Assessing the impacts of greenhouse gas mitigation measures on contaminant losses to water

A report for He Waka Eke Noa farm planning guidance

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1. Executive Summary

He Waka Eke Noa (HWEN) is a government-primary sector climate action partnership aiming to measure, manage and reduce greenhouse gas emissions (GHG) and build resilience to climate change. Through HWEN, farmers and growers are required to 'know their numbers' by December 2022 and have a written plan in place to manage GHG emissions by 2025. Farm Planning Guidance was developed to help farmers understand GHG reduction opportunities and give guidance for inclusion in their GHG farm plan. The guidance was first completed and released in December 2020 and includes a range of opportunities and actions for reducing GHG emissions. Many farmers and growers already have a farm plan, usually developed for improved water quality outcomes. These plans focus on options for reducing the loss of key contaminants to water: nitrogen (N), phosphorus (P), sediment and *Escherichia coli* (*E. Coli*, an organism used as an indicator of likely faecal pollution). Through the development of the GHG guidance, farmers and other stakeholders have reported their desire to better understand synergistic and antagonistic relationships between actions aimed at reducing GHG's and those aimed at improving water quality outcomes.

The purpose of this report was to update the Farm Planning Guidance with a likely direction of change in contaminant loss to water for each of the GHG mitigation actions listed. It is intended to support farmers and growers making informed decisions about mitigation options for both GHG and freshwater quality outcomes.

Forty-three GHG mitigation actions were assessed for their likely impact on water quality contaminant loss (direction of change; i.e., likelihood of increase, decrease, or no change), using expert guidance and supported by key assumptions, rationale and selected references. A summary of this assessment is provided in Table 2 of this report. The primary recommendation for updating the Farm Planning Guidance Table of Opportunities was to replace the "Other Benefits" column with "Contaminant loss to water" as per Table 2 of this report. Other minor recommendations were the removal, edit and addition of other Opportunities and Actions.

2. Background

2.1 Background

Through He Waka Eke Noa[1] (HWEN), all farmers and growers are required to 'know their numbers' by December 2022 and have a written plan in place to manage GHG emissions by 2025. Many farmers and growers already have a farm plan. A guidance document was developed to help farmers and growers incorporate GHG management into these plans. The Farm Planning Guidance set out four Good Farming Practice principles, one of which was to "Identify opportunities to reduce your farm's greenhouse gas emissions and capture carbon". A list of options is provided in a Table of Opportunities/Actions in the Farm Planning Guidance (He Waka Eke Noa, 2021).

Many farmers and growers are already implementing measures that mitigate contaminant losses to water, thus helping to improve outcomes for freshwater quality. As new GHG mitigations are introduced, there is an obvious need to understand their potential impacts on contaminant loss to water to ensure synergistic effects are maximised, trade-offs are minimised, and farmers and growers are supported to make informed environmental and business decisions.

2.2 Purpose

The HWEN Farm Planning Workstream has commissioned a short report to provide information on the direction of change in contaminant loss to water for each of the on-farm GHG Opportunities/Actions, to be used to update the current Farm Planning Guidance. The purpose of this report is to:

1. Provide a qualitative "direction of change" in contaminant loss to water for each of the GHG Actions/Opportunities in the Farm Planning Guidance, based on expert guidance, and

2. List the rationale, assumptions, selected references and recommendations based on (1) above.

This report can be used as background material for the updated Farm Planning Guidance.

[1] He Waka Eke Noa is a primary sector partnership between industry, Māori and government, seeking to reduce Aotearoa New Zealand's agricultural greenhouse gas (GHG) emissions and build resilience to climate change. The partnership aims to provide farmers and growers with tools and information to measure, manage, and reduce greenhouse gas emissions, recognise, maintain or increase carbon sequestration, and adapt to a changing climate. More information on He Waka Eke Noa (HWEN) can be found on the website www.hewakaekenoa.nz.

