Freshwater Management Tool

August 2021

FWMT Report 2021/6

Report 6

Literature Review of Primary Sector Responses to Water Quality: Efficacy and Cost

Auckland Council
Te Kaunihera o Tāmaki Makaurau

Freshwater Management Tool: Report 6. Literature Review of Primary Sector Responses to Water Quality: Efficacy and Cost

August 2021

Contributing authors:

Perrin Ag Consultants Limited
Carla Muller, Rachel Durie, Liz Dooley, Lee Matheson

Auckland Council Healthy Waters Department
FWMT Report 2021/6

ISSN 2815-9772

ISBN 978-1-99-100276-1 (PDF)

Recommended citation
Auckland Council (2021). Freshwater management tool: report 6. Literature review of primary sector responses to water quality: efficacy and cost. FWMT report, 2021/6. Prepared by Perrin Ag Consultants for Auckland Council.

Literature Review of Primary Sector Responses to Water Quality: Efficacy and Cost

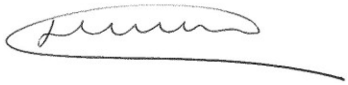
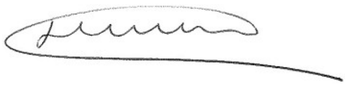
Prepared for Auckland Council

Final Report

17 January 2020

Perrin Ag Consultants Ltd

DOCUMENT QUALITY ASSURANCE

Bibliographic reference for citation: Muller, C., Durie, R., Dooley, E. and Matheson, L. 2020. Literature Review of Primary Sector Responses to Water Quality: Efficacy and Cost. Final report for Auckland Council. 82 pages;		
Prepared by:	Carla Muller BApplEcon, MEnvMgmt (Hons), MNZIPIM. ASNM Senior Consultant	
	Rachel Durie BAgSc (Hons) Consultant	
	Lee Matheson BApplSc (Hons), MNZIPIM (Reg.) ASNM Managing Director	
	Liz Dooley PhD (Agricultural Systems and Management) Senior Consultant	
Reviewed by	Lee Matheson BApplSc (Hons), MNZIPIM (Reg.) ASNM Managing Director, Perrin Ag Consultants Ltd	
Status:	Final report	17 January 2020

Executive Summary

Auckland Council (AC) is in the early stages of understanding how as a region it can improve water quality, including its response to the National Policy Statement for Freshwater Management (NPSFM). As part of this AC is developing a catchment water quality model (the Fresh Water Management Tool, FWMT) to account for contaminant yield, transformation and transport in surface waterways to receiving environments. The FWMT simulates baseline (current state) hydrology and contaminant concentration and load (e.g., nitrogen, phosphorus, sediment, faecal indicator bacteria, zinc and copper), continuously across the Auckland region including throughout 5,465 urban and rural sub-catchments. The FWMT also simulates mitigation strategies at sub-catchment for flow and/or contaminant outcome, from which to identify potential approaches to achieving instream grade and/or receiving environment loads of contaminant. The FWMT will inform AC's planning response to the NPSFM (and related legislation), including helping to evaluate the costs for planning options.

To enable such scenario modelling, the FWMT requires information about mitigation options including, opportunity, cost and effect. Auckland Council engaged Perrin Ag Consultants Ltd to prepare a comprehensive review of the literature on the efficacy of the range of primary sector responses to lower the contribution of water quality contaminants (accounted for by the FWMT) from farm systems in New Zealand and their accompanying economic impacts. The key mitigation strategies which are considered are:

- good management practices (GMP; individually and/or bundled as appropriate, depending on the approaches taken in prior work);
- edge of field mitigations (EOF; e.g., wetlands, detainment bunds); and
- land use change (separated by de-intensification, diversification and total land use change).

These are considered for the four major water contaminants, being nitrogen (N) and phosphorus (P) (dissolved and total), sediment and pathogens (using *E. coli* as an indicator), across agricultural land uses in the FWMT. Primarily, dairy, non-dairy pastoral (sheep, beef and deer), arable and horticulture and forestry but including other land uses such as lifestyle blocks where literature is available.

This literature review builds on existing research studies and reviews into GMP, EOF, de-intensification, system changes and land use change in New Zealand. Given the extensive research available in some of the areas of relevance, the experience of the authors in this field was used to concentrate on research and analysis from recognised experts in specific fields and make use of similar review exercises complied by leading individuals and organisations in this area in New Zealand. Output derived from the literature is presented for the framework of land types developed for the FWMT.

Literature was qualified by biophysical contaminant, methodology, cost and effectiveness measures. For some studies, all qualifying factors were not available. Given the range of assessed efficacy and often conflicting results, expert judgement has been applied to generate approximate input parameters for use by hydrologic response units (HRUs), the basis of land type within the FWMT. In the relevant literature, costs are typically presented as capital, maintenance and/or some profit metric (e.g. operating profit, earnings before interest and tax or gross margins). Efficacy metrics are typically presented for farm systems mitigations as changes in loads, often from the root zone. We note our lack of sufficient expertise to translate contaminant concentrations into loads or vice versa.

Mitigations were considered under four broad categories of interest to AC; GMP, system mitigations, EOF mitigations and land use change. The increasing convention to group mitigations into bundles that are likely to be introduced on farm together is challenging to align with the mitigation categories above. However, GMPs are typically able to be identified and implemented by farm environment plans, within a first stage (M1) bundle. System mitigations, targeted, low cost, EOF mitigations and limited de-intensification (changing intensity without altering overall land use) comprise a second bundle (M2). Large scale devices and significant de-intensification can be bundled together (M3) as the most costly suite of mitigations for rural land use. However, the exact segregation of mitigation options into bundles varies across the literature and not all align with the objectives of framework of AC's FWMT. A mitigation library has been recorded, with the main areas of interest summarised to allow application to the relevant HRUs.

Relative to other agricultural industries (e.g. horticulture, forestry and sheep and beef), **the dairy sector** has completed considerable work looking at the effect of both individual and bundled approaches to reducing N, P, sediment and *E. coli* losses to water. Research to date that has summarised a range of mitigation tools on contaminant loss from dairy systems includes: Doole (2015); McDowell and Nash (2012); McDowell et al (2013); and Monaghan (2008). Studies which have looked at the effects of bundling dairy mitigations include: Vibart et al (2015); NIWA (2010); and Daigneault and Elliott (2017). Many of the studies reviewed have evaluated approaches compared to a 'conventional' dairy farm system independent of spatial scale (i.e., lack sub-catchment or regional variation therein). Caution should therefore be taken when extrapolating data to the Auckland region as studies which use a 'typical' New Zealand dairy farm is unlikely to be representative of dairy farms in the Auckland region and studies that use regionally specific case studies, have different regional biophysical characteristics (including rain and soils).

The lower N loss footprint of the more extensive **sheep, beef and deer grazing systems** has resulted in significantly less research focus in the issue of diffuse N pollution relative to the dairy sector. Historically, much of the mitigation focus within this sector has been on erosion control, particularly on the fragile hill country of the North Island. However, over the last 10 years, more extensive case study work has been undertaken to quantify the environmental and economic impacts of the application of practice change (GMP) and de-intensification of sheep, beef and deer systems, primarily in catchments/regions of focus. While as a collective this analysis is rich and relatively diverse, the complexity and variety of farm systems within the sector makes definitive conclusions often hard to determine, with much of the economic impacts highly dependent on the relatively profitability of alternative stock classes/enterprises farmed.

Although **horticultural production** can have a significant environmental impact (Bloomer et al., 2019) the mitigation literature in this sector is comparatively sparse to the pastoral sector, both for change in contaminant yield and economic performance. Some research has been done to define and quantify field level erosion control mitigations, primarily the work of Barber (2014) which was summarised in Doole (2015). Additionally, many horticultural growers have been adhering to certified standards and best management practices / good agricultural practice determined by their grower organisations for many years. However, analysis on the economic impact of strategies to lower diffuse nutrient loss has been limited, not helped by the potential lack of suitability of OVERSEER for this purpose. A series of reports by The Agribusiness Group (2014, 2015 & 2016) prepared for HortNZ and MPI provide the most widely referred to analysis in this area.

Studies estimating the impact of changes to water quality policy under the NPSFM often focus on N and P and therefore, often **forestry** is not included in modelling as its primary impact is on sediment (for example Moran et al., 2017). Forestry is regularly considered as a mitigation for other land use types, however, there are still mitigations to reduce water quality impacts from forestry, albeit with limited research. In addition, given the long time horizons to realise income from plantation forestry and the variations in costs and benefits over time, estimations of costs and benefits are often best done in a cost benefit framework rather than farm systems modelling framework which generally compares two static points in time.

Other rural land uses that could have a potential impact on AC's use of the FWMT to optimise for freshwater contaminant objectives, primarily **lifestyle blocks and commercial equine blocks**, are virtually absent from the mitigation literature. Nationally, limited work has been done on these land uses due to the focus on land uses with significantly more scale and mitigation options. Indeed, many regions have excluded land parcels below certain thresholds (e.g., land area, stocking rates and/or cropping areas) from meeting certain regulations relating to contaminant losses (e.g. Horizons, Bay of Plenty and Waikato Regional Councils). However, given the influence of Auckland's urban areas across land use within the greater Auckland region, it is potentially important to consider if, and how, these land uses could be better incorporated into the FWMT than their current undifferentiated inclusion within the <10 SU/ha HRU.

Several **EOF mitigations** including use of barns on dairy farms and wetlands (regional, seepage) are relatively well considered in literature and others less so. Often these mitigation strategies are considered separately to de-intensification options. We'd consider this the best approach, primarily because often EOF mitigations have a significant impact on the farm system (effect and profit) meaning it is useful to consider only EOF options then consider de-intensification if still necessary for contaminant objective(s). However, some modelling includes targeted, low cost, EOF mitigations as part of bundled mitigation options rather than as stand-alone options.

Based on the review, it is recommended that AC will need to undertake some case study modelling of farming systems defined by the HRU framework within the FWMT in order to:

- Fill key information gaps
- Test applicability of transferring existing work to the Auckland region, assessing if literature estimates of GMP, EOF and de-intensification opportunities, costs and effects are valid to Auckland farm systems (HRUs);
- Develop new data for farm systems (HRUs) poorly researched to date for opportunity, cost and effect (e.g., horticulture, equine, porcine, caprine, cervine systems).

Further recommendations to inform the FWMT include:

- Horticulture and arable mitigations, including GMP, EOF and de-intensification. There is limited literature quantifying cost and benefit of mitigations on horticulture and arable farms. While there is one study which provides a starting point (The AgriBusiness Group, 2014) it covers limited crop rotations and it is not clear if the crop rotations considered are applicable to the Auckland region. In addition, the use of OVERSEER for horticulture and arable land uses has been criticised, especially as it does not estimate the impact of mitigations for sediment. It is likely that AC will need to consider if it is feasible to fill this key literature gap and if so, how this could be done in alignment with the HRU basis of the FWMT (e.g. through alternative modelling software, or empirical research).

