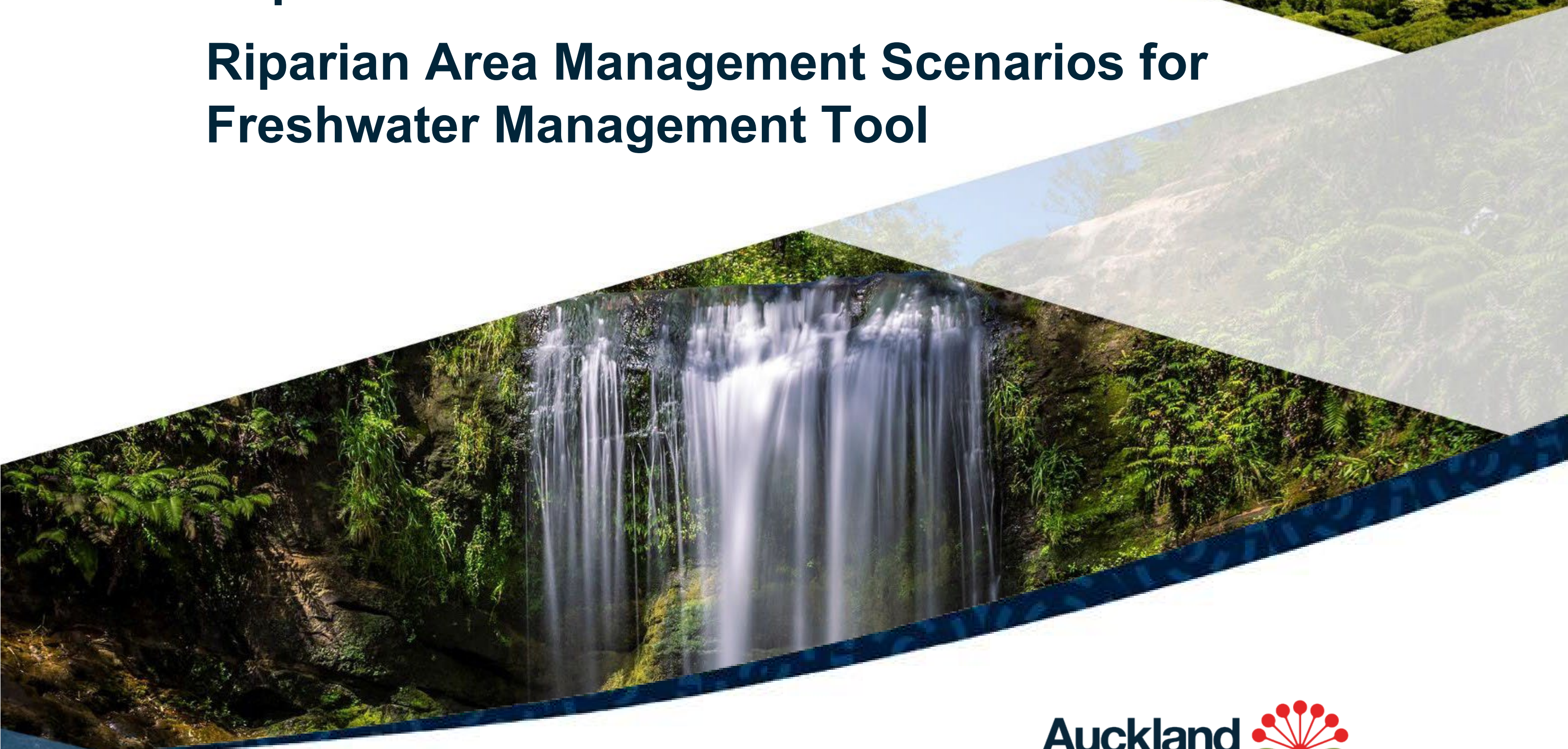
Freshwater Management Tool

August 2021 FWMT Report 2021/7

Report 7

Riparian Area Management Scenarios for Freshwater Management Tool



Auckland Council
Te Kaunihera o Tāmaki Makaurau

Freshwater Management Tool:
Report 7. Riparian Area Management Scenarios Freshwater Management Tool

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Executive Summary

Auckland Council (AC) has requested that as part of their ongoing development of their Fresh Water Management Tool (FWMT) Stage 1, a three-phased approach is pursued to support rural costs and benefits of mitigations being assigned logical conditions for cost-optimisation. In the first step, rural literature was reviewed by Muller et al. (2020) with the aim to provide initial estimates of mitigation options, cost and effectiveness. In the second phase, further examination is given to incorporating both further mitigations (e.g. especially for sediment and pathogens) as well as tailoring mitigations to the Auckland region and modelling requirements, whilst recognizing for the sectoral and contaminant, uncertainty of mitigations (see Muller et al., 2020). This report is an extension to the Stage 1 output (Muller et al., 2020) and intended to provide more refined estimates on riparian management (both planting and fencing) mitigations, including both cost and effectiveness estimates.

The purpose of this document is twofold, first to provide initial estimates of costs and benefits for rural riparian management options for inclusion in Stage 1 of the FWMT, and second to stimulate discussion on where these costs and benefits need to be improved as part of further modelling within the FWMT. This improvement could be undertaken through input from the rural sector, expert caucusing, field trials, additional evidence being provided and evidence and input from other stakeholders. It is not an isolated piece of work, but a part of the broader FWMT development process and as such should be read in conjunction with the other ongoing technical work being undertaken by AC.

The build of the AC FWMT is a continuous improvement process. Further builds will add complexity as necessary to better represent land use effects on water quality. A key principle of the FWMT's continuous development is that, where possible, defensible simplicity is adopted first.

The FWMT Stage 1 is already a relatively complex model build for freshwater contaminant accounting, including 66 rural land types (hydrologic response units – HRU) spanning pastoral and horticultural activities in the Auckland region (e.g., stratified on differing slope, soil, cover and intensity classes).

Similarly, the FWMT is being developed, not simply to assess spread in modern-day or baseline (2013-2017) water quality, but also to identify cost-optimised strategies to drive improved water quality and/or maintain water quality in the face of increasing pressures (e.g., development, intensification of productivity and/or climate change). For that purpose, pastoral and horticultural HRUs in particular, require a library of mitigation options to be developed, either targeted at, or across groups of, HRUs. Current state assessments in the FWMT Stage 1 have demonstrated that both pastoral and horticultural land activities are associated with disproportionate and often majorities of key contaminants (TN, TP, *E.coli*, TSS) (Bambic et al., in prep).

Development of a mitigation option requires three fundamental logical conditions:

1. Cost – the reduction in profit (including ongoing maintenance costs), necessary capital outlay associated with a 50-year life cycle of managing a mitigation option;
2. Effect (direct benefit) – the reduction in contaminant(s) associated with a mitigation option;
3. Opportunity – for which HRU's and contaminant(s) a mitigation option is effective.

Riparian management is a mitigation applied to both pastoral and horticultural HRUs. It includes both the fencing and subsequent retiring riparian margins and planting (revegetation) options. Other mitigations will be subsequently refined but a further consideration of riparian management logical

conditions from that considered in Muller et al (2020) was prioritized and will enable a rural catchment pilot of the cost-effect optimisation within the FWMT (i.e., for later regionalization).

Following a literature review, Perrin Ag Consultants Ltd (Perrin Ag) propose riparian management options are incorporated into the FWMT Stage 1 based on variations of four key variables: fencing, slope, buffer width and planting. Within each of these variables a set of ‘sub-categories’ are proposed for inclusion in the FWMT Stage 1 build described by **Figure *1***. The variables affecting design of riparian management options also enable alignment with factors discriminating HRUs (e.g., varying costs, effect and/or opportunity with slope, cover or intensity of production). For example, omitting fencing costs and effects from horticulture but including fencing in all riparian options for pastoral HRUs.

Fencing	Slope	Buffer width	Planting
• No fence • 2-wire electric • 4-wire electric • 8-wire non-electric post and batten	• Flat & rolling • Steep (only applicable to 4 & 8-wire fencing)	• 1 metre (fence only proxy) • 3 metres • 5 metres • 10 metres	• Riparian planting • Rank grass

Figure 1: Scenario variables FWMT- Stage 1

This report is structured as follows; Section 1 provides background information, including details of the scope and key assumptions made in this report. Section 2 explains what needs to be considered when including riparian management scenarios in a cost benefit analysis. Sections 3 and 4 provide detailed literature reviews of the benefits and costs of rural riparian management, respectively. Sections 5 and 6 identify “reasonably assured” cost and benefit information to include in the model (e.g., information of assured [peer-reviewed, published or reported by research agencies] and reasoned into a general measure of). Section 7 takes the suggested cost and benefit information and ensures it is provide at the same resolution for comparable scenarios and provides recommendations as to the input data for riparian management for the FWMT Stage 1. Finally, Section 8 provides key areas for further refinement to support the FWMT Stage 1 application to Auckland.

Contents

1. Background

Undertaking a cost benefit analysis for riparian management requires clear scenario boundary conditions to be defined. For example, if riparian management includes stock exclusion, the costs should include fencing and the benefits should include loss of direct access. If riparian management also includes revegetation, then costs and benefits should account also for the form and density of planting and the width of riparian area. Having clear definitions of scenario boundary conditions will enable variants of riparian management to be considered in a scenario (e.g., varying actions, costs and benefits between HRUs). The granularity and detail included in these scenarios at this stage is largely determined by the level of detail available in previous literature.

Muller et al. (2020) provided a literature review of rural mitigations options for reducing contaminants to fresh water, including riparian area management, for inclusion in stage 1 of the FWMT. The literature review focused on cost and benefit of mitigations – here benefit means the effect or reduction in total contaminant via surface and subsurface flow from a rural activity. This follow on report delves into more detailed scenarios of rural riparian management costs and benefits, including seeking industry feedback and detailing areas of further refinement in future FWMT versions.

Muller et al. (2020) found that there is limited consistent and Auckland-based information on benefits derived from riparian management for pastoral and horticultural farms. However, there is more evidence related to the cost of riparian management, albeit varying by component of fencing, planting and opportunity cost. Studies to date have also attempted only one, or a few, options for riparian management with little cumulative or discrete component costing from which to build riparian management cost and benefit data for some integrated practice (e.g., for varying setback across varying farm systems, soil, slope and climate). There is also a lack of consistency in how key variable have been treated across studies.

In this exercise we review cost and benefit data from various studies, before attempting to define boundary conditions for riparian management scenarios and then note the various considerations their application in the FWMT will require. For example, considerations on how to vary riparian management conditions for stream order, slope or land use intensity.

1.1. Scope & key assumptions

This report informs use of the FWMT Stage 1 and hence aligns assured riparian area management evidence to the HRU framework that underpins the water quality model. HRU classes and groups are not all well aligned to the costing literature, whilst the benefits literature is particularly coarse. Combined this requires assumptions on linking HRU classes to cost literature and limited granularity for assigning benefits (e.g., across multiple HRU classes into coarser groupings). Both such assumptions are summarised in **Table *1***.

Notably, pastoral land uses of more than 10SU/ha were distinguished into dairy or sheep and beef groups given both, their markedly differing cost profiles (e.g., operating profit, mitigation outlay) and contaminant benefit profiles (e.g., varying contaminant reduction effects of equivalent interventions). The need to do so, reflects a high likelihood that sheep and beef farms of more than 10SU/ha exist in the North Island. For instance, Beef+LambNZ Economic Farm Survey noting that intensive finishing farms in the Northern North Island possessed an average SU/ha of 12.6 (2018-19) (Beef+LambNZ, 2020).

Whilst Low impact horticulture (idle, orchards and fallow) was included in Muller et al. (2020), that was predicated on kiwifruit returns. Auckland Council has since indicated that kiwifruit orchards are accounted for within the High Impact Horticulture HRU. High Impact Horticulture in Muller et al. (2020) and this report are both based on vegetables, for which there is more publicly available, assured evidence on contaminant losses, mitigation cost and mitigation effectiveness than orcharding. There is a lack of assured information for idle land, fallow land and "other" orchards (e.g., any such remaining outside of berry fruit, stone fruit, pip fruit, kiwifruit, other fruit and nuts – accounted for in Medium and High Impact Horticulture). To ensure the Low Impact Horticulture is included within decision-making on interventions, required assigning the HRU costs and benefits of interventions from Medium Impact Horticulture. Doing so likely inflates such costs (e.g., carries greater opportunity cost) and possibly results in greater or lesser benefit (e.g., as based on other horticultural opportunities). However, the decision is likely to have marginal effect on scenario optimisation as Low Impact Horticulture accounts for <1% of any watershed area and also, <1% of edge-of-stream contaminant loads for all six contaminants simulated by the FWMT (see Bambic et al., 2020b).

In addition, Medium and High Impact Horticulture groupings are assigned mitigation estimates from limited assured evidence (e.g., arable information for Medium; vegetable growing for High). Doing so, whilst necessary if limiting evidence to the wider assured literature, fails to acknowledge various horticultural activities within each grouping might have widely varying profitability and contaminant cost or benefit. In addition, some mitigation options may not be applicable across all horticulture activity within an intensity grouping. For example, the applicability of vegetated buffer strips for tree crop orchards is likely to be much lower than on vegetable cropping (i.e., given lower presence of bare ground).

Whilst the FWMT Stage 1 is the first of several FWMT iterations, required to otherwise generalise and simplify complex contaminant mitigation options, it is strongly recommended that further development of the FWMT revisit the HRU framework to enable more robust, finger grained accounting. Potentially, with industry partners to support shared implementation uses for the FWMT (e.g., accounting for sustainable farming transitions). Included in that recommendation is further refinement of pastoral and horticultural classes (e.g., consideration of discretely representing deer farming operations whose mitigation costs and benefits can differ widely from other pastoral sectors).

