MANAGING RIPARIAN ZONES:

A contribution to protecting New Zealand's rivers and streams

Volume 1: Concepts

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FOREWORD

In the past, demands for water supply, waste disposal, power generation, flood control and land drainage had a major influence on New Zealand's rivers and streams. Today, a broader view of river and stream value prevails. I believe our demands now extend to a landscape that is sustained by healthy and biologically diverse rivers and streams. To acheive this we must manage the productive uses of land and water in a way that is ecologically and aesthetically sound.

Agriculture and forestry are of enormous significance to New Zealand's economy, but there is a growing realisation that, firstly, production must be sustainable within environmental limits, and, secondly, our primary products will become more marketable if they are grown in a healthy environment. This handbook is a contribution towards improving our land management systems.

The handbook was prepared by the National Institute of Water and Atmospheric Research (NIWA), with the support of the Department of Conservation and the Foundation for Research, Science and Technology. Its purpose is to provide a basis on which to address the protection of one of the most fragile parts of the landscape – the interface between productive land and freshwaters. Research both within New Zealand and overseas has shown the importance of this *riparian zone* in protecting the water quality and natural values of rivers and streams including their biodiversity.

The Institute itself has been one of the contributors to this world-wide body of knowledge and has an international reputation in this regard. The solutions offered are founded on a long record of New Zealand-based scientific study. Many of the older recipes for river and stream protection are examined and brought up to date; there is much that is new.

The handbook is designed to inform and not to regulate. It provides a wealth of information to show how rivers and streams in the rural landscape can be more sustainably managed by land-owners and management agencies alike. Apply the approaches in this handbook to your local stream or river and, in time, these actions will multiply through the landscape to the benefit of all. The key to riparian management is for the emergence of consensus as to the range of values appropriate to each site. These guidelines will assist landowners and those with water management roles and interests in deciding what land uses and practices are best to achieve the agreed goals.

*Atawhai parewai!**

Denis Marshall
Minister of Conservation

* "Look after the edges of rivers (literally "by the water")"

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1. PURPOSE AND SCOPE

1.1 INTRODUCTION

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 Section 3 of this volume).

1.2 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 Section 2 of this volume). 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 (DoC). 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 updated editions published.

1.3 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 this volume: *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 in *Volume 2: Guidelines*.

- 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

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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 Section 1.5.)

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.*

·If you wish to find out more about the science behind the concepts you are strongly recommended to read Quinn *et al.* 1993 (see 1.4 below 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 acquire the books listed in Section 1.4 below. You will be referred to some of these books for important information that is not covered in *Volume 2: Guidelines*.

·If you don't understand the techniques outlined in *Volume 2: Guidelines,* 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 *Volume 2: Section 2*). 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 features 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.

1.4 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 $20.00 and is available from *Publications Section, Science & Research Division, DoC, PO Box 10-420, Wellington*. This report contains guidelines on the management, restoration and making 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.

Figure 1 Changes in vegetation cover of New Zealand with time (adapted from McColl and Ward (1987), based on Molloy (1980)).

1.5 WHY THIS DOCUMENT IS NECESSARY

·*Many streams and rivers in New Zealand are in poor condition because of changes to land use in their catchments.*

A recent nationwide survey of resource managers highlighted widespread concern about the effects of land use on watercourses and the pressing need for guidelines on how these effects can be reduced (MAF 1993). Research and monitoring results clearly show that such concern is well-founded, with the water quality and biological communities of many New Zealand watercourses being adversely impacted by removal of native forest and development of their catchments, particularly to pastoral agriculture (reviewed by Viner 1987, MAF 1993, Quinn *et al.* 1993). Over 13 million hectares, or around 50% of New Zealand's land surface, has been converted to grazing land over the past 150 years, compared with over one million hectares in production forest and 91,000 ha in horticulture (Department of Statistics 1992; see also Figure 1).

Accompanying this land use change has been the introduction of around 70 million grazing animals (mostly sheep, beef and dairy cows), the introduction of nitrogen-fixing plants such as clover, the annual application of around 150,000 tonnes of phosphorus and 90,000 tonnes of nitrogen in fertiliser, artificial drainage of poorly-draining soils and swamps, extensive channel and riparian engineering works for flood protection purposes, and urbanisation and industrial development. All of these have caused a deterioration in water quality and damage to aquatic and riparian habitats.

Agricultural production is extremely important to the New Zealand economy, contributing 8.6% of the Gross Domestic Product in 1989 and making up 50% of our export income in 1992 (Department of Statistics 1992). New Zealand's export industries are coming under increasing pressure from environmentally conscious markets to live up to the "clean and green" image portrayed overseas, and produce goods in an environmentally sustainable manner. Can New Zealand lead the way in showing how this can be done?

1.6 WHY RIPARIAN ZONES ARE IMPORTANT

·*Riparian zones are three-dimensional zones of direct interaction between terrestrial and aquatic ecosystems (Gregory et al. 1991).*
·*Appropriate changes to the management of riparian zones can be a very effective means of*

Table 1 Summary of riparian zone functions that potentially buffer streams from various land use effects (modified from Quinn *et al.* 1993).

Riparian zone function	Potential in-stream effects
· Buffers banks from erosion · Buffers channels from localised changes in morphology · Buffers input of nutrients, soil, microbes and pesticides in overland flow · Denitrifies groundwater · Buffers energy inputs · Provides in-stream food supplies and habitat · Buffers floodflows · Maintains microclimate · Provides habitat for terrestrial species · Maintains dispersal corridors	· Reduces fine sediment levels · Maintains water clarity · Reduces contaminant loads · Prevents nuisance plant growths · Encourages growth of bryophytes and thin periphyton films · Maintains lower summer maximum temperatures · Increases in-stream habitat features and terrestrial carbon inputs · Maintains food webs · Reduces floodflow effects · Increases biodiversity

reducing the impacts of catchment development on watercourses while still maintaining production.

·*Because riparian zones occur where major ecosystems – aquatic and land-based – meet, they provide habitats not found elsewhere which are important for the survival of a number of native plants and animals.*

One of the solutions to achieving sustainable land use is to harness the natural abilities of riparian zones to absorb excess nutrients and to process waste materials before they enter watercourses. This provides the opportunity to manage riparian zones for the benefit of the river system while still allowing productive use of the land and, potentially, the development of alternative forms of income (e.g., agro-forestry). In addition, riparian zones strongly influence life in streams and rivers by providing shade and food and are often unique habitats in their own right.

The ecological functions that riparian zones can perform and the in-stream benefits that might accrue are summarised in Table 1.

1.7 THE VISION BEHIND THIS DOCUMENT

·*The implementation these guidelines will mitigate many of the adverse impacts of land development on water quality and habitat values of streams and rivers, particularly those flowing through lowland landscapes.*

The purpose of these guidelines is to encourage and assist in the rehabilitation of those New Zealand rivers and streams which have been adversely affected by land development, in the hope that this will foster a richer, more varied landscape in which productive land and healthy rivers and streams sit together.

The vision offered by these guidelines is that appropriate riparian management would reduce bank erosion, nutrient inputs and maximum summer water temperatures. The dappled light filtering through riparian vegetation to small streams would deter algae and aquatic weeds from proliferating. A biological community would develop in which thin algal layers on stones and leaves from riparian plantings provide food for a diverse community of aquatic insects which, in turn, provide food for fish and birds. Wood, fallen from riparian trees and retained in stream channels, would reduce substrate movement and increase the habitat available for fish.

A diverse terrestrial fauna would colonise planted riparian areas, utilising the foods supplied by streams and rivers, and using the riparian zones as corridors for movement up and down catchments. Plantings of appropriate native species would provide habitat and lead to an increase in native biodiversity.

1.8 THE LIMITATIONS OF RIPARIAN MANAGEMENT

Improving the riparian management is a long-term task requiring new investment in effort and materials. It may take many years for the benefits of riparian management to become apparent, especially when initially few landowners within a river system will adopt the new approaches advocated here. In this situation results will be achieved locally before they are noticed on a wider scale.

There are limits to what riparian management can achieve. The clock cannot be put back to what it was before development occurred. Realistic targets need to be set, especially in water quality management. It is also wrong to treat one target in isolation from the rest. Limited success in one area can be compensated for by unexpected success elsewhere. Small steady improvements in how the river and stream banks *look* have added capital value to many a property!

