Auckland
Regional Council
TE RAUHITANGA TAIAO

Review of Information on Riparian Buffer Widths Necessary to Support Sustainable Vegetation and Meet Aquatic Functions

August 2000 Technical Publication 350

Auckland Regional Council
Technical Publication No. 350, August 2000
ISSN 1175-205X
ISBN 978-1-877483-01-1

Review of information on riparian buffer widths necessary to support sustainable vegetation and meet aquatic functions

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Prepared for
Auckland Regional Council
Environmental Research

NIWA Client Report: ARC00262
August 2000

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Recommended Citation:
Parkyn, S.; Shaw, W.; Eades, P. (2000). Review of information on riparian buffer widths necessary to support sustainable vegetation and meet aquatic functions. Prepared by NIWA for Auckland Regional Council. Auckland Regional Council Technical Publication Number 350, 38 pages

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Reviewed by: Dr Kevin Collier

Approved for release by: Dr Bob Wilcock

Document formatting approved by:
P. Bradley or K. MacLeod, NIWA

1 Executive Summary

Due to the wide variety of functions that riparian buffer zones are believed to achieve in stream management, and the differences in widths necessary to provide these functions, the Auckland Regional Council has attempted to define a buffer width that can be used across a wide variety of streams based on the sustainability of the vegetation. Indigenous vegetation has been chosen, as this is believed to be more sustainable than exotic vegetation in the long term.

Auckland Regional Council requires information on the width that will be necessary to support a buffer that is self-seeding and able to suppress weed growth. This report provides a review of the terrestrial ecology literature on the factors that affect sustainability of linear tracts of vegetation and on the widths necessary for sustainability and weed control.

The literature review revealed that there was a paucity of research in this area. Guidelines from the Ministry for the Environment suggest "as wide as you are prepared to make it". Edge effects altering microclimate and permeability of the buffer to weed invasion were identified as important factors that would affect the sustainability.

We visited the Auckland farm parks of Awhitu and Shakespear Regional Parks to investigate riparian and linear plantings of various widths and ages to formulate recommendations on buffer widths for the Auckland area. The characteristics of these are described, and three possible width options are presented.

1) 5–6 m: On-going maintenance will be required to keep a buffer of this width weed free, and natural regeneration of indigenous species is likely to be limited. This should only be used on very small waterways or where there is no other option (a narrow buffer is better than no buffer).

2) c. 10 m: Allows for indigenous vegetation succession and should result in a relatively low maintenance riparian buffer strip. The marginal 1-2 metres is likely to suffer from long term weed infestations, which could have the potential to spread to the interior wherever canopy gaps occur. This could be used as a general guideline for a minimum buffer width.

3) 15–20+ m: Highly likely that the buffer strip will support self-sustaining, virtually no maintenance indigenous vegetation. Larger buffers (20+ metres) will be required on large waterways (rivers).

Therefore, a buffer width of >10 m on either side of a stream has been recommended as the minimum necessary for the development of sustainable indigenous vegetation. Most aquatic functions will be achieved by this width. Riparian management relevant to the common land uses and stream types in the Auckland area is discussed with respect to a >10 m buffer of indigenous vegetation.

Limitations of a 10 – 20 m buffer of indigenous vegetation include:

- Weed control may always be necessary along edges or for shade tolerant weeds
- Success depends on establishing closed canopy cover early
- Shading of groundcover plants by indigenous tree species may release sediments held in the banks of pasture streams
- A grass buffer may be better than tree species as a filter for sediment and nutrients
- Microclimate conditions comparable to those in forest interiors may not be achieved with buffers smaller than 40 m
- Headwater wetlands should be protected by fencing from stock and planted with wetland species rather than trees so that the wetland is not shaded or dried out.

In conclusion, a buffer width of >10 m will achieve most aquatic functions. However, in steep rural areas where nutrient filtration is required for maintaining good water quality and bank stability is important, the use of models from the DOC-NIWA guidelines may provide better resolution and more reliable results.

2 Introduction

The Auckland Regional Council is developing guidelines on riparian zone management. The guidelines will provide a strategic and technical framework for implementing riparian protection across the region. Riparian management and buffer strips around surface waterways are frequently advocated as measures to improve water quality. Defining the width of riparian buffer strips and the type of vegetation to be maintained or planted will be critical elements of the guideline. The regional guidelines will place a high priority on establishing riparian buffer strips of indigenous vegetation as they are thought to be self-sustaining and require minimal maintenance. Weed control will be an important issue because many of the riparian zones in the region are dominated by pasture grasses and weeds.

The Auckland Regional Council requires information on the width of riparian buffer zones that will be necessary to support sustainable regenerating vegetation and suppress weed growth. They also require information on the aquatic functions that may or may not be met by the proposed riparian management. The recommended width for sustainable buffer zones and the aquatic functions they are able to protect may differ according to land use, geology, slope and size of streams for catchments in the Auckland region. Therefore the Auckland Regional Council require some stratification of riparian buffer width recommendations based on these attributes for the Auckland region. The DOC-NIWA guidelines for riparian management (Collier et al. 1995) advocate a site-based approach to determining the most appropriate riparian management. The Auckland Regional Council does not have the resources to conduct site-based assessments and would like a discussion on the value and effectiveness of using a general buffer zone width as a riparian management strategy as opposed to site specific assessment.

Specific objectives were that the buffer zone width should be able to:

- Support sustainable indigenous riparian vegetation
- Allow for natural succession towards a sustainable climax community
- Control weeds
- Meet most aquatic functions

Information is provided in this report on riparian buffer zone functions, the ecological processes relevant to the establishment of a sustainable riparian buffer, the aquatic functions achieved by vegetated buffers, and issues relevant to different land uses. Three buffer width scenarios are presented based largely on expert opinion from a visit to riparian plantings in the Auckland area. Conclusions are provided on the use of a general width guideline versus site specific assessments.

3 Basis for implementation of Riparian Buffer zones

3.1 What are riparian zones?

The riparian zone generally encompasses the vegetated strip of land that extends along streams and rivers and is therefore the interface between terrestrial and aquatic ecosystems (Gregory et al. 1991, Martin et al. 1999). In addition to streams and rivers, the definition of riparian zones in the literature often includes the banks of lakes, reservoirs and wetlands.

Riparian zones are commonly areas with heterogeneous vegetation and soils and therefore provide a diverse habitat for terrestrial and semi-aquatic organisms, such as birds, insects, amphibians and plants (Boothroyd & Langer 1999). Vegetation in the riparian zone can influence water flow, both surface and subsurface (through root systems), and has direct effects on stream functioning. Trees alongside small-medium sized streams can provide shade and lower stream temperatures. High light levels often lead to increases in algal biomass and in-stream primary production, and changes to invertebrate community composition. Stream temperature has a direct impact on aquatic species as most metabolic processes are accelerated with increasing temperature and many fish and invertebrate species have thermal tolerances that can be exceeded in unshaded streams (Quinn 1999, Martin et al. 1999). Trees provide organic matter inputs in the form of leaves and woody debris, creating a diversity of food resources and habitats for in-stream fauna. Terrestrial insects may also be attracted to vegetated riparian zones and become a valuable food source for fish when they fall into the stream (Edwards & Huryn 1995, Barling & Moore 1994).

