Preliminary riparian buffer guidelines

Filtering surface runoff and nitrate removal from subsurface flow

Prepared for DairyNZ

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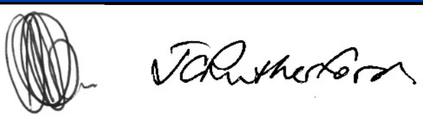
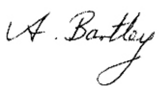
	Reviewed by:	N Hudson K Rutherford
	Formatting checked by:	Alison Bartley
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1 Introduction

Many landowners are in the process of identifying and implementing mitigations to reduce contaminants entering waterbodies under regional limit-setting processes required by the National Policy Statement for Freshwater Management (MfE 2017). Riparian buffer zones (RBZs) are key mitigation options available to farmers to reduce contaminant losses. Before landowners, agricultural industry bodies and councils commit to using of these mitigations, information is needed to quantify their effectiveness. To address this need, DairyNZ and NIWA are collaborating on the INTERCEPTOR project which, among other things, aims to prepare preliminary guidelines on RBZ design and contaminant attenuation performance. Scientifically defensible performance estimates are required to provide sufficient confidence for users to invest, and regulators to support, the uptake of RBZs for mitigation of sediment and nutrient losses in farm runoff.

These guidelines aim to provide design principles and quantify the likely efficacy of RBZs including uncertainty. The ultimate aim is to enable landowners to claim credit for the reduction of contaminant losses to waterways resulting from installation of RBZs (Figure 1). However, there are two constraints. Firstly, there is a wide range of different hillslope environments across New Zealand farmland and the effectiveness of RBZs varies for example with soil type, flow pathways and pasture condition – design is therefore site specific. Secondly, there is limited quantitative information about the effectiveness of RBZs under New Zealand conditions. There is a body of published work from overseas studies which is used in these guidelines to provide semi-quantitative information about their likely efficacy, together with qualitative information about the processes affecting removal that should inform design, construction and maintenance. Monitoring the effectiveness of RBZs in New Zealand is needed to refine design guidelines and reduce uncertainty in performance estimates.

Notwithstanding, the information supplied should assist farmers, farm advisors, rural contractors, and regional council staff to appropriately size, design, construct and maintain effective riparian buffer zones. These guidelines:

- Address the reduction of sediment, nitrogen and phosphorus in surface runoff and shallow subsurface flow from hillslopes (principally on dairy farms) under pasture and during pasture renewal and cropping.
- Do not include seepage wetlands.
- Do not address stream bank or channel erosion.
- Do not include other riparian buffer functions, such as fish habitat or bird corridors.
- Are not suitable for irrigated pasture (e.g., centre pivot), runoff from feedpads or farm dairy effluent application areas.

2 Riparian buffers

In these guidelines, a 'riparian buffer zone' (RBZ) is a zone established and managed as a buffer between agricultural land and a waterway (Figure 1). Typically an RBZ is a strip of land, usually fenced to exclude stock, where ground cover is encouraged and where trees or shrubs are often planted. Key terms features used in the guidelines are shown in Figure 1 and definitions provided in Table 1.

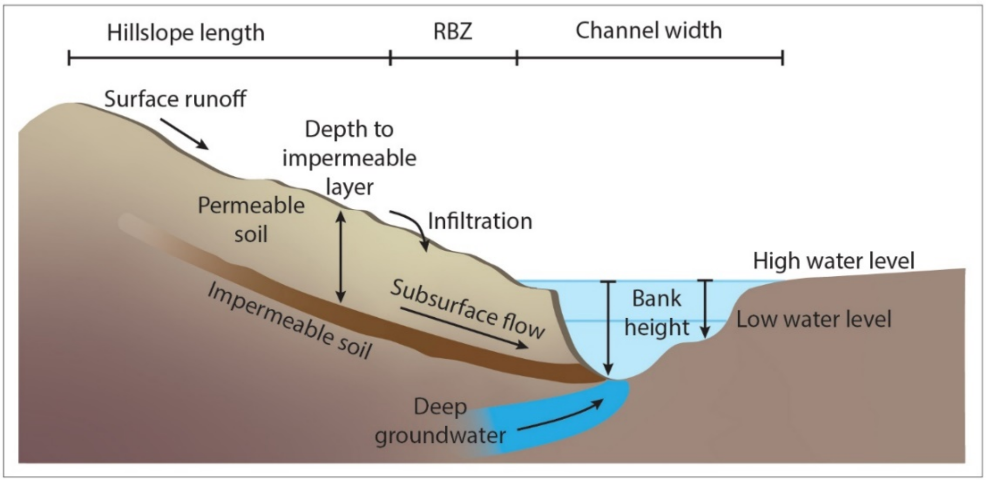

Figure 1: Description of riparian buffer zone features used in the guidelines.

RBZs may be managed for a range of functions to achieve values or outcomes, including terrestrial biodiversity, fish habitat, aesthetics, recreational benefits and cultural values (Quinn et al. 2001), but these guidelines focus on their role in removing contaminants that might otherwise degrade water quality in the receiving stream.

Different RBZ forms can be used, either individually or in combination, depending on the landscape, farming system and desired outcomes. Four commonly used RBZs are shown in Figure 2 and eight types are shown in Figure 4. Many dairy farms have invested in RBZ, typically a combination of livestock exclusion and a planted riparian buffer. On some farms grass strips either close to waterways or on the hillslope are used to trap sediment.

The two RBZ forms most commonly used overseas and in New Zealand are filters (also called filter strips) (FS) and planted riparian buffers (PRB) and these are the focus for these guidelines.

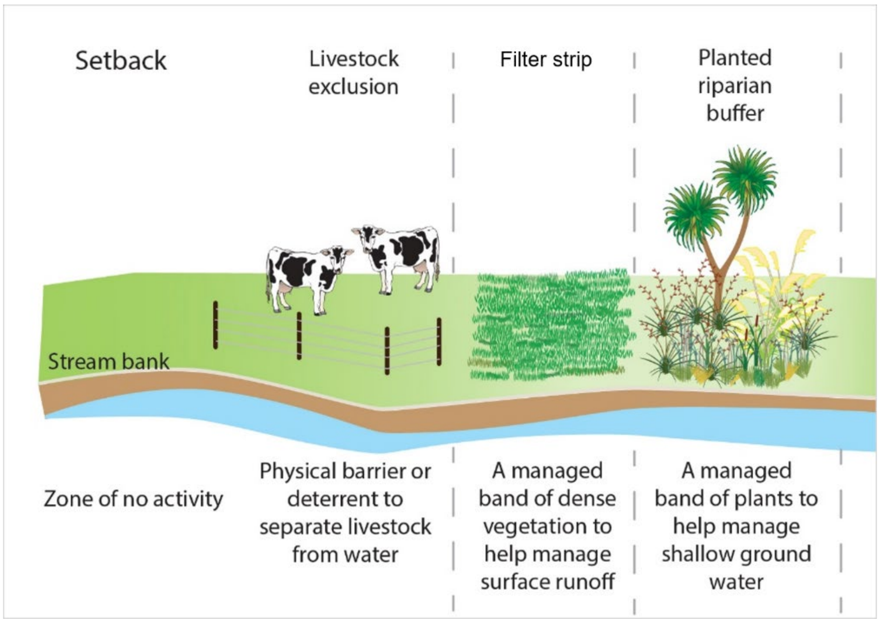

Figure 2: Schematic and definition of basic riparian buffer zone forms.

Focus	Reducing contaminant loads from pasture							
	Riparian buffer (or set-aside) type							
Forms	set back	livestock exclusion	seepage wetlands	**filter strip**	**planted riparian buffer**	productive riparian buffer	grassed waterway	saturated buffer
Key flowpath(s)	surface runoff	surface runoff	subsurface flow	surface runoff	subsurface flow &surface runoff	subsurface flow & surface runoff	surface runoff	tile drainage
Level of planning & design required	Low → High							
Other resources	Fertiliser Industry; FDE guidelines	DairyNZ riparian planner	NIWA Client reports for DairyNZ	DOC guidelines		Productive Riparian Buffers SFF project		Iowa State University and USDA preliminary guidance

Figure 3: Possible RBZ configurations for reducing contaminant loads from pasture. Definitions are provided in Table 1.

Table 1: Key terms and definitions used in these guidelines.