1.9 HOW *VOLUME 2: GUIDELINES* IS STRUCTURED

Volume 2: Guidelines is divided into three main sections. The first section contains introductory material to help you navigate. The second section describes how to begin planning a riparian management scheme; and the third section contains the individual guidelines.

Typically, each of the guidelines contains information on:

·Nature of the problems addressed by the guideline.
·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.

Volume 2: Guidelines contains the following guidelines:

·Increasing channel and bank stability (**STABILITY**)
·Protecting stream banks by planting trees and shrubs (**STABILITY: TREES**)
·Managing remnant vegetation on stream banks (**STABILITY: REMNANT**)
·Managing stock grazing on damaged stream banks (**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 the guidelines document. We do not currently have enough information to develop a generalised guideline for managing dissolved phosphorus concentrations in drainage waters.

2. RIPARIAN ZONES CONCEPTS

2.1 STRUCTURE, GEOGRAPHIC SCALE AND TIME

An understanding of how river and stream ecosystems are structured, their relative size and importance within a catchment, and the timescales over which processes within them occur is a pre-requisite to effective riparian management.

2.1.1 River and stream structure: management possibilities

The cross-section of a well-structured riparian zone (Figure 2) shows diverse vegetation and physical relief. This zone affects the river or stream in a number of beneficial ways. Human manipulation of the channel and its vegetation to increase these benefits forms the basis of riparian management.

Figure 2 Conceptual diagram of a stream and its riparian area showing geomorphic zones and management possibilities.

2.1.2 Importance of riparian vegetation

·Using riparian zones for the rehabilitation of in-stream ecological values and improvement of water quality depends primarily on effective management of riparian vegetation.
·The influence of riparian zones is much larger than would be expected from their size relative to the rest of the catchment.

Riparian zones can influence channel and bank stability, contaminant and nitrate levels reaching watercourses, light climate, water temperature, the type and amount of terrestrial carbon inputs to streams, the duration and magnitude of floodflows, and habitat for aquatic and terrestrial plants and animals. Vegetation is the easiest riparian attribute to manage.

2.1.3 Importance of watercourse size

·Riparian management will generally exert a relatively larger influence on stream functioning when carried out alongside small streams than it will alongside large lowland rivers.
·Improvements in lowland rivers are often achieved through riparian management upstream.

The influence of riparian zones on adjacent watercourses declines as watercourse size increases. This is a fundamental premise of the River Continuum Concept (Vannote *et al.* (1980)). Riparian zones along larger streams and rivers consist of two distinct parallel bands separated by the channel itself. In small, well-vegetated streams a functionally continuous canopy usually exists over the channel. As stream-bed area increases relative to the extent of overhanging vegetation with distance downstream, light penetration increases, and thus may lead to greater in-stream production by aquatic plants and higher water temperatures.

The production of aquatic plants such as algae in small streams is supported by nutrients arriving from the land. As a river system grows in size the recycling of nutrients already in the system becomes more important. Similarly, the relative importance of terrestrial carbon inputs (leaves, plant and animal detritus) to the production of invertebrates and fish usually declines with distance downstream. An exception to this is where there are extensive lowland riparian swamps.

Many of the conditions prevailing at a particular site along a river will reflect the processes occurring upstream. Thus, influencing lowland rivers through riparian management often requires that conditions upriver are managed. For instance, lowland river substrates are partly influenced by the erosion and transport of soils from upriver, and river temperatures can be influenced by riparian shading upriver. Managing the light climate in a river reach requires management of the immediately adjacent riparian zone, however. Riparian zones along large rivers also provide important cover and habitat for fish and birds.

Watercourse sizes are frequently referred to throughout this document in terms "stream order" according to Strahler (1957). A first order stream is the smallest tributary of a river system with permanently-flowing water. A second order stream is formed by two first order streams coalescing, a third order stream is formed when two second order streams merge, and so on. When a second order stream flows into a third order stream, the receiving stream remains third order.

2.1.4 Importance of riparian zone width

·*The required width of riparian zones will vary depending on the aquatic characteristic(s) to be managed.*

Little is known of the effects of different riparian forest widths on streams in New Zealand, but some information is available from North America (Figure 3). This indicates that the effectiveness of zone width on litter fall, woody debris inputs and shading approach 100% at around one half to a whole tree height from the channel edge, whereas the effects of root strength level out closer to the channel (Figure 3a). In New Zealand, the roots of willows (and some native riparian plants such as tree ferns) may extend into the stream channel (Green *et al.* 1989). The effectiveness of riparian forest width on microclimate varies with distance from the edge. In North America, soil moisture levels out at about one half a tree height from the edge, radiation and soil temperature at around one tree height, and air temperature, wind speed and relative humidity at 2–3 tree heights (Figure 3b).

2.1.5 Importance of timescales

·*The beneficial results of riparian zone management on streams are not always immediate and may take several years to become evident.*
·*Changes to stream morphology brought about by riparian management are likely to take considerably longer to become apparent than changes to vegetation.*

When riparian vegetation is being restored, a sequence of changes in the structure and composition of riparian plant communities will occur. This process is termed *succession*. Succession is usually slower where there is lower rainfall, humidity and temperature. If succession proceeds uninterrupted, it eventually leads to the establishment of a climax community in which diversity, complexity and quantities of carbon, nitrogen and other elements are at maximum (Wardle 1991). This may be followed by a prolonged steady state or sometimes by a slow decline in biomass, diversity and nutrient content as rates of growth and organic cycling decrease. External factors such as floods, fires and invasions by pest species may interrupt the development of climax communities and reset the succession process on some other pathway.

a

b

Figure 3 Generalised curves indicating percent of riparian ecological functions and processes (a), and microclimate attributes (b), occurring with varying distances from the edge of a forest stand (based on North American data; from various 1993).

Figure 4 Flow chart showing major interactions between riverine characteristics affected by riparian vegetation.

River systems are generally in a state of dynamic equilibrium with large scale changes in their shape (morphology) and location in the flood plain occurring naturally over periods of 100s to 1000s of years. Such changes are usually associated with the downward progression of a sequence of meanders, riffles and pools as bed materials move down-river. Streams in different parts of a catchment can change at different rates so that a range of developmental stages may be present. Changes that are discernible to the human eye mostly occur as the result of extreme events such as major floods or uplift of the earth's crust. Also, infilling of a channel may proceed at a relatively steady rate until a critical slope is reached at the downstream end causing the stream to begin cutting down into the channel.

Development frequently alters the natural rates of change. For example, forest clearance or large earthworks in stream headwaters may result in a rapid increase in sediment loadings and rates of bank erosion down stream. While such development-related changes can occur almost overnight, measures to mitigate them, such as planting headwaters and riparian zones, will take some time to become to become effective.

2.2 HOW RIVER AND STREAM CHARACTERISTICS ARE INFLUENCED BY RIPARIAN ZONES

2.2.1 In-stream biodiversity

·Riparian zones alter the physical environment of rivers and streams and influence both the presence and growth of aquatic plants and animals.

The assemblage of plants and animals inhabiting most rivers and streams is determined, to a large extent, by watercourse shape, channel substrates, sediment regime, flow regime, water chemistry, light climate, temperature regime and terrestrial carbon inputs. The interactions of these characteristics and their effects on aquatic animal communities are summarised in Figure 4. Diversity exists at various scales: within a cross-section, along a reach, and within an entire system from its origin as headwater streams to its outlet at a lake or on the coast. This diversity is further increased when the stream environment is considered together with the riparian environment. Together, the river and its banks provide a multitude of habitats for plants and animals. In total, the watercourse and its biological communities influence how the river or stream is valued scenically, recreationally, culturally, and for conservation purposes.

2.2.2 Flow regime of rivers and streams[3]

·Flow regime is primarily regulated by climate (rainfall and evaporation), rock type and the shape and nature of the land surface.
·Clearance of native forest cover in New Zealand (Figure 1) has generally resulted in more runoff, higher flood peaks and more rapid rise and fall of floodflows.
·In some circumstances, riparian zones can serve to store and retard the flow of drainage waters, especially during floods, but they may also reduce low flows.

Rainfall, through its affect on flood frequency and size, is a most important factor affecting rivers and streams. Rock type and surface materials determine groundwater storage capacity, seepage rates into the channel and the relative proportions of surface and sub-surface runoff. These affect the duration of flooding and low flows.

Total streamflow comprises *baseflow* and *quickflow*. Baseflow comprises groundwater seepage and spring and lake inflows, and is the relatively low and sustained flow between floods. Quickflow occurs during and after rainfall events and includes surface and fast sub-surface runoff (Figure 5).

