Manaaki Whenua
Landcare Research

# Riparian setback distances from water bodies for high-risk land uses and activities

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# Riparian setback distances from water bodies for high-risk land uses and activities

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# Summary


## Project and client

This project reviews and summarises the scientific evidence to define suitable distances to set back high-risk land uses and activities from water bodies. The review was commissioned by the Tasman District Council (TDC) to provide guidance for water management plan changes, and to support implementation of the Government's 2020 Essential Freshwater package, including the new Resource Management Act (RMA) section 360 stock exclusion regulations, which prescribe a minimum riparian setback of 3 m from defined water bodies.

This review of evidence supporting riparian setbacks (buffer widths) is intended to:

- help define appropriate regulatory response options for setbacks in TDC's regional plan
- inform discussions and education with industries and communities to define agreed setback good practice to manage freshwater risks from land-use practices and stock access, and obtain buy-in to implementation
- be used as supporting information for RMA plan changes in section 32 evaluation, and through the Schedule 1 consultation process.

## Methods

A literature review was completed, focusing on New Zealand research, guidelines and papers, but including key international literature on the effectiveness of riparian setbacks. The review adopts a catchment-scale approach whereby priority riparian functional objectives must first be defined.

The report reviews riparian setback widths from water bodies that would achieve each of the following six functional objectives:

1 reduce nutrient and other contaminant inputs via overland and subsurface flow

2 improve light exposure and water-body temperature regimes of water bodies

3 increase freshwater ecosystem health and terrestrial and aquatic habitat diversity, and improve inputs of terrestrial carbon to water bodies

4 improve channel and bank stability

5 pass and attenuate flood flows

6 provide for recreational, cultural, aesthetic and landscape values.

## Results

Riparian setbacks are just one component when designing interventions that will achieve agreed catchment outcomes, such as acceptable water quality and biodiversity outcomes. Because of the link between water bodies and their catchments, desired catchment objectives such as improved water quality and stream habitat will require improved land

management practices, including riparian management. One way to implement such practices would be through farm environment plans.

Riparian setbacks should be tailored to water body, farm and catchment scales to maximise their benefits and minimise costs. The costs of setbacks are heavily influenced by fence type, the extent, type and density of planting, the level of short-term weed control required, and the productivity of 'retired' buffer land.

Given the catchment management approach and functional objectives outlined in section 6, our general conclusions are that the wider the riparian setback along water bodies, the more functional objectives will be met and the less need there is for significant management intervention later.

For optimal riparian management, the best management practice is to begin from the headwaters, protecting and enhancing riparian remnants while achieving source control, then continuing downstream. This logically includes applying buffers to streams <1 m wide that do not have mandatory stock exclusion under current national rules. If this is not possible, the catchment manager's focus should be on classifying priority water body reaches or margins that would first achieve the chosen objectives.

**Conclusions and recommendations**

The brief for this review sought definition of suitable distances to set back high-risk land uses and activities from water bodies, especially for land uses and land management practices prevalent in Tasman District. The literature review found very few studies that relate to specific land uses or management practices. We have suggested that decisions on riparian setback distances need to be made on a catchment-by-catchment basis aimed at achieving agreed riparian functional objectives. This means that setbacks may not necessarily be the same for a specific land use in one catchment compared with another.

In the table below we present suggested long-term minimum setbacks for each of the six functional objectives reviewed in section 8 of this report, taking into account the opportunity costs for intensive land uses in Tasman District and other regions. For more extensive land uses such as forestry, and on steeplands, wider setbacks would be justified.

**Table S1. Riparian setback recommendations for the six functional objectives**

| Riparian functional objective | Minimum setback recommendations | Applicability |
|---|---|---|
| *Reduce nutrient and other contaminant inputs* | 10 m | For land with slope <10°. Aim is to filter out >80% sediment and pesticide, >70% nitrogen and phosphorus in overland flow, and remove c90% groundwater nitrate in fine shallow riparian sediments |
| | 20 m | For steeper land than 10° |
| *Improve light exposure and water body temperature* | 10 m | Mature trees needed for shading; buffer width should exceed mature tree height and channel width. Even a single line of trees is beneficial. |
| *Freshwater ecosystem health, terrestrial and aquatic habitat diversity* | 15 m | To sustain macroinvertebrates, fish, terrestrial biodiversity using a range of riparian vegetation. Riparian biodiversity is easier to sustain with a 15 m setback; smaller setbacks and weedy buffers require more management |
| *Improve channel and bank stability* | 10 m | Equivalent to the root-mass diameter of a mature riparian tree |
| *Pass and attenuate flood flows* | None | Base the riparian setback on the flood characteristics of specific catchment and river reach |
| *Recreational, cultural, aesthetic and landscape values* | 20 m | A balance of ecosystem service benefits achieved in the longer term |

We do not recommend using the setbacks in the table as minimum setbacks prescribed in regional rules, but as guidelines for property-scale achievement of functional objectives, assuming other properties in the catchment are taking a similar approach to riparian design.  Our suggestion is that a decision support tool, such as an enhanced Riparian Planner, would assist in delivering the recommended catchment-based approach.

The report concludes with some policy implications of the recommended riparian setbacks.

# 1 Purpose

Regional councils are mandated to maintain and improve freshwater quality and ecology, along with related land and water management objectives (s30 RMA). Their approaches involve combinations of regulation via regional plans and non-regulatory methods, including state of environment reporting (tracking progress), technical advice to land users, and incentives and support for catchment groups and farmers.

A proven action for protecting surface water quality and ecological values is riparian management, which separates and/or buffers the water body from the impacts of adjacent land uses (e.g. barriers or filters to reduce sediment loss from cultivation, and fencing to prevent defecation and trampling of beds and banks by livestock).

The Government's 2020 Essential Freshwater reforms have put in place national directions, which include stock exclusion from certain wetlands, lakes and rivers, and a minimum setback of 3 m from the edge of defined water bodies (see section 2 below). Regional council rules will need to comply with these national bottom lines but may require more stringent rules to protect local water-body values.

This project reviews and summarises the scientific evidence for deciding effective setback distances from water bodies. As prescribed in the project terms of reference, the project aims to define suitable distances to set back high-risk land uses and activities from waterbodies that:

A. achieve the desired outcomes for addressing risk to water quality and freshwater ecosystem health

B. ensure actions by land users in locating new infrastructure, or undertaking activities will:

   a be effective in addressing risks long term

   b be cost efficient and future proofed, by avoiding the need to be shifted or modified in the future as water bodies adapt to any changed management or as management requirements change.

# 2 Scope of advice

The review has been commissioned by the Tasman District Council (TDC) to provide guidance for drafting policy and rules in the Tākaka catchments water management plan change, and in plan changes for other catchments, which are required under the Government's 2020 National Policy Statement for Freshwater Management (NPSFM). The NPSFM has been updated and gazetted in 2020 as part of the Government's Essential Freshwater package, along with a new National Environmental Standard for Freshwater (NESF) and s360 stock exclusion regulations, all of which come into force on 3 September 2020. Locally, TDC's freshwater plan change for Tākaka will seek to implement recommendations from the 5-year Tākaka FLAG (Freshwater and Land Advisory Group) collaborative planning process (Fenemor & Booth 2020).

Both the national and catchment-level processes have highlighted the importance and intention of requiring livestock exclusion from water bodies and the setback of high-risk land use and activities from water bodies, especially to minimise water quality[1] impacts in water bodies.

This guidance will also be available to rural sectors, communities and land users to help inform the design and implementation of riparian setbacks that protect water quality and meet their legal and 'good neighbour' obligations, whether required through regional plans, national regulation or industry good practice requirements.

An example of industry good practice requirements is *Waterway Technical Notes* (DairyNZ 2016), which provides information to support dairy farmers, who are required under the Sustainable Dairying Water Accord[2] to have a riparian management plan for their farm by 2020. The Accord already required dairy farmers by May 2017 to have excluded stock from permanently flowing rivers, streams, drains and springs more than a metre wide and 30 cm deep, and from lakes and wetlands.

The Government's RMA s360 regulations[3] following consultation on the Essential Freshwater package are as follows (MfE 2020, p. 328):

> Prevent the access of dairy and beef cattle, pigs and deer from wetlands, lakes and rivers more than one metre wide as follows:
>
> a Exclude all dairy cattle, pigs, beef cattle and deer on land with an average slope across the land parcel of less than or equal to 10 degrees ('low-slope land') from wetlands, lakes and rivers more than one metre wide.
>
> b Outside the low-slope land area, exclude all dairy cattle and pigs, and high risk activities (grazing on irrigated pastures, break feeding animals, and fodder-cropping) from lakes and rivers more than one metre wide (measured as the bed of the river).
>
> c Outside the low-slope land area, exclude all cattle, pigs and deer from wetlands identified in regional or district plans and those identified as part of the NPS-FM compulsory values of threatened species and mahinga kai.
>
> d Where cattle, pigs and deer are excluded from a wetland, lake or river, those stock must also be excluded from a *minimum setback of three metres* from the bed of that water body.

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[1] 'Water quality' is a broad term used here to encompass effects on aquatic ecology and usability of water, and on values such as cultural, recreational and landscape values affected by the *state* of the water as opposed to the *amount* of water ('water quantity').

[2] www.dairynz.co.nz/wateraccord

[3] These regulations, in force from 3 September 2020, apply to a person who owns or controls beef cattle, dairy cattle, dairy support cattle, deer or pigs (stock).

http://www.legislation.govt.nz/regulation/public/2020/0175/latest/LMS379869.html e Cattle and pigs are not permitted to cross wetlands, lakes and rivers more than one metre wide except by a dedicated culverted or bridged cross point (unless that crossing is infrequent – no more than twice per month). (This requirement would not apply to deer.)

f Provide for an infringement fee of $2,000 for offences against the regulation.

The regulation will allow regional councils to adopt more stringent rules in their regional plans.

This project reviews relevant research across New Zealand and selected international reviews for multiple types of primary sector activity to create an information resource that is nationally applicable. While the review focuses on Tasman land uses and geography, it is of general applicability to other regions of New Zealand.

The key uses of this review by the council will be to:

- help define appropriate regulatory response options for setbacks in TDC's regional plan
- inform discussions and education with industries and communities to define agreed setback good practice to manage freshwater risks from land-use practices and stock access, and obtain buy-in to implementing these
- use as supporting information for plan changes in section 32 evaluation and through the Schedule 1 process.

The perspective adopted for this review identifies decisions on riparian setbacks as a *process* of prioritising riparian objectives to manage for, then identifying and synthesising relevant knowledge *content*[4] to guide decisions on setbacks that achieve those objectives.

This review acknowledges that although setback distance is a critical primary factor delivering desired outcomes instream, it is only one factor in effective riparian management. Setback distance interacts with other factors to deliver effectiveness, especially length of riparian buffers, composition and management of riparian vegetation, and topographic and climatic factors such as slope, soils and rainfall regime.

The remainder of this report covers the decision-making process recommended, then presents a synthesis of relevant knowledge affecting riparian setback effectiveness.

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[4] As elaborated in the Wheel of Water project, chapter 3 of Fraser et al. 2014.

# 3 Defining setbacks and buffers

Various terms are used in riparian management documents to define the width of a riparian protection zone.

*Setback* is the distance from the edge of a surface freshwater body (river, stream, lake, wetland) to a production area, such as fenced-off livestock or the edge of a cultivated land use. A setback is defined in the National Environmental Standards for Plantation Forestry[5] (NES-PF) as 'the distance measured horizontally from a feature or boundary that creates a buffer within which certain activities cannot take place'.

*Buffer* is the strip of land that connects an upland or hillslope area with streams, lakes or wetlands, where land-use activity is modified to prevent adverse effects on the water quality, biota and habitat within the watercourse (Parkyn et al. 2000). Buffers can range from grass filter strips with livestock or other agricultural activities excluded, to a completely vegetated native forest riparian strip (Parkyn 2004). Setback width or buffer width in this report means the width of a riparian buffer on one side of a water body only, recognising that buffers are preferred along both sides of waterways.

In both cases, and especially for determining compliance with rules prescribing a minimum setback, it is important to know how the edge of the water body is defined. A 2019 Environment Canterbury case taken to the Court of Appeal[6] determined that the bed of a river, defined in the RMA s2(1) as 'the space of land which the waters of the river cover at its fullest flow without overtopping its banks', is to be found by first identifying the river's banks rather than by first identifying the area covered at its fullest flow. A similar interpretation would apply to lake, wetland and tomo margins at their highest level. A riparian setback should not be measured from the water body itself, but from its bank or margin. We note that the s360 Resource Management (Stock Exclusion) Regulations 2020 (referenced above) are consistent with this.

# 4 Land uses and management practices considered

This review applies to land uses and land-use practices that may be a source of sediment, nutrients, disease-causing organisms or hazardous chemicals. These are mainly rural land uses and activities within Tasman District for which riparian setbacks may reduce risk to water and have wider benefits. Urban areas and roads also potentially have a high risk of contributing to water contamination, particularly where impervious surfaces are directly connected to surface waters with drains/pipes or combined sewer/stormwater systems overflow to water bodies. Thus, this setback guidance is also applicable to urban areas and land uses where the same riparian function is sought.

