Vegetated Buffer Strips

Background Material and Literature Review

VERSION 2.0

July 2025

Vegetated Buffer Strips

Background Material and Literature Review

Version 2.0

July 2025

Prepared to support the Erosion and Sediment Control Code of Practice.

Andrew Barber, Henry Stenning and Sarah Dobson from Agrilink NZ prepared the background material and revision for this document for the Vegetable Research & Innovation and Horticulture New Zealand.

This background document supports the Erosion and Sediment Control Code of Practice. It covers the existing literature and grower experience on the implementation, maintenance, and effectiveness of vegetated buffer strips.

Contents

Vegetated Buffers

Vegetated buffer strips, also known as riparian buffers, filter strips, field borders and conservation buffers, are defined as: "small areas or strips of land in permanent vegetation, designed to intercept pollutants and manage other environmental concerns"[1].

1. Summary

Vegetated buffer strips can significantly reduce non-point source pollution from horticulture. With the right installation and maintenance, they can reduce sediment, nutrient, and pesticide loadings in runoff water. Whilst several factors affect their performance and longevity, the main and most tricky consideration for growers should be maximising sheet flow and preventing channelisation across the vegetated buffer strip.

If this is done correctly vegetated buffers have the capacity to reduce up to 90% of sediment, 95% of phosphorous, and 76% of nitrogen from overland flow (based on a range of literature sources).

2. Introduction

Typically, in New Zealand, vegetated buffer strips (hereafter referred to as buffers or buffer strips) are commonly encountered at the riparian edge of waterways or at the base of paddocks on cultivated land. They act to slow runoff water and trap sediment through filtering and increased infiltration. Buffers can also act as windbreaks, increase biodiversity on the farm, reduce odour and noise, and attract pollinators, depending on their dimensions and vegetation mix.

The efficiency of buffers at removing sediment and other pollutants has been studied numerous times across different environmental conditions. This document summarises some of these studies, underpinning the associated Erosion and Sediment Control Code of Practice (available from HortNZ) with the latest research.

---

[1] United States Department of Agriculture National Resources Conservation Service.

3. Sediment removal

The ability for buffer strips to remove sediment from runoff water on cultivated land has been a contentious issue in the past. Almost all studies have been conducted on pasture. Overland flow from pasture is more likely to be sheet flow, and consequently buffers will perform better than if they had been below cultivated land that tends to result in more channelised flow.

Sediment removal depends on the buffer's dimensions, location, topography, and vegetation mix. As a result, the literature is often contradictory on the percentage effectiveness of buffers. The United States Department of Agriculture states that with proper installation and maintenance, buffer strips can remove up to and sometimes greater than 75% of sediment[1]. Early studies on sediment removal efficacy on cropping land showed that effectiveness decreased with time as sediment inundates the filter strips, eventually resulting in full coverage by deposited soil[2]. This study also found that the trial plots with an 11% (6º) slope across the buffer strip outperformed plots with 5% (3º) and 16% (9º) slopes[2]. The effect of width was also demonstrated, with 9.1m wide buffers generally performing 10-15% better than buffers with a 4.6m width[2].

Overall, this study concluded that buffers were ineffective in hilly areas due to concentrated flows in higher rainfall events inundating and bypassing the strips, though it was noted strips helped to prevent channel and gully erosion in waterways. On flatter land, the study noted that significant portions of runoff entered the strips as shallow uniform flow, underpinning their greater effectiveness in these areas. However, older buffers (1-3 years old) were often inundated in sediment, causing runoff to flow parallel to the strips before bypassing them at low points[2]. Section 8 of this review discusses ways of improving efficiency and correct installation.

More recent studies have generally supported the findings from Dillaha et al. (1989), though recorded sediment reduction efficiencies vary, dependent on experimental and buffer strip design. A literature review from 2009[3] found that buffer strips with a width of 1-3m on average reduced around 60% of sediment. This compares to the 70-80% reduction on average for buffer strips with widths between 4-6m, and an 80-90% reduction for strips greater than 6m wide. The range of efficiencies in the studies reported on in this review narrowed with wider buffers, indicating reduced variability in sediment removal with wider buffers – though the difference in reductions between 4-6m and >6m wide buffer strips was far less than that between 0-3m and 4-6m buffer strips. The marginal benefit from ever wider buffers reduces while direct and opportunity costs increase.

In support of insights from Yuan et al. (2009), a four-year project by Foundation for Arable Research (FAR) on cropping setbacks found that 5m setbacks in run-off events reduced

[1] United States Department of Agriculture National Resources Conservation Service.
[2] Dillaha et al., 1989.
[3] Yuan et al., 2009.

sediment loads by 63%, compared to 37% for a 1m setback[4].

Yuan et al. (2009) also analysed the effect of buffer slope on buffer efficiency, finding a large variability in results between different studies. On average slopes of less than 5% (3º) appeared to perform better than slopes greater than 5%, though this is by no means definitive, with another literature review from 2009 supporting an optimal slope of 10% (6º) for vegetated buffers[5]. The 2009 Yuan et al. review found little difference between vegetation type and buffer sediment removal efficiency, though this review noted that there was insufficient data to determine this for sure. This most likely reflects that a buffer strip's main mode of action is through soil infiltration rather than the filtering effects of the above ground vegetation.

The contribution of sediment particle size to buffer efficiency has also been analysed in several studies. One study found that larger aggregates (>40μm) were entirely removed within a 5-metre-wide strip but found that smaller aggregates could only be mostly removed with high levels of infiltration[6].

4. Paddock slope

Paddock slope has the single largest impact on erosion rates. There is approximately a 35 times difference between unmitigated sediment loss on an 7-degree paddock compared to a 1-degree paddock (Vegetated Buffer Strips Guidance). As the paddock slope increases, buffers are more likely to become overwhelmed, both from sediment load and channelised flow.

In the Land Use Capability Survey Handbook, Slope Group A is between 0 – 3 degrees and is described as flat to gently undulating. There is a 6-fold difference between 1 and 3 degrees. Therefore, we decided that it was not appropriate to base the risk categories using the LUC Slope Groups. Instead, we used them as guidance and modelled the impact of a range of different variables.

In the Guideline's paddock risk assessment, a low-risk paddock has a slope of less than 1 degree. The average erosion rate from a 1-degree paddock is approximately 0.6 t/ha/yr, based on over 1,000 scenarios using different soil types, slope lengths, and regions. This is approximately equivalent to a 5-degree pasture paddock.