Table 1: HRU groupings

Land cover	Original	Revised
	Intensity grouping	Intensity grouping
Pastoral	Less than 10SU/ha	Less than 10SU/ha (assumed to be sheep and beef farms)
	More than 10SU/ha	Sheep and Beef - More than 10SU/ha
		Dairy - More than 10SU/ha
Horticulture	Low Impact Horticulture – Orchards, idle & fallow	Medium Impact Horticulture – Arable, citrus, fodder, nuts & viticulture (Includes Low Impact Horticulture – Orchards, idle & fallow, and is based on an arable farm model)
	Medium Impact Horticulture – Arable, citrus, fodder, nuts & viticulture	
	High Impact Horticulture – Berryfruit, flowers, stonefruit, kiwifruit, nursery, pipfruit, fruit, vegetables & greenhouses	High Impact Horticulture – Berryfruit, flowers, stonefruit, kiwifruit, nursery, pipfruit, fruit, vegetables & greenhouses (based on a vegetable farm model)

This report does not consider the "opportunity" for riparian management scenarios (e.g., how many kilometres of fencing is possible across HRU's). Instead it presents the base costing and benefit information to scale any such mitigation scenario within the FWMT. The report does not also address whether scaling is linear or interactive (e.g., that effects are additive or some product when scaled to larger catchments). The latter is an important consideration for which no robust catchment-scale riparian studies yet exist in New Zealand (i.e., "dairy best catchment" studies attempted this exercise but without accounting for wider upstream and on-farm changes, preventing any meaningful assessment of the wider interactive or cumulative effects from riparian management on water quality [see Monaghan et al., 2009]).

An absence of robust assured evidence on the current baseline of riparian management adoption requires careful consideration in use of the FWMT Stage 1 (e.g., lack of audited, extensive information on degree of fencing, setback distance, planting, slope, soil types and management of riparian areas for Auckland region). The issue of scaling should be considered alongside the absence of key data on some riparian management options as priorities for future FWMT development.

Key riparian management caveats for the FWMT Stage 1, reflecting both a push for simplicity and the dearth of detailed information, include:

1. Applying benefits consistently across time and weather considerations – the FWMT continuously predicts hydrological and contaminant processes, meaning mitigation efficacy can be varied with flow rate. However, an absence of continuous monitoring for riparian benefits over varying climatic conditions prevents any such recommendations here.
2. Excluding bankside erosional benefits – there are very few quantitative studies of bank erosional change following riparian management. In the most recent review Hughes (2016) highlighted as much before identifying the challenges this presents in estimating the effects on stock exclusion and/or planting effects on mechanical erosion rate. Equally, numerous studies in Auckland have demonstrated that bankside erosion is principally driven by flow-driven hydraulic and mechanical erosion with lesser likelihood of improvement through stock exclusion alone (Simon et al., 2015, 2016 – also see Wilcock et al., 2013 where between 4-11% change in total suspended solids was "linked" to removal of cattle from riparian areas though without determining how such effects were also influenced by wider on-farm changes in grazing practices and riparian setbacks). Bankside erosional changes in contaminant generation will be estimated separately from but on basis of assumptions about, riparian management (e.g., directly in LSPC [Load Simulation Programme] and/or via an alternative approach). Caution will need to be exercised in configuring changes to bankside erosion from riparian mitigation options in the FWMT Stage 1, to minimise risks of double-accounting.
3. Applying benefits universally across New Zealand – the dearth of quantitative studies, and an almost entire absence of causative relationships between benefits and neighbouring soil, topography, slope and climate requires simple application of findings to the Auckland region even if variation is expected (see Collier et al., 1995).
4. Benefits considered relate to four key contaminants, nitrogen, phosphorus, sediment and *E. coli.* Other benefits are notable but otherwise excluded from this report as do no relate to water contaminant generation or attenuation (e.g., carbon sequestration, amenity, biodiversity, cultural health values). Those additional (non-contaminant) riparian benefits are important to broader waterway management decision-making but also suffer from limited assured evidence – especially, compared to the wider literature on water quality outcomes from riparian management.

5. While costs are considered over 50 years, there are limitations on how benefits are considered over time. For example, benefits are not phased over time and do not capture potential negative impacts on contaminants in the short term (e.g. if major earthworks were required for creating fence lines). Similarly, capital costs are likely to be incurred stochastically over time but otherwise represented as idealised outlay, continued maintenance and corrective maintenance costs here.

It is acknowledged that there are significant gaps in the benefit estimates presented for use in Sections 6 and 7 given the limitations in the literature available. However, rather than provide an estimate based on best professional judgement at this stage it is suggested that these research gaps are noted and a work plan is designed to address these based on further science and/or expert caucusing as appropriate. This is a key area for further work for future stages and versions of the FWMT.

Models are a simplification of reality, and therefore in addition to the scope limitations and key assumptions outlined above, it should be noted that not all cost and benefit combinations are considered in this report. For example, while in reality, planting costs may vary in density, or densities and plant costs may differ in relation to position on the stream bank, not all cost combinations can be considered here or within the FWMT model. Ongoing FWMT development should consider the need for future sensitivity analysis (e.g., planting density). However, every attempt has been made to provide the reasonably assured mitigation estimates for riparian management here, including appropriately restricting mitigation granularity to HRU groupings.

Lastly, whilst the literature has been extensively described, numerous studies fail to report factors affecting cost and benefit estimates (e.g., plant or fencing types, planting density, soil types, slope, setback distance). All relevant details as reported are reproduced here.

2. Scenario considerations

Riparian management covers the range of actions associated with livestock exclusion, revegetation and ongoing maintenance of areas adjacent to fresh waterways, for the protection of water quality (e.g., reduction in contaminant generation, increased contaminant interception and modification of near and instream processes to reduce contaminant effect) (see Collier et al., 1995). The scope of reporting here, as mentioned in Section 1.1, is restricted to contaminant generation and attenuation effects of riparian management on nutrients (nitrogen, phosphorus), sediment and faecal indicator bacteria (*E.coli*).

All scenarios require assumptions for simplification and to ensure the limitations of existing evidence are respected. These are clarified here to ensure limitations of future FWMT modelling can be determined. For example, what plant spacing has been assumed in vegetation costs and benefits or whether the costs account for access (gates) when estimating fencing costs Some of these considerations can also be considered in sensitivity analyses or at a basic level, in assigning "low", "moderate" and "high" cost estimates for actions. Low costs could be assumed be applicable to actions on relatively accessible and more rapidly fenced land (e.g. lowland) and high costs to more inaccessible and challenging land to fence (steep land); equally, low costs could apply to fencing types with fewer materials (e.g. two wire fences) while high costs could apply to eight wire fences)

There is a balance that needs to be struck between granularity of scenarios considered and the evidence base for riparian costs and benefits. For example, while it might be robust to price out the costs based on a particular plant spacing requirement, there may not be equal information on how benefits differ for different planting densities.

Key considerations when describing riparian area management scenarios:

- Is the riparian area fenced?
- If it is fenced, what stock is being excluded?
- What is the slope?
- If it is fenced, does the fence prevent stock that previously used the waterway as a drinking water source from accessing it, and if so what type of stock water reticulation system is required?
- What distance is the fence set back from the stream (buffer width)?
- Is it planted?
- If it is planted, is the whole buffer width planted (if not, what width is)?
- If it is planted, what type of plants are used (e.g. size, type, native versus non-native)?
- If it is planted, is there a desired plant spacing (this can also be assumed based on plant type)?
- Was the land that was included in the buffer width productive (or not)?
- If it was productive land, what was its relative productivity?
- If it was productive land, has the associated farm system changed (or intensified marginally on remaining area to compensate for lost area)?
- What was the land type that was removed for the buffer width (which drives underlying profitability)?
- What is the expected life of the fencing?
- Is maintenance (for fencing and planting if applicable) constant, or does it change over time?

The FWMT Stage 1 has a guiding principle for its continuous improvement - that simplification is adopted first and only modified for more complexity if required and supported by evidence. While it may be desirable to include many cost options, if the benefits are unable to be differentiated robustly, or included in the model then it may be more appropriate to reduce the granularity of cost variation.

3. Benefit analysis

The riparian management literature in New Zealand and overseas is inconsistent in study design for addressing similar questions of effect on contaminant generation, interception and/or processes modifying contaminant effect instream. Three large-scale reviews have been conducted in New Zealand: two for the Department of Conservation (Collier et al., 1995; Rutherford et al., 1999) and one for the Ministry for Agriculture and Forestry (Parkyn, 2004). All three highlight the same finding that studies are generally limited to local-scale trials of short duration (12 months or less) and focussed on contaminant concentration or mass. Seldom both, seldom numerous forms, or processes response for apparent changes. The most recent assessment of the literature in McKergow et al (2016) also highlights that many findings are likely to be site-specific with no catchment-scale riparian research conducted in New Zealand. Equally, in that absence it is as yet unclear if wider findings are highly site specific or readily transferable between regions (i.e., for variation in soil types, climate, farm systems and riparian topography – all of which are key factors varying effect on contaminant generation and interception).

This section presents a thorough overview of riparian management benefits reported in the literature. While some of the studies discussed in this section are the benefit equivalent to the cost section below, this is not always the case with some studies considering benefits or costs but not both.

The earliest and most exhaustive review of riparian effects is that of Collier et al (1995). The latter identified several factors affect riparian management benefits. Namely, whether flow paths are diffuse or channelised, particle size and adsorption to sediment, soil drainage, slope length and near-stream topography as well as vegetation type. All interact to generate altered infiltration, deposition and sorption rates for a range of contaminants.

A meta-analysis by Zhang et al (2010) found that the width of the riparian area alone accounted for 37%, 44% and 35% of the variance in removal efficacy for sediment, N & P respectively. They also found that the impacts of vegetation type on removal efficacy were statistically significant while soil drainage type was not. However, it must be noted that Zhang et al (2010) is not a New Zealand based study, and most of the literature reviewed considered N losses in overland flow or run-off, which in New Zealand pastoral systems is unlikely to be the primary pathway of non-point-source N loss to water (with leaching through the rootzone the primary loss pathway for N in New Zealand pastoral systems, Ledgard and Menneer, 2007). **Table *2*** summarises the predicted removal efficiency from N, P and sediment from Zhang et al (2010).

A more recent meta-analysis by Sweeney and Newbold (2014) suggests that the reported efficacies in Zhang et al. (2010) (and contributing reviews by Liu et al. [2008] and Yuan et al. [2009]) are likely optimistic of sediment attenuation by riparian buffers. Sweeney and Newbold (2014) reported sediment removal efficiencies of approximately 20-40% less than Zhang et al. (2010), with limited difference between planted or grassed margins. For instance, that a five metre grassed buffer yields a 46% reduction in total suspended solids transported by overland flow (with insignificant change whether planted). Alternatively, that a 5.4 metre buffer is required to halve suspended sediment concentration in runoff. Like earlier and subsequent reviews here, Sweeney and Newbold (2014) stress performance estimates assume uniformly-distributed (non-channelised) overland flows (e.g., performance would be less for areas of paddock with ephemeral flow paths).

Table 2: Zhang et al (2010) benefit estimates for sediment, N and P for a range of buffer scenarios varied by width, vegetation and slope (adapted from Table 3)

Contaminant	Scenario	Predicted removal efficiency (%) by buffer width			
		5m	**10m**	**20m**	**30m**
Sediment	Slope 5% Mixed grass & trees	67	76	78	78
	Slope 5% Grass/trees only	82	91	93	93
	Slope 10% Mixed grass & trees	77	86	88	88
	Slope 10% Grass/trees only	92	100	100	100
	Slope 15% Mixed grass & trees	58	67	68	68
	Slope 15% Grass/trees only	73	81	83	83
Nitrogen	Mixed grass and trees/grass only	49	71	91	98
	Trees only	63	85	100	100
Phosphorus	Mixed grass and trees/grass only	51	69	97	100
	Trees only	80	98	100	100

Doole (2015) provides a robust summary of the riparian literature for New Zealand regulatory purposes, which also suggested that the width of the buffer does have an impact on the extent of N loss reduction (inclusive of Zhang et al [2010] and Sweeney and Newbold [2014]). However, whether this was due to a greater interception area or a reduction in pastoral area (with a commensurate reduction in stocking rate and loading to streams) is unclear. The benefit estimates cover a range of scenarios and are summarised in **Table *3*** for N, P and sediment.

Table 3: Doole (2015) benefit estimates for N, P and sediment for a range of buffer scenarios and sources (adapted from Table 1, pages 4-6)

Scenario	Percentage reduction (%)			Source
	N	P	Sediment	
Fence out all stock	-	-	80	Palmer et al. (2013)
Fence out cattle only	-	-	30-90	McKergow et al. (2007)
Fence buffer 20 m	Additional 10–20% of mitigation achieved for fencing cattle out	Additional 15–30% of mitigation achieved for fencing cattle out	50-100	McKergow et al. (2007)
Fence out cattle only	7	10	40	Monaghan and Quinn (2010)
Fence out cattle and plant poplars	10	15	55	Monaghan and Quinn (2010)
Fence out all stock	15	15	50	Monaghan and Quinn (2010)
Fence out dairy cattle only	20	40	-	Monaghan et al. (2010)
Fence out all stock	10	30	-	Monaghan et al. (2010)
Fence out cattle only	18	39	60	Semadeni-Davies & Elliott (2012)
Fence out all stock	-	-	8	Daigneault (2015)
Fence out all stock	-	10-30	-	McDowell (2010)
Fence out all stock	23	24	24	Semadeni-Davies & Elliott (2012)
Grass buffer strips on free-draining soil	-	0-20	-	McDowell (2010)
Vegetated buffer strips	-	37-60	-	McDowell (2010)
Fence out all cattle	-	10-30	-	McDowell & Nash (2012)
Fence out all stock	-	55-60	20-25	McDowell et al. (2013)
Grass buffer strips	-	29-37	-	McDowell (2014)
Fence out all stock & 5m planted buffer	50	49	-	Zhang et al. (2010)
Fence out all stock & 10m planted buffer	73	71	-	Zhang et al. (2010)
Fence out all stock & 15m planted buffer	84	81	-	Zhang et al. (2010)
Fence out all stock & 5m planted buffer	9	-	46	Sweeney & Newbold (2014)
Fence out all stock & 10m planted buffer	18	-	63	Sweeney & Newbold (2014)
Fence out all stock & 15m planted buffer	26	-	72	Sweeney & Newbold (2014)

In Doole (2015) fencing-only effects were deemed minimal on total N, with direct depositional sources being considerably less dominant than diffuse sources (e.g., McKergow et al., 2007). Doole (2015) assumed 5 metre pasture buffer strips generated reductions in total N of 15% and 5% for dairy and drystock farms, respectively. For phosphorus, Doole (2015) discusses the performance of riparian management being heavily reliant on livestock exclusion; limited effect being expected from 5 metre buffers on dissolved P but modest effect on total P. Combined, Doole (2015) concluded it was appropriate to use modest levels of reduction (10% and 5% for dairy and drystock farms, respectively) in estimated losses of total phosphorus assigned to both fencing and 5 metre buffers. Notably, Doole (2015) assigned further reductions in phosphorus loss to waterways from reduced bank erosion separately. Effectively bankside erosional changes assumed from livestock exclusion (independent of stream characteristics, buffer width or planting) were assigned for "sediment" at 40% and 50% for dairy and drystock streams (i.e., presumably to total suspended sediment). Doole (2015) is unclear about how reduced "sediment" from livestock exclusion drove reduced total P (e.g., fencing only or from fencing and buffers), but that a considerable proportion of total P lost from farming is particulate or bound to sediment. Combined, this meant riparian buffer (5-metre) and fencing effects on total P were not presented separately, but that reduced bankside erosion from riparian management would result in additional P-reduction to the 5-10% reduction in total P assigned to both fencing and 5 metre buffers.