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[5] http://www.legislation.govt.nz/regulation/public/2017/0174/latest/DLM7373517.html

[6] Canterbury Regional Council v Dewhirst Land Co Ltd and Anor [2019], NZCA 486 [8 October 2019]

The land uses and land-use practices covered are primarily (but not limited to):

- cultivation, cropping and pasture renewal
- horticulture
- fertiliser use and effluent application
- stock wintering, intensive grazing / break feeding, loafing/wallowing, and supplementary feed areas
- stock access to waterbodies
- high-risk infrastructure, including offal pits, refuse pits, silage storage, fertiliser storage, water troughs, composting, chemical/fuel storage, effluent storage, onsite wastewater systems, raceways, and stock yards.

Riparian setbacks may both buffer water bodies from land uses and provide treatment for contaminants passing across or through them (Table 1).

**Table 1. Summary of riparian zone functions that potentially buffer water bodies from various land-use effects (modified from Quinn et al. 1993; Death 2018)**

| Riparian zone function | Potential in-stream effects |
|---|---|
| • Buffers banks from erosion<br>• Buffers channels from localised changes in morphology<br>• Excludes livestock, and their trampling, dung and urine<br>• Buffers input of nutrients, soil, microbes and pesticides in overland flow<br>• Denitrifies groundwater<br>• Buffers energy inputs, especially through shading<br>• Provides in-stream food supplies and habitat for aquatic invertebrates, native fish and salmonids<br>• Buffers flood flows<br>• Maintains microclimate<br>• Provides habitat and corridors for birds, terrestrial wildlife, but also weeds<br>• Provides for recreational, cultural, aesthetic and landscape values | • Reduces fine sediment levels<br>• Maintains water clarity<br>• Reduces contaminant loads<br>• Prevents nuisance plant growths<br>• Encourages growth of bryophytes and thin periphyton films<br>• Maintains lower summer maximum temperatures<br>• Increases in-stream habitat features and terrestrial carbon inputs, including leaves and woody debris<br>• Maintains food webs<br>• Reduces flood-flow effects<br>• Increases biodiversity<br>• Allows in-stream uses such as contact recreation and mahinga kai food gathering |

While riparian management is a key part of resolving biodiversity and waterbody health issues, it is not a silver bullet to solve all water quality problems in agricultural landscapes. There are three important caveats to the efficacy of riparian setbacks.

First, the influence of riparian zones on adjacent water bodies declines as water-body size increases. Improvements in lowland rivers will usually require riparian management upstream in headwaters, and this includes streams <1 m width and wetlands that do not meet the current national requirements for riparian setbacks.

Second, because base flows in rivers and streams originate predominantly from groundwater inflow rather than surface runoff, management of groundwater contamination also requires consideration.

Third, the beneficial results of riparian zone management on water bodies may take several years to become evident, and changes to stream morphology brought about by riparian management will take longer to become apparent than changes to vegetation.

# 5 Literature review

A literature review was completed, focusing on New Zealand research, guidelines and papers, but included key international literature on the effectiveness of riparian setbacks. A range of keyword combinations were used in Google Scholar to identify relevant published and grey literature on riparian setbacks in New Zealand. Most references were found when using the phrases 'buffer strip' or 'riparian management', and a small number when using 'riparian setback', so the former two were used. Table 2 shows the combinations of keywords which identified the most relevant local references.

**Table 2. Keywords and numbers of references found in Google Scholar searches, June 2020**

| Keywords | Number of hits |
|---|---|
| "buffer width" **AND** "riparian management" **AND** "Guidelines" **AND** "New Zealand" **AND** Sediment **OR** Nutrient **OR** E.coli **OR** Disease **OR** Chemical | 229 |
| "buffer width" **AND** "riparian management" **AND** "Guidelines" **AND** "New Zealand" **AND** Cultivation **OR** Cropping **OR** "pasture renewal" | 66 |
| "buffer width" **AND** "riparian management" **AND** "Guidelines" **AND** "New Zealand" **AND** Horticulture | 24 |
| "buffer width" **AND** "riparian management" **AND** "Guidelines" **AND** "New Zealand" **AND** "Fertiliser use" **OR** "effluent application" | 14 |
| "buffer width" **AND** "riparian management" **AND** "Guidelines" **AND** "New Zealand" **AND** "stock access" | 27 |
| "buffer width" **AND** "riparian management" **AND** "Guidelines" **AND** "New Zealand" **AND** "Stock wintering" **OR** "intensive grazing" **OR** "break feeding" **OR** loafing **OR** wallowing **OR** "supplementary feed areas" | 121 |
| "buffer width" **AND** "riparian management" **AND** "Guidelines" **AND** "New Zealand" **AND** Dairy **OR** Sheep **OR** beef **OR** "sheep and beef" **OR** deer | 100 |
| "buffer width" **AND** "riparian management" **AND** "Guidelines" **AND** "New Zealand" **AND** Fruit **OR** Arable | 43 |

While the initial searches returned large numbers of potential articles, many of these were either irrelevant or not New Zealand-focused. There were also duplicates between the different keyword searches. Twenty-six papers from the Google Scholar keyword search were reviewed in detail. References, mainly international, within those papers identified 16 relevant information sources. A further six papers were recommended for further review by experts from Manaaki Whenua – Landcare Research, NIWA, DairyNZ, and the Ministry for the Environment.

# 6 Prioritising objectives for riparian design

Collier et al. (1995) identify steps to be followed when designing a riparian management scheme, which we have revised in Table 3 below, modified from their Figure 1. These steps now recognise that government regulations and council plans may prescribe minimum standards for the riparian management scheme.

**Table 3. Riparian management scheme design steps (modified from Collier et al. 1995)**

| |
|---|
| 1 Management Issues: Identify the problems and where they occur in the catchment system. An inventory will help, recording the location of problems in the water bodies, their severity, and their likely causes. |
| 2 Contributing Factors: Identify the factors that have permitted the problem(s) to develop. The ability to tackle these factors at source will influence the effectiveness of riparian actions. |
| 3 Restoration Targets: Identify outcomes sought and set draft targets for the riparian management scheme using available guidelines (including these on riparian setbacks), iwi plans, and in compliance with Government standards and rules in the Council's regional plan(s). |
| 4 Restoration Feasibility: Determine the feasibility of using riparian management within current land operations to achieve the draft targets. Consider maintenance requirements. Are any other management actions necessary to achieve the desired outcome(s)?; for example, if nitrogen loss to water bodies is affected more by land management practices above upgradient groundwater sources than by riparian barriers, or if point sources such as stock crossings or roads are key contributors. |
| 5 Draft Design: Prepare a draft riparian management scheme proposal. Agree on the most important problems to solve; for example, by implementing different guidelines in different parts of the riparian zone or by staging implementation. |
| 6 Consultation: Assess community and industry views, interest and support, including review of benefits and costs to determine if riparian management is still feasible. Can riparian work be 'clipped on' to other programmes such as fencing of remnants, or river channel or willow management works? |
| 7 Final Design and Implementation: Design and implement a phased riparian management scheme using appropriate guidelines targeted to the site/s and land users. |

The effectiveness of riparian management is maximised when a whole-catchment or landscape approach is taken, because upstream land-use and management practices contribute to downstream outcomes. Where a whole-catchment approach is not possible, riparian management planning should be carried out at the scale of a river reach for rivers and streams, and at a segment scale for lakes and wetlands (i.e. zones in which the problems are similar).

Critical to the design of riparian zones is the decision on the specific outcomes sought and targets for their achievement (step 3 in Table 3). Is riparian protection aimed at filtering overland flow to improve water quality? Is it to allow a particular level of flooding to pass? Is it to improve on-farm biodiversity? Is it to shade the water body to encourage fish spawning? Is it to allow access for stock drinking-water? These examples immediately illustrate that riparian design usually aims to achieve multiple objectives, some of which will conflict with each other, so they need to be prioritised.

Understanding how riparian design can deliver environmental outcomes requires understanding how riparian zones function. These, in turn can be seen as functional objectives, which we have summarised as the six following (condensed and modified from Collier et al. 1995; Parkyn 2004; Death 2018).

## 6.1 Reduce nutrient and other contaminant inputs via overland and subsurface flow

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 particulates carried in water as suspended sediment.

Contaminant inputs to water bodies are best managed at source (critical source areas). After that, the most effective actions to manage phosphate and *E. coli* losses are to reduce sediment losses from land into water bodies; e.g. by enhancing interception (by vegetation), surface storage and infiltration. Within the riparian zone, overland flow can be slowed (and spread) sufficiently to allow suspended sediments to settle out or be adsorbed into the soil, allowing riparian vegetation to use some of the retained nitrogen and phosphorus to grow. However, surface drains, artificial drainage (mole and/or tile drains), and micro-or macro-channelising of runoff during larger storms short-circuit these filtration processes. Specific actions are needed to mitigate short-circuiting, such as installing constructed wetlands, level spreaders, bunding or sediment ponds.

Managing nitrogen losses requires more than simple riparian management: it requires actions across the entire property to maximise its uptake by plants and minimise losses, including leaching to groundwaters, especially where crops combined with leaky soils create vulnerable areas. However, nitrate in near-surface groundwaters can be reduced by denitrification where flows pass through anaerobic, organic-rich riparian seeps or artificially constructed woodchip barrier trenches.

## 6.2 Improving light exposure and water-body temperature regimes of water bodies

Heat and light reduce water quality. Most New Zealand streams and their ecosystems had forest canopy prior to pasture development and drainage, so they are adapted to cool, shaded conditions. High water temperatures may directly affect the distribution of invertebrates and fish in water bodies, as well as reducing dissolved oxygen levels needed by those species. High light levels combined with nutrient enrichment promotes aquatic plant growth, which strips oxygen from water.

Shading is widely recommended for aquatic plant control and can favour the development of 'clean-water' invertebrate communities. However, the influence of riparian shade declines as the channel or water body size increases.

Riparian vegetation reduces the amount of solar and atmospheric radiation that reaches the water surface and hence plays an important role in determining water temperature. Restoring riparian shading will reduce maximum water temperatures, especially in small streams. Narrow streams require relatively low riparian vegetation (e.g. ferns, sedges, grasses) to achieve shading, whereas wide channels and lakes require tall, mature trees. Light reaching the bed of water bodies is reduced by interception by the canopy of riparian shade plants, by topography, and by absorption and scattering (attenuation) within the water column.

## 6.3 Increasing freshwater ecosystem health, and terrestrial and aquatic habitat diversity, and improving inputs of terrestrial carbon to water bodies

The assemblage of plants and animals inhabiting most water bodies is determined, to a large extent, by water-body shape, channel substrates, sediment regime, flow regime, water chemistry, light exposure, temperature regime, and terrestrial carbon inputs. Invertebrate communities, supporting fish and birds up the food chain, feed on carbon sources from in-stream plants and from plants on the banks.

In large rivers and open streams aquatic plant growth is more important; in small, forested, headwater streams, leaf litter, terrestrial invertebrates and woody debris are the more important sources of habitat and food, which support aquatic invertebrates and fish. Unaffected headwater streams are needed to 'reseed' and 'repopulate' degraded downstream reaches. Where such headwater sources are absent, recovery of freshwater ecosystems is severely limited.

Loss of such habitat and food, especially in pastoral catchments, along with disturbance by livestock, has reduced native fish populations such as galaxiids and mudfish, exacerbated by physical and chemical blockages to fish passage.

Restoration of native riparian forest alongside pastoral and agricultural water bodies can help to increase freshwater ecosystem health, habitat diversity, and the diversity of native plant and animal communities; for example, for īnanga, kōkopu, frogs, and birds such as whio (blue duck). However, benefits are strongly dependent on the design – particularly the width – of strips.

Planting of riparian trees and shrubs alongside water bodies lined by grasses, rushes and sedges, especially the use of native plants, helps redress these impacts and increases the supply of terrestrial organic carbon to streams, thereby improving aquatic life, with tall overhanging vegetation particularly valuable.

Connectivity, both terrestrial and aquatic, is an undervalued benefit of riparian buffers, which requires greater prominence in a whole-catchment approach to riparian management.

## 6.4 Improving channel and bank stability

Planting riparian trees and shrubs and grasses can be effective in binding riverbank soils to depths of 0.5 to 1.5 m depth, and reducing inputs of suspended sediments from the banks, but has little influence on other forms of erosion beyond the water body.

Riparian vegetation also traps suspended sediment when floodwaters expand onto the floodplain and water velocities decline, or when soil is carried in overland flow from upland areas. Riparian vegetation can influence river and stream shape at a localised scale, but changes in stream shape can take a long time to reach a new equilibrium.

Retaining remnant vegetation and excluding stock from the banks of water bodies are important riparian management actions.

## 6.5 Passing and attenuating flood flows

Riparian zones can store and retard the flow of drainage waters, especially during floods.

In flatter terrains, extensive riparian wetlands, especially in headwaters, help to sustain base flows while damping flood flows downstream. Riparian zones may also reduce low flows through transpiration by riparian plants, where riparian vegetation is a large component of small sub-catchments.

However, the larger the storm, the lower the retardation of flood flows, as the influence of vegetation is overwhelmed. During larger storms, riparian vegetation may slow flood velocities but may also catch flood debris, exacerbating flood damage. Crack and grey willows established from layering or 'wilding' can catch and create such flood debris. Hence the selection of riparian species should take into account the flood regime of the river reach, avoid plants that are highly branched in the lower 1–2 m, and have a higher proportion of single-stemmed, apically dominant species (e.g. cabbage trees, kahikatea), and flexible plants such as harakeke in areas prone to overflows.