- Non-dairy pastoral systems vary widely in system types. For N and P, it is recommended that AC analyses the types of farming systems across the region in this land use class and then farm systems modelling is undertaken to estimate the impacts of reducing N and P from these farms.

- Validation of N and P mitigation options across Auckland dairy farms. No research was available specifically from the Auckland region despite being the most extensively researched farming sector for mitigations of N and P. Transferring wider regional or national estimates is possible but might warrant some verification that farm systems, contaminant losses and mitigation options are equivalent.

- For both dairy and non-dairy pastoral land uses there is limited research on sediment and *E. coli* mitigations. However, the biggest constraining factor on this has been tools available and AC will have to consider these model limitations when incorporating mitigation options.

- The impacts of land use change (whole farm) and diversification mitigation options have not been extensively considered in this report. To aid the FWMT, possible land use change can be modelled by estimating potential performance (environmental and economic) of the varying land uses. As such this report provides potential estimates of profitability for varying land uses within the Auckland region which could provide a very coarse metric for use in the FWMT. However, this should be re-evaluated in conjunction with industry and requires an understanding of potential future changes in land use (i.e., where land use could potential change based on biophysical, market and policy factors.

- There is reasonable literature on some EOF mitigations, however, others are emerging or not well researched. Some of these (e.g. riparian areas, wetlands and stock exclusion) could be included in modelling for the AC, and based on existing research and tools available, adjusted to represent the Auckland region. For some (e.g. N inhibitors, soil amendments and dung beetles) it is recommended that these are not included in modelling due to the limited empirical research available.

Further recommendations to the process of gathering above information to inform the FWMT include:

- Validation of baseline data (economic and environment performance) – from which any comparative assessment of mitigation outcomes is based.

- Validation of land management practices (e.g. what horticulture rotations are used) will ensure mitigations considered in the FWMT are appropriate and the relative performance of mitigation options is realistic.

- Agreement of general modelling assumptions. If farm systems modelling is undertaken in the Auckland region, general modelling assumptions should be agreed upon up front, including how to treat input and output prices, whether farm data is to be ’smoothed’ or not, what metrics to consider, how to deal with seasonality, if farm level system optimisation can occur, if average or case study farms should be used, what can and cannot be modelled and/or estimated and appropriateness of extrapolating results.

PERRIN AG CONSULTANTS LTD

Contents

List of Tables and Figures

Glossary

Farmer someone involved in animal-based agriculture.

Grower someone involved in plant-based agriculture.

Farm land used in pastoral or arable agriculture or row horticulture.

Orchard land used for the production of permanent tree or vine horticulture.

Economic cost is the combination of losses of any goods that have a value attached to them by any one individual, this includes opportunity costs.

Operating profit a profit from business operations (gross profit minus operating expenses) before deduction of interest and taxes.

Earnings before interest and tax (EBIT) is a business's net income before interest and income tax expenses have been deducted. Often this is used interchangeably with operating profit in farming enterprises. However, the technical difference is that EBIT includes non-operating income, non-operating expenses, and other income (if they exist).

Mitigation an action undertaken on farm which reduces a contaminant, or contaminants, from a farm.

Capital cost the one-off costs involved in initial construction of a mitigation, e.g. fencing construction costs.

Maintenance cost the ongoing costs involved in maintaining a mitigation option, e.g. weed control in riparian areas.

Opportunity cost the forgone alternative as the result of a decision, e.g. the annual profit forgone by retiring land.

Bundled mitigation a group of mitigations which is modelled together.

System changes a group of mitigations which do not change the underlying level of farm system intensity, but their whose adoption could have flow-on effects to the wider farm system e.g. integrating diverse pastures into a farm system.

De-intensification reducing the inputs to a farming system, e.g. reducing stocking rate or volume of vegetables grown.

Good Management Practice (GMP) on farm practices which have been widely agreed to represent a good level of practice, e.g. not applying fertiliser while it is raining.

Farm Environment Plan (FEP) a FEP is a farm specific tool to identify on-farm environmental risks and set out a programme of actions to manage those risks.

Diversification changing a proportion of a farm (both area and contribution to revenue) to an alternative land use.

Land use change changing an entire farm from one productive use to another, e.g. from dairy to horticulture.

Land retirement removing land from productive uses.

1. Introduction

Auckland Council (AC) is developing a continuous, process-based catchment model (the Fresh Water Management Tool, FWMT) to inform its implementation of the NPSFM (and related legislation) including helping to evaluate any potential plan changes. The FWMT is a freshwater accounting system, able to report changes in hydrology and contaminant generation and loss, instream and downstream, for both urban and rural land throughout the Auckland region. The FWMT includes capability to determine "current" or baseline state of contaminants, as well as "future" or scenario state of contaminants under changes in resource management (land cover, intensity of use, water consumption and discharge to water). However, enabling that scenario capability requires knowledge of mitigation opportunity, cost and effect for a menu of items available to land uses.

This piece of work forms the first stage of a two-stage project. The aim of this first stage is to undertake a review of the literature to date on the approximate costs and benefits of various mitigation strategies to reduce key contaminants to water from land use in the primary sector. It aims to consider both capital and on-going costs as well as reductions in water contaminant yields. It considers information drawn from research on mitigation strategies from across the country and focusses primarily on dairy, sheep and beef and horticulture (incorporating arable) land uses, largely due to the larger evidence base for these land uses. It includes information for other land uses where available.

Specifically, AC requires a comprehensive review of the literature on the efficacy of the range of primary sector responses to lower the contribution of key water quality contaminants from farm systems in New Zealand and their accompanying economic impacts. The key mitigation strategies which are considered are:

- good management practices (GMP; individually and/or bundled as appropriate, depending on the approaches taken in prior work);
- edge of field mitigations (EOF; wetlands, detainment bunds); and
- land use change (separated by de-intensification, diversification and total land use change).

These are considered for the four of six water contaminants simulated by the FWMT that are typically associated with agricultural activity: nitrogen (N) and phosphorus (P) (dissolved and total), sediment and pathogens (using *E. coli* as an indicator). Findings are defined for regionally predominant agricultural land uses: primarily dairy, non-dairy pastoral (sheep, beef and deer), arable and horticulture, and forestry. Other land uses such as lifestyle blocks are considered where there is literature available. Where possible, mitigations are quantified and aligned with the relevant hydrological response units (HRUs) that form the basis of land types within the FWMT (i.e., for which hydrological and contaminant processes are regionally parameterised to enable continuous simulation of losses to water by the FWMT). Rural productive HRUs are classified with a matrix of land cover, soil group, slope and intensity of use – the latter varying in its definition by land cover (i.e., stocking rate for pastoral uses; cropping type for horticulture).

This report is based on existing literature, no new farm modelling is conducted in this stage.

The results from this report are indicative for use in the FWMT but are limited by information gaps and varying sensitivity for which further research will improve FWMT simulations. It also uses information from across New Zealand and therefore, only where there is strong reasoning (such as similar biophysical characteristics and/or common estimates across a range of locations) should the results be considered suitable for use in the FWMT. The authors have highlighted where results could be extrapolated for use in the FWMT.

Finally, when considering the mitigations from the literature, it is important to note that while costs and effectiveness is based on a mixture of measured and modelled analysis, the reality is that these costs and effectiveness in real situations could be highly variable depending on specific contexts.

2. Methodology

This literature review will build on existing work and previous reviews, centring them in the context of the FWMT AC are developing, but does not provide for any new modelling.

There is a range of studies which look at the effectiveness and cost of both individual and bundles of mitigation strategies to improve water quality on rural land uses. Some of these strategies are included under the broad banner of "good management practice" or "good farming practice" (GMP, GFP) but these studies tend to use both terms inconsistently.

Previous mitigation studies in New Zealand have tended to focus on assessing effects on four primary contaminants to water: N, P, sediment and bacteria such as *Escherichia coli (E. coli*). The literature base, including both modelled and measured studies, continues to expand with studies ongoing. Several contaminants and farm system combinations are relatively well understood, others less so, further increasing the difficulty in assigning some region-wide effects base to mitigation modelling across the Auckland region.

This literature review draws from a range of sources including both empirical studies (e.g. Christensen, 2013) as well as modelling studies (e.g. Matheson et al., 2018). The current pool of literature has a range of assumption, approaches and applicability to contaminant accounting frameworks (e.g., the FWMT). Given the amount of work that could be required for AC to consider the economic impacts of mitigating contaminants from rural land uses within the FWMT, it is prudent for AC to utilise existing literature where it is appropriate (i.e., based on quality and quantity of work and applicability of studies to the Auckland region context; as a first step). For example, there has been considerable work undertaken on understanding how dairy farms could reduce N losses of reasonable spread, offering more reasonable application to the Auckland region. However, as with the wider suite of mitigation modelling across by farm types (HRU), it would be recommended that AC 'ground truth' prior research in New Zealand to ensure accuracy for use in the Auckland region. Mitigation modelling for farm types with scarce literature would benefit from more focussed analysis by AC.

Literature was compiled with key factors describing mitigation choice, effect and cost noted, including biophysical contaminants, methodology, cost and effectiveness estimates. Where all such factors were not quantified these uncertainties were noted. Wherever possible mitigations sourced from the literature were aligned to the HRUs used in the FWMT. Given the range of assessed efficacy and often conflicting results, expert judgement has been applied to generate approximate input parameters for aligning by HRU and input to the FWMT. No attempt has been made to translate changes in contaminant concentrations into loads or vice versa between studies.

Based on the literature review, recommendations have also been provided for estimates of GMP, de-intensification and some EOF mitigations which could be included in the FWMT. These recommendations include suggestions on where data may be transferred for use by the FWMT and where additional modelling should be carried out (e.g., testing assumptions and sensitivity analysis). Recommendations based on common challenges with mitigation modelling are also considered.

2.1. Hydrological response units

The FWMT simulates hydrology and contaminant response of land to climate and resource use, by typing all of the regions surface into one of 106 unique HRU classes on a two-meter grid. HRU classes are defined by combinations of land cover, intensity of use, hydrologic soil group and slope. All 5,465 sub-catchments configured within the FWMT have been assessed for the extent of all 106 HRU classes prior to continuous simulation of hydrological and contaminant processes (e.g., at sub-catchment scale, to modelled stream reach downstream of sub-catchment). Overall, 20 HRUs describe the range in pastoral land responses to climate and use whilst 30 HRUs characterize horticultural responses to climate and use. Each HRU is uniquely parameterized for hydrological and contaminant processes, on a regional basis in the FWMT (i.e., land titles of equivalent class, under identical climate, are assumed to generate identical hydrological and contaminant mass – noting that there are 5,465 sub-catchments able to experience unique climate by HRU composition or generate unique contaminant outcomes despite the FWMT's regionalized configuration).

