Addendum to: Lifecycle Costs and Benefits for Rural Mitigations in Freshwater Management Tool

Prepared for

Auckland Council

Report prepared by

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- Table 20 was updated to reflect an error in row labels.

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Executive Summary

Auckland Council (AC) has requested that as part of their ongoing development of the Fresh Water Management Tool (FWMT), a staged 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) and Muller and Stephens (2020) with the aim to provide initial estimates of mitigation options, cost and effectiveness. This was then incorporated into the FWMT based on the recommendations in Muller, Ira and Stephens (2022). As part of this process, there have been some changes required, including changes to the current rural sector interventions and the addition of new mitigations. These changes are detailed in this addendum report which should be read in conjunction with the previous reports.

The FWMT Stage 1 continuously simulates the baseline or current state of water quality (2013-2017) via process-modelling across the entire Auckland region, and enables optimization modelling across intervention types, to identify potential future states and associated management strategies (e.g., choice of intervention, targeted hydrologic response unit (HRU) type and sub-catchment, prioritised for cost over a 50-year discounted life-cycle). The FWMT Stage 1 enables both current and future states to be simulated for nutrients (nitrogen, phosphorus), heavy metals (copper, zinc), sediment and faecal indicator bacteria (*E. coli*). The FWMT thereby supports Auckland Council decision-making and management of water quality for existing, future development and climate associated pressures.

Muller et al. (2020) translated literature on rural water quality mitigations into a 50-year Life Cycle Cost (LCC). The LCC approach is consistent with urban water quality intervention recommendations produced in Ira, Walsh and Batstone (2021). This ensures the FWMT Stage 1 offers an integrated platform for water quality decision-making across the entire Auckland region. LCC estimates are based on capital, maintenance, replacement and where suitable, opportunity cost or reduced profit, throughout a 50-year period. LCC are supplied in Appendix 1 for a discount rate of 4%.

The changes that are detailed in this addendum are:

- Add a large rural constructed wetland which is larger and more expensive than the current rural facilitated wetland and will be used in the FWMT.
- Add additional riparian options, 2.5 m and 10 m wide buffer strips across the HRU types and both planted and grassed scenarios.
- Adjust the mitigation bundles for the dairy (> 10 SU/ha) HRU.
- Adjust the mitigation bundle M1 for high impact horticulture.

This report 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, underpinning a decadal model development programme. The FWMT Stage 1 is the first iteration which despite the complexity of a continuous and process-based approach, spanning 5,465 sub-catchments, 107 HRUs and multiple contaminants, is being developed from a principle of “defensible simplicity”. The granularity, cost and benefit estimates assigned to rural mitigations reflect that principle, ensuring only as fine a recommendation as defensible from the literature (e.g., to HRU group).

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1 Background

Auckland Council (AC) is continuing the development of their Fresh Water Management Tool (FWMT) Stage 1. As part of this work, Perrin Ag Consultants Ltd has been engaged to support inclusion of rural sector mitigation choices. This work included reviewing existing rural literature (Muller et al., 2020a) with the aim to provide initial estimates of mitigation options, cost and effectiveness. In future phases, further consideration will be given to incorporating both additional and refined mitigations as well as tailoring mitigations to the Auckland region whilst recognizing for the sectoral and contaminant uncertainty of mitigations.

The FWMT Stage 1 is already a relatively complex model build for freshwater contaminant accounting, including 50 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). 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.

Similarly, the FWMT is being developed not simply to assess spread in modern-day or baseline (2013-2017) water quality, but also 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. However, unless the literature demonstrates marked differences in impact of cost or benefit, those have been applied in more simplified approaches (e.g., in line with a principle of defensible simplicity).

This report is an extension of Muller et al. (2020a), Muller and Stephens (2020) and Muller et al. (2020b).

- Muller et al. (2020a) reviewed literature and provided a set of cost benefit estimates for bundled mitigation options and edge of field (EOF) mitigation options for pastoral and horticultural land uses for total nitrogen (TN), total phosphorus (TP), sediment (total suspended solids – TSS) and *E. coli*, offering indicative estimates for AC use in FWMT stage 1.
- Muller and Stephens (2020) provided a more in-depth analysis of the costs and benefits specifically for riparian management options.
- Muller et al. (2020b) details the combined cost and benefit information recommended by Muller et al. (2020) and Muller and Stephens (2020), for incorporation into the LCC model developed for both urban and rural mitigation options in the FWMT Stage 1 as well as providing detail on assumptions required to adjust the cost and benefit information from the previous reports to the LCC model framework. More detail on the LCC model can be found in Ira et al. (2021).

This report is a follow-up addendum to Muller et al. (2020b) to detail additional mitigation options and describe changes to previous mitigations to ensure compatibility with the FWMT Stage 1. The full detail on the underlying methodology for incorporating the rural sector mitigations into the FWMT and for the LCC process and assumptions used, is in Muller et al. (2020b), this is not all repeated in this report, which should be read in conjunction with Muller et al. (2020b).

2 Additional Intervention – Large Rural Constructed Wetlands

2.1 Reason for addition

Rural wetlands were included as an edge of field mitigation in Muller et al. (2020b). The cost and benefit estimates of these wetlands were based on established information that challenged the authors to separate cost components and whose limited evidence base restricted variation across HRU. The earlier rural wetland recommendations also intentionally described rural interventions distinguished from expensive/challenging constructed wetlands ("small and medium EOF wetland costs are an average between facilitated and constructed rural wetland costs.", Muller et al., 2020b). Rural "facilitated" wetlands are wetlands which are retired into naturally wetter areas in the rural landscape and do not require as much earthwork construction as rural constructed wetlands. These previously modelled wetlands were also smaller on-farm wetlands, typically expected to be less than 1 ha large.

Since this previous work, new information has been published in DairyNZ Wetlands Guide (Tanner et al. 2022) which provides information on "constructed" rural wetland design recommendations as well as cost and benefit estimates, separated by cost components and supported by 11 case studies. The FWMT programme now seeks to expand the rural intervention library to incorporate the more advanced and potentially, larger wetland options. These larger wetlands are seen as approximately 5 ha in size and treat contaminants from a range of properties. As such, it was requested that a new 'large rural constructed (LRC) wetland' mitigation be described for cost and generalised benefit, to guide its configuration within SUSTAIN for the FWMT.

This chapter documents the assumptions and recommendations to incorporate a new "rural constructed" wetland intervention in the FWMT Stage 1. All wetlands discussed in this report are based in the rural landscape.

2.2 Previous recommendations

The previous capital costs for rural facilitated/constructed wetlands were based on $16.40/m^2 of wetland surface area for wetlands under 1 ha in surface area and $12.40/m^2 of wetland surface area for wetlands over 1 ha in surface area. The difference in cost was based on the relationship detailed in Kadlec and Wallace (2019) which stipulated that there were efficiencies for larger wetlands based on earthworks etc. The capital cost estimates excluded fencing, opportunity cost and water reticulation costs, which were included separately to the wetland capital cost. It also explicitly excluded consent costs due to lack of estimates but included planting and earthworks as well as an implicit estimate of combined indirect and overhead costs that would include planning, consenting and construction of the wetland (i.e., an additional 17.5% of the construction cost). The costs from Muller et al. (2020b) for wetlands are summarised in Table 1 and Table 2. It was assumed that for every square meter of wetland 0.15 m of fencing was required (based on Martin Jenkins, 2020).

Table 1: Costs and benefit of wetlands, excluding fencing - for pastoral and horticulture HRU's

<table>
<tr><th rowspan="2"></th><th>HRU[1]</th><th colspan="4">Contaminant impact[2]</th><th colspan="3">Economic impact</th></tr>
<tr><th>Intensity</th><th>N</th><th>P</th><th>Sediment</th><th>E. coli</th><th>Capital ($/m²)[3]</th><th>Maintenance ($/ha/yr)[4]</th><th>Opportunity cost ($/ha/yr)</th></tr>
<tr><td rowspan="3">Small wetland</td><td>Less than 10 SU/ha</td><td rowspan="3">-10%</td><td rowspan="3">-45%</td><td rowspan="3">-65%</td><td rowspan="3">-55%</td><td rowspan="3">16.40</td><td rowspan="3">125</td><td>189</td></tr>
<tr><td>Sheep & beef - More than 10 SU/ha</td><td>323</td></tr>
<tr><td>Dairy - More than 10 SU/ha</td><td>632</td></tr>
<tr><td rowspan="3">Large wetland</td><td>Less than 10 SU/ha</td><td rowspan="3">-10%</td><td rowspan="3">-45%</td><td rowspan="3">-65%</td><td rowspan="3">-55%</td><td rowspan="3">12.60</td><td rowspan="3">250</td><td>189</td></tr>
<tr><td>Sheep & beef - More than 10 SU/ha</td><td>323</td></tr>
<tr><td>Dairy - More than 10 SU/ha</td><td>632</td></tr>
<tr><td rowspan="2">Small wetland</td><td>Low & medium impact</td><td rowspan="2">-10%</td><td rowspan="2">-45%</td><td rowspan="2">-65%</td><td rowspan="2">-55%</td><td rowspan="2">16.40</td><td rowspan="2">125</td><td>1,164</td></tr>
<tr><td>High impact</td><td>1,940</td></tr>
<tr><td rowspan="2">Large wetland</td><td>Low & medium impact</td><td rowspan="2">-10%</td><td rowspan="2">-45%</td><td rowspan="2">-65%</td><td rowspan="2">-55%</td><td rowspan="2">12.60</td><td rowspan="2">250</td><td>1,164</td></tr>
<tr><td>High impact</td><td>1,940</td></tr>
</table>

1. *No differentiation in slope (assumes wetlands only apply to flat and rolling land) or soil type*
2. *Based on Daigneault and Elliott (2017)*
3. *Muller (2019) and NIWA (2007), note no stock water reticulation costs are included, includes planting and earthworks*
4. *Muller (2019)*

Table 2: Capital and maintenance costs – fencing (2019$/m)

<table>
<tr><th rowspan="2">Fence type</th><th rowspan="2">Slope[1]</th><th>Year 0</th><th>Year 1-24</th><th>Year 25</th><th>Year 26-50</th><th rowspan="2">Annual maintenance cost ($/m/yr)</th></tr>
<tr><th colspan="4">Capital costs ($/m)</th></tr>
<tr><td>No fence</td><td rowspan="4">Flat & Rolling</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>2-wire electric</td><td>5.4</td><td>0</td><td>5.4</td><td>0</td><td>0.05</td></tr>
<tr><td>4-wire electric</td><td>8.4</td><td>0</td><td>8.4</td><td>0</td><td>0.08</td></tr>
<tr><td>8-wire non-electric post and batten</td><td>16.1</td><td>0</td><td>16.1</td><td>0</td><td>0.16</td></tr>
</table>

1. *Only flat and rolling fencing costs are included here as wetlands were not included in steep slope areas*

Table 3 shows the estimated benefit for the existing rural facilitated wetlands from Muller et al. (2020b). These are for both pastoral and horticulture wetlands, both small (<1 ha) and large (>1 ha).

