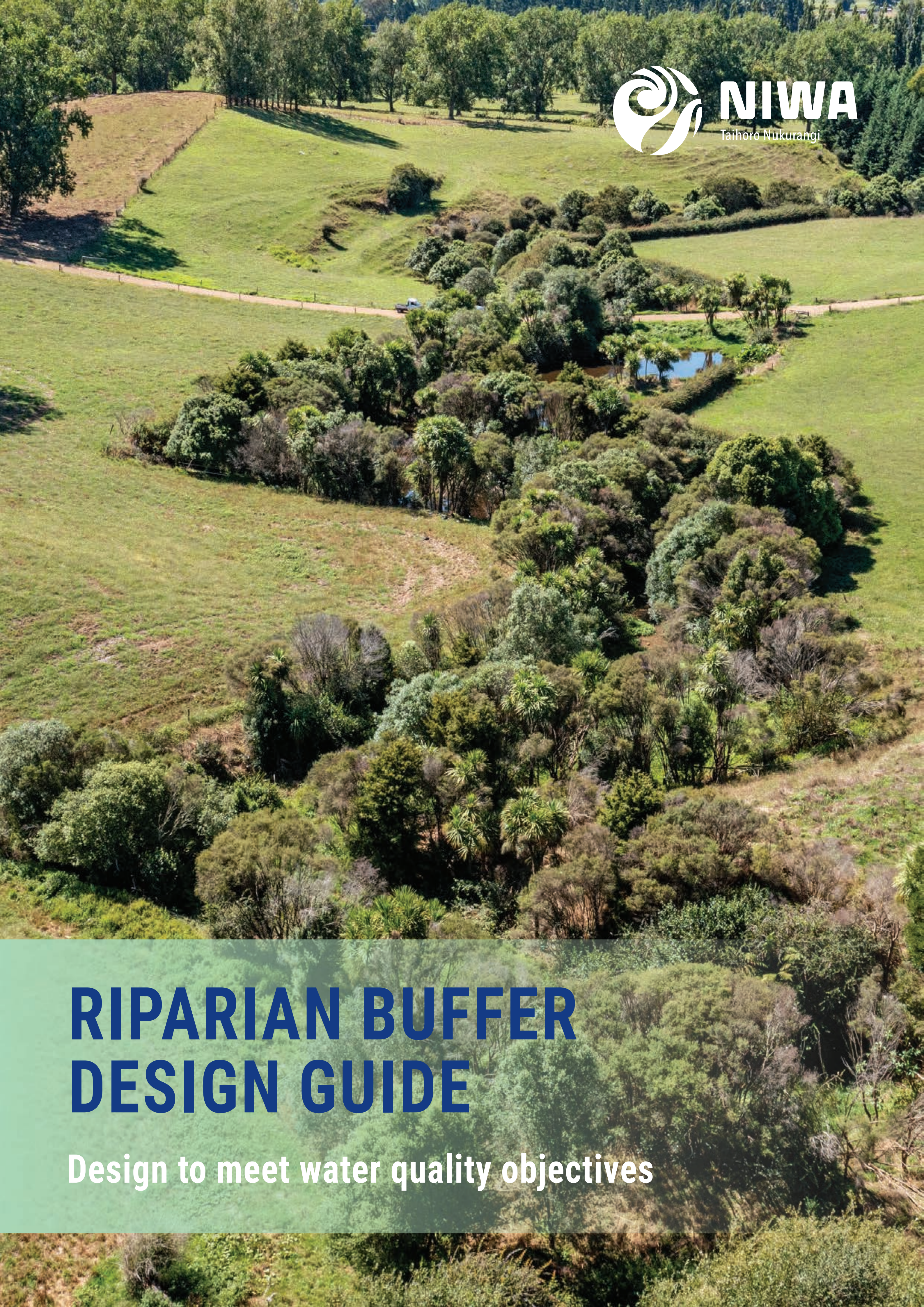

NIWA
Taihoro Nukurangi

RIPARIAN BUFFER DESIGN GUIDE

Design to meet water quality objectives

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Front cover and this page: An example of long-term riparian planting on a Waikato dairy farm owned by Grant Wills and Karo Preston (Stuart Mackay, NIWA).

Funded project FWRP2202

ISSN 1174-264X

NIWA Information Series 103

GETTING STARTED

Steps required to develop a riparian buffer that meets water quality objectives

1. Consider your GOALS

Is nitrogen a big environmental problem in your catchment or is it sediment or both? Do you need to retain phosphorus? Do you want to improve the aesthetics or biodiversity of your farm, or continue to use the riparian margin in a productive way? Is providing good conditions and habitat for aquatic life one of your motivations?

2. Find the EXPERTISE you need

Several organisations may be able to offer support for riparian buffer design and setup (including environmental and legal considerations). Your regional council's land management team is a good place to start. Landcare Trust, DairyNZ or your farm advisor may also be able to help.

3. Identify the riparian buffer FORM required and check landscape SUITABILITY

This guide will give you a good starting point. Do you need a multi-function buffer?

4. Develop a detailed draft PLAN and COSTING

By this point you'll have a clear picture of what you want and need. DairyNZ's Riparian Planner is a useful tool for estimating plant numbers & creating a planting plan.

5. Final PLAN

After review, develop a final plan and get started.

ABOUT THIS GUIDE

Purpose

This guide discusses design principles, and provides high-level information about the likely performance of riparian buffers.

The information in this guide is based on NIWA's "Preliminary riparian buffer guidelines. Filtering surface runoff and nitrate removal from subsurface flow" (McKergow et al. 2020b) and a review of New Zealand and international performance data (McKergow et al. 2020a).

This guide shows how riparian buffers may be used to reduce the inputs of suspended sediment (SS), nitrogen (N) and phosphorus (P) from agricultural lands to surface and groundwater (principally on dairy farms) under pasture and during pasture renewal and cropping. It does not address the use of plants to reduce stream bank or channel erosion, and is not suitable for irrigated pasture, runoff from feed pads or farm dairy effluent applications.