Rural productive HRUs are summarized in Table 1, as:

- Pastoral (land cover) by property parcel, classified further by:
    - Intensity – less than 10 stock units per hectare (low), more than or equal to 10 stock units per hectare (high).
    - Hydrological Soil Group (HSG)
        - A+ that are "very high infiltration" soils of "volcanic geology, medium to high soakage", highest free-draining soil types;
        - A that are "high infiltration" soils of "sand/loamy sand/sandy loam"
        - B that are "moderate infiltration" soils of "silt/silt loam/loam"
        - C that are "low infiltration" soils of "sandy clay loam"
        - D that are "very low infiltration" soils of "clay loam/silty clay loam/sandy clay/silty clay/clay"
    - Slope (defined from region-wide LiDAR) – less than 10% (~6 degrees) and greater than or equal to 10%. (flat to rolling land) and rolling to steep land.

For the purpose of this review, HSG have been grouped into three broader drainage classes to align with the GMP literature: A and A+ (free draining), B (moderate draining), and C and D (poorly draining). Likewise, slope classes used for the FWMT have been aligned to flat-to-rolling land (<10% slope) and rolling-to-steep land (≥10%). In addition, high intensity has been split into dairy and sheep and beef. These changes were to enable alignment of mitigation studies in existing literature to the HRU framework.

- Horticultural and arable (land cover), titles classified further by:
    - Intensity –
        - Orchards and idle fallow,
        - Arable, citrus, fodder, nuts and viticulture,
        - Berryfruit, flowers, fruit, kiwifruit, nursery, pipfruit, stonefruit, vegetables and greenhouses
    - Soil group –as per pastoral HRUs.
    - Slope – as per pastoral HRUs.

Table 1: Summary of HRUs

Land cover	Intensity	Soil group	Slope
Pastoral	Less than 10SU/ha	Free draining	Flat to rolling
			Rolling to steep
		Moderately draining	Flat to rolling
			Rolling to steep
		Poorly drained	Flat to rolling
			Rolling to steep
	More than 10SU/ha	Free draining	Flat to rolling
			Rolling to steep
		Moderately draining	Flat to rolling
			Rolling to steep
		Poorly drained	Flat to rolling
			Rolling to steep
Horticulture	Orchards & idle fallow	Free draining	Flat to rolling
			Rolling to steep
		Moderately draining	Flat to rolling
			Rolling to steep
		Poorly drained	Flat to rolling
			Rolling to steep
	Arable, citrus, fodder, nuts & viticulture	Free draining	Flat to rolling
			Rolling to steep
		Moderately draining	Flat to rolling
			Rolling to steep
		Poorly drained	Flat to rolling
			Rolling to steep
	Berryfruit, flowers, Stonefruit, kiwifruit, nursery, pipfruit, fruit, vegetables & greenhouses	Free draining	Flat to rolling
			Rolling to steep
		Moderately draining	Flat to rolling
			Rolling to steep
		Poorly drained	Flat to rolling
			Rolling to steep

3. Background

3.1. Primary contaminants

3.1.1. Nitrogen

Nitrogen (N) is lost to water as surface runoff and through subsurface drainage (leaching); when it is lost to water it is most commonly in the form of nitrate due to the soluble nature of nitrate ions (Decau, Simon & Jacquet, 2003; Ledgard & Menneer, 2005; van Es, Sogbedji & Schindelbeck, 2006). N losses vary across space and time due to climatic conditions and soil types. N can be lost directly to water through fertiliser or effluent application [via overland flow] more so for horticultural land uses. Whereas, the primary driver of N loss from pastoral systems is via urine deposition from livestock. Most mitigation practices in relation to reducing N loss to water from pastoral systems focus on improving N conversion efficiency by livestock (e.g., into food and fibre). Mineralisation of soil organic matter from cultivation or N fertiliser application is a more typical driver of loss in arable and horticultural systems.

3.1.2. Phosphorus

Phosphorus is most commonly lost to water as phosphate attached to soil particles. Phosphate is relatively insoluble and adheres strongly to soil particles. Therefore, pastoral activities which disturb soil contribute the majority of phosphorus losses and primarily through surface runoff (including cultivation and erosion), with considerably less lost through soil drainage (DairyNZ, 2013; Sharpley, 1985; McDowell, 2008). Phosphorus is also lost by direct deposition or runoff of dung, fertiliser or farm dairy effluent to waterways with potential for greater dissolved P lost to subsurface or surface pathways from horticultural activity.

On pastoral farms, treading damage causes less water to infiltrate the soil and therefore a greater runoff of water (Dewry & Paton, 2000; Smith & Monaghan, 2003). Whilst on arable and wider horticultural land, cultivation increases the amount of soil particles at risk of being lost through runoff (with phosphate attached). Phosphorus losses are not uniform across a property with McDowell (2007) suggested that typically 80% of P losses originate from 20% of the land area in so-called “critical source areas” (CSA). Others such as Sharpley, Gburek, Folmar and Pionke (1999) suggest this figure is even higher (up to 90% from 20% of land area). CSAs are created by the interaction of environmental factors (soil and vegetation characteristics), hydrological conditions (amount and rate of runoff) and management factors (fertiliser, stocking and cultivation practices). Some CSAs cannot be modelled within nutrient loss modelling tools at this stage (including laneways, races, troughs, gateways and stock camps).

3.1.3. Sediment

Sediment is predominantly inorganic material (particles of soil and rock eroded from the land) when received by water bodies (Hicks, Quinn & Trustrum, 2004). It is a by-product of erosion which is a natural process accelerated by land use to negatively impact freshwater quality by making water turbid, smothering aquatic life, altering water flows and exacerbating flooding risk ((Glade, 2003; PCE, 2012). There has been some work undertaken in New Zealand to reduce sediment losses, including planting and fencing waterways, replanting and retiring steeply contoured land and strategic planting of erosion prone farmland, but sedimentation is still an issue affecting water quality especially in storm events which exacerbate erosion (PCE, 2012).

3.1.4. Pathogens

Pathogens are disease causing micro-organisms (Davies-Colley & Wilcock, 2004) which can negatively impact human and animal health. *E. coli* is used as an indicator of freshwater bacterial contamination from animal faeces and associated pathogens. On productive rural land, pathogens are associated with animal effluent discharge (PCE, 2012) through direct deposition or via overland flow. Further sources include on-site wastewater systems which are not considered further here (e.g., septic tanks).

3.2. Modelling contaminant mitigation in farm and orchard systems

3.2.1. General principles

Estimating the impact of farmers and growers implementing mitigations to reduce diffuse (non-point source) contaminant losses to water is typically done through a modelling process, with the underlying models informed by empirical research and data. The process will generally involve modelling base/current state farm systems to estimate steady-state base loads and performance metrics. These systems are then adjusted in response to the implementation/application of mitigation strategies (as scenario) and then the new steady-state contaminant loads and performance metrics are re-evaluated and compared to the base system.

While the precise techniques (and the assumptions they choose to use) will vary between modellers, in general the following principles are adhered to:

- The farm or orchard system is assumed to be in a steady or “status quo” state. This infers that the same resources are available for use at both the start and the end of the model sequence, typically an annual time step for farm and orchard systems.
- Long-term average environmental and market data should be used.
- Assumptions around how the farm or orchard system will respond/adapt to the mitigation(s) are reasonable and informed by known practice. Where possible standardised decision rules should be consistently utilised and, unless lifting productivity is a specific mitigation being assessed, the production possibility frontier (Muller, 2017) held constant across all scenarios.
- Where the impact of multiple mitigations is to be assessed, individual mitigations within a group or bundle should be applied in the same sequence if applicable to each scenario.
- The relative change in any outputs between scenarios is often more important/reliable than the absolute change and, as a result, is a better measure of relative impact.

3.2.2. Concept of "bundling" of mitigations in farm system modelling

Given the significant number of mitigations that might be able to be implemented within a farm or orchard system, there has been a growing convention to consider individual mitigations in groupings or "bundles" that are considered likely be introduced on farm at the same time (Daigneault & Elliot, 2017). These tend to be defined within the context or framework of social and economic factors (i.e. complexity, cost, risk). This approach has been used by Everest (2013), Vibart et al (2014), Parsons et al (2015), Daigneault & Elliot (2017) and Matheson et al (2018), amongst others.

In general terms, three bundles tend to be used. While the specific mitigations included within them varies between analyses, in general terms, the bundles, derived from Daigneault & Elliot (2017) and Matheson et al (2018), can be broadly defined as follows:

(i) M1: relatively cost-effective measures with minimal complexity to existing farm systems and management i.e. a low barrier to adoption;

(ii) M2: mitigation that is less cost-effective than M1, but with capital costs and/or large system change i.e. moderate barrier to adoption;

(iii) M3: management options with large costs and/or are relatively unproven i.e. a high barrier to adoption, primarily defined by; significant reductions in pre-mitigation profitability and/or high capital costs.

Given that these bundles are predominantly grouped based on cost-effectiveness and complexity, there is no clear delineation in the literature of which mitigations fall into which bundle. For example, M1 does not always consist of only GMP, and EOF mitigations are sometimes included throughout the bundles to varying levels or excluded entirely. These bundles are also often modelled as being implemented sequentially. That is, M2 also includes the practices in M1, while M3 includes all of the (applicable) mitigations from M1 and M2. This assumption reflects the behaviour we would tend to observe in the field, where successful practices/mitigations are adopted permanently by farmers and growers, and an underlying premise that rational economic actors would apply/adopt least "cost" practices first.

3.3. Mitigation strategies

This section briefly introduces the four broad categories of mitigations to be assessed for possible use by the FWMT: GMP, system changes, EOF mitigations and land use change (including de-intensification). System changes were not included in the original scope but has been as a result of the review exercise. Each is briefly described for cost and effect, noting any key considerations associated with each that should be considered for their alignment to HRUs within the FWMT. The general definitions are summarised in the table below and expanded on in sections 3.3.1 to 3.3.4 below. How they will be subsequently bundled for modelling purposes is discussed in 3.3.5.

Table 2: Summary of mitigation categories

Mitigation category		Definition
Practice change		Modification to existing practices (how we do things) that do not change farm[1] system parameters (what we are doing)
System change		Modifications to an existing farm system (what we are doing) that do not alter farm intensity (how much we produce with what we are using).
Edge of field mitigations		Mitigations that intercept contaminants through physical modification or manipulation of soil chemistry or biology, irrespective of farm system.
Land use change	De-intensification	Modifications to an existing farm system (what we are doing) that reduces farm intensity (how much we produce with what we are using).
	Diversification (partial land use change)	A proportion of the land is changed to an alternate land use.
	Total land use change	All of the land is changed to an alternate land use.