Table 3: Benefit of rural facilitated wetlands – Muller et al. (2020b)

	HRU[1]	Contaminant impact[2]			
	Intensity	**N**	**P**	**Sediment**	***E. coli***
Small wetland	Less than 10 SU/ha	-10%	-45%	-65%	-55%
	Sheep & beef - More than 10 SU/ha				
	Dairy - More than 10 SU/ha				
Large wetland	Less than 10 SU/ha	-10%	-45%	-65%	-55%
	Sheep & beef - More than 10 SU/ha				
	Dairy - More than 10 SU/ha				
Small wetland	Low & Medium Impact	-10%	-45%	-65%	-55%
	High Impact				
Large wetland	Low & Medium Impact	-10%	-45%	-65%	-55%
	High Impact				

1. *No differentiation in slope (assumes wetlands only apply to flat and rolling land) or soil type*
2. *Based on Daigneault and Elliott (2017)*

2.3 Intervention cost – new LRC wetland intervention

It is recommended that the following assumptions are retained from Muller et al. (2020b):

- Wetlands only occur in flat and rolling areas.
- The capital costs related to the wetland are incurred in year 1 of the life cycle analysis period only, whereas fencing capital costs are incurred in year 1 and in year 25, assuming a 25-year life-span for fencing.
- The fencing costs are recommended to be the same as in Muller et al. (2020b), where fencing costs are applied for pastoral EOF wetlands, using a wetland area to perimeter ratio of 0.15 m fencing/m^2 wetland, derived for dairy, sheep and beef farms in the Kaipara Moana Remediation business case (Martin Jenkins, 2020).
- The opportunity costs assume that retired area was 50% less productive than the wider, effective farm area. The opportunity costs for these rural constructed wetlands will be the same as those in Muller et al. (2020b). These are likely to change as more regional specific information is modelled.
- Opportunity costs occur annually, as do both fencing and wetland maintenance costs over a 50-year interval (i.e., consistent with all other life cycle costing for rural mitigations).
- Indirect and overhead costs remain at 17.5% of the capital cost, this includes consenting and construction costs in line with other device options and is based on Ira and Simcock (2019).
- Given the range in construction costs for constructed wetlands and the uncertainty in these costs a 15% contingency for construction costs is also included, this is based on Ira et al. (2021).

2.3.1 Capital cost

As discussed in Muller et al. (2020b) there is considerable variation in the cost of constructing wetlands. Tanner et al. (2022) provides an indicative cost per hectare (in 2020 dollars) to establish a new treatment wetland if all work is undertaken by contractors at commercial rates. These costs are broken into key cost components and are detailed in Table 4.

Table 4: Indicative cost for constructing wetlands (Tanner et al., 2022)

Cost item	Indicative cost	$/ha (excl. GST)	Notes
Site survey and wetland design	Lump sum	$3,000 - $7,000	Survey of wetland site and design, including positioning of inlet and outlet structures, treatment basins and estimate of excavation works.
Earthworks	$6.25/m^2 of wetland surface area for initial site clearance. $15/m^3 for excavation.	$110,000 - $130,000	Includes excavation and re-laying of topsoil to form wetland base for planting, and construction of a suitable weir and outlet structure at downstream end. Excludes provision for fish passage structures.
Fencing	$5 - $10 /linear metre (plus gate)	$1,000 - $5,000	Two or four-wire electric fence on 2 or 4 sides of wetland; assumes optimised wetland shape to minimise fence length.
Plant purchase	$1.80 - $5 /plant	$25,000 - $60,000	2.04 plants per square metre (0.7 m spacings) within the wetland area to be flooded; all plants purchased from commercial nurseries.
Planting	$2 - $3/plant	$28,000 - $43,000	Assumes planting is done by commercial planters.
Replacement planting (blanking)	$1.80 - $5/plant	$2,500 - $5,000	5% mortality assumed; includes plant purchase and planting.
Project management	$1.00/m^2 of wetland	$10,000	Earthworks and planting supervision.
Resource consent	Variable	Variable	Dependent on regional council.
Maintenance/ weed control	Lump sum	$2,000 - $4000	Per annum. Assumes bi-yearly clean-out of sedimentation pond.
Total construction cost/ha		$175,000 - $260,000	Assumes all work is done by professional contractors at commercial rates. Excludes resource consent costs.

To assess the capital cost of LRC wetlands the following process was used:

- Key capital cost components were selected (Table 5).
- These were then calculated for the case study wetlands in Tanner et al. (2022), which are detailed in Table 6 and adjusted to a cost per square meter of surface area. This provides the base capital cost for the LRC wetland.
- Following this, fencing costs were added based on Table 2 and the assumption of 0.15 m of fencing per square meter of surface area.

Table 5: Capital cost components from Tanner et al. (2022) for calculating a capital cost for LRC wetlands

Cost item	Cost (excl. GST)	Year cost is incurred in	Notes	Source
Site survey and wetland design	$5,000	Year 1	Lump sum	Tanner et al. (2022)
Earthworks	$21.25	Year 1	$/m^2 of wetland surface	Tanner et al. (2022)
Planting (including plant purchase)	$17.94	Year 1	$/m^2 of wetland surface Assumes 2.04 plants/m^2	Tanner et al. (2022)
Project management	$1.00	Year 1	$/m^2 of wetland surface	Tanner et al. (2022)
Indirect and overhead costs	17.5%	Year 1	Including planning, consenting and construction costs in line with other device options	Ira & Simcock (2019)
Construction contingency	15%	Year 1		Ira et al. (2021)

Based on Table 6 the average construction cost for all wetlands is $37.51/m^2, when the outlier of wetland 3 is removed the average construction cost was $35.91/m^2. Wetland 3 was considerably smaller hence the higher cost given the fixed cost component. It is therefore recommended that the base capital cost (excluding fencing and opportunity costs) for the LRC wetland is $35.91/m^2. An additional 17.5% indirect and overhead cost allowance and a 15% construction contingency cost is included to this base for a total capital cost of $47.58/m^2.

Table 6: Wetlands capital cost based on Tanner et al. (2022) excluding fencing cost

Case Study	Surface area (m^2)	Percentage of catchment area	Capital cost $ (excl. fencing cost)	Capital cost $/m^2 (excl. fencing cost)
1	900	1.6%	$35,857	$39.84
2	2,700	0.6%	$97,572	$36.14
3	260	1.1%	$13,914	$53.52
4	3,400	4.5%	$121,572	$35.76
5	6,420	1.2%	$225,116	$35.06
6	23,000	0.7%	$793,578	$34.50
7	4,400	2.2%	$155,858	$35.42
8	16,000	0.9%	$553,576	$34.60
9	5,000	0.08%	$176,430	$35.29
10	3,000	1%	$107,858	$35.95
11	2,200	1.9%	$80,429	$36.56

2.3.2 Maintenance cost

Table 7 highlights the maintenance cost components for the LRC wetlands as well as the recommended source.

Table 7: Maintenance and opportunity cost components of LRC wetlands

Cost item	Cost (excl. GST)	Year cost is incurred in	Notes	Source
Maintenance (earthworks)	$3,000	Annual	Lump sum	Tanner et al. (2022)
Fencing- maintenance	See Table 2	Annual	Varies based on stock type	Muller et al. (2020b)
Opportunity cost	See Table 1	Annual	Varies based on stock type	Muller et al. (2020b)
Planting- maintenance	$4.13	Yr. 1	Annual cost $/m^2 of wetland surface	Plants spacing based on Tanner et al. (2022) Costs based on Muller et al. (2020b)
	$3.06	Yr. 2		
	$2.04	Yr. 3		
	$0.05	Yr. 4-50		

Tanner et al. (2022) estimated a replacement plant cost of $1.80 - $5/plant ($2,500 - $5,000/ha) which assumed 5% mortality and includes plant purchase and planting. Initial capital planting costs were based on the plant purchase and planting costs from Tanner et al. (2022). However, maintenance costs were based on Muller et al. (2020b) as this was broken down across the years and aligned with other planting maintenance estimates including for riparian areas. However, the costs in Muller et al. (2022) were adjusted to the plant spacing recommended in Tanner et al. (2022).

The maintenance costs for earthworks in Tanner et al. (2022) were utilised, however, the fencing maintenance costs were taken from Muller et al. (2020b) to ensure the maintenance costs aligned with the capital cost sources. The lump sum of maintenance costs of $3,000 for earthworks equates to an average of $0.98/m^2 for the case study wetlands in Tanner et al. (2020; excluding the outlier wetland 3). Given costs need to be on a square meter basis so they can be easily adjusted to a LCC it is recommended that an earthworks maintenance cost of $1.00/m^2 is used for LRC wetlands.

2.3.3 Summary of LRC wetland costs

Table 8 summarises the recommended capital costs for LRC wetlands, for both general capital costs (including planting) as well as the capital cost of fencing (incurred in both year 0 and year 25 and based on 0.15m of fencing per square meter of wetland surface area).