3.2 Riparian buffer zone functions

Riparian buffer zones are often advocated as environmental management tools for reducing impacts of land use activities on aquatic resources. The buffer zone, area, or strip is generally regarded as the strip of land that connects an upland or hillslope area with streams, lakes or wetlands. Land use activity is modified in this zone to prevent adverse effects on the water quality, biota and habitat within the watercourse. Buffer zones or strips have also been variously labelled as Stream Protection Zones, Streamside Management Zones, or Riparian Management Zones. In agricultural landscapes, buffer zones often consist of a fenced area alongside streams that stock are excluded from and this may be left as a grassy sward, or be planted with woody vegetation. In forestry systems, a buffer zone may be production trees left beside the stream when the surrounding area is harvested, or a strip of indigenous vegetation, or a planting setback that is allowed to regenerate.

Riparian buffer zones are used as a management tool to perform many functions (Table 1) including stabilising channels, filtering sediment and nutrients, purifying water of bacteria and pathogens, and providing terrestrial and aquatic habitat. Riparian vegetation can also provide ecological linkages or corridors for indigenous plants and animals between otherwise separate natural areas, although the spread of pest species can also be facilitated in this way.

A wide range of differing buffer widths can potentially address various aquatic functions. A problem that regional councils have to face when they propose riparian management is that they are often required to suggest a width for the riparian buffer zone that will be applicable to a variety of situations. As a means of determining this width, the ARC have suggested establishing a riparian zone of vegetation that would be sustainable, require no replanting and minimal maintenance, and would ultimately meet most of the buffer zone functions required to improve stream health. To define a buffer zone width that meets these requirements we reviewed the terrestrial ecology literature, and have made recommendations for the Auckland area.

Table 1: Summary of riparian zone functions.

Key riparian zone functions	Explanatory notes
Stream bank stability	The root systems of trees and grasses strengthen streambanks and groundcover reduces surface erosion – provides habitat stability in the form of refuges during floods.
Filtering overland flow	Surface roughness provided by grassy vegetation, or litter, reduces the velocity of overland flow, enhancing settling of particles. High infiltration of uncompacted soils encourages subsurface flowpaths, with resulting particulate filtering and nutrient uptake by plants and microbes.
Fish spawning habitat and fish cover	Inanga spawn amongst herbs and grasses near the upper edge of the salt wedge (usually Jan-May). Tree roots, overhanging branches and woody debris provide key habitat (hiding & resting places) for a wide variety of fish and for crayfish.
Suitable habitat (e.g., humidity, temperature, food resources) for adult phases of stream insects	Some stream insects spend extended periods (days – months) as adults in the terrestrial area. Information on their requirements is sparse, but riparian vegetation may be a key element of these species ability to persist in pastoral streams.
Shade for stream temperature	Removal of shade can result in summer temperatures that can be lethal to some invertebrates and fish, or winter temperatures that are too warm for successful trout spawning.
Shade for instream plant control	Shade removal provides light for instream plant growth, sometimes resulting in streams becoming choked and/or variations in dissolved oxygen and pH that stress invertebrates and fish.
Woody debris and leaf litter input	Riparian trees add leaf litter and wood that are an important source of habitat diversity for invertebrates and fish, particularly in silt-bed streams. Leaf litter is also a food resource for stream invertebrates.
Plant nutrient uptake from groundwater	Roots of riparian plants intercept groundwater reducing nutrient input to streams.
Denitrification N Control	Denitrifying bacteria can remove substantial quantities of nitrate from groundwater passing through riparian wetlands, venting this to the atmosphere as nitrogen gases.
Control of direct animal waste input	Preventing direct access of stock to waterways prevents hoof-damage to streambanks and direct input of nutrients, organic matter and pathogens in dung and urine.
Downstream flood control	Well-developed riparian vegetation increases the roughness of stream margins, slowing down flood-flows. This reduces the peak flows downstream but may result in some local flooding. Riparian wetlands provide temporary storage of water during rain events.
Terrestrial biodiversity	Riparian zones contain a high diversity of soil and water conditions, habitats, and food resources resulting in correspondingly diverse terrestrial plant and animal communities

4 Establishing a Sustainable Buffer of Indigenous Vegetation

While a range of species and vegetation types can be utilised for riparian management, Auckland Regional Council has specified that they would prefer to establish a buffer zone of indigenous vegetation in their guidelines for land users. The buffer would need to be wide enough to support a sustainable, self-seeding strip of native vegetation that requires little maintenance and is wide enough to minimise weed growth. Indigenous vegetation has a greater potential than exotic vegetation to establish a self-sustaining community that does not require replanting. Two approaches have been used to recommend appropriate buffer widths. Firstly, a literature review was undertaken and secondly, a field visit was made to selected sites in the Awhitu and Shakespear Regional Parks.

4.1 Literature Review

A review by Wildland Consultants Ltd of the scientific literature and technical reports that are relevant to the subject of riparian buffer width and design is presented below. The subject is separated into various topics, including sustainability and succession, edge effects, land use (rural, urban, plantation forest), and weed management.

4.1.1 Sustainability and succession

A recent report concerning waterway management on farmland (Ministry for the Environment 2000) suggests that it is difficult to state with any real certainty the ideal width for a riparian buffer zone to meet the range of desired aquatic functions. With this in mind, it would appear that the best option is to create the greatest width possible. A self-sustainable riparian strip must be of sufficient size to attract indigenous birds and insects, and be wide enough for the understorey to be protected from the climatic extremes of an edge. Natural regeneration of species such as tree ferns (*Cyathea and Dicksonia spp.*), kanono (*Coprosma grandifolia*), pate (*Shefflera digitata*), totara (Podocarpus totara) and kahikatea (*Dacrycarpus dacrydiodes*), is less likely if a protected understorey does not exist, nor are they likely to arrive if birds are not attracted to the site. The information reviewed by the Ministry for the Environment (2000) suggests that an absolute minimum width of 15-20 metres is necessary to create a sustainable example of riparian vegetation in isolation (roughly equivalent to the height of a medium-sized tree). However, a narrower planting would still contribute to indigenous biodiversity if there were other existing areas of indigenous vegetation within close proximity.

It is important for sustainability that natural succession be allowed to occur within a buffer zone. Although the extent to which a buffer zone develops towards a climax community may depend on the proximity of seed sources. A 24-year study of vegetation changes to Whangamata Stream, Lake Taupo catchment, following the establishment of riparian marginal strips, has demonstrated succession of indigenous species in a buffer zone

(Howard-Williams & Pickmere 1999). Indigenous species were planted among the pasture-grassed banks, using flax (Phormium tenax), toetoe (*Cortaderia toetoe*), hebe (*Hebe stricta*), with some red beech (*Nothofagus fusca*) and cabbage tree (*Cordyline australis*). The number of indigenous plant species present has risen continually, from six species in 1976 to 60 species in 1998. However, the width of this buffer is approximately 100 m. Stream sections with the longest planting history supported the greatest number of indigenous plant species, and in those areas without assisted planting of indigenous species, the original pasture grasses proved highly resistant to invasion. This site has a harsh, frosty microclimate, which may prevent establishment of other species. Such conditions are unlikely to be important in the Auckland Region.