5. Modelled sediment removal efficacy

Several studies have developed predictive models for sediment removal efficacy by buffer strips. These models are useful for planning buffer strip installation and modelling catchment scale sediment load reductions. Another literature review from 2009[4] used existing study data

[4] https://assets.far.org.nz/Environmental-research-2021-22.pdf
[5] Zhang et al., 2010.
[6] Gharabaghi et al., 2000.

to generate a predictive sediment removal efficacy model.

The model for sediment removal is dependent on buffer slope and vegetation mix. For grass only buffers the predicted sediment reduction (Y) is explained by the following equations:

≤10% (buffer slope): $Y = 21.7 + 2.0 \times X_{slope} + 61.0 \times (1 - e^{-0.35 \times Xwidth})$

>10% (buffer slope): $Y = 79.7 - 3.8 \times X_{slope} + 61.3 \times (1 - e^{-0.35 \times Xwidth})$

This predictive model has an optimal sediment reduction at a 10% (6º) buffer slope, with the greatest efficiency gains as the buffer increases up to 5m. After 10m the efficiency increase gained from increasing buffer width rapidly decreases, indicating that very wide buffers are potentially unnecessary (the relationship between width and sediment removal efficacy follows an exponential relationship).

This model is used to calculate the impact of buffer strips on sediment loss rates in the *Don't Muddy the Water (DMTW) erosion rate calculator web-app*. Unfortunately, this model does not consider the effects of channelisation or bunding causing bypass of the strip. For this reason, a simple *'channelisation factor'* was added to the app to account for this common issue. In the absence of robust predictive equations to account for runoff bypass this factor is a simple user-selected percentage that accounts for the proportion of the strip that is encountering sheet flow runoff. A strip with a channelisation factor of 80% would be 20% less effective than one with no channelisation.

With the increasing domestic and international calls for improving water quality there will be further research into buffer strips in the future, and conceivably better predictive models. The DMTW app will be part of a VR&I review cycle that will incorporate the latest research. The Erosion and Sediment Control Code of Practice will be part of the HortNZ review cycle of a suite of codes.

6. Nutrient removal

Nutrient loss through leaching and runoff is one of the largest environmental concerns for the horticulture industry. Vegetated buffers have minimal effect on leaching but can reduce concentrations of ecologically hazardous nutrients in runoff water.

One of the earliest studies on vegetated buffer efficiency found phosphorous removal by buffers ranged from 49-95% dependent on width and slope[2]. As most phosphorous in agricultural soils is attached to soil as particulate phosphorous removal of sediment will generally also remove bound phosphorous. Increased infiltration will also help reduce levels of dissolved reactive phosphorous (DRP), the soluble phosphorous present in runoff water.

The Zhang review modelled phosphorous removal efficacy (Y) with the following equation:

$Y = 30.5 + 147 \times (1 - e^{-0.03 \times Xwidth})$

Percent reductions in nitrogen have been measured by Dillaha et al. (1989), ranging between

63-76% dependent on buffer strip width and slope – with moderate sloping (11% / 6º) wide (9.6m) buffer strips outperforming other combinations[2].

The Zhang review modelled nitrogen removal efficacy (Y) with the following equation:

$$Y = 10.2 + 91.4 \times (1 - e^{-0.11 \times Xwidth})$$

Zhang et al. (2010) found that buffers composed of trees generally remove more nitrogen from runoff than grass only strips due to deeper rooting systems taking up more nitrogen in the subsoil following infiltration.

7. Pesticide removal

As with nutrients, the more that pesticide concentrations in runoff water can be reduced the better for the surrounding environment. There have been several studies on buffer strip efficacy for pesticide pollutant removal.

The Zhang et al. (2010) review modelled pesticide removal efficacy (Y) with the following equation:

$$Y = 93.2 \times (1 - e^{-0.22 \times Xwidth})$$

Currently the focus around the use of buffer strips on horticultural land in New Zealand is on sediment control but based on the literature management practices that increase the efficacy of buffers for sediment removal also reduce nutrient and pesticide loads on the receiving environment.

8. Factors affecting efficiency and correct installation / maintenance

According to Dillaha et al. (1989), installation of buffer strips in inappropriate areas due to topographic limitations is a large factor in buffer strip failure. The study concludes: “Unless VFS [vegetated filter strips] can be installed so that concentrated flow is minimised, it is unlikely that they will be very effective for agricultural nonpoint source pollution control.”

Trafficked headlands need to be between the cultivated paddock and the vegetated buffer strip. This is essential to prevent vehicles from driving across the buffer, causing both compaction and channelised flow.

Driving through the buffer strip can cause channelised flow.

November 2015

September 2019
The trafficked headland has been moved into the paddock, so no vehicles pass over the buffer. Not visible in this photo, but baffles have also been added to the drain.

Accessways below a buffer are a potential weak point (see below). Consideration should be given to moving the accessway to a more elevated part of the paddock, therefore avoiding passing through the buffer. If this cannot be achieved, then the accessway needs raising and contouring to avoid concentrated flows out flanking the buffer.

Channelisation, usually driven by local topography, is a primary mechanism for runoff water bypass of buffer strips, negating their usefulness in lowering contaminant load levels. Dosskey et al. (2002), analysed the relationship between sediment trapping efficiency and input load per unit of effective buffer area (i.e., the area of the buffer that contacts runoff). This study found that "concentrated flow through riparian buffers was common and substantial" with the concentration of these flows usually occurring before entry into riparian buffers[6]. The study's conclusion that "sediment-trapping efficiency of riparian buffers based on gross buffer area may greatly overestimate actual performance," supports the integration of a channelisation factor within the DMTW buffer model and indicates the importance of correct construction and maintenance for effective buffer operation.

Suggested practices from the Dosskey et al. (2002) study to mitigate channelisation include:

- Removal of sediment accumulations to prevent bund effects
- Ensuring the buffer is lower than the field margin
- Orientation of crop row direction to discourage flow into swales before reaching field margins (i.e., orient rows perpendicular to the buffer)
- In-field soil conservation practices and erosion control to reduce sediment loads and runoff volumes
- Spotting runoff pathways can be difficult in dense established buffer strips[7] so observations for maintenance purposes would be made easier during heavy rainfall events.

