Vegetated Buffer Strips

Background Material and Literature Review

Version 2.0 | September 2025

Horticulture New Zealand
Ahumāra Kai Aotearoa

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

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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 phosphorus, and 76% of nitrogen from overland flow. These figures are based on a range of literature sources, discussed later in this document.

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 blocks 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 risk assessment (available from HortNZ) with the latest research.

[1] United States Natural Resources Conservation Service (2015)

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 Mississippi Department of Environmental Quality (n.d.) states that with proper installation and maintenance, buffer strips can remove up to and sometimes greater than 75% of sediment. Early studies on sediment removal efficacy on cropping land showed that effectiveness decreased with time as sediment inundated the filter strips, eventually resulting in full coverage by deposited soil (Dillaha, Reneau, Mostaghimi, & Lee, 1989). This study also found that trial plots with an 11% (6^0) slope across the buffer strip outperformed plots with 5% (3^0) and 16% (9^0) slopes (Dillaha et al., 1989). The effect of width was also demonstrated, with 9.1m wide buffers generally performing 10-15% better than buffers with a 4.6m width.

Furthermore, Dillaha et al. (1989) concluded that buffers were ineffective in hilly areas due to concentrated flows in higher rainfall events inundating and bypassing the strips. However, it was noted strips helped to prevent channel and gully erosion in waterways. On flatter land, the study found 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 (Dillaha et al., 1989). Section 10 of this review discusses ways of improving efficiency and correctly installing buffers.

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. Yuan et al. (2009) found that buffer strips with a width of 1-3m on average reduced around 60% of sediment lost. This compares to a 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.

Looking at New Zealand-specific research, a Foundation for Arable Research project on cropping setbacks found that 5m setbacks reduced sediment load in run-off events by 63% and a 1m setback reduced loads by 37%, compared with the control (no setback) (Horrocks, 2022). This study also found that with increasing setback width, the additional benefit gained decreased in magnitude, supporting findings in Yuan et al. (2009).

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% (3^0) appeared to perform better than slopes greater than 5%, though this is by no means definitive, with Zhang et al. (2010) supporting an optimal slope of 10% (6^0) for vegetated buffers. Yuan et al. (2009) found little difference between vegetation type and buffer sediment removal efficiency, though they also noted that there were 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. Gharabaghi et al. (2001) 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.

4. Block slope

Block slope has the single largest impact on erosion rates. Erosion modelling calculates approximately a 35 times difference between unmitigated sediment loss on a 7-degree block compared to a 1-degree block (Figure 1). As block slope increases, buffers are more likely to become overwhelmed, both from sediment load and channelised flow.

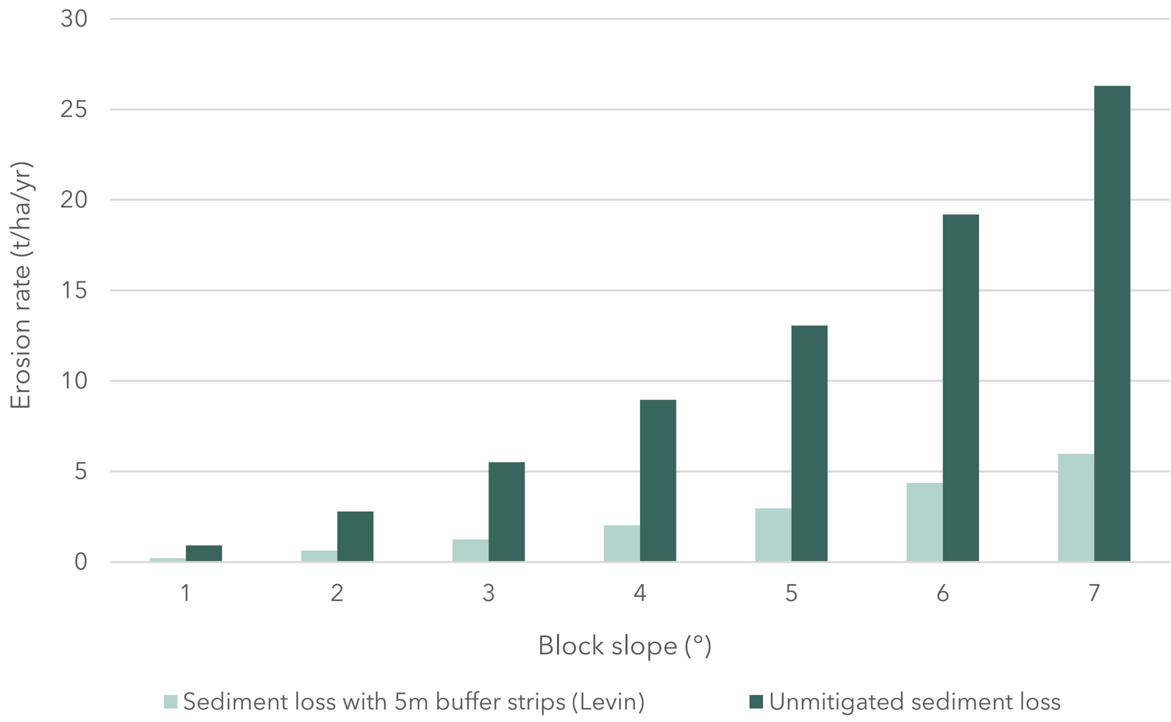


Figure 1. Modelled erosion rate against block slope using the Don't Muddy The Waters (DMTW) web-app, comparing cultivated sediment loss on an unmitigated block with a block that has a 5m buffer strip installed. Levin, Horowhenua was used for the modelling location.