[3] For a detailed discussion on flows, see Duncan (1992). This section is based largely on Duncan's document.

Figure 5 Sources of water inflow to streams.

Rivers that are mainly lake or spring-fed (e.g., in the Central Volcanic Plateau) have relatively stable flows. By contrast, catchments with impervious geological formations and shallow soils produce large floodflows and rapidly receding baseflows. Soil permeability affects land drainage and determines the relative proportions of surface to sub-surface runoff, and hence the pattern (e.g., flash flood versus lower but longer flood) and size of flood peaks and baseflows. Soils of low permeability tend to produce large, rapid quickflow responses. Freely-draining soils produce a slower delayed response with lower peakflows. Forest soils typically have very high permeability but this is lost when the forest is cleared and land is tilled or trampled.

The leaves of forest and scrub trap more rainfall than pasture. As a result, evaporation losses are higher in catchments with forest and scrub cover than those under pasture. Because of this, more of the rainfall landing on pasture catchments ends up in runoff (e.g., Duncan 1980). Flood peaks are also higher (Daveron 1986) and the rate at which floodflows rise and recede may also increase following forest removal.

Grazing stock puddle and compact soils, which reduces infiltration rates and soil permeability. The severity of trampling effects may vary widely with grazing practice and soil type (Climo and Richardson 1984). The reduced infiltration rates result in increased surface runoff, and this will contribute to higher flow yields and peakflows in pasture. Artificial drainage networks also increase floodflows. Channel straightening, deepening and stop-banking increase peakflows and the rate at which floodflows rise and recede.

Although the influence of riparian zones on flows is quite limited, because a river's flow regime is primarily regulated by climate and landform, there are some special situations where riparian management has a significant impact. By virtue of their low-lying situation and flat topography, riparian zones naturally serve to store and retard the flow of drainage waters across the landscape. This effect is most pronounced when there are extensive riparian wetlands which help to sustain baseflows whilst damping floodflows downstream. Artificial drainage of these wetlands increases flood peakflows and the rate at which floodflows rise and recede.

Dense riparian ground-cover retards surface flows from upslope, and slows down floodwaters which have topped the river or stream banks. Marginal vegetation, roots extending into the channel, and in-stream large woody debris also locally impede and redirect flows. The distance that parcels of water must travel is increased, and eddies, pools and backwaters are created. This has the benefit of reducing flood peaks downstream, but it can extend the duration of local flooding and result in deposition of materials on the banks.

Vegetation increases the amount of water returned to the atmosphere by evapotranspiration. During drought, riparian vegetation has the potential to reduce stream flows when the deep-rooting plants access groundwater before it reaches the stream. Further research is required to ascertain the significance of this effect.

2.2.3 River and stream shape[4]

- *Channel shaping depends on the erosion of soil and sediment, and their deposition in the river channel.*
- *Removal of forest vegetation can affect the shape and substrate of streams and rivers because floodflows and the sediment available for transport both increase.*
- *The vegetation in riparian zones has the ability to influence river and stream shape on a localised scale.*
- *The most dramatic impact of development on stream and river shape has been channel works to increase drainage of wet soils and reduce local flooding.*

River channels vary from gently sloping, tortuous meanders, to fast flowing, rocky channels and gravel-bed rivers with multiple braids. Channel shape is strongly influenced by the balance between the amount and type of sediment available for transport and the power of the stream. Most shaping of the channel occurs during floodflows when erosion, sediment transport and deposition is greatest. Bankfull discharge (floodflows that fill the channel to its brim) does most of the shaping. In most New Zealand rivers, bankfull discharge has a recurrence interval of about 1.5 years.

Extreme examples of channel re-shaping occurred in the Central Volcanic Plateau when the drainage network was scoured and enlarged by flooding when land was cleared for pastoral use during the late 1950s and 1960s (e.g., Selby 1967). In many other cases of land development, changes to the morphology and stability of watercourses have not been significant or deleterious and new steady-states have been reached.

Channel works alter channel shape through straightening and deepening. Maintenance works attempt to make the bed as smooth and regular as possible, and clear away flow obstructions on banks. These activities create a relatively uniform in-stream habitat which is physically much less diverse than that in unmodified channels. Channel substrates alter as a consequence. In some Southland streams, channel straightening caused down-cutting of the bed and exposed

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[4] For a detailed discussion on morphology, see Mosely (1992). This section is largely based on Mosely's document with additional information provided by R.K. Smith (NIWA).

unconsolidated shingle, boulders and/or bedrock. Previously the substrate in these streams had comprised fine silts and gravels (Williamson *et al*. 1992). Further downstream, stopbanks for flood protection have isolated these waterways from their associated floodplains and wetlands.

When the amount of sediment transported by the river exceeds that being supplied to a reach, the river scours and the bed and bank material comprise bedrock and boulders. When transport and supply are in balance, temporary storage and scour occur in different parts of the river-bed and a sequence of riffles, pools, and meanders migrate through the reach (see also Section 2.1.5). If sediment supply exceeds sediment transport then deposition occurs within the channel and braided channels, deltas, levees and alluvial fans form.

Diversity of shape occurs within rivers on a smaller scale as well. Water depth varies along and across each reach. Banks vary from relatively steep or undercut on the outside bends, to shallow and gently sloping on the inner bends. Overhanging banks provide shelter for fish and other animals. Pools, riffles and point bars provide different habitats.

Obstacles to flow within the channel, such as large woody debris or tree roots that extend into the channel, impede and redirect flows causing scouring and bank undercutting at specific sites, and deposition at other sites within a reach. The effects of riparian vegetation on floodflows were discussed in Section 2.2.2.

While the overall form of the stream and river is usually controlled by major factors such as flow and geology, riparian vegetation can strongly influence bank shape and the supply of large woody debris. This can dramatically alter the appearance of small streams as tree roots and woody debris enter the channel. This, together with any resulting sediment accumulation, markedly alters the shape of the stream. In extreme cases, willow swamps have formed in some lowland streams.

2.2.4 Channel substrate and sediment regime

·*Stream-bed substrate size reflects the type of sediment available and the ability of the stream to transport it.*
·*Substrate influences available habitats for plants, invertebrates and fish.*
·*Catchment development has increased suspended sediment in many streams and rivers.*
·*Riparian vegetation is effective in binding bank soils and reducing inputs of suspended sediments from the banks.*

High velocity, steeply-sloping headwater torrents have erosion resistant bedrock and coarse angular substrates because finer sediments are rapidly transported down-river. By contrast, in slow-flowing, lowland rivers, settling of fine sediments produces a sandy/silty substrate. Sediments are derived from erosion of the river-bed and banks or are delivered by mass movement (e.g., slips, slides, earthflows) from upland areas of the catchment. It should be remembered that there will be some natural variation in the amount of suspended sediment carried by streams and rivers. For example, those flowing through papa (mudstone) country are likely to be naturally "muddier" than those flowing through hard, unweathered rock, even without the effects of land development. Similarly, the effects of forest clearance and other development are likely to be more severe in areas of softer rock, as is evident on the east coast of the North Island.

The larger water plants (macrophytes) prefer fine substrates where roots can establish, while the algae growing on stones (periphyton) prefer more stable attachment sites such as cobbles. Certain invertebrates, such as worms and some midges, are favoured by mud or silt substrates, whilst the mayflies and caddis prefer gravels, cobbles and boulders. Fish species also differ in their substrate requirements. Trout require spawning gravels, the native torrentfish requires coarse substrates for refuge from high currents, and eels favour silty substrates.

Suspended sediment is a major factor affecting the optical clarity of water. This has implications for both recreational users and for the biota (Davies-Colley *et al.* 1993). Streams with moderate to high concentrations of suspended solids are scenically unappealing and unsuitable for bathing or other uses, such as town water supply.

Suspended solids influence the biota by:

·Reducing light penetration and thus the light available for plant growth.
·Reducing visual clarity for sighted organisms.
·Once settled or trapped in periphyton, reducing the food value to browsing organisms (Quinn *et al.* 1992a).
·Reducing the permeability of the substrate (Davies-Colley *et al.* 1992).

Suspended sediment yields are higher from pasture than from native forests (Hicks and Griffiths 1992). This has been attributed to increased surface runoff and thus capacity to erode surface soils, disturbance (trampling) of surface soils by stock (e.g., Sharpley and Syers 1976), and increased mass movement. The effects of stock on stream bank erosion and morphology are generally localised and vary with soil characteristics, stock type, and grazing practices. Studies in Southland have shown that effects can range from minor to severe, with stock crossing points often severely affected (e.g., Williamson *et al.* 1992).