In addition to the estimates of N, P and sediment, Doole (2015) also summarises literature estimates of *E. coli* reductions for a range of stock exclusion scenarios (e.g., fencing, independent of buffer setback). The literature review is summarised in **Table *4***.

Table 4: Doole (2015) benefit estimates for E. coli for a range of buffer scenarios and sources (adapted from page 9)

Reduction in E. coli delivery (%)	Land use	Source
20–35%	Cattle	McKergow et al. (2007)
40%	Cattle	Monaghan and Quinn (2010)
60%	Dairy and drystock	Monaghan and Quinn (2010)
25%	Dairy	Muirhead et al. (2011), Table 2
20%	Dairy	Longhurst (2012)
24%	Drystock	Longhurst (2012)
30–65%	Dairy and drystock	Quinn (2012)
20%	Dairy Drystock	Semadeni-Davies and Elliott (2012)
24%	Dairy and drystock	Semadeni-Davies and Elliott (2012)
20%	Dairy and drystock	Semadeni-Davies and Elliott (2012)
50%	Dairy and drystock	Semadeni-Davies and Elliott (2012)
20%	Dairy and drystock	Elliott et al. (2013)
50%	Dairy and drystock	Elliott et al. (2013)
50–60%	Drystock	McDowell et al. (2013)
20%	Dairy	Ross Monaghan (pers. comm., 2015)
30%	Median reductions in dairy and drystock	Ross Monaghan (pers. comm., 2015)
58%		Richard Muirhead (pers. comm., 2015)
65%	95th percentile reductions in dairy and drystock	Richard Muirhead (pers. comm., 2015)

The final reductions applied by Doole (2015) for the efficacy of streambank fencing for *E. coli* reduction were varied between a median load reduction of 58% and 95^{th} percentile load reduction of 65% (combined across both dairy and drystock sources) – in both applying such reductions in a simple modelling framework (e.g., steady state, statistical rather than continuous, process-based modelling – unalike to the FWMT). The latter were ultimately expert opinion-based after considering those studies in Table 3. Importantly, Doole (2015) applied benefits of stock exclusion for *E.coli* only (i.e., without variation for setback, riparian planting, soil or topographic variation. To support that, Doole (2015) notes that experimental research has shown that there is little benefit to riparian planting, compared with the presence of just pasture due to limited absorptive capacity of riparian plants during storm events (see also Semadeni-Davies and Elliott, 2017).

Daigneault and Elliott (2017) undertook a national study of contaminant loads and mitigations. National land use maps were sourced from national sources such as AgriBase Database and the Agricultural Production Survey. This was overlaid with baseline loads estimated from modelling tools such as CLUES and SPASMO. Mitigation costs and effectiveness estimates were derived from a range of literature, however, the values used were not linked to a specific literature source.

Daigneault and Elliott (2017) looked at fencing and riparian planting separately and segregated based on land use type but no other variables. They used the following scenario descriptions; stream bank fencing is "constructing fences to exclude stock from permanent waterways" while riparian planting is "fence streams with 5m buffer that is planted with grass and native vegetation". Daigneault and Elliott (2017) are unclear if their riparian planting benefits also account for the benefits of stream fencing (required prior to any planting on pastoral waterways). Their cost estimates cannot as the riparian planting mitigation is consistently less costly than fencing. However, the reverse is true with the benefits for riparian planting (e.g., being consistently higher than those for fencing streams only). Hence presumably, Daigneault and Elliott (2017) benefits for planting are inclusive of those for fencing, but whose costs are additive to fencing. The results from Daigneault and Elliott (2017) are summarised in **Table *5***. Daigneault and Elliott (2017) is a useful study as it separates estimates by fencing and fencing and planting across all key contaminants and separated by land use type. However, the difficultly in tracing where these estimates were derived from does mean that extrapolation should be considered with caution.

Table 5: Daigneault and Elliott (2017) benefit estimates for 5m5 metre setback on "riparian planting" and fencing streams for a range of land uses and contaminants (adapted from page 26)

Mitigation	Land use type	Percentage reduction (%)				
		N	P	Sediment	E. coli	GHG
Riparian Planting	Dairy	-56%	-66%	-75%	-60%	-3%
Fencing Streams	Dairy	-13%	-15%	-70%	-60%	0%
Riparian Planting	Sheep and beef	-56%	–50%	-75%	-60%	-10%
Fencing Streams	Sheep and beef	-13%	-15%	-70%	-60%	0%
Riparian Planting	Deer	–51%	–50%	–82%	–60%	–13%
Fencing Streams	Deer	–13%	–15%	–70%	–60%	0%
Riparian Planting	Arable cropping	–51%	–50%	–75%	–60%	–4%
Fencing Streams	Arable cropping	Not applicable				
Riparian Planting	Horticulture	–51%	–50%	–75%	–60%	–4%
Fencing Streams	Horticulture	Not applicable				

Daigneault, Dymond and Basher (2017a) consider the effectiveness of two sediment mitigation options on both land based and bank erosion. Land-based erosion included landslide, gully, earthflow, and surficial erosion. While the riparian planting and fencing scenario includes a 5 metre setback (regardless of vegetation type within this buffer area) it is not clear what setback, if any, is considered with the riparian planting-only option. It is assumed that it is a minimal setback with the purpose of stock exclusion only. Because of this assumption, while the riparian fencing-only option reduces bank erosion (from stock exclusion) it has no effect on land-based erosion through overland flow as there is minimal vegetation and area to intercept this flow. **Table *6*** summarises the mitigation effectiveness of mitigation scenarios.

Table 6: Daigneault et al (2017a) benefit estimates for different types of erosion for riparian fencing and fencing and planting scenarios (adapted from page 32)

Mitigation scenario	Mitigation Effectiveness (% from baseline)	
	Land-based Erosion	Bank Erosion
Riparian Fencing (construct fences along permanently flowing waterways, rivers and streams)	0	50
Riparian Fencing + Planting (construct fences along permanently flowing waterways (rivers and streams) and plant 5m strips of grass or other vegetation)	50	70

While Daigneault et al (2017a) is specific to the Kaipara Harbour (study area) the estimates appear to align with other work by the authors at a national level. In particular, Appendix 1 in Daigneault et al (2017a) provides erosion mitigation type and effectiveness estimates provided from Basher (2016). The estimates in Appendix 1 in Daigneault et al (2017a) which are sourced from Basher (2016) are also the same as what is represented in Basher et al (2019).

Basher et al. (2019) provide a review of literature on sediment mitigation control measures across wider farming practices (e.g., land management, riparian management, farm-forestry management) at a national level. The sediment mitigation options pertinent to riparian management in Basher et al.

(2019) are summarised in **Table *7***, while **Table *8*** summarises the corresponding benefits of riparian management. As with wider national reviews (Parkyn, 2004; McKergow et al., 2016). Basher et al (2019) note that the effectiveness of buffers varies widely depending on width, type, particle size of the sediment, the ability of the vegetation to slow flow, soil infiltration rate, the amount of runoff, slope gradient, and length of contributing slope. Notably, Basher et al (2019) found that increasing benefit is likely from increasing setback but that the rate is not linear, and nor too immediate (i.e., a two year lag before benefits are fully realised from riparian retirement can begin to be realised [Basher et al., 2019]). Because Basher et al (2019) do not specifically align their estimates of efficacy with any one scenario or context (e.g. location, slope, setback width or vegetation type) care should be taken when extrapolating these results to other scenarios that are differentiated by such factors. As with previous studies, it is reasonable to assume that their riparian fencing options do not include a setback of any significance, while the riparian fencing and plantation options do, though the width is not specified. For **Table *8*** it is not clear what the difference is between riparian fencing and stock water reticulation away from waterbodies, it is assumed both restrict stock access to the waterbody, but the width of the setback is not clearly defined.

Table 7: Basher et al (2019) benefit estimates for different types of erosion for various mitigation scenarios and land uses (adapted from page 19)

Erosion process	Mitigation treatment	Effectiveness (% reduction from baseline)	Land use	Comment
Surface erosion (sheet, rill)	Riparian grass buffer strip	40	Horticulture and pasture	Conservative estimate based on McKergow et al. (2007) – can be >80%. Will probably be highly slope dependent
Bank erosion	Riparian fencing	50	Pasture	The 80% used is based on a "conservative" adjustment of the Australian SedNet model parameter (Dymond et al. 2016). The available NZ data suggests the effectiveness is likely to be significantly lower; there is insufficient data to determine whether riparian planting significantly increases effectiveness above simply fencing (to restrict stock access) or to determine effect of width of fencing set back.
	Riparian fencing & planting	50	Pasture	

Table 8: Basher et al (2019) contaminant benefit estimates for riparian fencing, fencing and planting and stock water reticulation (adapted from page 30)

Mitigations	Sediment / Erosion	N loss	P loss	E. coli
Riparian fencing	40%	Uncertain	Uncertain	Uncertain
Riparian fencing and planted buffer around water bodies	40-50%	15% for dairy; 5% for drystock	10% for dairy; 5% for drystock	25–35%
Stock water reticulation away from surface waterbodies	40%	15% for dairy; 5% for drystock	10% for dairy; 5% for drystock	25–35%

Daigneault, Eppink and Lee (2017b) consider the relative performance of buffer width and passive afforestation versus active revegetation on GHG, N, P, sediment and biodiversity as a percentage change from baseline. These are summarised in **Table *9*** where changes greater than 100% indicate a net sink.

Table 9: Daigneault et al (2017b) contaminant benefit estimates for a range of buffer widths and vegetation types (adapted from page 32)

Scenario		Percentage change from baseline				
Vegetation	**Buffer width**	**GHG**	**N leaching**	**P loss**	**Sediment**	**Biodiversity (% of ideal)**
Passive afforestation	5m	-16	-51	-50	-82	2
	10m	-26	-74	-73	-90	4
	20m	-54	-88	-87	-92	8
	50m	-147	-90	-92	-93	23
Active afforestation	5m	-26	-51	-50	-82	0
	10m	-54	-74	-73	-90	0
	20m	-112	-88	-87	-92	0
	50m	-306	-90	-92	-93	0

In MfE and MPI (2016), AgResearch provided an assessment of the farm-scale effectiveness of stream fencing mitigation for reducing *E. coli* concentrations instream. The latter was based on a literature review. The effect of fencing on pastoral land was represented as load reduction factors (removal efficiency) and the effect varied by farm type. The percentile values of 10%, 50% and 90% were used to define the potential effectiveness for low, most likely and high effective categories respectively for each region considered. The results from this report are summarised in **Table *10*** and are independent of any particular setback (e.g., assigned directly to fencing only) though the study does not consider riparian planting or loss of productive land so it is a reasonable assumption that a minimal setback is assumed with costs and benefits derived only from stock exclusion.

Table 10: MfE and MPI (2016) benefit estimates for E. Coli for different regions and land uses (adapted from page 28)

Scenario description	Northern North Island			Southern North Island			South Island		
	Low	**Most likely**	**High**	**Low**	**Most likely**	**High**	**Low**	**Most likely**	**High**
Load reduction factors for fencing dairy cattle and deer	0.15	0.62	0.86	0.15	0.62	0.86	0.15	0.62	0.86
Load reduction factors for fencing beef cattle only on sheep and beef farms	0.13	0.53	0.73	0.11	0.44	0.61	0.10	0.40	0.55

Other estimates of benefits from buffer strips in horticulture include Barber (2014) who considers the effectiveness of setbacks and buffer strips for vegetable production, estimating these at 50-80% - derived from horticultural sector sediment control guidelines. This aligned with Keenan (2013) and it is assumed that both of these sources relate to the same base study; however, access to this base study appears limited due to referencing methods. Neither study links to a particular buffer width. The table that Barber (2014) uses to describe effectiveness estimates is summarised in **Table *11***. This is the most targeted effectiveness data for horticulture, however, care should be taken when extrapolating results due to the access to the underlying methodology.

Table 11: Summary of effectiveness for horticulture mitigation measures in reducing sediment (Barber, 2014, page 5).

Control measure	Range in effectiveness (%)
Detailed erosion management plan	-
Cover crop	90-99
Minimum tillage	-
Setback or buffer strip	50-80
Wind break crop	-
Stubble mulching	-
Wheel track ripping or dyking	50-80
Contour drains	30-70
Benched headlands	50-80
Super silt fence	80-95
Decanting earth bund	80-95
Silt trap	80-95
Silt trap maintenance	-

In summary, the benefit of riparian margins on waterway contaminant loss varies with slope, soil type, climate and setback width (whether of grass or native plantings). However, insufficient assured evidence prevents benefits being resolved to finer granularity (i.e., for varying buffer width, planting choices and slope or soil classes). The studies explored above either do not include a setback distance for reported benefit, or often include a single setback distance, even if collectively those span a range of 3-50 metre. Amongst latter studies, 5 metre is the most common setback distance for a benefit to be reported. Hence, greater confidence is afforded to contaminant benefits from 5 metre riparian buffers, albeit still with a notable lack of process-understanding in the literature (i.e., limited knowledge of how benefits vary for differing setbacks). Other setback widths are less prevalent in the literature, and so while increasing setback should be associated with increased benefit it is likely to be at a non-linear rate (e.g., as per Zhang et al., 2010 or Daigneault et al., 2017b). There is insufficient evidence in New Zealand, across pastoral and horticultural sectors to assign varying benefits continuously with increasing buffer width. Clearly, this limitation is worth prioritising for further research or expert caucusing if riparian management is a prioritised mitigation within the FWMT and for AC. In addition, there is limited information on the impact of planting beyond consideration of planted or grassed buffers (i.e., lacking information on type of, density, maintenance regime). Hence, benefits of planting must remain generalised at this stage in the FWMT.