A 2009 literature review noted that strips composed of stiff, tall, perennial grasses are more resistance to inundation by channelised flow and could offer an advantage over standard grass

[7] Dosskey et al., 2002.

buffer strips[8]. Other studies have compared the efficacy of buffer strips made of woody vegetation, shrubs, and grass[9], suggesting vegetation with deep rooting systems may be more effective at trapping sediment. However, while most horticultural operations buffers are composed mostly of grass, it could be worth considering different vegetation types, to potentially increase the effectiveness of nutrient removal[10].

9. Biodiversity enhancement

Buffer strips can have large positive effects on farm biodiversity levels by causing an edge effect, especially in riparian zones. Buffer strips of sufficient size can act as habitats for birds and beneficial insects[11]. Both riparian and non-riparian buffers can also be planted with beneficial plant species to attract insect pollinators. There are indications that this can sometimes increase product yield in adjacent paddocks[12]. Buffer strips can also act as linear connectors between habitats in areas that often do not have high levels of habitat connectivity (e.g. farmland)[10]. Ultimately though the effects on local biodiversity is extremely variable and dependent on location, local ecology, and vegetation species within the buffer strip. In general, it is commonly accepted that in most cases buffer strips will have some positive impact on biodiversity.

10. Erosion risk category justification

The Decision Tree Paddock Risk Assessment Diagram on page 5 of the Erosion and Sediment Control Code of Practice provides a pathway for readers to assess the inherent or baseline erosion and sediment loss risk of their cropping land. Risk is assessed at three levels: low, medium, and high. The decision tree was developed based on modelling 10,000 randomly generated scenarios, varying soil type, slope angle and length, and region. These were run through the *Don't Muddy the Water (DMTW) erosion rate calculator web-app*.

While the decision tree provides a good high-level guide, **the DMTW app will provide a more accurate estimate of sediment loss at a specific location** and can be used to better estimate unmitigated sediment loss and consequently risk. The app also models the impact of different mitigation practices.

Using the slope classes described in Land Use Capability Survey Handbook (see table below), and based on sediment loss modelling and analysis the low, medium and high unmitigated sediment risk categories were set at:

- Low risk: < 2 t/ha/year

[8] Yuan et al., 2009.
[9] Nsenga et al., 2024.
[10] Zhang et al., 2010.
[11] http://files.dnr.state.mn.us/publications/waters/buffer_strips.pdf
[12] Haddaway et al, 2018.

- Medium risk: 2 – 7 t/ha/year
- High risk: >7 t/ha/year

Table 26: Commonly recognised critical slopes for specified activities (modified from Bibby & Mackney 1969; McRae & Burnham 1981; MacDonald 1999; and Occupational Safety and Health Service 1999).

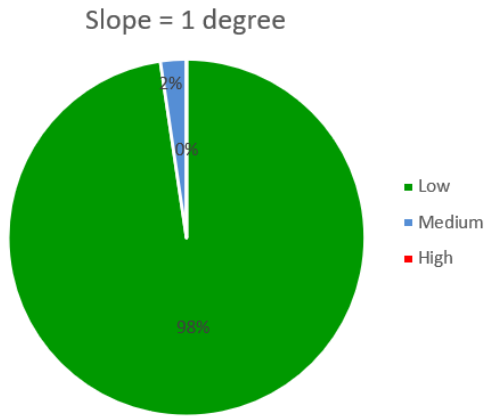
Slope group	Slope group (degrees)	Activities
A	0-3	Free ploughing and cultivation (1^0)
B	4-7	Soil erosion begins to be a problem (>3^0) Some heavy agricultural machinery restricted (6^0) Difficulties with weeders, precision seeders and some root crop harvesters (3^0–7^0)
C	8-15	Additional front weights to compensate for drag and steering difficulties for standard wheeled tractors (>11^0) Limit of two-way ploughing (depending on field configuration) (12^0) Limit of combine harvester operation (depending on field configuration) (15^0) Restricted loading and off loading of trailers (15^0)
D	16–20	Restricted crop rotations, higher cultivation costs, longer periods in pasture (>15^0) Typical maximum limit for rubber-tyred skidders (18^0 - 20^0)
E	21-25	Difficult to plough, lime and fertilise, higher cultivation costs, normal rotations impossible (>20^0) Occasional tillage for pasture improvement (20^0 - 25^0)
F	26-35	Soil movement and the formation of cross-slope stock tracks Typical maximum limit for tracked skidders (26^0) Specialised self-levelling tracked harvesting machines (26^0 up to 30^0)
G	>35	

Slope Group A is between 0 and 3 degrees. Across 1,023 scenarios the average unmitigated sediment loss rate at 1 degree cropping was 0.6 t/ha, 1.9 t/ha (989 scenarios) at 2 degrees, and 3.9 t/ha at 3 degrees. On this basis a conservative low risk level of sediment loss was set at 2.0 t/ha.

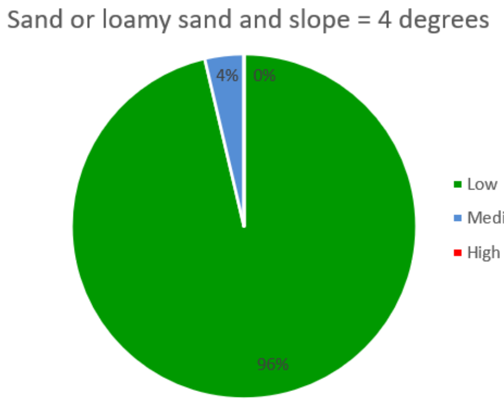
The upper end of Slope Group A is 3 degrees, with the comment that “soil erosion begins to be a problem at greater than 3 degrees”. At 4 degrees unmitigated sediment loss averages 6.6 t/ha. Any scenarios that generated greater than 7.0 t/ha was considered high risk. Therefore, the medium risk level of sediment loss sits between low and high risk at greater than 2.0 t/ha and less than 7.0 t/ha.