3. Approach

Over the past decades there has been considerable investment in research to mitigate GHG emissions and water quality impacts. Few projects (an exception being the report of Shepherd et al. (2016) and van der Weerden et al. (2018)) have specifically investigated both GHG and water quality impacts to determine any synergistic or antagonistic effects between mitigations for each purpose. Research that has investigated the relationship between water quality and GHG outcomes has tended to consider the impact of freshwater mitigations on GHG emissions, rather than the impact of GHG mitigation options on freshwater outcomes. It's the latter which is needed to update the Farm Planning Guidance.

We used an expert opinion approach to develop a qualitative assessment of likely co-benefits for water quality impacts from the GHG mitigation options identified for farmers and growers in the Farm Planning Guidance.

3.1 Expert guidance

The HWEN Farm Planning working group commissioned "expert guidance" for this task. Selected experts were the AgResearch co-authors of this report (Monaghan, Muirhead, Selbie, van der Weerden), additional experts consulted on our assumptions on specific topics (Dodd, Ledgard, Welten) and two peer reviewers acknowledged in this report (Dynes, de Klein).

The HWEN Farm Planning Guidance (He Waka Eke Noa, 2021), version 2, March 2021, contains a table of Opportunities and Actions (introduced on page 8 of the document). The list of Actions, associated examples and supporting information were the primary information sources used for the assessments reported here. The four key freshwater contaminants of concern that were considered are nitrogen (N), phosphorus (P), sediment and *Escherichia coli* (*E. coli*). The consensus of the expert group was to define, for each Action, a "direction of change" for each contaminant. The categories for this qualitative assessment are summarised in Table 1.

Some key assumptions and exclusions based on the scope of this work included:

- "For pasture renewal, use full inversion tillage every 30 years" (Action #35; see Table 2, Section 4 below) was considered out of scope (due to impending removal from Guidance) and therefore not assessed.
- Assumptions & rationale related to GHGs are provided for some Actions where additional information was critical to providing assessment for contaminant loss to water.
- Contaminant losses considered were N, P, sediment and *E. coli* thus other contaminants, such as pesticides and herbicides, were excluded from the assessment.
- Contaminant losses were considered on an area (per hectare) basis.

- Efforts were made to include relevant references (provided at the end of this report), but time and budget constraints meant this was not an extensive literature review.

- Additional experts were consulted for guidance on specific pieces of research, gaps in knowledge and checking general assumptions.

Table 1: Categories and symbols used to show likely direction of change in N, P, sediment and *E. coli* losses to water that are associated with GHG mitigations outlined in the Farm Planning Guidance (He Waka Eke Noa, 2021).

Symbol	Criterion	Definition
↓	Decrease	Decrease in contaminant loss to water (co-benefit)
↑	Increase	Increase in contaminant loss to water (trade-off)
NC	No change	Unlikely to change contaminant losses to water
?	Unknown	Insufficient knowledge available

3.2 Key principles of contaminant loss to water

Some key principles (based on scientific understanding of contaminant losses) that underpin the assessment include:

- N leaching risk increases with the total amount of N cycling through the soil-plant-animal system. Reducing N inputs (fertiliser or supplementary feed) and animal N intake will therefore have a significant impact on reducing N leaching risk.

- P loss risk is mainly associated with the amount of P in (as measured through soil testing) or on (dung-P) the soil and the propensity for surface runoff to flow directly to waterways (in near-stream areas) or via gullies, swales and artificial drainage systems.

- N leaching risk is not necessarily *directly* related to the timing of N application or urine deposition (e.g. N deposited in late summer or autumn can be at risk of loss later in the season when drainage occurs).

- *E. coli*, sediment and P loss risks are more directly related to the timing of grazing and any treading or pugging damage that may occur.