The information supplied will assist farmers, farm advisors, rural contractors, and regional council staff to appropriately size, design, construct and maintain effective riparian buffer zones designed for water quality outcomes.

Keep it legal

Establishment of riparian buffers is unlikely to require a consent unless you plan to undertake significant earthworks or vegetation clearance in sensitive areas of a catchment. Regional or territorial councils have rules regarding these activities near natural waterways. Most regional plans allow plant introduction or removal as a permitted activity (i.e., a resource consent is not required). However, conditions may need to be met, such as seasonal restrictions on vegetation removal to avoid disturbance of stream banks and beds during fish spawning or migration periods.

Regional councils can also help you identify potential funding sources, and to ensure that your plans meet current regulations (such as Resource Management (Stock Exclusion) Regulations (2020) and freshwater plans).

ABOUT RIPARIAN BUFFERS

What are they

A riparian buffer is a strip of land which separates agricultural activity from a waterway. Buffers are usually fenced to exclude livestock and establishment of a permanent ground cover of vegetation is encouraged. Many livestock farms have invested in riparian buffers, typically a combination of livestock exclusion fencing and planting of native grasses, shrubs, and trees.

To design riparian buffers that improve water quality outcomes, knowledge of the target contaminants and how they move through the landscape is required. Once you have defined your environmental goals, matched these goals to the specific contaminants and landscape setting, you may select a filter strip, planted riparian buffer or a combination - a multi-function buffer. (Figure 1).

A multi-function riparian buffer may be used to remove contaminants from both surface runoff (a filter strip) and subsurface flow (a planted riparian buffer) (Figure 1). However, in some locations only one function may need to be prioritised.

Filter strips are managed bands of dense vegetation (commonly grass) which run parallel to the stream, and act as physical barriers that slow surface runoff and trap sediment and coarse particles. On some farms these are placed on hillslopes and near to streams.

Planted riparian buffers are created by establishing a band of vegetation in the riparian zone (along a drain, stream or river), to promote nutrient uptake and processing. Plants selected usually include grasses, sedges, flax, shrubs, and trees. These will provide a range of water quality, aesthetic, aquatic and terrestrial biodiversity benefits. This guide primarily considers the water quality benefits which result from subsurface flow passing through the planted buffer's root zone.

If the vegetation type(s), and buffer location and design are selected carefully, the vegetation may be harvested periodically and used for other purposes, thereby creating a productive buffer. More information about recent NZ productive buffer research and case studies is available from NIWA and DairyNZ websites (see back page for weblinks).

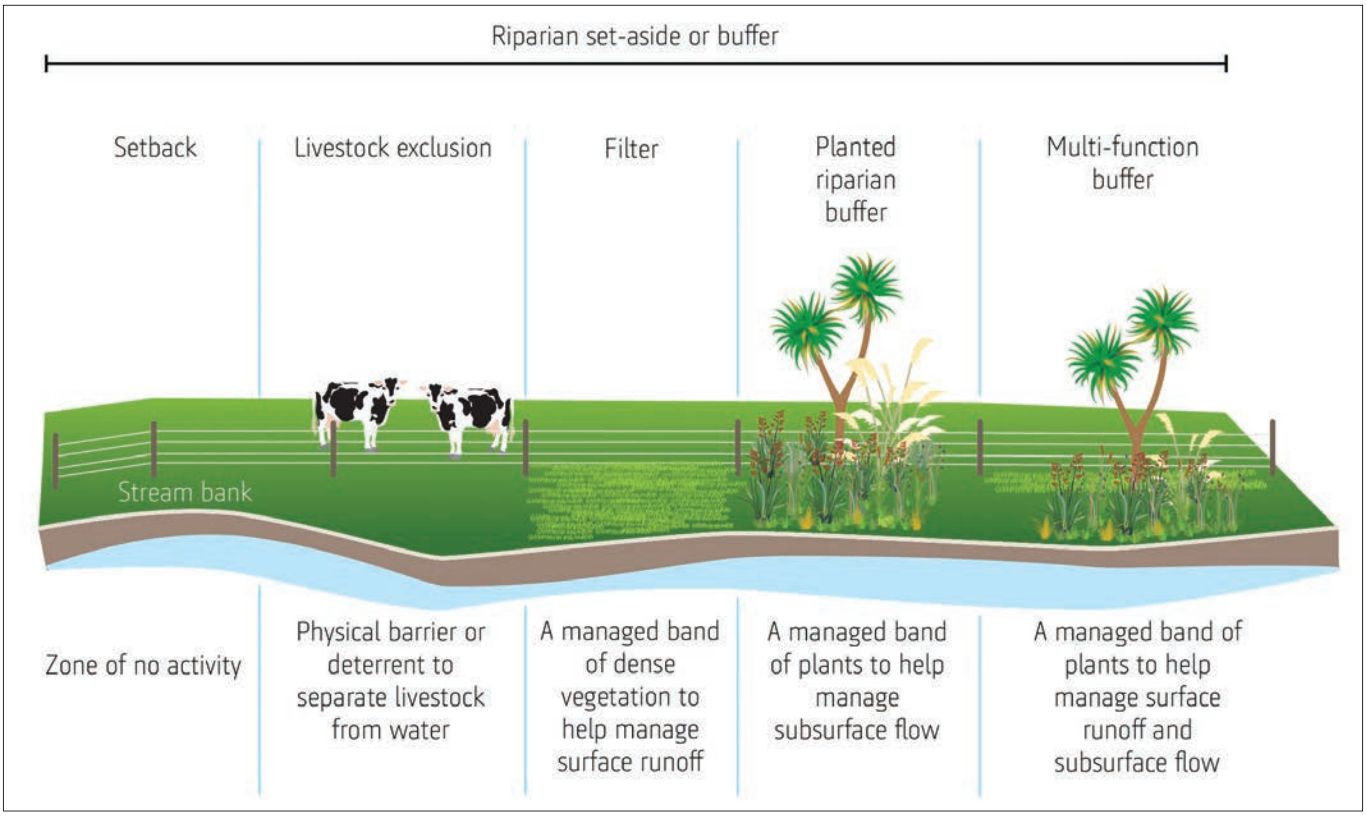

Figure 1. Common riparian buffer forms. A multi-function buffer includes both a filter strip and planted riparian buffer.