This flood management objective was previously the over-riding factor in river management, and is often in conflict with the other five objectives. It is still the dominant objective in areas with constrained flood volume capacity (e.g. narrow floodplains between stop banks). It was the domain of catchment engineers, who are now required to take a more nuanced approach to river function.

## 6.6 Providing for recreational, cultural, aesthetic and landscape values

Riparian zones can contribute to the natural character of landscapes, especially where natural vegetation is sparse, such as in lowland pastoral and agricultural areas.

Corridors of trees, shrubs and, in some landscapes, sedges, rushes and grasses can provide ecological connectivity across landscapes. In larger water bodies these may enhance recreational activities such as walking/cycling, fishing and swimming. The provision of shade and shelter sometimes needs to be balanced against access (especially for fishing) and views of water.

Riparian zones also contribute to cultural values. For example, mahinga kai is now a compulsory attribute to be considered for water bodies under the 2020 NPSFM and is closely linked to freshwater ecosystem health.

# 7 Process for deciding riparian setbacks

Building on the riparian management process summarised in Table 3, we have (Table 4) devised the following conceptual approach to specific decisions about riparian setbacks, based on principles of integrated catchment management.

**Table 4. A catchment-scale process for deciding riparian setbacks**

| |
|---|
| 1 Desired outcomes: define the desired outcomes (i.e. functional objectives, summarised in section 6) for riparian management at the catchment scale. |
| 2 Compliance: identify reaches/water bodies where mandatory riparian exclusion is required under the NPSFM, regional plans and other relevant guidance, initially assuming minimum mandatory riparian setback. |
| 3 Preferred locations: establish or identify reaches/water bodies where existing land management incentives (including avoided costs) would favour riparian buffers, assuming a minimum setback.* |
| 4 Long-term riparian programme: for the remaining reaches/water bodies, assume riparian management occurs stochastically within a defined time (10 years may be appropriate). |
| 5 Setbacks that achieve catchment outcomes: define by assuming some standard for fence placement and type, riparian plantings and/or natural regeneration, with pre-establishment vegetation management.** |

* For example, council may support fencing of native forest or wetland remnants, and economic factors may favour fencing of production woodlots and creation of shelter for adjacent land. Avoided costs include placing fences to remove hazards to stock or people (steep scarps, boggy areas), increase efficiency of stock movement/pasture feed budgeting, or remove critical source areas from production.

** For example, willow or poplar removal (or weed control) and post-establishment management and analysis of the upstream extent of riparian management will govern the determination of riparian setback distance(s), using relevant science to achieve the desired outcomes.

In order to implement this approach, it is necessary to understand:

- the dominance of hydrological factors in achieving environmental outcomes – including the return period of floods and droughts to be planned for
- the importance of managing and maintaining existing riparian vegetation, especially if it includes willows, poplars or alders established for erosion control, and for managing riparian plantings and stock exclusion infrastructure in the longer term
- the need to consider riparian management as one measure alongside other catchment-scale environmental management methods, especially including farm, forestry, industry, and urban environment plans.

# 8 Riparian setbacks that help to achieve specified riparian objectives

The approach taken in this review has been to summarise the key findings on riparian setback widths for each of the six listed riparian objectives identified in section 6. In each section we have summarised the conclusions of New Zealand studies that refer to setback widths, even if setback was not the focus of the study. Then we summarise meta-analyses. Key references of value for informing the tables of recommended widths below have been the review by Death (2018) for Greater Wellington Regional Council in the upper Ruamahanga River, the review by Hansen et al. (2010) completed for the Australian state of Victoria, and the US meta-analysis of ecologically functional agricultural riparian zones by Lind et al. (2019).

Finally, we summarise the factors affecting setback width for that particular riparian functional objective, with reference to the land uses and activities relevant to Tasman District and New Zealand more generally. For each of those six objectives, a summary table is provided of recommendations for riparian setback distances, together with comments about the applicability of those recommendations to New Zealand catchments. These recommended setbacks should be regarded as minima.

As expected, there is a significant spread across all recommended setbacks. We have attempted to summarise the setbacks in a final table, by functional objective. In reality, riparian setback distances should vary across a landscape in response to land cover, and geographical, climatic and hydrological factors, alongside policy objectives and land-user preferences and priorities.

Design and prescription of riparian management – not just setbacks – would ultimately benefit from the development of a catchment-based decision support tool that can account for all relevant factors and allow the individualisation that is needed to optimise overall benefits and minimise costs, perhaps (in due course) as an extension of the Riparian Planner Tool developed by Manaaki Whenua – Landcare Research for DairyNZ.

## 8.1 Reducing nutrient and other contaminant inputs via overland and subsurface flow

Upstream conditions matter. Streams within buffer zones can show variable nutrient and faecal contamination responses if upstream areas do not have riparian buffers. Canopy closure of buffered sections with unprotected upstream areas may actually increase the nutrient export from a rehabilitated reach if in-stream assimilation is reduced (Parkyn et al 2003; Hughes & Quinn 2014), for example, by shading of aquatic plants.

Rehabilitation of streams will be most successful when planting riparian zones begins from the headwaters down through the catchment and a contiguous buffer length is achieved. If this is not possible, the catchment manager's focus should be on classifying priority water-body reaches or margins that would first achieve the chosen objectives from Table 3. The length of the riparian buffer may be more important than the width, despite uncertainty over whether an appropriate width has been set back.

Parkyn (2004) reported sediment and total phosphorus removal rates of between 53% and 98%, and higher removal rates with increasing buffer width (4.6 m to 27 m). Larger sediment may be removed in 5 m of grass buffer, but finer particles may require up to 10 m of grass buffer (Gharabaghi et al. 2002), and this assumes sheet flow of water across the buffer.

In general, buffers need to be wider when the slope is steep because runoff is moving faster. The effectiveness of a buffer zone for contaminant removal can reduce over time; for example, due to shading out of ground cover by growing trees. Some researchers argue that widths may need to be larger than early stage studies suggested (Parkyn 2004).

Grass buffer strips are effective at filtering sediment and sediment-associated contaminants (particulate phosphorus and nitrogen) from surface runoff, but they are less effective at removing soluble nutrients such as nitrate, ammonia, and dissolved phosphorus. Nitrate removal from subsurface flows is considered to be greater in forested buffers, partly through uptake by plants (Parkyn 2004) and by the deeper rooting of trees.

Because of the different modes of particulate and dissolved contaminant transport, multi-tier or combination buffers are often advocated. Combination buffer systems in the USA often consist of an upslope grass buffer, a managed forest or shrub zone, and an undisturbed forest zone next to the stream.

In their review of riparian management challenges in New Zealand, McKergow et al (2016, their Table 2) note that contaminant transport in runoff is not uniform, so using denser plantings in micro- and ephemeral channels, and even detainment bunds on larger channels (Levine et al 2019), may be needed within the riparian setback. In the sub-urban context, level spreaders[7] are used to help ensure even flows of water across buffers. Another approach is to use earthworks to create evenly rough, dimpled topography to enhance infiltration and avoid bypass channels. In the Taupō catchment, 'flax baffles' are planted across the base of gullies to detain quickflow generated by summer thunderstorms on hydrophobic soils, and to promote infiltration (R Simcock, MWLR, pers. comm. 2020).

Riparian setbacks should also be considered for low-order streams, as research indicates that low-order streams not requiring stock exclusion under the DairyNZ Water Accord are estimated to supply 73% of the total nitrogen and 84% of the dissolved reactive phosphorus reaching New Zealand waterways (McDowell et al 2017).

The optimal width required for nutrient and sediment removal can be highly variable. Generally, buffer widths will need to widen as the slope length (ridge to stream distance) increases, slope angle (average degrees of slope ridge to stream) and clay content of the adjacent land increase, and soil drainage decreases (Collier et al. 1995; see p. 47 for CREAMS model results). However, note that clay content is a surrogate for infiltration rate,

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[7] E.g. http://content.aucklanddesignmanual.co.nz/regulations/technical-guidance/Documents/GD04%20WSD%20Guide.pdf

and that some clay soils have mineralogies that mean they have high infiltration rates (e.g. granular soils at Pukekohe).

The contaminant removal efficacy of riparian zones is impaired when flows concentrate due to microtopography, tile drainage and under intense rainstorms. This condition occurs in steep, hilly terrain, as overland flow is concentrated into channelised micro-topography, creating higher flow velocities. Thus, grass buffers need to extend further inland following swales and drains, resulting in a non-uniform setback along the length of the stream.

We look now at some specific New Zealand studies in varied catchment settings. A study by Collins et al (2013) evaluated the impact of 3–8.5 m native revegetated setbacks along four spring-fed streams in the flat, agricultural lowlands of the Waihora/Lake Ellesmere catchment. Setbacks benefited water quality in terms of increasing dissolved oxygen and decreasing turbidity, suggesting that even narrow, planted buffer strips may be effective for improving some water quality parameters. However, the narrowness of the buffers was probably a reason conductivity increased and nutrient and bacteria levels were unchanged between control and buffer sites.

Elsewhere in lowland Canterbury, Burrell et al. (2014) found in a study of 21 stream reaches that intensive, long-term agriculture at the catchment level increased both gross primary production and ecosystem respiration in streams, resulting in eutrophication. The study highlights the role of local riparian conditions – especially shade, and therefore setback width – in controlling trophic state, and the importance of riparian buffers as a tool to mitigate eutrophication in streams and rivers.

The scale of riparian restoration within a catchment was found to be critical in a study by Doehring et al. (2019) of stream functional response following fencing of 11 paired pastoral Waikato streams over a 30-year timespan. Fenced buffers had a mean setback of 23.1 m, with more shading than unfenced sites at 5.5 m. Perhaps surprisingly, the study showed that there was little benefit to ecosystem function if less than 2% of the upstream catchment area had been fenced. This result raised the question whether stream morphology needs to be improved before we can expect improvements in stream ecology. It is well documented that width, continuous canopy and length of forested riparian zones determine the effectiveness of restoration of stream structure. There appears to be a threshold of 1–2% of a catchment needing shading by riparian vegetation before a positive effect on stream health can be observed.

DairyNZ, with Manaaki Whenua, has produced the Riparian Planner tool[8], supported by planting guides for each region. For setbacks, the following is currently recommended:

> *A wider setback is needed on steeper paddocks, longer paddocks and heavier soils, because these all generate fast flowing runoff. On flat to undulating land, relatively small zones of 3–5 m are still capable of reducing nutrients, sediment and bacteria entering waterways. If you want to create shade for your stream*

[8] https://www.dairynz.co.nz/environment/waterways/riparian-planner/

*to reduce weed growth and keep streams cool, you may need wider zones to allow more space for the trees.*

Maseyk et al.'s (2018) study of ecosystem service benefits for 1 m and 5 m setbacks in Taranaki dairy lands using the OVERSEER model showed a substantial decrease in P lost to water once livestock were excluded from waterways and stream banks. However, the model suggested that implementing riparian margin management did little to prevent nitrogen loss to water.

If aquatic invertebrate community restoration is a primary objective, the aquatic substrate should be considered when choosing sites for planting. Low-gradient or discharge sites with silt present are unlikely to be flushed sufficiently to remove organic material and sediment and expose favourable substrates such as gravel, cobbles and rocks. As a consequence, these areas will not be conducive to colonisation by some invertebrate taxa, and perhaps restoration efforts should be focused elsewhere, unless alternative appropriate substrates (e.g. woody debris) are actively introduced into the stream bed, or the stream bed can be 'cleaned out' (as has occurred in Neimann Creek, Tasman District).

Nitrates are a particular issue for rural New Zealand water bodies. Much of the nitrogen reaching water bodies comes from groundwater so is not amenable to filtering processes that can treat overland flow. Denitrification is the dominant mechanism of nitrate removal, occurring at depth in many buffers, which contain buried organic-rich deposits. Riparian environments, including floodplains, bottomlands, wetlands, swamps and seeps, have all been shown to have a high capacity for denitrification, as have high-carbon interception barriers (e.g. wood waste denitrification walls) installed to intercept the water table. Nitrate removal efficiencies in riparian environments can exceed 90%, providing that the incoming nitrate has sufficient residence time in the riparian zone. Removal of incoming groundwater nitrate by riparian wetlands typically occurs within the first 5–10 m, which indicates, on a catchment-scale, that the effectiveness of a riparian wetland to act as a nitrate sink depends on the nitrate load arriving at its upslope edge (Collier et al 1995; Parkyn 2004).

Another nitrate removal mechanism is vegetation uptake, and this is directly affected by setback distances. Hill (2019) reviewed groundwater nitrate removal in riparian buffer zones, concluding that nitrate removal efficiency and the width required for removal are linked to riparian sediment texture and depth to an impervious layer (i.e. the hydrogeological properties of the riparian zone). Buffers with<4 m depths of *sand and gravel* sediments in sloping landscapes often achieve 90% nitrate removal efficiency within widths of 30–60 m, whereas many buffers with<4 m depths of *fine grained sediments* reach a 90% efficiency in a shorter distance, 10–20 m. Studies report that considerable increases in buffer widths are required for efficient nitrate removal, as permeable sediment depths increase to>4 m, and in some cases deep flow paths will bypass the buffer anyway.