4. Results and Discussion

4.1 Summary table

Table 2 provides a summary of the likely directions of change in contaminant losses to water for each of the Actions that have been documented to reduce GHG emissions in the Farm Planning Guidance. Table 2 should be read with reference to the examples provided in the Guidance document Table of Opportunities (beginning on page 10 of the document).

4.2 Recommendations

Arising from the assessment in Table 2, we make the following recommendations for the Table of Opportunities from page 10 onwards in the Farm Planning Guidance:

1 Include our qualitative assessment of the “direction of change” in contaminant (N, P, sediment, *E. coli*) loss to water for each of the GHG Actions/Opportunities in the Farm Planning Guidance by replacing the “Other Benefits” column in the Opportunity tables with the column headed “Contaminant loss to water” from Table 2 in this report.

In addition, we make the following recommendations for updating other parts of the opportunity tables:

2 Remove “Optimise the use of lime through targeted applications” (Action #5, Table 2). NZ field research shows no evidence of N_2O mitigation from deposited urine by elevating soil pH with lime application (van der Weerden et al. 2021). We note that this change will require Steering Group approval.

3 Replace Action #17 (Table 2) “Methane capture” with “Covered manure/effluent storage” and add “Methane capture” and “Reducing ammonia emissions” as two Examples. The associated direction of change for contaminant losses to water would be: NC for all four contaminants.

4 Remove “pasture protection” from Action: “Consider planting trees for animal welfare and pasture protection” (Action #24, Table 2).

5 Update the Table on page 8 (Overview) with the full list of opportunities and actions from the Table of Opportunities/Actions (beginning page 10).

6 Consider including “Salt Supplementation” (Ledgard et al. 2015) as an additional technology under Future Opportunities. Equivalent directions of change in contaminant losses to water would be: N ↓, P NC, Sediment NC and *E. coli* NC. Supplementary text is recommended: “Will increase the spread of urinary N onto pasture and thus reduce N leaching risk”.

7 Consider including “Effluent treatment with polyferric sulphate” (Cameron and Di, 2021; Chisholm et al. 2021) as an additional technology under Future Opportunities. Equivalent directions of change in contaminant losses to water would be: N NC, P ↓, Sediment NC and *E. coli* ↓. Supplementary text is recommended: “A single study shows that treated effluent and clarified water has reduced P solubility, leading to lower dissolved reactive P

losses when applied to land. Also, *E.coli* leaching was reduced due to the acidic nature of the treatment and bacteria being encapsulated in the flocculant".

Table 2: Direction of change for key contaminant losses to water for each Action identified to reduce greenhouse gas emissions (from HWEN Farm Planning Guidance Edition 2, March 2021 (He Waka Eke Noa, 2021)). N – Nitrogen; P – Phosphorus; Sed – Sediment; Ec – *Escherichia coli (E. coli);* ↓ Decrease; ↑ Increase; NC no change; ? Unknown. Methane (CH_4); nitrous oxide (N_2O); carbon dioxide (CO_2). Note: assessments should be read in the context of examples provided in the Guidance document.