Term	Definition
riparian vegetation	Any vegetation in the land-water interface, natural or managed.
riparian set-aside	A band of vegetation managed as a buffer between land and water.
riparian buffer zone	A band of vegetation managed as a buffer between land and water.
set-back	Vegetation managed to provide a barrier between human activity and waterbodies, such as a fertiliser or FDE set-back.
livestock exclusion	A physical barrier or deterrent, typically a fence, that excludes livestock from direct access to waterbodies.
filter strip	A managed band of vegetation that filters sediment in surface runoff from hillslopes. May increase soil infiltration, pond surface runoff and increase sediment settling.
planted riparian buffer	A fenced and managed riparian zone containing grasses, shrubs and/or trees. May remove sediment from surface runoff, increase infiltration, and remove nitrate from subsurface flow.
productive riparian buffer	A planted riparian buffer managed for agroforestry.
grassed waterway	An engineered ephemeral channel that filters surface runoff from hillslopes.
saturated buffer	A modified tile drain outlet which disperses flow through riparian soil, increasing opportunities for nitrate removal.
surface runoff	Visible flow of water over the ground surface
subsurface flow	Lateral flow of water in a saturated soil layer
groundwater	Water that occurs beneath the water table in soils and geologic formations that are fully saturated.
perennial stream	A stream that flows all year.
intermittent stream	A stream that ceases to flow during dry periods.
ephemeral channel	A channel that flows in response to rain.
headwater stream	The smallest stream channels, typically zero, first or second order streams
surface drain	A drain that removes standing water; flows increase with rain.
tile drain	A drain that remove subsoil water; flows increase with rain.
deposition	Setting of sediment, flocs, detritus from the water column.
infiltration	Entry of water and associated contaminants into the soil.
filtering	Sieving of coarse particles by plants or the soil matrix.
denitrification	Microbially-driven production of nitric oxide (NO) and nitrous oxide (N_2) and N_2 from nitrate.
sorption	Physical or chemical bonding of molecules to the surface of solid particles.
immobilisation	Accumulation of nutrients into biomass.
fine particulates	very fine particles (smaller than 1/1000th of a mm, e.g., fine clay, organic molecules, bacteria and viruses).

Two physical processes enable RBZs to remove contaminants – deposition and infiltration. Once contaminants have either settled or infiltrated, they are subject to physical, biological and biogeochemical transformations which contribute to attenuation. These include stabilisation of deposited sediment by grass growth, plant uptake of nutrients, microbial processing including denitrification, adhesion to plants and soil particles and chemical precipitation (see McKergow et al. 2007). Thus, three of the key riparian buffer processes (see Figure 2 and Figure 3) are:

1. settling of coarse particulates from surface runoff
2. infiltration of dissolved nutrients, fine particulates into the soil, and
3. removal of nutrients from subsurface flow by plant uptake and microbially-driven processes.

The section on filter strips focuses on deposition (settling) while the section on planted riparian buffers (PRB) discusses infiltration and sub-surface nutrient removal.

3 Filtering surface runoff

3.1 What are filter strips?

Filter strips are managed bands of dense vegetation (commonly grass) designed:

- To create a barrier to slow 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 4).
- To increase soil permeability and encourage surface runoff to infiltrate into riparian soil thereby increasing contact between soil and contaminants (dissolved nutrients, fine particulates) (Figure 4).

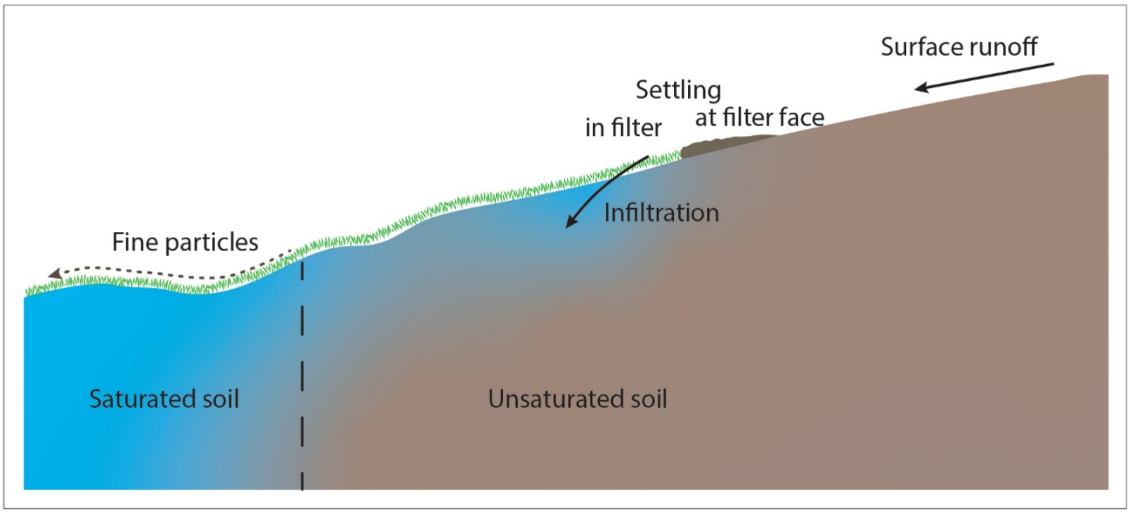

Figure 4: Main processes by which filter strips retain suspended sediment and nutrients.

3.2 How effective are filter strips?

We collated data from international and New Zealand studies of well-designed and maintained experimental filter strips in riparian areas that were monitored under natural rainfall conditions. Most of the data are for grass filter strips on cropping land in the United States. Sediment losses are generally higher from cropping land than from pasture. The cropping data is possibly more applicable to dairy crops and pasture renewal. There are some data available for New Zealand pastoral farms. A study at Scotsman Valley in the Waikato demonstrated that 10-13 m wide retired pasture filter strips on sloping (16-20%) pasture with silt loam soils can retain at least 40-50% of most contaminants (Smith 1989). Retired ryegrass hillslope filter strips were monitored on a Rotorua dairy farm (10-20% slopes) with heavy clay soils where at least 35% of contaminants were retained in 3 m wide ryegrass filter strips (McKergow et al. 2008).

The data show that well designed and maintained filter strips can be an effective tool for reducing contaminant loads from pasture runoff, but the data are sparse and efficacy is variable. Notwithstanding, the currently available data help quantify the likely benefits of filter strips but monitoring filter strips in a range of environments throughout New Zealand is desirable to reduce uncertainty and increase confidence in their efficacy.

For analysis we split the dataset into two groups; clay % <28.5% and clay ≥28.5%. The design aid (Figure 5) is for the group with soils <28.5% clay. There is large scatter in the dataset (Figure 5), so the fitted line and confidence intervals must be used with caution. The high clay dataset is too small to generalise; most values sit below the lower bound of the <28.5% clay dataset.

We related filter strip performance to filter width:contributing hillslope length ratio (hereafter width:hillslope ratio) (Figure 5). This approach has been used successfully overseas and allows the user to estimate the size of filter strip required to achieve a design attenuation knowing the length of contributing hillslope. We estimated nutrient attenuation efficacy from sediment attenuation using empirical relationships.

The design aid is most reliable where soils have <28.5% clay and paddocks have uniform slopes on flat to rolling land. Users can be confident that the percentage removal of coarse and medium textured sediment will fall within the bounds shown in Figure 5 for well-designed and maintained filter strips. Insufficient data is available to define the optimal width and to quantify performance for clay soils, unless the clay is transported as aggregates and has settling properties like silt.

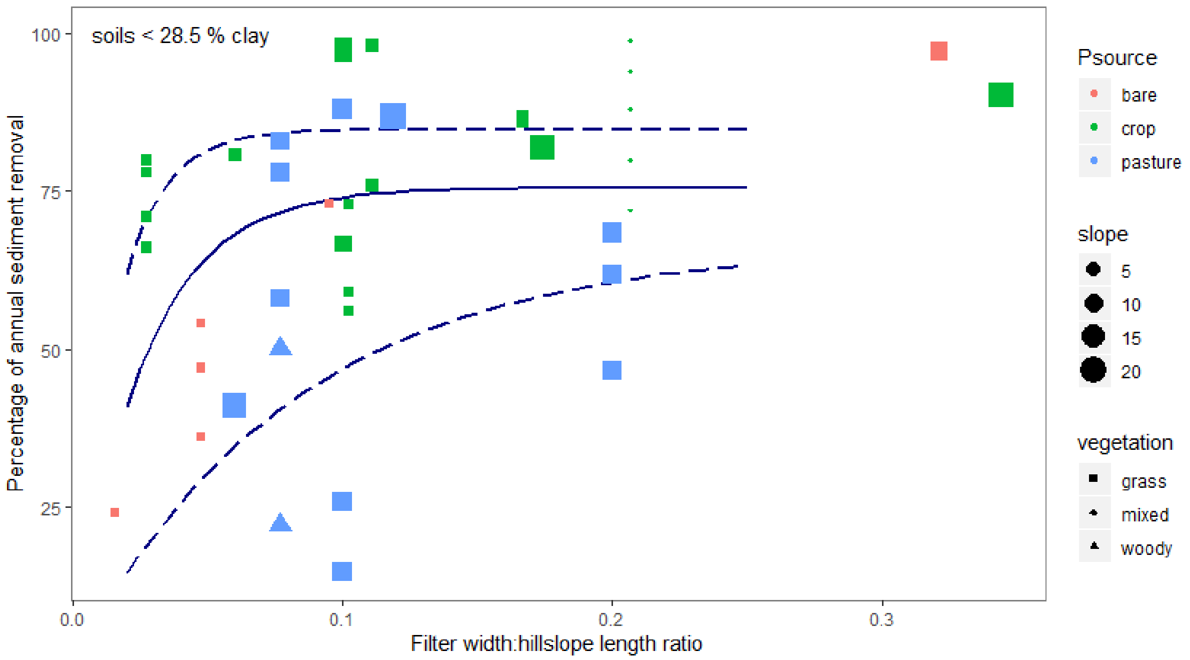

Figure 5: Preliminary guidelines for sediment removal by riparian filter strips for soils with <28.5% clay on uniform flat to rolling slopes (curves) compared with published data. The fitted lines are a non-linear regression (solid line) and 95% confidence intervals (dashed lines). Data points are coloured by source, sized by hill slope (%) and shaped by filter vegetation. For example, the largest blue square (at 85%) is data for a grass filter strip receiving runoff from pasture, on a moderate (~20%) slope.