Sometimes, erosion may increase particle size, as has been found in Southland (Williamson *et al.* 1990), because the dominant particle size of the bank is relatively coarse and because fines are flushed downstream where impacts may still occur.

The best way to reduce the input of fine sediments from eroding banks to streams and rivers is through management of riparian vegetation. When banks comprise erodible unconsolidated materials, the roots of riparian trees and other marginal vegetation can bind the soils and reduce susceptibility to erosion. In addition, riparian vegetation can trap suspended sediment when floodwaters expand onto the floodplain and water velocities decline (see Section 2.2.2), or when soil is carried down in overland flow from upland areas. The long term fate of this accumulated sediment is not known.

Riparian vegetation generally has little influence on the large scale erosion which is a natural feature of New Zealand mountain country. The debris from upland erosion scars can represent major source areas of suspended solids in steepland catchments. In many parts of New Zealand's hill country, soil conservation plantings are an essential adjunct to riparian management.

2.2.5 Nitrate and other contaminants

·Most stream and river contaminants (e.g., phosphate, pesticides, suspended sediments, bacteria) enter watercourses in surface drainage waters.

·*In streams and rivers that drain undeveloped catchments plant growth (primary production) is usually limited by the low availability of the nutrients nitrogen and phosphorus.*
·*Agricultural development has led to widespread increases in the levels of nitrogen and phosphorus in lowland watercourses and subsequent nuisance growths of algae and other aquatic plants.*
·*Catchment development has resulted in pesticide runoff and increased levels of microbes and suspended solids entering watercourses.*
·*The concentration of contaminant inputs in drainage waters varies along a river reach.*
·*Most nitrate in groundwaters passing through wet, organic rich riparian seeps is removed by denitrification.*
·*Contaminant inputs to watercourses are most effectively managed by targeting measures at important source areas.*

The processes that occur in developed landscapes generate materials that can contaminate waterways. Soil disturbance and earthworks release clay and soil particles. Nitrogen fixing plants, agricultural and horticultural fertilisers and animal excreta produce nitrogen and phosphorus compounds – commonly described as "nutrients", as they are important in plant growth. Animal excreta is also a source of microbes (bacteria, viruses etc.). Pesticides and herbicides can end up on the ground surface. These materials are generally washed into the ground with rainfall, where various processes immobilise or modify them. However, water flowing across the ground surface, or laterally within the soil can also pick up and transport them. Much of this water ends up in streams and rivers, where the dissolved and suspended material can reduce the water quality.

Surface runoff (overland flow) occurs either because rainfall intensity exceeds soil infiltration rates, or because groundwaters rise and emerge at the soil surface (see also Section 2.2.2). Catchment areas with soils of low permeability are a common source of contaminants in runoff. Groundwaters tend to emerge in low-lying and riparian areas and the source areas for surface runoff are therefore more restricted in area. The contaminants of most concern in runoff include the nutrients nitrogen and phosphorus, suspended solids, pesticides and bacteria.

Surface runoff becomes channelised during passage down the hillslope. Groundwaters also concentrate along flow lines. This leads to variations in the concentrations of contaminant input along streams. Nutrient inputs in surface and sub-surface drainage to a headwater stream in the Waikato were found to vary longitudinally in the order of 10–100 fold.

Preferential surface drainage pathways can be identified by the presence of *Juncus* or other vegetation types that prefer moist conditions. In agricultural catchments, preferential pathways are also highlighted by relatively lush green pastures during prolonged dry periods. Sites where sub-surface inflows to watercourses are concentrated are indicated by seeps.

Nitrates are highly soluble in water, whereas phosphates, ammonia, modern pesticides and herbicides and bacteria tend to be more commonly absorbed onto clay and other particulate matter which is then carried by the water (as suspended sediment).

Riparian zones can act in a number of ways to improve the quality of water flowing through them and, as a result, are often described as riparian filter zones. Chemical processes such as denitrification remove dissolved nitrates. Laterally moving water can be slowed sufficiently in riparian zones to allow suspended sediments (often with attached phosphorus, pesticides, bacteria etc.) to settle out or be absorbed into the soil; and vegetation in the filter zones use some of the nutrients for growth (uptake).

Denitrification (a microbial process whereby nitrate is converted to gaseous forms of nitrogen and returned to the atmosphere) helps to reduce the amount of nitrate contamination reaching streams. All soils do this to some extent, but riparian zones (variously described as floodplains, bottomlands, wetlands, swamps, seeps and muck soils in the scientific literature) have all been shown to have a high capacity for denitrification compared to terrestrial and aquatic soils (Schipper *et al.* 1991).

Because this process is quite well understood, nitrates are considered separately from other contaminants in *Volume 2: Guidelines*.

Dissolved reactive phosphorus (DRP) concentrations in streams draining forest and scrub catchments are typically less than 10 mg $m^{-3.}$ (10 parts per billion). At these concentrations aquatic plants suffer phosphorus shortage and their growth is limited by phosphorus availability. The growth of periphyton (the algae and other micro-organisms coating parts of the river-bed) reaches a maximum around 15–30 mg DRP m^{-3} (Perrin *et al*. 1987, Bothwell 1989, Horner *et al.* 1990, Stanley *et al.* 1990), and dissolved inorganic nitrogen (nitrate and ammonia) values around 40–100 mg m^{-3} (Stockner and Shortreed 1978, Grimm and Fisher 1986, Lohman *et al.* 1991). During summer baseflows, many New Zealand rivers have nitrogen and phosphorus concentrations around these ecologically important ranges (Close and Davies-Colley 1990) and, as a result, commonly experience excessive growths of algae and other aquatic plants.

The dissolved inorganic forms of the nitrogen group of contaminants (nitrate and ammonium) and dissolved reactive phosphorus are readily available for plant growth. Some of the phosphorus attached to soil particles is available to aquatic plants in rivers if it settles out as sediment. The forms of nitrogen and phosphorus attached to soil particles are of greater significance when they enter lakes and impoundments because they are available to the algae and plants for much longer than in a stream. Organic forms of nitrogen and phosphorus enter watercourses in plant debris (e.g., leaves) and in dissolved organic leachates from the riparian vegetation canopy. These organic forms are not immediately available for plant growth and their importance to stream/river ecosystems is not well known.

The introduction to New Zealand of nitrogen-fixing clovers and the use of nitrogen fertilisers has increased the amounts of nitrate leaching from pastoral catchments. Stock increase leaching by concentrating nitrogen in urine spots. Groundwater nitrate levels are higher in intensively farmed regions than in sparsely developed areas (see review by MAF 1993). Even though most nitrate is removed from groundwaters as they pass through riparian zones, the total amount of nitrogen entering streams from pasture is usually higher than from forested areas (Cooper and Thomsen 1988). Use of phosphorus fertilisers has increased the concentrations of phosphorus in watercourses through direct inputs during topdressing (Cooke 1988), and through increased inputs from drainage waters.

Figure 6 Groundwater nitrate concentrations in paired wells upslope and downslope of riparian wetlands and riparian soils at Scotsman Valley (adapted from data in Cooper 1990).

Artificial drainage pipes (mole and/or tile) cause drainage waters to bypass riparian zone soils. Because nutrients in groundwater are removed within this zone, it is reasonable to assume that sub-surface drainage works have increased nutrient levels entering our streams and rivers. Open drains are somewhat different; if marginal vegetation and aquatic plants are present they will trap and remove nutrients. Channel maintenance activities which remove vegetation will diminish nutrient trapping.

Pesticides used as animal remedies or to control crop and pasture pests can enter waterways in drainage waters. Modern pesticides are generally less persistent and more specific than their predecessors, but many are, nevertheless, highly toxic to aquatic organisms.

Animal faeces can enter streams and rivers in surface runoff and this poses a human health risk if the water is used for recreation or consumption.

Suspended solids (organic and inorganic material suspended in the water) can be derived from land surfaces and reduce the suitability of water for recreation and some aquatic life forms.