3.3.1. Good management practices [Practice change]

GMP is a term used by rural productive sectors and formalised in the *Industry-agreed Good Management Practices relating to water quality*[2]. This work was undertaken in 2015 for the Canterbury region and focused on practices linked to benefit for water quality. The latter has since become a commonly agreed basis of GMP and directly linked to plan changes such as by Environment Canterbury (ECAN, 2019) and indirectly linked to others such as Tukituki Plan Change 6 in Hawkes Bay (which refers to actions which are promoted by the industry as GMP; HBRC, 2015). Industry partners to the project included the industry good bodies for dairy (DairyNZ), sheep and beef (Beef & Lamb), deer (DeerNZ), pork (PorkNZ), horticulture (HortNZ) and arable farming (FAR). Industry good bodies have also developed sector-specific publications that expand on the Industry-agreed GMPs. It is important to note that GMP does not relate to a specific nutrient loss and for every farm operating at GMP there can be varying nutrient losses based on underlying biophysical and farm-system characteristics. This section does not describe all GMPs which can be found in the Industry-agreed GMP documentation and industry specific GMP guides, but briefly discusses how they have been incorporated into the literature to date.

[1] Or orchard
[2] https://api.ecan.govt.nz/TrimPublicAPI/documents/download/2378592

In general terms, we consider GMPs as a bundle of mitigations typically able to be identified, incentivised and implemented by a farm environment plan (FEP). In literature which uses a bundling approach, GMPs are typically considered as part of a M1 bundle (e.g. Matheson et al., 2018).

In some studies, various GMPs have been considered individually (e.g. Journeaux & van Reenan, 2017) while others have taken a bundling approach (e.g. Matheson et al., 2018). Some assume farms are already operating at GMP or do not explicitly consider GMP (e.g. Newman & Muller, 2017). The approach taken is determined by the aims of, or data used in, the studies. This stresses a key assumption required for use of GMP assessments by the FWMT, what is GMP on each farm, the degree of existing farms who implement GMP and to what extent.

OVERSEER is the principal tool by which past mitigation studies have attempted to quantify outcomes on N and P loss, particularly on pasture. However, there are many GMPs that are not able to be modelled in OVERSEER, including directly accounting for CSAs (i.e., many are not able to be simulated without further assumptions by OVERSEER). In addition, some farm system modelling excludes modelling GMP as it can be hard to ascertain how farmers are preforming relative to GMP without intensive consultation with each case study farm (Newman & Muller, 2017). OVERSEER in its base form will also assume some GMP is already implemented by so called "best practice", which may or may not occur in reality (i.e. fertiliser is applied in line with industry standards regarding calibration, overlap etc.). Hence, there are considerable limitations in use of earlier OVERSEER estimates for modelling GMP.

Some studies (e.g. Kalaugher et al., 2019) have used a FEP-based methodology to quantify the impact of actions, typically GMP. In this process, FEPs are used to identify where an individual farm sits in relation to practices typically aligned with GMPs and then estimates the quantum of expected costs and benefits of that farm adopting/implementing any practice gaps.

Other methods used to quantify the costs and effectiveness of GMPs are based on traditional cost benefit analyses (relative to farm modelling software). For example, analyses of the costs and effectiveness of stock exclusion (e.g. The AgriBusiness Group, 2016).

3.3.2. System changes

This additional characterisation of mitigations is required to capture on-farm management changes that fall between what might be considered GMP and those that are a pre-cursor to moving into de-intensification. These mitigations do not change the underlying level of farm system intensity (i.e. production (kg MS, kg meat/ha) and overall inputs (stock numbers, feed production) doesn't change but the manner in which that production is achieved does. However, adoption can have flow-on effects to the wider farm system and may require additional adaptation or changes (and costs). Examples of these mitigations can include temporary destocking (during a season i.e. winter grazing), changing calving or lambing dates, changing the sex ratios of non-capital stock (moving to finishing steers from heifers), the use of catch or cover crops after existing cropping activity, using new pasture species or changing to using low N feed supplements.

These changes would be typically captured within any bundling analysis in either M1 or M2, depending on their complexity of implementation and impact on farm system profitability.

3.3.3. Edge of field mitigations

EOF mitigations include mitigations that intercept contaminant loss typically through retirement of land from production with limited system changes required and may not be sector specific. Common examples include wetlands (creation or restoration), riparian buffers (grass filters, planted), detainment bunds, sedimentation ponds and filtration devices. For the purposes of this analysis, we have also included mitigations that intercept contaminants through manipulation of soil chemistry or biology.

EOF mitigations are typically not included in farm level contaminant mitigation modelling and instead the bulk of their literature is based on empirical studies (or reviews) (e.g. McKergow et al., 2017) or on cost benefit analyses (e.g. Grinter & White, 2016). Often, the spatial or geo-physical mechanics of the mitigation preclude many of their inclusion into farm system modelling tools. These mitigation options have been shown to have potential at both farm and catchment scale. EOF have been included in this literature review. Where EOF mitigations have been considered within bundles (e.g. Matheson et al, 2018; Vibart et al, 2015), smaller scale works and devices are typically considered within second stage (M2) mitigation bundles, while larger works and devices, often those that could intercept contaminants from more than one property but aren't valued in that context, would typically be included in third stage mitigation bundles (M3).

3.3.4. Land use change

There are typically three types of land-use change strategies that can be considered as mitigation strategies for contaminant loss from rural land uses; de-intensification, diversification and total land use change. While in practice how these mitigations are modelled and described in literature does vary, AC was interested in the range of mitigation strategies and these three groupings could broadly be applied across the range of studies.

De-intensification in this report covers two aspects, changing stock and/or cropping policies to those with a lower environmental footprint (often considered in "M2" bundles) and/or reducing stocking rates and/or crop area overall (typically considered within "M3" bundles). These have been considered on a sector specific basis. In both cases both farm inputs and outputs are reduced. While increasing productivity can be a strategy to maintain outputs while inputs are reduced, not all producers can achieve this and as such it is generally excluded from consideration. Because de-intensification is primarily focused on changing feed supply and/or demand, studies which do not consider the implications of a change on the remainder of the farming system (e.g. reducing stocking rates with no associated change in feed supply) should be treated with caution.

Diversification incorporates mitigation strategies where a proportion rather than all of the land is changed into an alternative land use(s).

Total land use change refers to an entire property changing the primary enterprise use.

Both diversification and total land use change are particularly challenging to model as it is hard to estimate how an alternative land use would be set up and managed and therefore often relies on average farm indicators (such as profit) or expert opinion.

3.3.5. Suggested application of bundling in the FWMT

As suggested in 3.2 above, bundling is different to the broad categorisation of mitigations considered in 3.3.1 to 3.3.4, which considers mitigations according to a technical or physical definition. The use of categories, not bundles, for applying mitigations within the FWMT, was the original approach explored by Auckland Council. The notable anomaly was the concept of good management practices (GMP), which combines a social construct ("good") with a technical concept ("practice change") and is strictly neither a category nor a bundle.

However, we believe that the adoption of a bundling approach for the mitigations to be applied within the FWMT is preferred, given the wide range of costs, efficacy and ease of adoption within most of the mitigation categories doesn't restrict mitigation categories to a single bundle. This is reflected in the literature available. However, the specific requirements of this initial iteration of the FWMT makes a slightly different approach valid.

Given EOF mitigations can be applied (albeit with variable levels of efficacy) to farm and orchard systems at any level of intensity and tend to not be farm system specific, it makes sense to "unbundle" these specific mitigations from others and allow any modelling to apply them "out of sequence" per se. This isn't necessarily an approach to that has been consistently applied based on the applicable literature (which makes extracting inputs for the FWMT from these sources somewhat fraught) , but it aligns nicely with the treatment of urban sector mitigations within the FWMT and the fact that larger EOF devices may have a wider impact than the individual farm or orchard on which they are sited. Given the high [fixed] cost of many of these EOF interventions and the fact that their efficacy can relate to the load they are designed to intercept, it may be useful to be able to apply then within the model at an earlier stage when they may be more effective (and have a lower cost per unit of contaminant intercepted) than when loads are lower, but their costs remain unchanged. We believe land retirement, considered in FWMT v1 as permanent land use change to native forest, should be treated in a similar fashion.

On this basis, we'd recommend the use of the following bundles within the rural sector FWMT modelling (acknowledging that the present version of the FWMT is limited to the outcomes of bundles as modelled available in existing literature which may not totally align):

- M1 – essentially the practice change and minor system change that might be considered to represent GMP (that could be expected to be identified by and implemented as a result of a farm environment planning process). These will vary across farm types (dairy, horticulture & sheep and beef) and align with the generally accepted position of M1 being low cost and [relatively] easy for adoption on farm.
- M2 – this will represent a combination of less costly bundled system changes and de-intensification and be cumulative of the M1 options – i.e. M2 is applied in addition to, not instead of M1.
- M3 – same as M2 but more expensive or challenging system changes, and/or further de-intensification, again cumulative of the mitigations in M1 and M2

The additional non-sequential/non-cumulative "bundles" should also be available for application in the model:

- EOF – edge of field mitigations;

- LR – land retirement to native vegetation intended for permanent afforestation;

These are presented figuratively below, with the colours reflecting the traditional bundling approach of M1 (green), M2 (yellow), M3 (salmon) and M4[3] (burnt orange). The cost of mitigations in the FWMT bundles are presented in Section 5 below.