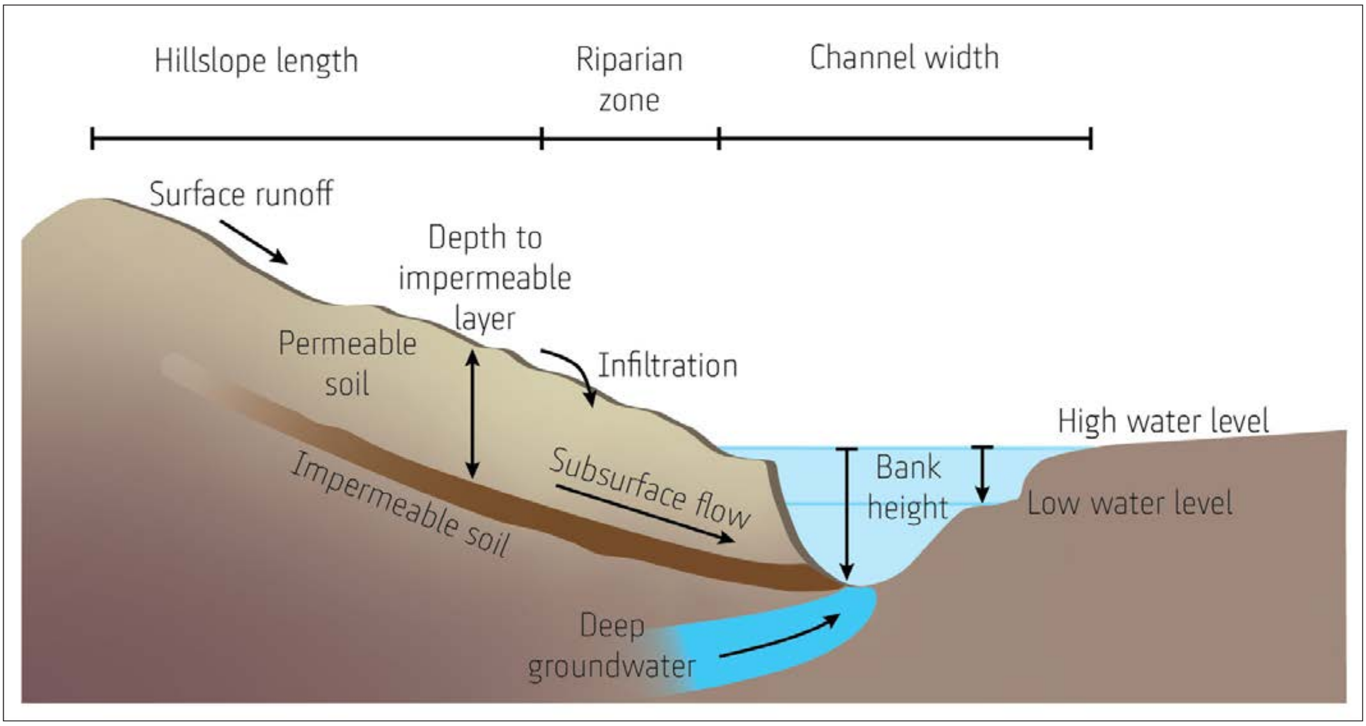

Figure 2. Schematic of key riparian buffer terms used in this guide.

Definitions

Some technical terms are used in this guide and Figure 2 indicates where these features or activities typically occur in the landscape. Detailed definitions and descriptions of these terms are available in the preliminary technical guidelines (McKergow et al. 2020b).

Planted riparian buffer on the Okana River, Canterbury. Carex is planted on the lower bank which might be flooded frequently, while flax, shrubs and trees are on the upper banks (Lana Young, NIWA)