Table 8: Summary of capital costs for LRC wetlands

HRU[1]		Capital cost ($/m^2)[2]	Capital Fencing cost[3] ($/m^2)
Pastoral	Less than 10 SU/ha	$47.58	$2.40 (8-wire non-electric)
	Sheep & beef - More than 10 SU/ha		$1.30 (4-wire electric)
	Dairy - More than 10 SU/ha		$0.80 (2-wire electric)
Horticulture	Low & Medium Impact	$47.58	0
	High Impact		

1. *No differentiation in slope (assumes wetlands only apply to flat and rolling land) or soil type*
2. *Based on Tanner et al. (2022)*
3. *Based on Muller et al. (2020b), incurred in yr. 0 and yr. 25- assuming 0.15m of fencing /m^2 of wetland surface area*

Table 9 summarises the recommended maintenance costs for LRC wetlands, for earthworks, fencing and planting. The annual opportunity cost is also included.

Table 9: Summary of maintenance costs for LRC wetlands

HRU[1]		Earthworks maintenance cost ($/m²/yr)[2]	Fencing maintenance cost ($/m/yr)[3]	Planting maintenance cost ($/m²)[4]	Opportunity cost ($/ha/yr)[5]
Pastoral	Less than 10 SU/ha	$1.00	$0.16 (8-wire non-electric)	Yr. 1: $4.13 Yr. 2: $3.06 Yr. 3: $2.04 Yr. 4: $0.05 Yr. 5-40: $0.05	$189
	Sheep & beef - More than 10 SU/ha		$0.08 (4-wire electric)		$323
	Dairy - More than 10 SU/ha		$0.05 (2-wire electric)		$632
Horticulture	Low & Medium Impact	$1.00	$0		$1,164
	High Impact				$1,940

1. *No differentiation in slope (assumes wetlands only apply to flat and rolling land) or soil type*
2. *Based on Tanner et al. (2022) adjusted to a m² basis based on case study wetland size and fixed sum of $3,000*
3. *Based on Muller et al. (2020b), note $/m/yr, not $/m²*
4. *Based on Muller et al. (2020b), annual cost $/m² of wetland surface area*
5. *Based on Muller et al. (2020b)*

Table 10 summarises the LCCs for LRC wetlands for a 4% discount rate and 50-year LCC period.

Table 10: Annualised LCC (NZ Dollars) for LRC wetland scenarios ($LCC/m²/yr) at 4% discount rate

Rural Land use Type	Description	Annualised/ m² LCC	Total Acquisition Cost
Pastoral	Less than 10 SU/ha (sheep & beef)	$1.66	60%
	More than 10 SU/ha (sheep & beef)	$1.63	60%
	More than 10 SU/ha (dairy)	$1.79	63%
Horticulture	Low and medium impact	$1.62	59%
	High impact	$1.66	58%

2.4 Intervention benefit – new constructed wetland intervention

Tanner et al. (2022) provides estimates of the benefit of wetlands in terms of reductions in sediment (total suspended sediment), N (total nitrogen) and P (total phosphorus). All estimates are based on appropriately constructed wetlands receiving surface drainage and run-off from pastoral farmland with catchment rainfall of 800-1600 mm/year. In addition, the sediment performance is estimated based on soils with less than 35% clay content. The N estimates differentiate between warm (average annual temperature >12°C) and cool (average annual temperature 8-12°C) climatic zones, Auckland is considered a warm zone. Phosphorus estimates do not apply for wetlands where the main source of flow is subsurface drainage containing predominantly dissolved forms of P. All estimates are based on the proportion of the contributing catchment area. Figure 1, Figure 2 and Figure 3 show the performance estimates from Tanner et al. (2022), the solid lines are the median and the shaded areas show the expected inter-annual and inter-site range of performance.

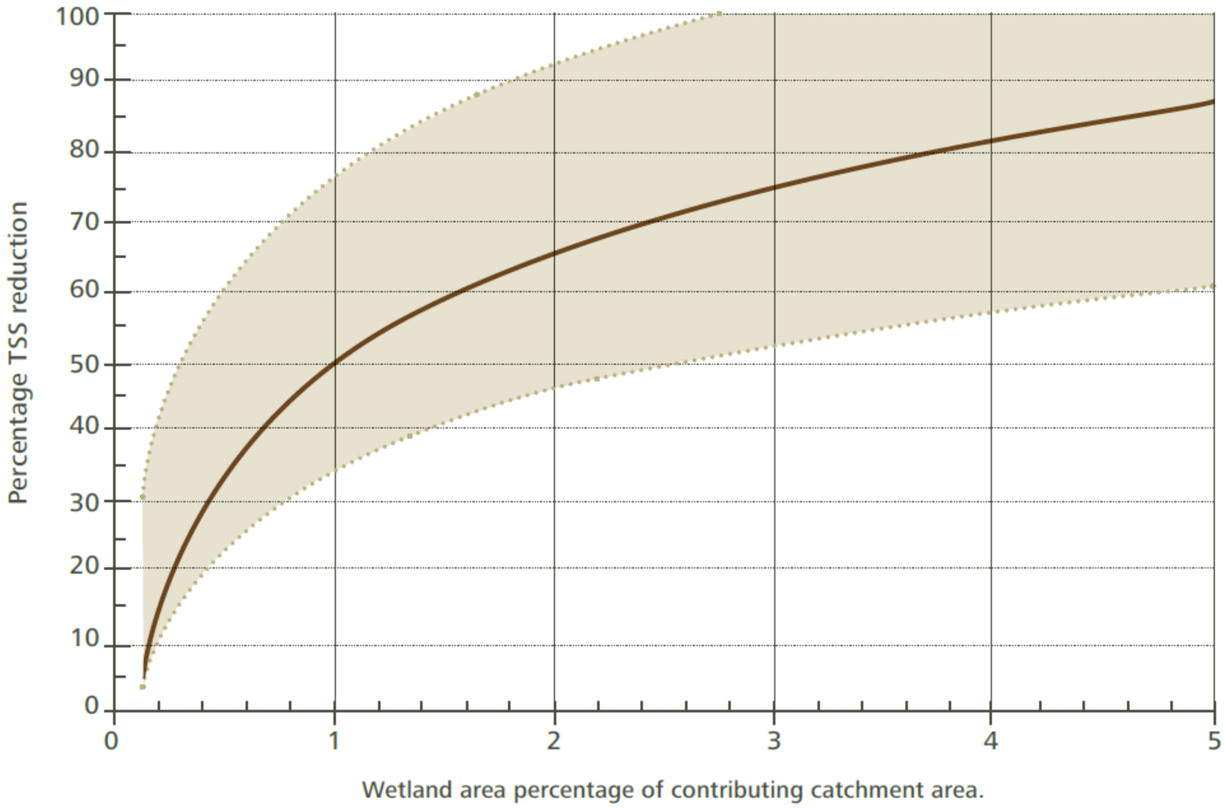

Figure 1: Long-term median annual performance expectations for reduction of total suspended solids (Tanner et al., 2022, p. 7)

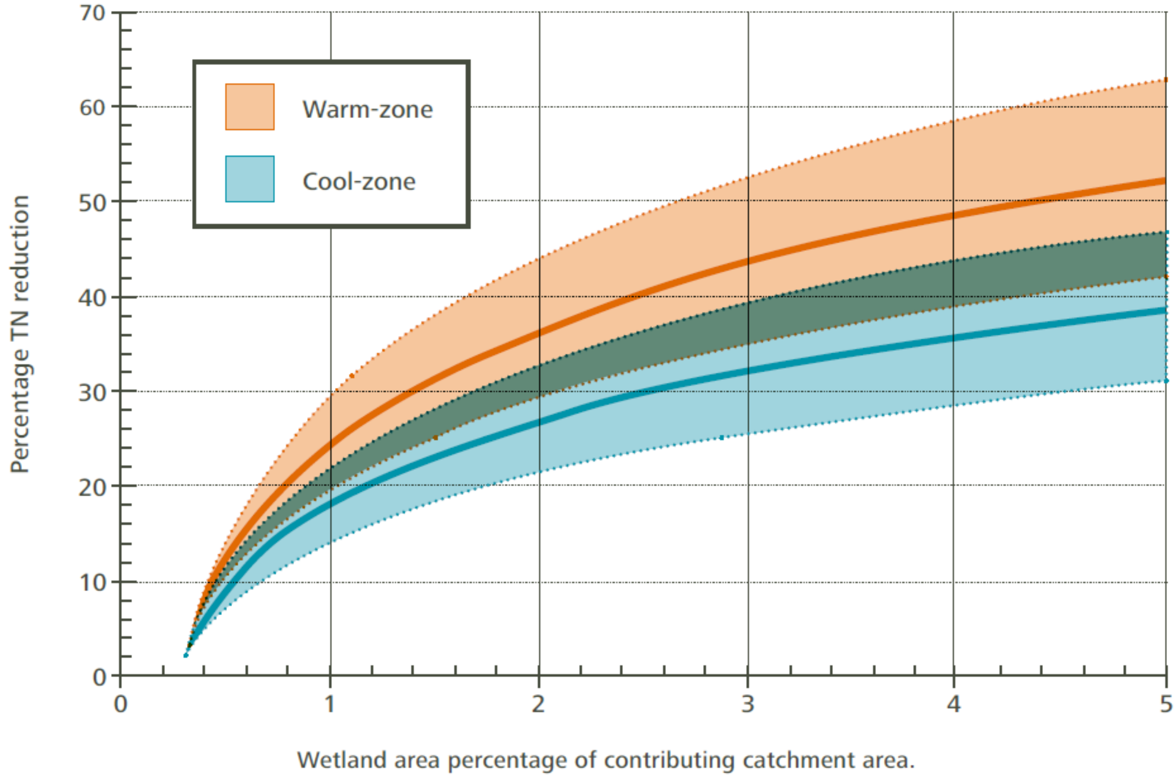

Figure 2: Long-term median annual performance expectations for reduction of total annual nitrogen (Tanner et al., 2022, p. 8)