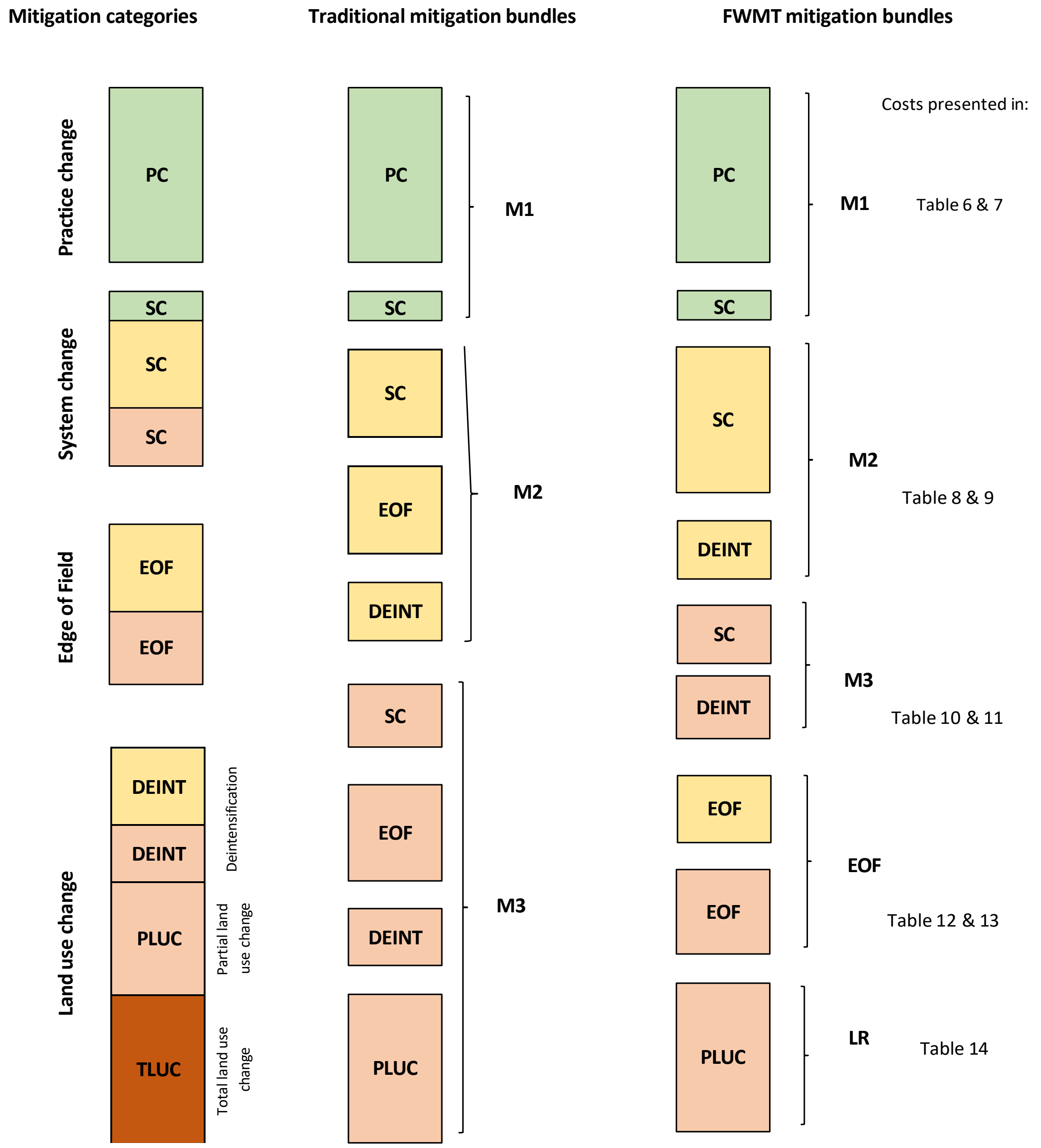


Figure 1: Mitigation bundling

[3] M4 – Total land use change

3.4. Baseline operating profit by land use type

Each farm business will have a different operating profit, debt level, tax obligations and other business considerations. Typically, existing farm mitigation modelling studies present economic results as percentage reductions from a base level of operating profit. Estimates of operating profit for the HRUs in the FWMT can be made and the percentage reductions from the literature applied to these. These estimates of operating profit are based on considerable assumptions and should be validated, and variation in operating profit should be also considered. Table 3 provides estimates of operating profit across the HRU intensity classes.

Table 3: Estimates of operating profit by HRU intensity class

Intensity class in HRU	Operating profit ($ per effective hectare per year)	Assumptions
Less than 10SU/ha	$420	Average operating profit per effective hectare based on an average between 2013-14 and 2017-18 excluding interest, tax and rent. Based on the Beef + Lamb NZ Economic Farm Survey for Class 4 N.I. Hill Country - Northland-Waikato-BoP (Beef + Lamb NZ, 2019).
More than 10SU/ha (sheep & beef)	$680	Average operating profit per effective hectare based on an average between 2013-14 and 2017-18 excluding interest, tax and rent. Based on the Beef + Lamb NZ Economic Farm Survey for Class 5 N.I. Intensive Finishing - Northland-Waikato-BoP (Beef + Lamb NZ, 2019).
More than 10SU/ha (dairy)	$1,330	Average operating profit per effective hectare based on an average between 2013-14 and 2017-18 excludes interest, tax and rent. Based on DairyNZ Economic Survey for owner operators in Waikato & Northland regions, weighted to represent production in Auckland territory local authorities (DairyNZ, 2018; DairyNZ & LIC, 2018).
Orchards, idle fallow	$50,000	Based on average kiwifruit orchard gate return across green and gold orchards. Considered the following sources: • Archer & Brookes (2018) - $33,389/ha, • Matheson et al (2018)- $19,500/ha (green) & $78,400/ha (gold), and • Zespri (2017)- $39,142/ha (2010), $60,758/ha (2016) & $68,868/ha (2017).
Arable, citrus, fodder, nuts, viticulture	$2,400	Based predominantly on the arable farm modelled in Matheson et al (2018), which estimated operating profit per hectare at $2,345.
Berryfruit, flowers, stonefruit, kiwifruit, nursery, pipfruit, fruit, vegetables, greenhouses	$4,000	Given the range of horticulture crops in this HRU class, a weighted average of modelled gross margin per hectare across three farm types (50% of extensive horticulture rotation, 45% intensive rotation and 5% market garden) modelled in Agribusiness Group (2014) was used.

3.5. Challenges with farm modelling

Any modelling study that attempts to estimate the cost and/or the effectiveness of mitigation strategies for contaminant losses from rural land uses will be based on a set of assumptions and no method will be a true representation of reality. However, modelling the expected results based on a robust and transparent set of assumptions is crucial for estimating impacts of things such as plan changes. It is just worth being cognisant of key challenges with modelling when interpreting results and/or designing studies. Key challenges to be aware of are discussed briefly below.

There are a range of modelling software available, each with their own strengths and weaknesses. Typical models used in New Zealand to estimate the effectiveness of mitigation measures on farm include: OVERSEER, APSIM, and MitAgator. Others such as NZFARM take a national or regional focus. NZFARM also considers economic elements, while OVERSEER is typically used in conjunction with an economic and biophysical model such as FARMAX. These different tools have a range of scales and assumptions inherent within them meaning the results are often not directly comparable. Other studies are based on modelled data from specific sites and economic analysis is also conducted as a cost benefit analysis. Probably the most widely used methodology for on farm mitigations is the use of OVERSEER and FARMAX together (i.e. Matheson et al., 2018; Newman & Muller, 2017; Parsons et al., 2015; Vibart et al., 2015). Again, both are models and therefore are not a perfect depiction of reality but have been widely used for N mitigation strategies from pastoral farms and for this use are reasonably well accepted. However, they do not capture sediment and *E. coli* losses, P is typically less well accepted at the scale of land form delineation typically adopted in OVERSEER, and the use of OVERSEER has been widely disputed for horticulture and arable farms (e.g., The AgriBusiness Group, 2006; FAR, 2013). Given this study is based off existing literature it is enough to note the methodology used. However, for any new case-study modelling AC should consider the best model(s) for their requirements and understand the limitations of each model. Whichever model(s) are used assumptions must be robust and transparent.

While monitored effectiveness can be a more robust measure than modelled results, such observations may not be easily extrapolated to wider contexts. Conversely modelled data is generally built on aggregated measured data and therefore, while it may be less accurate for a specific site, it is likely more robust to be used for a wide range of scenarios. Notably, the FWMT is being developed iteratively with the FWMT Stage 1 regionalised in configuration (i.e., set up to represent hydrological and contaminant processes for regional decision-making). As such, more broadly representative information is likely of greater immediate relevance.

As discussed in relation to GMPs, most models contain a non-exhaustive suite of mitigations. Therefore, there are some mitigations not well covered in existing literature, and there are some which will be beyond the ability of AC to model with current modelling tools. While this is not in the purview of AC to alter, alternative approaches might offer future value. Any mitigations that cannot be captured but are considered as potential solutions should be documented as limitations and decisions made with suitable flexibility later to incorporate these into mitigation strategies.

Most mitigation studies have explicit, or implicit, methodology for selection and ordering of mitigation strategies, and this varies between studies. For example, some apply the least cost mitigation strategies first (e.g., assuming the farmer or grower is a profit maximiser); others select mitigations based on farmer preference (e.g., the desire to utilise one big, typically capital intensive, mitigation, such as building an off-pasture structure, over least cost options). However, the latter relies on understanding the farmer and their goals, and former effectiveness for a prioritised contaminant (i.e., mitigation order of cost-effect can vary between contaminants). Both approaches can select identical or alternative strategies (orders of mitigations) and are suited to differing scenarios – neither is incorrect but the choice is framed by modelling objective. For example, if considering least cost mitigations first the real cost of mitigation may be higher for those who choose an alternative mitigation on their farm. When modelling the implication of policy and aggregating results, it is possibly beneficial to use a methodology which could be seen to be less easily manipulated. For example, a standard assumption, such as least cost, provides a clear rationale for every farm, whereas basing mitigation strategies on personal farmer/grower perspective could lead to accusations of manipulating selection to provide a specific result.

On-farm mitigation studies can also vary in use of real versus average data. Studies which utilise average farm data will not capture the range of potential benefits (or costs), with likelihood of variation across farms from any average. Alternatively selecting a range of case study farms, across a range of farm system types (e.g. intensity and practices within a land use type) will provide a range of potential impacts and allows some of the heterogeneity present in New Zealand farms to be captured, and an average can be derived from the case studies (although that might not be observed by any one farm in actuality) and presented with information on the range of results. Utilising case study farms require considerable farm data and time to simulate mitigation efficacy and was excluded from this analysis. Also, both methods, may need to be 'smoothed' to represent a reasonably typical season as OVERSEER is designed to model a long term steady state (MPI, FANZ & AgResearch, 2015).

There has been discussion on how to treat optimisation at a farm level (Muller, 2017). Two alternative approaches are available, one assumes that farmers are currently producing at the maximum of their ability and any changes which see farmers (and growers) become more efficient with their resources will have a cost, and the other assumes that farmers could optimise their farm system to become more efficient (e.g., deliver a 'win-win' where inputs decrease, associated costs and contaminant losses decrease, and profitability increases). From an economic perspective the second option (optimisation) would be unrealistic assuming that farmers and growers are rational (e.g. if a farmer could optimise, they would). Accordingly, optimisation must incur a cost to overcome some other impediment to the benefit of greater efficiency (e.g., time in upskilling or through the use of farm consultants). This is a key assumption and in any subsequent modelling AC will need to make a decision on this. It is recommended that AC includes all costs associated with changing a farm system (including the cost of achieving optimisation, if modelling is to include this).

Not all existing literature results are considered in comparable terms. How the cost of mitigation strategies is defined varies across studies. Cost has been defined as relative cost assessment, gross (absolute) costs, percentage reduction in profit, reduction in profit per unit of contaminant, and profit has been defined as earnings before interest and tax (EBIT) or EBIT excluding depreciation and amortisation (EBITDA). In addition, some costs are often excluded from on farm modelling studies, including the potential impact on land values, debt and interest payments. As with some of the other challenges presented in this section, there is no single right approach. However, in any subsequent work, AC should clearly state what measure and scope of cost is to be prioritised, including ideally, impact on profit and further business costs (including debt repayments, tax and capital re-investment).

There are mitigations which are currently being trialled, and no doubt over the long term, new mitigations that will be developed. Mitigations currently being trialled are not likely to be incorporated into literature reviewed here. Despite this, over the time period used for estimating the impact of policy, it is possible new mitigations will become available. It is not realistic to expect these to be incorporated into AC's subsequent work and it should be acknowledged that the relative cost of mitigating contaminants may change in the future.

4. Overall summary of review

The review of relevant literature has been summarised in the following tables. A more detailed library of mitigations has been appended to the report in Excel format.