4. Cost analysis

There is limited consistency between cost estimates in the New Zealand riparian literature. In particular, which cost components are included/excluded and how costs are presented (e.g. annualised, one-off capital costs etc.). This section presents a thorough overview of riparian management costs available in the literature. While some of the studies discussed in this section are the cost equivalent to the benefit section above, this is not always the case with some studies considering only benefits or costs. Costs should consider inflation when being adjusted for use in the FWMT Stage 1, for example, when utilising older studies, the costs should be updated to a consistent year, for example 2019, using appropriate inflation adjustment techniques.

Daigneault and Elliott (2017) looked at fencing and planting separately and cost information is segregated based on land use type but no other variables. Their cost estimates are based on the following options: (1) stream bank fencing is "constructing fences to exclude stock from permanent waterways"; and (2) riparian planting is "fence streams with 5m buffer that is planted with grass and native vegetation". Based on the cost estimates provided and the fact that the cost of riparian planting is consistently lower than the cost of fencing streams, it is assumed that the riparian planting scenario excludes the cost of fencing (e.g., if you want to stock exclude and plant on pastoral land, both fencing and planting cost estimates need to be considered).

Daigneault and Elliott (2017) do not provide a detailed breakdown on what cost components are included in their cost estimates for capital or maintenance costs (e.g., type of fencing, planting types and spacing, stock water reticulation), nor do they provide detail in how opportunity costs are calculated. Daigneault and Elliott (2017) do however, detail that for both options (1) and (2) capital and maintenance costs are included, and that option (2) includes an opportunity cost. Equally they do note that the initial capital and periodic maintenance costs are annualised over 25 years using a discount rate of 8% and that annual maintenance and opportunity costs are assumed to apply each year and thus are directly subtracted from the base net farm revenue figure. Based on this, the annualised cost represents the capital and periodic maintenance (adjusted to an annual equivalent) as well as the annual maintenance and opportunity cost information, though no detail is provided on the relativities between these cost components. In Daigneault and Elliott (2017) all costs are in 2012 dollars and are summarised in **Table *12***. Because of the uncertainty in what cost components are include within the capital, maintenance and opportunity costs care should be taken when extrapolating the costs.

Table 12: Daigneault and Elliott (2017) annual cost estimates (capital, maintenance and opportunity) projected for 25 years (adapted from Daigneault and Elliott, 2017; page 25 and 26).

Mitigation	Land use type	Net farm revenue ($/ha/yr)	Annualised Cost ($/ha/yr)	Earnings before income and tax (net farm revenue)
Riparian Planting	Dairy	3,418	71	-2.1%
Fencing Streams	Dairy		137	-4%
Riparian Planting	Sheep and beef	127	26	-21%
Fencing Streams	Sheep and beef		32	-25%
Riparian Planting	Deer	995	37	-3.7%
Fencing Streams	Deer		40	-4%
Riparian Planting	Arable cropping	1,650	11	-0.7%
Fencing Streams	Arable cropping		NA	
Riparian Planting	Horticulture	5,597	62	-1.1%
Fencing Streams	Horticulture		NA	

Doole (2015) considered two fencing mitigation options: option (1) focused on excluding cattle with a 3-wire electric fence with 2.5 mm wire, number 2 quarter round posts, and 7.5 metre spacing at a combined cost of $5/m (for one side). This excludes any provision for stock water reticulation and is applied to only dairy farms. This cost was annualised utilising an interest rate of 8% over a 25-year period, to a cost for fencing both sides of $0.47/m. There is no discussion of maintenance costs.

Option (2) in Doole (2015) focused on both sheep and cattle exclusion with a 5-wire fence including three electrified wires, 2.5 mm wire, and number 2 round posts at 5 metre spacing at a cost of $12.50/m (for one side). This cost was assumed to incorporate an annual cost associated with ongoing maintenance, erosion, and livestock damage over the fencing lifespan of 25 years. The total cost used in Doole (2015) was $35/m for fencing both sides of the stream, this was annualised to $3.28/m, utilising an interest rate of 8% over a 25-year period. This includes fencing costs of $12.50/m on each side and an additional $10/m for stock water reticulation. The cost of water reticulation (including maintenance costs, pumping, and installation) to provide stock drinking water was estimated at an additional $10/m, based on information from Northland Regional Council, it is unclear if this is both sides (i.e., $5/m on each side) or only one side. It is also not clear what is included in this stock water reticulation cost (e.g. what capital components are included). Due to the lack of detail on stock water reticulation costs, whilst useful this component of the study, should be treated cautiously and not utilised where more advanced and comprehensive costs are available.

Vibart et al (2015) bundled riparian and other mitigations preventing benefit information being derived for riparian management alone, but cost information was provided for fencing costs. Vibart et al (2015) state that "the cost of individual mitigation strategies was calculated and expressed on an annualised basis, and included depreciation, operational and maintenance costs" though the relevant timeframes were not clear (nor if one or both sides of a stream are being treated – likely only one based on costs). Despite this statement, it is not clear what proportion of the values provided for fencing costs are maintenance costs, operational costs, non-cash costs (i.e. depreciation) or capital costs. Vibart et al (2015) consider two options, dairy and sheep and beef. The dairy option used a fencing cost of $4.40/m for an electric fence with 2 wires using a Canterbury contractor (it is assumed this is for one-side though it is not stated either way). For sheep and beef farms, a fencing cost of $13.79/m was applied for a standard 8-wire fence (it is assumed this is for one-side though it is not stated either way) using a full contract rate from a Canterbury contractor. For both fencing options, costs were extracted from the Financial Budget Manual (Askin and Askin, 2012) so it is assumed costs are in 2012 values. The same fencing costs were used for riparian cost estimates and in addition, for riparian areas livestock numbers were adjusted to compensate for reduced effective grazing area. Because of a lack of detail on if costs relate to one or two sides of fencing and if fencing costs include capital and maintenance costs as well as the location specific costs (using Canterbury based contractor costs) care should be taken when extrapolating these costs.

Harris and Doole (2018) generated costs for various riparian management scenarios based on national scale figures adapted using feedback from rural stakeholders and for Greater Wellington Regional Council. The costs for fencing and riparian planting options are summarised in **Table *13***, these costs appear to be capital costs (except for the annual maintenance costs, and it is not clear if the land retirement costs are annual or a one-off cost). There is no discussion on stock water reticulation costs so it is assumed that these are excluded. Harris and Doole (2018) used a figure of $20/m of fencing costs for sheep and beef farms (one-side to exclude sheep and cattle) – notable for land of up to 15 degree slope only (i.e., steeper land would likely carry a more expensive cost reflecting more challenging terrain and access). Harris and Doole (2018) estimated additional costs of $25/m for planting a 5 metre buffer (one-side) and $50/m for a 10 metre buffer (one-side) for planting with natives. The authors noted such costs were relatively high, but were inclusive of pest management, continued herbicide application, and site visits for establishment and maintenance. Harris and Doole (2018) included planting maintenance costs in the cost of planting, meaning further "annual maintenance costs" likely apply to fencing maintenance. The costs used in this study are quite specific to the Greater Wellington Region and also the sheep and beef costs are relatively high compared to other studies. Consequentially, it is not recommended that these costs are transferred to the Auckland region.

For planting costs, Harris and Doole (2015) suggested that these costs were spread 60%, 20% and 20% for years 1, 2 and 3 to allow for follow up release spraying and maintenance. Annual maintenance costs for fencing and planting were applied subsequent to year 3. This is the only study which appears to stagger capital planting costs; however, maintenance costs for planting are likely to be higher in initial years, which would also reflect the follow up release spraying and maintenance costs in years 1-3 that Harris and Doole (2015) consider.

Table 13: Harris and Doole (2018) cost estimates including capital and annual cost categories as detailed in the mitigation column (adapted from page 5)

Mitigation	Scenario	Cost	Metric	Area applied to
Stream fencing	Fencing one side to exclude sheep and larger animals, flat slope	$20	$/linear metre	Sheep and beef, lifestyle not currently fenced
Planting 5m strip	Cost of planting one side of a stream	$25	$/linear metre	Sheep and beef, lifestyle not currently fenced
Land retired with 5m buffer strip	From value of retired land	$5.35	$/linear metre	Sheep and beef, lifestyle not currently fenced
Planting 10m buffer	Cost of planting one side of a stream	$50	$/linear metre	Sheep and beef, lifestyle not currently fenced
Land retired with 10m buffer strip [a]	From value of retired land	$10.70	$/linear metre	Sheep and beef, lifestyle not currently fenced
Annual maintenance of fence and buffer [b]	Cost of maintenance one side of stream	$2.50	$/linear metre	Sheep and beef, lifestyle not currently fenced
Retirement ($/ha capital costs)	20th percentile of QV per ha values	$10,700	$/ha	6e, 7e, 8e sheep and beef, lifestyle

[a] *It is noted that in the report by Harris & Doole (2015) this is noted as land retired with a 5m buffer, however, this is double the cost of the preceding row for land retried with a 5m buffer strip and so we have interpreted this as an error and should be applied to land retired with a 10m buffer strip.*

[b] *It is not clear how the annual maintenance cost varied by buffer width as costs were provided per linear metre, it is assumed that this is likely to apply to the fencing costs, with planting maintenance costs included in the capital costs (as previously mentioned).*

Daigneault et al. (2017b) account for fence construction, construction of alternative stock water supplies, as well as the opportunity costs of taking land out of current production, in their assessment of stock exclusion costs – tiering those into low, medium and high bands. The costs of constructing fencing, planting and alternative water supplies were annualised over 25 years at a discount rate of 5% (planting and alternative water supply costs were then converted to a per hectare basis). Such costs are established from a variety of sources and are summarised in **Table *14***.

Table 14: Daigneault, et al. (2017b) cost estimates including capital and maintenance costs (adapted from page 4)

Cost components	Low	Medium	High
Fencing ($/m)[a]	2	8	16
Alternative water supply ($/ha)[a, b]	50	250	500
Vegetation planting ($/ha)[b]	0	1,000	5,000
Opportunity cost (% of farm earnings)[c]	0	50	100

[a] O*nly apply to pastoral land uses.*

[b] *Refers to dollars per hectare of farmland not per hectare of buffer.*

[c] *Applies to area of buffer.*

Fencing costs in Daigneault et al (2017b) were presented as 'low', 'medium' and 'high'. Each of these categories was then applied to all pastoral land uses, i.e., regardless of stock type or slope variables. The cost of constructing alternative stock water supplies was based on cost estimates for a 50-ha farm and the costs per hectare provided relate to a cost per hectare of farm not per hectare of riparian buffer or length of stream fencing, this makes it challenging to apply these to other studies. Daigneault et al (2017b) note that the cost of vegetating riparian margins can vary significantly depending on the species planted and level of effort required. As a result, their low-cost scenario assumes the buffer vegetation naturally establishes without any planting effort (or cost) – notably, possible though less probable to support benefits in the short-term and likely to be associated with greater ongoing maintenance costs (e.g., to account for no targeted planting otherwise excluding weed incursions of previously pastoral land). The medium scenario ($1000/ha) presumes planting manuka at the recommended density and the high-cost analysis ($5000/ha) includes the services of landscape planning, contracting and planting – noting caution about the medium scenario costs being considerably lesser than likely full planting costs (see later costings per plant, scaled to 1.5m spacing before severalfold greater). As with stock water supplies, planting costs are based on a cost per hectare of land, not per hectare of buffer width (and need to be adjusted based on the assumptions of how many metres of fencing was assumed per hectare).

Table 15 adjusts the planting and stock water costs based on a back calculation of how many kilometres of streams were assumed per hectare in Daigneault et al (2017b). The opportunity costs of taking land out of production were assumed to be equal to net farm revenue, which varies depending on the type, size, and location of the farm. Opportunity costs were offset in some cases to account for alternative production returns (e.g., reduced soil loss, less stock drowning and improved stock health leading to higher return of effective area).

Daigneault et al. (2017b) also consider varying buffer widths (5, 10, 20 and 50 metre on each side of waterway). However, for each different width they apply the three cost categories (low, medium and high) and summarise results at a national level. Because of how the costs are constructed, described and applied it makes it challenging to follow how their costs provided on a per unit basis (as per **Table *5*** in this report) translate to each metre of stream fencing and each buffer width estimate. Because of this and a lack of detail in how their costs were derived these costs should be used with care.

Table 15: Translating costs provided as dollars per hectare of land to dollars per metre of stream fencing from Daigneault et al. (2017b)

Land use	Area	Stream length		Planting		Water supply		
	kha	km	m /ha	Medium ($/m)	High ($/m)	Low ($/m)	Medium ($/m)	High ($/m)
Dairy	2,085	31,802	15.25	66	328	3.28	16.39	32.78
Sheep and Beef	11,025	226,909	20.58	49	243	2.43	12.15	24.29
Other pasture	1,263	22,027	17.44	57	287	2.87	14.33	28.67
Arable and horticulture	341	2,709	7.94	126	629	Not applicable		
Forestry	1,926	36,486	18.94	53	264			
Native	8,698	160,233	18.42	54	271			
Other land	2,028	28,505	14.06	71	356			

Basher et al. (2019) provide a literature review of both the costs and benefits of sediment control measures, including riparian management options, planting, fencing and grass buffer strips. While definitions of mitigations are provided in Basher et al. (2019), there is no detail provided on width of setbacks or type of spacing of planting. Table 16 summarises the costs utilised and where they sourced these costs from. The footnotes provided to the data in Table 16 are sourced directly from Basher et al. (2019).

Table 16: Basher et al. (2019) mitigation capital cost estimates (adapted from page 30)

Mitigations	Nominal cost	Additional details	Reference
Riparian fencing	$7.10/m – $34.60/m[1]	Fencing estimated at $7.10/m to fence out cattle (and provide water supply). Fencing out all stock estimated at $34.60/m	Daigneault et al. (2017a)
Riparian fencing and planted buffer around water bodies	$255/ha[2]	A minimum of $255/ha, subject to the opportunity cost of buffer, its width and range of waterbodies are excluded.	Doole (2015); Dymond et al. (2016); Keenan (2013); Monaghan & Quinn (2010)
Stock water reticulation away from surface waterbodies	$142–601/ha (capital cost) and $3.13–12.56/ha (operating cost)[4]	Results in good medium-term payback, but some benefit may be extracted through higher carrying capacity, which may increase N losses	Doole (2015); Journeaux & Van Reenen (2017)

[1] Cost of riparian fencing for dairy is estimated at $7.5 per metre while for sheep and beef is estimated at $35 per metre (Daigneault & Samarasinghe 2015). Other estimates of fencing 5-wire electric fence with electrified wires, 2 plain wires, 2.5-mm wire, number 2 posts and 5 metre spacing for dairy farms was at $5 per metre (Doole 2015). However, costs of fencing 5wire electric fence with electrified wires, 2 plain wires, 2.5-mm wire, number 2 posts and 5 metre spacing for sheep and beef farms was at $35 per metre (Doole 2015).