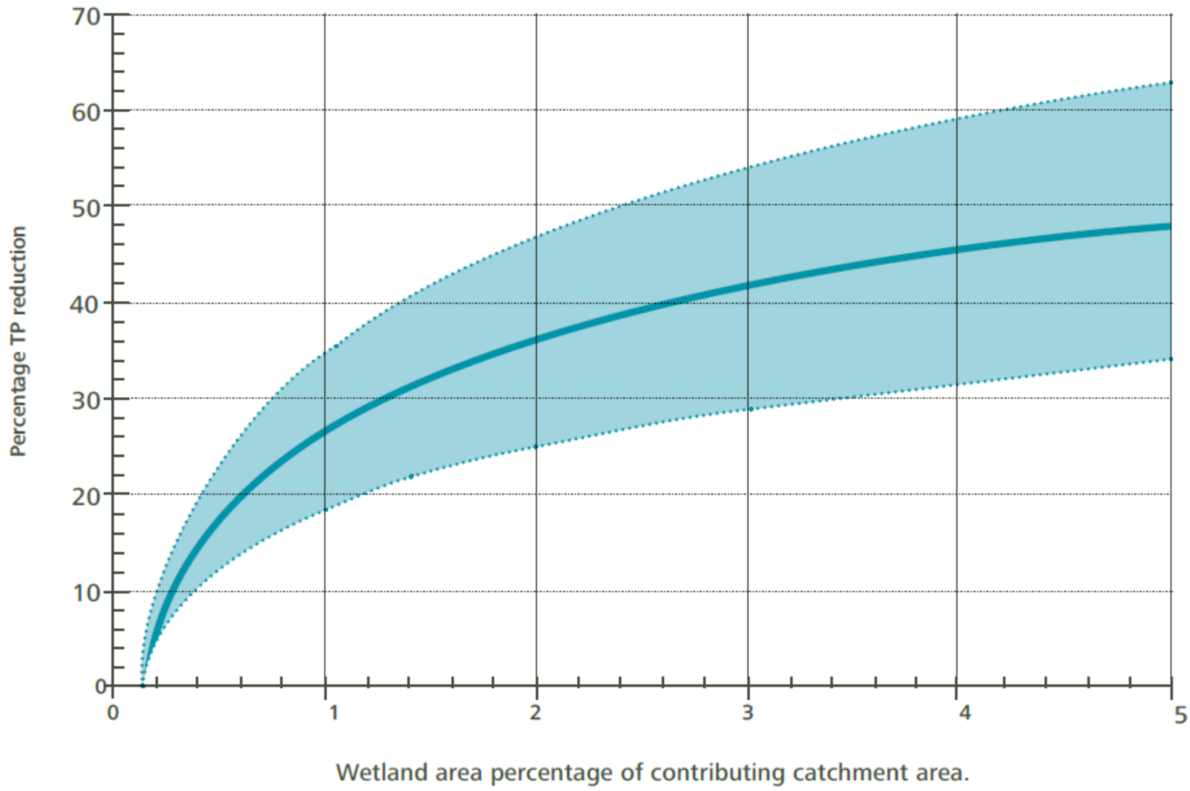

Figure 3: Long-term median annual performance expectations for reduction of total annual phosphorus (Tanner et al., 2022, p. 9)

Because Tanner et al. (2022) is based on pastoral farming, and predominantly dairy farms, it is recommended that the estimates from Muller et al. (2020b) for the horticulture LRC wetlands are retained. There are no *E.coli* estimates in Tanner et al. (2022) and so it is recommended that these are also retained from Muller et al. (2020b). In addition, as with Muller et al. (2020b) there is not enough information to differentiate between pastoral HRU types and so there is no difference between dairy and sheep and beef, or across stocking intensity.

Tanner et al. (2022) presents benefit estimates as a curve based on the wetland area as a proportion of the contributing catchment area. This is challenging for the FWMT which needs a adopts a consistent area-ratio based estimate of treatment performance (rather than numerous per device varying measures). Noting the FWMT will ultimately then take the generalised performance estimate this creates, to guide process-representation and ultimately, create variation in wetland treatment per sub-catchment to optimise action plans with. For instance, the general performance (point on the curves in Figure 2 and 3) will not actually constrain each wetland device's performance in FWMT, and latter will vary in line with temporal variation in loads received from localised upstream catchment area to device as well as device specific parameters like detention volume.

In Tanner et al. (2022) there are 11 case study wetlands. These average 1.4% of the catchment area and range from 0.08% to 4.5%. For a wetland that is 1.4% of the catchment area it is expected that there would be approximately 57% TSS removed, 30% of TN and 30% of TP. Alternatively a wetland that is 2% of catchment will typically remove between 46 - 92% of sediment (from soils with low clay content); 28 - 44% of nitrogen in warm zones, and 25 - 46% of particulate phosphorus.

Table 11: Benefit of LRC wetlands

Wetland size (% of catchment area)	HRU[1]	Contaminant impact[2, 3]			
	Intensity	N	P	Sediment	*E. coli*
<2%	Less than 10 SU/ha	-25%	-27%	-50%	-55%
	Sheep & beef - More than 10 SU/ha				
	Dairy - More than 10 SU/ha				
	Low & Medium impact	-10%	-45%	-65%	-55%
	High impact				
2%	Less than 10 SU/ha	-36%	-36%	-65%	-55%
	Sheep & beef - More than 10 SU/ha				
	Dairy - More than 10 SU/ha				
	Low & Medium impact	-10%	-45%	-65%	-55%
	High impact				
>2%	Less than 10 SU/ha	-44%	-42%	-75%	-55%
	Sheep & beef - More than 10 SU/ha				
	Dairy - More than 10 SU/ha				
	Low & Medium impact	-10%	-45%	-65%	-55%
	High impact				

1. *No differentiation in slope (assumes wetlands only apply to flat and rolling land) and soil type*
2. *Values for N, P and sediment in pasture are based on Tanner et al. (2022)*
3. *Values for horticulture and E.coli are based on Daigneault and Elliott (2017) and the same as in Muller et al. (2020b)*

Two benefits are provided here, these are based on estimates that are for LRC wetlands that are less than 2% of the catchment area (these are based on the benefit for wetlands that are 1% of catchment area) and those that are more than 2% of the catchment area (these are based on the benefit for wetlands that are 3% of catchment area). An impact on contaminant loads for a wetland that is 2% of the catchment area is also included. These are summarised in Table 11.

2.5 Intervention opportunity – new constructed wetland intervention

The LRC wetland intervention is based on large wetlands, it is assumed that these are over 1 ha in size and more likely 5 ha. As such the opportunity for these is based on the FWMT mapping and is distinct from areas that will have rural facilitated wetlands applied.

3 Additional Riparian Buffer Area Scenarios – 2.5 m and 10 m

3.1 Reason for addition

The Mahurangi East Land Restoration (MELR) Project is a $5 million, a 5-year long sediment reduction programme to restore the health of the Mahurangi Harbour. Auckland Council and Ngāti Manuhiri Settlement Trust have partnered on the programme, which is funded by the 'Jobs for Nature' Ministry for the Environment's (MfE) fund. The programme supports the vision, values and mahi from previous foundational projects, notably the community-led Mahurangi Action Plan; and strives to work in with ongoing community initiatives with the hope that locals will tell stories of life in the river for generations to come. Auckland Council and Ngāti Manuhiri Settlement Trust are designing and delivering the project in partnership. The FWMT is supporting MELR by providing optimised action plans for sediment load reductions to coast. MELR interventions include a broader suite of riparian management options that are reported here in an addendum to Muller et al. (2020). These updated riparian management options are not unique to MELR use and are suitable for regionwide application in the FWMT.

The previous FWMT interventions included the following riparian scenarios:

- 1 m rank grass – pasture – flat and rolling
- 1 m rank grass – pasture – steep
- 5 m planted – pasture – flat and rolling
- 5 m planted – pasture – steep
- 5 m rank grass – pasture – flat and rolling
- 5 m rank grass – pasture – steep
- 5 m rank grass – horticulture – no difference in slope and no fencing costs included
- 5 m planted – horticulture – no difference in slope and no fencing costs included

The pasture scenarios in the above list are considered across the three pasture types (e.g., more than 10 SU/ha dairy, less than 10 SU/ha sheep and beef and more than 10 SU/ha sheep and beef). The horticulture scenarios are considered across the three horticulture impact groups that were modelled in the FWMT Stage 1 (e.g., low, medium and high impact horticulture). For sheep and beef farms (both more than and less than 10 SU/ha) the scenarios were considered with and without the cost of stock water reticulation.

3.2 Additional scenarios

The MERL project wanted to include additional riparian scenarios, namely:

- 2.5 m rank grass – pasture – flat and rolling
- 2.5 m rank grass – pasture – steep
- 2.5 m rank grass – horticulture – no difference in slope and no fencing costs included
- 2.5 m planted – pasture – flat and rolling
- 2.5 m planted – pasture – steep
- 2.5 m planted – horticulture – no difference in slope and no fencing costs included
- 10 m rank grass – pasture – flat and rolling
- 10 m rank grass – pasture – steep
- 10 m rank grass – horticulture – no difference in slope and no fencing costs included
- 10 m planted – pasture – flat and rolling
- 10 m planted – pasture – steep
- 10 m planted – horticulture – no difference in slope and no fencing costs included

The pasture scenarios in the above list are considered across the three pasture types (e.g., more than 10 SU/ha dairy, less than 10 SU/ha sheep and beef and more than 10 SU/ha sheep and beef). The horticulture scenarios are considered across the three horticulture impact groups that were modelled in the FWMT- Stage 1 (e.g., low, medium and high impact horticulture with low and medium impact horticulture combined). The sheep and beef scenarios (both more than and less than 10 SU/ha) include the costs of introducing reticulated stock water because of fencing.

3.3 Intervention cost – new scenarios

The cost assumptions for riparian scenarios in Muller et al. (2020b) are all retained for these new scenarios. The only difference is the scaling of the costs based on the different riparian buffer widths, namely the planting costs and the opportunity costs. Table 12 to Table 16 show the component costs for 2.5 and 10 m buffer widths. Table 17 and Table 18 show the Annualised LCC cost at a 4% discount rate.