A meta-analysis of the mitigation efficiency of vegetated buffers by Zhang et al. (2010) has been widely cited as a source of data on riparian setbacks, including in the Government's Action for Healthy Waterways (Essential Freshwater) decisions (MfE 2020). Zhang et al. develop exponential equations relating contaminant removal efficacy with buffer width for a wide range of reported field studies. Using these equations, buffer width alone explains 37, 60, 44, and 35% of the total variance in removal efficacy for sediment, pesticides, nitrogen, and phosphorus, respectively. The removal efficacy increases quickly with increase in buffer width until the efficacy approaches the removal capacity, as seen in Figure 1.

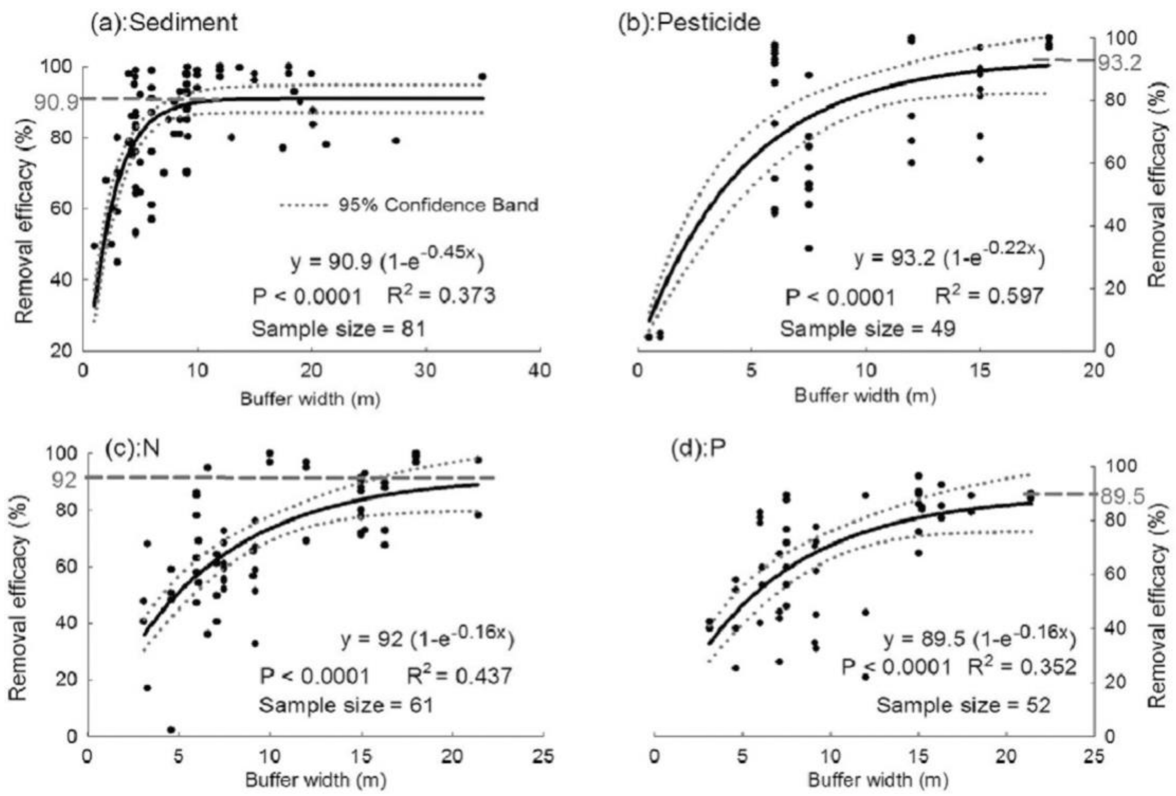


**Figure 1. Contaminant removal efficacy vs. buffer width for each contaminant. Black dots are data and lines are model predictions. Grey numbers with dashed lines are maximum removal efficiency. Source: Fig. 3 from Zhang et al. 2010.**

Slope is an important variable for contaminant removal. Sediment removal efficacy increases as slopes increase from 0 to 10%. Despite wide data scatter, buffers steeper than 10% become less effective with increasing slope, as shown in Figure 2. While there were insufficient data available on the effect of slope on nitrogen, phosphorus and pesticide removal, Zhang et al. (2010) concluded that slope would have had significant impacts on buffer efficacy given the significant contribution of slope to the sediment removal model.

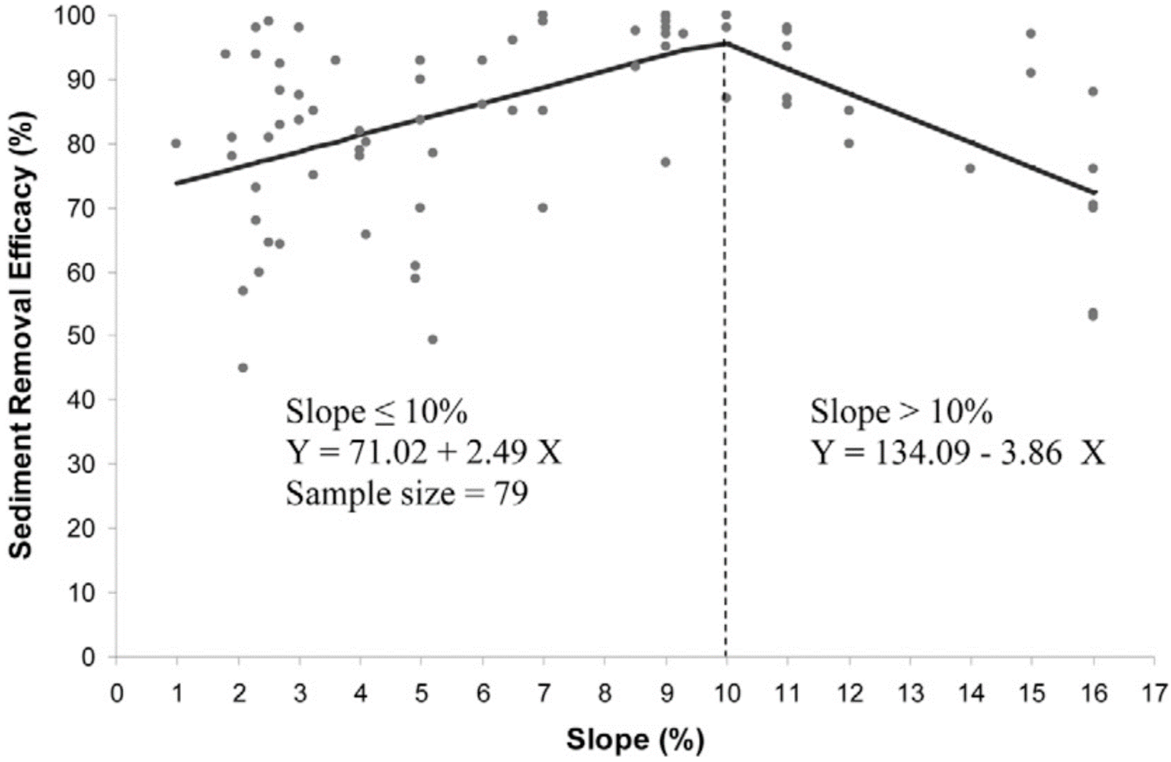


**Figure 2. Correlation between sediment removal efficacy and buffer slope. Source: Fig. 4 from Zhang et al. 2010.**

Increasing the buffer width from 5 to 10 m would increase the removal efficacy by about 20% for nitrogen and 18% for phosphorus. A 20 m buffer removes about 91 to 100% of nitrogen and 97 to 100% of phosphorus (see summary Table 6). Zhang et al. (2010) conclude that a 30 m buffer under favourable slope conditions (c. 10%) removes more than 85% of all the studied contaminants. Increasing buffer width to more than 20 m does not appreciably increase sediment removal efficacy.

Hansen et al. (2010) have recommended setbacks for Victoria, Australia, aimed at protecting flowing waters and biodiversity (Table 5). Setback widths differ with land-use intensity. High-intensity land uses include dairy, dryland cropping, and market gardening; medium-intensity land uses include orchards and lower-intensity grazing; and low-intensity land uses include pasture cropping and grazing, and forestry. We assume they allow for the broader-scale topography, eucalypt vegetation and drier climate regime, as setback recommendations of up to 200 m for improving terrestrial biodiversity in high-intensity landscapes are at the upper end of those from New Zealand and the USA. Hansen notes that these recommendations compare with median actual setbacks from 34 studies of 12 m for moderate-intensity land use and 25 m for high- and low-intensity land uses. Given the Australian climate and topographical context for these recommendations, we consider them of limited applicability for New Zealand.

**Table 5. Minimum setbacks for Victorian riparian zones (distances in metres). Source: Hansen et al. 2010**

| Landscape context / management objective | Land-use intensity high | Land-use intensity moderate | Land-use intensity low | Wetland/ lowland floodplain/ off-stream water bodies | Steep catchments, cleared hillslopes, low-order streams |
|---|---|---|---|---|---|
| Improve water quality | 60 | 45 | 30 | 120 | 40 |
| Moderate stream temperatures | 95 | 65 | 35 | 40 | 35 |
| Provide food and resources | 95 | 65 | 35 | 40 | 35 |
| Improve in-stream biodiversity | 100 | 70 | 40 | Variable* | 40 |
| Improve terrestrial biodiversity | 200 | 150 | 100 | Variable * | 200 |

*Variability in width is related to the lateral extent of hydrological connectivity, and so any recommendation will be site specific.

Death (2018) has also completed a useful meta-analysis of current knowledge relevant to the management of flood risk and river ecosystem health in the Upper Ruamahanga catchment in Wairarapa. In relation to sediment removal, he notes that effective widths vary from 1 m in relatively well-drained flat areas to as much as 60 m in steeper areas with more impermeable soils (i.e. lower infiltration rates and higher surface runoff). On average, almost 70% of sediment can be removed by a 5 m-wide buffer. However, Hughes (2016) found that the exclusion of livestock from riparian areas was generally the principal factor in the measured improvements rather than buffer width or vegetation type. Both Wenger (1999) and Barling and Moore (1994) recommend riparian setbacks that take slope into account (see summary Table 6).

A review of vegetated buffers in agriculture and their regulation in the USA and Canada by Gene et al. (2019) comments on the efficacy of riparian setbacks for cropland and specifically focuses on pesticide losses. Regulated vegetated setbacks varied from 1 m to 60.7 m wide. Past studies have shown that pesticide residues in runoff can be reduced from between 47 and 100% when vegetated buffers are incorporated in an agricultural paddock. Mandatory setbacks and other pesticide application information are detailed on North American pesticide labels, and also mandated by the US Environmental Protection Agency (e.g. 18 m setback for ground applications, and a 61 m setback for aerial pesticide applications in some states). The use of two-zone (trees/shrubs with grass further from the water body) or three-zone buffers (trees, trees/shrubs then grass) are common for North American croplands, and are probably relevant for horticultural and arable land uses in New Zealand, while noting that pesticide removal appears less of an issue in the New Zealand context compared with nutrients and sediment.

Another useful North American review is the meta-analysis for establishing ecologically functional riparian zones in agricultural landscapes by Lind et al. (2019). They analysed literature since 1984 that has quantified services provided by riparian zones and use this information to recommend minimum buffer widths.

- For sediment trapping (trapping efficiency 77–100%), their work shows the average buffer width needed is 8.8 m (range: 3.3–18 m). Sandy-textured soils have high infiltration rates and hence deliver very little overland runoff to riparian buffers compared to finer soils.

- For trapping nitrogen (trapping efficiency 75–100%), the average buffer width needed is 11 m (range: 0.7–30 m).
- For trapping phosphorus (trapping efficiency 75–98%), the same average buffer width of 11 m is needed (range: 4–18 m).

Lind et al. (2019) provide a useful step-by-step Ecologically Functional Riparian Zones (ERZ) framework (see Figure 3) which we consider has relevance for riparian design in New Zealand. Ecologically functional comprises both aquatic and terrestrial ecosystem functionality.