The broad assessment of contaminant impact (and its associated economic impact) are intended to provide the basis for mapping across to the HRUs used in the FWMT.

We have attempted to grade the extracted data on the basis of applicability for direct inclusion into the FWMT.

In general terms, the colour referencing in Table 4 and Table 5 is as follows:

5	Auckland specific analysis.
4	Analysis from similar regions or sufficiently applicable across sector.
3	Robust analysis, but with outputs highly sensitive to regional variance or volatility in assumptions.
2	Generic conclusions appropriate, but lack of field measurment or gaps in published methodology.
1	Significant data gap.

Figure 2: Applicability of data extracted from literature to AC FWMT modelling

In the absence of nationally standardised bundling methodologies, it is difficult to assign a confidence grade higher than 4 to any of the outputs from the bundled analyses.

Table 4: Summary of efficacy of responses to lower the contribution of key water quality contaminants for the dairy and non-dairy pastoral sectors

Land use type	Mitigation level	Mitigation	Contaminant impact N	P	Sediment	E coli.	Economic impact	Comments
Dairy	GMP	Stock exclusion from waterways	-15%	-10%	-40-50%	-20-25%	$10-$20/m	Stock exclusion with 5m grass buffer.
		Reduce soil P test to optimum		-5-20%				
		Use of RPR where suitable					$0-20/kgP conserved	
		Effluent management		-10-90%			$26/cow or $5-35/kgP conserved	
		Bundled FEP actions	-0-21%	-0-74%				Depends on actions taken and current farm preformance
		Bundled GMP	-16-26%	-35-75%	-7-15%	-45-79%	-3-20%	
	System mitigations	Wintering cows off farm	-20-30%					Moves the impact elsewhere
		Duration controled grazing	-52%					
		Winter crop management (incl. CSA)	-80%	-80%	-82-89%			Reductions from the crop area, N as ammonium N
		Cover crops after summer crops	-70-80%					Reductions from crop area
		Restricted crop grazing		-26%	-35%			Total P and suspended sediment concentration, grazing restricted to 3 hours/day
		Diverse pastures	-20-82%					Depends on plant species and mix
	De-intensification	Bundled de-intensification	-10%				-2-8%	Waikato and Waipa estimates more applicable than Southland results
		Bundled de-intensification	-20%				-6-14%	Waikato and Waipa estimates more applicable than Southland results
		Bundled de-intensification	-25%				-9-18%	Waikato and Waipa estimates more applicable than Southland results
		Bundled de-intensification		-5%			-10%	Southland based study
		Bundled de-intensification		-10%			-15%	Southland based study
		Bundled de-intensification		-15%			-25%	Southland based study
	Bundled mitigations	Improved nutrient management	-9-24%	-30-71%			+1-5%	
		Improved nutrient management & animal productivity	-18-33%				+1-5%	
		Improved nutrient management & animal productivity & restricted grazing	-34-46%				-14-17%	
		Bundled GMP & edge of field	-44-62%	-63-89%	-51-77%	-57-93%	-4-19%	
		Bundled GMP & edge of field & herd home	-50-69%	-63-89%	-51-77%	-57-93%	-11-13%	
		Low cost mitigations e.g. optimising fertiliser, stocking rates, effluent management	-23%	-14%	-58%	-51%	0%	
		Medium cost mitigations e.g. wetlands, feed pads, reduced N fertiliser	-38%	-30%	-60%	-51%	-1%	
		High cost mitigations e.g. winter off cows, restricted grazing, applying alum, no winter feed crops over 14 t/ha	-60%	-34%	-62%	-51%	-22%	
Sheep, beef & deer	GMP	Stock exclusion from waterways	-5%	-5%	-35%	-24-40%		
		Matching stock class to land form					$7/ha/year over a 324ha farm in exra labour costs	Estimated in Matheson et al (2018)
		Stock water reticulation	up to -10%	up to -10%	-30%	-40%	Positive (53%) IRR on investment	
		Appropriate location of troughs within landscape	Not quantified				$4/ha as a one-off cost	Assumes 5% of paddocks would need a trough moved
	System mitigations	Changing age class	-20%				-60% profit	
		Changing stock class ratios	-2% to -20%				Variable - depends on enterprise profitability	
		Diverse pastures	-9% to -35%				0 to +16% in profit	Cantebury analysis, exlcuded establishment costs
	De-intensification	Reduce forage cropping area	-4%-13%				No impact	
		Reduce cash cropping area	Up to -66%				14% reduction	Waikato based, but imapct depends on % of farm cropped
		Reduce N fertiliser use	Up to 20%				+10% to -10% change in profit	Depends on how N fertiliser is used in system
		Reduce stocking rate	-20%				-25%	Assumes a maximum reduction of 25% of SR
		Planting steepland in trees	-4%	-16%			Short-term -4% profit decline,	Carbon excluded from these estimates
		Gorse control	-50%/ha				-$30/ha/year over a 500ha farm	
	Bundled mitigations	Stock exclusion and progressively wider buffer strips	-4% to -24%	-6% to	-18% to 40%	-24% to -45%	Not quantified	Waikato region
		M1: Low barrier to adoption: ephemral flow management, improved	-1%	-23%			-43%	Bay of Plenty (4 case studies)
		M2: Moderate barrier to adoption: install small scale erosions devices,	-15%	-24%			-74%	Bay of Plenty (4 case studies)
		M3: High barrier to adoption: constructed wetlands, lower order stream exclusion, no N fert (inclusive of M2)	-23%	-23%			-95%	Bay of Plenty (4 case studies)
		M1: RPR, wetland development	-30%	-30%			-4%	Southland based study
		M2: stock exclusion, improve productivity (inclusive of M1)	-30%	-40%			-2.6% (cumulative)	Southland based study
		M3: Plant riparian margins, loafing pad for beef cows (inclusive of M2)	-34%	-40%			-20% (cumulative)	Southland based study

Table 5: Summary of efficacy of responses to lower the contribution of key water quality contaminants for the horticulture and forestry sectors and edge of field mitigations

Land use type	Mitigation level	Mitigation	Contaminant impact N	P	Sediment	E coli.	Economic impact	Comments
Horticulture	GMP	No tillage/low impact cultivation	Not quantified	Not quantified				
		Grass buffer strips (2m) around cropping paddocks	Not quantified	Not quantified				
		Cover crops between cultivation cycles	-25-80%				-$80/ha	
		Detainment bunds			-88%		-$130/ha	
		Contour strip cropping			-40%		-$82/ha	
	De-intensification	Reducing fertiliser use	-11-13%				100% reduction in operating profit	
		Bundled mitigations	None					
Forestry	GMP	Setbacks	-10%	-15%	-20%		-3% reduction in plantable area (gross margin of $773/ha/yr)	
Edge of field		Detainment bunds		-25-33%	-65-76%			American based study
		Dung beetles			-73-100%	-35%		Limited research
		Soil amendments		-29%			USD$157-830/kg P conserved at 25 kg Al/ha.	Alum dosing soil
		N inhibitors	-20-30%					
		Spaced erosion control planting		-20%	-70%			
		Riparian areas	-37%	-44%	35%		$20/m	Based on Zang et al 2010 which is largely international
		Wetlands	-30 to -8100 mg N/m2/day				$6-$30/m^2 depending on type of wetland (only construction costs, excludes fencing and planting)	
		Housing	-33 to +47%	-32% to +367%			$934- $6,744 per cow	

5. Recommended inputs for the FWMT

Tables Table **6**Table 14 below provide inputs which the AC can use to test the first version of their FWMT. It is not recommended that these inputs are used in the creation of policy, rather that they can provide proxies which can be utilised by AC to test their FWMT while undertaking analysis to provide more robust inputs. It will also allow the AC to test the FWMT for key sensitivities which will help prioritise future data analysis for more refined inputs. To this extent, they can be considered informed place holders.

The tables and wider literature review identify significant gaps in knowledge of the effects of GMP and bundled mitigation on sediment and *E. coli* losses and more broadly across all four contaminants for horticulture. Consequently, the ability to distinguish varying mitigation effects on sediment and *E. coli*, and across all four contaminants in horticulture is limited (i.e., preventing segmentation of the HRUs by horticulture type, slope and soil type).

The tables have been developed to indicate the most appropriate data for AC to use in testing their FWMT. It provides a balance between the extensive literature that exists and providing inputs in a comparable and usable format for the FWMT (e.g., aligned to the HRU basis of the FWMT). In order to provide estimates that align with the FWMT often a singular study has been selected on the basis that it is most appropriate, based on considerations such as similar biophysical data, modelling processes and assumptions. Assessment focuses on GMP and the other bundled mitigation strategies. Specific system mitigations were not considered in this summary as the focus was on testing the HRU and FWMT set up. Studies such as Doole (2015) provide inputs which would also be appropriate for use in testing the FWMT which focus on specific mitigations (such as changing the sheep and cattle ratios) and include information on a granular level that could be used to split results based on intensity, soil type and slope, for some land uses (primarily sheep and beef).

The FWMT incorporates EOF mitigations uniquely as devices within SUSTAIN whilst land use change (including de-intensification) is also treated separately as an option within SUSTAIN in addition to GMP (i.e., uniquely described opportunity, cost and effect for rural productive HRUs). However, the literature used in this review to ascertain justifiable inputs for the FWMT does not always align with this methodology. This means that some of the estimates of cost and benefit considered in the tables below include the impact of EOF mitigations in bundles M1 (GMP), M2 and M3, which does not align with the FWMT. As a result, some of the benefits and costs may be overestimated through double counting, as some EOF (such as stock exclusion) is included in the bundled mitigation as well as discretely in the EOF mitigation options. This can be overcome in future iterations if AC groups mitigations into specific bundles which better align with their FWMT.

The estimates for mitigation bundles M1 (GMP), M2 and M3 and EOF mitigations are provided as percentage reductions. This is because the absolute results are from a range of studies and locations which have differences in underlying biophysical characteristics. For example, the absolute contaminant losses (before mitigation) vary considerably based on the specific study characteristics and translating these into the FWMT would lead to unrealistic results. Given that the FWMT can estimate the base contaminant losses from varying HRUs, for this iteration it is considered most appropriate to apply the percentage reductions from the literature to these baseline estimates. The efficacy results are also presented as percentage reductions for losses of contaminants from the root zone, rather than loads received by waterways.

Whilst this summary selects the most appropriate literature for aligning to HRUs, caution should be taken to consider associated assumptions of the relevant studies.