Table 12: Dairy (>10 SU/ha) – cost summary for new riparian scenarios

Scenario description[2]	Costs[3]				
	Capital costs		Maintenance costs		Opportunity cost ($/buffer width m²/yr)
	Fencing[1] ($/m)	Planting ($/buffer width m²)	Fencing ($/m/yr)	Planting ($/buffer width m²/yr)	
2.5 m buffer width Rank grass Flat/rolling	Yr. 0: $5.40 Yr. 25: $5.40	-	$0.05	Yr. 1-50: $0.13	$0.16
2.5 m buffer width Rank grass Steep	Yr. 0: $7.70 Yr. 25: $7.70	-	$0.11	Yr. 1-50: $0.13	$0.16
2.5 m buffer width Riparian plants Flat/rolling	Yr. 0: $5.40 Yr. 25: $5.40	Yr. 0: $13.75 ($5.50/linear metre of fence)	$0.05	Yr. 1: $5.13 Yr. 2: $3.85 Yr. 3: $2.57 Yr. 4-50: $0.13	$0.16
2.5 m buffer width Riparian plants Steep	Yr. 0: $7.70 Yr. 25: $7.70	Yr. 0: $13.75 ($5.50/linear metre of fence)	$0.11	Yr. 1: $5.13 Yr. 2: $3.85 Yr. 3: $2.57 Yr. 4-50: $0.13	$0.16
10 m buffer width Rank grass Flat/rolling	Yr. 0: $5.40 Yr. 25: $5.40	-	$0.05	Yr. 1-50: $0.13	$0.64
10 m buffer width Rank grass Steep	Yr. 0: $7.70 Yr. 25: $7.70	-	$0.11	Yr. 1-50: $0.13	$0.64
10 m buffer width Riparian plants Flat/rolling	Yr. 0: $5.40 Yr. 25: $5.40	Yr. 0: $55.00 ($5.50/linear metre of fence)	$0.05	Yr. 1: $5.13 Yr. 2: $3.85 Yr. 3: $2.57 Yr. 4-50: $0.13	$0.64
10 m buffer width Riparian plants Steep	Yr. 0: $7.70 Yr. 25: $7.70	Yr. 0: $55.00 ($5.50/linear metre of fence)	$0.11	Yr. 1: $5.13 Yr. 2: $3.85 Yr. 3: $2.57 Yr. 4-50: $0.13	$0.64

1. *Assumes 2-wire electric fencing for dairy farms*
2. *No difference in soil type considered*
3. *Where costs are $/buffer width m², this is $/2.5 m² or $/10 m² as relevant*

Table 13: Sheep and beef (<10 SU/ha) – cost summary for new riparian scenarios

Scenario description[2]	Costs[3]				
	Capital costs		Maintenance costs		Opportunity cost ($/buffer width m²/yr)
	Fencing[1] ($/m)	Planting ($/buffer width m²)	Fencing ($/m/yr)	Planting ($/buffer width m²/yr)	
2.5 m buffer width Rank grass Flat/rolling	Yr. 0: $16.10 Yr. 25: $16.10	-	$0.16	Yr. 1-50: $0.13	$0.05
2.5 m buffer width Rank grass Steep	Yr. 0: $18.20 Yr. 25: $18.20	-	$0.32	Yr. 1-50: $0.13	$0.05
2.5 m buffer width Riparian plants Flat/rolling	Yr. 0: $16.10 Yr. 25: $16.10	Yr. 0: $13.75 ($5.50/linear metre of fence)	$0.16	Yr. 1: $5.13 Yr. 2: $3.85 Yr. 3: $2.57 Yr. 4-50: $0.13	$0.05
2.5 m buffer width Riparian plants Steep	Yr. 0: $18.20 Yr. 25: $18.20	Yr. 0: $13.75 ($5.50/linear metre of fence)	$0.32	Yr. 1: $5.13 Yr. 2: $3.85 Yr. 3: $2.57 Yr. 4-50: $0.13	$0.05
10 m buffer width Rank grass Flat/rolling	Yr. 0: $16.10 Yr. 25: $16.10	-	$0.16	Yr. 1-50: $0.13	$0.20
10 m buffer width Rank grass Steep	Yr. 0: $18.20 Yr. 25: $18.20	-	$0.32	Yr. 1-50: $0.13	$0.20
10 m buffer width Riparian plants Flat/rolling	Yr. 0: $16.10 Yr. 25: $16.10	Yr. 0: $55.00 ($5.50/linear metre of fence)	$0.16	Yr. 1: $5.13 Yr. 2: $3.85 Yr. 3: $2.57 Yr. 4-50: $0.13	$0.20
10 m buffer width Riparian plants Steep	Yr. 0: $18.20 Yr. 25: $18.20	Yr. 0: $55.00 ($5.50/linear metre of fence)	$0.32	Yr. 1: $5.13 Yr. 2: $3.85 Yr. 3: $2.57 Yr. 4-50: $0.13	$0.20

1. *Assumes 8-wire non-electric post and batten fencing*
2. *No difference in soil type considered*
3. *Where costs are $/buffer width m², this is $/2.5 m² or $/10 m² as relevant*

Table 14: Sheep and beef (<10 SU/ha) – cost summary for new riparian scenarios

Scenario description[2]	Costs[3]				
	Capital costs		Maintenance costs		Opportunity cost ($/buffer width m²/yr)
	Fencing[1] ($/m)	Planting ($/buffer width m²)	Fencing ($/m/yr)	Planting ($/buffer width m²/yr)	
2.5 m buffer width Rank grass Flat/rolling	Yr. 0: $8.40 Yr. 25: $8.40	-	$0.08	Yr. 1-50: $0.13	$0.08
2.5 m buffer width Rank grass Steep	Yr. 0: $10.80 Yr. 25: $10.80	-	$0.17	Yr. 1-50: $0.13	$0.08
2.5 m buffer width Riparian plants Flat/rolling	Yr. 0: $8.40 Yr. 25: $8.40	Yr. 0: $13.75 ($5.50/linear metre of fence)	$0.08	Yr. 1: $5.13 Yr. 2: $3.85 Yr. 3: $2.57 Yr. 4-50: $0.13	$0.08
2.5 m buffer width Riparian plants Steep	Yr. 0: $10.80 Yr. 25: $10.80	Yr. 0: $13.75 ($5.50/linear metre of fence)	$0.17	Yr. 1: $5.13 Yr. 2: $3.85 Yr. 3: $2.57 Yr. 4-50: $0.13	$0.08
10 m buffer width Rank grass Flat/rolling	Yr. 0: $8.40 Yr. 25: $8.40	-	$0.08	Yr. 1-50: $0.13	$0.32
10 m buffer width Rank grass Steep	Yr. 0: $10.80 Yr. 25: $10.80	-	$0.17	Yr. 1-50: $0.13	$0.32
10 m buffer width Riparian plants Flat/rolling	Yr. 0: $8.40 Yr. 25: $8.40	Yr. 0: $55.00 ($5.50/linear metre of fence)	$0.08	Yr. 1: $5.13 Yr. 2: $3.85 Yr. 3: $2.57 Yr. 4-50: $0.13	$0.32
10 m buffer width Riparian plants Steep	Yr. 0: $10.80 Yr. 25: $10.80	Yr. 0: $55.00 ($5.50/linear metre of fence)	$0.17	Yr. 1: $5.13 Yr. 2: $3.85 Yr. 3: $2.57 Yr. 4-50: $0.13	$0.32

1. *Assumes 4-wire electric fencing*
2. *No difference in soil type considered*
3. *Where costs are $/buffer width m², this is $/2.5 m² or $/10 m² as relevant*

Table 15: Medium impact horticulture and low impact horticulture – cost summary for new riparian scenarios

Scenario description[1, 2]	Costs[3]		
	Capital costs	Maintenance costs	Opportunity cost ($/buffer width m^2/yr)
	Planting ($/buffer width m^2)	Planting ($/buffer width m^2/yr)	
2.5 m buffer width Rank grass	-	Yr. 1-50: $0.13	$0.29
2.5 m buffer width Riparian plants	Yr. 0: $13.75 ($5.50/linear metre)	Yr. 1: $5.13 Yr. 2: $3.85 Yr. 3: $2.57 Yr. 4-50: $0.13	$0.29
10 m buffer width Rank grass	-	Yr. 1-50: $0.50	$1.16
10 m buffer width Riparian plants	Yr. 0: $55.00 ($5.50/linear metre)	Yr. 1: $20.50 Yr. 2: $15.38 Yr. 3: $10.26 Yr. 4-50: $0.50	$1.16

1. *No difference in slope considered as no fencing costs included and no difference in benefits available*
2. *No difference in soil type considered*
3. *Where costs are $/buffer width m^2, this is $/2.5 m^2 or $/10 m^2 as relevant*

Table 16: High impact horticulture – cost summary for new riparian scenarios

Scenario description[1, 2]	Costs[3]		
	Capital costs	Maintenance costs	Opportunity cost ($/buffer width m^2/yr)
	Planting ($/buffer width m^2)	Planting ($/buffer width m^2/yr)	
2.5 m buffer width Rank grass	-	Yr. 1-50: $0.13	$0.49
2.5 m buffer width Riparian plants	Yr. 0: $13.75 ($5.50/linear metre)	Yr. 1: $5.13 Yr. 2: $3.85 Yr. 3: $2.57 Yr. 4-50: $0.13	$0.49
10 m buffer width Rank grass	-	Yr. 1-50: $0.50	$1.94
10 m buffer width Riparian plants	Yr. 0: $55.00 ($5.50/linear metre)	Yr. 1: $20.50 Yr. 2: $15.38 Yr. 3: $10.26 Yr. 4-50: $0.50	$1.94

1. *No difference in slope considered as no fencing costs included and no difference in benefits available*
2. *No difference in soil type considered*
3. *Where costs are $/buffer width m^2, this is $/2.5 m^2 or $/10 m^2 as relevant*

Table 17: Annualised LCC (NZ Dollars) for 2.5 m riparian scenarios ($LCC/m/yr) at 4% discount rate