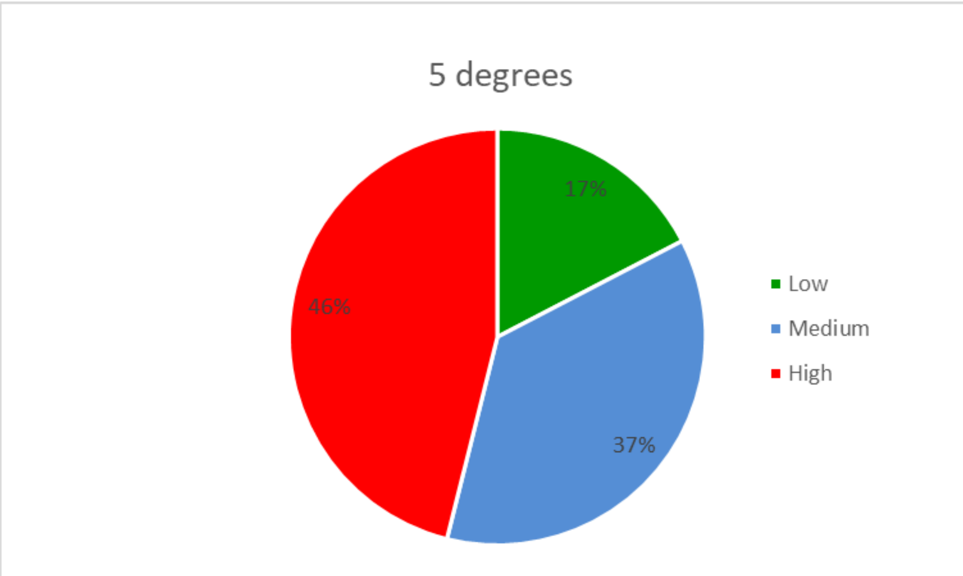
The Paddock Risk Assessment (Buffer Strip Guide) was developed in part based on the following results.

Slope is the dominant driver of erosion. Flat land at 1 degree has an average sediment loss of 0.6 t/ha/yr. Ninety eight percent of the 1,023 scenarios tested at a slope of 1 degree were in the low-risk category (<2 t/ha).

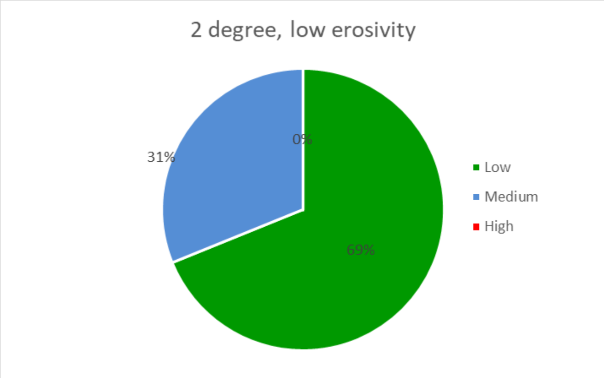


Sand and loamy sand soil texture have much lower erodibility than all other soil types. Through modelling we were able to show that on these two soil types, slopes can increase to 6 degrees and still have an average sediment loss rate of less than 2.0 t/ha. At 10 degrees the rate of erosion is less than 6 t/ha.

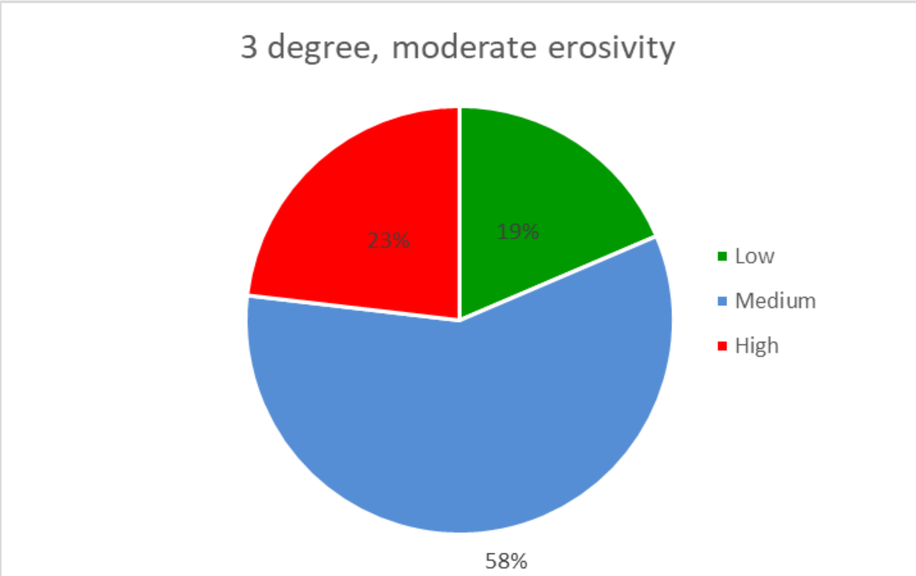




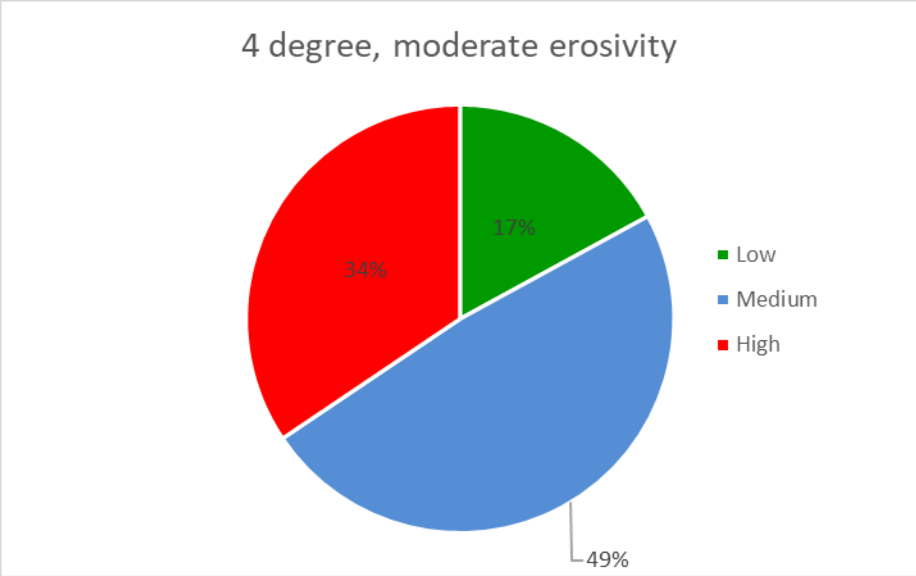
Slope is the dominant driver of erosion. Irrespective of the region and soil texture (excluding sand or loamy sand) when the slope is 5 degrees, 46% of the scenarios fell into the high-risk category of greater than 7 t/ha/yr. Average unmitigated sediment loss was 9.4 t/ha. Even in low erosivity areas (750 $MJ.mm.ha^{-1}.h^{-1}$) the average sediment loss was 6.0 t/ha, and 9.2 t/ha at 6 degrees.