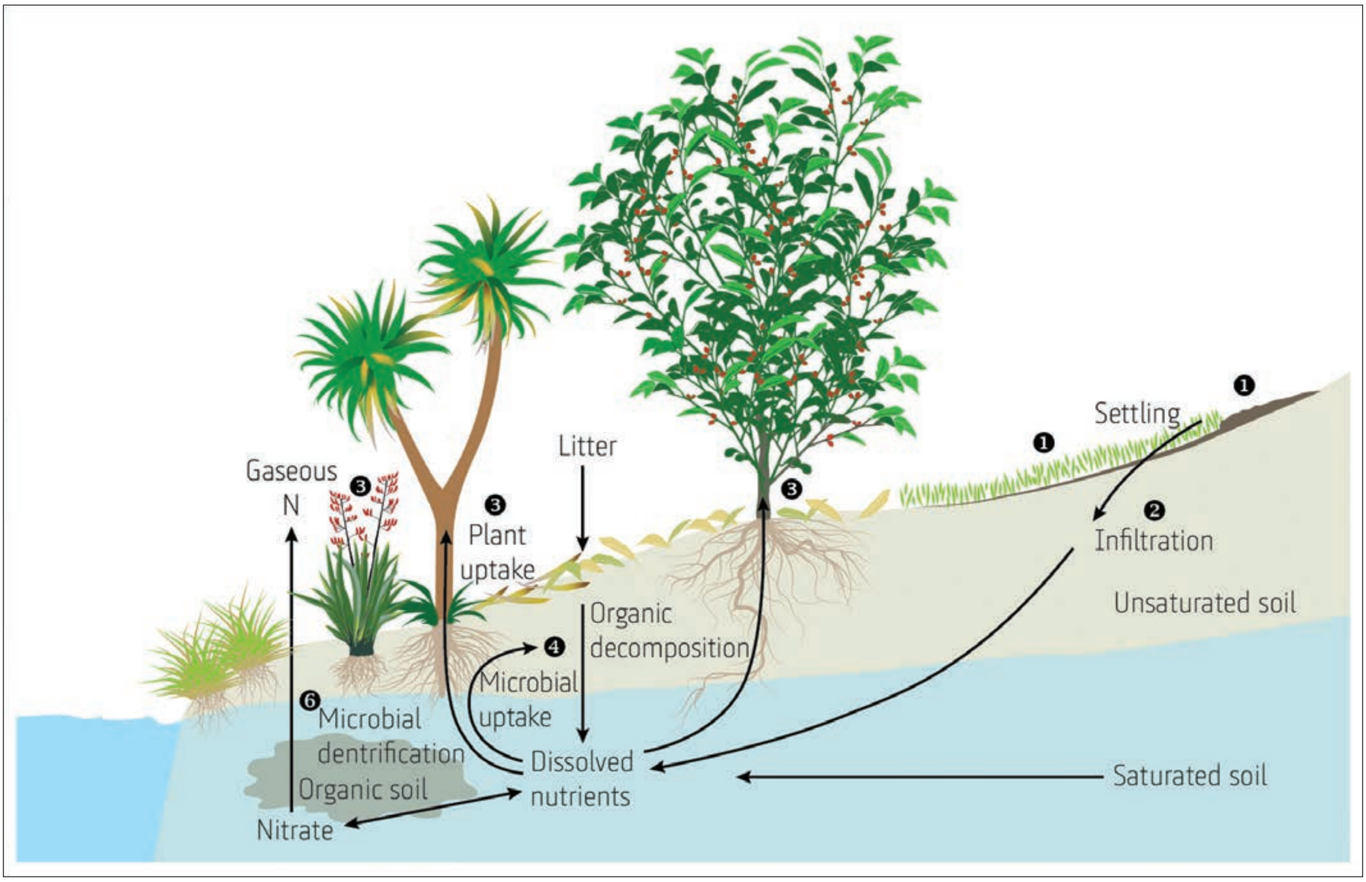

Figure 3: **Main processes by which filter strips and planted riparian buffers retain suspended sediment and nutrients.** The main processes are (1) settling and (2) infiltration of water and dissolved contaminants following settling of particulates. Note: some fine particles (e.g., clay) may not settle in a filter strip. Key processes for dissolved nutrients are (3) uptake through roots into plant tissues, (4) microbial uptake, (5) immobilisation as soil organic matter and (6) microbial denitrification.

How they function

Riparian buffers remove contaminants through a combination of physical and biological processes. The most important processes for filtering particulates from surface runoff and for removing dissolved nutrients from shallow subsurface flow are shown in Figure 3.

Filter strips work by:

- slowing shallow surface runoff, allowing particles (soil particles, aggregates, dung, plant litter) to settle in the backwater created at the filter face, and slowing the velocity of runoff through the filter (Figure 3), and
- increasing soil permeability which may allow more surface runoff to infiltrate into the riparian soil, increasing contact between soil and contaminants (dissolved nutrients, fine particles) (Figure 3).

Settling in filter strips is enhanced by dense vegetation cover in the filter strip at ground level (e.g. dense grass sward) which increases friction, reduces water velocities, and gives particles more time to settle. Trees and shrubs can be part of a filter strip as long as dense groundcover is present to provide roughness and slow surface runoff. Patchy grass cover or clumped vegetation may encourage the development of micro-channels, allowing high water velocities in parts of the filter strip, allowing contaminants to bypass the trapping elements.

Sediment size determines where and how quickly sediment settles in a filter strip.

- coarse sediment (sands, >2 mm) is deposited in the backwater upslope of the filter face and in the first few metres of a filter strip.
- finer particles (silts and fine silts; 0.002-0.06 mm) have lower settling rates and although some silts may settle in the backwater, much is carried into the filter strip where trapping occurs through a combination of settling and infiltration.
- unless they form aggregates, clay particles (<0.002 mm) settle very slowly in standing water – about 20 cm in 8 hours.

Vegetation in a planted riparian buffer can remove contaminants by:

- acting as a filter strip if vegetation is dense at the ground surface,
- using nutrients in shallow subsurface water for plant growth (Figure 3),
- improving soil structure (notably soil permeability) and increasing the ability of water to infiltrate, and,
- providing organic litter which creates conditions that enhance water retention, allow nutrients to attach to soil (fine particles and phosphorus), and support microbially-driven processes such as denitrification (nitrate, Figure 3).

Planted riparian buffers can significantly reduce nitrogen losses from agricultural land by removing nitrate from subsurface flow. Nitrate removal can be attributed to the presence of a planted riparian buffer where an impermeable soil layer forces subsurface flow to move through the root zone of riparian soils. Under these conditions, high levels of nitrate removal have been measured and attributed to plant uptake and microbial denitrification.

Microbial denitrification is a key nitrogen removal process in many riparian buffers. In this process, naturally occurring denitrifying bacteria and fungi found in wet soils convert nitrate (NO_3) in water into atmospheric nitrogen gas. The microbes use the oxygen attached to the nitrogen atom for their own respiration. Organic carbon from decomposing organic material provides the energy source microbes need to remove the oxygen from the nitrate molecule. Planted riparian buffers will accumulate organic carbon on the soil surface and in the root zone over time.

The uptake of dissolved nitrogen and phosphorus by riparian plants is also an important nutrient removal pathway. Nutrients taken up by the plant are transformed into plant biomass and are either remineralised or accumulate in the soil following decay processes. In some instances, after many years riparian buffer soils may release some of the nutrients accumulated, in dissolved form. Periodic harvesting of plant material, such as occurs in a productive buffer, allows nutrients incorporated in plant growth to be removed off-site.