A review of riparian zone ecology (Naiman & Decamps 1997) discusses models of riparian zone management. One model (Hubbard & Lowrance 1994) uses three interactive zones to provide a stream with protection from agricultural impacts. The zone closest to the waterway consists of a strip of forest trees about 10 metres wide, and serves to influence the stream environment (temperature, light, channel morphology, etc.). The next zone comprises a 4 metre width of shrubs and trees, and aims to control pollutants in sub-surface flow and surface runoff. The outermost strip, bordering on the agricultural land, is a 7 metre strip of herbaceous vegetation, and facilitates deposition of sediments. Clearly, however, choice of species will influence the sustainability of these strips. For example, if exotic grasses are utilised in the herbaceous strip, there may be some tendency for their invasion into the other strips. There are few, if any equivalent low-growing indigenous species that would resist invasion by weed species. Conversely, without maintenance/grazing, tree and shrub species may naturally spread throughout all three zones, influencing the functional efficiency of this design of riparian buffer zone.

4.1.2 Edge Effects

An understanding of the phenomena collectively known as "edge effects" is crucial when attempting to design/recommend an effective riparian buffer zone. However, this is not facilitated by the confusing and often conflicting nature of the existing information regarding the manifestation of vegetation edge effects. A review of forest edge effects is provided by Murcia (1995).

Edge effects can be divided into three types (Murcia 1995). (1) Abiotic effects involve changes in environmental conditions; (2) direct biological effects comprise changes in the abundance and distribution of species; (3) indirect biological effects consist of changes in species interactions, such as predation and competition.

Edge effects can be defined in terms of influences on microclimate and vegetation. Edge microclimate, relative to interior conditions, typically has higher light intensity, air and soil temperatures, wind speed, and vapour pressure deficit, and lower relative humidity, and soil/litter moisture. Responses of vegetation to edge environments can include increased presence of exotic plant species, altered distributions of plant species, and increased tree mortality from windthrow (Gehlhausen et al. 2000).

An investigation into microclimate and vegetation edge effects in podocarp-broadleaf forest remnants in the North Island (Young & Mitchell 1994) identified distinct forest edge microclimate regimes that were associated with differences in vegetation composition and structure. Some differences could be related to timing of germination and early establishment in different plant species. Penetration of gross microclimatic edge effects was approximately 50 metres regardless of remnant size.

Davies-Colley et al. (2000) carried out a study of microclimate gradients across a forest edge in a mature New Zealand broadleaf rainforest. They found that the gradient of microclimate near to the edge was abrupt for soil temperature and light exposure, with almost complete change over c.10 m. The gradient for wind speed, air temperature and vapour pressure deficit was less steep, with at least 40 metres being necessary to stabilise these variables with a wind direction perpendicular to the forest edge. They suggest that buffer widths of 40 metres on either side of a stream may be required to protect streams from climatic exposure.

Conversely, in a study of kahikatea (*Dacrycarpus dacrydioides*)-dominant forest stands in lowland alluvial plains of western Waikato (Burns 1997), no evidence of an edge effect was found, with regard to plant species composition, species abundance, and kahikatea diameter growth rate.

Clearly different habitats, vegetation types, vegetation architecture, and geographical location will contribute to the influence (if any) of edge effects upon the plant species and communities present.

4.1.3 Land Use

Adjoining land use will have an important influence on the width and ecological character of riparian buffers. However, there is little scientific research into the issue of buffer widths or sustainability of a linear strip of vegetation in different land uses.

4.1.3.1 Urban

Buffers located in urban areas or adjacent to residential dwellings will always have a greater risk of weed invasion as a result of garden escapes or the dumping of garden waste. This is perhaps one of the greater threats to the ecological sustainability of riparian buffers. Christchurch City Council has a long-standing waterway protection programme that involves substantial riparian buffer planting. They have defined different riparian setback distances for the various types of waterway in the city, but these are not supported by specific research (R.Barker, pers. comm.):

Utilities waterway (piped)	-	3 m
Open utilities waterway	-	5 m
Environmental asset (natural tributary)	-	7 m
New waterway	-	7 m
Upstream river	-	20 m
Downstream river	-	30 m
Hill waterway	-	10 m
Coastline (above MHWS)	-	20 m

4.1.3.2 Rural

Fencing to exclude livestock is an essential part of developing an effective and self-sustaining riparian marginal strip as trampling will effectively halt regeneration (Ministry for the Environment 2000). It is common to see groves of kahikatea (*Dacrycarpus dacrydiodes*), cabbage trees (*Cordyline australis*), kowhai (*Sophara spp.*,) and totara (Podocarpus totara) along riparian margins, exposed to heavy grazing and with no undergrowth. In these situations establishment of seedlings is unlikely, and the riparian strip will be unsustainable. Likewise, exclusion of stock is necessary where planting of indigenous species is undertaken.

Restoring riparian vegetation at sites where scrub and tree cover exists will often require more than just stock exclusion. Depending upon the proximity of suitable seed sources, replenishment planting of the interior of an existing riparian zone may be necessary for some years, to ensure the re-establishment of many species of canopy, sub-canopy and understorey plants.

Agricultural weeds (e.g. gorse, blackberry) may look unsightly in a riparian buffer zone in farmland but, if contained to limited areas by vigorous indigenous plant communities, they may pose little or no threat to the viability and sustainability of a riparian buffer. They may even provide a useful protective margin, restricting predator movement and reducing edge effects.

4.1.3.3 Plantation Forestry

Forestry as an adjoining land use to riparian buffers will have different influences on sustainability due to possible shading effects of adjacent trees and the effects of harvesting. Native vegetation can regenerate under plantation forest, but the greatest impact on sustainability will be when the plantation trees are harvested exposing the previously sheltered vegetation to climatic extremes. There appears to be no relevant research addressing whether these buffers are able to remain viable during the time it takes for the next rotation of trees to become large enough to provide shelter.

4.1.4 Weed Management

4.1.4.1 Canopy cover

Ministry for the Environment (2000) provides a number of recommendations on plant spacing. It is important to achieve a closed plant canopy as quickly as possible, to reduce maintenance costs, and to exclude invasive weeds. However, overcrowded plantings can exclude slower growing species, and facilitate weed invasion. They suggest that most colonising indigenous trees and shrubs will form a canopy within three to five years when planted at a spacing of 1.5-2 metres. Spacing wider than three metres may encourage invasion of weeds such as pampas grass (*Cortaderia jubata* and *C. selloana*) and blackberry (*Rubus fruticosus* agg.). However, smaller grasses, sedges and groundcover species may need to be planted as close as one metre.

It is important that the space requirements of mature trees should not govern the spacing regime utilised at planting time. The rapid establishment of a closed canopy is more important than the loss of some individuals due to competition for space. Wildland Consultants Ltd have planned and implemented large scale planting of indigenous species, and based on observations in the Auckland region recommend plant spacings of 0.75 - 1.1 metres to minimise weed invasion.

The degree of flooding and the resulting diversity of microhabitats that become available for colonisation can also influence the potential for weed invasion in riparian areas. A review of riparian zones by Naiman & Decamps (1997) indicates that, in general, the most species rich riparian communities support the greatest proportion of exotic species, both along rivers as a whole and within specific sites. This suggests that the most diverse riparian communities are the most likely to be invaded by weed species (see also Levine 2000), which was attributed to the environmental heterogeneity produced in riparian areas after moderate floods.

