the amount of shading compared to direct solar radiation varies throughout the day, being highest in the morning and evening (when the solar elevation is low so that hills and stream banks shade the water surface) and lowest near solar noon (when the sun is almost overhead). For convenience, only the daily total value is reported. Thus 95% shade means that the daily total radiation falling on the water surface is only 5% of the daily total radiation available above the canopy at a site unshaded by hills.

Figure 3 shows the predicted temperature increases in streams leaving a reach heavily shaded by native bush (95% shade, typical of bush streams at Whatawhata) and entering more open pasture reaches (with 75%, 50% and 25% shade). Solar radiation, air temperature, wind speed, relative humidity and barometric pressure were set to the long term average values measured at Whatawhata (N.Z. Met. Service 1986).

Regional differences in these meteorological parameters can be expected which will affect the absolute values of the predicted water temperatures, but it is likely that the changes in water temperature resulting from changes in riparian shade will be similar throughout the country in channels similar to those in Figures 3–5.

For a very long, uniform channel and for regular diurnal solar radiation and air temperature cycles, the model predicts stream temperatures which eventually follow a regular diurnal pattern (i.e., reach a dynamic equilibrium). The initial water temperatures in Figure 3 were the predicted equilibrium temperatures under conditions typical of bush streams (95% shade, wind speed 1 m s^{-1}) and were found to match reasonably closely measured bush stream temperatures at Whatawhata. The air temperature, humidity and wind speed were assumed identical in the bush and pasture reaches and only the percent shade was altered (reduced from 95% in the bush to either 75%, 50% or 25% in the pasture).

Measurements at Whatawhata indicate that there is a substantial amount of shading in small pasture streams (average 55%) arising from topography and overhanging vegetation (grass, fern and sedges).

In the South Auckland region the 25% shade factor used in Figure 3 represents a likely lower bound estimate of shade, 50% is more typical of small pasture streams, and 75% is typical of small streams with sparse tree plantings along the banks.

Table 1 Summary of channel parameters for streams of different order used in Figures 2–4.

	First order	Third order	Fifth order
flow (m^2s^{-1})	0.013	0.08	0.25
width (m)	1.3	1.6	3.3
mean depth (m)	0.10	0.3	0.5
mean velocity (ms^{-1})	0.10	0.165	0.15

Predicted temperature changes from high to lower shade

Figure 3 indicates that stream temperatures increase with distance from the bush-pasture boundary (0 km) and eventually reach a new dynamic equilibrium. We show only the daily maximum and minimum temperatures in Figures 3–5. Daily maximum equilibrium temperatures (closed symbols) increase markedly as the degree of shading decreases. For example, in first order streams the daily maximum equilibrium temperature increases from 18°C to 29°C as shading decreases from 75% to 25%. As the amount of riparian shading decreases, more solar radiation reaches the stream and more heating occurs during the day. This behaviour is well documented in the literature (e.g., Brown 1969).

It is noticeable that the daily maximum equilibrium temperature decreases with increasing stream size; in the case of 25% shading, from 29°C in the first order stream to 24°C in the fifth order stream. This reflects the fact that stream depth increases with increasing stream order (see Table 1) and the fact that for the same flux of solar radiation across the water surface, the rate of change of temperature is inversely proportional to the water depth. Thus, the thermal inertia of the stream increases with stream order and as a result the daily maximum temperature decreases. The equilibrium temperature is reached more quickly in first order than in the third and fifth order streams. This also reflects differences in thermal inertia between streams.

Thus small, shallow streams are much more susceptible to heating as a result of the removal of riparian shade than are large, deep streams.

Daily minimum temperatures change least in the first order stream. This is because at night the rate of heat loss (from back-radiation and evaporation) is rapid in a shallow stream and offsets the heating which occurs during the day. Third and fifth order streams show slightly higher increases in daily minimum temperature.

Few first order streams are more than about 1 km long. Figure 3 indicates that daily maximum temperature increases of the order of 5°C are possible when shade is reduced from 95% to 50% over 1 km. By comparison, temperature increases of 5°C are only likely to occur in third and fifth order streams if shade is reduced from 95% to 50% over distances of 10 and 20 km respectively.

If low stream temperatures need to be maintained throughout a stream network (e.g., to maintain suitable fish or invertebrate habitat) then it is more important to maintain dense shade along the small (first and second order) than along the large (third and fifth order) streams.

This point is illustrated by way of an example in Appendix 3.

There is very little published data from New Zealand on temperature increases in small streams. Hopkins (1971) found that, in a small stream near Wellington which flowed from the bush into pasture, the daily maximum temperature increased by 3–4°C over 500 m during clear days in summer. He also found that daily minimum temperatures did not change significantly in the same reach, even though the daily maximum temperatures increased significantly. The predictions for a first order stream shown in Figure 3 are in close agreement with these observations.

There is some published data for larger New Zealand streams. Dymond and Henderson (1981) observed increases in the daily maximum temperature of 2–3°C on clear days during December 1980 in a 7.5 km unshaded reach of the Stony River, Taranaki (low flow 3.5–4.5 $m^3 s^{-1}$, average width 18 m, mean depth 0.45 m, mean velocity 0.60 $m s^{-1}$). Jowett (1982) predicted a mean temperature increase of 5.3°C (range 3.9–7.2°C) in a 24.5 km reach of the Whakapapa River in which the mean flow increased from 2.5 $m^3 s^{-1}$ (range 0.6–5.3 $m^3 s^{-1}$) at the top of the reach to 7.5 $m^3 s^{-1}$ (range 3.2–19.7 $m^3 s^{-1}$) at the bottom. The standard error of these predictions was 0.69°C. Hockey *et al.* (1980) observed increases in daily maximum temperature of 2.0-2.5°C in a 12.5 km reach of the unshaded and braided Hurunui River, North Canterbury (average width 60 m, mean depth 0.7 m, flow 60–80 $m^3 s^{-1}$) during December 1979.

Predicted temperature changes from low to higher shade

Figure 4 shows the predicted temperature decreases in streams which flow from an open (25% shaded) pasture channel into channels with 50%, 75% and 95% shade. The initial temperatures were those predicted at equilibrium in pasture channels with 25% shade, and are the same as the downstream equilibrium temperatures in Figure 3. Figure 5 shows temperature predictions in streams which leave a 50% shaded channel and enter channels with 75% and 95% shade. Cooling occurs as a result of decreased solar radiation input to the streams and eventually a dynamic equilibrium is reached at new lower temperatures. The downstream equilibrium temperatures in Figures 4 and 5 are the same as the initial temperatures in Figure 3.

Cooling occurs more rapidly in first order than third and fifth order streams because the former are shallow and hence have lower thermal inertia. Figure 4 indicates that in first order streams reductions in the daily maximum temperature of the order 5°C are feasible over distances of about 1 km provided dense (95%) shade can be restored. By comparison 5 and 12 km of dense (95%) shade are required to reduce temperatures by 5°C in third and fifth order streams, respectively.

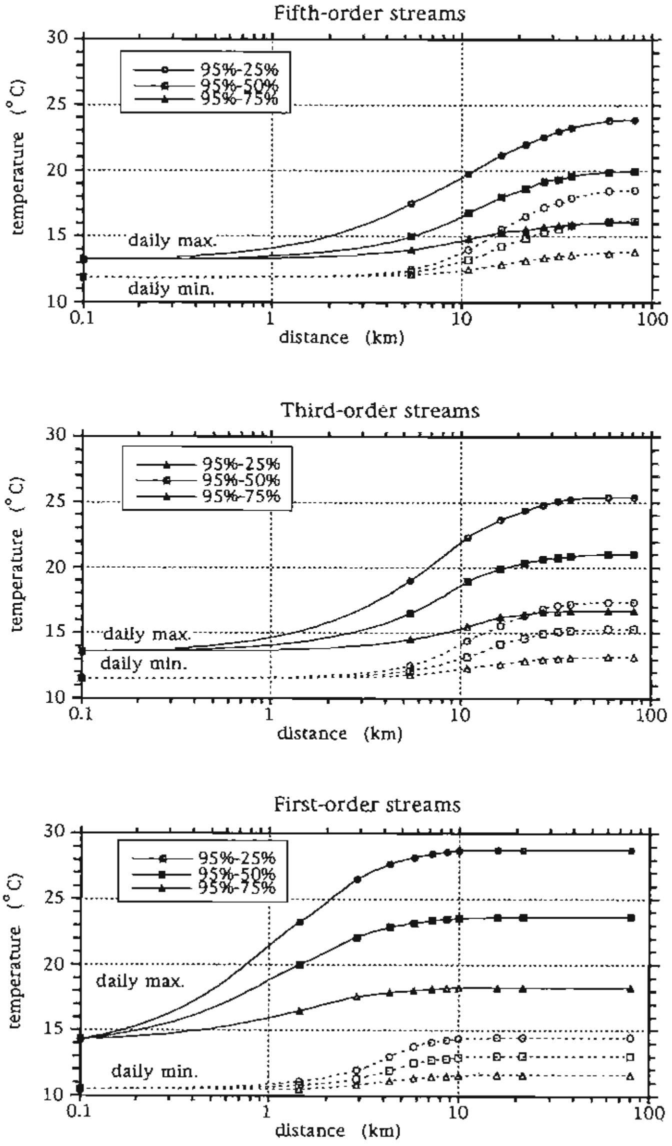


Figure 3 Predicted water temperatures in uniform stream channels originally at equilibrium under heavy (95%) shade as they flow through partially shaded (75%, 50% and 25%) channels. Channel parameters are given in Table 1. The solid and dashed lines are the daily maximum and the daily minimum temperatures, respectively. Note the log scale on the horizontal axis.