The relative importance of plant uptake and denitrification varies seasonally. Nutrient uptake is high when plants are growing rapidly (spring-summer) but low in winter. Nutrients taken up by plants are converted into tissue and stored. When plants shed their leaves, nutrients can be released as leaves decompose and recycled in the next growing season. For deciduous vegetation nitrogen storage in leaves is around 90% of nitrate uptake. Denitrification rates vary with temperature, being highest in summer. However nitrate leaching is often higher in winter. Consequently, the potential for nitrogen removal by planted riparian buffers may be similar among seasons.

Leaf litter accumulating in a well-established planted riparian buffer at Whatawhata, Waikato (Brian Smith, NIWA).

LANDSCAPE SUITABILITY

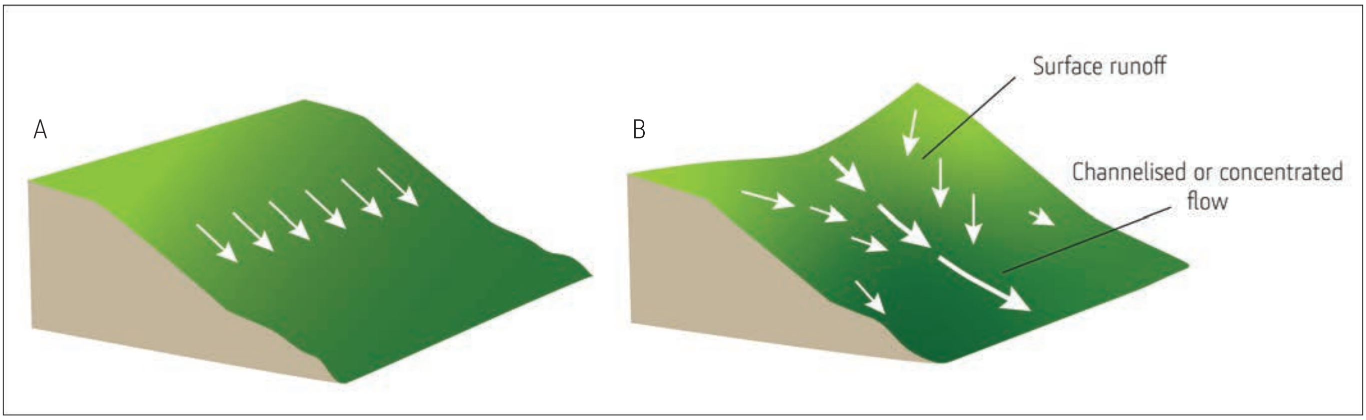

Figure 4: Flow convergence effect on runoff across filter face. (a) No flow convergence on a uniform slope; runoff enters the filter strip along the entire filter face at low depth and velocity, (b) Flow convergence causes runoff to enter the filter in a channel at high velocity.

LANDSCAPE SUITABILITY FOR A FILTER STRIP

Location suitability checklist

☐ **Surface runoff** typically travels in micro-channels, like fingers of water. A filter strip will perform well if many fingers of runoff arrive at the filter face, but when runoff converges into fewer, larger, and deeper channels (Figure 5), the vegetation may be unable to slow the runoff enough to allow particles to settle. Where flow convergence is visible in the landscape, additional measures may be required to distribute water across the filter face and reduce flow rates. Options include installing wider filter strips in convergence zones, creating dams, berms, or ponding areas that reduce flow rates and increase dispersion.

Note that extreme storm events (e.g. 1 in 100 year events) are likely to overwhelm, and possibly damage, even the best designed filter.

☐ **Soil moisture** conditions at the site should be favourable for establishing and maintaining filter strip vegetation; key factors include water table depth and likely flood levels. Filter strips are best located on unsaturated soils because this will favour removal of contaminants by both infiltration and settling. Filter strips will be less effective where water is unable to infiltrate into the soil (Figure 5), or where water bypasses riparian soils in subsurface cracks or macropores and enters the stream channel rapidly.

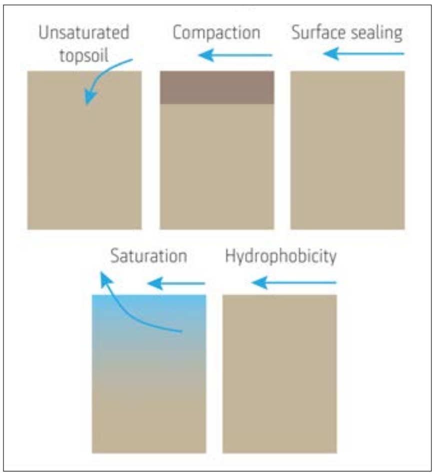

Figure 5: Effect of factors influencing soil condition on water and contaminant flow and ultimately filter strip performance.