Mitigation Type	Rural Land Use Type	Description	Annualised LCC	Total Acquisition Cost
Grass Buffer Strip (fencing for pastoral land and 2.5 m rank grass strip; stock water for sheep and beef)	Pastoral	More than 10 SU/ha (dairy): Flat & rolling	$0.31	41%
	Pastoral	More than 10 SU/ha (dairy): Steep	$0.41	45%
	Pastoral	Less than 10 SU/ha (sheep & beef): Flat & rolling	$0.96	64%
	Pastoral	Less than 10 SU/ha (sheep & beef): Steep	$1.09	61%
	Pastoral	More than 10 SU/ha (sheep & beef): Flat & rolling	$0.70	62%
	Pastoral	More than 10 SU/ha (sheep & beef): Steep	$0.81	61%
	Horticulture - Low Impact	Orchards, idle fallow - no fencing	$0.19	N/A
	Horticulture - Medium Impact	Arable, citrus, fodder, nuts, viticulture - no fencing	$0.19	N/A
	Horticulture - High Impact	Berryfruit, flowers, stonefruit, kiwifruit, nursery, pipfruit, fruit, vegetables, greenhouses - no fencing	$0.27	N/A
Planted Buffer Strip (fencing for pastoral land and 2.5 m riparian planted strip; stock water for sheep and beef)	Pastoral	More than 10 SU/ha (dairy): Flat & rolling	$0.85	54%
	Pastoral	More than 10 SU/ha (dairy): Steep	$0.94	54%
	Pastoral	Less than 10 SU/ha (sheep & beef): Flat & rolling	$1.49	63%
	Pastoral	Less than 10 SU/ha (sheep & beef): Steep	$1.62	61%
	Pastoral	More than 10 SU/ha (sheep & beef): Flat & rolling	$1.23	62%
	Pastoral	More than 10 SU/ha (sheep & beef): Steep	$1.34	61%
	Horticulture - Low Impact	Orchards, idle fallow - no fencing	$0.71	46%
	Horticulture - Medium Impact	Arable, citrus, fodder, nuts, viticulture - no fencing	$0.71	46%
	Horticulture - High Impact	Berryfruit, flowers, stonefruit, kiwifruit, nursery, pipfruit, fruit, vegetables, greenhouses - no fencing	$0.80	42%

Table 18: Annualised LCC (NZ Dollars) for 10 m riparian scenarios ($LCC/m/yr) at 4% discount rate

Mitigation Type	Rural Land Use Type	Description	Annualised LCC	Total Acquisition Cost
Grass Buffer Strip (fencing for pastoral land and 10 m rank grass strip; stock water for sheep and beef)	Pastoral	More than 10 SU/ha (dairy): Flat & rolling	$0.69	20%
	Pastoral	More than 10 SU/ha (dairy): Steep	$0.78	25%
	Pastoral	Less than 10 SU/ha (sheep & beef): Flat & rolling	$1.18	52%
	Pastoral	Less than 10 SU/ha (sheep & beef): Steep	$1.32	51%
	Pastoral	More than 10 SU/ha (sheep & beef): Flat & rolling	$0.96	46%
	Pastoral	More than 10 SU/ha (sheep & beef): Steep	$1.07	46%
	Horticulture - Low Impact	Orchards, idle fallow - no fencing	$0.74	N/A
	Horticulture - Medium Impact	Arable, citrus, fodder, nuts, viticulture - no fencing	$0.74	N/A
	Horticulture - High Impact	Berryfruit, flowers, stonefruit, kiwifruit, nursery, pipfruit, fruit, vegetables, greenhouses - no fencing	$1.09	N/A
Planted Buffer Strip (fencing for pastoral land and 10 m riparian planted strip; stock water for sheep and beef)	Pastoral	More than 10 SU/ha (dairy): Flat & rolling	$2.82	51%
	Pastoral	More than 10 SU/ha (dairy): Steep	$2.91	51%
	Pastoral	Less than 10 SU/ha (sheep & beef): Flat & rolling	$3.31	58%
	Pastoral	Less than 10 SU/ha (sheep & beef): Steep	$3.45	57%
	Pastoral	More than 10 SU/ha (sheep & beef): Flat & rolling	$3.09	56%
	Pastoral	More than 10 SU/ha (sheep & beef): Steep	$3.20	56%
	Horticulture - Low Impact	Orchards, idle fallow - no fencing	$2.86	46%
	Horticulture - Medium Impact	Arable, citrus, fodder, nuts, viticulture - no fencing	$2.86	46%
	Horticulture - High Impact	Berryfruit, flowers, stonefruit, kiwifruit, nursery, pipfruit, fruit, vegetables, greenhouses - no fencing	$3.21	42%

3.4 Intervention benefit – new scenarios

Table 19 contains the estimated efficacy of the riparian scenarios in Muller et al. (2020b). These generalised benefit estimates were sourced from three sources (e.g., Doole, 2015 and Daigneault and Elliot, 2017 for pastoral land uses; Daigneault and Elliott, 2017 and Basher et al., 2019 for horticulture land uses). Latter were assessed as most applicable for the Auckland region and accurate of the broader sources in Muller et al. (2020b).

Table 19: Estimated benefits of riparian scenarios in Muller et al. (2020b)

Land use type	Previous estimates	Efficacy (% change)			
	Scenario	Nitrogen (TN)	Phosphorus (TP)	Sediment (TSS)	*E. coli*
Dairy (Flat, rolling & steep)	1 m buffer width Rank grass	-	-	-	-58%
	5 m buffer width Rank grass	-15%	-10%	-70%	-60%
	5 m buffer width Riparian plants	-56%	-50%	-75%	-60%
Sheep and beef (<10 SU/ha) (Flat, rolling & steep)	1 m buffer width Rank grass	-	-	-	-58%
	5 m buffer width Rank grass	-5%	-5%	-70%	-60%
	5 m buffer width Riparian plants	-56%	-50%	-75%	-60%
Sheep and beef (>10 SU/ha) (Flat, rolling & steep)	1 m buffer width Rank grass	-	-	-	-58%
	5 m buffer width Rank grass	-15%	-10%	-70%	-60%
	5 m buffer width Riparian plants	-56%	-50%	-75%	-60%
All horticulture types (Flat, rolling & steep)	5 m buffer width Rank grass	-	-	-40%	-
	5 m buffer width Riparian plants	-51%	-50%	-75%	-

This earlier riparian approach distinguished benefits between low intensity sheep and beef farms (<10 SU/ha) and higher intensity sheep and beef and dairy pastoral farming (≥10 SU/ha) in total nitrogen and total phosphorus loads (but retained equivalent benefits on TSS and *E.coli* loads for equivalent setback distance and vegetation). No differentiation in benefit was included by slope or soil group (with latter effects already part-captured through differences in loading in the HRU configuration of riparian corridors that include hydrologic soil group and slope-class based differences – in received load rather than in treatment effect).

3.4.1 Intervention benefit – new pastoral scenarios (2.5 m, 10 m; grass, planted)

To arrive at expanded benefits assessments, for 2.5 m (grass, planted) and 10 m (grass, planted) riparian device options, a consistent approach to Muller et al. (2020b) is desirable – to permit comparison between riparian device options within SUSTAIN the relativistic benefits should ideally be from an equivalent study (i.e., permit direct comparison). However, pastoral and riparian studies recommended for use in the FWMT by Muller et al. (2020b) did not include 2.5 m and 10 m riparian benefits assessments.

Instead, the approach adopted to assign new pastoral riparian benefits estimates, involved:

- Adopting Doole (2015) *E.coli* benefits of 1 m (fence only) option on the 2.5 m grass and planted options (equivalent across pastoral types). Adopting the Daigneault and Elliott (2017) *E.coli* benefits of 5 m (grass, planted) on the 10 m grass and planted options (equivalent across pastoral types; no additional benefit for planted over grass). This is because both studies indicate a minor difference in *E.coli* load reduction for increasing distance of setback (i.e., the stock exclusion is the principal method for reducing *E.coli* loads rather than the width of the buffer) and Doole (2015) indicates limited benefit from riparian plants over grass in excluded areas.
- For nitrogen, phosphorus and sediment, Muller et al. (2020b) identified only one study that reported comparative differences in benefit for 2.5 m and 10 m setbacks on nitrogen, phosphorus and sediment loads: Zhang et al. (2010). It was assumed they were equivalent to total nitrogen, total phosphorus and total suspended sediment.
- Zhang et al. (2010) involved a meta-analysis to derive empirical relationships for various functions of riparian buffers on contaminant removal (i.e., fitting statistical relationships to a range of reported benefits by setback to best explain differences in treatment across other studies; demonstrating setback or "buffer width" as being the greatest determinant on contaminant removal, alone explaining 35-44% of effect across sediment, nitrogen and phosphorus). Zhang et al. (2010) amalgamates a range of trials that do not consistently examine the same form of contaminant, nor adopt the same field and laboratory methodology, but whose diversity of studies offers a powerful dataset for establishing load reduction (benefit) relationships. The estimates of contaminant removal by buffer width from Zhang et al. (2010) are shown in Figure 4.