4.1.4.2 Maintenance

Quinn et al. (1993) review the effectiveness of riparian buffer strips in the management of stream systems. It is stated that planting of indigenous (and exotic) trees and shrubs can reduce weed infestations, partly because their successful growth relies upon initial removal of weeds, and also because they will eventually shade out any weeds.

Restoration of a riparian strip from open pasture is particularly difficult, as exotic pasture sward species can be extremely aggressive competitors, especially in fertile conditions. Ministry for the Environment (2000) recommend herbicide spraying at least two months prior to planting, and regular weeding, up to 3-4 times per growing season in warm, fertile sites. Circles of 1 metre diameter or more should be cleared around each planting point prior to planting, and gorse and blackberry (and kikuyu) in particular need to be removed altogether if possible.

Effective control of pest animals will often be necessary before planting. Less palatable species can also be planted along strip edges, where rabbits and hares often have easier access. Pukeko may need to be removed from a site, or alternatively, the use of larger plants (40 cm high seedlings) can overcome the problem (Ministry for the Environment 2000).

Riparian strips will encourage the growth and dispersal of weeds if trees and shrubs are planted too far apart, or are poorly maintained, resulting in gaps in plantings (Ministry for the Environment 2000). Relatively close plantings, and replacement of dead seedlings, will facilitate rapid weed exclusion, however site maintenance will be necessary, at least in the early years of planting. The need for weed control will diminish substantially as soon as a canopy starts to form.

Van Kraayenoord & Hathaway (1986a & b) and Pollock (1986) provide further detailed information on planting densities, thinning and pruning, climatic limitations of recommended species, and procedures for control against weed infestations.

4.2 Examples of Riparian Planting in the Auckland Region

In addition to reviewing the scientific literature as an aid to recommending sustainable riparian buffer widths, the project team also examined existing examples of riparian planting in the Auckland Region. A number of sites were visited at Awhitu and Shakespear Regional Parks, in August 2000. Width of planting strips at these sites varied from c.5 metres to more than 20 metres, and age of planting ranged from one year old to c.30 years. Site descriptions have been grouped according to planting width.

4.2.1 5-6 metres wide

Awhitu Regional Park Site 3

This is a 6 metre wide planted strip of mixed indigenous species, providing a wind break for a camp ground. The planting is approximately 20 years old, displays good canopy closure, (canopy c.6 metres high), and has a thick litter layer. Weed incursion extends approximately 1 metre in from both edges, or about one third of the width of the strip.

There are few weeds in the adjacent pasture, and it is probable that adventive species would be far more abundant in the planted strip if the adjacent pasture was weedier. Planted species include lemonwood (tarata; *Pittosporum eugenioides*), *Olearia arborescens*, broadleaf (kapuka; *Griselinia littoralis*), ngaio (*Myoporum laetum*), flax (harakeke; *Phormium tenax*), and pohutukawa (*Metrosideros excelsa*).

4.2.2 c.10 metres wide

Shakespear Regional Park Site 1

The vegetation community consisted of remnant manuka (*Leptospermum scoparium*) roughly 4-5 metres high with additional planted species, extending 8-10 metres either side of a small stream. Planted species include kauri (*Agathis australis*), broadleaf, karo (*Pittosporum crassifolium*), mapou (*Myrsine australis*), totara (*Podocarpus totara*), akeake (*Dodonaea viscosa*), with a thick sward of the indigenous grass *Microlaena stipoides*. The overall cover of woody species varies markedly from 50-80%, and exotic grasses (cocksfoot; *Dactylis glomerata*) extend 1-2 metres in from the margins.

Awhitu Regional Park Site 2

This site was an extensive planting of manuka (c.10 metre width) on higher ground above a stream, and adjacent to pasture, which displays generally good canopy closure (60-100%) at 4 years old, with plants reaching 2.5 metres in height.

- 60% canopy cover: associated with a thick weedy ground layer of Yorkshire fog (*Holcus lanatus*), with occasional cocksfoot (*Dactylis glomeratus*), white clover (*Trifolium repens*), and lotus (*Lotus pedunculatus*).
- 100% canopy cover: very sparse groundcover of weeds, with some litter layer development. Occasional woolly nightshade (*Solanum mauritanum*) occurs in the canopy.

Awhitu Regional Park Site 4

This is a 10-year old (5 metre high) planting of manuka, c.10 metres wide, edging an artificial pond. This site exhibits virtually 100% canopy closure, with dense shade and bare ground. Occasional weed incursions were observed, including inkweed (*Phytolacca octandra*). Limited regeneration of self-seeded *Coprosma robusta*, *Doodia media* and turawera (*Pteris tremula*) was also noted.

Awhitu Regional Park Site 5

This is a c.10 metre wide stand of mixed planted species (25-30 years old), on both sides of a small stream, with a canopy height of approximately 10-14 metres. There is good canopy closure (c.70-80%) and a thick litter layer. Planted species include titoki (*Alectryon excelsus*), puriri (*Vitex lucens*), kauri, rewarewa (*Knightia excelsa*), rimu (*Dacrydium cupressinum*), miro (*Prumnopitys ferrugineus*), totara, tanekaha (celery pine; *Phyllocladus* *trichomanoides*), kawaka (*Libocedrus plumosa*), kahikatea (*Dacrycarpus dacrydiodes*), cabbage tree (ti kouka; *Cordyline australis*), silver fern (ponga; *Cyathea dealbata*), and houhere (lacebark; *Hoheria populnea* var.). The understorey now includes silver fern, totara, and houpara (*Pseudopanax lessonii*), with some self-sown houhere, cabbage tree, and flax. Occasional weeds are also present throughout the planting, including woolly nightshade, pampas, and lillypilly (*Acmena smithii*).

Shakespear Regional Park Site 2

This site supports a c.10 metre wide mixed planting (approximately 30+ year old), including some large spreading pohutukawa. There is evidence of regeneration of indigenous species, including many seedlings of *Coprosma robusta* and mapou. Occasional weeds are scattered through the planting, with some old, somewhat derelict clumps of gorse (*Ulex europaeus*), and pampas (*Cortaderia selloana*) is present in gaps.

4.2.3 >15 metres wide

Shakespear Regional Park Site 3

This provides an example of a natural cover of manuka in a gully that has been fenced off from the adjacent pasture for some time. The vegetated strip stretches approximately 15-20 metres on either side of a small stream. The manuka is fairly mature, and canopy cover is only c.60-70%, with a high degree of canopy collapse causing the vegetation to open up. There is abundant regeneration of manuka, *Coprosma robusta*, cabbage tree, mingimingi (*Leucopogon fasciculatus*), hangehange (*Geniostoma rupestre* var.). Groundcover consists of abundant *Microlaena stipoides*, and seedlings. There are a few large patches of gorse, and occasional pampas. Bracken (*Pteridium esculentum*) is present on the edges.

Awhitu Regional Park Site 1

A 20+ metre wide strip of 1-2 year-old planting is dominated by manuka, with occasional kanuka (*Kunzea ericoides*), and *Coprosma robusta*; located alongside a small stream close to its entry to the sea. One year-old manuka/kanuka was c.1 metre high, and two year-old manuka/kanuka was c.1.8-2 metres in height. Full canopy closure will not occur for another 2-3 years. A thick sward of weedy grass species is present around the bases of the plants, dominated by Yorkshire fog (*Holcus lanatus*) and narrow-leaved plantain (*Plantago lanceolata*), with occasional tall fescue (*Festuca arundinacea*). Kikuyu (*Pennisetum clandestinum*) is beginning to become a problem along the edges of the planting.