In the Land Use Capability Survey Handbook (Lynn et al., 2009), Slope Group A is between 0 – 3 degrees and is described as flat to gently undulating. There is a 6-fold difference in sediment loss between 1 and 3 degrees (see Section 12). Therefore, we decided that it was inappropriate 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 Erosion and Sediment Control Code of Practice risk assessment, a low-risk block has a slope of less than 1 degree. The average erosion rate from a 1-degree block is approximately 0.6 t/ha/yr (see Section 12). This is approximately equivalent to a 5-degree pasture block.

5. Erosivity

Rainfall and its kinetic energy, expressed by rainfall erosivity, drives soil erosion processes by water. One of the most commonly used erosivity parameters is the rainfall-runoff erosivity factor R of the Revised Universal Soil Loss Equation. The R factor is a numerical value that reflects the potential of rainfall to cause erosion. It is typically expressed in units of $MJ·mm.ha^{-1}.h^{-1}.yr^{-1}$ (Megajoule millimetres per hectare per hour per year). This unit captures the kinetic energy of rainfall and the intensity of storms over time.

Higher R values mean more erosive potential, due to frequent, intense storms that generate heavy rainfall and high runoff. The R factor is computed based on long-term rainfall records and reflects the average annual erosivity. It is often derived from historical weather station data, specifically focusing on:

- Rainfall amount
- Rainfall intensity (especially the 30-minute peak intensity)
- Storm frequency and duration

Klik, Haas, Dvorackova, & Fuller (2015) investigated the spatial distribution of annual rainfall erosivity across New Zealand. Results from Klik et al. (2015) were also considered in the development of the Risk Assessment. Figure 2 contains an erosivity map created in this study. The DMTW app triangulates the three closest weather stations to a block's position to estimate its erosivity. At a regional level Pukekohe was found to have the highest erosivity at approximately 2,800 $MJ·mm.ha^{-1}.h^{-1}.yr^{-1}$, while Canterbury was the lowest at approximately 350 $MJ·mm.ha^{-1}.h^{-1}.yr^{-1}$. Figure 3 shows the erosivity across 7 growing centers. As evident in Figure 2, places close to the coastline like Te Puke can have an R factor of around 1,600. As you travel further inland, into the ranges, erosivity increases to 2,000 – 3,000+ $MJ·mm.ha^{-1}.h^{-1}.yr^{-1}$.