Because contaminants enter watercourses unevenly along the channel, (e.g., from drains, or major seeps), it is most cost-effective to target these important source areas rather than apply catchment wide measures. Riparian management can strongly influence the speed at which contaminants are trapped and later released as they move downstream. In New Zealand, nitrate removal efficiencies in riparian environments have been shown to exceed 90%, when the incoming nitrate has sufficient residence time within the riparian zone (Schipper *et al.* 1991 and 1993, Cooper 1990 and 1993). As a result, extremely low nitrate concentrations leave the riparian zone and enter adjacent watercourses. The median nitrate concentration leaving the riparian wetlands (seeps) in Cooper's (1990) study was only 23 mg N m^{-3} (Figure 6) which is well below the range regarded as limiting plant growth in streams.

Denying stock access to streams by fencing allows bank and stream vegetation to flourish and initially reduces the amount of nutrient entering the stream waters (Hearne and Howard-Williams 1988). Later when the riparian vegetation matures, the trees can shade out periphyton and macrophytes thereby decreasing nutrient uptake (Cooper *et al.* 1987; Smith 1992; Cooper and Bottcher 1993). Although there is some evidence that riparian zones are capable of removing particulate forms of phosphorus in a similar way to other contaminants in overland flow there is currently not enough information to develop specific guidelines for removing dissolved phosphorus by riparian management.

The long term fate of many contaminants trapped in the riparian areas is poorly understood.

2.2.6 The light climate of streams and rivers

- *The light reaching the bed of streams is reduced by interception by the canopy of riparian shade plants, by topography, and by absorption and scattering (attenuation) within the water column.*
- *Light is important for photosynthesis and animal vision.*
- *New Zealand streams that drain forested catchments typically have >90% shading.*
- *The conversion of tall, overhanging riparian vegetation to low growing plant species has increased sunlight exposure of streams and rivers.*
- *Shading is widely recommended for aquatic plant control and can favour the development of "clean-water" invertebrate communities.*

In small streams, the reduction in lighting by terrestrial shade from stream banks and riparian vegetation is usually more important than the light reduction (attenuation) that occurs within the water column (Westlake 1966). In a typical headwater stream, the water column may trap 50% of the incident light but riparian vegetation and topography may reduce light *before it reaches the water column* by 90% or more.

Attenuation in the water column varies greatly with water depth and with the optical characteristics of the water, and therefore with stream size and state of flow. Other factors affecting light climate at the stream-bed are bank height in relation to channel width, bank angle, and reach alignment with the sun (aspect). Many streams in steep, hilly country (notably upland streams) are shaded by hillsides, while many small streams (notably those which are deeply incised) are shaded by their stream banks. The influence of riparian shade declines as channel size increases. Figure 7 illustrates some important concepts associated with stream shade.

Figure 7 Schematic cross-section of a stream channel indicating different types of shade from both diffuse skylight and direct sunlight.

Only half of the total solar radiation at sea level is visible "light" or, in other words, photosynthetically available radiation (PAR). The other half is near-infrared radiation (NIR) (Szeicz 1966), which is not used by plants for photosynthesis, but strongly influences stream temperature regimes (see Section 2.2.7). As well as being essential for photosynthesis by aquatic plants, sunlight illuminates submerged objects so that they can be seen by sighted aquatic animals such as fish and birds (Davies-Colley *et al.* 1993). In heavily-shaded reaches of streams, dim lighting provides hiding places for predator animals and cover (refuges) for prey animals, especially when combined with camouflaging colours and patterns. These effects on animal behaviour are rather poorly understood. Ultraviolet wavelengths in solar radiation also have bactericidal and photo-oxidizing properties which may help maintain water quality.

Animal and plant communities in small, forested streams have evolved in New Zealand under conditions of heavy shade. The low light levels in forested streams encourage the development of thin algal films on stones. Shade also encourages the growth of bryophytes (mosses and liverworts) on stable substrates which can provide important habitats for many aquatic invertebrates in small streams (e.g., Suren 1993).

Sunlight exposure following land clearance is believed to have resulted in the widespread loss of shade-adapted native aquatic plants and mosses (see Howard-Williams *et al.* 1987). Where nutrient levels are adequate, as is usually the case in pasture systems, the increased light levels markedly increase aquatic plant growth and frequently it is introduced species which are favoured.

Abundant aquatic plant growth at open sites can interfere with a variety of in-stream uses (MfE 1992), and shading is widely recommended to control undesirable growths (e.g, Dawson and Haslam 1983, Harper 1983). The abundance of rooted macrophytes in lowland pastoral streams near Auckland was strongly related to the lack of riparian shading (Figure 8). Where macrophytes and algae are present at high biomass, they are usually severely self-shading. That is, plant tissue at the top of the "canopy" shades tissue lower down. A self-shaded association of plants is light-limited, such that reductions in light level will reduce production, and ultimately the biomass of the community.

The combination of little shade and high nutrient levels, as described in section 2.2.5, can lead to excessive growth of algae and aquatic plants in streams, especially during summer. Increasing the shading by planting riparian zones can reduce this growth, even in waters with high nutrient levels. This can provide a more rapid way of improving water quality while measures to reduce the nutrient loading are put in place, and may be the only remedy available where it is difficult to reduce inputs.

In silty/sandy-bedded streams with little wood debris, aquatic plants can greatly increase the habitat for aquatic invertebrates. Partial rather than dense (< 10% light) riparian shading may control macrophytes at an abundance at which they still provide invertebrate habitat but do not cause adverse impacts. Dawson and Haslam (1983) recommend about 50% shade to maintain macrophytes below nuisance biomass levels.

Shade affects the invertebrate communities in stony streams and this can vary depending on the plant communities present in the stream and its nutrient status. Riparian shading of nutrient-rich streams in Southland eliminated thick mats or filamentous growths of periphyton. This favoured the "cleanwater" invertebrate species (such as leptophlebiid mayflies and helicopsychid caddisflies) and reduced the abundance of chironomids, algal-piercing caddisflies, and ostracods (Quinn *et al.* 1992a,b). By contrast, in a nutrient deficient stream where only thin periphyton films occurred in open reaches, partial riparian shading resulted in lower invertebrate densities and no major changes in community composition.

Figure 8 Comparison of percentage macrophyte cover of the stream-bed during summer at 74 sites with different levels of riparian shade on three lowland rivers near Auckland. Box represents interquartile range, bar the median, and whiskers the range. Outliers (O) and extreme outliers (*) are identified. Hatched areas are approximate nonparametric 95% confidence intervals for comparison of medians. From McBride *et al.* (1991).

2.2.7 The temperature regime of rivers and streams

·*Stream water temperature is determined by several processes but the most important are the input of solar (shortwave) and atmospheric (longwave) radiation.*

Figure 9 Pathways and processes of stream heating and cooling.

·The rates of heat gain and loss vary depending on the weather conditions.
·Stream water temperature is highly variable both in time and space.
·Riparian vegetation reduces the amount of solar and atmospheric radiation which reaches the water surface and hence plays an important role in determining streamwater temperature.
·Topographic shading affects water temperature in some streams.
·High water temperatures have the potential to affect the distribution of aquatic life.
·Land clearance has altered the water temperature regimes in streams over much of the country.
·Restoring riparian shading will reduce maximum water temperatures, especially in small streams.

Stream and river temperatures exert an important influence on stream ecosystems and many animal species, including some fish, cannot tolerate high water temperatures.

The principal sources of heat input to a stream (in decreasing order of importance) are:

·Direct and diffuse solar (shortwave) radiation.
·Atmospheric (longwave) radiation.
·The heat content of rainfall and inflows.
·Radiation (longwave) emitted by riparian vegetation.

Figure 10 Distribution of maximum recorded temperatures at 254 New Zealand river sites (from data in Mosley (1982)).

The principal causes of heat loss from a stream (in decreasing order of importance) are:

·Back radiation (longwave radiation emitted by the water).
·Evaporation.
·Conduction to (or from) the air and/or the stream-bed.

These sources and sinks are summarised in Figure 9.

The amount of solar radiation reaching the ground varies with geographic location and season, and decreases as the amount of cloud cover increases. The amount of atmospheric radiation increases with humidity and air temperature, and is highest on hot, cloudy days. Wind, humidity and atmospheric pressure affect temperature by altering the rates of evaporation and conduction, but they are less important than atmospheric radiation in determining stream water temperature (Novotny and Krenkel 1972). Conduction of heat to and from the stream-bed is important, especially in shallow, open streams with little riparian vegetation cover.

At a given site on a stream, water temperature changes principally as a result of daily and seasonal variations in solar and atmospheric radiation. Water temperature changes along the channel as a result of changes in shading and stream depth and through inflows from tributaries and groundwater seepages.