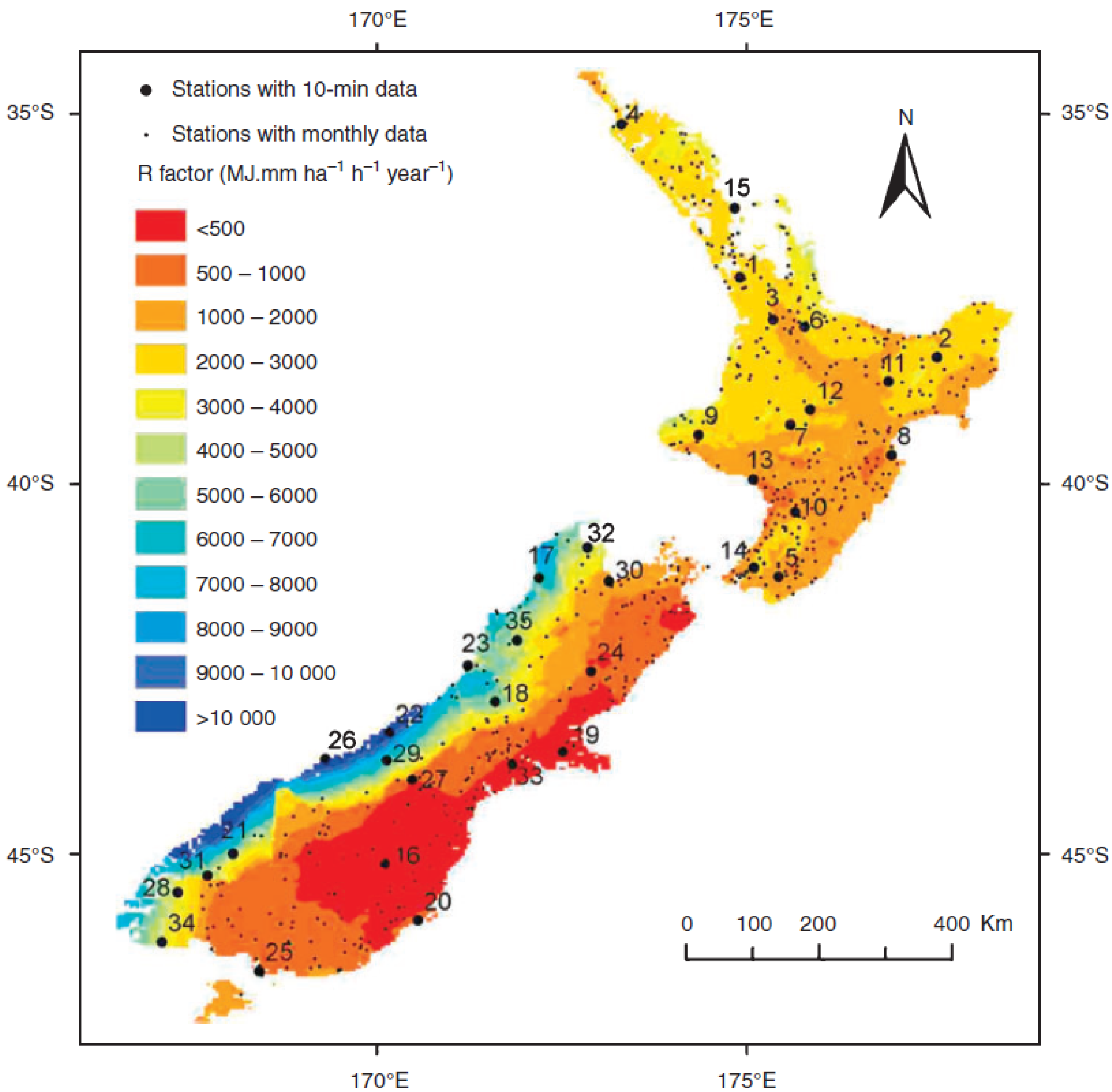
Rainfall intensity and soil erosivity varies around the country. In cropping areas this varies from a high in Pukekohe to a low in Canterbury. Based on NIWA modelling the lowest erosivity regions are Canterbury, Hawke's Bay, and Southland. These low erosivity areas (<1,000 MJ.mm.ha^{-1}.h^{-1}) had a sediment loss at a slope of 2 degrees of 1.6 t/ha. This group was categorised as low risk.



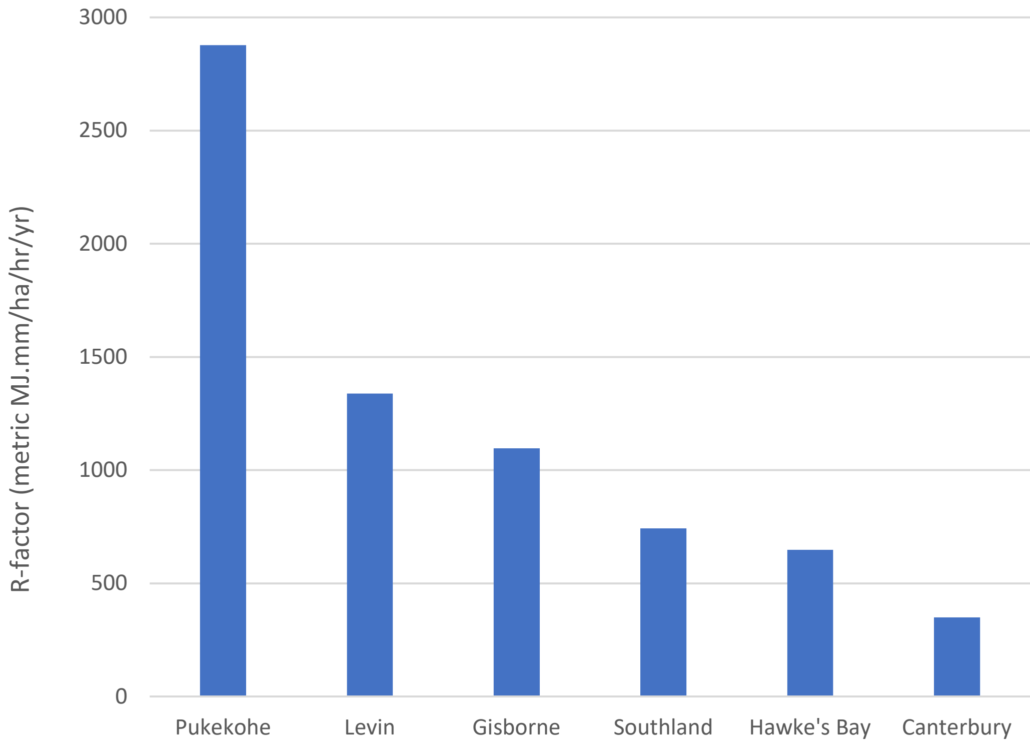
Where the area had an erosivity of low or moderate (<1500 MJ.mm.ha^{-1}.h^{-1}), a slope of 3 degrees had 77% of the scenarios classified as a low or medium risk. Average unmitigated sediment loss at 3 degrees and 1,500 MJ.mm.ha^{-1}.h^{-1} was 5.0 t/ha. This falls into the medium risk category.