	Action	GHG	Contaminant loss to water				Assumptions / rationale
			N	**P**	**Sed**	**Ec**	
Improve the efficiency of pasture and crop production							
1	Minimise N-Surplus through reduced use of N-fertiliser and/or supplementary feed	N_2O	↓	NC	NC	NC	• Reduced inputs of N at a farm scale will reduce the amounts of N cycling through the soil-plant-animal system. This will help to minimise the accumulation of surplus N in soil (urinary N in particular), thus decreasing N leaching risk. • The magnitude of this benefit will depend on the amounts of N imported onto farms via fertiliser, supplement and effluent, and the biophysical attributes of the farm (e.g. soil type, rainfall). • Unlikely to have an effect on other contaminants.
2	Select inhibitor-coated N fertilisers to reduce the amount of N applied	N_2O	NC	NC	NC	NC	• No significant effect on N leaching losses expected, provided the total amount of fertiliser N applied is reduced by 10% (to account for the N that is no longer lost via ammonia volatilisation). • No effect on other contaminants. • *Reduced ammonia volatilisation due to urease inhibitors results in lower amounts of N being redeposited onto land downwind, which decreases indirect emissions of N_2O.*
3	Manage timing and placement of N fertiliser applications to reduce the amount of nitrogen applied	N_2O	↓	NC	NC	NC	• Less surplus soil N accumulation and lower risk of losses due to better timing and placement of N fertiliser inputs and efficient uptake by pastures/crops. • The magnitude of this benefit will depend on the amount of fertiliser N used on farm. • Unlikely to influence other contaminants.
4	Manage pasture and crop husbandry to optimise production	N_2O	↓	↓	↓	↓	• A shift to good management practices – such as maintaining optimal fertility and good soil structure, use of lime, irrigation efficiency – will encourage the utilisation of soil nutrients and infiltration of water, thus minimising the risk of contaminant transport.

	Action	GHG	Contaminant loss to water				Assumptions / rationale
			N	P	Sed	Ec	
5	Optimise the use of lime through targeted applications[2]	N_2O	NC	NC	NC	NC	• Dairy: typically, only small increases in pasture grown and nutrient use efficiency (NUE) will be expected. • Some of the GHG effect will be partially offset by the CO_2 emitted from lime. • Hill country: lime can significantly increase pasture production and intake (subsequently increasing CH_4 emissions).
Reduce total feed eaten on farm							
6	Identify and cull less productive stock early	CH_4, N_2O	↓	NC	NC	NC	• Having fewer animals on-farm in autumn will reduce N excretion and thus N leaching risk during the drainage season, although the effect is likely to be relatively small. • Reductions in losses of other contaminants are likely to be small and, as yet, unproven. • The GHG mitigation effect will only occur if culling happens earlier than normal. For dairy farms, this will in practise currently depend on climate (e.g. drought conditions), pasture cover, the body condition of the herd and access to slaughter facilities. For sheep, beef and deer farms, this also requires that no additional stock are then purchased e.g. finishing lambs.
7	Reduce wastage rates (unplanned losses) so replacement rates can be optimised, and total feed eaten reduced	CH_4, N_2O	↓	NC	NC	NC	• Reduced stocking rate assumed, mainly through less replacement stock. • A small reduction in N leaching risk can be expected. • Reductions in losses of other contaminants are likely to be small and, as yet, unproven.
8	Adjust livestock class or ratios within the farm system to reduce the total feed eaten	CH_4, N_2O	↓	NC	NC	NC	• Assumes a reduction in total feed eaten. • Apart from N, reductions in losses of other contaminants are likely to be small and, as yet, unproven.
9	Use genetic selection over time to increase animal performance	CH_4, N_2O	↓	NC	NC	NC	• Assumes a reduction in stocking rate due to an increase in per-animal-production. • Only small reductions in N losses expected, although cumulative effects over time will be important.

[2] We recommend this option is removed from the Farm Planning Guidance as new evidence no longer supports this as a N_2O mitigation option (van der Weerden et al. 2021). However, we have provided our assessment for this option in case it remains in the Guidance.