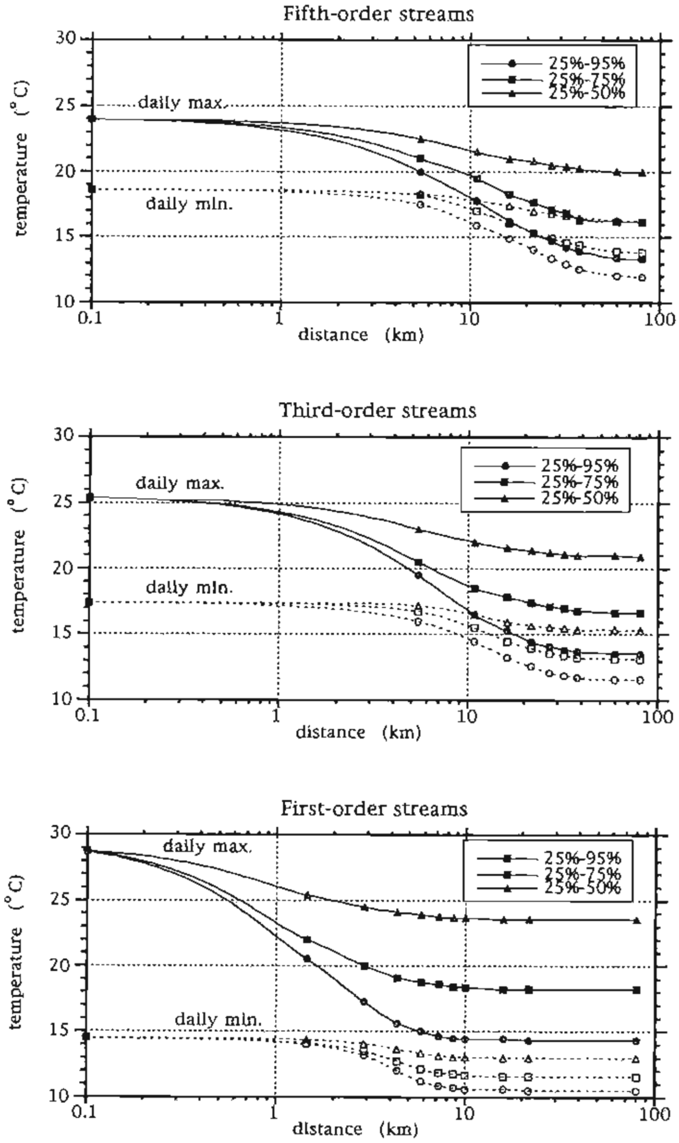


Figure 4 Predicted water temperatures in uniform stream channels originally at equilibrium under low (25%) shade as they flow through heavily shaded (95%, 75% and 50%) channels. Channel parameters are given in Table 1. The solid and dashed lines are the daily maximum and daily minimum temperatures, respectively. Note the log scale on the horizontal axis.

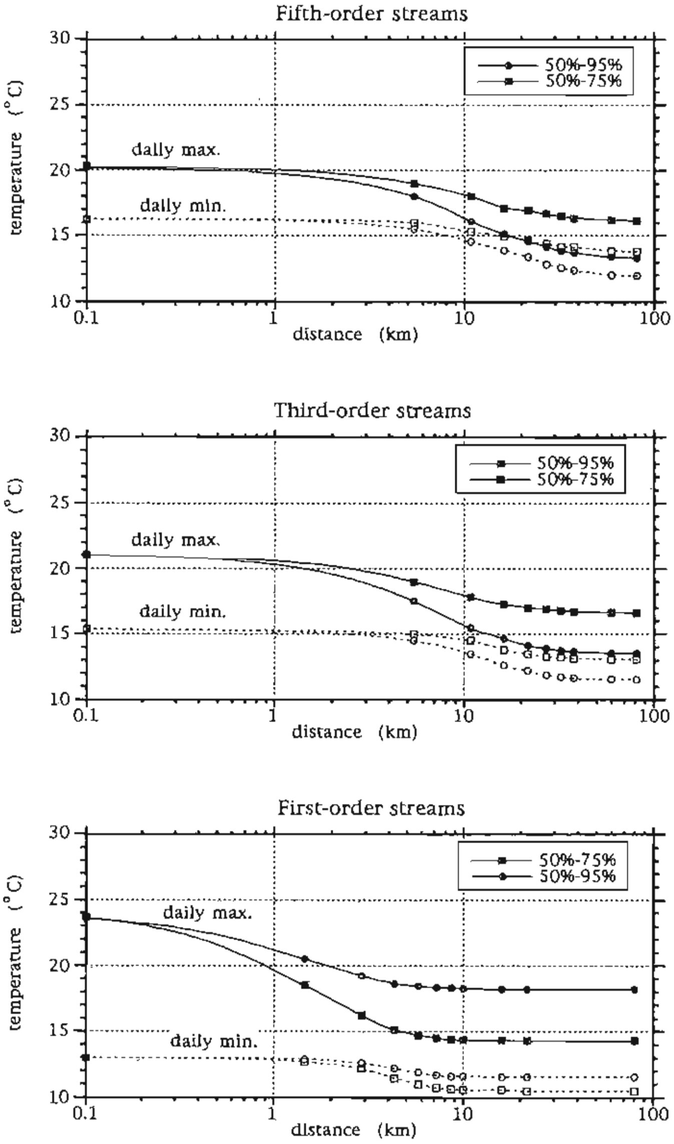


Figure 5 Predicted water temperatures in uniform stream channels originally at equilibrium under moderate (50%) shade as they flow through heavily shaded (95% and 75%) channels. Channel parameters are given in Table 1. The solid and dashed lines are the daily maximum and daily minimum temperatures, respectively. Note the log scale on the horizontal axis.

APPENDIX 3 The importance of stream size

The point has been made earlier that water temperature changes more rapidly in response to changes of riparian shading in first order than in third and fifth order channels. This point is illustrated using two examples.

Example 1

Consider the hypothetical stream network shown in Figure 6. Three identical first order streams leave the bush (where they are assumed to be at equilibrium under 95% shade) at points A, B and C. They then flow for 500 m through open (25% shade) pasture (channels A1, A2, A3) before meeting at point J to form a third order channel (Channel B). Channel B then flows for another 1500 m through open (25% shade) pasture to point K.

First consider the likely daily maximum stream temperatures. From Figure 3 the equilibrium bush temperature in a first order stream at points A–C is 14.2°C. After 500 m of 25% shade this temperature can be expected to increase to 18°C. Now for a fifth order stream, Figure 3 indicates that a temperature of 18°C occurs at 4.5 km in a channel with 25% shade. Thus the starting point for assessing temperature changes in Channel B is at a distance of 4.5 km. Figure 3 predicts that a further 1.5 km downstream the temperature is 19.5°C.

Consider two possible options for reducing stream temperatures:

- ***Option A***: Restore full (95%) shade to reaches A1, A2 and A3 while leaving reach B unshaded,
  OR
- ***Option B***: Leave reaches A1, A2 and A3 unshaded while restoring full (95%) shade along reach B.

In both cases 1500 m of stream planting is required. The question arises whether the two options achieve the same degree of temperature reduction at point K.

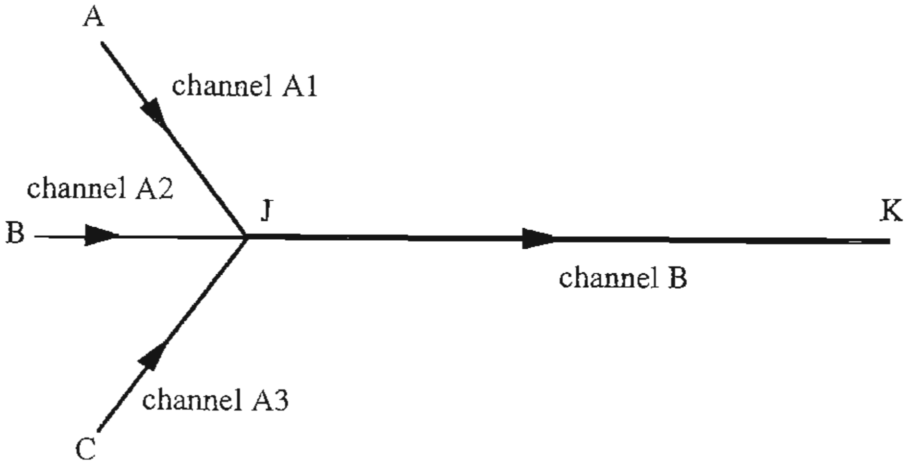


Figure 6 Sketch of three identical first order channels (A1–A3) each 500 m long which meet at hypothetical point J where a 1500 m third order channel (B) is formed.

Option A

Because channels A1, A2 and A3 are fully shaded, their temperature at point J remains at 14.2°C. From Figure 3, a temperature of 14.2°C occurs at 700 m in a third order channel with 25% shade. This is the starting point for assessing the temperature increase in Channel B. Figure 3 predicts that heating along a further 1500 m of a third order channel with 25% shade increases the temperature to 16.5°C.