[2] The cost of one plantation around $11.10 (Daigneault & Samarasinghe 2015). Doole (2015) estimated the cost of riparian buffer strip for horticulture land use at $175 per hectare. Chris Keenan (2013) estimated the cost of riparian grass buffer strip for pasture and horticulture land uses at $225 per hectare. Chris Keenan (2013) estimated the cost of riparian grass buffer strip for horticulture land uses at $750–1300 per hectare treated.

The Agribusiness Group (2016) as part of the National Stock Exclusion Report (MfE & MPI, 2016) undertook perhaps the most comprehensive fencing cost analysis to date, including providing costs for a wide range of scenarios including segregating costs by slope, fencing type and region. Their fencing costs are built on a set of clear assumptions, namely standardised to:

- One km fence (one side of stream).
- Nine angle assemblies.

- One gateway assembly (per km of fence).
- Post driver able to be used on flat and rolling terrain, but not steep terrain.
- Posts spaced at 4 metres for non-electric and 10 metres for electric fences, where possible.
- Topography does not influence the cost of fencing materials but does influence labour costs.
- Rolling country was defined in the study as land with a slope greater than 7 degrees and less than 16 degrees, and steep country was defined as up to 28 degrees in slope.
- Fencing estimates do not allow for rocky, swampy or extremely heavy clay conditions.

The costs are summarised in **Table *17*** at a national level as well as for the Auckland Region, these are capital costs only and it is assumed they are in 2016 dollars, they include labour, site preparation and materials. The Agribusiness Group (2016) also separates out material and labour costs, though these are not summarised here given that both should be included in total economic costs. The Agribusiness Group (2016) used a nationwide survey, as well as quotes from suppliers to ascertain an estimate of various fencing costs.

Table 17: The Agribusiness Group (2016) cost estimates (capital costs including materials and labour) – National and Auckland Region (adapted from page 4)

Stock type	Fence type	Topography	Maximum ($/m)	Average ($/m)	Minimum ($/m)	Auckland region ($/m)
Sheep/cattle	Non-electric 8-wire	Flat	16.36	13.02	9.90	15.00
		Rolling	17.88	13.66	10.38	15.40
		Steep	24.88	16.64	12.06	21.50
	Non-electric netting	Flat	15.91	11.99	8.82	14.10
		Rolling	19.93	12.63	8.82	14.50
		Steep	26.81	16.01	10.32	22.8
	Electric 4-wire	Flat	11.21	6.56	4.40	7.50
		Rolling	12.21	6.88	4.40	7.90
		Steep	13.21	8.25	4.90	10.20
Cattle	Electric 2-wire	Flat	8.58	4.67	2.91	5.10
		Rolling	10.58	4.89	3.21	5.10
		Steep	11.58	5.94	3.66	7.30
Deer	Non-electric Netting Boundary fence	Flat	28.90	18.90	13.70	21.30
		Rolling	28.90	19.68	14.20	22.00
		Steep	32.55	22.71	15.70	28.6

The Agribusiness Group (2016) also provide a useful summary of potential costs (and benefits) that are excluded from their cost analysis, largely due to difficulty in quantification. The following were excluded from costs: improved stock health, improved safety for people and stock, improved pasture quality, more efficient stock movements, aid prolific weed growth causing seed transfer and fire risk and an increase in farm infrastructure costs – realigning existing fence lines, adding culverts.

MfE and MPI (2016) advanced the costs provided by The Agribusiness Group (2016) to produce a national riparian cost benefit analysis. The most notable difference being the addition of maintenance costs assumed to be 1% of total material costs for permanent fencing on all bar steep land where maintenance was increased to 2 percent (i.e., fences on steep land are known to be subject to more environmental damage (wind, erosion) and damage by animals than fencing on flat or rolling land).

The Agribusiness Group (2016) considered planting costs predominantly based on WET (2011). They calculated the average cost of riparian planting was $5.50 per plant (plants, ground preparation and labour – for native riparian species). The most common plant density in their survey was 4,500 plants per hectare of retired riparian margin, equating to approximately $3.67 per linear metre of planting (plants at 1.5 metre spacing). While in reality plant density may vary based on characteristics such as the riparian area, waterway and position in the riparian zone, the literature is generally simplified preventing such granular variation being accounted for here. In line with assured evidence, our recommendations for riparian cost and benefit are generalised to an average planting density.

The Agribusiness Group (2016) also captured costs based on multiple rows of plants and if one stream bank, or two were being planted (**Table *18***). For comparison purposes for one linear metre of stream bank planting (one side), a 5m wide buffer strip would cost $18.33 given the plant costs and spacings from WET (2011), while a 10m wider strip would cost $36.67. These are just the capital outlay and exclude maintenance, it is assumed they are based on 2011 dollar values.

Table 18: WET (2011) planting cost estimates including capital for plants, labour and site preparation

Cost per metre (NZ$)		
Rows of plants	**Planted one side**	**Planted two sides**
1	3.67	7.34
2	7.34	14.80
3	11.01	22.02
4	14.68	29.36

WET (2011) analysed their costs of planting riparian areas over two seasons, their average planting cost was $29,430 per hectare, based on an estimate of 4,500 plants per hectare and an average planting cost of $6.54 per plant. This included planning, preparation, seeds, fertiliser and sprays, labour and logistics. This cost uses approximately 15% large trees, 45% small trees/large shrubs and 40% understorey shrubs/grasses – all were native species. It is not clear why these variations were used on the relative difference in costs, but presumably reflected assumptions related to different types and grades of plants for the varying sizes. WET (2011) planting costs are generally higher due to variety of labour used, including community/volunteer planting days, commercial contractors, or prison labour crews, all of which required some degree of organisation and supervision. Seedling cost was the highest cost component and is variable according to plant species and if subsidies are available. Ongoing maintenance costs were dependent on-site characteristics but were estimated at $1.50 to $2.50 per seedling per year, for at least 2 years.

WET (2011) and The Agribusiness Group (2016) note that the true cost of planting is largely related to plant longevity, especially in the immediate year after planting. WET (2011) provides a comparison between plantings with survival percentages of 95%, 68% and 16% costing $7.89, $9.55 and $37.50 per live plant respectively. WET (2011) also note that most plants ‘do well’ at 1.5m x 1.5m spacings and this equates to an average of 4500 plants per hectare.

The DairyNZ Riparian Planner (DairyNZ, 2018) uses a base rate of $3.50 per plant and an equivalent labour cost of $2 per plant. These are national estimates and do not include features such as plant protectors. In addition, no information was available on types of grades used, spacing of 1.25m is used.

Stock water reticulation systems are considered in The Agribusiness Group (2016) who developed a cost based on providing an alternative water supply for a 10 ha and 50 ha blocks. They note that these costs are highly variable across different farm systems and in different parts of the country. **Table *19*** provides the capital cost framework developed in The Agribusiness Group (2016), the costs are materials only and exclude site preparation and labour.

Table 19: The Agribusiness Group (2016) cost estimates for stock water reticulation (adapted from page 21)

Component	Size	Unit cost	10 hectares		50 hectares	
			Number needed	Cost	Number needed	Cost
Concrete trough	750 litres	442.50	1	442.50	5	2,212.50
Alkathene pipe	200m 25mm	312.56	1	312.56	5	1,562.80
Culvert	5m, 400mm	603.30	0	0	1	606.30
Ram pump	20,500 litres/day	6,500	1	6,500	1	6,500
Ferguson windmill	2,300 litres/day	2,778.26	1	2,778.26	0	0
Water tank	25,000 litres	2,695.65	1	2,695.65	1	2,695.65
Total				6,832.27		13,574.65

The Agribusiness Group (2016) briefly touch on additional capital costs and associated maintenance costs. These may include culverts, water reticulation schemes and re-fencing paddocks. Maintenance costs for this extra infrastructure is estimated at 1% per annum of capital cost for fencing and up to 5% of the capital cost per annum for reticulated water depending on water system type (The Agribusiness Group, 2016).

Journeaux and van Reenen (2016) provide an analysis of the costs of implementing stock water reticulation systems on actual hill country sheep and beef farms. While this study does not specifically relate to fencing waterways, it provides valuable data on real farms who have implemented stock water reticulation schemes. The farms selected for analysis were spread throughout the country (although predominantly North Island based); two in Northland, one on the East Coast, five in Horizons, one in the Wairarapa, and two in North Canterbury. The analysis used an investment cost-benefit approach based on calculating the NPV and IRR over a 20-year cash flow, using a base discount rate of 8% real. This involved consideration of the capital costs of the stock water scheme, plus the marginal costs and benefits associated with the scheme, for example increased stock numbers and/or performance offset by any increased operating costs.

Capital costs per hectare are shown in Table 20, where total capital includes the capital involved in the water reticulation scheme as well as additional capital costs experienced by case study farmers such as subdividing fencing and increased/changed stock numbers, and water only capital includes only the capital involved in the reticulation scheme. A comparison of operating costs is also included, these costs considered repairs and maintenance, insurance (if involved), plus electricity and/or fuel costs. Repairs and maintenance costs were assumed to be 1.5% of capital costs initially, inflating at 1% per year.

Table 20: Journeaux and van Reenen (2016) cost estimates for stock water reticulation (capital and operational) (adapted from page 20 and 22)

Farm	Total capital cost ($/ha)	Water only capital cost ($/ha)	Operating cost ($/ha)
Horizons 1	342	98	5.86
Horizons 2	507	245	6.50
Horizons 3	601	280	6.83
Horizons 4	132	132	3.13
Horizons 5	509	125	4.84
Northland 1	134	130	4.30
Northland 2	811	246	12.56
East Coast 1	293	200	11.29
Wairarapa 1	206	108	3.90
Canterbury 1	303	134	3.90
Canterbury 2	142	126	5.47
Weighted average	311	154	4.77
Average	362	166	
Median	303	132	

Journeaux and van Reenen (2016) also discussed the impact of stock water reticulation on land values, and found that, relative to a similar farm with only natural water supply, a stock water system that provided reliable, good quality water in every paddock could (a) add 1.5 – 5.0% additional value to the property; and (b) may result in the property being sold more quickly. However, they concluded this was likely to be hugely variable and therefore excluded these costs from analysis.

Other sources of cost information include Keenan (2013) who noted that the cost of establishing riparian vegetation strip is around $255/ha for horticulture but noted that this will vary depending on the choice of any planted vegetation. Barber (2014) also considered the cost of a 'setback or buffer strip' though this is assumed to be focused on the cost of lost productive land, rather than riparian planting. Barber (2014) estimated that a setback or buffer strip would likely cost $100 - $250/hectare (it is assumed this is in 2014 dollars). As noted in Muller et al (2020), Bay of Plenty Regional Council advised (in 2018) that a native sedge vegetation riparian planting strip could be established at an average cost of $20/m (linear) of waterway planted, assuming both sides of the waterway were planted), with annual weed control costs of $130/ha retired (De Monchy 2018, pers. comm).

Daigneault et al. (2017a) consider the cost of two sediment mitigation options; costs included capital, maintenance and opportunity costs. **Table *21*** summarises these costs while **Table *22*** annualises these costs by land use type. It is assumed that because these costs are largely predicated on Doole (2015) the sheep and beef costs include water reticulation and are costs for both sides, whereas dairy costs are for one side only and exclude stock water reticulation.

Table 21: Daigneault et al. (2017a) costs estimates for capital, maintenance and opportunity costs (adapted from page 32)

Mitigation scenario	Cost component		
	Initial Capital (year 0)	Maintenance	Annual opportunity
Riparian Fencing (construct fences along permanently flowing waterways, rivers and streams)	S&B: $35/m, including materials, construction, and reticulation (for both sides) to fence out all stock Dairy: $7.50/m, including materials, construction, and reticulation (for one side) to fence out cattle	None	None
Riparian Fencing + Planting (construct fences along permanently flowing waterways (rivers and streams) and plant 5m strips of grass or other vegetation)	Sum of above and $4/m2 for planting costs	Periodic	50% of farm income in area occupied by riparian planting

The costs in Daigneault et al. (2017a) were annualised over 25 years using a discount rate of 8% (**Table *22***). Annual maintenance and opportunity costs are assumed to accrue on a yearly basis and thus are directly subtracted from the base net farm revenue figure.

Table 22: Daigneault et al. (2017a) annualised costs estimates including capital, maintenance and opportunity costs annualised over 25 years (adapted from page 42)

Scenario	Mean annual mitigation cost by land use ($/ha/yr)			
	Dairy*	Sheep & Beef*	Deer*	Lifestyle Blocks*
Riparian Fencing (construct fences along permanently flowing waterways, rivers and streams)	12	29	34	35
Riparian Fencing + Planting (construct fences along permanently flowing waterways (rivers and streams) and plant 5m strips of grass or other vegetation)	140	69	96	92

**Dairy costs are for one side, all other pastoral types for both sides and inclusive of water reticulation.*

As previously mentioned, there is limited consistency between cost estimates in the New Zealand riparian literature. In particular, which cost components are included/excluded and how costs are presented (e.g. annualised, one-off capital costs). Consequently, comparing results across studies or extrapolating variation in costs across all HRU classes robustly, is challenging. In regards HRU classes, there is greater assured evidence available on cost components than of riparian water quality benefits. However, while more granular and robust, much of the granularity in cost information cannot be matched by the same granularity in benefit estimates.

5. Costs suggested for FWMT

It is proposed the following scenarios are considered for assessing the costs of riparian management in the FWMT Stage 1. Riparian management options should discriminate between fencing only and fencing and planning scenarios for pastoral systems, and planting options for horticultural systems, across a range of buffer widths and varying by slope. The cost information proposed is not exhaustive but provide for some variation in mitigation costs within the bounds of limited consistent evidence to date. While the information provided in this section recommends cost data, these may need to be further refined/amalgamated to match the benefit data for inclusion in the FWMT Stage 1.

Scenarios should consider key riparian management variables of fencing type, slope, buffer width and planting practices. A scenario must consider at least one sub-category for each key variable. For example, considering fencing costs without considering the costs of a buffer width would underrepresent the true cost as no cost of land retirement would be included in the calculation. Key riparian scenario variables are described in Figure 2.