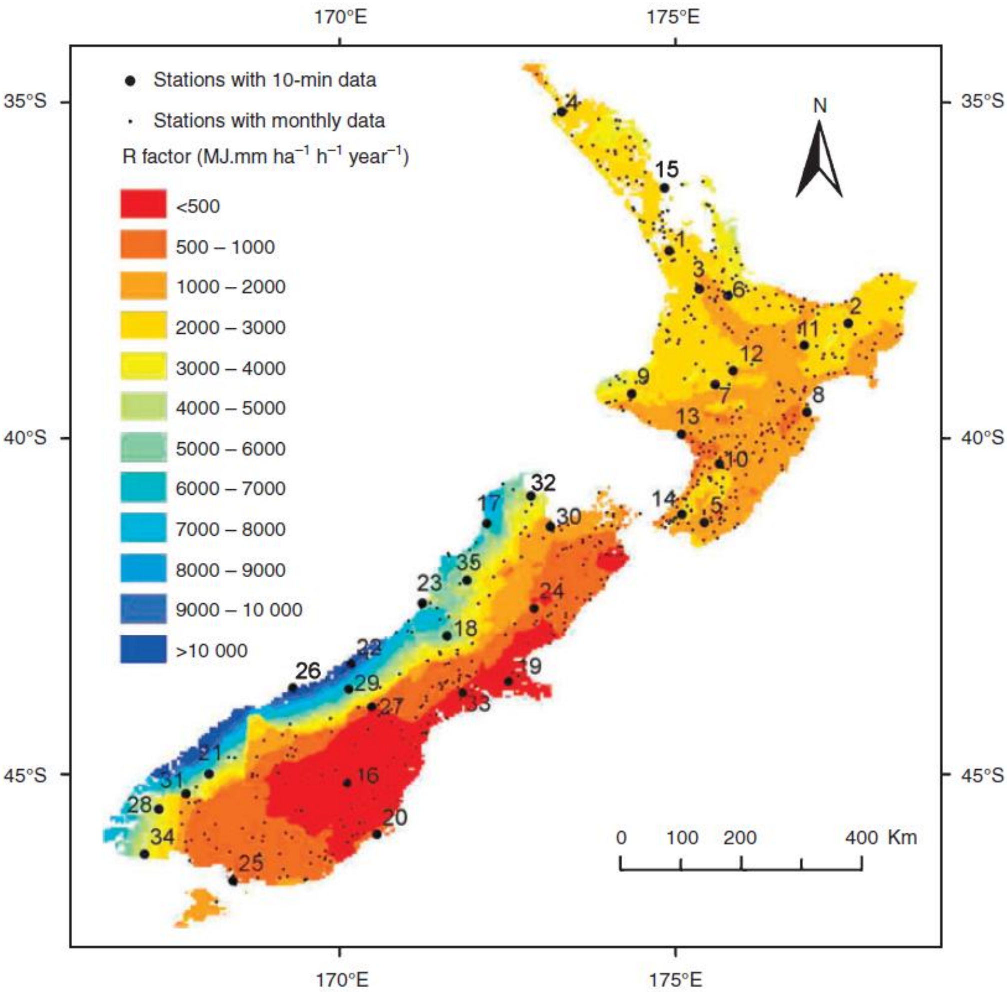


Figure 2. Spatial distribution of annual rainfall erosivity (Klik et al., 2015).

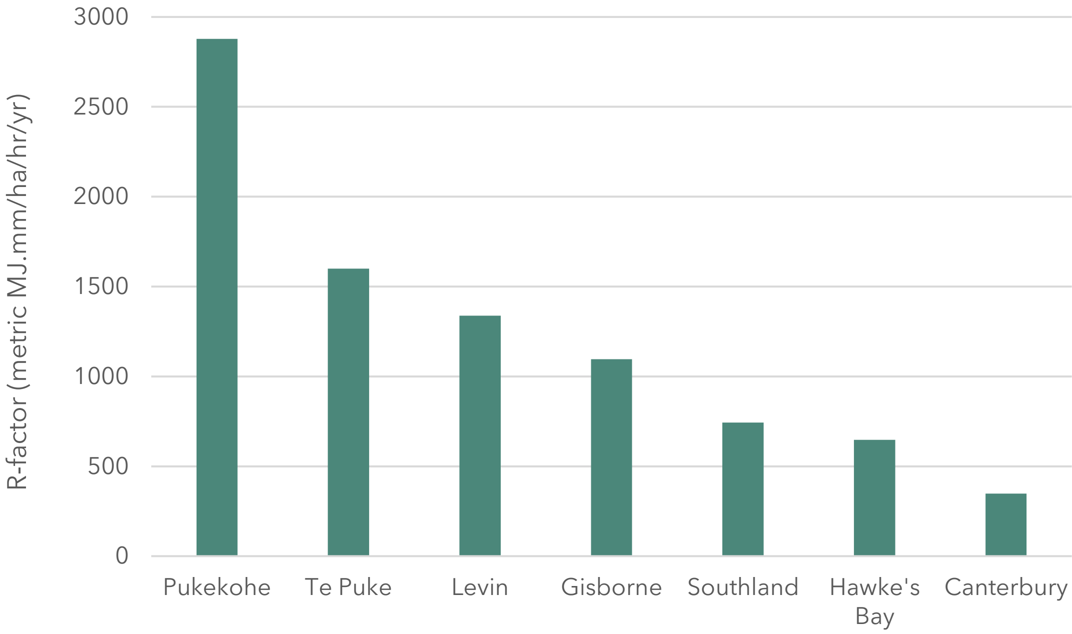


Figure 3. Erosivity across seven growing centers/regions.

6. Soil type

The third main driver of soil erosion is soil type, which influences how easily soil particles can be detached, transported, and deposited by rainfall and surface runoff. In the Universal Soil Loss Equation (USLE), this is captured by the K factor, or soil erodibility factor. Soil erodibility is shown across twelve soil textures (Figure 4). Fine particles (like silt) are highly erodible because they are easily detached by raindrop impact and are light enough to be carried away by water. At the other end of the spectrum, sandy soils both resist detachment and have high permeability, resulting in low run-off.