Option B

After 500 m of 25% shade the temperature of channels A1, A2 and A3 is predicted by Figure 3 to increase from 14.2°C to 18°C. This is then the initial temperature of the third order stream at point J. From Figure 4 a temperature of 18°C occurs at 8000 m in a third order channel with 95% shade. Then Figure 4 predicts that cooling along a further 1500 m of heavily shaded (95%) channel reduces the temperature to 17.5°C.

In this example, shading 1500 m of first order stream channel (*Option A*) gains an additional temperature reduction at point J of the order 1 °C (6%) over shading the same length of third order stream (*Option B*).

Example 2

If there is important habitat (e.g., for fish or invertebrates) along the entire length of each of channels A1–A3 and B, then it may not be sensible to compare the predicted temperatures for Options A and B at just a single point (e.g., point K). Rather, for each option it may be sensible to integrate the water temperature along each channel and then compare the total degree-kilometres between *Options A* and *B*. This is illustrated as follows.

Option A

The average temperature in Channel B is approximately (14.2+16.5)/2 = 15.4°C, giving a total of 23.0°C per km in Channel B. In Channels A1–A3 the temperature is constant at 14.2°C giving a total of 21.3°C per km in Channels A1–A3. The total for *Option A* is then 44.3°C per km.

Option B

The average temperature in Channels A1–A3 is (14.2+18)/2 = 16.1°C, giving 24.2°C per km. The average temperature in Channel B is (18+17.5)/2 = 17.75°C, giving 26.6°C per km. The total for *Option B* is 50.8°C per km, which is 6.5°C per km (14%) higher than for *Option A* for the same total length of riparian shading.

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GUIDELINES FOR MANAGING INPUTS OF TERRESTRIAL CARBON TO WATERCOURSES

INTRODUCTION

Riparian vegetation supplies energy in the form of organic carbon to help drive the production of invertebrate and fish populations in streams and rivers. The main terrestrially-derived carbon sources are:

- Dissolved organic matter (DOM).
- Coarse particulate organic matter (leaves, bark etc.) and their breakdown products.
- Logs and branches (woody debris).
- Terrestrial invertebrates like spiders and beetles.

The roles of the different terrestrial carbon sources and the effects of catchment clearance on them are described in detail in *Volume 1: Concepts: Section 2.2.8*. Terrestrially-derived DOM can enter rivers directly by leaching out of leaves that have fallen into the water or that are overhanging the river channel, and indirectly though soilwater and groundwater which has leached DOM from decomposing organic matter adjacent to the river. Leaves, bark and other coarse particulate organic inputs enter streams directly from overhanging trees or upstream reaches, or fall onto the forest floor where they may partially decompose before being blown into the river or washed in during floods. Most woody debris enters streams from adjacent forests with a small proportion coming down the stream channel. Terrestrial invertebrates enter a stream reach by falling into the water from overhanging vegetation, being washed in by floods, being blown in, and by drifting in from upstream sections.

The amount of energy provided by these can vary considerably between different types of carbon sources, and even between different species of plants comprising one source (e.g., different leaf species). As well as entering the stream directly, leaves and wood that have fallen onto floodplain areas (and may have partially broken down there), and dissolved and particulate organic matter produced in riparian wetlands may be transferred to stream channels during high flows if hydrological links between floodplains, riparian wetlands and streams are intact.

Leaf fall and stream retentiveness

In New Zealand, most native trees are evergreen and lose leaves year round, particularly during storms. Peaks in leaf-fall typically occur as old leaves are replaced around spring (exact timing depends on the climate and tree species), with minor peaks sometimes in autumn following seasonal rainfalls. This contrasts with introduced deciduous trees characteristic of many riparian zones (e.g., willows and poplars) which lose all their leaves in autumn. Six species of native trees and shrubs are fully deciduous (see Table 1); these lose all of their leaves in spring and are often found associated with unmodified watercourses. Several other species are deciduous in some areas of New Zealand but not in others (Table 1).

Once in streamwater, aquatic fungi and bacteria enhance the nutritional value and palatability of leaves to leaf-eating invertebrates (*shredders*) by increasing the amount of protein and lipids available through the growth of microbial cells, by breaking down indigestible

Table 1 List of native deciduous tree species (from Salmon 1986, Wardle 1991).

FULLY DECIDUOUS		DECIDUOUS IN SOME AREAS	
Species	**Common name**	**Species**	**Common name**
Fuchsia excorticata	kotukutuku	*Aristotelia serrata*	wineberry
Plagianthus regius	manatu	*Aristotelia fruticosa*	
Hoheria glabrata	mountain ribbonwood	*Brachyglottis hectori*	kohuhurangi
Hoheria lyallii	mountain ribbonwood	*Urtica ferox*	tree nettle
Discaria toumatou	matagouri	*Muehlenbeckia* spp.	
Olearia hectori	deciduous tree daisy	*Sophora microphylla*[1]	kowhai
		Nothofagus fusca[2]	red beech

[1] – some races in colder districts

[2] – some young saplings may lose all but their youngest leaves

components of the leaf, and by making leaf protein more available. Thin, soft leaves break down more quickly in streams than thick, leathery leaves with waxy cuticles and large amounts of structural material such as lignin. This means that soft leaves may become palatable sooner and break down to fine particulate organic matter (FPOM) faster than hard leaves. However, hard leaves can be available in streams for longer periods.

The extent to which this conditioning process occurs in a given stream reach depends on various physicochemical factors such as water temperature, and on the ability of a stream to retain leaves long enough for them to become palatable. *Stream retentiveness of leaf inputs is of major importance in determining whether shredders are relatively abundant.* Retentiveness is influenced by factors such as physical stability, flow variability, leaf shape and the presence of retention structures such as logs and boulders. Rounick and Winterbourn (1982) surveyed 43 streams throughout New Zealand and found shredders only in streams with relatively stable channels, apparently because of the ability of those streams to retain leaves.

Use of the guidelines

The guidelines that follow have been divided into sections that suggest ways to:

- Manage the supply of leaves, wood and terrestrial invertebrates to streams (see **CARBON: SUPPLY**).
- Improve the quality of terrestrial plant material in watercourses (see **CARBON: QUALITY**).
- Increase the retention of terrestrial plant material in the channel so that it can be used by aquatic invertebrates (see **CARBON: RETENTION**).

The combinations of these guidelines that are applied in practice will depend on the nature of the perceived problems and the resources available. Suggestions of combinations of guidelines that can be used to address different management goals are presented in Table 2. Managers will need to use judgement when deciding which of these guidelines to apply. For example, if the planting of trees and other management practices will lead to an improvement in stability, it may then be worthwhile to also manage carbon inputs. Management of carbon inputs will probably be a secondary consideration following decisions on how best to manage for bank and channel stability, contaminant and nitrate inputs, shade levels and/or water temperatures.

The guidelines that follow are most applicable to streams and small rivers as terrestrial carbon inputs become less important in the energy budgets of large rivers. This is because, as watercourses become larger, streambed area increases relative to the extent of riparian vegetation and instream production by aquatic plants increases. Where management actions are taken to increase the supply of leaves to streams of low physical stability, it will also be necessary to consider management practices which enhance leaf retention (see **CARBON: RETENTION**).

Table 2 Combinations of CARBON guidelines that could be used to address possible management goals. Guideline numbers correspond to those in the following sections.

Possible management goals	Suggested CARBON Guidelines
To achieve more natural conditions	**SUPPLY** nos. 1, 2 and 5 **RETENTION** no. 2
To increase instream habitat diversity	**SUPPLY** nos. 2, 3, 4 and 5 **QUALITY** no. 1 **RETENTION** nos. 1, 2 and 3
To increase diversity of the aquatic invertebrate community	**SUPPLY** nos. 2, 3, 4 and 5 **QUALITY** nos. 1 and 2 **RETENTION** nos. 1, 2 and 3
To increase the density of shredders	**SUPPLY** nos. 2, 3 and 4 **QUALITY** nos. 1 and 2 **RETENTION** nos. 1, 2 and 3
To increase the terrestrial invertebrate food supply for certain fish species	**SUPPLY** nos. 1, 4 and 5 **RETENTION** no. 2

Guidelines for Managing the Supply of Terrestrial Carbon to Watercourses

OBJECTIVE(S)

To maintain regular inputs from a range of terrestrial carbon sources throughout the year by:

- Increasing the supply of terrestrial invertebrates that can enter the stream food chain.
- Increasing the supply of woody debris to streams.
- Increasing the amount of leaf inputs to streams at different times of year.
- Maintaining inputs of carbon from associated floodplains and wetlands.

GUIDELINE(S)

1. Plant low vegetation that overhangs the channel along the edges of streams to provide a source of terrestrial invertebrates for fish that may be in the stream beneath. Native species that should be suitable for this include flax (*Phormium tenax*), toetoe (*Cortaderia toetoe*) and some tree ferns (*Cyathea* and *Dicksonia* spp.).

2. Also plant rapidly-growing, woody plant species with short life spans (see Table 3 for suggested native species) along the stream to a width equivalent to the estimated height at maturity of the largest tree planted to provide a source of woody debris. Some hardwood species that are resistant to decay should also be planted to provide a source of woody debris over the long term. Species such as totara (*Podocarpus totara*) and beech (*Nothofagus* spp.) should be suitable for this.

3. Include a mixture of deciduous and evergreen species alongside streams to about one half the height of the largest tree from the channel edge. Table 1 lists native deciduous species that are large leaved or fast growing. A range of potentially suitable introduced species are listed in **STABILITY: TREES**. This procedure should provide year-round inputs of leaves from the evergreens, and pulses of leaves in spring and autumn from the native and introduced deciduous species, respectively.