Fencing	Slope	Buffer width	Planting
• No fence • 2-wire electric • 4-wire electric • 8-wire non-electric post and batten	• Flat & rolling • Steep (only applicable to 4 & 8-wire fencing)	• 1 metre (fence only proxy) • 3 metres • 5 metres • 10 metres	• Riparian planting • Rank grass

Figure 2: Scenario variables FWMT- stage 1

Where costs are utilized from other studies, they are all adjusted to 2019 New Zealand Dollars (2019 $NZD) and are GST (goods and services tax) exclusive. Where costs were extracted from other studies to adjust all values to 2019 $NZD, the Farm Expenses Price Index (FEPI) was used. Specifically, the FEPI-All Farms Excluding Livestock index. Prices were adjusted to 2019 Quarter 1. Where the data sources did not specify what dollar values they were using, quarter 1 of the year the study was published was assumed, which provides some minimisation of seasonal differences. Costs estimated out to future years are not discounted and are therefore in present (2019$NZD) values.

Where applicable, cost estimates assume that solutions are implemented using best practices. For example, when fencing in flood prone areas best practices are followed such as, putting fence wires on the paddock and/or downstream side of posts so they pop their staples and drop rather than breaking and using un-barbed staples so wires can pop more easily – assuming good practice enables a typical lifespan for fencing to be set at 25-years with greater confidence.

For the purpose of simplicity and dearth of evidence, indirect costs or benefits (returns) are not considered (e.g., not accounting for greater biodiversity, habitat, amenity or cultural value). Costs without adequate information or evidence are also excluded, for example the increased risk of pest spread due to connecting riparian planting with neighbors.

5.1. Fencing & slope

Four key fencing sub-categories are proposed: no fence, a 2-wire electric fence, a 4-wire electric fence and an 8-wire non-electric post and batten fence. These could be considered as broadly being suitable for dairy cattle (2-wire and 4-wire options), other cattle enterprises (4-wire option) and enterprises with a prevalence of sheep (8-wire option). Horticultural riparian management scenarios do not require stock exclusion. As mentioned in Section 1.1 not all stock classes are considered in this report.

Deer farming in particular is not distinguished by HRU classes but is associated with a higher fencing cost than ascribed for dairy, beef and sheep and beef farming here.

It is suggested that the cost estimates are predominantly based on costs from The Agribusiness Group (2016) including their key assumptions, namely that prices are based on a 1-kilometre long fence line, nine angle assemblies, one gateway assembly (at one end of the fence), posts spaced at 4 metres for non-electric and 10 metres for electric fences, and that the costs do not allow for rocky, swampy or extremely heavy clay conditions. Other key assumptions include that the no-fencing and 2-wire options are applicable only to flat and rolling land, not steep land (i.e., that for FWMT stock exclusion scenarios, no dairy or horticulture HRU's are located on steep land). Finally, no additional costs are included for earthworks, culverts, stock crossings or consents.

Because fencing costs vary significantly by slope, it is recommended to include two slope categories, flat or rolling, and steep. These two groups have been used based on the underlying assumption in The Agribusiness group (2016) of being unable to use a post driver on steep slopes. Flat and rolling land was considered to be up to 16 degrees while steep land was considered to be between 16 and 28 degrees.

The costs provided by The Agribusiness Group (2016) for the Auckland region have been adjusted to reflect inflation (adjusted using FEPI for quarter 1 between 2016 and 2019) as well as to consider alignment with other cost estimates from the literature where these were deemed suitable and robust and to be adjusted to combine flat and rolling estimates. It is not an exact average of data points but a consideration of robust data points using best professional judgement. The Agribusiness Group (2016) had the greatest influence on results, as such, the results can be read as including the same assumptions as in that report (for example post spacing and gate inclusion). Costs are provided on a per linear metre of stream basis so they can be applied to varying stream reaches in the FWMT. The capital costs used for the various fencing options are captured in **Table *23*** and include materials and labour and site preparation. The fences are assumed to have a lifespan of 25-years after which they need to be entirely replaced. All costs are for a single side of stream to be stock excluded.

Table 23: Capital costs – fencing (2019$/m)

Fence type	Slope	Year 0	Year 1-24	Year 25	Year 26-50
		Low estimate ($/m)			
No fence	Flat & Rolling	0	0	0	0
2-wire electric		4.3	0	4.3	0
4-wire electric		7.8	0	7.8	0
8-wire non-electric post and batten		15	0	15	0
No fence	Steep	0	0	0	0
2-wire electric		6.2	0	6.2	0
4-wire electric		8.65	0	8.65	0
8-wire non-electric post and batten		18.2	0	18.2	0
		Medium estimate ($/m)			
No fence	Flat & Rolling	0	0	0	0
2-wire electric		5.4	0	5.4	0
4-wire electric		8.4	0	8.4	0
8-wire non-electric post and batten		16.1	0	16.1	0
No fence	Steep	0	0	0	0
2-wire electric		7.7	0	7.7	0
4-wire electric		10.8	0	10.8	0
8-wire non-electric post and batten		18.2	0	18.2	0
		High estimate ($/m)			
No fence	Flat & Rolling	0	0	0	0
2-wire electric		6.5	0	6.5	0
4-wire electric		9	0	9	0
8-wire non-electric post and batten		17.2	0	17.2	0
No fence	Steep	0	0	0	0
2-wire electric		9.3	0	9.3	0
4-wire electric		13	0	13	0
8-wire non-electric post and batten		27.3	0	27.3	0

Maintenance costs are assumed to be 1% of the capital cost for fences on flat and rolling land and 2% for fences on steep land (The Agribusiness Group, 2016). In lieu of better information, it is suggested that maintenance costs are assumed to be constant across years. The recommended annual maintenance costs are included in **Table *24***.

Table 24: Maintenance costs – fencing (2019$/m/yr)

Fence type	Slope	Annual maintenance cost ($/m/yr)		
		Low estimate	Medium estimate	High estimate
No fence	Flat & Rolling	0	0	0
2-wire electric		0.04	0.05	0.07
4-wire electric		0.08	0.08	0.09
8-wire non-electric post and batten		0.15	0.16	0.17
No fence	Steep	0	0	0
2-wire electric		0.09	0.11	0.13
4-wire electric		0.16	0.17	0.18
8-wire non-electric post and batten		0.30	0.32	0.34

Stock water reticulation is required where waterways are fenced where they provided a water source for stock, this is most likely to be on sheep and beef farms, given that dairy farms have fenced significant waterways already through various industry initiatives. Stock water reticulation costs are likely to vary considerably farm to farm (Journeaux and van Reenen, 2016) as such, understanding the costs for stock water reticulation on case study farms is important rather than just relying on hypothetical information. Therefore, it is recommended that the costs provided in Journeaux and van Reenen (2016) are utilised for stock water reticulation. It is recommended that only the capital costs of stock water reticulation are included. While this will underestimate the total capital spend, the associated capital costs (such as subdividing paddocks) and farm system changes are beyond the scope of riparian management. **Table *26*** summarises the costs for stock water reticulation, capital and maintenance, based on Journeaux and van Reenen (2016), they are adjusted for inflation. The low estimate is based on the minimum estimate in Journeaux and van Reenen (2016) while the medium estimate is based on the median and the high estimate is based on the maximum. These costs are provided in dollars per hectare, and relate to the area over which stock water is required, not the riparian area.

The capital, operational and maintenance costs included are described in more detail in Journeaux and van Reenen (2016). However, it is worth noting that they considered operating costs and maintenance costs as changing over time, particularly because they are the only study that explicitly considers operational and maintenance costs for stock water reticulation. Journeaux and van Reenen (2016) provide a weighted average of operating costs and note that within these operating costs, repairs and maintenance were assumed to be 1.5% of capital costs initially, inflating at 1% per year. Based on these assumptions, operating costs and repairs and maintenance costs were separated and calculated (**Table *25***). The repairs and maintenance component was calculated as 1.5% of capital costs in year 1 and is assumed to increase at a rate of 1% each year. As only one total operating cost (including repairs and maintenance) was provided, the medium repairs and maintenance cost was removed and the balance was assumed to be the operating cost component which is static across cost estimates and across time. These costs are included here as they are an explicit estimate of maintenance and operating costs associated with stock water reticulation systems based on case study farms, and should be included when stock water reticulation costs are included as a cost of stock exclusion.

Table 25: Stock water reticulation costs (capital and maintenance) (2019$/ha/yr)

Cost component	**Cost ($/ha)**		
	Low estimate	Medium estimate	High estimate
Water only capital cost (one-off)	104	140	296
Operating cost total (year 1)		5.05	
Operating cost repairs and maintenance component (year 1) [a]	1.56	2.10	4.44
Operating cost 'other' component (annual)[b]	2.95	2.95	2.95

[a] *This is assumed to increase at 1% per year*

[b] *This is the operating costs excluding repairs and maintenance and is assumed to be static every year.*

5.2. Buffer width

Buffer width is a key cost consideration due to lost productive land and its influence on revegetation costs but also a key factor in distinguishing benefits. As such, the costs in this section are considered for three buffer widths (three, five and ten metres) as well as 'stock exclusion' captured by one metre buffer width. While there is information for the costs across these buffer widths, these are reconsidered in Section 7 to match the available granularity of the benefit estimates available. The single metre setback is recommended to be included with any fence only scenario (e.g., with no riparian planting or grass benefit built in). These buffer widths can be applied to any of the fencing, slope and planting sub-categories, although noting real-world constraints exits (e.g. of terrain).

Buffer width is not considered to have a capital or maintenance cost associated with it, but there is an opportunity cost from lost production. This is based on the underlying land use. In addition, because the literature estimates range from 0% to 100% reduction in baseline productivity, it is recommended that a low cost and high cost option of 25% and 75% relative productivity is considered for each buffer width, with a median otherwise of 50% (i.e., recognising that much riparian area is not as productive as other effective farmed areas given frequent inundation and excess soil-moisture – McKergow et al., 2016).

Opportunity cost is an annual cost based on lost productivity, as represented by operating profitability. It is represented on a square metre basis so that it can be applied to any length of fencing. The relative change in productivity of remaining farmed areas are not considered.

The profitability estimates are based on Muller et al (2020) adjusted to reflect the revised HRU groupings (discussed in Section 1.1) which used long term estimates of operating profit by key land use types (**Table *26***). While these land use types do not directly align with the land intensity classes in the FWMT, they are more aligned to published industry data on profitability and therefore are used.

Table 26: Estimates of operating profit by land type (from Muller et al., 2020, pg.25)

Intensity class in HRU	Operating profit ($/effective hectare/year)	Assumptions
Less than 10SU/ha	$420	Average operating profit per effective hectare based on an average between 2013-14 and 2017-18 excluding interest, tax and rent. Based on the Beef + Lamb NZ Economic Farm Survey for Class 4 N.I. Hill Country - Northland-Waikato-BoP (Beef + Lamb NZ, 2019).
Sheep & Beef- More than 10SU/ha	$680	Average operating profit per effective hectare based on an average between 2013-14 and 2017-18 excluding interest, tax and rent. Based on the Beef + Lamb NZ Economic Farm Survey for Class 5 N.I. Intensive Finishing - Northland-Waikato-BoP (Beef + Lamb NZ, 2019).
Dairy- More than 10SU/ha	$1,330	Average operating profit per effective hectare based on an average between 2013-14 and 2017-18 excludes interest, tax and rent. Based on DairyNZ Economic Survey for owner operators in Waikato & Northland regions, weighted to represent production in Auckland territory local authorities (DairyNZ, 2018; DairyNZ & LIC, 2018).
Low Impact Horticulture- orchards, idle & fallow Medium Impact Horticulture- Arable, citrus, fodder, nuts, viticulture	$2,400	Based predominantly on the arable farm modelled in Matheson et al (2018), which estimated operating profit per hectare at $2,345.
High Impact Horticulture- Berryfruit, flowers, stonefruit, kiwifruit, nursery, pipfruit, fruit, vegetables, greenhouses	$4,000	Given the range of horticulture crops in this HRU class, a weighted average of modelled gross margin per hectare across three vegetable farm types (50% of extensive horticulture rotation, 45% intensive rotation and 5% market garden) modelled in Agribusiness Group (2014) was used. Other crops such as tree crops were not considered (see Section 1.1).

The annual opportunity cost of buffer widths is captured in **Table *27***. They are presented in dollars per effective hectare which is then adjusted to represent the width of the buffer strip on a square metre basis (i.e. a 5 metre buffer strip has an opportunity cost determined from retiring 5m^2 for every linear metre of waterway). These costs relate to only one side of a waterway.

Table 27: Opportunity costs – retiring riparian margins ($/buffer width m^2/yr)

Land use	Operating profit		Annual opportunity cost ($/buffer width m^2/yr)		
	($/ha/yr)	($/m^2/yr)	Low estimate	Average estimate	High estimate
			1 metre buffer		
Sheep and beef (<10SU/ha)	420	0.04	0.01	0.02	0.03
Sheep and beef (>10SU/ha)	680	0.07	0.02	0.03	0.05
Dairy	1,330	0.13	0.03	0.07	0.10
Arable (Medium Impact Horticulture)	2,400	0.24	0.06	0.12	0.18
Vegetable (High Impact Horticulture)	4,000	0.40	0.10	0.20	0.30
			3 metre buffer width		
Sheep and beef (<10SU/ha)	420	0.04	0.03	0.06	0.09
Sheep and beef (>10SU/ha)	680	0.07	0.05	0.10	0.15
Dairy	1,330	0.13	0.10	0.20	0.30
Arable (Medium Impact Horticulture)	2,400	0.24	0.18	0.36	0.54
Vegetable (High Impact Horticulture)	4,000	0.40	0.30	0.60	0.90
			5 metre buffer width		
Sheep and beef (<10SU/ha)	420	0.04	0.05	0.11	0.16
Sheep and beef (>10SU/ha)	680	0.07	0.09	0.17	0.26
Dairy	1,330	0.13	0.17	0.33	0.50
Arable (Medium Impact Horticulture)	2,400	0.24	0.30	0.60	0.90
Vegetable (High Impact Horticulture)	4,000	0.40	0.50	1.00	1.50
			10 metre buffer width		
Sheep and beef (<10SU/ha)	420	0.04	0.11	0.21	0.32
Sheep and beef (>10SU/ha)	680	0.07	0.17	0.34	0.51
Dairy	1,330	0.13	0.33	0.67	1.00
Arable (Medium Impact Horticulture)	2,400	0.24	0.60	1.20	1.80
Vegetable (High Impact Horticulture)	4,000	0.40	1.00	2.00	3.00

5.3. Planting

Two riparian planting sub-categories are considered: either riparian planting or no planting (e.g., rank grass and/or passive regeneration of native riparian species assumed). Only two options are proposed given the limited extent of benefits-assessments in the literature. The capital costs for the two planting sub-categories are summarised in **Table *28***. As discussed in Section 1.1 no consideration is given to how benefits vary with time.