3.3 Factors affecting performance

Research demonstrates that filter strips can vary widely in their ability to remove sediment and nutrients.

3.3.1 Sediment size

Contaminant removal decreases with decreasing sediment size. Lower filter width:hillslope ratios (0.01-0.02) provide reasonable performance when transported sediment is coarse (e.g., sands or aggregates; >2mm). Coarse sediment is deposited in the backwater upslope from the filter face and in the first few metres of the filter strip. Larger filter width: hillslope ratios (>0.05) are required for finer particles (silts and fine silts; 0.002-0.06 mm) because their settling rate is low. 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. Consequently, little settling is likely from surface flow passing through filter strips (Figure 6) and removal depends on infiltration and adhesion.

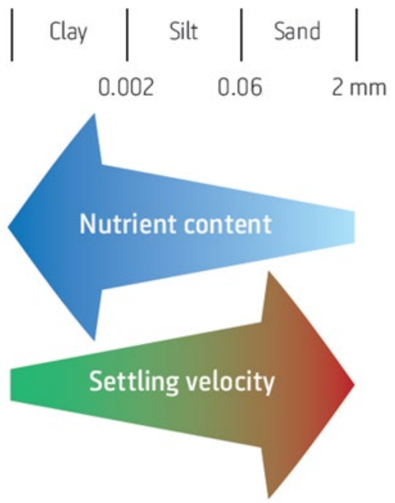

Figure 6: Classification of suspended sediment particle sizes and some aspects of their behaviour.

3.3.2 Soil condition

Any process which reduces infiltration in the filter strip soil reduces the trapping of fine sediment and nutrient removal by soil microbes. Compaction (by livestock or farm vehicles), surface sealing, saturation and hydrophobic soils reduce infiltration of runoff into the soil (Figure 7). Conversely, plant root growth, earthworm activity and mechanical aeration increase infiltration. Fine particles (silts and clays) can clog macropores and reduce infiltration rates over time, reducing the ability of filter strip soils to 'trap' fine sediment.

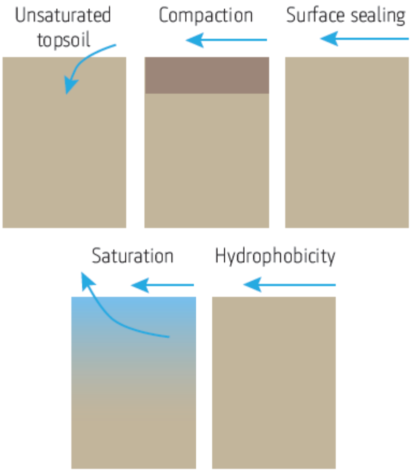

Figure 7: Effect of factors influencing soil condition on water and contaminant flow and ultimately filter strip performance.

3.3.3 Flow distribution

Sediment trapping is high when surface runoff reaches the filter face in a thin sheet; is shallow (< 10 cm deep) and dispersed (viz., evenly distributed along the filter face) (Figure 8 a). Shallow, dispersed flow is uncommon, 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 8 b), the vegetation is unable to slow the runoff enough to allow settling - the runoff will pass unattenuated through the filter strip. In addition, during storms short periods of high inflow can overwhelm a filter strip.

Where flow convergence is visible in the landscape, additional measures may be required to distribute water across the filter face and reduce flow rates, for example, wider filter strips in convergence zones, dams, berms or ponding areas that disperse flow.

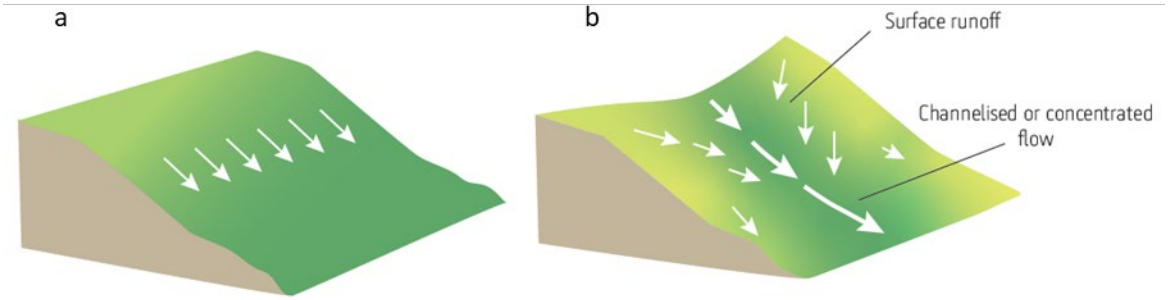

Figure 8: Flow convergence effect on runoff across filter face. (a) No flow convergence on a uniform (planar) slope; runoff enters the filter strip along the entire filter face at low depth and velocity, (b) Flow convergence causes runoff to enter the filter along only part of the filter face at high velocity and depth. The filter receives little runoff at other locations.

3.3.4 Vegetation cover

Trapping is enhanced by dense vegetation cover in the filter strip at ground level (e.g., dense grass sward). Most of the research on filter performance is for dense grass filter strips where the role of vegetation is to increase friction, cause water to pond upslope from and within the filter, reduce water velocity and give 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 so that contaminants bypass the trapping elements. Surface runoff channels and flow convergence are common where groundcover is low and Smith (1992) observed channels through unconsolidated pine litter in a 25-35 m wide *Pinus radiata* RBZ near Moutere.

In locations where large volumes of sediment accumulate in a filter strip it may be necessary to remove it mechanically, although grass growing through the deposited material will reduce erosion during subsequent rainfall events. Mowing may be required to maintain a healthy and uniform grass sward.

3.3.5 Placement

Filter strips should run parallel to contours so that the filter face is horizontal – this will minimise water draining laterally along the filter face and bypassing the filter strip. Ideally filter strips should form a continuous band across the hillslope to increase their effectiveness given that surface runoff varies in both space and time.

3.4 Design guidance

3.4.1 When and where is a filter strip useful?

Filter strips are useful when:

1. Surface runoff moves across the paddock upslope from the filter strip when it rains heavily.
2. The paddock has low groundcover (e.g., heavy grazing, cropping, pasture renewal).
3. There are signs of erosion in the paddock (e.g., rills).
4. Sands and coarse silts (or aggregates) are the dominant particle sizes in surface runoff.

Filter strips are less effective when:

1. Runoff converges into channels on the hillslope.
2. Runoff is 'flashy' (filters may be overwhelmed during major runoff events and floods).
3. Fine silts and clays are the dominant particle sizes (unless they form aggregates).

Filter strips can be located:

1. On hillslopes.
2. In combination with planted riparian buffer zones.
3. In headwater streams, channels and drains before runoff enters larger streams.
4. In seasonally saturated areas with surface runoff and high pollutant loadings.

3.5 Designing a filter strip

3.5.1 Objectives

Objectives and consequent design criteria depend on:

1. The problem arising from pasture runoff (e.g., soluble nutrient inflows to streams during summer, annual nutrient load to lakes, sediment runoff during storms).
2. Statutory requirements (e.g., meeting annual average TN and TP targets from OVERSEER).
3. Non-statutory goals (e.g., landcare group goals to improve stream health).
4. On-farm opportunities, constraints and goals.

In these guidelines the objective is to reduce sediment and nutrient loads. Information relevant to that objective and subsequent design includes:

- Current and proposed land use.
- Paddocks likely to generate sediment and/or nutrient.
- Location of the paddocks in relation to streams, drains and ephemeral waterways.
- Paddocks that require mitigation.
- Targets for sediment and nutrient reduction.

A map or aerial photograph will help set objectives and guide design. A planning worksheet is provided in Appendix A.

3.5.2 Identifying suitable sites

The suitability of potential sites for filter strips can be assessed using the framework in Table 2.

Table 2: Framework for evaluating the suitability of sites for filter strips. Items are listed in decreasing order of importance.

Question	Reason	Suitability
Does surface runoff move across the paddock when it rains?	Filter strips intercept surface runoff.	Filter strips are a potential mitigation tool.
Are there signs of erosion in the paddock?	Filter strips can remove sediment from runoff.	Filter strips are a potential mitigation tool.
Is runoff uniform? Is paddock slope uniform?	Filter strips work best when flow enters evenly along the filter face.	Efficacy likely to be high.
Does runoff converge? Is paddock slope convex?	Convergent flow reduces sediment and nutrient removal.	Efficacy may be low. Additional mitigation may be required.
Are there a few large runoff events or a several small runoff events?	Large runoff events bypass filter strips.	If more than 60% of flow arrives as concentrated flow, consider additional mitigation options to slow runoff and/or other mitigation tools.
Does runoff occur in discrete channels at the filter site?	Runoff may bypass parts of the filter strip and inundate others.	Efficacy may be low. Additional mitigation may be required (e.g., wider filter strip,).
Do soils become saturated at the filter site?	Infiltration will be negligible. Seepage outflow may mobilise previously deposited contaminants.	Sediment may be trapped but nutrient removal may be low. Planting trees and shrubs may be beneficial.