4. Decrease the density of tree plantings away from the stream channel to enhance windblow through riparian forests with the aim of increasing the supply of leaves from the forest floor and terrestrial invertebrates from overhanging vegetation.

5. Where possible, maintain hydrological links between riparian floodplains and wetlands, and the stream channel by preventing the construction of stopbanks inside the floodplain area, the drainage of associated wetlands etc.

JUSTIFICATION AND ASSUMPTIONS

Justifications and assumptions for guidelines **1** – **5** above are, in corresponding order:

- Several studies have shown that terrestrial invertebrates from riverside vegetation are an important food for some native fish (e.g., Main and Winterbourn 1987, Main and Lyon 1988, McDowell 1990).

- Trees growing up to one tree length from the channel are likely to contribute woody debris to streams (*Volume 1: Concepts: Figure 3*). Rapidly-growing species with short life spans would provide an initial source of woody debris, but hardwood species that are resistant to decay in the channel are more likely to be important in the long term. Woody debris is important in streams because it traps leaf litter, creates depositional zones, helps stabilise channels, serves as emergence sites for aquatic insects, and provides important shelter for fish.

- Assumes that the supply of tree leaves is a factor limiting invertebrate diversity and shredder production, and that maximising litter inputs will, on the whole, be beneficial to the stream ecosystem. For this guideline to be successful, leaves will have to be retained long enough for them to become suitably conditioned (see **CARBON: RETENTION**). The effectiveness of riparian forests to deliver leaf inputs to streams declines at distances greater than approximately one half the tree height away from the channel (see *Volume 1: Concepts: Figure 3a*).

- Assumes windblow is an important mechanism for transferring leaves and terrestrial invertebrates to streams.

- Assumes that floodplains and wetlands are important sources of carbon (especially FPOM) and that their stored carbon will be transferred to streams and rivers during floods. Some fish (e.g., eels) also feed in floodplain areas when they become inundated during high flows.

SIDE EFFECTS AND LIMITATIONS

Side effects/limitations for guidelines **1** – **5** above are, in corresponding order:

- Overhanging vegetation will alter the light and radiation climates (see **LIGHT** and **TEMPERATURE**), and may result in bank erosion by preventing the growth of the grass sward beneath (see **STABILITY**). Such vegetation will also assist in slowing down floodwaters (see **FLOW**).

- Likely to be ineffective in the longer term if streams are subject to frequent flow extremes unless fallen logs and branches are secured, or unless the size of the fallen material is large enough to resist movement during high flows (see **CARBON: RETENTION**). Effectiveness may be reduced if the channel is narrow and incised because fallen logs may not enter the wetted part of the stream. Dense plantings of trees may increase bank erosion by preventing the growth of the grass sward beneath (see **STABILITY** and **LIGHT**). Woody debris accumulations may form pools upstream resulting in inundation of adjacent land during high flows, and may act as flow deflectors causing erosive cross-currents. Overall, however, woody debris reduces current velocities in floods and hence reduces bank erosion.

  Plantings of trees and shrubs may also slow large floodflows when floodwaters overflow into the riparian zone (see **FLOW**), alter water temperature regimes downstream (see **TEMPERATURE**), and re-introduce landscape and terrestrial riparian diversity (see

HABITAT). Riparian forest may harbour plant and animal pests, and corridors of forest may enhance wildlife movement generally.

- Loss of leaves during spring and autumn may temporarily alter the light climate (see LIGHT), and this may prove favourable for the growth of grass and other vegetation beneath the trees. Use of introduced tree species may be inappropriate where it is intended to protect or enhance New Zealand native vegetation and wildlife values (see HABITAT). The accumulation of too much leaf material in the stream may cause localised oxygen depletions and smother the substrate in some small, stable streams.

- The presence of dense undergrowth may limit the effectiveness of windblow. Enhancing windblow could cause some trees in the riparian zone to blow down during storms. May also cause a change in microclimate.

- The floodplain may occasionally flood. Wetlands also provide habitat for certain native fish species (e.g., mudfish), and a variety of plants, insects and birds (see HABITAT).

CONFIDENCE

Moderate for guidelines **1**, **2**, **3** and **5**. Guideline **4** is intuitively based.

Table 3 Characteristics of some native woody trees and shrubs that have large leaves (>20 cm^2) or are fast-growing and short-lived according to Wardle (1991). Large leaves may be retained in stream channels more readily than small leaves, and fast-growing, short-lived woody species may provide rapid sources of woody debris. Hardness of mature leaves is also indicated based on an arbitrary scale of "soft" (S), "medium" (M) and "hard" (H). For distribution, NI=North Island, SI=South Island, *=localised. Species that typically live on stream or river banks are also indicated.

Species	Common name	Distribution	Large leaves	Fast growing /short-lived	Leaf type	Typical of stream/ river banks
Alectyron excelsus	titoki	NI/SI(*)	+[4]		H	
Alseuosomia macrophylla	pere	NI(*)/SI(*)	+		S	
Aristotelia serrata[7,8]	wineberry	NI/SI	+	+	S	+
Ascarina lucida	hutu	NI/SI		+	H/M	+
Beilschmiedia tarairi	taraire	NI(*)	+		H	
Brachyglottus kirkii	kohurangi			+	S	
Brachyglottus repanda[5]	rangiora	NI/SI(*)	+	+	H	+
Carpodetus serratus	putaputaweta	NI/SI		+	H	
Coprosma grandifolia[8]	kanono	NI/SI	+	+	H	
Coprosma lucida[8]	karamu	NI/SI		+	H	
Coprasma repens[8]	taupata	NI/SI(*)		+	H	+
Coprasma robusta[8]	karamu	NI/SI	+	+	H	
Coriaria arborea[5,7]	tutu	NI/SI		+	S/M	
Corynocarpus laevigatus[7]	karaka	NI/SI	+		H	
Cyathea colensi		NI(*)/SI	+++	(+)	H	+
Cyathea cunninghami		NI/SI(*)	+++	(+)	H	
Cyathea dealbata	ponga	NI/SI	+++	(+)	H	
Cyathea medullaris	mamaku	NI/SI	+++	(+)	H	+
Cyathea smithii	katote	NI/SI	+++	(+)	H	+
Dicksonia fibrosa	kuripaki	NI/SI	+++	(+)	H	
Dicksonia lanata		NI(*)/SI(*)	+++	(+)	H	+
Dicksonia squarrosa	wheki	NI/SI	+++	(+)	H	
Dodonaea viscosa[7]	akeake	NI/SI(*)		+	H	
Dysoxylum spectabile[8]	kohekohe	NI/SI(*)	++[4]		H/M	+
Elaeocarpus dentatus	hinau	NI/SI	+[6]		H	
Enteleo arborescens	whau	NI(*)	+		S	+
Fuchsia excorticata[7,8]	kotukutuku	NI/SI	+		S	
Griselinia littoralis[7]	papauma	NI/SI	+		H/M	
Hebe parviflora var. *arborea*	koromiko-tarenga	NI/SI(*)		+	S	+
Hebe salicifolia[7]	koromiko	SI		+	S	+
Hebe stricta	kormiko	NI		+	S	
Hedycarya arborea[8]	pigeonwood	NI/SI(*)	+	+	H	
Ixerba brexioides	tawari	NI(*)	+		H	
Knightia excelsa[8]	rewarewa	NI/SI(*)	+[6]		H	
Macropiper excelsum[7,8]	kawakawa	NI/SI(*)	+		S	
Melicytus novae-zelandiae		NI		+	H	
Melicytus obovatus	porcupine plant	NI/SI		+	H	+
Melicytus ramiflorus[7,8]	mahoe	NI/SI	+	(+)	S	
Myrsine australis[8]	matipo	NI/SI		+	H	
Myrsine salicina	toro	NI/SI(*)	+		H	

Species	Common name	Distribution	Large leaves	Fast-growing /short-lived	Leaf type	Typical of stream/ river banks
Nestegis cunninghamii	black maire	NI/SI(*)	+		H	
Olearia arborescens	common tree daisy	NI/SI	+	+	H	+
Olearia avicenniaefolia	akeake	SI		+	H	+
Olearia colensoi	leatherwood	NI(*)/SI	+		H	
Olearia fragrantissima	fragrant tree daisy	SI(*)		+	H	+
Olearia furfuracea	akepiro	NI(*)		+	H	+
Olearia lacunosa	rough-leaved tree daisy	NI(*)/SI	+[6]		H	
Olearia paniculata	akiraho	NI/SI(*)		+	H	
Olearia rani	heketara	NI/SI(*)	+		H/M	+
Pisonia brunoniana	parapara	NI(*)	+		S	
Pittosporum crassifolium[7,8]	karo	NI(*)		+	H	+
Pittosporum eugenioides[8]	lemonwood	NI/SI	+	+	H	+
Pittosporum tenuifolium[8]	kohuhu	NI/SI		+	H	
Pseudopanax arboreum[8]	fivefinger	NI/SI	+[4]		H	
Pseudopanax colensoi	orihau	NI/SI	+	+	H	
Pseudopanax crassifolius	lancewood	NI/SI	+[6]	+	H	
Pseudopanax edgerleyi	raukawa	NI/SI	+	+	H	
Pseudopanax ferox	toothed lancewood	NI/SI	+[6]		H	
Pseudopanax laetus		NI(*)	+	+	H/M	
Pseudopanax lessonii	houpara	NI(*)	+	+	H	
Pseudopanax linearis		SI	+		H	
Pseudowintera axillaris	pepper tree	NI/SI(*)	+		H	
Rhopalostylis sapida	nikau	NI/SI(*)	+++		H	
Schefflera digitata	pate	NI/SI	++[4]	+	S	+
Weinmannia racemosa	kamahi	NI/SI	+		H	+

1 – from p. 37 of Wardle 1991. +++ = oblong leaves with dimensions c. 80x25cm; ++ = dimensions c. 20x10 cm; + = dimensions from c. 6x4 cm.