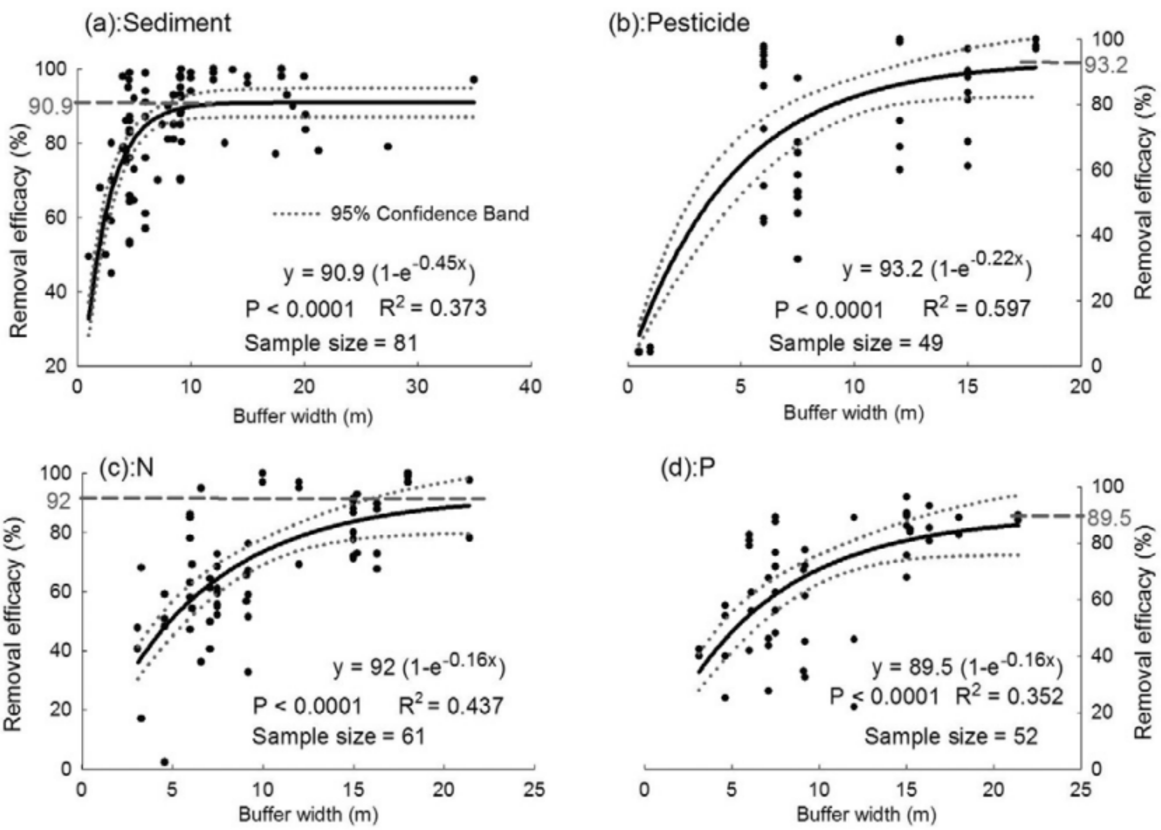

Figure 4: Contaminant removal efficacy and buffer width for sediment, pesticide, nitrogen and phosphorus (Zhang et al., 2010, p. 80)

- Zhang et al. (2010) is widely cited for benefits estimates of pastoral riparian management, including the Government's Action for Healthy Waters (Essential Freshwater) decisions (MfE, 2020). Importantly, Zhang et al. (2010) reported an exponential relationship for treatment, rapidly decreasing with increased setback (e.g., majority of contaminant removal occurs in first 5 m) – a finding commonplace in riparian benefits research (e.g., Collier et al., 1995; Parkyn, 2004; McKergow et al., 2016; Fenemor and Samarasinghe, 2020). Hence, any new riparian option for 10 m should have lesser benefit per unit of distance than the 5 m option and even less than the 2.5 m option (i.e., an important effects-pattern to retain in the additional FWMT options benefit estimates to enable their comparability within SUSTAIN).
- Benefits values for all 5 m planted riparian (pastoral) options in Daigneault and Elliott (2017) are remarkably similar to Zhang et al. (2010) (e.g., 56% TN, 50% TP and 75% TSS reduction for 5 m planted option versus 51%, 49% and 81% in Zhang et al., 2010, respectively). So, Zhang et al. (2010) relationships were used directly to assign riparian benefits for pastoral 2.5 m and 10 m planted riparian options.
- Given the objective in assigning new (2.5 m, 10 m) riparian options benefits is to permit comparison across alternative setback distances (1 to 10 m) and/or between planted or grassed variants, the 2.5 m and 10 m grassed options (sheep and beef both above and below 10 SU/ha and dairy) need TN, TP and TSS benefits that retain the effects-pattern in "planted" options (i.e., show similar relative variation by distance, if on a lower value relative to planted corridors). So, the proportionate change in % treatment of 2.5 m and 5 m, and 5 m and 10 m planted options were calculated (i.e., a scaling factor derived showing the degree of change in % treatment between each pair, separately for TN, TP and TSS). Latter proportionate changes were then applied to the existing 5 m grassed benefits, for all pastoral land uses. This created unique percentage treatment estimates for each of 2.5 m grassed sheep and beef (<10 SU/ha), 2.5 m grassed sheep and beef (≥10 SU/ha) or 2.5 m dairy, 5 m grassed sheep and beef (<10 SU/ha), 5 m grassed sheep and beef (≥10 SU/ha) or 5 m dairy.

The benefits of this approach include reliance on widely utilised relationships that already align well with existing FWMT riparian options (e.g., Daigneault and Elliott, 2017 – 5 m option), retention of a power-function effects pattern across setback distances (relatively less increase in benefit with increasing distance) and the pattern of reduced benefits for grassed over planted buffers (even if minor) noted in Muller et al. (2020b). So, the outcome is a set of benefit estimates that enable optimisation by setback distance and vegetation type (e.g., all existing and new riparian options continue to be directly comparable in SUSTAIN).

All pastoral riparian option benefits estimates are presented in Table 20, with the 2.5m and 10m options assigned values directly from Zhang et al. (2010) if planted and indirectly, via the scaling factors of planted options for all grassed options and the 1 and 5 m options from Muller et al. (2020b).

Table 20: Estimated benefits of all pastoral riparian scenarios 1 m, 2.5 m, 5 m and 10 m (planted and grass)

Land use type	Scenario	Efficacy (% change)			
		Nitrogen (TN)	Phosphorus (TP)	Sediment (TSS)	*E. coli*
All pastoral and slopes	1 m buffer width Rank grass	-	-	-	-58%
Sheep and beef (<10 SU/ha) (Flat, rolling & steep)	2.5 m buffer width Rank grass	-3%	-3%	-57%	-58%
	5 m buffer width Rank grass	-5%	-5%	-70%	-60%
	10 m buffer width Rank grass	-7%	-7%	-84%	-60%
Sheep and beef (>10 SU/ha) (Flat, rolling & steep) Dairy (flat, rolling & steep)	2.5 m buffer width Rank grass	-8%	-6%	-57%	-58%
	5 m buffer width Rank grass	-15%	-10%	-70%	-60%
	10 m buffer width Rank grass	-20%	-14%	-84%	-60%
All pastoral and slopes	2.5 m buffer width Riparian plants	-30%	-30%	-61%	-58%
	5 m buffer width Riparian plants	-56%	-50%	-75%	-60%
	10 m buffer width Riparian plants	-73%	-71%	-90%	-60%

3.4.2 Intervention benefit – new horticultural scenarios (2.5 m, 10 m; grass, planted)

As above, a consistent approach to Muller et al. (2020b) is desirable in assigning new 2.5 m and 10 m grassed and planted riparian options for horticultural land in FWMT – to permit comparison between riparian device options within SUSTAIN the relativistic benefits should ideally be from an equivalent study (i.e., permit direct comparison). However, horticultural riparian studies recommended for the FWMT in Muller et al. (2020b) lacked 2.5 m and 10 m assessments.

Instead, the approach adopted to assign new horticultural riparian benefits estimates, involved:

- Benefits values for all 5 m planted riparian (horticultural) options in Daigneault and Elliott (2017) are very similar to Zhang et al. (2010) (e.g., 51% TN, 50% TP and 75% TSS reduction for 5 m planted option versus 51%, 49% and 81% in Zhang et al., 2010, respectively). So, Zhang et al. (2010) relationships were used directly to assign riparian benefits for horticultural 2.5 m and 10 m planted riparian options.
- Then as per the new pastoral options, a scaling approach was used to determine the proportionate increase in treatment of a planted 5 m option over the 2.5 m planted equivalent. This was repeated for 10 m option over the 5 m equivalent. The latter factors were then applied to the rank grass 5 m estimate of TSS treatment effect from Basher et al. (2019) to derive new treatment effects for rank grass 2.5 m and 10 m options. Muller et al. (2020b) noted a dearth of information on the performance of rank grass filters in horticulture for treating TN, TP and TSS at a range of sizes precluding grass performance estimates on TN or TP.

- Since Muller et al. (2020b), Barber and Stenning (2021) produced a Code of Practice for Vegetated Buffer Strips. This code details the reduction in sediment from vegetated buffer strips of varying widths. This found the optimal range was 4 to 6 m with diminishing returns after 5 m. This work by Barber and Stenning (2021) utilises field performance estimates which were also used in Daigneault and Elliott (2017) coupled to revised-Universal Soil Loss Equations. The latter is a marked advance in knowledge of riparian TSS benefits on horticulture.
- Barber and Stenning (2021) TSS benefit estimates are highly similar to Zhang et al. (2010) scaled 2.5 m planted (67% and 61% respectively) and 5m planted riparian options (78% and 75% respectively). Although Barber and Stenning (2021) suggest limited TSS benefit beyond 8 m riparian setbacks (82%) whereas the scaled Zhang et al (2010) 10 m riparian benefit is notably greater (90%) as latter suggest removal efficiency becomes constant at 15 m setback.
- Varying pastoral riparian device benefit, not simply by type of pastoral activity (impact group), setback (1 m – 10 m) and vegetation cover (grassed, planted) is already a complex approach to modelling environmental benefit from targeted action. Coupled to dynamic, intervention optimisation in the FWMT on a catchment-by-catchment basis, our recommendation is not to add further complexity by varying horticultural riparian benefits further by soil group and slope class. The reason for this is the alignment between Barber and Stenning (2021) and the scaled values from Zhang et al. (2010) for all bar the 10 m option (planted). In addition, incorporating soil differences would add considerable modelling computational demand (i.e., SUSTAIN computations would then increase by a factor of 10 (for x5 soils by x2 slope classes for horticultural HRUs).
- The effect of any such added complexity is likely minor on both prioritisation of which riparian option to favour within a catchment for a local (sub-catchment) objective, the spatial prioritisation of the options between catchments for an integrated (cumulative) objective, and the sequencing in optimised plans regardless (i.e., the 10 m option will always retain a markedly lower efficiency due to modest increase in benefit for markedly greater cost compared to the 5 m option; minor differences in benefit of 10 m planted option between scaled Zhang et al. [2010] and Barber and Stenning [2021]). Effectively including further complexity will not add meaningful benefit to the FWMT Stage 1 applications or purpose.
- Based on all of this, our recommendation is to continue a scaled Zhang et al. (2010) based approach to ensure comparability of options, rely on robust evidence *and* ensure a match between modelling complexity and meaningful difference in output.