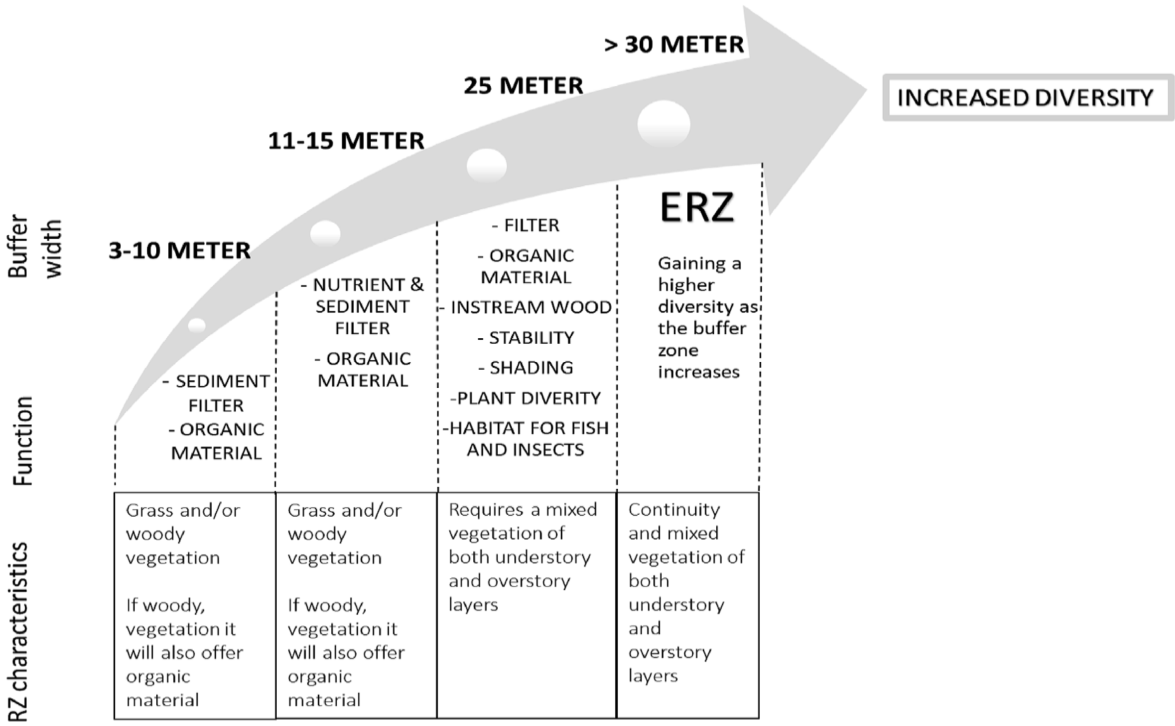


**Figure 3. Step-by-step ERZ framework. Source: Fig. 6 from Lind et al. 2019.**

Lind et al.'s analysis of the literature and ERZ framework (Figure 3) show that a 30 m-wide setback ensures an ecologically functional riparian zone, with stable water temperature, and a high floral diversity that delivers sufficient organic material, instream wood, and bank stability. An 11–15 m-wide setback with trees and shrubs would also contribute with organic material, filter the drainage, and support the system to some extent with instream wood and bank stability. Even a 3–10 m-wide setback has positive effects as a filter, mainly for sediment, and will contribute organic material essential for many instream organisms and processes.

Drainage size also matters for sediment and nutrient removal, with wider buffers recommended along larger streams. The physical environment can be improved by adding a 5 m buffer with mixed vegetation (grasses and woody vegetation), while achieving a wider diversity of organisms often requires buffer widths of>30 m (which is also wide enough to support large trees). Lind et al's review indicates that in steeper terrain there is a need for woody vegetation, whereas in flat terrain a grass covered riparian buffer is sufficient for removal of sediments and nutrient

The Regulatory Impact Statement (RIS) for the Government's Essential Freshwater programme summarised the basis for setback proposals in 2019 (a 5 m average per farm, 1 m minimum) and then the Government's decision in 2020 (a 3 m minimum, which has led to this review). The 2019 RIS (MfE 2019) states that for gently rolling land, widths of 1 to 3 m per 100 m of slope feeding into the water body may be sufficient to filter out contaminants, especially sediment. In areas with steeper slopes and poorly draining soils (i.e. a higher proportion of runoff), a grass margin of 10 to 15 m per 100 m of the adjacent slope may be needed. However, runoff can flow in defined channels across paddocks to reach water bodies, bypassing setback/riparian strips. On hill-country farms with long slopes, wide margins are most effective across drainage channels. Buffers 10 to 15 m wide may be less likely to need long-term ongoing weed control than narrower buffers, because once riparian plants have shaded the surface, most light-demanding weeds are largely excluded. However, where shade-tolerant weeds or vines are present upstream, or in the local landscape, weed invasion can be constant (e.g. grey and crack willow, Japanese walnut, alder, ivy, convolvulus, privets, old man's beard).

Most research on the benefits of buffers has been undertaken on setbacks of at least 5 m. While wider buffers do generally offer greater benefits, the RIS states that this comes with significantly greater costs for the land user, although the ecosystem services study of Maseyk et al. (2018) discussed above would suggest that the benefits of riparian buffers to land users may be underestimated.

The final (MfE 2020) RIS has focused on sediment removal by riparian zones. It includes Figure 4 below, showing sediment removal efficiency from four studies, three of which show a rapid fall in removal efficiency once riparian setback width exceeds 5 m (the Sweeney study shows a more gradual change).

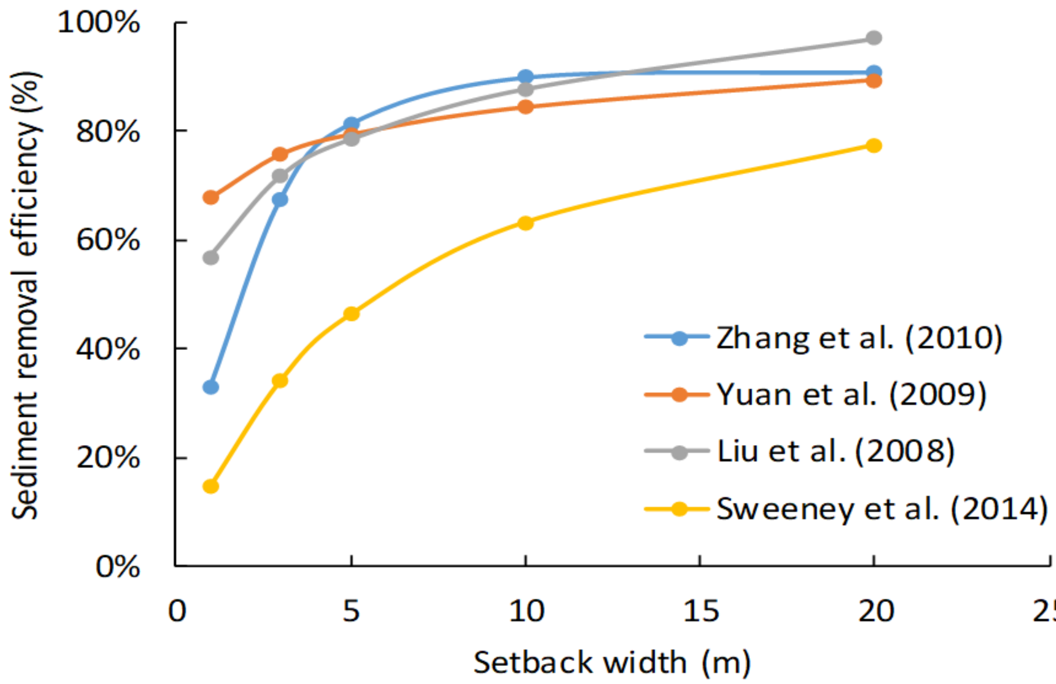


**Figure 4. Four studies of sediment removal versus riparian setback width. Source: MfE 2020.**

The reduction in an average 5 m setback to a minimum 3 m in the Government's Essential Freshwater decisions recognises that the benefits in terms of contaminant interception in setbacks are comparatively smaller in lowlands than in hill country, but loss of productive land in the lowlands carries higher costs. Therefore, the RIS concludes that reducing the setback area has relatively low foregone environmental benefits without imposing high costs.

Turning to current setback policy outside the 3 m minimum now gazetted in the 2020 stock exclusion regulations, EDS (2019) reviewed the effectiveness of the National Environmental Standards for Plantation Forestry (NES-PF) and concluded that its setback provisions are inadequate. They state that these are either set at a distance for which there is no ecological justification (5 m for perennial rivers<3 m wide), or at a distance (10 m for rivers >10 m wide) which, in light of damage that occurs during forest harvesting, will effectively be halved. They conclude that a minimum setback width of 10 m is needed to achieve improvements in instream habitat and provide sustainable riparian areas, based on such factors as the sensitivity of the water body, and buffer zone slope, soil, and local rainfall.

We can conclude that contaminant removal by riparian buffers, and therefore determination of setback width for this purpose, depends primarily on the following factors (with increased setbacks needed as each factor increases):

- land slope within the buffer
- slope length to nearest ridge
- soil infiltration rate – influenced by permeability, drainage and water-holding capacity as well as surface storage in depressions/microtopography, and hydrophobicity
- climatic zone and its variability
- degree of uniformity of vegetative cover within the buffer (with diverse trees, shrubs and grass allowing narrower buffers)
- presence of micro-channels where concentrated flow can bypass the zone
- amount and type of livestock with access to the water body
- absence of denitrifying conditions such as wood waste, wetlands and anaerobic groundwaters
- age of buffer vegetation beyond maturity
- scale, length and placement of upstream riparian buffering, taking account of the type and intensity of upstream land uses and the types of contaminants they generate.

Table 6 summarises the quantitative recommendations for minimum setback widths for contaminant removal from literature sources cited in this review. The variability in the tabulated recommendations highlights the importance of understanding the factors (such as those listed above) that so broadly influence setback width.

**Table 6. Setbacks for contaminant removal**

| Setback width | Reference | Applicability |
|---|---|---|
| 5–10 m | Gharabaghi et al. 2002 | For sediment removal by grass buffer strips only |
| 5 m | Death 2018 | Removes about 70% of sediment |
| 5–10 m | Collier et al. 1995 | For nitrogen removal by riparian wetlands only |
| 10 m | Zhang et al. 2010 | Sediment removal efficacy is 67–100% for riparian buffer slope of 5–15% planted with grass and trees<br>N removal is 71–85%<br>P removal is 69–98%<br>Pesticide removal is 83% |
| 20 m | Zhang et al. 2010 | Sediment removal efficacy increases only 1–2% to 68–100% compared to 10 m setback<br>N removal increases markedly to 91–100%<br>P removal increases markedly to 97–100%<br>Pesticide removal increases markedly to 92% |
| 30 m | Zhang et al. 2010 | 30 m setback removes more than 85% of the sediment, nitrogen, phosphorus and pesticides studied, assuming a buffer slope around 10 degrees |
| 30–60 m | Hansen et al. 2010 | For the state of Victoria, Australia, based on Victorian and international studies<br>Low intensity land use = 30 m<br>Moderate intensity = 45 m<br>High intensity = 60 m<br>Steeplands and headwaters, cleared slopes = 40 m |
| 8.8–11 m | Lind et al. 2019 | Average buffer widths needed, from their North American international review<br>Sediment 77–100% efficacy: 3–18 m (average 8.8 m)<br>Nitrogen 75–100%: 0.7–30 m (average 11 m)<br>Phosphorus 75–98%: 4–18 m (average 11 m) |
| 10–20 m (fine sediments)<br>30–60 m (sand & gravel) | Hill 2019 | 90% nitrogen removal in riparian groundwater only, when riparian sediments are fine-grained and less than 4 m deep. Wider setbacks needed for deeper and coarser riparian sediments.<br>Table 2 in Hill provides more detail in relation to sediment texture |
| Setback width = 15.2 + 0.61 per 1% of slope (m) | Wenger 1999 | US recommendation taking into account slope of riparian zone.<br>For flat land this gives a setback of 15 m and for a 10% slope the setback is 21 m. |
| Setback width = 8 + 0.65 x slope (m) | Barling & Moore 1994 | Australian recommendation taking into account slope of riparian zone.<br>For flat land this is a 8m setback, and for a 10% slope a 15m setback. |
| CREAMs model | Collier et al. 1995 | Page 47 on and Appendices 1 and 2 provide a modelling framework taking account of slope, slope length and clay content (infiltration rate). Their worked example for a pastoral North Auckland catchment produced setbacks of 2 to 97 m, with the largest proportion in the 1–10 m and 30–40 m ranges. |
| 5 m | MfE 2020 | Sediment removal efficiency reduces when setback exceeds 5 m, based on four overseas studies |

## 8.2 Improving light exposure and water-body temperature regimes

Canopy closure over the water body, long buffer lengths, and protection of small tributaries and headwaters are needed to reduce water temperatures and, in turn, rehabilitate invertebrate communities and reduce periphyton abundance. Shading provided by planting or vegetation retention along the northern and western sides of water bodies is particularly beneficial.

Death's (2018) review states that even 5 m setbacks could reduce daily maximum air temperature from 30°C to 25°C in pastoral streams, noting that some invertebrates die at air temperatures of 22–23°C and are sensitive to water temperatures above 19–20°C. Young et al. (2013) propose a maximum daily average temperature target for Auckland streams of 20°C, based primarily on the thermal tolerance of New Zealand aquatic fauna. Meleason and Quinn (2004) found that a single line of fully grown trees can provide about 80% of the shade needed for small streams.

Lind et al.'s North American review (2019) found that to generate stable water temperature (shading), an average of 21 m (range 5–30 m) of forested riparian buffer was needed.

A 15 m riparian buffer in a pastoral Waikato catchment was one of five scenarios modelled by Collier et al. (2001) to forecast changes to stream ecosystem attributes. Shading provided by all planting scenarios led to decreases in daily maximum water temperature after 15–20 years to levels that would be suitable for sensitive invertebrate species.

Retaining a forested buffer following logging of pine forest has been shown to mitigate stream impacts in a Coromandel study (Boothroyd et al 2004). The study was of 28 sites with native riparian vegetated buffers ranging in width from 2.5 to 30 m (mean 15.1 m), or no riparian zones but a mean riparian width to the first pine of 2 m. Riparian buffers of native forest vegetation within pine plantations showed considerable stability after logging of the surrounding pines and appeared to greatly reduce changes in stream geomorphology, lighting, temperature and periphyton biomass.