2 – from p. 23 of Wardle 1991 for "broad-leaved small trees and shrubs on lowland forest and bush", or from other published work indicating important source of woody debris (in parentheses). Tree ferns (*Cyathea* and *Dicksonia* spp.) have been indicated in parentheses as their fronds can act as important retention structures in small streams.

3 – according to Department of Conservation (no date); Eagle 1975,1982; Poole and Adams 1990; Salmon 1986, or personal observation.

4 – leaflet of a compound leaf.

5 – plant toxic to mammals.

6 – unbranched saplings bear long, stiff, narrow leaves. Adult leaves are shorter.

7 – also recommended for use in Table 8 of **STABILITY**.

8 – also recommended for use in Table 1 of **HABITAT**.

Guidelines for Improving the Quality of Terrestrial Carbon in Watercourses

OBJECTIVES(S)

To improve the quality of leaf litter in streams by providing an on-going supply of leaf material at different stages of decomposition.

GUIDELINE(S)

1. Determine the Pfankuch (1975) stability score for the stream/reach in question (see Appendix 1). If the Pfankuch score is less than 100, plant an even mixture of soft- and hard-leaved species next to the channel. Otherwise, plant predominantly soft-leaved species next to the stream channel (see **CARBON: SUPPLY**: Table 3 for suggested native species) (see also **CARBON: RETENTION**).

2. Plant increasing proportions of hard-leaved tree species with distance away from the stream edge.

JUSTIFICATION AND ASSUMPTIONS

Justifications and assumptions for guidelines **1** and **2** above are, in corresponding order:

- Based on a survey of 43 streams by Rounick and Winterbourn (1982) who found shredders only in streams with Pfankuch scores < 100, apparently because the stable streams retained leaves. Assumes that some leaf material will be retained in the stream for a short period at least, that hard leaves will be available to shredders later and for longer periods than soft leaves, and that soft leaves will be a source of fine particulate organic matter (FPOM) for other invertebrates.

- Assumes that at least some leaves will enter the stream from the forest floor, and that terrestrial pre-conditioning (decomposition) of hard leaves before entry to streams will enhance their palatability to aquatic invertebrates.

SIDE EFFECTS AND LIMITATIONS

Pfankuch (1975) stability scores depend on subjective judgements and may vary between users. The scores obtained before planting will probably be higher (i.e., poorer channel stability) than scores obtained after the planted riparian zone has developed, due to improvements in stream stability. Where possible, this will need to be taken into account when making stability assessments by envisaging the likely improved condition under planting. Little information is available on the palatability of different leaf species to aquatic invertebrates in New Zealand, although work carried out overseas indicates that there can be considerable variability between plant species.

Plantings of trees and shrubs may also slow large floodflows when floodwaters overflow into the riparian zone (see **FLOW**), alter water temperature and light regimes downstream (see **LIGHT** and **TEMPERATURE**), and re-introduce landscape and riparian diversity (see **HABITAT**).

Riparian forest may harbour plant and animal pests, and corridors of forest may enhance wildlife movement generally.

CONFIDENCE

Moderate for guideline **1**; low for guideline **2**.

Guidelines for Increasing the Retention of Terrestrial Carbon Inputs

OBJECTIVE(S)

To increase the retention time of terrestrial leaf and wood inputs by:

- Improving physical stability of the stream.
- Increasing the supply of woody debris to act as retention structures.
- Improving the *trapability* of leaves entering the stream.

GUIDELINE(S)

1. Stabilise areas of bank erosion (see STABILITY). This will help reduce sediment inputs and bed movement (along with trapped leaves) during floods.

2. Plant trees for the production of coarse woody debris as described in CARBON: SUPPLY: guideline 2. The size of woody debris retained in the channel for long periods decreases with stream size. Equations modelling this relationship do not exist in New Zealand and are likely to vary regionally depending on the flow regime. However, estimates of minimum stem diameter for passive retention can be obtained for similar sized streams nearby, and, if appropriate, trees of this size can be placed into the channel to create retention structures. Retention is improved if root mats and branches are left intact. Alternatively, in streams that experience regular floods or occasional extremely high flows, trees can be anchored to the bed or streambank so that they remain stable during floods. Only a few retention structures of this type down a stream may be sufficient to enhance productivity and habitat diversity in moderately-stable channels.

3. Plant predominantly tree species with large leaves next to the stream (see CARBON: SUPPLY: Table 3).

JUSTIFICATION AND ASSUMPTIONS

Guideline 3 assumes that larger leaves will be retained more readily than smaller leaves and that large leaves will be as equally palatable to aquatic invertebrates as smaller leaves.

SIDE EFFECTS AND LIMITATIONS

Effectiveness may be reduced if the channel is narrow and incised because fallen logs may not enter the wetted part of the stream. Dense plantings of trees may increase bank erosion by preventing the growth of the grass sward beneath (see STABILITY). Woody debris accumulations may form pools upstream resulting in inundation of adjacent land during high flows, and may act as flow deflectors causing localised erosive cross-currents. Overall, however, woody debris reduces current velocities in floods and hence reduces bank erosion overall (see FLOW).

Plantings of trees and shrubs may also alter the light climate (see LIGHT), reduce maximum water temperatures downstream (see TEMPERATURE), and re-introduce landscape and riparian diversity (see **HABITAT**). Riparian forest may harbour plant and animal pests, and corridors of forest may enhance wildlife movement generally.

CONFIDENCE

Moderate.

APPENDIX 1: Description of the Pfankuch method for assessing river stability.

GOLDEN RULES OF EVALUATION

- The evaluation form is tailored to best fit second, third and fourth order streams and should ideally be used for streams of these sizes. A second order stream is formed by two first order streams merging, and a third order stream is formed when two second order streams coalesce, and so on. However, when a second order stream flows into a third order stream, the stream remains third order (see *Volume 1: Concepts: Section 2.1.3*).

- Where possible, the reach evaluated should be of sufficient length (greater than about 100 m) to provide the observer with enough information to make a sound selection from the available alternatives presented on the evaluation form.

- The channel should be assessed only during periods of low flow so that the observer can see the substrate clearly.

- Do not key in on a single variable or group of variables when scoring the river section. Work through the form methodically.

- If conditions fall between those described, cross out the proposed score and write an intermediate value which better expresses the situation as observed.

- Do not attempt an evaluation without reading the explanatory notes in the following sections. If possible, get hold of Collier, 1992, (see *Volume 2: Guidelines: Introduction – Important reading kit*) which explains the following procedures in more detail and also includes some useful diagrams.

WHAT AREAS ARE BEING ASSESSED?

Upper banks: That portion of river cross-section from the break in general slope of the surrounding land to the normal high water line. Terrestrial plants and animals normally inhabit this area. In deeply incised channels or where a bank is very steep this would be the area above the normal high water line where perennial vegetation starts even though there is no discernible change in slope. Where the channel is braided, upper banks usually occur at the extreme edges, although some large islands may also qualify.

Lower banks: That portion of river cross-section from the normal high water line to the water's edge during summer low flow which is intermittently submerged. This section is usually sparsely colonised by perennial plants although rapidly growing species may become abundant during extended periods of low flow, especially on braided channels.

Bottom: That portion of river cross-section which is almost always submerged and can be considered a totally aquatic environment.

INTERPRETATION OF THE VARIABLES

The descriptors for each variable are phrased in fairly general terms to maximise their applicability. The notes below are intended to assist you in interpreting the evaluation forms and should be used in association with those forms. A blank evaluation form is given at the end of this Appendix.

Upper banks

Landform slope: The steepness of the land adjacent to the channel determines the extent to which banks can be eroded and the potential volume of material that can enter the water. Look at both banks and score them according to the descriptions on the form.

Mass-wasting: This describes the extent of existing or potential detachment of large pieces of ground and their movement into waterways below. Mass movement of banks by slumping or sliding introduces large volumes of soil and debris into rivers causing constrictions that can increase flow velocities, cutting power and sedimentation rates.

Debris jam potential: Tree trunks, limbs, twigs and leaves are deposited on river banks and form the source of the bulk of the obstructions, flow deflectors and sediment traps rated for the lower banks. Debris jam potential indicates the likelihood of increasing these impediments to the uninterrupted direction and force of flow *where they now lie or could lie under certain flow conditions*.

> ***Excellent*** – debris may be present on the banks but is of such a size or location that the stream is not able to push or float it into the channel. The potential for debris jam formation is therefore essentially absent.
> ***Good*** – The debris present offers some bank protection for a while but is small enough to be floated away in time. Only small jams could be formed with this material alone.
> ***Fair*** – There is a noticeable accumulation of all sizes and the stream is large enough to float it away at certain times thus decreasing bank protection and adding to the debris jam potential downstream.
> ***Poor*** – High flow will float some debris away and the remainder will probably cause channel changes.