All horticultural riparian option benefits estimates are presented in Table 23, with the 2.5 m and 10 m options assigned values directly from Zhang et al. (2010) if planted and indirectly, via the scaling factors of planted options for all grassed options (noting only TSS is assessed for treatment removal by grassed options). The benefits of this approach are as per Section 3.4.1 (e.g., all existing and new riparian options continue to be directly comparable in SUSTAIN).

Table 21: Estimated benefits of all horticulture riparian scenarios 1 m, 2.5 m, 5 m and 10 m (planted and grass)

Land use type	Scenario	Efficacy (% change)			
		Nitrogen (TN)	Phosphorus (TP)	Sediment (TSS)	*E. coli*
All horticulture groups (low, medium and high impact)	2.5 m buffer width Rank grass	-	-	-33%	-
	5 m buffer width Rank grass	-	-	-40%	-
	10 m buffer width Rank grass	-	-	-49%	-
	2.5 m buffer width Riparian plants	-30%	-30%	-61%	-
	5 m buffer width Riparian plants	-51%	-50%	-75%	-
	10 m buffer width Riparian plants	-73%	-71%	-90%	-

4 Adjustments to the Bundled Mitigations for Dairy

4.1 Reason for adjustment and previous scenarios

The previous recommendation for the M1 bundle for dairy included estimates for three different soil types as well as an average, these were based on NIWA (2010). The mitigations for M2 and M3 were separated based on N and P, the N estimates were based on DairyNZ (2014) and the P estimates were based on Newman and Muller (2017). The M1 bundle for poorly drained soils estimated a positive impact on operating profit of 2% (NIWA, 2010). Table 22 highlights the previous input data for the dairy mitigation bundles in the FWMT.

The Manukau pilot of the FWMT optimisation revealed negative costs generate an "infinite" efficiency which biases optimisation routines in SUSTAIN[1]. As such, the M1 bundles for dairy need to be adjusted to remove the negative cost.

[1] Note SUSTAIN coding has been updated to overcome this problem since publication of this report but the underlying cause and effects of splitting M1 high impact (dairy) benefits by soil group remained problematic, requiring changes to M1 benefit and cost recommendations for FWMT Stage 1.

Table 22: Previous input data for dairy mitigation bundles

Mitigation bundle		Contaminant impact (kg contaminant/ha/yr)				Economic impact	Mitigation description
		N	P	Sediment	*E. coli*	Op. profit	
M1[1]	Free draining	-16%	-75%	-15%	-79%	-20%	Bundled GMP including full stock exclusion from streams using single-wire fencing. Soil Olsen phosphorus levels reduced from 38 to 32. Effluent areas enlarged appropriate to effluent potassium loading rates. Additional one month's effluent pond storage; low application depth.
	Moderately draining	-17%	-68%	-15%	-62%	-9%	
	Poorly drained	-17%	-61%	-15%	-45%	+2%	
	Average of all soil groups	-17%	-68%	-15%	-62%	-9%	
M2 N[2]		-36%	-68%	-15%	-62%	-15%	Based essentially on reducing N inputs (feed and fertiliser) and stocking rates. Stocking rate reduced from 3.1 to 2.9 cows/effective hectare. N fertiliser reduced from 116 to 60 kg N/ effective hectare. Bought feed (as % of total offered) reduced from 17 to 16%.
M2 P[3]		-17%	-78%	-15%	-62%	-24%	Based on reducing P inputs as per OVERSEER, fertiliser, effluent and cropping and adjusting stocking rates as needed.
M2 combined		-36%	-78%	-15%	-62%	-30%	Combined M2 N and M2 P options with the simple average of M1 for dairy.
M3 N[4]		-61%	-68%	-15%	-62%	-24%	Based essentially on reducing N inputs (feed and fertiliser) and stocking rates. Stocking rate reduced from 3.1 to 2.8 cows/effective hectare. Nitrogen fertiliser reduced from 116 to 29 kg N/ effective hectare. Bought feed (as % of total offered) reduced from 17 to 15%.
M3 P[5]		-17%	-93%	-15%	-62%	-49%	Based on reducing P inputs as per OVERSEER, fertiliser, effluent and cropping and adjusting stocking rates as needed.
M3 combined		-61%	-93%	-15%	-62%	-64%	Combined M3 N and M3 P options with the simple average of M1 and combined M2 for dairy.

1. *Based on NIWA (2010) for free draining and poorly draining.*
2. *Based on DairyNZ (2014; mitigation level 2) utilising the Waipa and Franklin weighted average farm.*
3. *Based on Newman & Muller (2017) which utilised Southland dairy farms.*
4. *Based on DairyNZ (2014; mitigation level 3) utilising the Waipa and Franklin weighted average farm.*
5. *Based on Newman & Muller (2017) which utilised Southland dairy farms.*

4.2 Revised mitigation bundles for dairy

Table 23 revises the mitigation bundles for dairy. The simplest way to manage this in the FWMT Stage 1 is to remove the M1 mitigation options for the free draining, moderately draining and well drained soils and to retain the simple average across each of these as the M1 dairy bundle. M2 and M3 mitigation bundles remain the same as presented in Muller et al. (2020b).

Table 23: Revised input data for dairy mitigation bundles

Mitigation bundle	Contaminant impact (kg contaminant/ha/yr)				Economic impact	Mitigation description
	N	P	Sediment	*E. coli*	Op. profit	
M1[1]	-17%	-68%	-15%	-62%	-9%	Bundled GMP including full stock exclusion from streams using single-wire fencing. Soil Olsen phosphorus levels reduced from 38 to 32. Effluent areas enlarged appropriate to effluent potassium loading rates. Additional one month's effluent pond storage; low application depth.
M2 N[2]	-36%	-68%	-15%	-62%	-15%	Based essentially on reducing N inputs (feed and fertiliser) and stocking rates. Stocking rate reduced from 3.1 to 2.9 cows/effective hectare. N fertiliser reduced from 116 to 60 kg N/ effective hectare. Bought feed (as % of total offered) reduced from 17 to 16%.
M2 P[3]	-17%	-78%	-15%	-62%	-24%	Based on reducing P inputs as per OVERSEER, fertiliser, effluent and cropping and adjusting stocking rates as needed.
M2 combined	-36%	-78%	-15%	-62%	-30%	Combined M2 N and M2 P options with the simple average of M1 for dairy.
M3 N[4]	-61%	-68%	-15%	-62%	-24%	Based essentially on reducing N inputs (feed and fertiliser) and stocking rates. Stocking rate reduced from 3.1 to 2.8 cows/effective hectare. Nitrogen fertiliser reduced from 116 to 29 kg N/ effective hectare. Bought feed (as % of total offered) reduced from 17 to 15%.
M3 P[5]	-17%	-93%	-15%	-62%	-49%	Based on reducing P inputs as per OVERSEER, fertiliser, effluent and cropping and adjusting stocking rates as needed.
M3 combined	-61%	-93%	-15%	-62%	-64%	Combined M3 N and M3 P options with the simple average of M1 and combined M2 for dairy.

1. *Based on NIWA (2010) average of soil types.*
2. *Based on DairyNZ (2014; mitigation level 2) utilising the Waipa and Franklin weighted average farm.*
3. *Based on Newman & Muller (2017) which utilised Southland dairy farms.*
4. *Based on DairyNZ (2014; mitigation level 3) utilising the Waipa and Franklin weighted average farm.*
5. *Based on Newman & Muller (2017) which utilised Southland dairy farms.*

Table 24 summarises the LCCs for LRC wetlands for a 4% discount rate and 50-year LCC period.

Table 24: Annualised LCC loss of profit (NZ Dollars) for the revised diary mitigation bundles at 4% discount rate and the associated contaminant impact

Mitigation Bundle	Rural Land Use Type	Annualised LCC loss of profit	Contaminant Impact - Nitrogen	Contaminant Impact - Phosphorus
M1	Pastoral: More than 10 SU/ha (dairy)	$51	-17%	-68%
M2	Pastoral: More than 10 SU/ha (dairy)	$169	-36%	-78%
M3	Pastoral: More than 10 SU/ha (dairy)	$361	-61%	-93%

5 Adjustments to the Bundled Mitigation M1 for High Impact Horticulture

5.1 Reason for adjustment and previous scenarios

The M1 bundle for High impact horticulture was based on the Agribusiness Group (2014) work in the Lower Waikato catchment. The M1 bundle had no impact on operating profit, though it reduced N loss by 2%. The Manukau pilot of the FWMT optimisation revealed negative costs generate an "infinite" efficiency which biases optimisation routines in SUSTAIN[2]. Table 25 has the previous mitigation bundles for high impact horticulture.

Table 25: Previous input data for horticulture mitigation bundles

Mitigation bundle	Contaminant impact (kg contaminant/ha/yr)				Economic impact	Mitigation description
	N	P	Sediment	*E. coli*	Op. profit	
M1	-2%				0%	Limiting any one application of N to 80 kg N/ha per month, no reduction in yield.
M2	-10%				-60%	Reduce N fertiliser use by 10% with a reduction in yield of 10% (summer potatoes, onions & carrots), 15% (squash, broccoli, lettuce, cabbage, spinach & cauliflower) and 25% (winter potatoes & barley).
M3	-14%				-121%	Reduce nitrogen fertiliser use by 20% with a reduction in yield of 20% (summer potatoes, onions & carrots), 25% (squash, broccoli, lettuce & barley), 30% (cabbage, spinach & cauliflower) and 35% (winter potatoes).

5.2 Revised mitigation bundles for high impact horticulture

Because the three mitigation bundles for high impact horticulture are cumulative M1 is inherently included in M2. The current bundles are based on the best available information, namely The Agribusiness Group (2014). Given these reasons it is recommended that M1 as a separate mitigation bundle is removed and M2 and M3 are retained. It is likely easiest to retain these named as M2 and M3 for clarity. There will be no separately modelled M1 mitigation bundle for high impact horticulture.

[2] Note SUSTAIN coding has been updated to overcome this problem since publication of this report but the underlying cause and effects of splitting M1 high impact (dairy) benefits by soil group remained problematic, requiring changes to M1 benefit and cost recommendations for FWMT Stage 1.

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