A similar study, but using modelling (Davies-Colley et al. 2009), explored three strategies to restore the riparian zone of a pastoral stream in Pureora Forest Park to native New Zealand podocarp-hardwood forest by: (1) passive regeneration; (2) planting then abandonment of a *Pinus radiata* plantation; and (3) active restoration by planting selected native trees with fencing and active management of weeds until year 5.

Active restoration strategies outperformed passive regeneration in shade, temperature and stream wood volume for most of the simulation time (800 years), providing strong support for active planting to accelerate stream ecological recovery. Stream shade was strongly dependent on stream size, assessed by channel width. This is because the ratio of canopy height to stream width is the single most important factor controlling stream light exposure. Abandonment of a pine plantation to form a riparian buffer can provide a valuable 'nursery' for mid- to late-successional native species and outperformed both active native planting and passive native regeneration by providing more stream shade and wood for the first 200 years. However, the study did not directly evaluate the effect of buffer width.

We conclude that using riparian buffers to reduce light exposure and heating of water bodies, and the setback widths needed for this purpose, depend primarily on the following factors (with increased setbacks needed as each factor increases):

- stream size (channel width, stream depth, channel incision and stream flow)
- fine sediment vs. gravel channel substrate
- microclimate along the water body, as affected by canopy height and adjacent land use (with trees preferred)
- whether active restoration (i.e. planting) or passive (i.e. regrowth) is implemented.

Table 7 summarises the quantitative recommendations for minimum setback widths for moderating light exposure and water temperatures in water bodies, from literature sources cited in this review.

**Table 7. Setbacks for light exposure and water body temperature**

| Setback width | Reference | Applicability |
|---|---|---|
| 15 m | Collier et al. 2001 | Waikato study modelled result 15–20 years after riparian planting |
| 10 m | Parkyn 2004 | Depends on stream width and flow, as shading is needed to reduce stream temperatures |
| Ratio of canopy height to stream width > 1 | Davies-Colley et al. 2009 | No specific setback recommendation made in this reference; even a single line of trees is beneficial |
| 35–95 m | Hansen et al. 2010 | For the state of Victoria, Australia, to moderate stream temperatures under Victorian climate<br>Low = 35 m. Moderate = 65 m. High = 95 m<br>Steeplands and headwaters, cleared slopes = 35 m |
| 5–30 m | Lind et al. 2019 | Forested buffers providing shading, average width 21 m |

## 8.3 Increasing freshwater ecosystem health, terrestrial and aquatic habitat diversity, and improved inputs of terrestrial carbon to water bodies

Freshwater ecosystem health (Clapcott et al. 2018) including aquatic habitat diversity is highly correlated with the functional objectives discussed in the previous two sections of this report. Terrestrial habitat within a riparian zone and its role as a source of organic matter, including woody debris into water bodies, is an associated but separable ecological benefit.

Parkyn et al. (2003) conclude that improvement in aquatic invertebrate communities is most strongly linked to decreases in water temperature, suggesting that restoration of in-stream communities would only be achieved after canopy closure over the stream, with long buffer lengths and protection of headwater tributaries. Invertebrate communities approaching those of native forest streams should only be expected after canopy closure has occurred (or significant shading), and then only with long (or continuous) buffers.

Inadequate recolonisation sources or pathways may limit invertebrate community rehabilitation, even when habitat is suitable. Inadequate invertebrate recolonisation typically occurs when headwater and ephemeral streams are cleared of natural vegetation or removed (e.g. ploughed, drained). Parkyn et al (2003) found a loose relationship between improvements in invertebrate communities and riparian setback width (Figure 5).

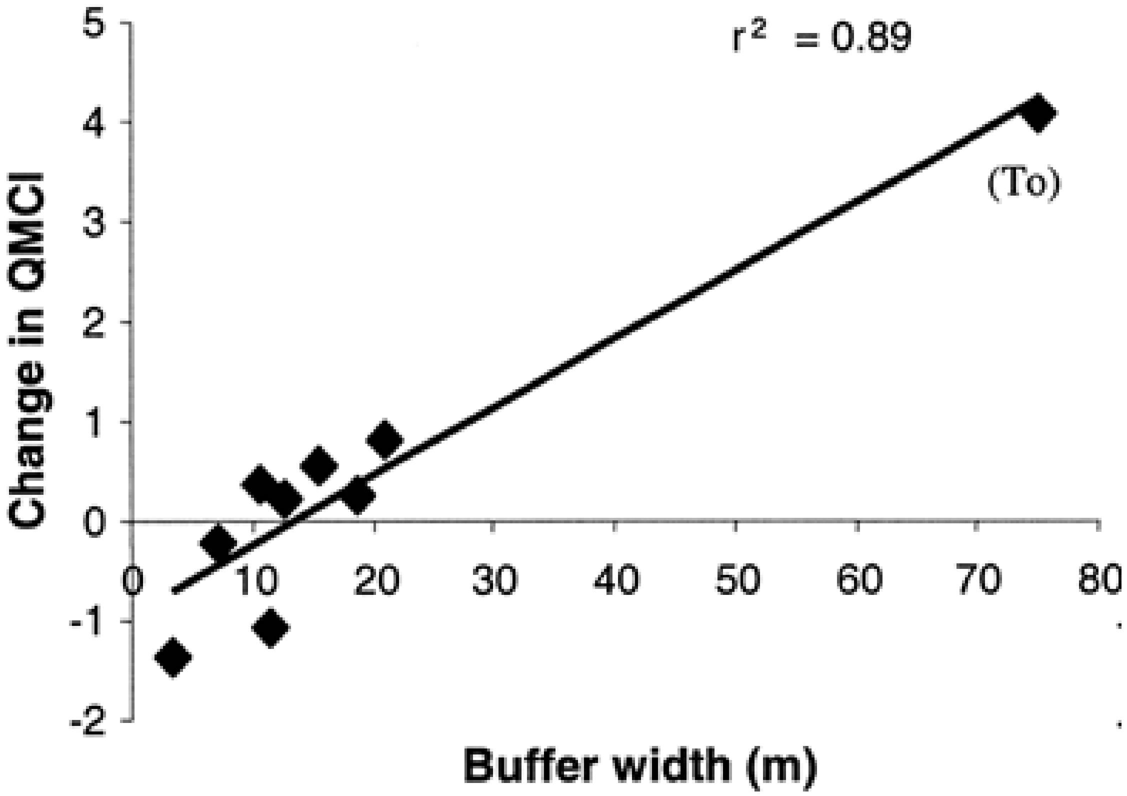


**Figure 5. Improved macroinvertebrate community index QMCI when Waikato grass buffers had been fenced 2–24 years prior. Source: Parkyn et al. 2003.**

Catchment differences will often more strongly influence invertebrate communities than riparian condition (Parkyn et al. 2003). This is a common problem with the interpretation of riparian buffer zone studies because of the inherent variability of streams, which, often reflecting wider catchment factors such as the flow and climatic regime, means that the same management technique can have variable outcomes in different stream systems.

Greenwood et al. 2012 reached a similar conclusion when assessing the effectiveness of <1 to 5 m-wide vegetated buffers along 64 Canterbury agricultural waterways up to 9.5 m wide. Considering the instream biota, they found that sedimentation and low water velocity had negative impacts and that smaller waterways were generally more affected. Only 6% of the variation was accounted for by riparian management. They concluded that management of small streams is likely to be particularly critical, as these are more vulnerable to adjacent land-use effects because of their size and lack of protection in policy. Because small streams are so common, the negative effects of upstream land use can accumulate in downstream, larger reaches, overwhelming local riparian management in these larger streams. Intensive management, such as in-stream habitat or channel morphology modification, may be needed to address historical factors such as low velocity and sedimentation, which otherwise may continue to limit community recovery.

Parkyn et al. (2003) note that rehabilitation of shade and temperature may take decades, and the structure and habitat function of woody debris in streams may take centuries to develop.

The buffer width required to decrease stream temperatures may be less than that required to provide a microclimate similar to forested conditions. The effect of setback width on the microclimate affecting stream ecology was evaluated in a study by Davies-Colley et al. (2000) in Pirongia Forest Park. The gradient of light exposure was very steep near the forest edge, with levels characteristic of interior forest reached within 5 m (related to the high density of foliage). The extent of wind penetration and associated temperature and moisture changes may, however, vary with site factors such as topography, edge canopy development, and foliage density of the shrub layer in forest. Edge effects on microclimate were found to extend at least 40 m into native forest.  This work suggests that forest buffers around 40 m wide may be needed on both sides of small streams to protect riparian ecology where the surrounding land use is open pasture or cropland.  Narrower buffers may be suitable in tree plantations where the adjoining land is only exposed for part of the timber crop rotation (i.e. after clear-cutting).  Where setbacks are less than 40 m wide, this implies benefits of including dense trees or hedging to reduce edge effects.

Parkyn et al. (2000) made recommendations to Auckland Regional Council (2001, see below) on the riparian buffer widths necessary to support sustainable vegetation and meet aquatic functions. Three different buffer widths with regard to producing self-sustaining, low-maintenance, indigenous vegetation were assessed based on canopy closure, weed invasion and natural regeneration. Their conclusions were as follows.

- 5–6 m setback: ongoing maintenance will be required to keep a buffer of this width weed free, and natural regeneration of indigenous species is likely to be limited due to high light levels supporting dense groundcover.
- c. 10 m setback: allows for indigenous vegetation succession and should result in a relatively low-maintenance riparian buffer strip. The marginal 1–2 m is likely to suffer from long-term weed infestations, which could have the potential to spread to the interior wherever canopy gaps occur.
- 15–20+ m setback: highly likely that the buffer strip will support self-sustaining, virtually-no-maintenance, indigenous vegetation. Meets most aquatic functions.

Parkyn recommended that a 10 m buffer be used as a general guideline for a minimum buffer width. A buffer width of >10 m on either side of a stream was recommended as the minimum necessary for the development of sustainable indigenous vegetation, although the ability to withstand weed invasion is doubtful in weedy environments (R. Simcock, MWLR, pers. comm. 2020). Larger buffers (20-plus metres) will be required on large waterways (rivers).

These recommendations were refined in Auckland Regional Council 2001, which stated that a buffer width of more than 10 m (15 m preferred) of a range of riparian vegetation will achieve most of the identified aquatic benefits, such as shade, food supply and habitat (based on Parkyn et al. 2000).

Collier et al. (1995) recommend planting a range of species and morphologies (different heights and shapes) at mixed (including clumped) densities and in mixed combinations. Plantings should extend to three times the height of the largest tree from the channel edge to allow the development of a suitable microclimate.

Looking at native terrestrial biodiversity as the functional objective, a thesis by Krejcek (2009) investigated the restoration success of managed lowland riparian margins in Taranaki. She compared five different management categories: unfenced (cattle have access), fenced (1–4 years, no plantings, grass only), medium aged (4–7 years with native plantings), old aged (8–12 years native planting), and baseline naturally regenerated field sites (fenced >20 years) by mapping vegetation and conducting 5 min bird counts. Krejcek observed that managed riparian margins in New Zealand are usually narrow, with an average width of 4–10 m due to a management approach that mainly aims for water-quality improvements.

The study did not record any threatened or habitat-sensitive plant or bird species, possibly due to the young age of sites (all but one treatment <20 years old, indicating lack of structural complexity and probably coarse wood) and edge effects caused by the riparian margins being too narrow. Bird species richness was positively related to vegetation height and the vegetation cover (sky cover) above 2 m and negatively influenced by the occurrence of invasive plants.

Krejcek suggests a riparian landscape approach for buffer width determination whereby application of riparian buffer guidelines should not be uniformly applied across the landscape; for example, a management objective (for birds) for riparian areas would be to maintain large-diameter and tall trees in these areas.

In a study of 138 Waikato streams, Death and Collier (2010) looked at links between the extent and location of indigenous cover and stream health, concluding that the percentage of indigenous native forest or scrub at the catchment level, rather than at the site or segment level, had the greatest influence on diversity and ecological condition (assessed by Macroinvertebrate Community Index indices). This is consistent with the findings of Doehring et al. (2019) discussed earlier. This means that riparian management aimed at enhancing macroinvertebrate biodiversity and the ecological condition of streams is likely to be more successful when focused on protecting and/or restoring headwater catchments rather than short stretches of stream. On average, streams draining catchments with 40– 60% upstream native vegetation cover retain 80% of the mean biodiversity present in pristine forest streams.

Looking at taxonomic richness within buffer zones along 88 small agricultural waterways within the Canterbury region, Renouf and Harding (2015) found mean taxonomic richness was highest in buffers 25–30 m wide and lowest in buffers ≤5 m wide. The majority of buffers (65%) were no greater than 5 m in width, with 17% less than 2 m wide. Weeds such as gorse, elderberry, blackberry and broom dominated the sites.

Environment Canterbury has recommended 2–3 m of 'set aside' dense pasture grass in combination with fencing as the minimum protection of small agricultural waterways in flat landscapes, with sloping or inadequately drained soils requiring wider margins. Use of native vegetation was recommended to mitigate increases in land-use intensity.