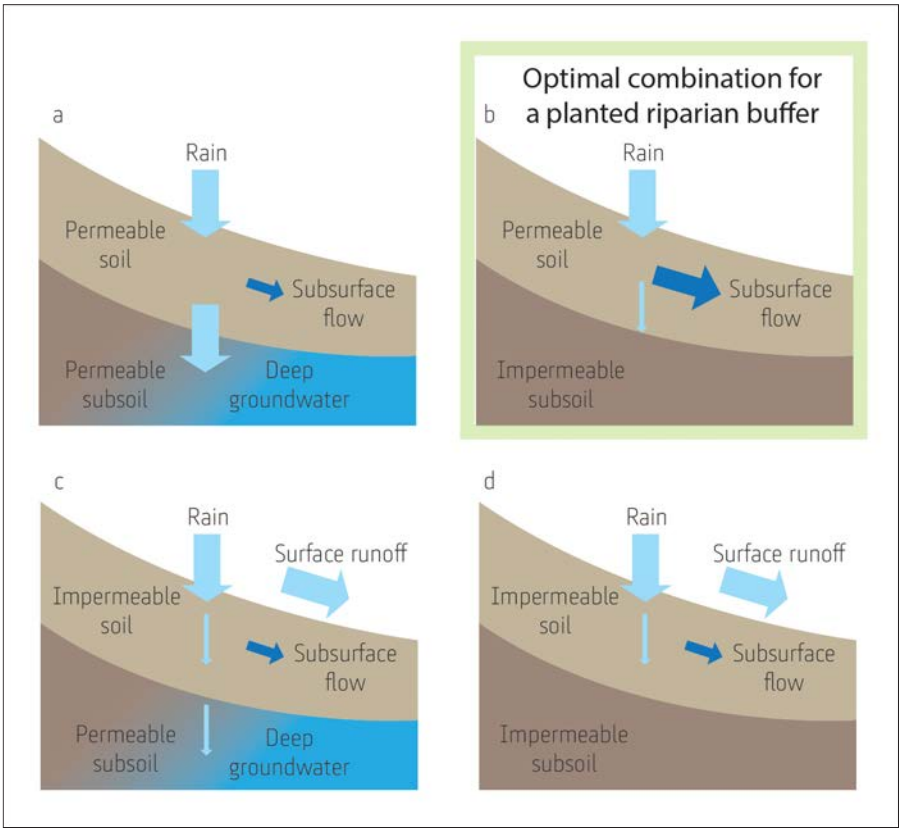

Figure 6: Major flowpaths for water on hillslopes with combinations of permeable and impermeable soils. Width of the arrow indicates relative magnitude of flow.

PLANTED BUFFER FOR NUTRIENT PROCESSING LANDSCAPE SUITABILITY

Location suitability checklist

- ☐ Optimal removal of nitrate in a planted riparian buffer occurs when an impeding soil layer (typically at depths <2 m) forces subsurface flow with a high nitrate concentration into the plant root zone. Shallow impeding layers, or aquicludes, in the soil create barriers to the downward movement of infiltrating water, resulting in horizontal subsurface flow (Figure 6). If impeding layers are absent, or occur at depth, groundwater is likely to flow deep in the soil, away from the influence of riparian plants (Figure 6 a).
- ☐ If stream banks are high (>2 m) and the channel bed is incised, careful design is required. Plants may be lost through active bank erosion and plant roots may not be able to access shallow subsurface flows. Trees with deeper rooting systems (extending to >2 m depth) may be needed. Bank re-battering could be considered on low slope land, but local rules need to be checked before proceeding with this, and advice about timing and consenting should be sought from regional council staff. Councils will advise what is needed to comply with regional and local rules, and indicate whether employing a geomorphologist or other specialists is required to obtain specialist advice.

CONTAMINANT REMOVAL ESTIMATES

Performance estimates for filtering sediment, total nitrogen and total phosphorus from surface runoff

The performance estimates for contaminant reduction by filter strips are based on published field studies and expert opinion. Few New Zealand studies have documented filter strip performance relative to their contributing hillslope length, and the performance estimates provided here are based on information derived from local and international studies (McKergow et al. 2020a).

Figure 7 can be used to:

1) estimate sediment and particulate nutrient removal (for soils with <28.5% clay on flat to gently rolling land with slopes <11 degrees), for given filter strip dimensions, or

2) estimate the dimensions of a filter strip likely to achieve target removal rates.

In both cases hillslope length must be measured. The top of the effective hillslope may be the ridge, or a structure such as a farm track with drain may define a shorter, effective hillslope length. Drainage upslope of the track may be diverted away from the filter strip.

Filter strip width may need to vary in response to local topography, runoff hydrology and filter hydraulics. Performance figures do not apply in circumstances where concentrated flow paths occur. Concentrated flow (>10 cm depth) is likely to force runoff through a narrow zone of the filter face (rather than allow the flow to enter a broad width of th filter strip, and the flow is likely to overwhelm the filter, leading to well below anticipated contaminant removal performance.

To use Figure 7, the width of an existing or new filter strip is sized relative to the contributing hillslope length and converted to a percentage.

$$\frac{\text{filter width (m)}}{\text{hillslope length (m)}} \times 100$$

Then from Figure 7 estimates are made of performance – the likely average and range of contaminant removal for suspended sediment (left axis). Total nitrogen and total phosphorus removal are read from the right axes. Alternatively, Figure 7 is used to estimate the range of filter width to hillslope length required to achieve an average target contaminant removal percentage.

Performance estimates must be checked to account for local conditions - these may increase likely performance where conditions enhance attenuation, or decrease performance where conditions are less favourable.

For example, a proposed filter strip has a width:hillslope length ratio of 7% (e.g. a 7 m wide filter receiving surface runoff from a 100 m long hillslope or a 3.5 m wide filter receiving runoff from a 50 m long hillslope), so the estimated average annual sediment removal is 70% but annual removal may vary between 38 and 84% (green bands), depending on local conditions.

The guidelines are data driven and confidence intervals are used to create bands to adjust performance estimates.

If local condition adjustments are required, then the average performance estimate is increased or decreased. When more than one adjustment is required, they are summed together to create a larger adjustment. For example, if the 7% width:hillslope length filter currently has low density/patchy vegetation, performance is likely to be below average (light green lower band, between 40 and 70%). If the soils in the same filter also have low water infiltration rates, then performance will be lower than 40%. However, if the same filter is receiving coarse sediment its performance will return to the light green lower band (40-70%).

Fewer nutrient removal values have been reported, making it necessary to use a relationship between SS removal and nutrient removal to estimate nutrient removal. For the example above, if sediment removal is 70%, then average TN removal is 63% and TP removal is 56%.