Stream water temperature depends on the flux of both optical and thermal (longwave) radiation. As described in Section 2.2.6, riparian vegetation reduces the amount (flux) of visible light (optical radiation) reaching the stream. Thermal radiation is emitted by water vapour (and so is high on cloudy days), and also by riparian vegetation, banks and hillsides. Overall, however, riparian vegetation produces a net reduction in the total radiation flux (optical plus thermal) reaching the stream and hence reduces water temperature.

Riparian vegetation removes more incident optical radiation than thermal radiation. This distinction is important if you wish to manage the amount of shading or the amount of light available for photosynthesis.

Figure 11 Diurnal temperature variations in a riparian protected reach of a small Southland stream (catchment area 3.3 km^2) and a more open, riparian grazed and channelised reach 2.4 km downstream (adapted from Quinn *et al.* 1992b).

The shading caused by hillsides and banks is termed *topographic shading* (see also Section 2.2.6). Topographic shading remains fairly constant unless major channel works (straightening, widening etc.) change the channel orientation and bank heights.

Stonefly abundance declines markedly in New Zealand rivers once typical maximum summer temperatures exceed 19°C (Quinn and Hickey 1990). In recent laboratory studies of thermal tolerance, temperatures between 20.9 and 23.5 °C caused 50% of test animals (a stonefly and two mayfly species) to die within 96 hours. Because maximum observed temperatures exceeded 21°C at the majority of the river sites throughout New Zealand studied by Mosley (1982) (Figure 10), water temperature clearly has the potential to directly affect the distribution of invertebrates (and possibly some fish) in our rivers. A list of known temperature preferences and tolerances for native fish and some salmonids is presented in Appendix 1 of Guideline: **TEMPERATURE**.

Water temperature affects the rates at which aquatic insects grow. Warmer temperatures result in faster growth provided critical temperatures for species are not exceeded. High water temperature can indirectly affect sensitive aquatic organisms by reducing the saturation of dissolved oxygen and increasing (oxygen-demanding) microbial respiration rates which may lower dissolved oxygen below tolerable limits.

The removal of tall vegetation (which overhangs and shades watercourses) increases the daily maximum water temperatures, daily mean temperatures, and causes increased daily water temperature fluctuations, especially during summer (e.g., Graynoth 1979). Daily minimum water temperatures are generally little affected when riparian vegetation is removed. Daily maximum water temperatures are of greater significance for stream organisms.

Daily maximum summer river temperatures are likely to have increased over much of the country where land clearance has removed riparian shade. An example of typical differences between a shaded reach (protected) and an open reach (grazed) on the same river is presented in Figure 11. Increases in daily maximum water temperatures of 4.2-10.2°C were recorded in summer.

Restoring riparian shade will decrease daily maximum temperatures (Quinn *et al.* 1992b). For a given surface heat flux, the rate of change of water temperature is inversely proportional to the water depth. Consequently, shallow streams have a low "thermal inertia", exhibit large daily temperature variations (Mosley 1983), and are susceptible to cooling if riparian shade is restored. Narrow streams require relatively low riparian vegetation (e.g., ferns, sedges, grasses etc.) to achieve shading whereas wide channels require tall, mature trees.

The stream microclimate (wind speed, air temperature and humidity) will be altered by removing or restoring tall riparian vegetation and this, in turn, will affect the rates of evaporation and conduction to the atmosphere. Longwave radiation reaching the stream from riparian vegetation will be affected by removing or restoring bankside vegetation. The effects of riparian management on evaporation, conduction and riparian radiation are far less important than changing the inputs of solar and atmospheric radiation.

2.2.8 Terrestrial carbon inputs

- *In small, forested streams terrestrially-derived food sources are usually important because aquatic plant growth is often restricted by low nutrient and light levels.*
- *Leaf litter retention appears to be a particularly important factor affecting the role of coarse terrestrial carbon in stream ecosystems.*
- *Wood that is retained in river channels serves many important functions.*
- *Removal of riparian native forest has altered the type, amount, timing and retention of terrestrial carbon inputs to watercourses.*
- *Removal of riparian forest has affected many fish and invertebrate species.*
- *Planting trees and shrubs alongside developed watercourses will increase supplies of terrestrial carbon to streams.*

Invertebrate communities (and ultimately fish and birds) in running water ecosystems depend for their growth on a combination of foods (carbon) from in-stream plants and from land plants. In large rivers and open streams aquatic plant growth is most important; in small, forested, headwater streams external food (which falls or is washed into the water) is most important because aquatic plant growth is restricted by low nutrient and light levels. Figure 12 describes the pathways by which the different terrestrial carbon inputs provide energy to aquatic animals.

The terrestrial food sources provided by riparian vegetation are:

·Dissolved organic matter.
·Coarse and fine particulate organic matter.
·Terrestrial invertebrates.

Figure 12 Major pathways (solid lines) by which terrestrial carbon sources (woody debris, leaves, dissolved organic matter, terrestrial invertebrates) fuel the production of aquatic invertebrate, fish and bird populations in stream and river ecosystems. Dashed lines indicate interactions with various ecosystem processes.

·Woody debris.

Terrestrially-derived *dissolved organic matter* (DOM) leaches into rivers from leaves that are overhanging or have fallen into the water or leaches from decomposing organic matter adjacent to the river. In the river, DOM is taken up by microbes or it flocculates and precipitates on the bottom as *fine particulate organic matter* (FPOM). Aquatic microbes are consumed by Protozoa and other micro-invertebrates, which in turn are eaten by macro-invertebrates.

Leaves and other *coarse particulate organic matter* inputs (along with their associated terrestrial fungi and bacteria) 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. Many New Zealand invertebrates in riparian-shaded streams seem to feed predominantly on fine particulate organic matter (FPOM) which is a by-product of the breakdown of coarse particulate matter both on the land, in wetlands and in the water. Faeces etc. produced during invertebrate feeding and DOM that has flocculated or precipitated from the water column also contribute FPOM.

Leaf litter from riparian vegetation is an important food source for leaf-eating invertebrates (*shredders*) in small streams with relatively stable flow regimes (e.g., Linklater 1991, Linklater and Winterbourn 1993). In streams and rivers in which high flows are frequent, shredders are a minor component of the invertebrate fauna (Winterbourn *et al.* 1981, 1984, 1988; Quinn *et al.* 1992a).

In the water, leaves are colonised by aquatic fungi and bacteria. These break down indigestible components of the leaf and make the leaf protein, lipids and carbohydrate more available to invertebrates. This process is known as *conditioning*. How much conditioning occurs depends on factors such as leaf hardness, water temperature and the length of time the leaves remain in the stream. Stream retentiveness is influenced by factors such as physical stability, flow variability, leaf shape and, in particular, the presence of in-stream retention structures such as logs and boulders.

Terrestrial invertebrates like spiders and beetles fall into the water from overhanging vegetation or are washed or blown in by floods and wind. They provide food for fish, and can be important in the diet of species such as giant kokopu, banded kokopu and eels. Most woody debris enters streams from adjacent forests with a small proportion coming down the stream channel.

Woody debris in the watercourse traps leaf litter and prevents its loss downstream. It also creates depositional zones that trap FPOM and stabilise river channels by trapping mobile river-bed sediments. Woody debris serves as emergence sites for aquatic insects, and provides important shelter and habitat diversity for aquatic animals such as fish. New Zealand streams tend to contain less woody debris (typically less than 10% of bed area) than many overseas countries because they are flood prone.

Reduced inputs of terrestrial leaf litter and changes in light climate (see Section 2.2.6) associated with land clearance are likely to have affected the composition of aquatic invertebrate communities, particularly in some stable streams where shredders may previously have been relatively abundant. Increased floodflows caused by forest clearance (see Section 2.2.2) and the loss or non-replacement of woody debris from stream channels can be expected to have reduced the ability of streams to retain leaf litter within the reach and to have reduced habitat diversity.

Dissolved organic matter inputs may decline with conversion from native forest to pasture. For example, West Coast streams draining native forest have humic-stained waters, but these often become clear when their catchments are converted to pasture.

All native freshwater fish and introduced salmonids are predators and most are opportunistic feeders (Sagar and Eldon 1983; Scrimgeour 1986). They are likely to be able to adapt to varying degrees to changes in food supply associated with altered riparian vegetation. However, some of the larger galaxiid fish (giant kokopu and banded kokopu) feed largely on terrestrial insects and depend on riparian native forest for breeding sites (Main and Lyon 1988; Hanchet 1990; Swales and West 1991). Removal of natural riparian vegetation, and its associated input of terrestrial drift, is believed to have had direct effects on the distribution of these species. Our three species of mudfish are also strongly associated with marginal vegetation and wetland habitats in riparian zones, and their distribution appears to have been severely restricted due to activities associated with pastoral development of catchments (McDowall 1990).