The riparian planting option is based on the entire setback riparian area being planted by a mix of native riparian species at 1 metre spacing (e.g., 10,000 plants/ha of retired riparian margin) inclusive of labour, plant and site preparation. The riparian literature covers a range of plant spacings, where information on spacing is available, but an average of 1 metre spacing was identified as generally good farming practice.

Planting options exclude costs for fertiliser, weed matting or plant guards (i.e., costs will be greater on properties with pest management issues). Planting costs were based on $4.25/plant (low), $5.50/plant (medium) and $7.00/plant (high), inclusive of labour which was assumed at $2.00/plant. Latter costs are based on all proceeding discussion as well as market prices for plants and best professional judgement. Variation in latter costs might be expected of larger scale or voluntary planting exercises but is not accounted for here.

To ensure consistency with opportunity costing of the buffer width, planting costs are presented as dollar costs per m^2 of buffer. While it may be more intuitive to present these as areal costs, scenario modelling in the FWMT will be tied to discrete waterways owing to a regionwide LiDAR-based flow path layer and FWMT reach network. Hence, costs per linear metre of waterway are better aligned to FWMT scenario development. Costs which do not vary by area (e.g. fencing) are presented as linear metre costs, while costs that do vary by area (e.g. planting costs) are presented as costs per square metre of buffer width (which equates to 1 linear metre of stream multiplied by the applicable buffer width).

Table 28: Capital costs – planting (2019$/buffer width m^2)

Planting option	Buffer width	Capital ($/buffer width m^2)		
		Low estimate	Medium estimate	High estimate
Riparian planting (sedges and shrubs)	3	12.75	16.5	21
Riparian planting (sedges and shrubs)	5	21.25	27.5	35
Riparian planting (sedges and shrubs)	10	42.5	55	70
Rank grass	1	0	0	0
Rank grass	3	0	0	0
Rank grass	5	0	0	0
Rank grass	10	0	0	0

The annual maintenance costs of planting sub-categories are considered in **Table *29***. These costs are based on all proceeding discussion as well as market prices for plants and best professional judgement. Plant prices are considered as replacement plant costs are included in years 1-4.

For rank grass maintenance is zero for the low estimate, $500/ha (adjusted to a m^2 of buffer area equivalent) for the medium estimate and $800/ha for the high estimate. These apply from year 1 to 50 and include general maintenance such as spraying under fence lines and weed control.

For riparian planting, the general maintenance costs applied to rank grass also apply to the riparian planting maintenance costs for year 1. Maintenance costs in years 1-4 also include replacement plant costs for some plant die off, this is based on $1.50/plant (low), $2/plant (medium) and $2.50/plant (high). This can represent a cost per all plants, or the full replacement cost for a proportion of plants. The maintenance costs in year 1 are then adjusted to 75% in year 2 and 50% in year 3. Years 4-50 exclude additional plant costs and instead are based on the general maintenance costs applied to rank grass.

Table 29: Maintenance costs – fencing (2019$/ buffer width m²)

Planting options	Buffer width	Year 1	Year 2	Year 3	Year 4-50
		Low estimate ($/buffer width m²/yr)			
Riparian planting (sedges and shrubs)	3	4.5	3.38	2.25	0
Riparian planting (sedges and shrubs)	5	7.5	5.63	3.75	0
Riparian planting (sedges and shrubs)	10	15	11.25	7.5	0
Rank grass	1	0	0	0	0
Rank grass	3	0	0	0	0
Rank grass	5	0	0	0	0
Rank grass	10	0	0	0	0
		Medium estimate ($/buffer width m²/yr)			
Riparian planting (sedges and shrubs)	3	6.15	4.61	3.08	0.15
Riparian planting (sedges and shrubs)	5	10.25	7.69	5.13	0.25
Riparian planting (sedges and shrubs)	10	20.5	15.38	10.25	0.5
Rank grass	1	0.05	0.05	0.05	0.05
Rank grass	3	0.15	0.15	0.15	0.15
Rank grass	5	0.25	0.25	0.25	0.25
Rank grass	10	0.5	0.5	0.5	0.5
		High estimate ($/buffer width m²/yr)			
Riparian planting (sedges and shrubs)	3	7.74	5.81	3.87	0.24
Riparian planting (sedges and shrubs)	5	12.9	9.68	6.45	0.4
Riparian planting (sedges and shrubs)	10	25.8	19.35	12.9	0.8
Rank grass	1	0.08	0.08	0.08	0.08
Rank grass	3	0.24	0.24	0.24	0.24
Rank grass	5	0.4	0.4	0.4	0.4
Rank grass	10	0.8	0.8	0.8	0.8

6. Benefits suggested for FWMT

The literature on riparian management effects (benefit) is considerably less detailed than that for cost. Whilst general principles are well known (e.g., non-linear increasing effect for increasing setback), precise effects of varying riparian management scenarios across gradients in soil, topography and planting are relatively poorly quantified or explained (see Collier et al., 1995 and McKergow et al., 2016). The FWMT can accommodate such uncertainty by simplifying representation of riparian management benefits in Stage 1. However, removing granularity of costing will unnecessarily incur greater error in costs accounted for by the FWMT. Sensitivity testing can reveal the importance of further research to quantify the performance of differing options (e.g., varying setback).

Benefits from riparian management cannot include robust estimates of reduced bankside erosion given considerable lack of understanding and complexity in the latter across the literature – ongoing research by AC has already identified hydrological variation coupled to mechanical changes in bankside structure appear most critical to explaining bankside erosional processes (e.g., soil shear stress, profile and vegetation type – see Simon et al., 2015, 2016). Hence, riparian management benefits should be applied to edge-of-stream HRU yields within the FWMT Stage 1 – doing so will under-estimate likely reductions in bankside erosion from the exclusion of livestock (i.e., removal of direct mechanical forces from stock treading and indirectly benefit mechanical resistance through increased vegetation cover following removal of stock browsing [see Parkyn, 2004]). Meaning, further consideration needs to be given in FWMT scenario testing, to modelling bankside erosional changes directly within the FWMT (i.e., considering effects of altered vegetation cover, root structure and altered mechanical action of livestock on bank structure).

All riparian management benefits must be applied from some baseline – all riparian management scenarios will require some prior degree of adoption to be assumed or determined for the baseline period (2013-2017). Any baseline assumption on prior adoption should also affect scenario costs.

This section details the benefits for both pastoral and horticultural land uses from riparian management options with as much granularity as possible from robust literature.

6.1. Pastoral riparian management benefits

To apply earlier reported riparian benefits, those studies must be aligned to the HRU framework. Pastoral HRU's are classified by slope (less than and greater or equal to 10 degrees), soil type (five hydrological soil groups) and intensity (less than and greater or equal to 10 stock units per ha).

For the purposes of this review, it is assumed that intensity is separated into three groups, (1) less than 10 stock units per hectare which is assumed to equate to low intensity sheep and beef farming, and two groupings of greater than 10 stock units per hectare which are assumed to be (2) high intensity beef and (3) dairy (see **Table *1***). These assumptions are predicated on the relative presence of cattle to sheep and the contaminant loss profile of these different animal types.

Then benefits are described as fencing only (assumed to have a 1 metre setback for practicality purposes) or fencing and planting scenarios (with applicable widths noted) where possible, based on the literature available. Where possible, vegetation differences (rank grass, or planted) are considered. No slope differences have been considered due to a lack of data.

For nitrogen, Doole (2015) and Daigneault and Elliott (2017) are primarily used to estimate the efficacy of various riparian management options. Neither differentiate by slope type, and a 5 metre buffer is the basis thereof. The estimates for fencing rank grass are based on Doole (2015) which is similar to Daigneault and Elliott (2017). The efficacy of fencing with riparian plants is based on Daigneault and

Elliott (2017), however it must be noted that they use the same estimates for sheep and beef and dairy for riparian planting.

For phosphorus it is important to consider the type of phosphorus being removed as while they can reduce total phosphorus loadings (e.g. Zhang et al., 2010). However, their ability to reduce dissolved forms of phosphorus to streams is limited, unless riparian vegetation is harvested regularly (e.g. McDowell et al., 2004). It is therefore important to not double count the phosphorus benefits with sediment benefits, especially for particulate phosphorus. The benefits for phosphorus loss in Table 30 are based on Monaghan et al. (2010) and Semadeni-Davies and Elliott (2012) (as reviewed in Doole, 2015) and represent both dissolved and particulate phosphorus.

For sediment, Daigneault and Elliot (2017) provide estimates of sediment removal across pastoral land uses for 5 metre riparian buffers (with and without planting). Because they provide estimates with detail on land use and width of buffer these estimates are used. These estimates are higher than Basher et al. (2019), however, given the lack of detail on buffer width and land use types, Basher et al. (2019) was not used.

For *E. coli*, the estimates in Doole (2015) are used. These are in line with Daigneault and Elliott (2017), however Daigneault and Elliott (2017) use an estimate of 60% across all land use types and does not differentiate between riparian plants and rank grass. Doole (2015) does not consider the efficacy of riparian planting separate to fencing, because experimental research has shown that there is little benefit to riparian planting, compared with the presence of just pasture due to the absorptive capacity of riparian plants during high flow rates (e.g. storms). The benefits from Doole (2015) are assumed to be for a 5 metre buffer strip.

Table 30: Pastoral benefits from riparian management for use in FWMT Stage 1 scenario testing

Contaminant	Slope	Soil type	Planting option	Buffer width	Sheep and beef	Beef**	Dairy**	Source
					Efficacy (percentage removal)			
Nitrogen (TN)	Not differentiated		Fencing only	1m	-	-	-	No reliable source
			Rank grass	5m	5%	15%	15%	Doole (2015)
			Riparian plants	5m	56%	56%	56%	Daigneault & Elliott (2017)
Phosphorus (TP)	Not differentiated		Fencing only*	1m	-	-	-	No reliable source
			Rank grass	5m	5%	10%	10%	Doole (2015)
			Riparian plants	5m	50%	50%	50%	Daigneault & Elliott (2017)
Sediment (TSS)	Not differentiated		Fencing only*	1m	-	-	-	No reliable source
			Rank grass	5m	70%	70%	70%	Daigneault & Elliott (2017)
			Riparian plants	5m	75%	75%	75%	
E. coli	Not differentiated		Fencing only*	1m	58%	58%	58%	Doole (2015)
			Rank grass	5m	60%	60%	60%	Daigneault & Elliott (2017)
			Riparian Plants	5m	60%	60%	60%	

**Fencing only scenarios will not directly account for reduced bankside erosion as changes in erosion should be simulated remotely in LSPC via changes to FWMT reach type (e.g., erosivity, vegetation effects) and hydrology. Those affects should only be applied to streams with fencing and/or fencing and 5 metre setback (i.e., any fencing-based reduction in bankside erosion is accounted for elsewhere through changes in FWMT reach processes but which will not be felt on streams with livestock access and continued browsing/mechanical damage to bank structure).*

***Similar effects for beef only and dairy only systems reflects the literature but also the principle that mitigation efficacy should be alike all things even (e.g., same management of same stock type – cattle – should have same effect; management of cattle and sheep appears to have differing benefit presumably from a differing mixed source of contaminant and stock behaviours in-paddock coarsely approximated by the reported benefits). However, these are separated here due to different cost assumptions.*

The rational basis for Table 29 is preference for more recent studies, particularly those of national or Auckland relevance (e.g., Daigneault and Elliott, 2017) or of broad national review (e.g., Doole, 2015). Ensuring that increasing buffer width results in equivalent or increased effect, even if minor (e.g., Collier et al., 1995; Rutherford et al., 1999; Basher et al., 2019). So, that 5m buffers have increased effect on 1m buffer (fencing only). Also that planted buffers have no better an effect on E.coli (e.g., Doole, 2015) but cause greater attenuation of TN, TP and TSS through improved uptake, complex vegetation forms (greater cover/height) and improved soil drainage (McKergow et al., 2016). The choice of 5m buffer for rank grass or planting scenarios, was rationalised from more recent and more numerous evidence being generated for 5m or greater buffers (see Doole, 2015; Daigneault and Elliott, 2017; Daigneault et al., 2017b), and that 5m is likely to capture the greater majority of otherwise 10m and 20m buffer effects on contaminant losses to streams (Zhang et al., 2010). Note, lengthier buffers are readily able to be costed if considering more than water quality contaminant purposes (e.g., biodiversity, climate change, cultural or aesthetic qualities). However, 5m is the minimum setback for which the greater part of the literature estimates riparian management effects on waterway contaminants.

Note fencing only scenarios include no direct reduction in TN because there is evidence for minimal TN-loads from pasture being direct-deposited instream (e.g., McKergow et al., 2007). Equally, fencing only scenarios include no direct reduction in TSS or TP because the few studies attempting to quantify latter reductions do so for fencing and markedly larger setbacks combined without discriminating the fencing only effects (see Doole, 2015). However, that is not to then suggest livestock exclusion does not reduce bankside erosion as sufficient studies exist to indicate as much, from reduced mechanical action of stock hooves and increased vegetation cover resulting in greater mechanical bank strength from root systems (e.g., McKergow et al., 2016). Instead, bank erosion could be modelled in LSPC and effects from livestock exclusion (fencing only or fencing and setback options) indirectly accounted for by being assigned only to streams with pastoral riparian management options (i.e., modelled in LSPC but only for streams subject to the livestock exclusion practices; all other streams remaining alike to baseline conditions and no less eroded). Such indirect accounting reflects the scant evidence for fencing only effects on livestock exclusion and the configuration of the FWMT Stage 1 to model bankside and gully (tributary) erosion from predicted hydrology and FWMT reach groups (see Bambic et al., 2020).

6.2. Horticulture riparian management benefits

There is limited information available on the efficacy of various options for riparian areas in horticulture. In particular, there is limited to no information differentiation between the various types of horticulture considered in the FWMT stage 1 (characterised here by orchards, arable and vegetables), buffer widths and planting options (grass or planted). Fencing is typically not considered as stock are not a consideration. For the purposes of stage 1 of the FWMT there is a base assumption that there is no horticulture land use on steep land.