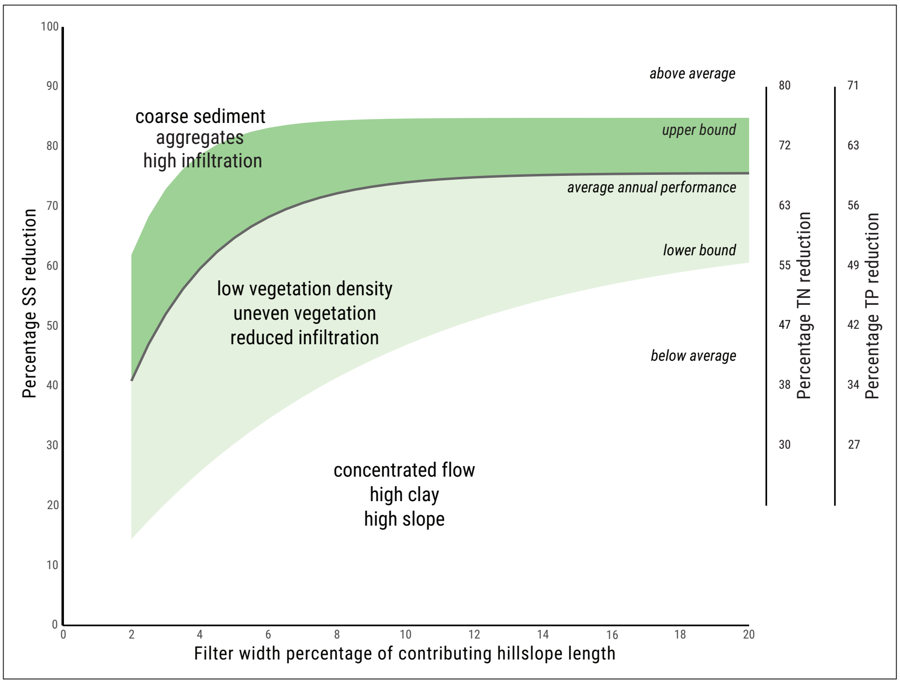

Figure 7. Long-term median annual reduction of suspended sediment (SS), total nitrogen (TN) and total phosphorus (TP) with local condition adjustments. Applicable to areas without clay soils (<28.5% clay content) and low to gently rolling slopes (<11 degrees). The solid line shows expected long-term average performance, with shaded ± 95% confidence intervals.

Filter width percentage of contributing hillslope	% SS annual removal			% TP annual removal			% TN annual removal		
	average annual	lower bound	upper bound	average annual	lower bound	upper bound	average annual	lower bound	upper bound
2	41	14	62	35	16	50	38	15	56
3	52	20	73	43	20	58	48	21	66
4	60	26	79	49	24	62	54	25	71
5	65	30	82	52	27	65	59	29	73
6	68	35	83	55	30	66	62	33	75
7	71	38	84	57	33	66	64	36	75
8	72	41	84	58	35	67	65	39	76
9	73	44	85	59	38	67	66	41	76
10	74	47	85	59	39	67	67	43	76
11	75	49	85	59	41	67	67	45	76
12	75	51	85	60	42	67	67	47	76
13	75	53	85	60	44	67	68	49	76
14	75	54	85	60	45	67	68	50	76
15	75	56	85	60	46	67	68	51	76
16	75	57	85	60	47	67	68	52	76
17	75	58	85	60	48	67	68	53	76
18	76	59	85	60	48	67	68	54	76
19	76	60	85	60	49	67	68	55	76
20	76	61	85	60	49	67	68	55	76

Table 1. Tabular version of Figure 7. Long term median annual reduction of suspended sediment (SS), total nitrogen (TN) and total phosphorus (TP) with local condition adjustments. Applicable to areas without clay soils (<28.5% clay content) and low to gently rolling slopes (< 11 degrees). The upper and lower bounds are the 95% confidence intervals around the long-term average annual performance.

Riparian buffer removal estimates for nitrate in subsurface flows

We recently used a dataset derived principally from studies undertaken in North America and Europe to describe nitrate removal from subsurface flow by planted riparian buffers (McKergow et al. 2020a). These data indicate nitrate removal in conditions where nitrate-rich subsurface flow passes through the plant root zone (0-2 m below the soil surface).

Insufficient information exists to quantify how nitrate removal varies with planted buffer width or soil depth. For these guidelines we have used expert opinion guided by published data to make semi-quantitative estimates of the ability of planted riparian buffers to remove nitrate from subsurface flow (Figure 8).

Nitrate removal from subsurface flow	
> 80%	Soil saturated for many months. Water fills soil pore spaces creating low oxygen conditions suitable for microbial denitrification. Fine textured soils. Soil water will move slowly through fine textured soils (in the absence of macropores).
< 70%	Low soil temperatures. Low soil temperatures (<8°C) slow denitrification rates. Coarse textured soils with sands and gravels. Water flows rapidly through coarse textured soils limiting contact time between the water and soil.

Figure 8. Indicative nitrate removal performance guideline values for subsurface flows in soils with varying textures and local conditions.

DESIGNING A FILTER STRIP

Design checklist

- ☐ **The filter face** should follow a hillslope contour line to promote uniform surface runoff into the filter strip, rather than along the upper edge (which would favour concentration of flow, causing it to bypassing the filter strip).
- ☐ **Filter strip width** may need to vary in response to local slope, hillslope lengths, runoff hydrology and filter hydraulics, to maximise contact between contaminants and the filter strip.
- ☐ **Any stiff-stemmed grass** that provides high stem density at ground level will slow surface runoff and promote settling. Tall fescue and perennial rye grass have been well-tested as filter strip grasses in overseas research. Kikuyu filter strips require careful management to prevent matting which will reduce vegetation density at the ground surface.
- ☐ **Pasture retirement** is a rapid and low-risk method for establishing a filter strip which reduces the risk of weeds establishing on disturbed ground.
- ☐ **If establishing a new filter,** planting practices which establish higher stem density will create a more effective filter strip.
- ☐ **Trees and shrubs** may be part of a filter strip but should be carefully selected and managed to provide surface roughness and resistance to surface runoff. In locations where soils do not become seasonally saturated, tree and shrubs may enhance infiltration.
- ☐ **Species selected need to be** (1) able to tolerate sediment deposition, (2) stiff stemmed and have a high stem density near the ground surface, and (3) suited to current site conditions.
- ☐ **Patchy grass cover** or clumped vegetation may encourage the development of micro-channels, allowing high water velocities in parts of the filter strip, which may cause much of the contaminant load to bypass the filter.