Planting of riparian trees and shrubs alongside watercourses lined by grasses increases the supply of terrestrial organic carbon to streams, which, if it is retained in the channel for sufficient time, should become available to aquatic invertebrates. Little is known of the food preferences of most native stream invertebrates. A reasonable assumption might be that native plant species characteristic of the region will be preferred by native invertebrates over introduced species. Tree planting may be inappropriate alongside agricultural streams which once flowed through tussock grassland.

2.2.9 Riparian habitats for plants and animals

- *Riparian zones and their associated wetlands are attractive to a wide variety of wildlife and are areas of high biodiversity.*
- *Clearance of native riparian plant communities has resulted in loss of habitat complexity and native species diversity in the lowlands of New Zealand.*
- *Restoration of native riparian forest alongside developed streams should increase habitat diversity and the diversity of native plant and animal communities.*

Riparian forest creates a microclimate near the stream with its own wind speed, humidity and air temperature. This favours certain types of plants (see Figure 3b for a summary of the expected effects of riparian zone width on microclimate). The complex riparian vegetation community generated provides habitats and food for a wide range of animals. Inanga, the dominant species in New Zealand's whitebait fishery, spawn in riparian vegetation near the upstream extent of salt water penetration in river estuaries (Mitchell and Eldon 1991). Some banded kokopu populations spawn in flooded riparian vegetation (Mitchell and Penlington 1982). Fish such as eels feed in riparian areas during floods.

Most stream insects use riparian vegetation in some way for breeding habitat. A study in California, U.S.A., indicated that the adults of some caddisflies show preferences for particular heights and distances from the channel within riparian forests (Jackson and Resh 1989). The needs of adult stream insects for special riparian vegetation types or special microclimate conditions are not known in New Zealand but are currently being investigated. Preliminary results suggest that the abundance of mayflies, stoneflies and caddisflies declines to low levels about 20m away from the channel edge in native forested riparian zones, but that many caddisfly taxa can be found considerable distances from the stream edge. The abundance and biodiversity of adult insect faunas in riparian areas appear to be enhanced by the openness of the forest and the presence of riparian seepage streams.

Another animal closely associated with riparian zones is the rare Hochstetters frog which is found in moist conditions where it feeds on insects. Some bird species show strong associations with riparian zones and may depend on the river itself or the plant species which occur there. Blue duck inhabit moderate to high gradient upland rivers, often nest on banks close to the river's edge and appear to prefer native riparian forest (Collier *et al.* 1993). Riparian trees provide cover and perching and nesting sites for a variety of birds including waterfowl, shags and kingfishers. Riparian vegetation is important for birds such as kereru which survive in the lowlands of New Zealand by opportunistically exploiting a variety of seasonally available foods in the landscape.

Physical and structural diversity in New Zealand's formerly extensive lowland forested riparian zones was provided by, for example, contrasting patches of partial light and dense shade in forests, and by a wide variety of plant morphologies. Clearings in riparian forests would have caused localised changes in microclimate, and the wide variety of native plant species would have provided habitats for a range of terrestrial insects and birds. Replacement of this diversity with low-growing species (e.g., pasture grasses) has led to a decline in the biodiversity of riparian zones over much of New Zealand's lowlands.

This loss of biodiversity has been exacerbated by the drainage of over 90% of our wetlands, many of which were probably associated with watercourse riparian areas. In addition, the invasion of introduced weeds and animal pests into riparian environments from adjacent developed areas has led to changes in habitats and the success of native species.

The habitat requirements of many of our native terrestrial animals, particularly the invertebrates, are poorly known. It seems reasonable to assume, however, that native species of plants are more likely to provide appropriate conditions for native animals than introduced species. Restoring riparian forest should help maintain appropriate habitat for many species.

3. THE LEGAL FRAMEWORK

3.1 INTRODUCTION

The Resource Management Amendment Act 1993 (RMA) and the Conservation Amendment Act (No. 2) 1993 provide the legal setting for resource managers. Requirements under these Acts for the purpose of protecting New Zealand's freshwaters have consequences for the management of riparian zones.

3.2 RESOURCE MANAGEMENT ACT 1991

3.2.1 The Act

Part II, Purpose and Principles of the Act presents the broad framework for environmental management of New Zealand's natural and physical resources. These resources include, amongst others, land, water, soils, plants and animals. Contained within Part II are explicit requirements relating to the management of riparian environments. Other sections implicitly require that riparian zone management strategies be considered as a means of managing our freshwaters. Section 5(1) (Part II) states:

"The purpose of the Act is to promote the sustainable management of natural and physical resources"

Sustainable management is the management of resources so that they provide for the well-being (in a broad sense) of people now and in the foreseeable future within environmental limits, and while

"Avoiding, remedying, or mitigating any adverse effects on the environment" (Subsection 5(2)(c)).

In effect, subsection 5(2)(c) necessitates that local authorities consider riparian management as one option for minimising adverse effects of agricultural land use on our freshwater ecosystems, although this should enable communities to also provide for their social, economic and cultural well being.

In section 6 (a) (Part II), the preservation of the natural character of wetlands and lakes and rivers and their margins is stated to be a matter of national importance. That is, our freshwater riparian zones are of national importance. They are to be protected from "inappropriate subdivision, use and development". The Act does not, however, define "inappropriate", and this is a issue that is open to debate.

Section 6(c), and more especially Section 7, have implications for riparian zone management. The latter requires that functionaries consider maintaining and enhancing the environment (Subsection 7(c)) and protecting trout and salmon habitats (Subsection 7(h)) when making decisions about the use, development, and protection of resources. Implementing appropriate riparian management strategies could help to achieve these objectives.

Part III of the Act describes Duties and Restrictions under the Act. Sections 13 and 17 are pertinent to riparian management. In Section 13(c) the planting or introduction of any plants and the disturbance, removal, damage or destruction of plants or the habitats of any plants or animals in, on or under the bed of any lake or river is prohibited unless it is expressly allowed for by a regional plan rule or by a resource content. In this context, 'bed' includes a varying portion of the riparian zone. For instance, for a river it is "the space of land which the waters of the river cover at its fullest flow without overtopping the banks".

Section 17 deals with adverse effects and obliges managers to avoid, remedy, or mitigate any adverse effect on the environment arising from an activity they undertake or are responsible for. The Act provides means of enforcing this individual duty or responsibility under Sections 314 and 322, relating to Enforcement Orders and Abatement Notices respectively.

Part IV of the Act deals with functions, powers, and duties of central and local government. The Governor-General may approve national policy statements on matters of national significance that are relevant to achieving the purpose of the Act, (Section 52) and make regulations (i.e., National Environmental Standards) relating to, for example, water quality (Section 43). However, much of the responsibility for implementation of the Act lies with regional councils.

3.2.2 Regional council responsibilities

It is mandatory for regional councils to prepare regional policy statements. Regional plans are optional, but the regional council is to consider the desirability of preparing a regional plan (Subsection 65(3)) when the following, amongst other situations, arises

"(a)Any significant conflict between the use, development, or protection of natural and physical resources or the avoidance or mitigation of such conflict:"

"(b)Any significant need or demand for the protection of natural and physical resources or of any site, feature, place or area of regional significance:"

"(f)The restoration or enhancement of any natural and physical resources in a deteriorated state or the avoidance or mitigation or any such deterioration:"

"(h)Any use of land or water that has actual or potential adverse effects on...water quality:"

Regional plans may be prepared for the whole or part of a region or cover specific issues (such as river water quality) in the region. Any person may request that a regional council prepare or change a regional plan.

A regional policy statement is required to identify significant regional issues while a regional plan deals with a stated issue(s). They are quite similar in approach. Both present objectives, policies relating to the objectives and issue(s), methods used or to be used to implement the policies, main reasons for adopting the policies, objectives and methods, and the anticipated environmental results. Regional plans may (after taking into consideration the actual or potential effects of activities on the environment) include rules which prohibit, regulate or allow activities.

Policies and plans are likely to endorse riparian management strategies for the protection of our freshwaters. Experience to date (e.g., in the Proposed Regional Policy Statement for Manawatu-Wanganui, Manawatu-Wanganui Regional Council 1993) suggests that the methods to be used to implement the policies will incorporate the commitment of resources to:

·The gathering and provision of educational information on suitable riparian management practices.
·Advocating riparian strategies for protecting watercourses.
·Providing technical information on high priority watercourses or reaches requiring protection.