3.5.3 Sizing and performance

Figure 9 (a simplified version of Figure 5) is used to estimate sediment and particulate removal (for low clay soils on flat to rolling land) given filter strip dimensions, or to estimate filter strip dimensions to achieve a target removal. In both cases hillslope length must be measured. The top of the hillslope may be a ridge or a structure (e.g., farm track with drain) that diverts all surface runoff from above the hillslope.

The width of an existing or candidate filter strip is measured at its narrowest point and the size ratio calculated:

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

Then from Figure 9 estimates are made of performance - the likely average and range of contaminant removal. Alternatively, Figure 9is used to estimate the range of filter width: hillslope length required to achieve an average target contaminant removal.

Next, Table 3 is used to adjust the performance estimates (from Figure 9) depending on local conditions: increasing performance where conditions favour attenuation and decreasing it where conditions are unfavourable.

For example, a proposed filter strip whose width:hillslope length ratio is 0.07 (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) the estimated average annual sediment removal is 70%, but removal may vary from

38% to 84% depending on local conditions. However, if the filter strip currently has sparse vegetation it will perform below the average, and sediment removal is reduced to 38-70% (see Table 3).

To estimate annual average TP and TN removal (%) use Table 4. These values were derived from strong correlations between SS removal and nutrient removal. For the example above, with 38-70% SS removal, annual average removals are 33 to 56% TP and 37 to 63% TN.

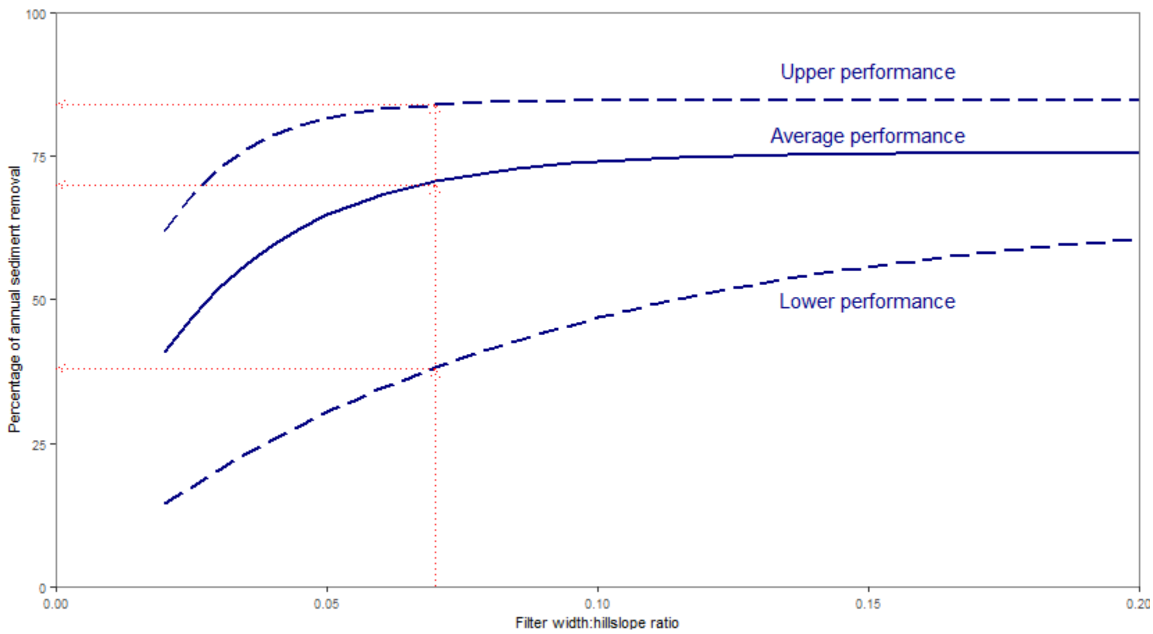

Figure 9: Sediment guideline curves for a well-designed and maintained filter with soils containing <28.5% clay. This is a simplified version of Figure 5 - the lower and upper performance curves are 95% confidence intervals around the fitted average performance curve. Red dotted lines indicate the upper, average and lower performance of a filter strip with a 0.07 width:hillslope ratio. The curves are those shown in Figure 6.

Table 3: Attenuation line adjustment for filter strips.

Local condition	Adjustment	Justification
Concentrated flow	Lower bound (at best)	Concentrated flow forces runoff through a narrow zone of the filter face.
High slope	Lower bound (at best)	Slopes >5% require additional measures.
Low vegetation density	Below average	Low friction, reduced ponding and settling.
Uneven vegetation	Below average	Water flows around and between plants
Soil compaction, surface sealing, crusting, hydrophobicity	Below average (fine particulates & nutrients)	Infiltration reduced. Low nutrient removal. Sediment trapping may remain high if vegetation is dense.
High infiltration	Upper bound possible (fine particulates & nutrient)	Infiltration dominant. Macropores may allow subsurface flow to bypass soils.
Aggregates and coarser sediment	Upper bound likely	Coarse sediments settle rapidly. Soils transported as aggregates behave like coarser sediment sizes.

Table 4: Estimation of TP and TN performance from SS removal.

SS removal (%)	TP removal (%)	TN removal (%)
30	27	30
40	34	38
50	42	47
60	49	55
70	56	63
80	63	72
90	71	80

In some cases, the filter width estimated to achieve a desired level of trapping efficiency may exceed what a landowner is willing to set aside for a filter strip. These situations call for alternative or additional mitigation practices to reduce contaminants.

3.6 Implementation

Implementation requires a design plan, which includes location, configuration, vegetation, site preparation and maintenance. The following is a check list to help implementation.

3.6.1 Location and configuration

1. Filter strips should be positioned to intercept flows from a hillslope effectively. They are best located on unsaturated soils because this allows both infiltration and settling to remove contaminants from runoff.

2. Filter strips can be established upslope of planted RBZ which moves them out of seasonally saturated riparian areas, increasing the likelihood of infiltration.

3. Site soil saturation, including water table depth and flood levels, should be favourable for establishing and maintaining filter strip vegetation.

4. Filter strips will be less effective where water bypasses riparian soils in cracks or macropores and enters the stream channel rapidly. SMAP online[1] provides estimates of the risk of bypass flow and the DairyNZ Soil Risk for FDE Pocket Planner provides field guidance when assessing the risk of water bypassing soils.

5. Ideally the filter face should follow a contour line because this will promote surface runoff flowing uniformly into the filter strip rather than along it, accumulating and bypassing the filter strip.

6. Filter strip width may need to vary in response to local topography, runoff hydrology and filter hydraulics (Figure 10).

[1] https://smap.landcareresearch.co.nz/

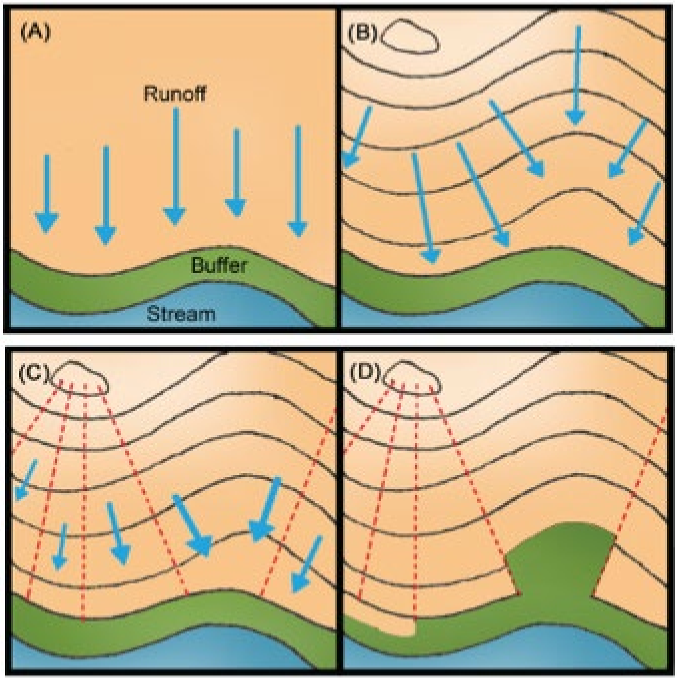

Figure 10: Fixed width and variable (or site-specific) filter strip widths for different landscape components. Where uniform runoff occurs, fixed widths will perform well (A); when runoff is converging or diverging (B) due to topography the filter strip width should be designed for each hillslope (C) and can be widened and narrowed (D) to account for differences in runoff and loads (Bentrup 2008).

3.6.2 Vegetation

1. 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.

2. 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.