Maintenance checklist

- ☐ **Filter strips** should be inspected to ensure high grass density and to identify where the filter design capacity is being exceeded. It is useful to observe the filter strip when it is raining heavily and check that (1) runoff does not flow along the filter face, (2) fingers of runoff do flow into the filter strip, (3) concentrated flows are shallower than 10 cm, and that (4) infiltration is reasonable (i.e., there is no crust, the soil is unsaturated and not compacted).
- ☐ **If large volumes** of sediment accumulate locally within a filter strip it may be necessary to re-grade or re-establish the filter strip. Accumulated sediment may cause surface runoff to run along the filter face rather than through the filter.
- ☐ **Mowing may be** required to maintain a healthy and uniform grass sward. In the Waikato, Smith (1989) observed that a rank ryegrass filter strip standing 50 cm high was flattened by spring rain and wind. Mowing during dry periods, or using a brush-cutter, should reduce the risk of soil compaction.
- ☐ **Woody weeds** (e.g. blackberry and gorse) should be controlled to ensure the filter strip has dense vegetation at ground level, minimise flow channelization, and prevent the filter strip being a weed source for adjacent pasture. DairyNZ's planting guides will help identify weeds commonly found in riparian areas.

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Other useful resources

DairyNZ Riparian Planner https://www.dairynz.co.nz/environment/waterways/riparian-planner/

DairyNZ regional planting guides https://www.dairynz.co.nz/environment/waterways/planting-waterways/

DESIGNING A PLANTED RIPARIAN BUFFER FOR FILTERING SUBSURFACE FLOW

Design checklist

- ☐ **Self-sustaining, weed free planted riparian buffers** are more likely to be achieved when buffers are wider (10+ m) than narrower (5-6 m, Parkyn et al. 2000). Wide planted riparian buffers provide more opportunities for nutrient uptake and storage in plant tissue and soil, and more opportunity for microbial denitrification.
- ☐ **Two or more planting zones are commonly used** – the lower bank is suitable for sedges and rushes which cope with frequent flooding and waterlogging, while trees, shrubs and flaxes are more suited to higher banks which may be flooded every couple of years.
- ☐ **A fence zone of rank grass** is usually required to separate trees and shrubs from electric fences and browsing livestock. The fence zone could also be a well-designed filter strip.
- ☐ **A mix of vegetation types**, species and ages will provide a diversity of: (1) rooting depths and root densities, (2) litter types and (3) litter decomposition rates.
- ☐ **Plants meet most of their nutrient needs** from soil water and shallow subsurface flow via their roots. Plants such as pukio (*Carex virgata*), toetoe (*Austroderia richardii*) and tī kōuka/cabbage tree (*Cordyline australis*), and harakeke (*Phormium tenax*) have high root densities, high biomass and high growth rates – all traits beneficial for nitrogen uptake (Franklin et al. 2019).
- ☐ **Native grass-like plants** may be better at storing nitrogen than similar aged shrubs – pukio and tī kōuka have leaf litter that decomposes slowly thereby immobilising nitrogen for long periods. Optimal conditions for denitrification may take time to develop as organic matter gradually accumulates, although some soils will contain carbon from historic vegetation. Rapidly decomposing plant litter (typically soft, thin leaves) will accelerate the build-up of organic carbon required to support denitrifying microbes.
- ☐ **In nitrogen sensitive catchments**, it may be best to avoid planting nitrogen fixing plants. Kowhai, kākābeak/ngutu kākā and many exotic species can fix nitrogen, potentially increasing nitrogen concentrations in riparian soils and soil water (see Appendix C in McKergow et al. (2020b).
- ☐ **Consideration** should also be given to planting green firebreaks comprising a high proportion of low-flammability species such as whauwhaupaku, manatu, karamū, mahoe, hangehange and kapuka (Wyse et al. 2016).
- ☐ **To create shade to cool adjacent streams** and to manage nuisance aquatic plants and algae, once mature, the planted riparian vegetation should be as tall as the stream is wide, and create a dense screen (see DairyNZ regional planting guides).
- ☐ **Numerous planting guides list suitable plants**, their preferred conditions, and additional benefits (e.g. nectar for birds). Regional planting guides available from DairyNZ identify fast-growing plants suitable for different regions. Guides are also available from other agencies (e.g. regional councils, Beef+Lamb, Landcare Trust, etc.). The DairyNZ Riparian Planner tool guides users through tasks such as estimating plant spacings and numbers, budgeting, scheduling planting in manageable stages and communicating the planting plan (e.g. nurseries, suppliers, contractors).
- ☐ **Planting guides identify common weeds** found in riparian areas, and several weed plant species lists and specialist information sources exist (e.g. Weedbusters).

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FOR MORE INFORMATION, CONTACT

NIWA 0800 746 464

https://niwa.co.nz/freshwater-and-estuaries/research-projects/effective-mitigation-systems-to-manage-contaminant-losses

www.dairynz.co.nz/news/research-into-productive-riparian-buffers/

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Citation

McKergow, L., Matheson, F., Goeller, B., Woodward, B. (2022) Riparian buffer design guide: Design to meet water quality objectives. *NIWA Information Series 103.* 16pp.

Acknowledgements

This guide was developed by NIWA. Preliminary guidelines and a technical literature review were funded by the DairyNZ dairy farmer levy and NIWA's Strategic Science Investment Funding provided by the Ministry of Business, Innovation and Employment (MBIE). Diagrams were created by Lucy McKergow and Erika Mackay (NIWA).

niwa.co.nz/freshwater