In the Waikakahi catchment of South Canterbury, Holmes et al. (2016) found that fenced riparian margins of 0–17 m (mean 5.7 m), even if containing only ungrazed grass, had a positive influence on various aspects of instream eel and trout structural habitat quality compared with unfenced margins. Their findings indicated that riparian segments with 5 m-wide stock exclusion fences on both banks are required to achieve instream fine sediment cover below 20% (to protect invertebrate food resources and recruitment of eels and trout) in downstream reaches. A 5 m riparian width is therefore proposed as an interim recommendation for wadable, spring-fed streams, with the caution that it is based on a correlative study in a single stream catchment and is unlikely to be directly transferable to rain-fed streams. Wider, fenced riparian areas would be required in streams with greater erosive power, although decreased channel stability, and thus increased sediment loading, might be countered by increased flushing of bed sediment.

Wood supply to streams is increasingly promoted as positive for instream ecosystems. Meleason and Hall (2005) compared the modelled implications of two riparian management scenarios on the wood supply to streams. In the first option, the pines were harvested to the stream edge and a buffer of a given width was set aside from future harvest to allow native species to colonise. In the second option, pines were retained within a riparian buffer of a given width and excluded from future harvest, allowing native species to establish under the pine canopy. This study suggests that excluding a portion of the plantation forest adjacent to the stream from future harvests enhances woody debris in-stream when compared to the recruitment provided by the re-establishment of a native forest after a harvest to the stream edge. Buffer width (5, 10, 15, 20, 25, and 50 m) was found to be an important factor in determining wood recruitment, and the model simulations suggest that buffer widths less than maximum tree height will limit the supply of wood to the channel. In general, wider buffers (5–50 m) produced greater wood volumes, and as the forest aged, volumes were greater for wider buffers.

Summarising studies of relevance to New Zealand, Death (2018) suggests, based on a meta-analysis by Sweeney and Newbold (2014), that setbacks should be at least 30 m wide to protect key aspects of forested small-stream ecosystems.

The North American review by Lind et al. (2019) stated that to maintain floral diversity, an average of 24 m (range 10–40 m) of forested riparian buffer was typically needed. To preserve birds, the forested riparian buffer width needed to be, on average, 144 m (range 40–500 m). For amphibians and small mammals combined, an average of 53 m of forested riparian buffer was needed for protecting this group of organisms (range: 20–100 m). Fish and insects required about 25 m of forested riparian buffer (ranges 15–30 m, and 15–33 m, respectively). New Zealand birds and amphibians have different needs, with populations primarily limited by mammalian predation. However, lack of habitat is implicated as a key factor reducing native forest and wetland bird populations in lowland pastoral landscapes (e.g. Burge at al. 2017). However, our sole native terrestrial mammals (bats) do forage along waterways and require large trees with cavities for roosting. Lind et al.'s recommendations for fish and insects should also be relevant for New Zealand.

The greatest improvements in terrestrial habitat diversity are likely to occur when riparian management involves planted or regenerated trees or remnant forest (Parkyn 2004). McKergow et al. (2016) note that biodiversity enhancement from riparian buffers is limited where buffers are narrow and patchy and a continuous corridor might be required to meet biodiversity objectives. However, terrestrial ecologists note that continuous corridors may help the movement of mammalian pest species, whereas our common native birds can fly over corridor gaps, even if native invertebrates, lizards and amphibians may not be able to cross.

In a national benefit–cost analysis for riparian setbacks across New Zealand, Daigneault et al. (2017) observed that 5 m margins offer very little biodiversity gain. Allowing passive afforestation or regeneration increases terrestrial biodiversity strongly only when margins are 20–50 m wide.

We conclude that using riparian buffers to improve aquatic and terrestrial habitats, and the setback widths needed for these purposes, depends primarily on the following factors (with increased setbacks needed as each factor increases):

- all factors listed above for contaminant removal and for moderating light exposure and water body temperature
- size of water body
- current state of aquatic and riparian habitats, with benefits from retaining or gradually replacing riparian vegetation rather than removing and replanting, especially where existing vegetation is tall (such as pines, poplars or willows)
- the potential for vegetation succession in the riparian zone, with narrower buffers requiring ongoing management but wider ones being more self-sustaining (at least outside very weedy areas such as Auckland)
- the amount of upstream indigenous vegetation in the catchment, especially around intact headwater streams and seepages
- livestock exclusion
- whether weed invasion is a concern or not.

Table 8 summarises the quantitative recommendations for minimum setback widths for aquatic and terrestrial habitat improvement from literature sources cited in this review.

**Table 8. Setbacks for habitat provision**

| Setback width | Reference | Applicability |
|---|---|---|
| >10 m | Parkyn et al. 2003 | For Waikato streams, QMCI was strongly correlated with buffer width, especially for those greater than 10 m (Figure 5) |
| 35–200 m | Hansen et al. 2010 | For the state of Victoria, Australia, to provide food and in-stream and terrestrial biodiversity<br>Low = 35–100 m<br>Moderate = 65–150 m<br>High = 95–200 m<br>Steeplands and headwaters, cleared slopes = 35–200 m |
| 15–30 m (fish)<br>15–33 m (insects)<br>10–40 m (floral diversity) | Lind et al. 2019 | North American international review, which may have limitations for application in New Zealand |
| 40 m | Davies-Colley et al. 2000 | Setback needed to protect riparian ecology at a level equivalent to native bush margins within pastoral catchments (smaller setbacks may be justified for timber plantations) |
| 10 m | Parkyn et al. 2000 and Auckland Regional Council 2001 | Auckland recommendations, but self-sustaining, low-maintenance, indigenous vegetation may require 15–20 m setbacks (and more in highly weedy environments) |
| 10 m | Renouf & Harding 2015 | Based on Canterbury streams with native planting, and taking into account landowner willingness to implement |
| 5 m | Holmes et al. 2016 | Wadable spring-fed streams only, based on South Canterbury study. More erodible flashy streams need wider setbacks |
| Tree height | Meleason et al. 2005<br>Collier et al. 1995 | For wood supply to streams, based on New Zealand modelling<br>For supply of carbon to the stream |
| 3 × tree height | Collier et al. 1995 | For terrestrial biodiversity |

## 8.4 Improving channel and bank stability

A modelling study by Collier et al. (2001) emphasised the need for a long-term perspective when attempting to define the likely benefits from planting pastoral catchments and riparian areas in trees. They found that stream channels may widen following planting of a 15 m riparian buffer with pine in a pastoral catchment. The catchment manager might therefore favour no action (status quo) if the primary objective were to rehabilitate a sensitive estuary downstream by minimising sediment inputs, whereas total catchment re-afforestation or riparian planting of the second-order and larger streams may be favoured if onsite ecological characteristics were most highly valued.

Hughes (2016) summarised the findings of the New Zealand-based studies that have attempted to measure differences in erosion rates between sites that have had some form of riparian management intervention implemented and those that have not. It is important to understand the prevailing catchment erosion processes if planned riparian management interventions are to effectively reduce erosion rates and/or sediment yield (e.g. preparatory erosion, which is sub-aerial/local, fluvial entrainment, such as scour and mass failure processes such as slumping).

In the lower reaches of a catchment, where mass-failure mechanisms are likely to be of most importance, removal of livestock from riparian areas and/or the planting of small shrubs and trees are unlikely to have a significant effect on reducing the contribution of sediment from these reaches. An intervention measure that provides some structural support to the banks (such as the planting large-growing tree species) would be more appropriate. The suppression of groundcover vegetation by taller vegetation may increase preparatory erosion processes.

Most of the studies attribute the measured improvements or differences in bank erosion to the exclusion of livestock from riparian areas. Because of the high connectivity between stream banks and streams, the prevention of physical damage to the banks is likely to be effective. The effects of riparian planting on stream bank erosion are more equivocal. Only two New Zealand studies (Hicks 1992; Boothroyd et al. 2004) specifically reported that the establishment of riparian vegetation actually resulted in reduced bank erosion.

Bank stability is determined by the properties of the bank materials, with both soil cohesion and dispersivity important. Size and species of tree or shrub required to stabilise the streambank depends on the intensity of erosion. In catchments that still have significant stands of native trees, shrubs or tussock near stream channels, the retention of a buffer zone 2–5 m wide is all that is necessary to maintain or improve bank stability in most cases (Collier et al. 1995). Sometimes (such as in tussock-lands), floodplains provide a natural indication of appropriate buffer width.

Marden et al. (2007) carried out research on the stabilising characteristics of New Zealand indigenous riparian plants. Broadly, the root spread mirrors the breadth of the tree, so setbacks for bank stabilisation need to allow sufficient distance for those roots to bind the soil. If the height of the bank is greater than the root depth, the riparian vegetation will be of less use for stabilising the bank. In relation to smaller streams up to 10 m wide and with bank heights less than 2 m, a setback of at least one mature tree width is needed; a minimum would be 5 m, but 10 m is preferable, depending on the species (C. Phillips, MWLR, pers. comm. 2020). An 80% reduction in bank erosion is the New Zealand rule of thumb for fenced, stock-excluded riparian margins (H. Smith, MWLR, pers. comm. 2020).

Smith et al. (2019) are developing and testing a new bank migration model in New Zealand for large catchment applications that (1) better represents spatial variability in factors influencing bank erosion and (2) improves predictive performance. The presence of riparian woody vegetation does not necessarily produce low bank migration rates but depends on other reach-scale factors such as soil texture and channel sinuosity. As noted above, different erosion processes may act upon stream banks in different parts of a catchment, and so catchment managers need to consider this when implementing riparian management interventions.

We conclude that using riparian buffers for channel and bank stabilisation, and the setback widths needed for these purposes, depends significantly on local conditions such as sediment characteristics and channel geomorphology, as well as upstream sediment dynamics. However, the following factors are relevant (with increased setbacks needed as each factor increases):

- existing land cover, with pastoral catchments having narrower channels and forested catchments wider channels
- stock exclusion, which reduces bank damage
- upstream erosion and sediment transport regime
- height of stream banks, as high banks can only be stabilised by deeper-rooting trees, and banks over about 1.5 to 2 m height are unlikely to be effectively stabilised by trees.

Table 9 summarises the quantitative recommendations for minimum setback widths for aquatic and terrestrial habitat improvement, from literature sources cited in this review.

**Table 9. Setbacks for channel and bank stabilisation**

| Setback width | Reference | Applicability |
| --- | --- | --- |
| 15 m | Collier et al. 2001 | Modelling study, but found stream widening may occur when pastoral catchments have the buffer planted in trees |
| 2–5 m | Collier et al. 1995 | Minimum mentioned in the DOC guidelines |
| 10 m | Phillips (pers. comm.) | Based on work by Marden and Phillips on root stabilising characteristics of New Zealand riparian indigenous plants |

## 8.5 Passing and attenuating flood flows

As noted by Hansen et al. (2010), one of the primary governors of riparian zone efficacy is the hydrological regime. This includes the frequency and magnitude of overbank flows through the zone, and any upstream flow regulation such as dams.

Planting of stiff riparian vegetation with high degrees of roughness will slow flow velocities, attenuating downstream flood flow and reducing the erosive power of floodwaters. Tall vegetation has greater roughness, but when undercut or toppled can exacerbate stream sediment movement. Collier et al. (1995) recommend interspersing frangible species such as toetoe, harakeke, ferns, herbs and sedges among more widely spaced riparian trees in order to maintain enough light at ground-level to support a dense ground cover.

The focus of river managers has moved in the past 30 years from maximising rapid passage of floodwaters to managing a more diverse river corridor. This does not mean that flood risk and damage are no longer an issue. Alongside riparian management, floodplains need to be managed in a way that minimises flood damage and risks to people while promoting the sustainable use of flood and erosion-prone land, including riparian zones. Fuller et al (2020) propose a natural character index (NCI) describing the form and function of a river now and in the past, with the objective of managing to a quasi-equilibrium condition prior to deliberate modification. Parameters comprising NCI include sinuosity, floodplain width, active channel width, bar area (at a given flow) and riparian vegetation.

A common approach for river engineering in the past was defining the floodplain fairway boundaries within which the river is allowed room to move rather than being constricted by more and more hard boundaries, such as rock rip-rap and groynes. For example, in the upper Motueka River near Tapawera, a fairway width of 100–200 m each side of the river has previously been adopted, within which the active channel and riparian willows and invasive plants require management.  Another example is the Taylor River passing between stopbanks through Blenheim, within which the floodplain is managed for cycling, walking, and even grape and olive growing while allowing passage of peak flows from the Taylor Dam upstream (Brin Williman, Marlborough District Council, pers. comm. 2020).

Internationally there is increased attention on concepts such as natural flood management, in which wetlands, detention ponds and riparian vegetation are managed at catchment scale to reduce flood peak flows. However, the larger the catchment and the larger the flood, the less scope there is for slowing the flood or reducing the flood hazard (Dadson et al. 2017). River managers are also encouraged through policies like the EU Water Framework Directive (European Commission 2000) to naturalise river hydromorphology to improve instream life and allow rivers room to move. Thus consideration of riparian setbacks needs to be part of the wider strategy for river channel management, involving regional council river engineers alongside environmental and policy staff.  Floodplain models such as MIKE-FLOOD (from DHI NZ) are needed to determine the frequency and degree of inundation of riparian zones so that resilient setbacks can be decided.