3. Species selected need to be:

   - able to withstand partial burial from sediment deposition
   - stiff stemmed and have a high stem density near the ground surface
   - suited to current site conditions.

3.6.3 Site preparation

1. To establish a new site, earthworks and planting/sowing seed need to occur at a time and under conditions that maximise establishment, growth and survival of selected species. Planting practices that establish higher stem density will create more effective filter strip. Weed control on disturbed ground may be required.

2. Pasture retirement is a rapid and low-risk method for establishing a filter strip which reduces the risk of weeds establishing on disturbed ground.

3. Ideally filter strips should not be established when the hillslope is vulnerable to sediment and nutrient loss (e.g., during pasture renewal) unless they can be established with minimal soil disturbance.

4. Guidelines for pasture renewal are applicable to grass filter strips and are available from DairyNZ.[2]

5. Use of fertiliser during filter strip establishment and planting should be minimised in nutrient sensitive catchments.

6. If riparian soils are compacted or pugged, aerating the soil to create a soil structure suitable for grass growth and to promote infiltration should be considered. Soil compaction can be assessed visually making use of tools such as the Visual Soil Assessment Field Guide[3], which will equip farmers to assess soil quality easily, quickly, reliably at the paddock scale.

3.6.4 Maintenance

1. Filter strips should be inspected to ensure high grass density and to identify where the filter design capacity is being exceeded. It is desirable to observe the filter strip when it is raining heavily and check that:

    - runoff does not flow along the filter face
    - fingers of runoff flow into the filter strip
    - concentrated flows are shallower than 10 cm
    - infiltration is reasonable (i.e., there is no crust, the soil is unsaturated and not compacted).

2. Mowing filter strip vegetationwill help maintain dense vegetation cover at ground level. Overseas research and experience has identified that experimental grass filter strips typically require mowing twice a year to maintain grass density and reduce wind or rain damage. In the Waikato, Smith (1989) observed that a rank ryegrass filter strip standing 50 cm high was flattened by spring rain and wind. A brush-cutter provides a rapid way to maintain dense grass cover, without risking soil compaction.

3. 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. Other useful reference materials include the weed plant species list (Appendix D) and materials provided by Weedbusters.[4]

4. If a filter strip has deposits of sediment at points along the filter face, sediment may need to be removed to minimise bypassing.

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[2] https://www.dairynz.co.nz/feed/pasture-renewal/
[3] https://soils.landcareresearch.co.nz/describing-soils/visual-soil-assessment-vsa-field-guide/
[4] https://www.weedbusters.org.nz/

5. Using heavy machinery in riparian zones is not recommended; when such use is necessary, care should be taken to ensure that the soil structure is not altered.

6. As a filter strip matures (over years-decades) it may become less effective. Sediment may build up and alter runoff pathways. There may be some leaching of dissolved nutrients (especially P) from nutrient-rich sediments trapped in the filter strip and from accumulated organic matter. For cropped land in the US, filter strips are designed for a 10-year lifespan; after this period the filter strip is renewed by removing the trapped sediment and renewing the grass.

4 Filtering subsurface flow

4.1 What are planted riparian buffers?

Planted riparian buffers (PRB) are created by fencing along a drain, stream or river and planting a band of vegetation in the riparian zone. PRBs usually contain long grass and sedges and are frequently planted with flaxes, shrubs and trees for water quality, aesthetic, aquatic and terrestrial biodiversity benefits. This guideline only considers water quality benefits.

PRBs usually contain a mix of freely-draining mineral soils and poorly-draining organic soils. The latter often give rise to seepage wetlands near the stream banks. Seepage wetlands are zones of saturated, unconsolidated organic soils where groundwater seeps to the surface. These guidelines do not consider seepage wetlands for which guidelines have been provided elsewhere (Rutherford et al. 2007; Rutherford et al. 2016).

PRBs may include a zone of agroforestry with a PRB near the stream that remains undisturbed during harvest. Such buffers are therefore wider, with a two-zone design. These guidelines do not cover the harvesting phase or maintenance.

PRBs attenuate contaminants in four different ways:

1. Long grass and sedges may act as a filter strip and remove particulates from surface flow as described in Section 3.
2. Plants within the PRB will take up nutrients.
3. Over time stock exclusion and plant growth (notably shrubs and trees) lead to an improvement in soil structure (notably soil permeability) and increased infiltration.
4. Nutrient removal occurs within the soil by sorption (fine particulates and phosphorus), and microbially-driven processes such as denitrification (nitrate) (Figure 11).

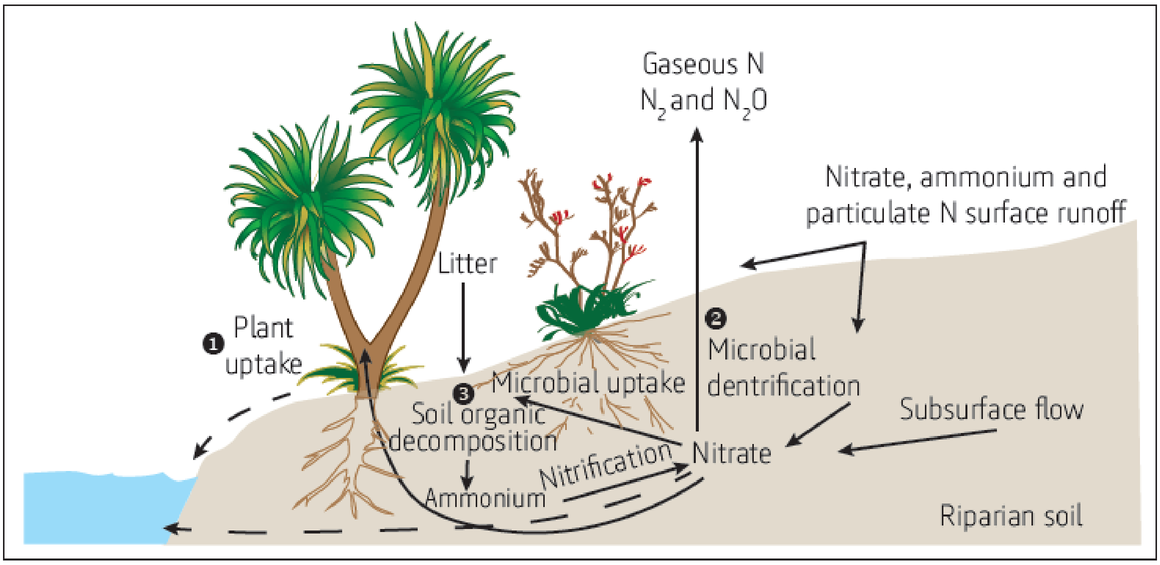

Figure 11: The main processes by which planted riparian buffers retain nitrogen. (1) uptake through roots into plant tissues, (2) microbial denitrification and (3) immobilisation as soil organic matter (after Franklin et al. 2019).

4.2 How effective are planted riparian buffers?

4.2.1 Nitrate removal from subsurface flow

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 PRB where an impermeable layer forces subsurface flow to move through the root zone of riparian soils. Under these conditions, high levels of nitrate removal have been measured as a result of plant uptake and denitrification. The relative importance of plant uptake and denitrification varies seasonally. Nitrate uptake is high when plants are growing rapidly (spring-summer) but low in winter. Nitrate taken up by plants is converted into tissue and stored. When the plant shed leaves nitrogen is released – for deciduous vegetation nitrogen storage in leaves is around 90% of nitrate uptake. Denitrification rates vary with temperature, being highest in summer. Consequently, the potential for nitrogen removal by PRBs tends to be high in spring-summer and low in autumn-winter.

We compiled a dataset of nitrate removal from subsurface flow by riparian buffers, mostly from studies in North America and Europe. We base our guidance on this dataset:

1. Nitrate attenuation in an established planted riparian buffer with a shallow (<2 m) impeding soil layer is likely to lie in the range 40-100% (**Figure 12** a; median removal from subsurface flow 94%).
2. Nitrate attenuation will be higher than 70% (the 25th percentile or bottom of the box in **Figure 12** a) for soils that are finer textured (clay through to sandy loam, **Figure 12** c) through which water travels slowly.
3. Nitrate attenuation will be lower (40-70 %) for highly permeable soils (containing sands and gravels, **Figure 12** c) through which water travels quickly.

Nitrate attenuation may also be in the lower range where there is more subsurface flow coming from the hillslope soils than can pass through the permeable layer in the PRB. These conditions may be identified from the frequent occurrence of areas of seepage.