Shakespear Regional Park Site 4

This is an old planted riparian strip approximately 20 metres across. Planted species include poplar (which have recently been poisoned), cabbage tree, rimu, puriri, kauri, karo, kawaka, *Coprosma robusta*, mapou, and *Cyperus ustulatus*. A thick sward of *Microlaena* *stipoides* is present, except under puriri, where there are seedlings of kawakawa (*Macropiper excelsa*), *Cyperus ustulatus* and *Muehlenbeckia complexa*. Canopy closure is varied, and there is a large open area on one side of the stream with abundant weedy species, including creeping buttercup (*Ranunculus repens*) and *Polygonum spp*.

4.3 Assessment of Buffer Widths for the Auckland Region

Based on these examples of planted riparian buffer strips, an assessment of the relative value of three different buffer widths, with regard to producing self-sustaining, low maintenance, indigenous vegetation is presented below. Factors that were considered included canopy closure, weed invasion and natural regeneration.

1) 5-6 metres wide

   The narrowness of this buffer width makes it unlikely that canopy closure will exclude light sufficiently to prevent weed invasion from being a continual problem. On-going maintenance will be required to keep a buffer of this width weed free, and natural regeneration of indigenous species is likely to be limited.

2) c.10 metres wide

   Whilst weeds are still likely to be present, the greater width of this buffer means that once a good degree of canopy closure is attained, low light levels should effectively exclude most weeds from the majority of the buffer. The marginal 1-2 metres are likely to suffer from long-term weed infestations, which could have the potential to spread to the interior wherever canopy gaps occur. However, indigenous vegetation succession through natural regeneration should result overall in a relatively maintenance-free riparian buffer strip.

3) 15-20+ metres wide

   Greater width of the riparian buffer strip should ensure that marginal weed infestations affect only a small proportion of the buffer strip, further reducing the probability of weed incursion into the interior. The greater buffer width should reduce the need for maintenance, and enhance the succession of indigenous vegetation, maximising the likelihood that the buffer strip will support self-sustaining indigenous vegetation with virtually no maintenance required.

It should be noted that all of the scenarios considered above are based on examples in Auckland Regional Parks and that all of the sites have probably been subject to ongoing weed control, at least on the margins of the planted strips. Only limited examples of narrow buffers (5-6 metres) were inspected but it was clear that with incursion of weeds commonly extending 1-2 metres into the margins of a riparian buffer, 5 metres is likely to be too narrow in most cases. Having said that, any riparian buffer is better than no buffer, and 5 metres on either side of small waterways will in effect produce a 10 metre strip of vegetation if canopy closure is achieved over the stream.

4.4 Discussion

There is relatively little definitive published or unpublished literature on riparian zone width and the sustainable management of riparian vegetation. This conclusion has been derived from a literature review and from discussions with other ecologists working on riparian management and research. Other authors have also reached similar conclusions, including a Ministry for the Environment (2000) review which, in answer to the question "how wide do I need to make the riparian planting?", concluded "as wide as you are prepared to make it."! This same report suggests that an "absolute minimum" width should be "in the order of 15-20 metres (and possibly more), roughly equivalent to the height of a medium sized tree".

Edge effects are an important consideration for sustainability of riparian buffer zones. The published (and unpublished) evidence of edge effects in New Zealand vegetation is very limited, and is somewhat contradictory. There is published evidence of edge effects extending c.50 metres into forest margins, and we have observed forest remnants where visible edge effects extend c.10-20 metres (WBS pers. obs.). Other studies have found no evidence of edge effects in New Zealand forest remnants. Widths of 30-50 metres have only limited potential application to riparian zones unless particularly wide strips are being considered, say >100 metres in width, and only for forest vegetation. This width is based on the assumption that a waterway margin also provides an edge, as well as the outer margin of a vegetated riparian buffer. There is no information on edge effects in non-forest vegetation such as flaxland or scrub. Relatively open vegetation, such as shrubland, is in some respects all edge, since any canopy gaps provide establishment opportunities for invasive weeds (and other species). The influence of edge effects will decrease as vegetated buffers develop towards a closed canopy.

New Zealand experience to date generally tends to indicate that particularly wide forested riparian zones would be required to obtain a core zone with no edge effects. It must also be noted that even if this were the case, the outer margins, say 10-50 metres, would still likely be subject to edge effects. These effects are likely to be evident on both sides of a buffer, on each side of a waterway. However, if a waterway is relatively narrow, up to 3.5 metres after which lighting has been found to increase rapidly (Davies-Colley & Quinn 1998), and vegetated on both sides, edge effects may be reduced as a result of the combined width of the riparian zones.

This leads to the inevitable conclusion that if riparian buffers are used, at least subtle edge effects may always be evident, which may indicate the need for a different conceptual approach. Rather than edge effects, perhaps the major consideration should be the relative *permeability* (or vulnerability) to invasion by ecologically threatening weed species (rather than exotic species *per se*.) and the *sustainability* of indigenous riparian buffers. Sustainability is a function of the amount of active management required to retain a healthy riparian buffer dominated by indigenous species.

Permeability to weeds during the establishment phase of a riparian buffer, is a function of the degree of canopy closure and the time taken to achieve closure. More rapid closure will be obtained with dense (0.75 - 1.1 metre) spacing of fast growing bushy species such as manuka, kanuka, and *Coprosma robusta*.

It is evident from the field component of this project that exotic species will persist in a 1-2 metre strip along the outer margins of a riparian buffer. Five metre buffers may be sustainable on very small streams where complete canopy closure is obtained, but 10 metre buffers are likely to be a minimum width to ensure improved viability and sustainability of the buffer. Wider strips (say 20 metres on each side of a stream) will be better still.

4.5 Summary

A summary of the issues that need to be considered in relation to the determination of the width and sustainability of riparian buffers is set out below:

- Five metre buffers should only be used on very small waterways or where there is no other option (a narrow buffer is better than no buffer).
- Ten metres could be used as a general guideline for a minimum buffer width that is sustainable for native vegetation.
- Larger buffers (20+ metres) will be required on large waterways (rivers) where edge effects are present on both edges of the buffer on each side of the stream.
- A good understanding is required of vegetation ecology, particularly successional sequences in different situations, and weed ecology. Some weeds are serious threats to the ecological sustainability of riparian buffers while others will eventually be replaced with indigenous species as a succession develops.
- "Permeability" of the vegetated buffer is a key issue. The intention should be to establish a closed canopy from an early stage, to minimise the risk of weed invasion. Close plantings, at spacings of c.1 metre, should be used to ensure rapid canopy closure, to minimise the risk of weed invasion.
- Weed control (i.e. removal) will be critical prior to the establishment of plantings.
- Plantings will need to be selected carefully to suit the landform and substrate. Careful consideration should be given to the species that would occur naturally on particular types of site.
- Fast growing indigenous species should be planted. Simple suites of species should be used, reflecting likely natural successional sequences. In the Auckland area, these planting suites could be based largely on manuka and kanuka with lesser amounts of other species such as *Coprosma robusta*, flax, titoki, puriri and pohutukawa.
- Locally sourced plant material should be used, suitably hardened prior to planting to maximise the likely success of any planting operation and to reduce the likelihood of subsequent weed invasion or the expansion of existing populations.
- Monitoring and follow-up maintenance will always be a key issue with the establishment of riparian buffers.
- Further work is recommended on the documentation (and publication) of experience with the establishment and management of riparian buffers. Indigenous riparian

buffers have been established widely in New Zealand (e.g. Auckland, Waikato, Bay of Plenty, Christchurch) yet little of this experience is readily available as published or even unpublished reports.