Vegetative bank protection: The soil on banks is held in place by plant roots. Deep root systems offer more bank protection than shallow root systems. In addition to the root mat stabilising the bank, stems help reduce the velocity of flood flows by taking some of the energy out of the water. The larger the stems and the greater their density, the more energy is dissipated. The more diverse the plant community on the banks the better. Young plants which grow and reproduce rapidly are better than old plants. Where there is a mix of vegetation types along a reach, select a score that best describes the average situation.

> ***Excellent*** – Openings in the >90% vegetative cover are small and evenly dispersed. A variety of plant species of different ages is present. Growth is vigorous and reproduction of under- and over-storey plants appears to be proceeding at a rate that ensures continued ground cover. A deep, dense root mat is inferred.

Good – Scrub more prevalent than forest. Openings in the tree canopy are larger than the space resulting from the loss of mature single trees. Vigour of growth is good for all species, but the likelihood of continued long term reproduction may be small or absent. This could infer a deep root mat that is not continuous and potential for the expansion of current openings.
Fair – Lack of vigour is evident in some individuals and/or species. No seedling reproduction.
Poor – Trees essentially absent. Shrubs largely exist in scattered clumps, or are absent.

Lower banks

Channel capacity: This variable reflects the ability of the lower banks to contain changes in discharge. The width, depth, gradient and roughness of the river channel adjust to changes in riparian vegetation, run-off and prevailing climate. Where adjustments are in progress widening and/or deepening of the channel may be occurring and this can affect the ratio of width to depth. Low width to depth ratios indicate a deep channel which can accommodate normal increases in flow whereas high ratios indicate a wide and shallow channel whose lower banks commonly overflow. When the capacity of the channel is exceeded, deposits of sediment are found on the lower banks and organic debris may be trapped in bank vegetation. These are indications of a recent flood event. Longer term indicators will be more difficult to find. You may need to use your knowledge of the river to estimate normal peak flows and whether the present cross-section is adequate to handle the load without bank deterioration. Bear in mind that spring-fed streams may have high width to depth ratios but rarely overflow their banks because flows are so stable.

Bank rock content: The composition of bank materials indicates the capacity of the bank to resist erosion by flow. Since vegetation is generally lacking from the lower banks, the volume, size and shape of the rock component primarily determine the resistance of banks to flow forces. Bank rock content (i.e., the proportion of bank materials that are rock) can be determined by examining areas where banks are already exposed.

Obstructions/ flow deflectors/ sediment traps: Objects like large rocks, embedded logs and bridge pylons will change the direction and sometimes the velocity of flow. These may cause problems where the flow is deflected against unstable banks and bottom materials. Where velocity falls, coarse sediments drop out of the water.

Excellent – Obstructions to flow are firmly embedded and produce a pattern of flow which does not erode the banks or cause sediment build up.
Good – Obstructions cause some minor bank and bottom erosion. Some obstructions are newer, not firmly embedded and move to new locations during high flows. Some sediment is trapped in pools, decreasing their capacity.
Fair – The frequent and often unstable obstructions cause noticeable erosion of the channel. Considerable sediment accumulates behind obstructions.
Poor – Obstructions and traps cause continual shift of sediments. As sediment traps are filled soon after they are formed, the channel migrates and widens.

Cutting: Erosion of banks by flow can cause near vertical walls with overhanging sods of roots that eventually topple into the water. Sometimes, under-cutting can occur in the absence of vegetation where different soil layers are compacted to different degrees. In other situations where banks are loosely-consolidated, the flow constantly nibbles away, yet little overhang develops.

Excellent – Raw, eroding banks are infrequent, cuts are short and predominantly less that 15 cm high.
Good – Eroded areas equivalent in length to one channel width or less and vertical cuts are less than 30 cm high.
Fair – Significant bank cuts occur frequently in the reach.
Poor – Undercutting, sod-root overhangs and vertical side failures may be frequent.

Deposition: Deposition on the less steep lower banks and on the downstream sides of flow deflectors can be quite large. The appearance of sand and gravel bars where they did not previously exist can be one of the first signs of upstream erosion. If disturbances continue, these bars tend to widen in a shoreward direction. Deposition may also occur on the inside of bends, particularly if cutting is taking place on the opposite bank. Deposits of sediment are also found below constrictions where there is a sudden flattening of stream gradient.

Excellent – Very little or no deposition of fresh silt, sand or gravel in channel bars in straight reaches or point bars on the inside banks of curved reaches.
Good – Some fresh deposits behind obstructions.
Fair – Bars are enlarging and pools are filling so riffle areas predominate.
Poor – Extensive deposits of fresh fine sands, some silts and small gravels. Storage areas full of sediments and fine particles may move during periods of low flow.

Bottom

Rock angularity: Angular fragments of rock are more resistant to tumbling than rounded rocks which pack poorly and, depending on size, may be easily moved downstream. Rock surfaces generally become smoother with time, although the degree of smoothness depends on the type of rock.

Brightness: Stones in motion gather no moss or substantial growths of algae and become polished (i.e., brighter) by frequent tumbling. Constantly moving stones are not conducive to the establishment of abundant and diverse invertebrate faunas. The degree of perceived staining by vegetation can also depend on water temperature, season, nutrient levels, light conditions and other factors which can affect the utility of this variable. Staining can also be caused by minerals or organic matter dissolved in the water. Rocks that feel slippery can be assumed to be stained by algae. Do your best – this variable is given a low weighting. Look first for changes in the sand and gravels and then compare their brightness with that of larger substrates if they are composed of the same rock type.

Consolidation or particle packing: Under stable conditions in streams fed by runoff, rock particles pack together and larger rocks tend to overlap providing stable interstitial spaces for invertebrates and small fish. This packing makes the bed very resistant to movement by flow forces. Keep in mind the type of flow regime (fed by run-off or spring water) when assessing this as spring-fed streams can have relatively poor particle packing but still have stable substrates because flows rarely increase enough to move the stones. Try kicking the substrate with your boot to assess particle packing.

Excellent – Difficult to dislodge by kicking.
Good – Rocks may be overlapping in fast water parts of the channel. Some rocks might be dislodged by higher than average flow conditions.
Fair – Most elements moved by average high flow conditions.
Poor – Loose array easily moved by less than high flow conditions and move underfoot while walking on the bottom. These rocks tend to be round and of a similar size.

% stable materials: Rocks remaining on a stream bottom partly reflect gradient and recent flow regime. Normally, there is an array of sizes that you would expect to see in a given location and some experience will enable you to sense abnormal conditions. Bedrock and boulders (>26 cm diameter) can generally be considered stable elements. Smaller rocks in smaller channels may also be classified as stable. If you are re-visiting sites regularly, you may wish to monitor the movement of stones coloured with enamel paint to get an indication of substrate stability.

Scouring and/or deposition: Earlier assessments of size, angularity and brightness should assist you in coming to some conclusions about the amount of scouring and/or deposition that is occurring on the channel bottom (i.e., the percent of channel undergoing change).

Excellent – Neither scouring nor deposition are much in evidence. Up to 5% of either process or both processes in combination may be present along the reach (i.e., up to 5 m in a 100 m reach).
Good – Sediment in pools tends to move on through so pools change only slightly in depth.
Fair – Moderate changes occurring. 30–50% of the bottom in a state of flux. Pools filling in with sediment and decreasing in size.
Poor – Cutting and deposition common. More than half the bottom is moving, not necessarily just during periods of high flow.

Aquatic vegetation: Changes in volume of flow and/or sedimentation rates may cause temporary losses of clinging aquatic vegetation. Algae (mats covering upper rock surfaces and filamentous growths) and mosses do not have roots and can be washed away during high flows. To some extent the distribution and abundance of aquatic vegetation in a river will be influenced by season, light conditions, nutrient levels and the time elapsed since preceding flood events. Make the best assessment you can, taking into account your knowledge of the river; this variable is given a low weighting. For algae, concentrate more on the extent of mats rather than on filamentous growths which can appear quickly and be transient.

Excellent – Clinging plants abundant throughout the reach from bank to bank. A continuous mat of vegetation is not required but moss and/or algae are readily seen in all directions across the stream.
Good – Plants common in slower portions of the reach but thin out markedly in swift flowing portions.
Fair – Plants almost totally absent from swifter portions of the reach and may also be absent in some of the slow and still water areas.
Poor – Clinging plants rarely found anywhere in the reach.

Evaluation Protocol

Ideally, you would do an evaluation for each reach in the section of river you are assessing. However, this may not always be feasible where there are many bends in the river, and it may not even be necessary where the physical state of the river changes little in a number of reaches. In this instance, you could simply make evaluations of representative reaches and note the river length represented by each assessment. New evaluations can be made where the river changes noticeably. Maps and aerial photographs can be used to help you determine the length of reach represented by different assessments. Where the river shows no obvious physical change over a long distance, carry out at least three assessments at different points and take the average. You can then multiply the overall ratings by the length of river that they represent. The sum of these totals divided by the total length of river assessed will provide an average rating for that section (see example below).

Stability score	Length of reach	Score x length
64	1.0 km	64
58	2.5 km	145
103	0.5 km	52
Totals =	4.0 km	261

Average stability rating for river section = 261/4.0 = 65

Obviously, land and water management should not be based on averages. Sections with high scores (i.e., lower stability) may represent "weak links" in the system (e.g., the 0.5 km section in the example above). Take note of these. They could indicate areas where some more intensive forms of management upstream are desirable . You can also compare the ratings for river sections in different seasons or years to understand what changes are occurring over time. You should do your assessments in the same reaches each year to determine this.