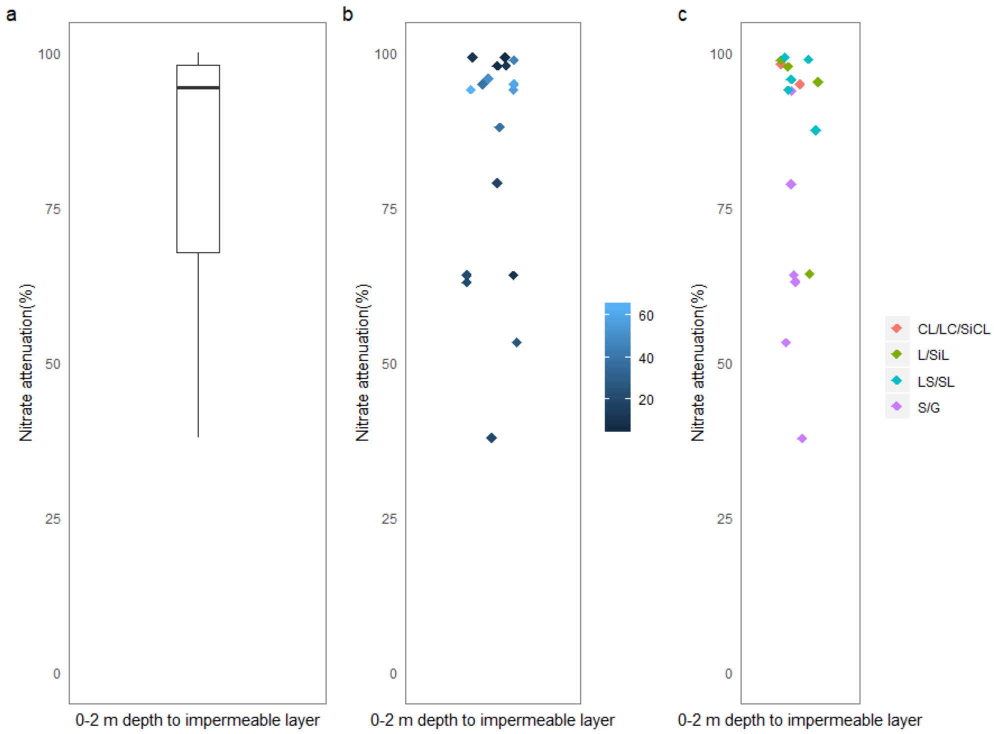

Figure 12: Performance guidelines for nitrate removal from subsurface flow in soils with a shallow (<2m) impermeable horizon.(a) boxplot summary, box contains the 25th to 75th percentiles and median is the dark line, (b) data values with colour gradation of buffer width (m) and (c) data values coloured by soil texture group (S/G = sand/gravel, LS/SL = loamy sand/sandy loam, L/SiL = loam/silt loam, CL,LC,SiCl=clay loam/loamy clay/silty clay loam).

The published data (**Figure 12**) give an indication of likely nitrate removal where nitrate rich subsurface flow passes through the plant root zone. However, there is insufficient information in the published data (notably on path lengths and residence times of subsurface flow) to quantify how removal varies with buffer width and soil depth. For these guidelines we have used expert opinion guided by published data to make semi-quantitative estimates of the ability of PRB to remove nitrate from subsurface flow (Table 5, supported by **Figure 12** b and c).

Table 5: Semi-quantitative estimates of nitrate removal by PRB based on expert opinion guided by data in Figure 13.

Category	Probable %removal	Justification
Coarse textured soils	Lower range (<70%)	Water flows rapidly through coarse textured soils limiting contact time between the water and soil.
Fine textured soils	Upper range (>80%)	Soil water will move slowly through fine textured soils (in the absence of macropores).
Soil saturation for many months	Upper range (>80%)	Water fills soil pore spaces creating low oxygen conditions suitable for microbial denitrification.
Low soil temperature	Lower range (<70%)	Low soil temperatures (<8°C) slow denitrification rates.

4.2.2 Phosphorus removal

A substantial proportion of phosphorus lost from pasture occurs as phosphorus attached to fine particulates. Where soils in a PRB are permeable, surface flow infiltrates and carries phosphorus into the soil. Soluble phosphorus is removed by plant and microbial uptake and chemical processes in the soil. Phosphorus uptake by plants varies with plant age, species, season and availability and will be high when plants are growing rapidly. While P may be removed at certain times of the year, soil-bound P may be remobilised (depending on soil chemistry and saturation status) and plant-bound P released at other times.

4.3 Factors affecting performance

Research undertaken across a range of landscapes has shown that the performance of PRBs varies depending on water flowpath characteristics.

4.3.1 Hydrology

Hydrology is a key controlling factor on nitrate removal in PRBs. Soil permeability and layering are important determinants of water flowpaths. Permeable soils promote infiltration that results in either horizontal subsurface flow or drainage to deep groundwater (Figure 13). Shallow impeding layers, or aquicludes, in the soil create barriers to the downward movement of infiltrating water, resulting in horizontal subsurface flow (Figure 13 b, c, d). Shallow subsurface flow (at depths < 2 m) can be intercepted by planted riparian buffers. If no impeding layer is present, or is very deep, groundwater is likely to flow deep in the soil, away from the influence of riparian vegetation (Figure 13 a). Thus, optimal removal of nitrate in a PRB occurs when an impeding soil layer (typically at depths < 2 m) forces high nitrate subsurface flow into the root zone.

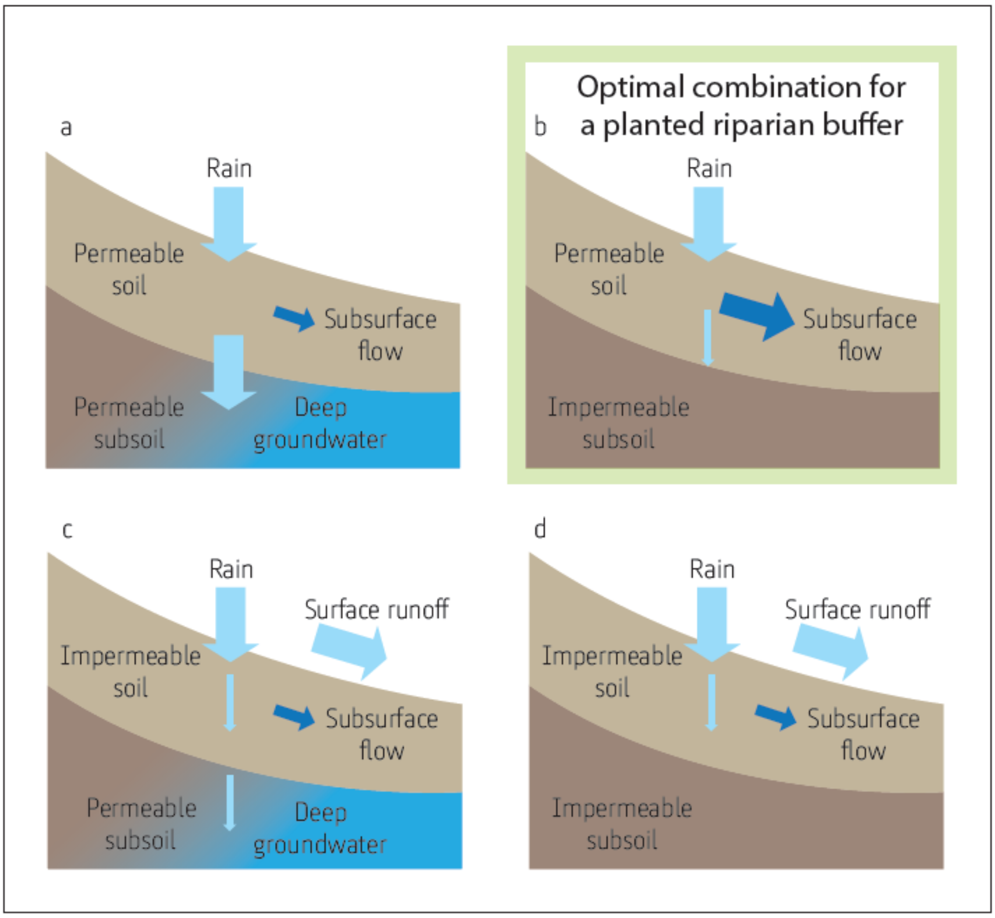

Figure 13: Major flowpaths for water on hillslopes with combinations of permeable and impermeable soils. Width of the arrow indicates relative magnitude of flow.

4.3.2 Vegetation

Plants have three main roles in RBZ – improving soil structure, using nutrients to make biomass and providing energy sources for microbes (Figure 11).

Plant roots penetrating the soil create macropores that enhance the infiltration capacity of the soil. Detritus from riparian vegetation (dead leaves, twigs etc.,) and washed in from the hillslope builds up in the soil, increases its organic content and (in the absence of compaction by stock or machinery) soil permeability increases.

Water flowing at shallow depths (< 2 m below ground surface) will interact with plant roots. Plants meet most of their nutrient needs from soil water and remove soluble nitrogen and phosphorus from shallow groundwater through 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).

Plants supply energy (carbon) to soil microbes as root exudates and decomposing plant litter. In PRB newly established on pasture soils, optimal conditions for denitrification may take time to develop as organic matter gradually accumulates although some soils will contain carbon from historic vegetation. Recent research suggests that 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. On the other hand, plant litter that decomposes rapidly will accelerate the build-up of organic carbon for denitrification.

4.3.3 Size

Wide PRB provide more opportunities for nitrogen uptake and storage in plant tissue and soil, and more opportunity for microbially mediated denitrification. Wide PRB also allow rainfall (low in nitrate) to dilute high nitrate runoff from pasture.