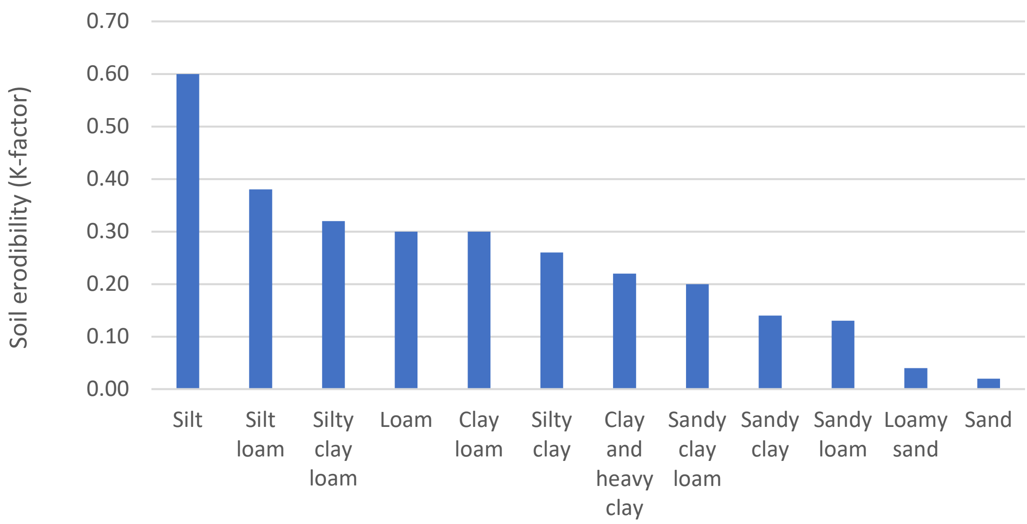
Where the area had an erosivity of low or moderate (<1500 MJ.mm.ha^{-1}.h^{-1}), a slope of 4 degrees, and short row lengths of less than 200 m then 66% of the scenarios were classified as a low or medium risk. Average unmitigated sediment loss was 5.9 t/ha. This falls into the medium risk category.



Rainfall erosivity map for New Zealand. Source: Klik et. al., 2015.