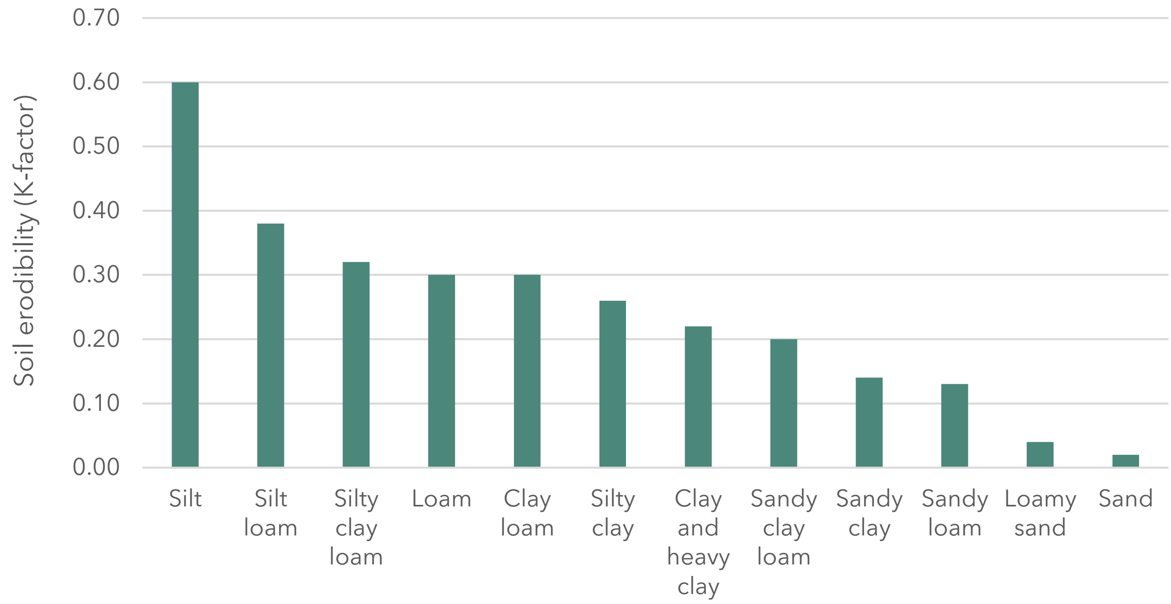


Figure 4. Soil erodibility.

7. 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. Zhang et al. (2010) used existing study data 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:

$\leq 10\%$ *(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% (6^0) 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).

The model in Zhang et al. (2010) was 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 '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.

8. 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 phosphorus removal by buffers ranged from 49-95% dependent on width and slope (Dillaha et al., 1989). As most phosphorus in agricultural soils is attached to soil as particulate phosphorus removal of sediment will generally also remove bound phosphorus. Increased infiltration will also help reduce levels of dissolved reactive phosphorus (DRP), the soluble phosphorus present in runoff water.

The Zhang et al. (2010) review modelled phosphorus 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% / 6^0) 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.

9. 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:

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

While the focus of buffer strip implementation on horticultural land is for sediment control, practices that increase the efficacy of buffers for sediment removal also reduce nutrient and pesticide loads on the receiving environment. Additional benefits such as these further support the installation and use of buffer strips.

10. Factors affecting buffer strip efficiency

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. Dillaha et al. (1989) concluded that "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" (p. 519). Several key factors affecting buffer strip efficiency are outlined below.

8.1 Location of trafficked headlands

Trafficked headlands need to be between the cultivated block and the vegetated buffer strip. This is essential to prevent vehicles from driving across the buffer, causing both compaction and channelised flow. Figure 5 provides an example of how this might occur.

Figure 5. Driving through the buffer strip can cause channelised flow.

Figures 6 and 7 show the before and after of a vegetated buffer strip installation on a cropped block, Figure 7 showing how the trafficked headland has been moved, to avoid compromising the buffer strip and risking channelised flow.

Figure 6. Cropping block before buffer strip installed. Photograph taken in November 2015.

Figure 7. Established buffer strip in September 2019. The trafficked headland has been moved into the cropped block, so no vehicles pass over the buffer. Not visible in this photo, but baffles have also been added to the drain.

8.2 Elevating block accessways

Accessways below a buffer strip are a potential weak point (Figure 8). Consideration should be given to moving the accessway to a more elevated part of the block, therefore avoiding passing through the buffer. If this cannot be achieved, then the accessway needs raising and contouring to avoid concentrated flows outflanking the buffer.

Figure 8. Buffer strip compromised by accessway running through the buffer.

8.3 Preventing channelisation

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).

They found that "concentrated flow through riparian buffers was common and substantial", with the concentration of these flows usually occurring before entry into riparian buffers (Dosskey et al., 2002, p. 339). The study's conclusion that "sediment-trapping efficiency of riparian buffers based on gross buffer area may greatly overestimate actual performance" (p. 341) 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 Dosskey et al. (2002) 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 so observations for maintenance purposes would be made easier during heavy rainfall events.

Furthermore, Yuan et al. (2009) noted that strips composed of stiff, tall, perennial grasses are more resistant to inundation by channelised flow and could offer an advantage over standard grass. Other studies have compared the efficacy of buffer strips made of woody vegetation, shrubs, and grass, suggesting vegetation with deep rooting systems may be more effective at trapping sediment (Nsenga et al., 2024). Figure 9 illustrates the range in rooting system size between North American grass species. However, while most buffers in horticultural operations are composed mostly of grass, it could be worth considering different vegetation types, to potentially increase the effectiveness of nutrient removal (Zhang et al., 2010).

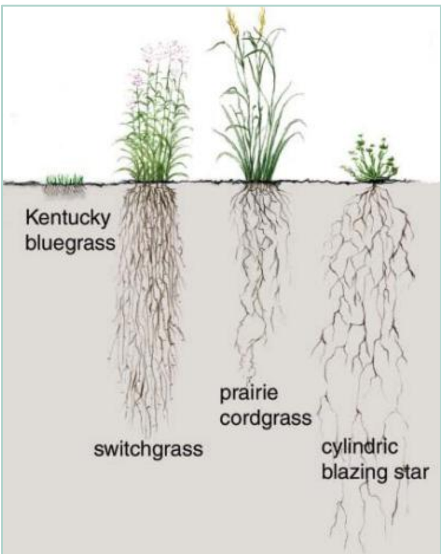


Figure 9. A depiction of different grass species rooting systems. Deeper roots encourage more infiltration and should be a consideration when choosing vegetation species for a vegetated buffer (Minnesota Department of Natural Resources, 2007).