	Action	GHG	Contaminant loss to water				Assumptions / rationale
			N	P	Sed	Ec	
	and decrease livestock maintenance requirements						• Reductions in losses of other contaminants are likely to be small and, as yet, unproven.
10	Manage animal health	CH_4, N_2O	↓	NC	NC	NC	• Assumes a reduction in stocking rate due to an increase in per-animal-production. • Small reductions in N loss risk expected. • Reductions in losses of other contaminants are likely to be small and, as yet, unproven.
11	Retire less productive land from grazing	CH_4, N_2O	↓	↓	↓	↓	• If retired areas are significant sources of contaminants, then reductions in contaminant losses to water are expected; lag times and legacy effects can in some circumstances delay the visible effects of this measure. Assumes stocking rate on remaining area does not increase.
12	High value land use change	CH_4	?	?	?	?	• Cannot provide a direction of change due to the potentially wide range of land use change options that may be possible. If changing from permanent grassland cover to reduced soil cover/protection (e.g., pasture to flower crops), then some contaminant loss risks could increase.
Match feed demand with pasture growth and utilisation							
13	Optimise pasture quality and production to better meet feed demand	CH_4, N_2O	↓	NC	NC	NC	• Assumes reduced N intake, less N excretion and therefore reduced N leaching. Unlikely to have an effect on other contaminants.
14	Optimise supplementary feed inputs to better meet feed demand	CH_4, N_2O	↓	NC	NC	NC	• Assumes reduced N intake, less N excretion and therefore reduced N leaching. Unlikely to have an effect on other contaminants.
15	Use of alternative forages to reduce protein in the diet	CH_4, N_2O	↓	NC	NC	NC	• Assumes reduced N intake, less N excretion and therefore reduced N leaching.

Improve the management of livestock effluent							
16	Avoid storing effluent in anaerobic conditions	CH_4, N_2O	NC	NC	NC	NC	• Not relevant to soil-based processes
17	Methane capture[3]	CH_4	NC	NC	NC	NC	• Not relevant to soil-based processes
18	Use all captured effluent as a fertiliser enabling reduced N fertiliser use	N_2O	↓	↓	NC	↓	• More efficient off-paddock capture of effluent and its safe return to land will reduce the risk of N, P and *E. coli* transfers to water. • Note: CH_4 emissions can increase when effluent/manures are captured and stored.
Capture and store carbon in vegetation							
19	Consider converting less productive land into indigenous vegetation	CO_2	↓	↓	↓	↓	• If converted areas were key sources of contaminants, then reductions in contaminant losses to water are expected; lag times and legacy effects can in some circumstances delay the visible effects of this measure.
20	Consider converting less productive land into exotic forest	CO_2	↓	↓	↓	↓	• Although tree harvesting can accelerate sediment and P losses in the short term, reductions in all water contaminants are expected over an assumed 30-year forest rotation cycle.
21	Consider establishing wetland forests	CO_2, CH_4	↓	↓	↓	↓	• Assuming a pasture area is being converted (i.e. not originally a wetland).
22	Consider planting riparian setbacks	CO_2	↓	↓	↓	↓	• Assumes setback distances and planted areas have increased. • If grazed area decreases, then a decrease in all contaminants can be expected.
23	Consider planting erosion control trees where erosion is active or could occur	CO_2	NC	↓	↓	NC	• Assuming no change in pasture production or stocking rate.
24	Consider planting trees for animal welfare and pasture protection	CO_2	NC	↓	↓	NC	• Assuming no change in pasture production or stocking rate; if tree planting is widespread and feed N intake is accordingly reduced, then reductions in N leaching risk can also be expected.
25	Consider diversifying land use by establishing perennial tree crops (fruit or nut trees for example)	CO_2	↓	↓	↓	↓	• Assuming a change from grazed to un-grazed pasture area or un-cultivated land area.

[3] We recommend this option is replaced with "Covered manure/effluent storage" and instead, "Methane capture" and "Reducing ammonia emissions" added as two Examples.