4.3.4 Seasonal variability

Rates of microbially-driven processes vary spatially and temporally. Denitrification rates have been shown to be high in small areas, such as where lenses of organic soil or elevated concentrations of organic carbon occur. Removal of nitrate by denitrifying microbes is more rapid at warmer temperatures, so denitrification rates will generally be higher in warmer regions of the country. During spring, uptake and denitrification can be equally important, while in the cooler months denitrifying microbes may be responsible for greater removal of nitrate than plants.

4.4 Where and when is a planted riparian buffer useful?

Planted riparian buffers are most useful where:

- hillslope runoff can be intercepted before it enters a stream
- an impeding soil layer forces water to flow horizontally as shallow subsurface flow
- plant roots penetrate into the subsurface flow
- a high water table saturates soil, promoting microbial-driven nitrate removal processes.

4.5 Designing a planted riparian buffer

Objectives and consequent design criteria depend on:

1. the problem arising from pasture runoff (e.g., soluble nutrient inflows to streams during summer, annual nutrient load to lakes, sediment runoff during storms)
2. statutory requirements (e.g., meeting annual average TN and TP targets from OVERSEER)
3. non-statutory goals (e.g., landcare group goals to improve stream health)
4. on-farm opportunities, constraints and goals.

In these guidelines the objective is to reduce nutrient loads. Information relevant to that objective and subsequent design includes:

- current and proposed land use
- paddocks likely to generate nutrients
- location of the paddocks in relation to streams, drains and ephemeral waterways
- paddocks that require mitigation

- targets for nutrient reduction.

A map or aerial photograph will help set objectives and guide design. A planning worksheet is provided in Appendix B.

4.5.1 Identifying suitable sites

A map or aerial photograph will help planning and the Riparian Planner tool[5] guides farmers through the processes of mapping waterways on farms. Areas known to be seasonally saturated may be good places for planting riparian buffers.

Potential sites need to examined for suitability using the framework in Table 2.

Table 6: Framework for evaluating the hydrologic suitability of riparian zones to remove nitrate from subsurface flow. Items are listed in decreasing order of importance.

Check list	Reason	Suitability
Check for shallow subsurface flow.	Subsurface flow occurs -vertical flow inhibited by a heavy subsoil or layer of impermeable soil.	Riparian buffers designed for nitrate removal are a potential mitigation tool for this landscape.
Check for water table.	Soil saturation in the plant root zone (<2 m soil depth).	A planted RBZ might be a sound option for these soils.
Check for soil saturation.	Water seeping out of the soil during wet periods.	A planted RBZ might be a sound option for these soils.
Check plant rooting depth versus impermeable soil layer.	Plant uptake can occur where plant roots intercept subsurface flow.	Careful design is required. Plants may not be able to access subsurface flow.
Check for incised channel.	Plant roots may not be able to access subsurface flow.	Careful design is required. Consider re-battering.

Where the stream has incised and banks are high and unstable, bank re-battering could be considered. Re-battering removes a wedge of the streambank, decreases the bank gradient and reduces the bank height. The roots of plants established on re-battered slopes may better intercept subsurface flow. Bank re-battering is suitable for headwater streams and drains on low slope land where the risk of extreme flood events during the earthworks and plant establishment phase is low. Re-battering trials have been completed on lowland streams in Canterbury (Halswell catchment, Snake Creek and Te Waihora streams[7]) with the goal of increasing stream shade to reduce aquatic weed growth, and on two eroding sections of the Waituna Creek[8], Southland to reduce bank erosion.

Modification of channels and banks may require a resource consent. Re-battering sites may require vegetation and fence removal prior to earthworks. A digger will then reduce the bank slope (ideally 1:1). After re-battering, laying a natural fibre mat is recommended to stabilise the new bank surface and provide better conditions for growing plants.

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

4.5.2 Width

Unfortunately, the published studies that we collated do not contain enough information to reliably relate PRB width to nitrate removal (see widths plotted on **Figure 12**). Self-sustaining, weed free PRBs are more likely when they are wider (10+ m) than narrower (5-6 m, Parkyn et al. 2000).

4.5.3 Planting zones

Planting is typically undertaken with recognition of several zones (Figure 14):

- High flow zone - the *upper bank* may be flooded every couple of years. It is generally drier and not as susceptible to waterlogging. Trees, flaxes and shrubs should be established in this zone.
- Low flow zone – the *lower bank* is prone to more frequent flooding and waterlogging, and soils are generally wetter. Sedges and rushes will thrive under these conditions.
- Fence zone – the fence zone is a narrow strip of rank grass. It creates a physical separation between farmland and the riparian buffer. Absence of shrubs and trees will prevent plants from shorting electric wires or being grazed. The fence zone could also be a well-designed filter strip if surface runoff occurs when it rains (see Section 3).

Figure 14: Planting zones. (Dairy NZ).

4.5.4 Plant selection

Planting guides list suitable plants and their preferred conditions, typical plant sizes as well as the benefits provided by specific plants and riparian buffers generally. Regional planting guides are available from Dairy NZ (Regional Planting Guides)[6] which 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 Riparian Planner tool[7] guides farmers through the processes of calculating plant spacings and numbers, budgeting, scheduling planting in manageable stages and communicating the plan to others (e.g., nurseries, suppliers, and trades-people etc.).

[6] https://www.dairynz.co.nz/environment/waterways/planting-waterways/
[7] https://www.dairynz.co.nz/environment/waterways/riparian-planner/

A mix of vegetation types, species and ages will provide a diversity of:

- rooting depths and root densities
- litter types
- litter decomposition rates.

In nitrogen sensitive catchments, nitrogen fixing plants should be avoided. Kowhai, kākābeak/ngutu kākā and many exotic species that fix nitrogen should be avoided in planted riparian buffers (see Appendix C).

Planting guides identify common weeds found in riparian areas, and several weed plant species lists (e.g., Appendix D) and specialist information sources exist (e.g., Weedbusters).[8]

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).

4.6 Implementation

Implementation requires a design plan, which includes fencing, planting season, site preparation, planting and maintenance. The following is a check list to help implementation.

4.6.1 Fencing

1. Permanent fencing is required to prevent livestock from browsing and trampling plants in PRBs.

4.6.2 Planting season

1. Consult regional planting and maintenance calendars to identify the best planting season for your region. For example, in Southland planting is most successful in spring, while in Northland winter is the best planting period. An example two-year planting and maintenance calendar is provided in each of DairyNZ's Regional Planting Guides (reproduced in part in Figure 15).

[8] https://www.weedbusters.org.nz/

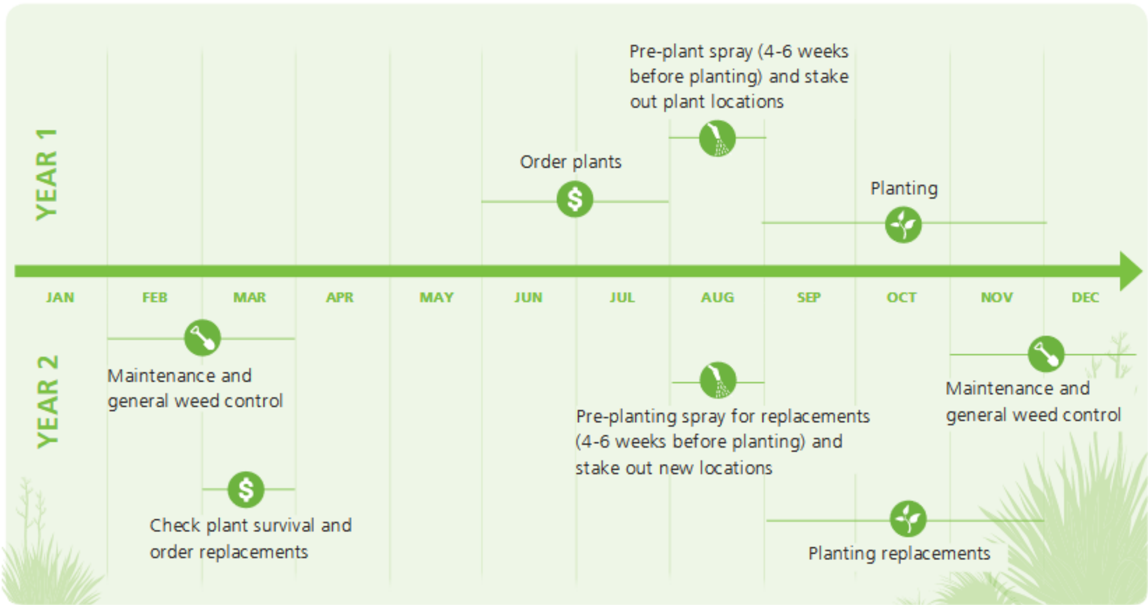

Figure 15: Riparian planting calendar for Southland. (DairyNZ).