11. 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 (Minnesota Department of Natural Resources, 2007). 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 blocks (Haddaway et al., 2018). 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) (Zhang et al., 2010). Ultimately, the effects on local biodiversity are extremely variable and dependent on location, local ecology, and vegetation species within the buffer strip. However, it is commonly accepted that in most cases buffer strips will have some positive impact on biodiversity.

12. Development of the Erosion Risk Assessment

The Erosion Risk Assessment in the Erosion and Sediment Control Code of Practice (also provided in Appendix A of this document) provides a pathway for growers to assess the inherent or baseline erosion and sediment loss risk of their blocks. Risk is assessed at four levels: very low, green, amber, and red. The risk assessment was developed based on modelling 10,000 randomly generated scenarios, varying soil type, slope angle and length, and region, through the Don't Muddy the Water (DMTW) erosion rate calculator web-app. While the risk assessment (Appendix A) provides a good high-level guide, the DMTW web-app will provide a more accurate estimate of sediment loss at a specific location. It can also be used to better estimate unmitigated sediment loss and can model the impact of different mitigation practices.

Using the slope classes described in Land Use Capability Survey Handbook (Table 1) and sediment loss modelling and analysis, the low, medium and high unmitigated sediment risk categories (based on erosion rate) were set at:

- Green risk: < 2 t/ha/year
- Amber risk: 2 – 7 t/ha/year
- Red risk: >7 t/ha/year

A Very Low category was created during the 2026 review of the Erosion and Sediment Control Code of Practice to direct growers that did not cultivate and or had less than 25% of the ground bare (i.e. permanent horticulture) to a set of suitable practices.

Table 1. Commonly recognised critical slopes for specified activities. Sourced from the Land Use Capability Survey Handbook (Lynn et al., 2009).

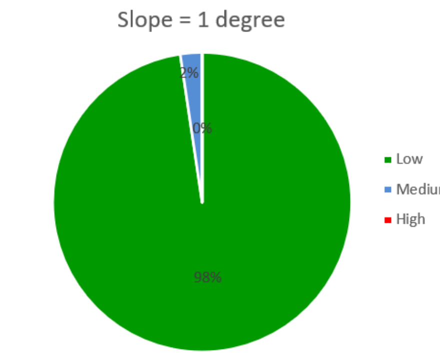
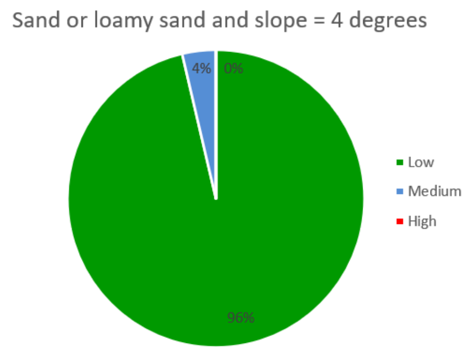
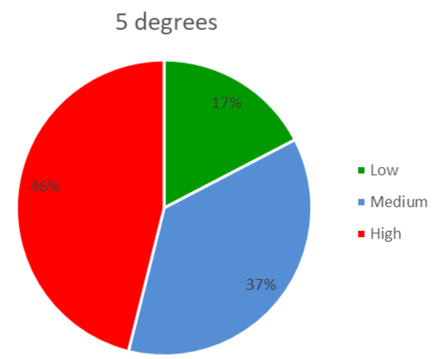
Slope group	Slope group (degrees)	Activities
A	0 - 3	Free ploughing and cultivation (1^0)
B	4 - 7	Soil erosion begins to be a problem (>3^0) Some heavy agricultural machinery restricted (6^0) Difficulties with weeders, precision seeders and some root crop harvesters (3-7^0)
C	8 - 15	Additional front 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) (12^0) 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-tyre skidders (18-20^0)
E	21 - 25	Difficult to plough, lime and fertilise, higher cultivation costs, normal rotations impossible (>20^0) Occasional tillage for pasture improvement (20-25^0)
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 Erosion Risk Assessment (Appendix A) was developed, in part, based on the following results in Table 2.

Table 2: Modelling results from scenarios run through the DMTW web-app to develop the erosion risk assessment in the Erosion and Sediment Control Code of Practice.

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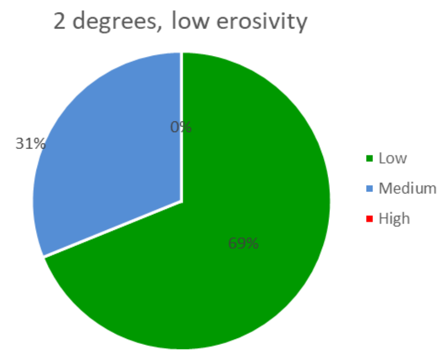
<tr><td>Rainfall intensity and soil erosivity varies around the country. In cropping areas this varies from a high in Pukekohe to a low in Canterbury. Based on NIWA modelling the lowest erosivity regions are Canterbury, Hawke's Bay, and Southland. These low erosivity areas (<1,000 MJ.mm.ha^{-1}.h^{-1})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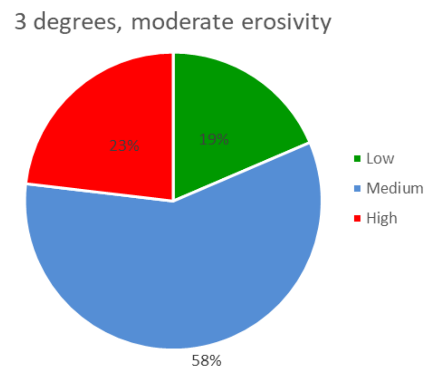
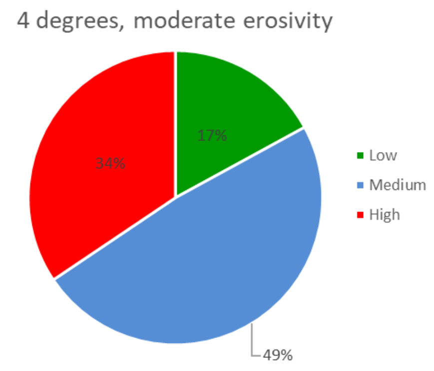
</table>