26	Consider fencing and pest control for existing and newly planted indigenous vegetation	CO_2	↓	↓	↓	↓	• Fewer animals defecating in water or eroding vulnerable landscapes.
Capture and store carbon in soils							
27	Minimise time soils are left fallow i.e. with no growing vegetation	N_2O, CO_2	↓	↓	↓	?	• Assumes no additional feed intake (and CH_4 emissions) from cover/catch crop. • Impact on *E. coli* dependent on land use and/or management. • N_2O emissions are also likely to decrease due to less accumulation of soil mineral N.
28	Increase the duration of pasture in crop rotations	CO_2	?	↓	↓	?	• Depends on the livestock type and crop rotation. • More pasture cover will provide greater soil protection from raindrop impact and surface erosion.
29	Retain and incorporate crop residues where possible	CO_2	NC	NC	NC	NC	• Assuming minimal soil disturbance (which may otherwise release CO_2 and mineralise soil organic N). • The supply (or sink) of N from residues should be considered when making fertiliser decisions for subsequent crops in rotation. If this component is ignored, then nitrate leaching and nitrous oxide emissions could increase (or decrease if residues act as a sink).
30	Add external organic amendments such as manure, compost or biochar	CO_2	↑	↑	NC	↑	• Assumes large inputs over time would be needed to increase soil organic C contents; if material is animal-based then associated inputs of N & P would therefore also be relatively large and provide an external source of *E. coli* into the system. • More soil disturbance could lead to increased sediment loss risk if amendments need to be incorporated. • Biochar unlikely to have any measurable effect on contaminant losses. • N_2O emissions are also likely to increase through the addition of manure and compost due to associated N inputs. In contrast, the effect of biochar on N_2O emissions is still unclear.
31	Optimise water table depth for peat soils	CO_2	?	?	?	?	• Cannot provide a direction of change as it depends on seasonal fluctuations of the water table. • Possible risk of increased P losses if subsoil conditions become less aerobic.
32	Restore or create wetlands	CO_2	↓	↓	↓	↓	• Assuming a pasture area is converted (i.e. not originally a wetland).

33	Protect and manage erosion prone land	CO_2	NC	↓	↓	NC	• Assuming no commensurate change in pasture production or stocking rate.
34	Increase the different types of plant species in pasture swards	CO_2	?	?	?	?	• Assuming the specific effects of plantain and other plant species on N cycling are excluded; this option instead refers to the diversity of function of different types of pasture species. • If plantain is included and represents a significant (> 20%) proportion of the sward, then N loss risk would decrease.
35	~~For pasture renewal, use full inversion tillage every 30 years~~	~~CO_2~~					~~• Action removed from Guidance document by HWEN.~~
Future opportunities: Technologies that reduce methane or nitrous oxide production							
36	Application of feed additives and rumen methane inhibitors, and vaccines	CH_4	NC	NC	NC	NC	• No effects on water contaminants expected.
37	Application of feed additives that bind surplus dietary N and render it indigestible	CH_4, N_2O	↓	NC	NC	NC	• Will reduce the excretion of urinary N and thus N leaching risk.
38	Genetic selection for lower emission animals	CH_4, N_2O	?	NC	NC	NC	• For N leaching risk, conceptually possible but, as yet, unproven.
39	Potential development of genetically modified plants	CH_4, N_2O	↓	NC	NC	NC	• Plant traits that can reduce N intake and/or urinary N excretion will reduce N leaching risk.
40	Application of nitrification inhibitors to the soil that slow the nitrification of ammonia and reduce N_2O emissions	N_2O	↓	NC	NC	NC	• Assumes that a nitrification inhibitor can be made commercially available.
Other considerations: Reduce fossil fuel emissions							
41	Reduce fossil fuel use by minimising machine usage	CO_2, N_2O	↓	↓	↓	NC	• Assumes cultivation was avoided, which will improve the synchronicity between pasture N demand and supply and help to maintain soil cover and structural integrity (thus reducing sediment and P losses due to soil erosion). • Reduced tillage techniques are likely to have similar but smaller effects, as will reductions in other types of mechanical operations such as spraying crops or applying fertilisers.

42	Reduce fossil fuel use by selection of more efficient or electric machinery	CO_2	NC	NC	NC	NC	• Not relevant to soil-based processes
43	Reduce electricity use from the grid through more efficient energy use, and /or on-farm solar, wind and water generation	CO_2	NC	NC	NC	NC	• Not relevant to soil-based processes

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