REACH INVENTORY AND CHANNEL STABILITY EVALUATION FORM

Date: Observer:

River: Reach Location:

Length represented by reach:

UPPER BANKS	EXCELLENT		GOOD		FAIR		POOR	
Landform slope	bank gradient <30° on both banks	2	bank gradient 30-35° on 1 or sometimes both banks	4	bank gradient >35-50° common on 1 or both banks	6	bank gradient ≥50° common on 1 or both banks	8
Mass wasting (existing or potential)	no evidence of past or any potential for future mass wasting into channel	3	infrequent &/or very small. Mostly healed over. Low future potential	6	moderate frequency and size, with some raw spots eroded by water during high flow	9	frequent or large, causing sediment nearly year-long or imminent danger of this	12
Debris jam potential (floatable objects)	essentially absent from immediate channel area	2	present, but mostly small twigs and limbs	4	present, volume and size both increasing	6	moderate to heavy amounts, predominantly larger sizes	8
Vegetative bank protection	>90% plant density. Vigour & variety suggest a deep, dense, soil-binding root mass	3	70-90% density. Fewer plant species or lower vigour suggests a less dense or deep root mass	6	50-70% density. Lower vigour and still fewer species form a somewhat shallow and discontinuous root mass	9	<50% density plus fewer species and less vigour indicate poor, discontinuous and shallow root mass	12
Sub-total								

LOWER BANKS	EXCELLENT		GOOD		FAIR		POOR	
Channel capacity	ample for present & some increases. Peak flows contained. Width to depth ratio <7	1	adequate. Overbank flows rare. Width to depth ratio 8-15	2	barely contains present peaks. Occaisional overbank floods. Width to depth ratio 15-25	3	inadequate. Overbank flows common. Width to depth ratio >25	4
Bank rock content	>65% rocks with large angular boulders >30cm numerous	2	40-65% rock, mostly small boulders to cobbles 15 to 30cm	4	20-40%, with most in the 8 to 15cm diameter class, although larger ones may be present	6	<20% rock fragments of gravel sizes, 2.5 to 8cm or less	8
Obstructions/ flow deflectors/ sediment traps	rocks & old logs firmly embedded. Flow pattern without cutting or deposition. Pools and riffles stable	2	some present causing erosive cross currents & minor pool filling. Obstructions and deflectors newer and less firm	4	moderately-frequent, moderately-unstable obstructions & deflectors move with high water causing bank cutting and filling in of pools	6	frequent obstructions & deflectors cause bank erosion year-long. Sediment traps full, channel migration occurring	8
Cutting	little or none evident. Infrequent raw banks less than 15cm high generally	4	some, intermittently at outcurves and constructions. Raw banks may be up to 30cm high	8	significant. Cuts 30-60cm high. Root mat overhangs and sloughing evident	12	almost continuous cuts, some over 60cm high. Failure of overhangs frequent	16
Deposition	little or no enlargement of channel or point bars	4	some new increase in bar formation mostly from coarse gravels	8	moderate deposition of new gravel & coarse sand on old and some new bars	12	extensive deposits of predominantly fine particles. Accelerated bar development	16
Sub-total								

LOWER BANKS	EXCELLENT		GOOD		FAIR		POOR	
Rock angularity	sharp edges & corners, plane surfaces roughened	1	rounded corners & edges, surfaces smooth & flat	2	corners & edges well rounded in 2 dimensions	3	well rounded in all dimensions, surfaces smooth	4
Brightness	surface dull, darkened or stained by algae or minerals. Bright surfaces <5% of area	1	mostly dull, but may have up to 35% bright surfaces, some on larger rocks	2	mixture, 50-70% dull & bright, ± 15% (i.e., 35-65%)	3	predominantly bright, >65% exposed or scoured surfaces	4
Consolidation or particle packing of substrate	assorted sizes tightly packed &/or overlapping	2	moderately-packed with some overlapping	4	mostly a loose assortment with no apparent overlap	6	no packing evident, loose assortment, easily moved	8
% stable materials	stable materials 80-100%	4	stable materials 50-80%	8	stable materials 20-50%	12	stable materials 0-20%	16
Scouring & deposition	<5% of the channel length affected by scouring & deposition	6	5-30% affected. Scour at constrictions & where grade steepens. Some deposition in pools & backwaters	12	30-50% affected. Deposits & scour at obstructions & bends. Some filling of pools	18	>50% of the bottom in a state of flux or change nearly year-long	24
Clinging aquatic vegetation (mosses & algae)	abundant. Growth largely moss-like, dark green, year-round. In swift water too	1	common. Algal forms in low velocity and pool areas. Moss here too and in swifter waters	2	present but spotty, mostly in backwater areas. Seasonal blooms make rocks slick	3	perennial types scarce or absent. Yellow-green, short term bloom may be present	4
Sub-total								

TOTAL STABILITY SCORE = ______ + ______ + ______ = ______
(sum of sub-totals)

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GUIDELINES FOR ATTENUATING FLOODFLOWS

INTRODUCTION

Floodflow (specifically, quickflow volume; see *Volume 1: Concepts: Section 2.2.2*) responses to precipitation are regulated by large scale catchment characteristics such as geology, soil type, catchment slope and degree of forest cover. Riparian management will have little influence on the total quickflow generated from within the catchment. Nevertheless, it may be possible to reduce water velocities (and hence erosive power) and attenuate flood peaks by increasing the "roughness" of the channel above the low flow level (i.e., up the riverbank) and on the floodplain (Evers and Rouve 1980). Judicious selection and planting (or retention where naturally occurring) of tall and sturdy vegetation with high degrees of roughness (i.e., the capacity to cause drag and therefore slow water down) will moderate surface runoff velocities and impede floodflows when water levels rise above normal.

The flow-retarding effect of riparian vegetation increases with increasing size (stem radius) and density of the species planted (Kowobari *et al.* 1972). Vegetation height relative to floodwater depth is important as submerged, flexible vegetation (e.g., grasses) loses much of its capacity to reduce water velocities. The density of riparian tree and shrub plantings may have to be such that sufficient light penetrates to ground level to maintain a complete cover of close ground vegetation on banks and in floodplain areas (see **LIGHT**). This may be required to filter contaminants from surface runoff generated in the uplands (see **CONTAMINANT**) and for bank stability (see **STABILITY**).

The prime objective of retaining instream and bank vegetation to impede floodwaters is to induce localised flooding in the headwaters and therefore reduce the erosive power of floodwaters both onsite and downstream. This will reduce the risk of large scale flooding in the lowlands and place less strain on lowland flood control measures, thus reducing the need for such measures.

Another method of retarding and attenuating floodflows is to retain riparian wetlands as natural ponding areas. Some runoff is stored in wetlands and is slowly released after the flood peak has passed, tending to reduce the magnitude of flooding downriver. Other techniques for slowing down floodflows or attenuating flood peaks, such as installing headwater farm retention dams or reinstating meanders where channelisation has occurred, are not dealt with here as they are not directly related to riparian management.

Guidelines for Attenuating Floodflows Using Riparian Vegetation

OBJECTIVE(S)

To retard floodflows in headwater streams so that the risk of extensive flooding in lowland areas is reduced.

GUIDELINE(S)

1. For first to third order watercourses, establish whether large flood waters inundate plantable land. (For explanation of stream order see *Volume 1: Concepts: Section 2.1.3.*)

2. If they do, plant vegetation that has high roughness on riverbanks. Marginal species such as tussock, toetoe, flax, ferns, herbs, and sedges are recommended if interspersed with trees (see **STABILITY** and **CARBON** for some potential tree species).

   Dense plantings of taller shrubs and trees (particularly evergreen species) are not recommended because it is imperative for effective flood flow retardation that a dense close ground cover is maintained (see **STABILITY**). Fencing may be necessary if palatable shrubs and trees are planted in areas that are accessible to grazing stock. However, maintaining a dense ground vegetation cover is paramount and thus managed grazing may be necessary.

3. Retain riparian wetlands wherever possible (see also **NITRATE**, **CARBON** and **HABITAT**). Buxton, 1991, New Zealand Wetlands – A Management Guide, provides practical advice on retaining, enhancing and making wetlands (see *Important reading kit* earlier in this volume for details).

JUSTIFICATION AND ASSUMPTIONS

The presence of vegetation with a high degree of roughness within the channel and on the floodplain is known to impede floodflows when water levels rise above "normal", and when floodwaters overtop the channel (e.g., Klaassen and van der Zwaard 1974). Additionally, vegetation with high roughness in the riparian zone will reduce surface runoff velocities in the zone (Smith 1989) and the rate at which water is delivered to the open channel network.

SIDE EFFECTS AND LIMITATIONS

This technique is not appropriate where localised flooding could be a problem and it will not be effective in streams where the permanent channel is not overtopped. Planting of deep rooting species can increase evapotranspiration rates in areas with a seasonal moisture deficit causing local groundwater levels to drop. This could cause flows to decline even further during and immediately following prolonged dry spells (Smith 1992).

Channel and bank erosion rates would be reduced if plantings of evergreen trees and shrubs do not shade out close ground cover (Smith 1992) (see also **STABILITY**). Shrub and tree planting will promote sediment deposition on the riverbank/riparian zone, resulting in the formation of a natural levee. Additionally, taller shrubs and trees will shade streams (see

LIGHT), reduce instream temperatures (see **TEMPERATURE**) and provide terrestrial sources of organic carbon (see **CARBON**) for the stream ecosystem. Trees and shrubs will also re-introduce landscape and riparian diversity (see **HABITAT**). Riparian zones may harbour plant and animal pests, and corridors of riparian forest may enhance wildlife movement generally.