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.

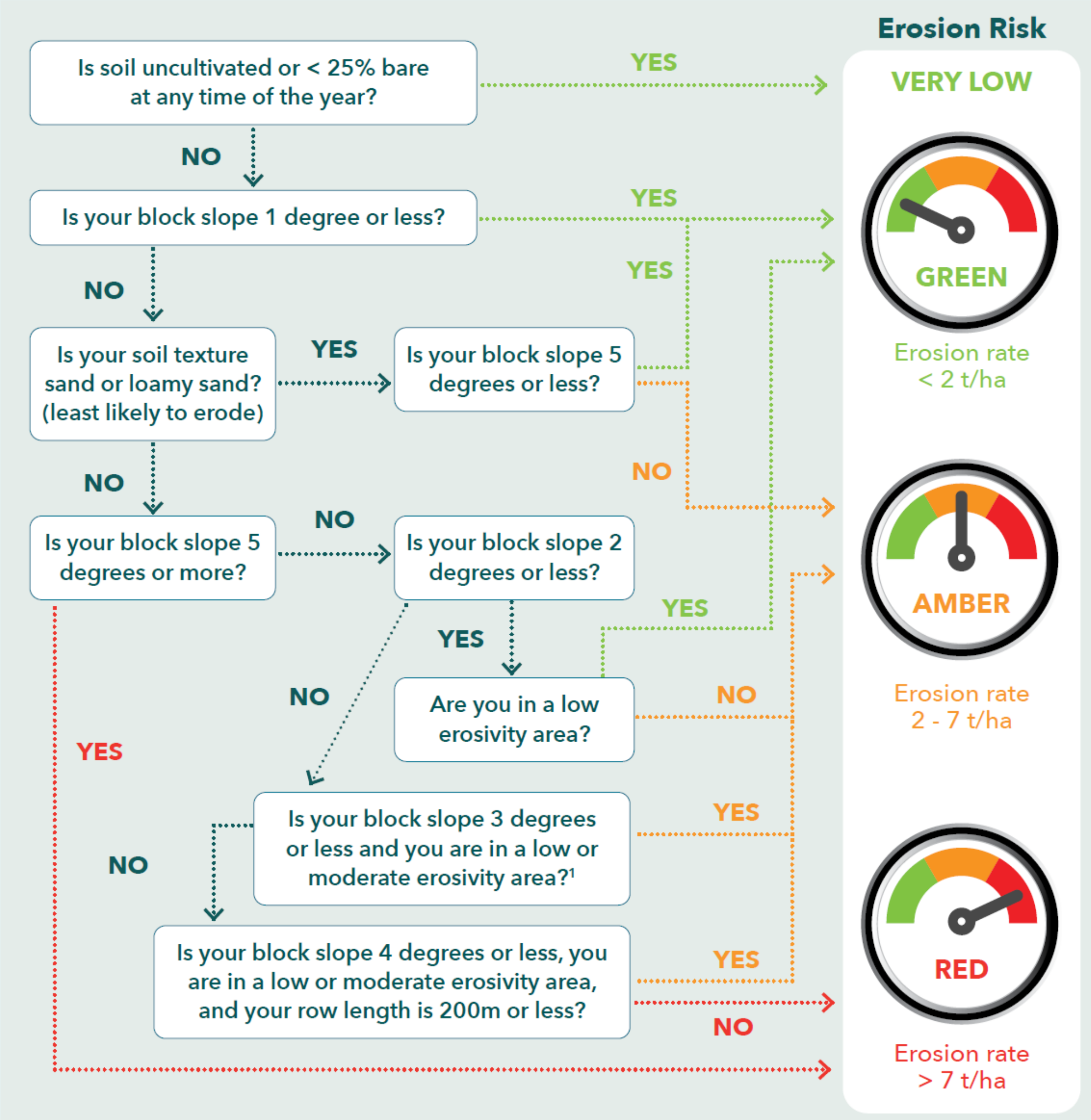


Where the area had an erosivity of low or moderate (<1500 $MJ.mm.ha^{-1}.h^{-1}$), a slope of 4 degrees, and short row lengths of less than 200 m then 66% of the scenarios were classified as a low or medium risk. Average unmitigated sediment loss was 5.9 t/ha. This falls into the medium risk category.