5 How wide should a Buffer Zone be to fulfill Aquatic Functions?

There are few studies that have specifically addressed the issue of how wide a buffer zone needs to be to protect stream health. Most research has focused on the ability of buffer zones to trap sediment and nutrients, in particular nitrate (N) and phosphorus (P).

The consensus in the literature is that grass buffer strips are effective at filtering sediment and sediment-associated pollutants (particulate P and N) from surface runoff. However, nitrate removal from subsurface flows is considered to be greater in forested buffers partly through uptake by plants (Fennessy & Cronk 1997, Martin et al. 1999). In a summary of experimental studies of nutrient removal by both grass and forested buffers, Fennessy & Cronk (1997) found that almost 100% of nitrate can be removed by buffers 20 – 30 metres wide, and buffers as small as 10 metres wide commonly removed greater than 50% of the nitrate input.

Where a grass buffer strip has been designed sensibly to treat sheet flow rather than channelised flow, most researchers report sediment removal occurs within a few metres of the upslope boundary (Barling & Moore 1994, Fennessy & Cronk 1997). John Quinn (NIWA, pers. comm.) has established some grass filter widths that would effectively remove suspended solids in surface runoff in Waikato pastoral catchments for riparian areas classified by topography (Table 2). Estimates were obtained from methods in the DoC/NIWA guidelines and data from Quinn (1999) and McLaren & Cameron (1990). Most buffer widths necessary were found to be < 10 m. Australian guidelines recommend a width of 10 metres for a forest buffer on low gradient land and 5 metres for a dense grass buffer on steeper riparian land (Prosser et al. 1999).

The effectiveness of grass buffer strips as filters for nutrients and sediment is less in hilly terrain than flatter land as overland flow is concentrated in natural drainage-ways and the flow that crosses the buffer strip is not uniform. In this case grass buffers may need to extend further inland following a drainage way, resulting in a non-uniform buffer width along the length of the stream. Wetland areas and seeps that intercept drainage-ways before the flow enters streams are also likely to be very important in hilly areas for sediment trapping and denitrification.

There is little information on the width of buffers necessary to stabilise stream banks, although it is likely that most benefit to stream banks will occur within the root zone of a single row of trees. Bank erosion is strongly influenced by the density and type of riparian vegetation cover (Rutherfurd et al. 1999). For streams with low banks (<0.5 m), grasses and other dense groundcovers may stabilise overhangs through their root systems, although there is little protection if the undercuts occur below the root zone. Large trees can stabilise higher banks but not all trees are suitable for this purpose (Collier et al. 1995). Trees with rooting depths equivalent to at least the height of the bank will be necessary to stabilise bank collapses. Indigenous plants may not be as vigorous as willows or poplars for stabilising rapidly eroding stream banks. However, indigenous vegetation is best for long term stability and sustainability, as exotic species commonly require ongoing management.

In Australia, Davies & Nelson (1994) found that small buffers (<10 metres wide), retained after forest harvesting, did not significantly protect streams from changes in algal, macroinvertebrate and fish biomass and diversity. Buffer widths of >30 metres appeared to provide protection from short-term impacts in a variety of forest types and geomorphologies. However stream temperatures were only increased when buffer widths were below 10 m. The buffer width required to decrease stream temperatures may be less than that required to provide a microclimate similar to forested conditions. A single line of trees can provide about 80% shade to streams when the trees have grown tall enough to achieve canopy closure (Collier et al. 1995). However, Brosofske et al. (1997) concluded that a buffer of at least 45 metres was necessary to maintain a natural riparian microclimate after harvesting of Douglas fir and western hemlock. Research in New Zealand suggests that a buffer of 40 metres may be necessary to protect streams from climatic exposure (Davies-Colley et al. 2000).

Table 2: Estimated grass filter widths required for removal of suspended solids in surface runoff for Waikato pastoral catchments. L = low, M = moderate, H = high. (From Dr J. Quinn, NIWA, unpublished data and Quinn (1999)). Filter widths may need to be widened by 1 metre if cattle are grazing under fences.

Riparian Class	Slope category	Clay category	Slope length (m)	Filter width (m)
Lower floodplain	L	H	20	1
Entrenched floodplain	L	M	30-50	1
Upper floodplain low relief	L	H	30-100	1-9
Upper floodplain high relief	L	M	30-100	1-2
V-shaped entrenched	M	H	50-150	2-6
V-shaped hill valley	M	M	50-150	5-15
U-shaped hill valley	L	M	30-100	1-2
Shallow V-shaped rolling	L	M	50-150	1-3
Vegetated drain	L	M	30	1
Headwater wetland	L-M	L-H	30-40	1-4

6 Aquatic Functions met by Recommended Buffer Width for the Auckland Region

The Auckland region is characterised by extensive urban development and small catchments, where stream systems are typically short and drain into the sea, tidal harbours or estuaries (Wilding 1996). Many of the region's streams have been adversely affected by total removal of adjoining vegetation, stock damage and piping or channelisation of the watercourse (ARC 1995). Many urban streams are severely degraded by discharges such as sewer overflows, urban stormwater and litter (ARC 1995).

The outcome of the investigation into the buffer width necessary to achieve sustainable indigenous vegetation was that a buffer width of >10 m was most likely to be self-sustaining, provided that stock are excluded from the buffer zone by fencing and that active weed control is practised. In the absence of site based classification for any part of the Auckland region, assessment of the effect of a buffer zone width of 10 – 20 m can only be applied in a broad sense based on the common soil and topography characteristics, stream and catchment sizes, and land uses of the Auckland region.

Soil types of the Auckland region are predominantly leached clays and volcanic soils (Pohlen 1979). Ken Becker (ARC, pers. comm.) has classified the region's soils into four main types: western sand dunes, upland clay, lowland clay and volcanic soils.

According to Campbell et al. (1982), the Hoteo, Kaipara, Rangitopuni and Wairoa rivers are the most important natural resources in the region. The Kaipara and Wairoa rivers and several smaller streams in the urban Auckland area have been identified as potential flooding hazards to the adjacent land (Regional Growth Forum 1997).

There are two factors of the proposed riparian management that are important to consider in addressing whether the buffer zone will achieve the goal of protecting stream health; (1) the choice of indigenous trees as riparian vegetation and (2) whether a width of 10 – 20 m is satisfactory. The aquatic functions that will be achieved with the proposed riparian management are outlined below for each main land use in the Auckland area and summarised in Table 3.

6.1 Rural (farming and lifestyle)

- Exclusion of stock will eliminate stream bank damage from trampling and nutrients and pathogens that result from the direct input of faeces.
- Stream bank stability will be enhanced to a certain extent, although indigenous species are not generally as effective as vigorous growing poplars and willows for urgent stabilisation. However, exotic species are unlikely to be as sustainable in the longer term. Tree ferns on stream edges provide good dense roots and many indigenous shrub species have woody roots and deeper rooting than introduced

grasses. However, dense shading from plantings designed to keep weed growth down may suppress groundcover growth and stream banks may be less cohesive without this support.