4.6.3 Planting

1. Remove grass and weeds. Four to six weeks before planting, spray 1 m diameter circles with a glyphosate-based herbicide at each planting location (Figure 16).
2. Plant and mulch. Dig a hole that is big enough to accommodate plant roots without them being curled up or bent in the hole. On drier soils, ensure the base of the stem is 1-2cm below the soil surface. On permanently wet soils, place the base of the stem about 2 cm above the soil surface with soil mounded up to the stem, over the root ball.
3. Mulch around plants will help keep soils damp, reduce weeds and provide nutrients. Good mulches include straw, staked down cardboard or wool. Surround each plant with at least a 30-40 cm diameter of biodegradable weed mat, mulch or old woollen carpet to suppress weed growth. Avoid using plain wood chip around the plant as it will strip all the nitrogen out of the soil causing the plant to yellow off and die.
4. Fertiliser tablets may leach nutrients and are probably not required in riparian soils.
5. Put a stake beside plants (unattached; Figure 16 c) to enable plants to be easily seen when weeding; these stakes will also help identify where plants have died and need replacing. Use painted stakes if kikuyu grows high and fast at your site.

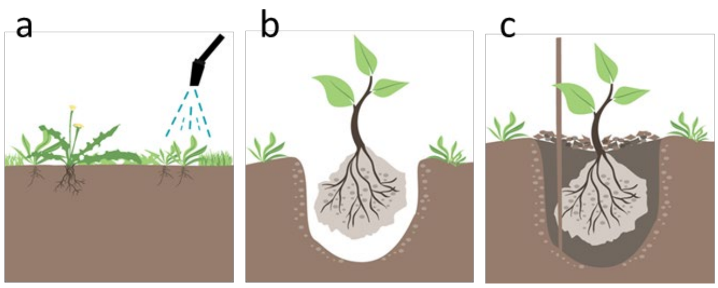

Figure 16: Schematic summary of planting steps. (DairyNZ).

4.6.4 Maintenance

1. Stake each plant for easy location and brush cut, hand weed or carefully spray with a glyphosate-based herbicide twice a year. If spraying, follow product guidelines – desirable plants are usually sensitive to herbicides so caution must be taken to protect against spray drift.

2. Woody weeds (e.g., blackberry and gorse) should be controlled to ensure the PRB has dense vegetation at ground level, minimise flow channelization, and prevent the PRB being a weed source for adjacent pasture. DairyNZ's planting guides will help identify weeds commonly found in riparian areas. Other useful reference materials include the weed plant species list (Appendix D) and materials provided by Weedbusters.[9]

[9] https://www.weedbusters.org.nz/

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Appendix A Draft planning sheet for filter strips

	Project	**Site**	**Date**
Goals	**Individual goals**	**Regulatory requirements**	**Community goals**
Location	where is your farm in the catchment?		
Farm	identify waterways, including intermittent and permanent streams, drains group paddocks which have similar characteristics (cover, slope)		☐ ☐
Site 1	**Hillslope** current landcover landcover change? where does water flow when it rains? signs of erosion? does water flow down hillslope in channels? hilllslope form - concave, convex, straight? does the topography converge? is the topsoil permeable? is there an impeding layer?	**Riparian zone** can water infiltrate easily? does the soil near the stream become saturated in winter? does water seep out of the hillside? are there boggy areas? is the topsoil permeable? is there an impeding layer?	**Stream** ephemeral, seasonal or permanent? headwater (flowing water starts)

Appendix B Draft planning sheet for planted riparian buffer for nitrate removal.

	Project	**Site**	**Date**
Goals	**Individual goals**	**Regulatory requirements**	**Community goals**
Location	where is your farm in the catchment?		
Farm	identify waterways, including intermittent and perennial streams, drains group paddocks which have similar characteristics (cover, slope)		☐ ☐
Site 1	**Hillslope** current landcover landcover change? where does water flow emerge from the soil when it rains? is the topsoil permeable? is there an impeding layer?	**Riparian zone** can water infiltrate easily? does the soil near the stream become saturated in winter? does water seep out of the soil in the riparian zone? are there boggy areas? is the topsoil permeable? is there an impeding layer?	**Stream** ephemeral, seasonal or permanent? headwater (flowing water starts) what's the bank height? is the channel incised?

Appendix C Nitrogen-fixing plant species

Common name	Scientific name
Alfalfa	*Medicago sativa*
Asparagus pea	*Tetragonolobus purpureus*
Black locust	*Robinia pseudoacacia*
Bladder senna	*Colutea arborescens*
Blue lupin	*Lupinus angustifolius*
Broom	*Carmichaelia spp.*
California lilac	*Ceanothus papillosus roweanus*
California mountain mahogany	*Cercocarpus betuloides*
Cape broom	*Genista monspessulana*
Carob	*Ceratonia siliqua*
Caucasian Alder	*Alnus subcordata*
Chickpea	*Cicer anetinum*
Chinese licorice	*Glycyrrhiza uralensis*
Chinese wisteria	*Wisteria sinensis*
Chinese yellow wood	*Maackia amurensis*
Crimson clover	*Trifolium incarnatum*
Demand white clover	*Trifolium repens*
Dyers greenweed	*Genista tinctorial*
Earthnut pea	*Lathyrus tuberosus*
Elaeagnus	*Elaeagnus punguns/ Elaeagnus x reflexa*
Paper Bush/Silver Berry	*Elaeagnus x ebbingei*
Cherry oleaster	*Elaeagnus multiflora*
Evergreen laburnum	*Piptanthus nepalensis*
Golden rain tree	*Koelreuteria paniculata*
Honey Locust	*Gleditsia triacanthos v. inermis*
Icon “semi winter active” lucerne	*Medicago sativa*
Italian alder	*Alnus cordata*
Judas tree	*Cercis siliquastrum*
Kākābeak/ngutu kākā	*Clianthus*
Kidney vetch	*Anthyllis vulneraria*
Kōwhai	*Sophora spp.*
Licorice	*Glycyrrhiza glabra*
Marlborough weeping broom	*Chordospartium stevensonii*
Matagouri	*Discaria toumatou*

Common name	Scientific name
New Jersey tea	*Ceanothus americanus*
Oleaster, Russian Olive	*Elaeagnus angustifolia*
Peanut	*Arachis hypogaea*
Pink tree broom	*Notospartium glabrescens*
Tainui/ Dogwood	*Pomaderris apetala*
Kūmarahou	*Pomaderris hamiltonii*
Purple coral pea shrub	*Hardenbergia violacea*
Red alder	*Alnus rubra*
Sea berry/buckthorn	*Hippophae rhamnoides*
Buttercup bush	*Senna multiglandulosa*
Siberian pea shrub	*Caragana arborescens*
Silk tree	*Albizia julibrissin rosea*
Silver wattle	*Acacia dealbata*
Spring vetchling	*Lathyrus vernus*
Tree lucerne	*Chamaecytisus palmensis*
Tutu	*Coraria spp.*

Appendix D Pest plant species

For the most up to date information check weedbusters.org.nz.

Common name	Scientific name
Agapanthus	*Agapanthus praecox*
Arum lily	*Zantedeschia aethiopica*
Banana passionfruit	*Passiflora mollissima*
Bamboo	*Phyllostachys* species
Barberry	*Berberis glaucocarpus*
Blackberry	*Rubus fruticosus*
Blue morning glory	*Ipomoea indica*
Broom	*Cytisus scoparius*
Buddleia	*Buddleja davidii*
Cape ivy	*Senecio angulatus*
Chilean rhubarb	*Gunnera tinctoria* and *G. manicata*
Climbing asparagus	*Asparagus scandens*
Climbing dock	*Rumex dagittatus*
Cotoneaster	*Cotoneaster franchetii*
Elaeagnus	*Elaeagnus* x reflexa
Fennel	*Foeniculum vulgare*
German ivy	*Senecio mikanioides*
Gorse	*Ulex europacus*
Greater bindweed, , also known as convolvulus	*Calystegia silvatica*
Hawthorn	*Crateagus monogyna*
Hemlock	*Conium macultum*
Himalayan honeysuckle	*Leycesteria formosa*
Japanese honeysuckle	*Lonicera japonica*
Jasmine	*Jasminum polyanthum*
Kikuyu	*Pennisetum clandestinum*
Large-flowered mallow	*Malva sylvestris*
Mexican daisy	*Erigeron karvinskianus*
Mile-a-minute	*Dipogon lignosus*
Montbretia	*Crocosmia* x *crocosmiiflora*
moth plant	*Araujia sericifera*
Nasturtium	*Tropaeolum majus*
Old man’s beard	*Clematis vitalba*

Common name	Scientific name
Onion weed, three cornered garlic	*Allium triquetum*
Pampas	*Cortaderia selloana/jubata*
Periwinkle	*Vinca major*
Plectranthus	*Plectranthus ciliatus*
Privet	*Ligustrum lucidum* and *L. sinense*
Grey willow/Pussy Willow	*Salix cinerea*
Crack willow	*Salix x fragilis*
Smilax	*Asparagus asparagoides*
Tutsan	*Hypericum androsaemum*
Wandering willie	*Tradescantia fluminensis*
Wattle	*Paraserianthes lophantha*
Wild ginger	*Hedychium gardnerianum* and *H. flavescens*
Woolly nightshade	*Solanum mauritianum*
Yellow flag iris	*Iris pseudacorus*