Table 6: Pastoral GMP (M1) inputs for use in the FWMT

Hydrological Response Unit			Contaminant impact (kg contaminant/ha/yr)				Economic impact	Mitigation description	Confidence level	Comments & explanation
Intensity	**Soil group**	**Slope**	**N**	**P**	**Sediment**	***E. coli***	**Operating profit**			
Less than 10SU/ha	Free draining	Flat to rolling	-2%	-9%			-37%	Bundled GMP including; improved nutrient budgeting and maintenance of Olsen P, efficient fertiliser use technology, stock class management within landscape, improved winter cropping practices, laneway run-off diversion, relocation of troughs, appropriate gate, track and race placement, targeted space planting of poles, slow release RPR fertiliser, adoption of low N leaching forages, full stock exclusion from all waterbodies greater than 1m wide at any point adjacent to farm (including drains) and wetlands (2m average vegetated and managed buffer around rivers, streams, lakes and wetlands; 1m around drains; 3m average buffer on slopes greater than 8 degrees; 5m average buffer on slopes greater than 16 degrees).	Low	Based on Rangitāiki sheep and beef farm in Matheson et al (2018; mitigation bundle M1). Does include diverse pastures and stock exclusion, which could be considered beyond M1. Farm systems and soil types are expected to be quite different between Auckland and Rangitāiki.
		Rolling to steep								
	Moderately draining	Flat to rolling								
		Rolling to steep								
	Poorly drained	Flat to rolling								
		Rolling to steep								
More than 10SU/ha (sheep & beef)	Free draining	Flat to rolling	-1%	-18%			-81%		Low	Based on Kaituna-Pongakawa-Waitahanui (KPW) sheep and beef farm in Matheson et al (2018; mitigation bundle M1). Does include diverse pastures and stock exclusion, which could be considered beyond M1. Farm systems and soil types are expected to be quite different between Auckland and KPW.
		Rolling to steep								
	Moderately draining	Flat to rolling								
		Rolling to steep								
	Poorly drained	Flat to rolling								
		Rolling to steep								
More than 10SU/ha (dairy)	Free draining	Flat to rolling	-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.	Moderate-high	Based on NIWA (2010) for free draining and poorly draining. Estimates were based on modelled Waikato farms using OVERSEER (for N and P) and other literature for sediment and *E. coli*. Variation will depend on which action each farm takes and current farm performance, as well as biophysical factors. Would pay to ground truth on some Auckland farms to see observed results match expected.
		Rolling to steep								
	Moderately draining	Flat to rolling	-17%	-68%	-15%	-62%	-9%			
		Rolling to steep								
	Poorly drained	Flat to rolling	-17%	-61%	-15%	-45%	+2%			
		Rolling to steep								

Table 7: Horticulture GMP inputs for use in the FWMT – M1

Hydrological Response Unit			Contaminant impact (kg contaminant/ha/yr)				Economic impact	Mitigation description	Confidence level	Comments & explanation
Intensity	**Soil group**	**Slope**	**N**	**P**	**Sediment**	***E. coli***	**Operating profit**			
Orchards, idle fallow	Free draining	Flat to rolling							No data	
		Rolling to steep								
	Moderately draining	Flat to rolling								
		Rolling to steep								
	Poorly drained	Flat to rolling								
		Rolling to steep								
Arable, citrus, fodder, nuts, viticulture	Free draining	Flat to rolling	-9%	-1%			-7%	Bundled GMP including; grass or planted buffer strips, maintain optimal Olsen P and appropriate P fertiliser use, efficient fertiliser use technology, cover crops between cultivation cycles, manage risk from contouring, reduced tillage practices.	Low	Based on Matheson et al (2018; mitigation bundle M1). Uses a 40ha maize silage production system (which incorporates ryegrass and in situ grazing as well as bales).
		Rolling to steep								
	Moderately draining	Flat to rolling								
		Rolling to steep								
	Poorly drained	Flat to rolling								
		Rolling to steep								
Berryfruit, flowers, stonefruit, kiwifruit, nursery pipfruit, fruit, vegetables, greenhouses	Free draining	Flat to rolling	-2%				0%	Limiting any one application of N to 80 kgN/ha per month, no reduction in yield.	Moderate	From Agribusiness Group (2014) from work in the Lower Waikato catchment. Weighted average of their results based on 50% of extensive horticulture rotation, 45% intensive rotation and 5% market garden.
		Rolling to steep								
	Moderately draining	Flat to rolling								
		Rolling to steep								
	Poorly drained	Flat to rolling								
		Rolling to steep								

Table 8: Pastoral de-intensification (M2) inputs for use in the FWMT

Hydrological Response Unit			Contaminant impact (kg contaminant/ha/yr)				Economic impact	Mitigation description	Confidence level	Comments & explanation
Intensity	Soil group	Slope	N	P	Sediment	*E. coli*	Operating profit			
Less than 10SU/ha	Free draining	Flat to rolling	-4%	-9%			-49%	Bundled mitigation: improved nutrient budgeting and maintenance of Olsen P, efficient fertiliser use technology, stock class management within landscape, improve winter cropping practices, laneway run-off diversion, relocation of troughs, appropriate gate, track and race placement, targeted space planting of poles, slow release RPR fertiliser, adoption of low N leaching forages, elimination of N fertiliser applied to accelerate liveweight gain, develop a detention bund, complete protection of gully heads, management of gorse, whole paddock space planting of poles, full stock exclusion from permanently flowing waterbodies less than 1m wide (REC Order 2 and above) and 1m average vegetated and managed buffer (2m average buffer on slopes greater than 8 degrees, 3m average buffer on slopes greater than 16 degrees [with associated stock water reticulation, if any]), afforestation of erosion prone land, changing stock ratios to reflect lower N leaching potential.	Low	Based on Rangitāiki sheep and beef farm in Matheson et al (2018; M1 and M2 bundles which are cumulative). Does include stock exclusion which could be a separate EOF mitigation. Farm systems and soil types are expected to be quite different between Auckland and Rangitāiki.
		Rolling to steep								
	Moderately draining	Flat to rolling								
		Rolling to steep								
	Poorly drained	Flat to rolling								
		Rolling to steep								
More than 10SU/ha (sheep & beef)	Free draining	Flat to rolling	-25%	-38%			-156%		Low	Based on KPW sheep and beef farm in Matheson et al (2018; M1 and M2 bundles which are cumulative). Does include stock exclusion which could be a separate EOF mitigation. Farm systems and soil types are expected to be quite different between Auckland and KPW.
		Rolling to steep								
	Moderately draining	Flat to rolling								
		Rolling to steep								
	Poorly drained	Flat to rolling								
		Rolling to steep								
More than 10SU/ha (dairy)	Free draining	Flat to rolling	-19%	-10%			N: -6% P: - 15%	N mitigation: 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%. P mitigation: based on reducing P inputs as per OVERSEER, fertiliser, effluent and cropping and adjusting stocking rates as needed.	Medium-high for N. Low for P.	N mitigations: Based on DairyNZ (2014; mitigation level 2) utilising the Waipa and Franklin weighted average farm which only consider N mitigations, not P, sediment or *E. coli*. P mitigations: Based on Newman & Muller (2017) which focused on Southland which has a different climate to Auckland and a predominance of winter cropping which is very different to that in Auckland. **Note- the P and N modelling is taken from different studies and should not be combined.**
		Rolling to steep								
	Moderately draining	Flat to rolling								
		Rolling to steep								
	Poorly drained	Flat to rolling								
		Rolling to steep								

Table 9: Horticulture de-intensification (M2) inputs for use in the FWMT

Hydrological Response Unit			Contaminant impact (kg contaminant/ha/yr)				Economic impact	Mitigation description	Confidence level	Comments & explanation
Intensity	**Soil group**	**Slope**	**N**	**P**	**Sediment**	***E. coli***	**Operating profit**			
Orchards, idle fallow	Free draining	Flat to rolling	-7%	0%			-6%	Bundled mitigation including; maintain optimal Olsen P, complete protection of existing wetlands, laneway run-off diversion, efficient fertiliser use, efficient irrigation practices, use of grass swards under canopy and minimising bare ground.	Low	Based on one crop (kiwifruit) in Matheson et al (2018). Modelled in OVERSEER so no impact on sediment or *E. coli* captured. The greatest impact on N losses would appear to be associated with irrigated orchards improving water use efficiency, with its subsequent reductions in soil drainage.
		Rolling to steep								
	Moderately draining	Flat to rolling								
		Rolling to steep								
	Poorly drained	Flat to rolling								
		Rolling to steep								
Arable, citrus, fodder, nuts, viticulture	Free draining	Flat to rolling	-6%				-35%	Reduce N fertiliser use from 216kgN/ha/yr across feed wheat, milling wheat and barley to 140kgN/ha/yr. The reduction in fertiliser yield is modelled to reduce yield from 12t/ha (wheat) and 10t/ha (barley) to 8t/ha (wheat and barley).	Low.	Based on Mathers (2017; mitigation level 2) which focused on Southland which has a different climate to Auckland and different cropping rotations. This arable mitigation was applied to feed wheat, milling wheat and barley crops within a hypothetical farm on well-drained soils receiving approximately 840 mm of rainfall a year. Didn't consider mitigations for P.
		Rolling to steep								
	Moderately draining	Flat to rolling								
		Rolling to steep								
	Poorly drained	Flat to rolling								
		Rolling to steep								
Berryfruit, flowers, stonefruit, kiwifruit, nursery pipfruit, fruit, vegetables, greenhouses	Free draining	Flat to rolling	-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).	Low-moderate	From Agribusiness Group (2014) from work in the Lower Waikato catchment. Weighted average of their results based on 50% of extensive horticulture rotation, 45% intensive rotation and 5% market garden. Need to consider if the rotations used are representative of the Auckland region. Based on OVERSEER modelling. Mitigation considered was 2 (de-intensification) with a 10% reduction.
		Rolling to steep								
	Moderately draining	Flat to rolling								
		Rolling to steep								
	Poorly drained	Flat to rolling								
		Rolling to steep								