CONFIDENCE

Moderate. Principles well established but the technique has not been widely used in New Zealand.

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GUIDELINES FOR INCREASING TERRESTRIAL HABITAT DIVERSITY

INTRODUCTION

Riparian zones are areas of high *biodiversity*. This is because they:

- Support species associated with both terrestrial and aquatic ecosystems.
- Contain steep environmental gradients (i.e., changes in microclimate, water table etc. over short distances).
- Are areas of change (e.g., occasional inundation by flood waters).
- Can be physically complex.

A number of "aquatic" species use riparian areas at some stage of their life cycle (see *Volume 1: Concepts: Section 2.2.9*). For example, many freshwater insects have winged adult life stages that utilise riparian zones to varying degrees. These can provide food for other riparian zone inhabitants such as the insectivorous fantail. Several other birds also use riparian areas for nesting and cover, or as perching sites to locate aquatic food sources.

Riparian areas form the edges between distinct ecosystems – aquatic and land based – and conditions change sharply over short distances. These steep environmental gradients can lead to a high diversity of plant (and animal) species associated with specific riparian conditions. Depending on the width of riparian zones (see *Volume 1: Concepts: Figure 3b*), microclimates may provide high humidity and low wind speed in areas of relatively dense forest, and low humidity and high wind speed on the riparian zone edges. High water tables near the edges of streams may favour certain species of plants whereas drier soil further away may favour other species. These gradients are also seen in riparian wetlands. The variety of habitats that can occur in riparian areas enhance overall diversity.

Floodplains are areas of "intermediate disturbance" in the sense that they are occasionally inundated by floodwaters. The physical changes and movement in organic matter etc. associated with flooding may increase the ranges of habitats and energy supplies present and lead to increased biodiversity (although abundance may decline as a result). Planting of riparian zones in trees and other plants characteristic of a particular locality provides structural complexity which increases the range of habitats available. This can be expected to lead to a corresponding increase in the diversity of animals which occupy these habitats.

Guidelines for Increasing Terrestrial Habitat Diversity

OBJECTIVE(S)

- To increase the biodiversity of riparian zones by increasing physical habitat complexity.
- To increase the native biodiversity by encouraging the establishment of appropriate native vegetation.

GUIDELINE(S)

1. Plant a range of species and morphologies (different heights and shapes) at mixed (including clumped) densities and in mixed combinations. In areas of bank erosion, plant clumps of species with good bank stabilisation properties (see **STABILITY: TREES**). Plantings should extend to three times the height of the largest tree from the channel edge to allow the development of a suitable microclimate.

2. In preference, plant species that:
    - Do not invade channels.
    - Are locally-sourced natives characteristic of the region.
    - Provide food for birds and insects. Appropriate species for birds are listed in Table 1.

3. Where possible, plant areas along a river system to link up remnant riparian forests with each other. This should improve the utility of riparian zones as corridors for the movement of terrestrial species up and down catchments.

4. Undertake pest control to reduce invasions by introduced species (for methods of pest control see Van Kraayenoord and Hathaway 1986a, 1986b, Porteus 1993, Timmins and Mackenzie 1995, and Buxton 1991. Details of these publications are provided in *Important reading kit* earlier in this volume).

5. Protect riparian wetlands from drainage and other forms of degradation.

6. Control access to stock (see **STABILITY: STOCK**).

JUSTIFICATION AND ASSUMPTIONS

Justification/assumptions for guidelines **1** – **6** above are, in corresponding order:

- Monocultures are less diverse than mixed stands. Assumes diversity of plant species, morphologies and planting densities will result in increased diversity of animals colonising riparian zones. Recommended riparian zone width to maintain microclimate is based on Figure 3b in *Volume 1: Concepts*.
- Plants which invade channels (e.g., crack willow), may degrade land/water transition areas by excluding other plant species from developing, although they can provide cover for

some fish and waterfowl. Assumes native plants are likely to provide habitats and food sources that are more appropriate for native insects, birds etc. than introduced species, and that there is a nearby source of birds etc. for colonisation. Local sourcing of native species planted will prevent genetic pollution of local gene pools. (West, 1994, contains information on invasive and non-invasive willows and poplars, and methods for controlling them. See *Important reading kit* earlier in this volume.)

- Assumes riparian areas of open developed land represent barriers to the movement of plants and animals up and down catchments. This will presumably depend on the distance between riparian forest remnants.

- Weeds are likely to outcompete native species, especially in the establishment phase, if not controlled. Introduced predators such as possums and stoats eat plants and bird eggs and may reduce diversity and/or the density of certain species.

- Riparian wetlands favour many species uncommon in other habitats (e.g., fernbird, Australasian bittern).

- Stock trample and graze vegetation, and heavy stocking can cause degradation of stream edges.

SIDE EFFECTS AND LIMITATIONS

Side effects/limitations for guidelines **1** – **6** above are, in corresponding order:

- Planting trees and shrubs will alter the light climate in streams (see **LIGHT**), possibly shading out the grass sward beneath causing erosion (see **STABILITY**), increase terrestrial carbon inputs, especially if the trees are deciduous (see **CARBON**), and may alter water temperature regimes downstream (see **TEMPERATURE**). Trees and shrubs will also slow floodflows when floodwaters overflow into the riparian zone (see **FLOW**).

- Planting of trees that provide food for birds may also attract pests.

- Linking forest remnants may increase the spread of native wildlife and of pest species.

- Wetland protection may also help reduce nitrate inputs (see **NITRATE**), maintain inputs of terrestrial carbon to streams (see **CARBON**) and attenuate floodflows (see **FLOW**).

- Total exclusion of stock from grassy margins in some lowland rivers has apparently decreased the suitability of these areas for whitebait spawning. Some low level grazing outside the spawning season may be appropriate in the tidal zones of such rivers to maintain appropriate grass densities for whitebait spawning (Mitchell 1993).

CONFIDENCE

Moderate.

Table 1 List of trees considered suitable for encouraging birds (from Ell 1981).

SPECIES	COMMON NAME	COMMENTS
NATIVE		
Aristotelia serrata[1,3,4]	wineberry, makomako	Berries in late summer
Clianthus puniceus		Flowers November-December
Coprosma spp.[1,2,3,4]		Fruit profusely over extended period. *C. lucida*, *C. repens* and *C. robusta* particularly valuable
Corokia spp.		Red, orange, yellow berries
Dysoxylum spectabile[4]	kohekohe	Fruits ripen July-August
Fuchsia excorticata[2,3,4]	tree fuchsia, kotukutuku	Berries ripen December-March. Deciduous
Fuchsia perscandens[2]		Dark purple berries
Fuchsia procumbens[1,2]		Bright rosy pink berries
Hedycarya arborea[2,4]	pigeonwood	Flowers October-December, fruit ripens October-December following year
Hymenanthera chathamica		White, purple flecked berries
Hymenanthera crassifolia		Green, yellow or pale blue fruit ripen October-March
Hymenanthera obovata		Purple berries
Knightia excelsa[4]	rewarewa	Flowers December
Macropiper excelsum[1,3,4]		Suitable for shady situations. Orange-yellow fruit favoured by pigeons
Melicope ternata	wharangi	Flowers September-October, black shiny seeds
Melicytus ramiflorus[1,2,3,4]	mahoe,whitywood	Flowers November-January, violet blue berries
Metrosideros excelsa[3]	pohutukawa	Flowers December
Metrosideros fulgens		Orange-red flowers in winter
Metrosideros robusta	northern rata	
Metrosideros umbellata	southern rata	
Myrsine australis[4]	red matipo, mapou	Flowers December-February, black berries
Phormium colensoi	mountain flax	Flowers produce copious quantities of nectar November-January
Pittosporum spp.[3,4]		Supply nectar and seeds. *P. tenuifolium*, *P. crassifolium* and *P. eugenioides* particularly recommended
Podocarpus ferrugineus[2]	miro	Large red berries ripen in winter
Pseudopanax arboreum[1,2,4]	fivefinger	Flower February-March, fruit March-April
Schefflera digitata[2,3,4]	pate	Flower February-March, fruit March-April
Sophora microphylla[1,3]	kowhai	Important source of nectar in early spring
S. tetraptera[1,3]	kowhai	Important source of nectar in early spring
Tetrapathaea tetrandra[1]	New Zealand passion flower	Orange coloured fruit in summer and autumn
Vitex lucens	puriri	Pink or red flowers and fruit for much of the year
INTRODUCED		
Arbutus unedo	Irish strawberry tree	
Banksia spp.	Australian honeysuckles	
Callistemon citrinus	"splendens" bottlebrush	
Chaenomeles spp.		
Cotoneaster spp.[1,5]		
Cytisus proliferus[1]	tree lucerne	A favourite of native pigeons
Erythrina crista-galli	flame tree	
Eucalyptus spp.[1]	eucalypts	*E. leucoxylon "rosea"* which flowers in autumn and winter particularly recommended
Grevillea spp.		
Homalanthus spp.		
Lambertia formosa	honey flower	
Melaleuca spp.		
Prunus spp.[5]		*P. avium* can be a weed
Viburnum japonicum		

[1] – fast-growing species
[2] – several have to be planted to ensure fruiting
[3] – also recommended for use in Table 8 of **STABILITY**
[4] – also recommended for use in Table 3 of **CARBON**
[5] – can be a weed in some situations – check

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