Erosivity across the 6 modelled regions



Soil type erodibility

Gallery

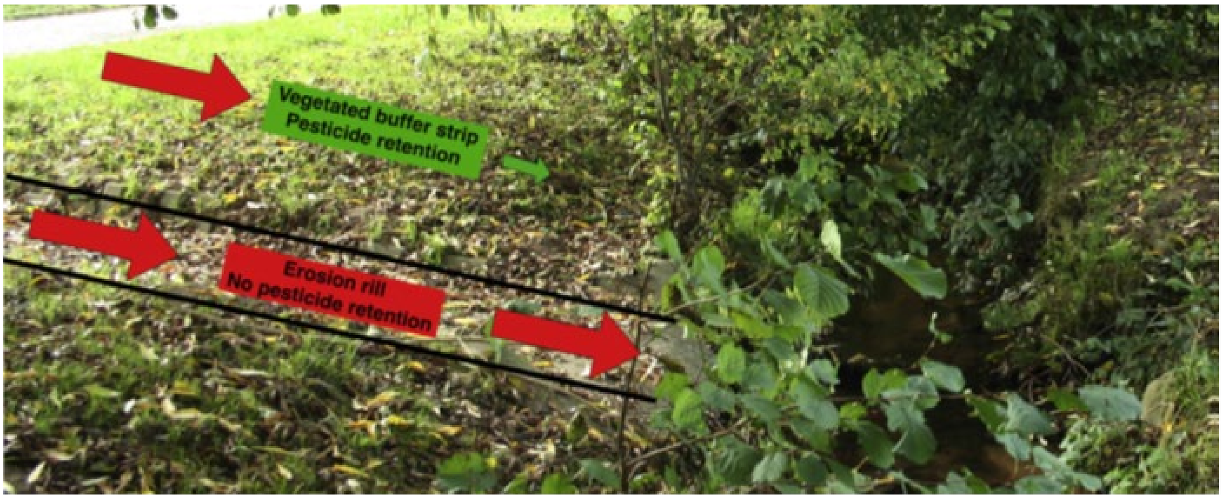
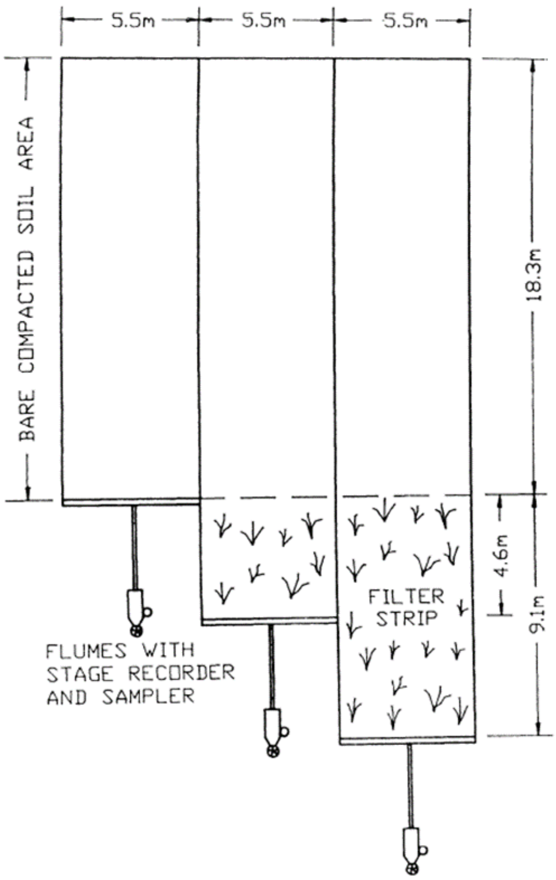
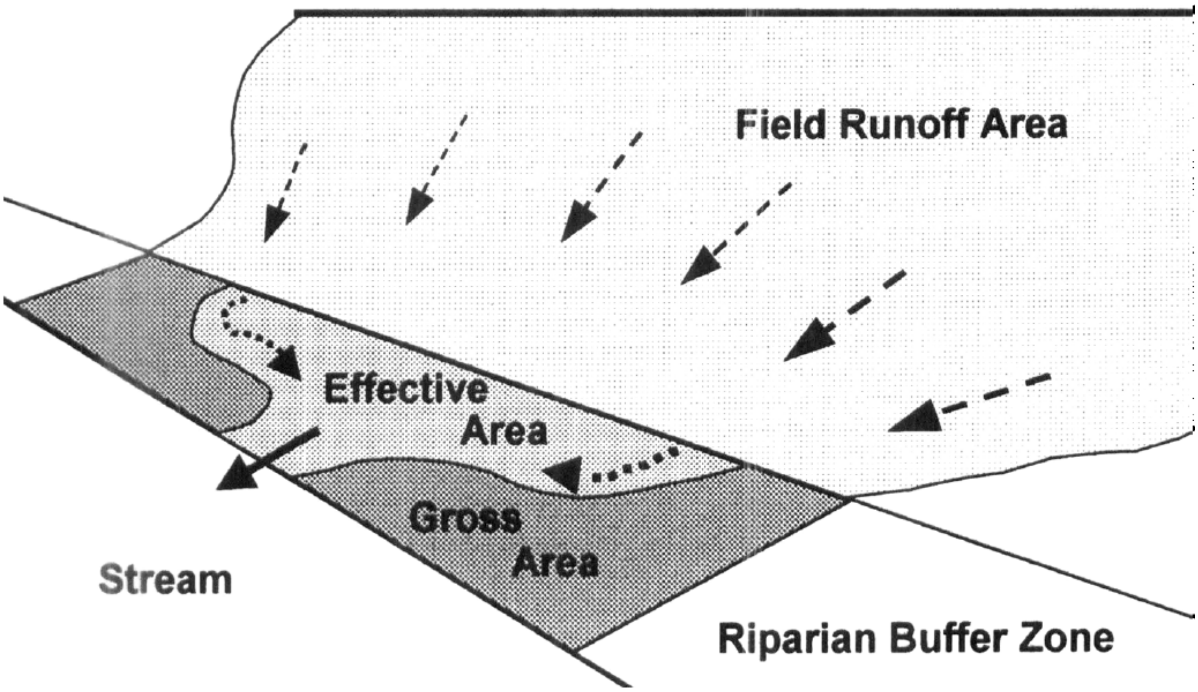


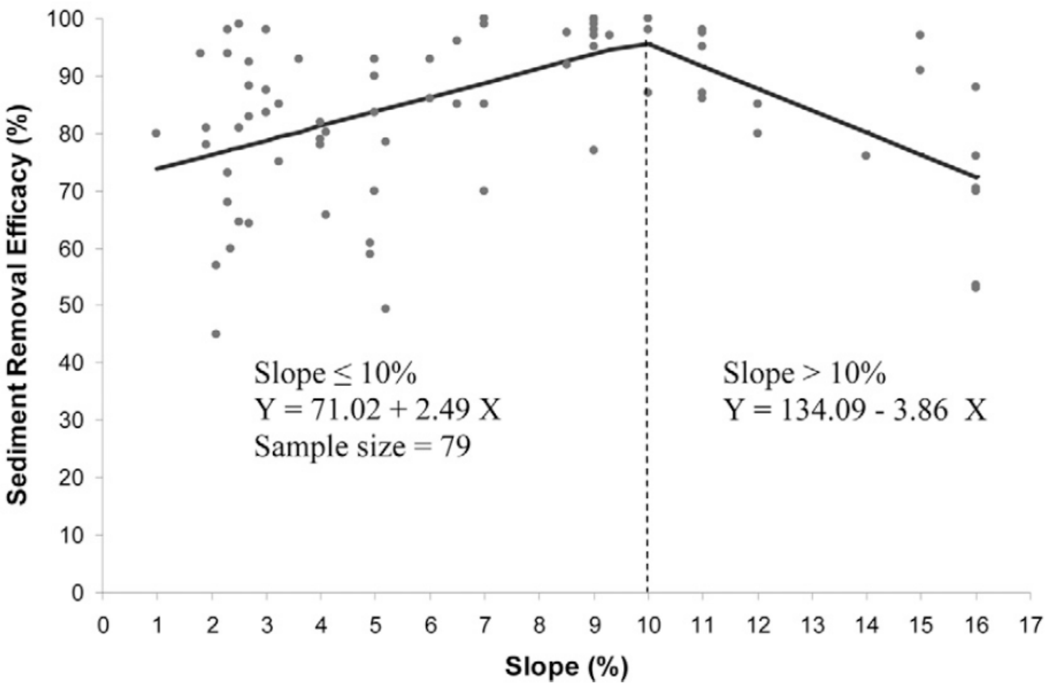
Figure 1: *Channelisation bypassing buffer strips and its effects on pesticide retention (From Stehle et al, 2015)*