The benefits presented here are predicated on two main sources, Daigneault and Elliott (2017) and Basher et al. (2019), neither of these consider varying buffer widths. Daigneault and Elliott (2017) separate arable and horticulture (but there is no difference in benefits listed) they consider only planted buffer strips and only 5 metre buffer widths. **Table *31*** describes the best possible information for efficacy of riparian areas for horticulture at the most granular level possible based on current literature.

Table 31: Horticultural benefits from riparian management for use in FWMT Stage 1 scenario testing

Contaminant	Planting option	Buffer width	All horticulture land types (Low, Medium & High Impact) Efficacy (percentage removal)	Source
Nitrogen (TN)	Rank grass	5m	-	No source available
	Riparian plants	5m	51%	Daigneault & Elliott (2017)
Phosphorus (TP)	Rank grass	5m	-	No source available
	Riparian plants	5m	50%	Daigneault & Elliott (2017)
Sediment (TSS)	Rank grass	5m	40%	Basher et al (2019)
	Riparian plants	5m	75%	Daigneault & Elliott (2017)**
*E. coli**	Rank grass	5m	-	No reliable source
	Riparian plants	5m	-	

**Note E. coli attenuation assigned to pastoral setbacks was on basis that fencing alone accounted for a 58% attenuation with only a further 2% derived from a 5m setback. The 2% effect could be carried over here into horticulture for consistency but would be inaccurate given the markedly different baseline loads between pasture and horticulture (i.e., 5m setbacks might have more marked relative effect on a lower horticultural E.coli yield to waterways). However, there is no reliable source for such attenuation estimates and besides, the decision is immaterial as baseline E.coli contributions from horticulture are negligible in the FWMT Stage 1 (i.e., any riparian management effect even if 100% would have a marginal overall effect on E.coli loads to waterways from horticultural HRU's).*

*** Assumes sediment attenuation is equivalent to pasture in absence of robust information and given equivalent vegetation cover. Sediment yields are broadly equivalent between some pastoral and horticultural HRU's meaning any equivalent effect would also be from equivalent baseline. As with pastoral riparian management, the effects of reduced bank erosion from 5 metre setbacks should be accounted for through altered stream configuration and hydrology in LSPC.*

7. Scenarios suggested for FWMT Stage 1

While the cost information presented in section 4 would capture key variation in costs of different riparian area management options, as shown in section 5 there is limited granularity in benefit information and therefore there is limited granularity in scenarios that can be considered for stage 1 of the FWMT. While detailed costs could be included, if the same granularity in benefits is not included the results would need to be interpreted with caution, i.e. if there is a difference in costs between a three and 10 metre buffer strip but no difference in the benefit it could lead to perverse outcomes. The lack of detail and granularity available for estimating efficacy of various riparian area management scenarios is the key limitation in including mitigation option in stage 1 of the FWMT.

The costs and benefits in **Table *32*** to **Table *36*** are based on the data provided in Sections 4 and 5 and should be read in conjunction with the assumptions in these (and preceding) sections. All costs presented are based on the medium cost scenarios. Slope is included as it has an impact on cost and will enable the FWMT to consider fencing various slope classes (e.g. only fencing flat and rolling land or steep land). However, there is no data to vary the benefits by slope at this stage. No soil differences are considered.

Table 32: Dairy (>10SU/ha) – cost and efficacy summary, medium cost

	Costs						**Efficacy (% change)**			
Scenario description [b]	**Capital costs**			**Maintenance costs**		**Opportunity cost ($/buffer width m^2/yr)**	**Nitrogen (TN)**	**Phosphorus (TP)**	**Sediment (TSS)**	***E. coli***
	Fencing [a] **($/m)**	**Planting ($/buffer width m^2)**	**Stock water reticulation**	**Fencing ($/m/yr)**	**Planting ($/buffer width m^2/yr)**					
Fencing only 1m buffer width Rank grass Flat/rolling	Yr. 0: $5.40 Yr. 25: $5.40	-	NA [c]	$0.05	Yr. 1-50: $0.05	$0.07	-	-	-	-58%
Fencing only 1m buffer width Rank grass Steep	Yr. 0: $7.70 Yr. 25: $7.70	-		$0.11	Yr. 1-50: $0.05	$0.07				
Riparian buffer 5m buffer width Rank grass Flat/rolling	Yr. 0: $5.40 Yr. 25: $5.40	-		$0.05	Yr. 1-50: $0.25	$0.33	-15%	-10%	-70%	-60%
Riparian buffer 5m buffer width Rank grass Steep	Yr. 0: $7.70 Yr. 25: $7.70	-		$0.11	Yr. 1-50: $0.25	$0.33				
Riparian buffer 5m buffer width Riparian plants Flat/rolling	Yr. 0: $5.40 Yr. 25: $5.40	Yr. 0: $27.50 ($5.50/linear metre of fence)		$0.05	Yr. 1: $10.25 Yr. 2: $7.69 Yr. 3: $5.13 Yr. 4-50: $0.25	$0.33	-56%	-50%	-75%	-60%
Riparian buffer 5m buffer width Riparian plants Steep	Yr. 0: $7.70 Yr. 25: $7.70	Yr. 0: $27.50 ($5.50/linear metre of fence)		$0.11	Yr. 1: $10.25 Yr. 2: $7.69 Yr. 3: $5.13 Yr. 4-50: $0.25	$0.33				

[a] *Assumes 2-wire electric fencing for dairy farms*
[b] *no difference in soil type considered*
[c] *assume dairy does not require stock water reticulation costs*

Table 33: Sheep and beef (<10SU/ha) – cost and efficacy summary, medium cost

Scenario description [b]	Costs							Efficacy (% change)			
	Capital costs			Maintenance costs			Opportunity cost ($/buffer width m^2/yr)	Nitrogen (TN)	Phosphorus (TP)	Sediment (TSS)	*E. coli*
	Fencing [a] ($/m)	Planting ($/buffer width m^2)	Stock water reticulation ($/ha)	Fencing ($/m/yr)	Planting ($/buffer width m^2/yr)	Stock water reticulation					
Fencing only 1m buffer width Rank grass Flat/rolling	Yr. 0: $16.10 Yr. 25: $16.10	-	$140	$0.16	Yr. 1-50: $0.05	R&M yr 1: $2.10[c] Other yr1-50: $2.95	$0.02	-	-	-	-58%
Fencing only 1m buffer width Rank grass Steep	Yr. 0: $18.20 Yr. 25: $18.20	-	$140	$0.32	Yr. 1-50: $0.05	R&M yr 1: $2.10[c] Other yr1-50: $2.95	$0.02				
Riparian buffer 5m buffer width Rank grass Flat/rolling	Yr. 0: $16.10 Yr. 25: $16.10	-	$140	$0.16	Yr. 1-50: $0.25	R&M yr 1: $2.10[c] Other yr1-50: $2.95	$0.11	-5%	-5%	-70%	-60%
Riparian buffer 5m buffer width Rank grass Steep	Yr. 0: $18.20 Yr. 25: $18.20	-	$140	$0.32	Yr. 1-50: $0.25	R&M yr 1: $2.10[c] Other yr1-50: $2.95	$0.11				
Riparian buffer 5m buffer width Riparian plants Flat/rolling	Yr. 0: $16.10 Yr. 25: $16.10	Yr. 0: $27.50 ($5.50/linear metre of fence)	$140	$0.16	Yr. 1: $10.25 Yr. 2: $7.69 Yr. 3: $5.13 Yr. 4-50: $0.25	R&M yr 1: $2.10[c] Other yr1-50: $2.95	$0.11	-56%	-50%	-75%	-60%
Riparian buffer 5m buffer width Riparian plants Steep	Yr. 0: $18.20 Yr. 25: $18.20	Yr. 0: $27.50 ($5.50/linear metre of fence)	$140	$0.32	Yr. 1: $10.25 Yr. 2: $7.69 Yr. 3: $5.13 Yr. 4-50: $0.25	R&M yr 1: $2.10[c] Other yr1-50: $2.95	$0.11				

[a] *Assumes 8-wire non-electric post and batten fencing*
[b] *no difference in soil type considered*
[c] *Assumed to increase at 1% per year*

Table 34: Sheep and beef (>10SU/ha) – cost and efficacy summary, medium cost

Scenario description[b]	**Costs**							**Efficacy (% change)**			
	Capital costs			**Maintenance costs**			**Opportunity cost ($/buffer width m^2/yr)**	**Nitrogen (TN)**	**Phosphorus (TP)**	**Sediment (TSS)**	***E. coli***
	Fencing[a] **($/m)**	**Planting ($/buffer width m^2)**	**Stock water reticulation ($/ha)**	**Fencing ($/m/yr)**	**Planting ($/buffer width m^2/yr)**	**Stock water reticulation**					
Fencing only 1m buffer width Rank grass Flat/rolling	Yr. 0: $8.40 Yr. 25: $8.40	-	$140	$0.08	Yr. 1-50: $0.05	R&M yr 1: $2.10[c] Other yr1-50: $2.95	$0.03	-	-	-	-58%
Fencing only 1m buffer width Rank grass Steep	Yr. 0: $10.80 Yr. 25: $10.80	-	$140	$0.17	Yr. 1-50: $0.05	R&M yr 1: $2.10[c] Other yr1-50: $2.95	$0.03				
Riparian buffer 5m buffer width Rank grass Flat/rolling	Yr. 0: $8.40 Yr. 25: $8.40	-	$140	$0.08	Yr. 1-50: $0.25	R&M yr 1: $2.10[c] Other yr1-50: $2.95	$0.17	-15%	-10%	-70%	-60%
Riparian buffer 5m buffer width Rank grass Steep	Yr. 0: $10.80 Yr. 25: $10.80	-	$140	$0.17	Yr. 1-50: $0.25	R&M yr 1: $2.10[c] Other yr1-50: $2.95	$0.17				
Riparian buffer 5m buffer width Riparian plants Flat/rolling	Yr. 0: $8.40 Yr. 25: $8.40	Yr. 0: $27.50 ($5.50/linear metre of fence)	$140	$0.08	Yr. 1: $10.25 Yr. 2: $7.69 Yr. 3: $5.13 Yr. 4-50: $0.25	R&M yr 1: $2.10[c] Other yr1-50: $2.95	$0.17	-56%	-50%	-75%	-60%
Riparian buffer 5m buffer width Riparian plants Steep	Yr. 0: $10.80 Yr. 25: $10.80	Yr. 0: $27.50 ($5.50/linear metre of fence)	$140	$0.17	Yr. 1: $10.25 Yr. 2: $7.69 Yr. 3: $5.13 Yr. 4-50: $0.25	R&M yr 1: $2.10[c] Other yr1-50: $2.95	$0.17				

[a] *Assumes 4-wire electric fencing*
[b] *no difference in soil type considered*
[c] *Assumed to increase at 1% per year*

Table 35: Medium Impact Horticulture (arable, citrus, fodder, nuts, viticulture) & Low Impact Horticulture (orchards, idle & fallow) – cost and efficacy summary, medium cost

Scenario description [a, b]	Costs			Efficacy (% change)			
	Capital costs	Maintenance costs	Opportunity cost ($/buffer width m^2/yr)	Nitrogen (TN)	Phosphorus (TP)	Sediment (TSS)	*E. coli*
	Planting ($/buffer width m^2)	Planting ($/buffer width m^2/yr)					
Riparian buffer 5m buffer width Rank grass	-	Yr. 1-50: $0.25	$0.60	-	-	-40%	-
Riparian buffer 5m buffer width Riparian plants	Yr. 0: $27.50 ($5.50/linear metre)	Yr. 1: $10.25 Yr. 2: $7.69 Yr. 3: $5.13 Yr. 4-50: $0.25	$0.60	-51%	-50%	-75%	-

[a] *no difference in slope considered as no fencing costs included and no difference in benefits available*
[b] *no difference in soil type considered*

Table 36: High Impact Horticulture (berryfruit, flowers, stonefruit, kiwifruit, nursery, pipfruit, fruit, vegetables, greenhouses) – medium cost

Scenario description [a, b]	Costs			Efficacy (% change)			
	Capital costs	Maintenance costs	Opportunity cost ($/buffer width m^2/yr)	Nitrogen (TN)	Phosphorus (TP)	Sediment (TSS)	*E. coli*
	Planting ($/buffer width m^2)	Planting ($/buffer width m^2/yr)					
Riparian buffer 5m buffer width Rank grass	-	Yr. 1-50: $0.25	$1.00	-	-	-40%	-
Riparian buffer 5m buffer width Riparian plants	Yr. 0: $27.50 ($5.50/linear metre)	Yr. 1: $10.25 Yr. 2: $7.69 Yr. 3: $5.13 Yr. 4-50: $0.25	$1.00	-51%	-50%	-75%	-

[a] *no difference in slope considered as no fencing costs included and no difference in benefits available*
[b] *no difference in soil type considered*

8. Areas for further refinement

There are some key areas to further refine the estimates costs and benefits of riparian management in the FWMT.

1. Refining the efficacy estimates.

Currently the available efficacy estimates lack the desired granularity that would match them with the detailed cost information available. This limits the types of scenarios that can be tested in the FWMT and therefore how the results can be interpreted.

2. Application of the riparian management scenarios.

Consideration needs to be given to how applicable the suggested scenarios are to rural land uses in the Auckland region. This is likely by land use initially but could also consider factors such as type and size of waterbody, slope and type of riparian management in place. For example, what proportion of streams are already fenced, by land use and with what typical buffer width. While some of this information is available (for example what proportion of waterways are fenced on dairy farms), it is not consistently available across all land uses and does not contain all desirable information such as buffer width. Understanding how applicable each scenario is will be important for understanding the magnitude of costs and benefits from applying a particular management scenario to the remaining applicable area.

3. Accommodation of limitations underpinning estimates.

The estimates of riparian buffer attenuation of contaminants in surface and subsurface flows presented here, are widely informed by literature or mechanistic modelling. The latter assume uniformly distributed flows into buffers from paddocks or forested land. Equally the latter do not inform how benefit (attenuation) changes over time within a buffer. Both are important matters to resolve for any application of riparian area management to the FWMT, having potential to cause wide variation in benefit modelled for scenarios.

4. Refining the cost and benefit estimates by land use.

As discussed in Section 1.1 the current definitions of the HRUs means some land uses, such as deer farms and horticulture land uses such as orchards (as horticulture is based on an arable model for Medium Impact and a vegetable model for High Impact) are not considered in this Stage of the FWMT. Refining the cost and benefit estimates to explicitly consider some of these land uses would provide improved estimates, however, this is dependent on accessing benefit estimates for these land uses.

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