- Research has shown that shading of pasture streams is likely to change stream morphology as pasture grasses are shaded out and bank erosion leads to channel widening (Davies-Colley 1997). This may result in increased sediment yields and lowered water clarity for sometime (several years to decades) until the stream channel stabilises. It may be possible to design plantings in lowland areas where semi-deciduous indigenous trees such as kowhai and tree fuschia are used near banks, or some coniferous species as opposed to broadleaved plants, to allow greater light to the stream. However, there has been little research done on the advantages and disadvantages of different types of indigenous plants as riparian tools.
- The planned buffer zone will not act as effectively as a dense grassy filter strip designed to remove sediments and contaminants from overland flow. However, research suggests that forested buffers are effective in soluble nitrate removal. While a >10 m buffer of trees may achieve some filtering of nutrients and sediment, a grassy filter strip located upslope from the vegetated buffer could be a viable management option to most effectively remove sediments and nutrients and slow flood overland flow. This strip need not be as wide as a buffer with trees and could be mown for hay by the landowners as this enhances dense grass growth. In steep, hilly terrain, surface runoff is likely to be concentrated into rills and natural drainageways produced by the irregularity of the terrain. Where this is the case, filter strips are less effective and the buffer zone could be extended up into the natural drainageways to increase the chance of trapping sediments and nutrients and slowing overland flows before reaching the stream.
- Shade will be provided by the planned indigenous plantings. In small streams flaxes, sedges, and native grasses may be adequate to shade the stream in cases where stream banks are stable and do not require the anchoring of large trees. Once the canopy has closed over the stream channel shading will be >90% of open sites, although this will be less in large streams where canopy closure does not occur. Indigenous tree species, being generally evergreen, provide dense shade. The benefits of indigenous riparian plantings are that streams will return to more natural conditions, indigenous biodiversity is enhanced, stream temperature will be lowered, and algal growth will be reduced. However, dense shade may impact on the growth of groundcover species that can stabilise soils and filter sediment and nutrients, and on the growth of beneficial macrophytes within the water column. Recent research on the role of macrophytes in lowland streams suggests that certain types, particularly submerged macrophytes, are beneficial by providing habitat for invertebrates, oxygen to the water, and removing nutrients. 50% average shade has been recommended to maintain macrophytes at non-nuisance levels. However, the benefit of dense shade is that it may facilitate the growth of native macrophyte species (Dr M. Scarsbrook, NIWA, pers. comm.).
- Temperature decreases are likely to occur if the planted buffer zones extend over several hundred metres of shallow stream systems. This will be most effectively achieved by dense plantings in headwater streams (first and second order) rather

than 3rd or 5th order streams, as the thermal inertia is less in shallower streams. Air temperature and humidity can affect stream temperature as well as shade. The width of buffer zones will affect air temperature and humidity, and a thin buffer of trees will be unlikely to lower either one. However shade has by far the greatest effect on temperature and one line of trees can provide about 80% shade streams when the trees have grown tall enough to achieve canopy closure.

- Planted buffer zones will provide carbon inputs (leaf litter and woody debris) as food resources and habitat. It may take many decades before appreciable amounts of woody debris enter streams, so incorporating fast growing woody trees for a supply of debris may increase this. Stable streams are more likely to retain leaves and therefore these will have greater time to become conditioned and palatable to invertebrates. Planting soft-leaved species in unstable streams will provide more readily obtainable energy to the stream system.
- Headwater and riparian wetland areas and seeps can reduce nitrate concentrations in water that is channelled through them before entering streams. Landowners should be encouraged to fence off riparian wetlands, protect them from drainage and to encourage the development of indigenous wetland plant species. Tree planting near wetlands should be undertaken with the knowledge that trees can dry out wetland areas so a buffer of flaxes or species that will not absorb most of the water from the wetland may be useful between the wetland and riparian tree plantings.
- Large lowland rivers may need large trees for bank stabilisation and shade, and the vegetation may need to be tolerant of flooding. Kahikatea could be planted in association with a species such as manuka, to provide canopy cover and exclude weeds. Manuka is also very tolerant of wet sites and root submergence. Lowland rivers may also have important functions providing tidal habitat for estuarine fish and birds, and providing good spawning habitat for whitebait, such as grasses and herbaceous groundcovers, near the upper extent of the salt wedge.

Table 3 Recommended riparian management of a fenced zone of 10 - 20 m and planted in indigenous vegetation.

Riparian zone functions	Met by proposed riparian management	Comments
Stream bank stability	Yes	Initial destabilisation during transition from pasture to indigenous forest may occur
Filtering overland flow of sediment and pollutants	In part	Grass buffers generally better. Shading may reduce groundcover in indigenous forest
Fish spawning habitat and fish cover	Yes	
Suitable habitat (e.g., humidity, temperature, food resources) for adult phases of stream insects	In part	Research suggests buffers of >40 m may be required to achieve forest interior conditions
Shade for stream temperature	Yes	
Shade for instream plant control	Yes	Although excessive shade can limit growth of some submerged macrophytes that are beneficial particularly in lowland streams; shade may benefit native macrophytes
Woody debris and leaf litter input	Yes	Although woody debris may take many years to enter stream
Plant nutrient uptake from groundwater	Yes	Trees more effective than grasses
Denitrification of N	Yes	If riparian soils and wetlands protected
P retention	In part	Better for particulate than soluble P. Absorption of P by buffer is finite and buffer may become saturated
Control of direct animal waste input and damage to banks	Yes	With fencing
Downstream flood control	Yes	Vegetation roughness
Terrestrial biodiversity	Yes	

6.2 Forestry

- Most production forests in the Auckland region are found on sand and clay soils, except for the forest near Hunua, based on maps of land use and geology in the Auckland region. Forestry in the Auckland region is not associated with any large, lowland rivers. Therefore, the streams are likely to be small, mainly headwater streams, and draining small, hilly catchments.

- Nutrient additions to streams within production forests are not believed to be high enough to cause significant water quality problems in New Zealand streams, except where nutrient-rich treated wastewaters are sprayed in forests (Boothroyd & Langer 1999). Sediment intrusion into waterways from forest harvest and roading activities is, however, a major impact on stream water quality. The amount of sediment lost from a catchment depends on site factors such as slope, soil type, and harvesting operations, but in general, road and landing-area construction are believed to be the major sources of sediments from forests (Boothroyd & Langer 1999). Research with vegetated filter strips and simulated rainfall indicates that buffer widths of less than 10 m are effective at trapping sediment as most of the sediment is trapped in the first 2 m (Fransen 2000).

- Buffer widths of 10 or 20 m may fulfil many of the stream temperature, shade, and instream habitat functions as outlined above for rural streams. However, buffer widths below 10 m have been found to be inadequate for retaining stream communities in their preharvest condition in Australian streams (Davies & Nelson 1994).

- A riparian zone decision support system is currently under development by NIWA and Forest Research to define a procedure for determining the applicability of riparian management to production forest environments. Many forestry companies are developing, or have developed, their own riparian management zone guidelines. Most Regional councils have opted for non-regulatory methods for riparian management, such as provision of information on riparian zones and education programmes aimed at the industry. Of the councils that have produced guidelines with rules specific to riparian management, none have designated widths for riparian buffer zones (Boothroyd & Langer 1999).