Appendix A: Erosion risk assessment

The Erosion and Sediment Control Code of Practice (COP) contains an erosion risk assessment for growers to assess their risk of erosion at a block level, available on page 10 of the COP. This diagram is followed by an erosion control decision tree to guide growers to practices they should implement.



Appendix B: Gallery

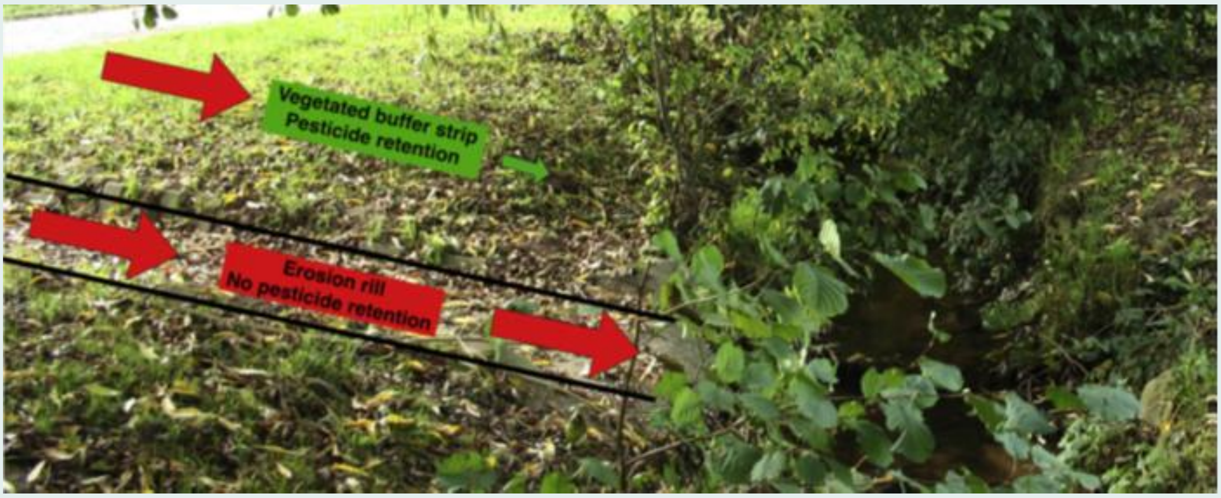


Figure 10. Channelisation bypassing buffer strips and its effects on pesticide retention (Stehle et al., 2015).

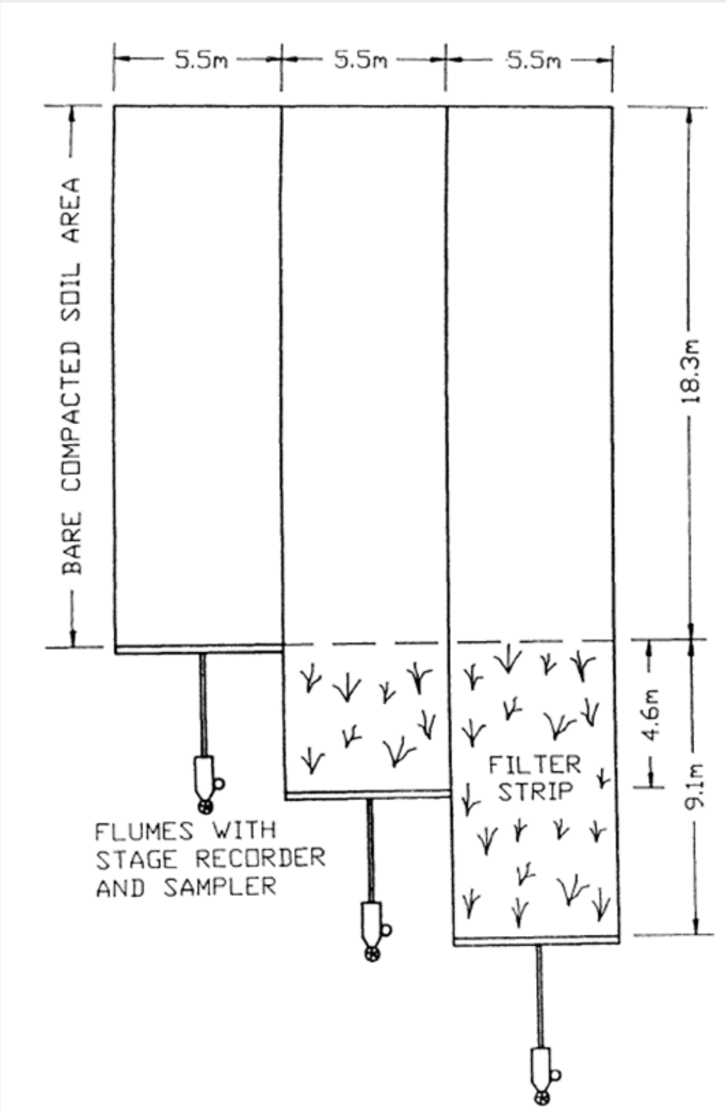


Figure 11. An example of an experimental buffer strip trial setup (Dillaha et al., 1989).