We conclude that designing riparian buffers for passing and attenuating flood flows is more a matter of what vegetation they contain rather than a matter of setback widths *per se*. River engineers will want riparian buffers that can withstand foreseeable flood flows while moderating peak flows, and so consultation between them and catchment managers and communities is needed, especially for larger rivers prone to damaging floods (Table 10). Adaptation to climate change is seeing greater consideration of strategies such as retreat from flood plains and creating more space for rivers to flow.

**Table 10. Setbacks for flood passage and attenuation**

| Setback width | Reference | Applicability |
|---|---|---|
| Base on local flood studies | Fuller et al 2020 | Catchment managers and land users should consult with council river engineers |

## 8.6 Providing for recreational, cultural, aesthetic and landscape values

It has not previously been widely recognised in planning for riparian management that there are broader aesthetic and landscape-scale considerations that should be accounted for, and these considerations may, for some water bodies, allow enhancement of values such as cultural and recreational values. The latter could include harvesting of mahinga kai and safe recreational contact with water (e.g. wading and swimability).

Hansen et al. (2010) note that two primary factors for riparian zone efficacy are the degree of fragmentation of the riparian zone (in terms of longitudinal connectivity of riparian vegetation) and the presence of invasive plant species. In the New Zealand context, movement of pests such as possums, rats and stoats should also be added. These may affect the aesthetic and landscape values of the catchment and affect both establishment and maintenance requirements for riparian zones.

Considering the benefits and costs of a national riparian restoration programme in New Zealand, Daigneault et al. (2017) took into account costs of fencing, alternative stock-water supplies, planting and opportunity costs of restoring riparian margins, alongside a range of benefits including using water-quality benefits based on the equations of Zhang et al. (2010). The low-cost option consisted of passive afforestation and zero planting cost, medium cost was planting mānuka at the recommended density, and high cost required landscape planning, contracting and planting services. Daigneault et al. suggest optimal margin widths of 30 m or more for the low-cost assumption, 27 m for medium costs, and 17 m for high costs. Despite the simplicity and assumptions behind the modelling, this study illustrates the trade-offs against cost when deciding setback widths.

In a similar vein, Maseyk et al. (2018) modelled changes in ecosystem service provision for lowland Taranaki dairy farmland, comparing grazed margins with a 1 m fenced grass strip and a 5 m setback planted in a mix of grasses, shrubs and trees. They conclude that establishing multi-tier riparian margins should positively influence the provision on a wider range of ecosystem services. However, they also observe that riparian management alone is not adequate to address detrimental outcomes of land use on receiving environments and should be part of wider farm management practices that maximise ecosystem services. Considering the current statutory environment (2020) we suggest this might best be delivered through incorporating riparian management within a farm environmental planning framework (actioned through Farm Environmental Plans), which must be consistent with regional and national planning rules and limits. Land users do not want multiple plans with potentially conflicting objectives, so there should be efforts to integrate regional council requirements with industry farm planning (e.g. Beef+Lamb NZ, Fonterra Tiaki Farm Environment Plans, NZ Good Agricultural Practice for horticulture).

Maseyk et al.'s modelled estimates indicate that per-cow milk production is no less as a result of the loss of 1–5 m setback grazed pasture area; production may increase if the effects of shade and shelter are taken into account. Production benefits linked to riparian buffers are being investigated by DairyNZ (E. Kalaugher, DairyNZ, pers. comm. 2020), who are focusing on the potential for multiple-use riparian areas to produce fodder for stock, food for people or nutraceuticals, while also providing for other environmental benefits.

For example, recent ESR research indicates that mānuka roots speed up die-off of microbial contaminants and may reduce nitrogen leaching (Prosser et al. 2016). Riparian strips could support mānuka and kānuka honey production, growing native culinary plants (e.g. horopito, kawakawa), textiles (harakeke) and traditional medicine/rongoā (e.g. koromiko, harakeke, kawakawa or kūmarahou). Incorporating these uses may improve the viability and acceptability of wider setbacks. In addition, vegetated, ungrazed buffers can provide habitat and floral resources for native pollinators and invertebrate predators, potentially providing increases in crop pollination and crop yield (Wratten et al. 2012; Case et al 2020.

Well-adjusted river systems are best understood as operating within a dynamic equilibrium (Fuller & Death 2018). Allowing rivers more room to move reconnects the river with its corridor and adjacent floodplain. This may have significant cultural value, since iwi and hapū value the catchment as a whole. However, Death (2018) comments that planting should ideally not proceed until an equilibrium width has been attained, because the river will widen via bank erosion, removing plantings in this zone. Interventions such as gravel extraction, channel realignment or provision of off-channel wetlands may be needed to protect plantings, as alternative approaches.

We conclude that design of setback riparian buffers to enhance recreational, cultural, aesthetic and landscape values should consider the following factors (with increased setbacks needed as each factor increases):

- upstream discharges and land-use effects
- invasiveness of plants and animal pests that will need controlling
- natural regeneration potential of native plants
- benefits vs opportunity costs for adjacent land uses such as fencing, alternative stock-water provision and riparian planting
- benefits of riparian strips for adjacent land management through shelter, safety, efficient fertiliser use, etc. (often influenced by locating fences in locations that assist management)
- production potential within the riparian buffer, such as honey production, supporting crop pollination, and supporting natural predatory invertebrates
- cultural uses and values within the riparian buffer, such as rongoā and mahinga kai
- cultural and aesthetic benefits of allowing rivers and streams room to move more naturally, and for riparian corridor connectivity, both of which provide improved ecosystem services at landscape scale.

Table 11 summarises the quantitative recommendations for minimum setback widths for improving recreational, cultural, aesthetic and landscape values, from literature sources cited in this review.

**Table 11. Setbacks for recreational, cultural, aesthetic and landscape values**

| Setback Width | Reference | Applicability |
|---|---|---|
| 17–30 m | Daigneault et al. 2017 | Setbacks optimising benefits and costs at New Zealand national scale.<br>Low cost (natural regrowth) = >30 m<br>Medium cost (planting mānuka) = 27 m<br>High cost (diverse plantings) = 17 m |
| >5 m | Maseyk et al. 2018 | Did not research ecosystem services benefits of more than 5 m setbacks (in Taranaki dairy lands) |

# 9 Summary, policy implications and recommendations

An over-riding conclusion from this review is that riparian setbacks should be only one factor when designing interventions to achieve agreed functional objectives within the whole catchment. Setbacks should be specific to the water body, farm and catchment. Tailoring setbacks to include wider values and practices valued for people and catchment is needed to maximise their benefits and minimise costs.

Important catchment contexts that will need to be considered when assessing suitable riparian zone widths for each water body are:

- longitudinal continuity of the riparian zone
- catchment land use (dominant form of land use, e.g. pasture, forestry)
- adjacent land uses (especially agricultural activities that directly contribute excess nutrients and sediment, although localised industrial, infrastructure and urban land uses can also have significant impacts)
- water-body size, permanence and location within the drainage network (e.g. small headwater streams are important for reducing nutrient exports downstream, headwater wetlands are important for mitigating peak flows)
- flow regulation (including the extent, timing and duration of flooding and effects of water storages)
- climate, soil types (particularly low-permeability soils) and catchment physiography
- proximity to, and connection with, source populations of invertebrates, fish and plants in terrestrial and aquatic refugia
- groundwater depth and fluctuation.

Given the catchment management approach and functional objectives outlined in section 6, our general conclusions are that the wider the riparian setback along water bodies, the more functional objectives will be met and the less need for significant management intervention later.

For optimal riparian management, the best management practice in most cases would be to begin from the headwaters, protecting and enhancing remnants while also achieving source control, then continuing downstream. This logically includes applying buffers to streams <1 m wide, which do not have mandatory stock exclusion under current national rules. If that is not possible, the catchment manager's focus should be on classifying priority water body reaches or margins that would first achieve the chosen objectives from Table 3.

Riparian management options will need to be designed with the hydrological pathways, soil drainage, and topography of the catchment in mind, and targeted to areas where the most benefit can be achieved. Assessment of catchment and regional hydrology, such as soil drainage profiles, critical source areas and mapping of wetlands as focal areas for denitrification, as well as grouping water bodies and riparian zones into classes according to their potential effectiveness for water quality and biodiversity objectives, are approaches that will assist with catchment-scale outcomes.

Fencing and planting of riparian margins are important contributions to achieving or maintaining contact recreation values but cannot deliver contact recreation standards where point-source discharges remain an issue at the catchment scale.

Because of the link between water bodies and their catchments, improved land management, including riparian management (e.g. through farm environment plans delivering whole-catchment outcomes consistent with regional plan policies and limits) is required to achieve desired objectives such as improved water quality and stream habitat.

The costs of setbacks are heavily influenced by fence type, extent and density of planting, level of short-term weed control required, and productivity of 'retired' buffer land. For example, lower-production-value areas can be prioritised for riparian setbacks while providing production benefits such as shelter during lambing, fodder during extreme drought, or offsets for greenhouse gas emissions. Cultural, aesthetic and 'in-buffer' production benefits are strongly influenced by plant species and cover, with the cultural and aesthetic viewpoints often differing greatly between individuals and groups. Hence, local and catchment consultation is critical.

In general, the wider the buffer, the greater the range and size of benefit. Death's (2018) review concludes that efficient setbacks can range from 5 m for bank stabilisation and stream shading, to 20 m for self-sustaining buffers, to over 50 m for biodiversity gains. Several meta-analyses have indicated that 30 m buffer strips are needed to protect stream health, while others have recommended a 50 m buffer strip.

The brief for this review sought definition of suitable distances to set back high-risk land uses and activities from water bodies, especially for land uses and land management practices prevalent in Tasman District. The literature review found very few studies that relate to specific land uses or management practices. We have suggested that decisions on riparian setback distances need to be made on a catchment-by-catchment basis aimed at achieving agreed riparian functional objectives. This means that setbacks may not necessarily be the same for a specific land use in one catchment compared with another.

In Table 12 we present suggested long-term minimum setbacks for each of the six functional objectives reviewed in section 8 of this report, taking into account the opportunity costs for intensive land uses in Tasman District and elsewhere around New

Zealand. For more extensive land uses such as forestry, and on steeplands, wider setbacks would be justified.

However, a 'rule' that requires a minimum approach is likely to deliver much lower overall outcomes than can be achieved when site-specific approaches are used (e.g. placing a fence to also exclude stock from a scarp, or to exclude stock from a critical source area (wetland)). Guidelines should support site-specific approaches.

Therefore, we do not recommend the setbacks in Table 12 be used as minimum setbacks prescribed in regional rules, but as guidelines for property-scale achievement of functional objectives, assuming other properties in the catchment are taking a similar approach to riparian design. Our suggestion is that a decision support tool such as an enhanced Riparian Planner would help deliver the recommended catchment-based approach.

**Table 12. Riparian setback recommendations for six functional objectives**

| Riparian functional objective | Minimum setback recommendations | Applicability |
|---|---|---|
| *Reduce nutrient and other contaminant inputs* | 10 m | For land with slope <10°. Aim is to filter out >80% sediment and pesticide, >70% nitrogen and phosphorus in overland flow, and remove c90% groundwater nitrate in fine shallow riparian sediments |
| | 20 m | For steeper land than 10° |
| *Improve light exposure and water body temperature* | 10 m | Mature trees needed for shading; buffer width should exceed mature tree height and channel width. Even a single line of trees is beneficial. |
| *Freshwater ecosystem health, terrestrial and aquatic habitat diversity* | 15 m | To sustain macroinvertebrates, fish, terrestrial biodiversity using a range of riparian vegetation. Riparian biodiversity is easier to sustain with a 15 m setback; smaller setbacks and weedy buffers require more management |
| *Improve channel and bank stability* | 10 m | Equivalent to the root-mass diameter of a mature riparian tree |
| *Pass and attenuate flood flows* | None | Base the riparian setback on the flood characteristics of specific catchment and river reach |
| *Recreational, cultural, aesthetic and landscape values* | 20 m | A balance of ecosystem service benefits achieved in the longer term |

When considering the implications of these recommendations in policy setting, the following could be considered.

- Policy needs to consider the transition time for implementation. One policy approach to implementing setbacks that require forfeiting highly productive land could be
  - initial stock exclusion, with revegetation, at least 3 m from the bank of the water body, then
  - secondary relocation of the setback to the optimal setback, either at the end of the life of the fence or at 20 years, whichever is sooner.

- If riparian setbacks already exist, they should be retained even if wider than those in Table 12.
- On steeper slopes (e.g. >10°), treat the setback requirement as a horizontal distance (which means that steeper slopes require longer setbacks upslope), but locate fences back from the edges of natural terraces or lower slope areas.
- For wetlands and tomos, which may act as conduits for nitrogen, consider planting with species that remove nitrogen and that can be harvested and removed before winter die-back and reintroduction of nitrogen into the water.
- Livestock exclusion (including of any high-density species such as farmed waterfowl) should be a top priority along all permanent water bodies, and also for ephemeral water bodies where possible.
- Occasional grazing of ephemeral water bodies when dry may be permissible, provided there is no grazing loss of preferred riparian species. Likewise, economic production from riparian zones (e.g. for honey or selectively logged timber) may be permitted and could provide an incentive to implement wider setbacks.

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