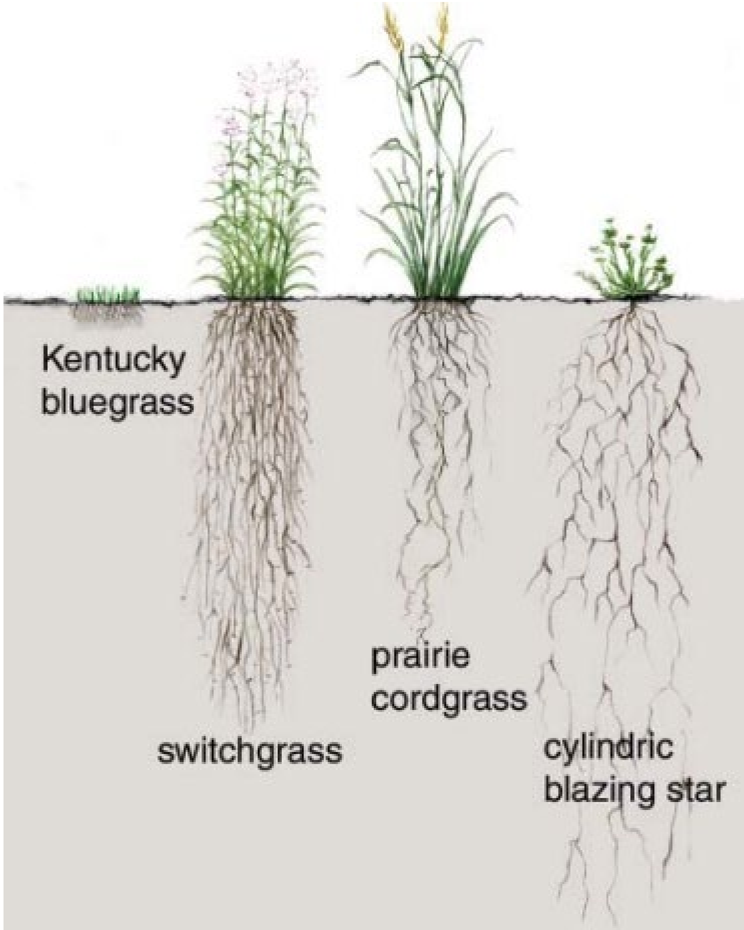
An example of an experimental buffer strip trial setup (Dillaha et al., 1989)



Depiction of channelisation through a riparian buffer (Dosskey et al., 2002)



Correlation of buffer sediment removal efficiency and slope based on a literature review of multiple studies (Zhang et al., 2010)



A depiction of different grass species rooting systems. Deeper roots encourage more infiltration and should be a consideration when choosing vegetation species for a farm buffer (http://files.dnr.state.mn.us/publications/waters/buffer_strips.pdf)

The installation of an effective buffer strip. The headland is moved into the paddock by approximately 7m and the buffer strip prepared by levelling the ground to minimise channelised flow and then a grass vegetated cover is well established. The headland itself needs to be regularly well graded to avoid bunding along the buffers leading edge, which would otherwise result in concentrated channelised flow at the lowest point.


September 2019


Watch for flow short circuiting the buffer

References

Basher, L. 2016. Erosion mitigation and prediction on cropland. Landcare Research. Prepared for Horticulture New Zealand.

Basher, L., Peterson, P. 2018. Don't muddy the water: Erosion measurements at Levin, Pukekohe, and Gisborne Final Report. Landcare Research. Prepared for Horticulture New Zealand.

Dillaha, T. Reneau, R., Mostaghimi, S., Lee, D. 1989. Vegetative Filter Strips for Agricultural Nonpoint Source Pollution Control. American Society of Agricultural Engineers. Vol 32(2).

Dosskey, M., Helmers, M., Eisenhauer, D., Franti, T., Hoagland, K. 2002. Assessment of concentrated flow through riparian buffers. Journal of Soil and Water Conservation.

Gharabaghi, B., Rudra, R., Whiteley, HR., Dickinson, WT. 2000. Sediment removal efficiency of vegetative filter strips. Annual Research Report of Guelph Turfgrass Institute http://131.104.104.3/00anrep/vegfilter.pdf

Grismer ME, O'Geen AT, Lewis D 2006. Vegetative filter strips for nonpoint source pollution control in agriculture. Publication 8195 University of California Agriculture and Natural Resources. http://anrcatalog.ucanr.edu/pdf/8195.pdf

Haddaway, N., Brown, C., Eales, J., Eggers, S., Josefsson, J., Kronvang, B., Randall, N., Uusi- Kämppä, J. 2018. The multifunctional roles of vegetated strips around and within agricultural fields. Environmental Evidence volume 7, Article number: 14 (2018).

Horrocks, A. (2022). Good management practices for cropping setbacks (Project code X18-22). Foundation for Arable Research. https://assets.far.org.nz/Environmental-research-2021-22.pdf

Klik, A., Haas, K., Dvorackova, A., Fuller, C., 2015. Spatial and temporal distribution of rainfall erosivity in New Zealand. Soil Research, 53, 815–825.

Nsenga, M., Akter, S., Li, X, Dzakpasu, M, Ifon, B. E., Manirakiza, B., Muyembe, D. K., Zhang, Y, Huang, J, & Guadie, A. (2024). Nutrient and sediment retention by riparian vegetated buffer strips: Impacts of buffer length, vegetation type, and season. Agriculture, Ecosystems & Environment, vol 369(109050).

Stehle, S., Dabrowski, J., Bangert, U., Shulz, R. 2015. Erosion rills offset the efficacy of vegetated buffer strips to mitigate pesticide exposure in surface waters. Science of the Total Environment. 545-546 (2016) 171-183.

United States Department of Agriculture (USDA) Natural Resources Conservation Service. Buffer Strips: Common Sense Conservation. Accessed June 2020. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/newsroom/features/?cid=nrcs143_023568

Weissteiner, C., Pistocchi, A., Marinov, D., Bouraoui, F., Sala, S. 2014. An indicator to map diffuse chemical river pollution considering buffer capacity of riparian vegetation – a pan European case study on pesticides. http://dx.doi.org/10.1016/j.scitotenv.2014.02.124

Yuan, Y., Bingner, R., Locke, M. 2009. A Review of effectiveness of vegetative buffers on sediment trapping in agricultural areas. Ecohydrology. 2, 321-336 (2009). DOI: 10.1002/eco.82.

Zhang, X., Liu, X., Zhang, M., Dahlgren, R. 2010. A Review of Vegetated Buffers and a Meta-analysis of Their Mitigation Efficacy in Reducing Nonpoint Source Pollution. J. Environ. Qual. 39:76-84 (2010) DOI:10.2134/jeq2008.0496

Horticulture New Zealand

Email: info@hortnz.co.nz

Horticulture New Zealand
Ahumāra Kai Aotearoa

AGRI LINK

Vegetable RESEARCH+ INNOVATION