The Act does provides regional councils with authority (Section 30) to control the use of land for the purpose of soil conservation, or to maintain and enhance the quality of water in water bodies. The Proposed Regional Policy Statement for Southland refers to this power and links water quality problems with riparian management (Southland Regional Council 1993). However, the restraining Section of the Act (Section 32) may limit the power of regional councils to implement and enforce riparian management strategies for the purpose of protecting water bodies. This section requires that before adopting any objective, policy, rule or other method, a functionary shall -

"(a)Have regard to-
(i)The extent (if any) to which any such objective, policy, rule, or other method is necessary in achieving the purpose of this Act; and
(ii)Other means in addition or in place of such objective, policy, rule, or other method which .... may be used in achieving the purpose of this Act, including the provisions of information, services, or incentives, and the levying of charges (including rates); and
(iii)The reasons for and against adopting the proposed objective, policy, rule, or other method and the principal alternative means available, or of taking no action where this Act does not require otherwise; and
(b)Carry out an evaluation.....of the likely benefits and costs of the principal alternative means including ....; and
(c)Be satisfied that any such objective, policy, rule, or other method (or a combination thereof:
(i) Is necessary in achieving the purpose of this Act; and
(ii) Is the most appropriate means of exercising the function, having regard to its efficiency and effectiveness relative to other means."

Furthermore, any rule (e.g., a rule requiring riparian margins to be fenced and retired) can be challenged under Section 85. This allows the Planning Tribunal to direct the local authority (also applies to rules in a district plan, see below) to modify, delete or replace a rule if it renders land "incapable of reasonable use" or if it places "an unfair and unreasonable burden" on any person that has an interest in the land.

3.2.3 Territorial authority responsibilities

Territorial authorities are required to have a district plan. These contain objectives, policies, methods of achieving the policies (that is, have a similar format to regional policy statements and plans). They may incorporate district plan rules that prohibit, regulate, or allow activities. Any person may request a territorial authority to change a district plan Section 73(2)).

Section 77 of the Act allows territorial authorities to make rules to provide for esplanade reserves to be set aside on subdivision of lands along the bank of any river, or along the margin of any lake (width greater or less than 20 metres) (Section 77 (1)(a)). Likewise, esplanade strips may be created (Section 232; Section 235) upon subdivision. An esplanade reserve or esplanade strip has, amongst other purposes as outlined in Section 229(a):
"(a)To contribute to the protection of conservation values by, in particular:

(i)Maintaining or enhancing the natural functioning of the adjacent sea, river, or lake; or
(ii)Maintaining or enhancing water quality; or
(iii)Maintaining or enhancing aquatic habitats; or
(iv)Protecting the natural values associated with the esplanade reserve or esplanade strip......"

Within this context, a river means a river whose bed has an average width throughout or adjoining an allotment, of 3 metres or more where the allotment in less than 4 hectares; and lake means a lake whose bed has an area of 8 hectares or more. District Councils can establish esplanade reserves on rivers or lakes of any size when allotments exceed 4 hectares, but compensation must be paid. An esplanade reserve is vested in and to be administered by the territorial authority. An esplanade strip remains the property of the land owner. The esplanade provisions of the Act have recently been amended. It is unclear how territorial authorities will deal with the new provisions.

3.2.4 Concluding comments

Under the Act, regional councils could consider making rules relating to the management of riparian zones, such as a rule prohibiting grazing within 20 m of an open watercourse. In practice, any such proposed rule may not withstand scrutiny under the requirements of Section 32.

Presently, regional councils are favouring the use of educational tools and incentives to bring about changes in land management that will benefit our freshwaters. Some are also providing expertise to help individuals/communities design and implement riparian protection measures. Furthermore, they are addressing their obligations to avoid, remedy, or mitigate adverse effects on the environment by promoting appropriate riparian management strategies in regional policy statements.

3.3 CONSERVATION ACT 1987 AND AMENDMENTS

The Conservation Amendment Act (No. 2) 1993 aims to promote the conservation of New Zealand's natural and historic resources. For the purposes of the Act, "conservation" means the preservation (maintenance of intrinsic values) and protection (maintenance of current state but also includes *restoration to a former state*, and *augmentation, enhancement or expansion*) of natural and historic resources for the purpose of maintaining their intrinsic values, providing for their appreciation and recreational enjoyment by the public, and safe-guarding the options for future generations.

"Natural resources" cover all animals and plants (including algae, bacteria and fungi), the air, water or soil on which they live or may live, landscape and landform, geological features, and systems of living interacting organisms and their environment. "Historic resource" means an historic place (see Historic Places Act 1980). The requirement to conserve historic resources implies that managers should consider the implications of planting trees in riparian zones where historic places are present (e.g., root penetration of archaeological sites), and balance this against possible deterioration if riparian management is not carried out (e.g., loss of the site through bank erosion).

Part III of the Act deals with Conservation Areas. These are any land or foreshore (including any part of the bank of a river or creek covered or uncovered by the flow and ebb of the tide at ordinary spring tides) held for conservation purposes or in which a similar interest is held. Thus riparian areas may form part of a Conservation Area. Management plans are required for conservation areas either individually or in combination with other areas (Section 10), and these may be reviewed at any time to take account of increased knowledge or changed circumstances. If deemed necessary, the Minister may close all or part of a conservation area to public entry for conservation purposes (Section 13).

Part IV of the Act deals with Specially Protected Areas. The Minister may establish Specially Protected Areas to afford areas specific protection or ensure their preservation. Specially Protected Areas include Conservation Parks (Section 19), Ecological Areas (Section 21), Watercourse Areas (Section 23) and Marginal Strips (Section 24). Watercourse Areas are certain sections of land adjoining any lake, river or stream for which a Water Conservation Order has been made or that is protected in some other way, and which has outstanding wild, scenic or other recreational characteristics when considered with the associated aquatic habitat. Conservation Parks are managed primarily to *protect* natural and historic resources, and Ecological Areas are managed to *protect* whatever value they are held for.

The most important aspect of the Act in terms of riparian management lies in its provisions for the conservation of Marginal Strips. These are pieces of land that lie on the high side and within 20 m of any foreshore, of any lake exceeding 8 ha or any bay or inlet of these lakes, and along the bank of any river or stream that has an average width of 3 m or more (excluding canals under the control of ECNZ). A manager can be appointed to manage the marginal strip; this could be the adjacent land owner. The Minister can waive (i.e., not establish) marginal strips or reduce their width under special circumstances.

A Marginal Strip is to be managed for the conservation of its natural and historic resources and *those of the adjacent water*, and, subject to the conservation of those resources, to enable public access to the adjacent water. The Marginal Strip provisions of the Conservation Act are currently under review.

3.4 CONVENTION ON BIOLOGICAL DIVERSITY

The Convention on biological diversity was drawn up at the United Nations Conference on Environment and Development Earth Summit 1992, and was ratified by our Government in September 1993. Prior to ratification by any country, that country was required to ensure existing legislation was compatible and in accordance with the convention. Both the RMA and Conservation Act met these requirements.

The Convention is a legally binding convention requiring Governments to variously advocate/implement/set policies etc. that preserve and enhance biological diversity[5] within their country.

[5] Biological diversity means the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.

The convention has a philosophy that has much in common with our Resource Management Act. Furthermore, it has some relevance to the management of our riparian zones. Thus, several matters raised within the Convention are briefly discussed below.

In Article 6, Governments undertake to "develop national strategies, plans, or programmes for the conservation and sustainable use of biological diversity." Furthermore, signatories undertake to raise public awareness and understanding of the importance of, and measures needed for the conservation of biological diversity. The convention notes that "where there is a threat of significant reduction or loss of biological diversity, lack of full scientific certainty should not be used as a reason for postponing measures to avoid or minimise such a threat".

Article 8 addresses the issue of *in-situ* conservation. Each government shall (amongst other undertakings), as far as possible and as appropriate,

"Endeavour to provide the conditions needed for compatibility between present uses and the conservation of biological diversity and the sustainable use of its components;"

"Promote the protection of ecosystems, natural habitats and the maintenance of viable populations of species in natural surroundings";

"Rehabilitate and restore degraded ecosystems and promote the recovery of threatened species, *inter alia*, through the development and implementation of plans and other management strategies;"

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