- Nevertheless, buffer zone widths in conjunction with best management practices have been suggested in guidelines for forest industries overseas (Boothroyd & Langer 1999). Riparian zone guidelines from various states in America range from 7.5 to 100 m buffers but are commonly suggested to be 15 – 30 m depending on the type of stream. Streams are classified by size, importance to human use, wildlife and fisheries, or by substrate and channel morphology, in order to avoid adverse water quality and mass erosion. Buffer widths are often extended to include wetlands or ponds adjacent to the stream. Buffer widths in Britain are determined by risk of sediment movement and the streams are classified by size. Headwater streams <1 m = 5 m buffer; 1 - 2 m wide = 10 m buffer, and > 2 m wide = 20 m buffer.

- Before guidelines are set for forestry in the Auckland region, we strongly suggest consultation with the forestry companies and forest industry on the management practices and riparian management guidelines that may already be in use.

6.3 Urban

- The main uses for riparian buffer zones in Auckland urban areas will be to:
  - Provide vegetation roughness to slow bank overflow during floods; increased amounts of vegetation in the catchment will also aid interceptance of rainwater
  - Provide instream habitat for invertebrates and fish, including spawning habitat for inanga
  - Provide shade for light and temperature control
  - Improve aesthetics of urban streams for enhancement of urban areas and human recreation that will hopefully discourage littering (or discourage access to the stream)
  - Stabilise banks in streams where the banks have not been artificially stabilised.
- A 10 or 20 m buffer of native forest vegetation may be an achievable goal in new subdivisions, but is unlikely to be achieved in all existing urban areas. However, the type of vegetation that could be used in a buffer to meet the objectives above may not require 20 m to be sustainable. For instance, a dense planting of native grasses, sedges and flaxes may be preferable to act as a filter for overland flow. These species would be able to regenerate in a lighter environment than native forest species and may not be affected by edge effects. Therefore a 5 m, densely planted buffer that resists weed invasion, with taller, light tolerant native species nearer the stream banks for shade and stabilisation, may be a viable option in urban streams.

7 General Guideline versus Site Specific Assessment

Many authors stress the importance of identifying source areas of run-off, soil characteristics, topography, vegetation and regional weather before implementing riparian management (Barling & Moore 1994, Collier et al. 1995). However there is some merit in establishing a guideline width for a buffer zone that will achieve most functions to protect stream habitat and water quality and be easily implemented by land users. The danger of a general rule is that the problems associated with land use can be very site specific and the buffer zone may not alleviate the problems in all cases. Research on the effectiveness of buffer zones is generally lacking and unrealistic expectations may be created by producing a "magic width" that will be able to address the multitude of impacts from land use on riparian zones.

The approach that the Auckland Regional Council has taken is to (1) determine that a buffer of native riparian vegetation is likely to be long lived and self-sustaining and (2) seek information to determine the width that would be required to keep a sustainable, regenerating buffer with minimal maintenance. This approach goes a long way to addressing terrestrial biodiversity issues and landscape enhancement, as well as stream health. The choice of a buffer zone of indigenous, regenerating vegetation may also avoid problems of replanting in the future that are likely to be necessary with exotic species like willows and poplars. However, pre-setting the type and width of a buffer reduces the flexibility of riparian management. For instance, some small headwater streams may not require a buffer of 10 m on either side to protect stream functions, but this width may still be required to allow regeneration of the vegetation. Similarly, in some cases trees may be unsuitable, i.e. where it is desirable to protect riparian wetlands or where dense grassy swards are required to filter overland flow. Specific limitations are outlined in 'Conclusions' below. A native forest buffer also excludes the landowners from developing forest buffer zones using income generating species such as those employed in indigenous systems of tropical agroforestry where non-timber products (fruits, nuts and ornamentals) can be harvested (Robles-Diaz-de-León & Kangas 1999).

The alternative is to conduct more detailed site-specific assessments following the DOC-NIWA guidelines. This could be achieved by providing knowledge and information to landowners so that they can make educated decisions on questions such as where to place fences, and which types of vegetation to plant for certain sizes of streams. On a coarse level, council staff could use GIS methods to establish slope lengths and angles within farming catchments, and with an estimation of clay and drainage types would then be able to apply the model outlined in the DOC-NIWA guidelines for establishing widths of grass filter strips. Using the DOC-NIWA guidelines allows better resolution and more focussed riparian management, than applying a set width. However, the model for estimating filter widths does not take into account patterns of overland flow and may be irrelevant for steep, hilly catchments.

In conclusion, the establishment of native vegetation for riparian management is an excellent proposal for terrestrial biodiversity and long term sustainability, and a buffer width of 10 - 20 m should meet most of the aquatic functions provided by riparian vegetation. However, there should always be room for flexibility (particularly where the proposed riparian management is inappropriate as outlined below) and sound knowledge of the issues involved in riparian management should be included alongside the suggested buffer width in the Auckland Regional Council guidelines.

8 Conclusions

Riparian buffer zones are not a substitute for good land management to minimise contaminant loadings, but they can be a key element of integrated sustainable catchment management. Buffer widths of c. 5 m are unlikely to be self-sustaining and weed control may be a significant problem. A buffer width of 10 - 20 m on either side of the stream has been recommended from this report to support sustainable native forest vegetation, and this width should protect most aquatic functions. However, flexibility should be allowed for in terms of the aims of riparian management and the types of native vegetation to be planted. The limitations of a vegetated buffer of native trees that is 10 - 20 m wide are outlined below:

- Active weed management may be necessary at the land use edge of the buffer, and to control shade tolerant weeds.
- Quick establishment of closed canopy cover is necessary to reduce the permeability of the buffer to invasion by weeds. Plantings should be dense, 0.75 – 1.1 m apart.
- Indigenous tree species will shade the banks of small pasture streams that contain stored sediment. Streams may widen to the widths seen in native forest streams under dense shade and this could lead to significant amounts of sediment being released downstream until a new channel equilibrium is reached.
- Microclimate conditions equivalent to those of forest interiors may not be achieved with buffers smaller than 40 m.
- Headwater and riparian wetlands should be protected from stock damage (fenced) as they are important for denitrification, and planted in wetland species rather than tree species. Trees may either dry out the wetland or shade it out, resulting in a loss of sediments downstream.
- Small streams with low banks may not need trees for shading and stabilisation. Therefore tall grasses, sedges and flaxes may provide the functions of indigenous tree species and require less width for sustainability.
- Buffer widths for larger rivers may need to be larger than 20 m as wide rivers may cause edge effects at both the stream and land use edges of the buffer reducing the sustainability of a strip of vegetation.
- Types of vegetation suitable for urban buffer zones may not require a width of 10 m to be sustainable and regenerating. (e.g. dense grasses with row of tall, light tolerant native trees near stream banks for shade and stabilisation).

9 Acknowledgements

Useful information and advice has been provided by Sarah Beadel (Wildland Consultants Ltd.), Colin Meurk and Bruce Burns (Landcare Research), and Rachel Barker (Christchurch City Council), and Auckland Regional Council staff (John Maxted, Tim Lovegrove, Ken Becker, Tony Thompson). Ian Boothroyd, John Quinn and Kevin Collier (NIWA) provided discussions that were helpful in the formation of this report.

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