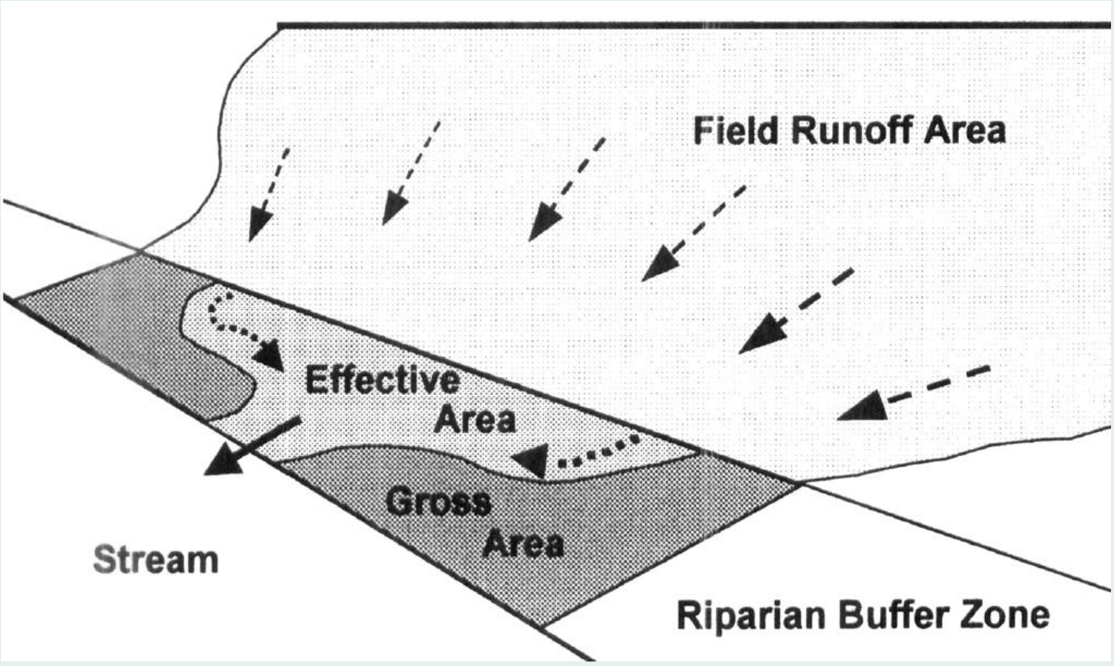


Figure 12. Depiction of channelisation through a riparian buffer (Dosskey et al., 2002).

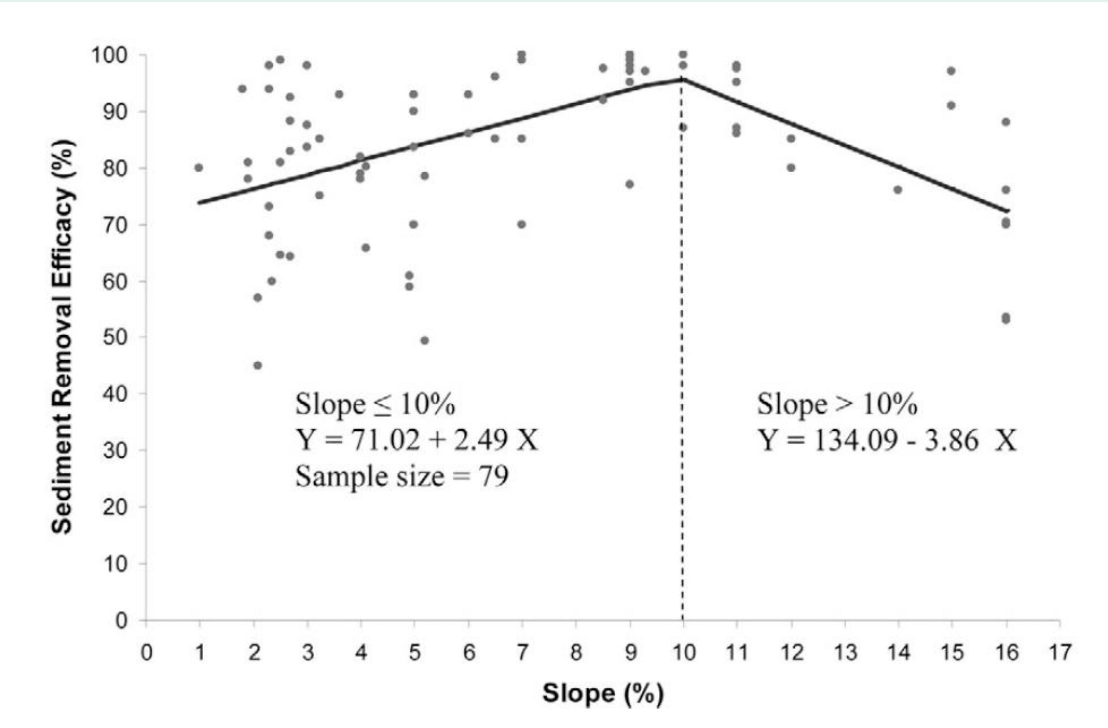


Figure 13. Correlation of buffer sediment removal efficiency and slope based on a literature review of multiple studies (Zhang et al., 2010).

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