Table 10: Pastoral de-intensification (M3) inputs for use in the FWMT

Hydrological Response Unit			Contaminant impact (kg contaminant/ha/yr)				Economic impact	Mitigation description	Confidence level	Comments & explanation
Intensity	**Soil group**	**Slope**	**N**	**P**	**Sediment**	***E. coli***	**Operating profit**			
Less than 10SU/ha	Free draining	Flat to rolling	-14%	-10%			-59%	Bundled mitigation: improved nutrient budgeting and maintenance of Olsen P, efficient fertiliser use technology, stock class management within landscape, improve winter cropping practices, laneway run-off diversion, relocation of troughs, appropriate gate, track and race placement, targeted space planting of poles, slow release RPR fertiliser, adoption of low N leaching forages, elimination of N fertiliser applied to accelerate liveweight gain, develop a detention bund, complete protection of gully heads, management of gorse, whole paddock space planting of poles, afforestation of erosion prone land, changing stock ratios to reflect lower N leaching potential, full stock exclusion from REC Order 1 watercourses less than 1m wide and 1m wide average vegetated buffer, creation of new wetlands, elimination of N applications to support capital livestock.	Low	Based on Rangitāiki sheep and beef farm in Matheson et al (2018; M1, M2 and M3 bundles which are cumulative). Does include stock exclusion which could be a separate EOF mitigation. Farm systems and soil types are expected to be quite different between Auckland and Rangitāiki.
		Rolling to steep								
	Moderately draining	Flat to rolling								
		Rolling to steep								
	Poorly drained	Flat to rolling								
		Rolling to steep								
More than 10SU/ha (sheep & beef)	Free draining	Flat to rolling	-31%	-38%			-184%		Low	Based on KPW sheep and beef farm in Matheson et al (2018; M1, M2 and M3 bundles which are cumulative). Does include stock exclusion which could be a separate EOF mitigation. Farm systems and soil types are expected to be quite different between Auckland and KPW.
		Rolling to steep								
	Moderately draining	Flat to rolling								
		Rolling to steep								
	Poorly drained	Flat to rolling								
		Rolling to steep								
More than 10SU/ha (dairy)	Free draining	Flat to rolling	-25%	-15%			N: -9% P: - 25%	N mitigation: 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%. P mitigation: based on reducing P inputs as per OVERSEER, fertiliser, effluent and cropping and adjusting stocking rates as needed.	Medium-high for N. Low for P.	N mitigations: Based on DairyNZ (2014; mitigation level 3) utilising the Waipa and Franklin weighted average farm which only consider N mitigations, not P, sediment or E coli. P mitigations: Based on Newman & Muller (2017) which focused on Southland which has a different climate to Auckland and a predominance of winter cropping which is very different to that in Auckland. Economic impact is on operating profit per hectare. **Note- the P and N modelling is taken from different studies and should not be combined.**
		Rolling to steep								
	Moderately draining	Flat to rolling								
		Rolling to steep								
	Poorly drained	Flat to rolling								
		Rolling to steep								

Table 11: Horticulture de-intensification (M3) inputs for use in the FWMT

Hydrological Response Unit			Contaminant impact (kg contaminant/ha/yr)				Economic impact	Mitigation description	Confidence level	Comments & explanation
Intensity	Soil group	Slope	N	P	Sediment	*E. coli*	Operating profit			
Orchards, idle fallow	Free draining	Flat to rolling	-7%	0%			-6%	Bundled mitigation including; maintain optimal Olsen P, complete protection of existing wetlands, laneway run-off diversion, efficient fertiliser use, efficient irrigation practices, use of grass swards under canopy and minimising bare ground, develop a detention bund.	Low	Based on one crop (kiwifruit) in Matheson et al (2018). Modelled in OVERSEER so no impact on sediment or E coli captured. The greatest impact on N losses would appear to be associated with irrigated orchards improving water use efficiency, with its subsequent reductions in soil drainage.
		Rolling to steep								
	Moderately draining	Flat to rolling								
		Rolling to steep								
	Poorly drained	Flat to rolling								
		Rolling to steep								
Arable, citrus, fodder, nuts, viticulture	Free draining	Flat to rolling	-6%				-58%	Reduce N fertiliser use from 216kgN/ha/yr across feed wheat, milling wheat and barley to 100kgN/ha/yr. The reduction in fertiliser yield is modelled to reduce yield from 12t/ha (wheat) and 10t/ha (barley) to 6t/ha (wheat and barley).	Low.	Based on Mathers (2017; mitigation level 2) which focused on Southland which has a different climate to Auckland and different cropping rotations. This arable mitigation was applied to feed wheat, milling wheat and barley crops within a hypothetical farm on well-drained soils receiving approximately 840 mm of rainfall a year. Didn't consider mitigations for P.
		Rolling to steep								
	Moderately draining	Flat to rolling								
		Rolling to steep								
	Poorly drained	Flat to rolling								
		Rolling to steep								
Berryfruit, flowers, stonefruit, kiwifruit, nursery pipfruit, fruit, vegetables, greenhouses	Free draining	Flat to rolling	-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).	Low-moderate	From Agribusiness Group (2014) from work in the Lower Waikato catchment. Weighted average of their results based on 50% of extensive horticulture rotation, 45% intensive rotation and 5% market garden. Need to consider if the rotations used are representative of the Auckland region. Based on OVERSEER modelling. Mitigation considered was 2 (de-intensification) with a 20% reduction.
		Rolling to steep								
	Moderately draining	Flat to rolling								
		Rolling to steep								
	Poorly drained	Flat to rolling								
		Rolling to steep								

Table 12: Edge of field (EOF) mitigations inputs for use in the FWMT - 1

EOF Mitigation	HRU				Contaminant impact				Economic impact			Comments & explanation
	Land cover	**Intensity**	**Soil**	**Slope**	**N**	**P**	**Sediment**	***E. coli***	**Capital**	**Maintenance**	**Opportunity cost ($/ha/yr)**	
Small wetland	Pastoral	Less than 10SU/ha	All	All	10%	45%	65%	55%	$16.40/m^2	$125/ha/yr	$210	Average between facilitated and constructed wetland costs. Same percentage benefit, but a bigger base load is likely to be intercepted by large wetland than small. Includes planting but excludes fencing. Small wetlands are those <1ha, while large is >1ha. Assumes land removed from production had a relative productivity of 50% which is lost.
	Pastoral	More than 10SU/ha (sheep & beef)	All	All	10%	45%	65%	55%	$16.40/m^2	$125/ha/yr	$340	
	Pastoral	More than 10SU/ha (dairy)	All	All	10%	45%	65%	55%	$16.40/m^2	$125/ha/yr	$665	
Large wetland	Pastoral	Less than 10SU/ha	All	All	10%	45%	65%	55%	$12.60/m^2	$250/ha/yr	$210	
	Pastoral	More than 10SU/ha (sheep & beef)	All	All	10%	45%	65%	55%	$12.60/m^2	$250/ha/yr	$340	
	Pastoral	More than 10SU/ha (dairy)	All	All	10%	45%	65%	55%	$12.60/m^2	$250/ha/yr	$665	
Stock exclusion	Pastoral	Less than 10SU/ha	All	Flat to rolling	13%	15%	70%	60%	$13/m	$0.15/m/yr	$0	Permanent fences to exclude stock from permanent waterways. Cost includes a range of fence types. No reduction in productive land and cost provision for stock water reticulation is not included.
	Pastoral	More than 10SU/ha (sheep & beef)	All	Rolling to steep	13%	15%	70%	60%	$15.50/m	$0.35/m/yr	$0	
Detainment bunds/ sediment traps	Pastoral	All	All	All	0%	15%	80%	50%	$250/ha of catchment	$12.50/ha catchment/yr	$0	Assumes a bund sufficient to detain 40ha of catchment. No confirmed loss of production from ponding area, but anecdote suggests some production loss.

Table 13: Edge of field (EOF) mitigations inputs for use in the FWMT - 2

EOF Mitigation	HRU				Contaminant impact				Economic impact			Comments & explanation
	Land cover	Intensity	Soil	Slope	N	P	Sediment	*E. coli*	Capital	Maintenance	Opportunity cost ($/ha/yr)	
Riparian planting 5 m width	Pastoral	Less than 10SU/ha	All	All	43%	35%	5%	0%	$\$4.17/\text{m}^2$	$\$1.50/\text{m}^2/\text{yr}$	$210	5m buffer that is planted with grass and native vegetation alongside waterways (excludes fencing costs and benefits). Includes planting and labour but excludes weed matting. Assumes medium pot plants and 1.5m spacing for plants. Assumes land removed from production had a relative productivity of 50% which is lost.
	Pastoral	More than 10SU/ha (sheep & beef)	All	All	43%	35%	5%	0%	$\$4.17/\text{m}^2$	$\$1.50/\text{m}^2/\text{yr}$	$340	
	Pastoral	More than 10SU/ha (dairy)	All	All	43%	51%	5%	0%	$\$4.17/\text{m}^2$	$\$1.50/\text{m}^2/\text{yr}$	$665	
	Horticulture	Arable, citrus, fodder, nuts, viticulture	All	All	51%	50%	75%	60%	$\$4.17/\text{m}^2$	$\$1.50/\text{m}^2/\text{yr}$	$1,200	
	Horticulture	Berryfruit, flowers, fruit, stonefruit, kiwifruit, nursery, pipfruit, vegetables, greenhouses	All	All	51%	50%	75%	60%	$\$4.17/\text{m}^2$	$\$1.50/\text{m}^2/\text{yr}$	$2,000	
Space planting of erosion control trees	Pastoral	Less than 10SU/ha & More than 10SU/ha (sheep & beef)	All	All	0%	20%	70%	0%	$1,000/ha	None	$0	Shading impact of trees (50 stems/ha) as they mature is expected to have limited impact on pasture production. Combined with the reduction in soil loss and positive impacts that shading will have on animal welfare, the net production impact on the farm system is considered negligible.

Table 14: Land retirement (LR) mitigations inputs for use in the FWMT

Land cover	Intensity	Capital cost ($/ha)	Carbon income ($/ha)	Opportunity cost ($/effective ha/yr)	Comments & explanation
Pastoral	Less than 10SU/ha	$15,000	$4,600	$420	Assume 184 tCO_2/ha based on MPI Carbon Look Up Tables (post 1989 forest) average over 50 years. Establishment costs of $15,000/ha (including $4,000/ha subsidy from Government). Assume no salvage value of farm (e.g. selling salvaged fencing) and no salvage cost (e.g. removing fences). Assume carbon price of $25/tonne CO_2 equivalent.
	More than 10SU/ha (sheep & beef)	$15,000	$4,600	$680	
	More than 10SU/ha (dairy)	$15,000	$4,600	$1,330	
Horticulture	Orchards, idle fallow	$15,000	$4,600	$50,000	
	Arable, citrus, fodder, nuts, viticulture	$15,000	$4,600	$2,400	
	Berryfruit, flowers, stonefruit, kiwifruit, nursery, pipfruit, fruit, vegetables, greenhouses	$15,000	$4,600	$4,000	

6. Sector specific reviews

6.1. Dairy

Relative to other agricultural industries (e.g. horticulture, forestry and sheep and beef), the dairy sector has completed considerable work looking at the effect of both individual and bundled approaches to reducing N, P, sediment and *E. coli* losses to water. While not every study includes all of the four contaminants and the financial impact of implementing such mitigations there tends to be considerable research available to draw conclusions from a range of studies. Research to date that has summarised a range of mitigation tools on contaminant loss from dairy systems includes Doole (2015), McDowell and Nash (2012), McDowell et al (2013) and Monaghan (2008). Studies which have looked at the effects of bundling mitigations include Vibart et al (2015), NIWA (2010) and Daigneault and Elliott (2017). Many of the studies reviewed have evaluated approaches compared to a 'conventional' dairy farm system and do not focus specifically on regions. Caution should therefore be taken when extrapolating data to the Auckland region.

For many of the mitigations described below the potential reductions in contaminant loss are also not yet captured within the OVERSEER model. For instance, crop grazing management as outlined by Orchiston et al (2013), detainment bunds, soil amendments, dung beetles, alternative forages and the emerging Spikey technology cannot be input into OVERSEER yet due to a lack of published data. We expect that as more science becomes available to validate the effects of each of these mitigations on nutrient management then these tools will be progressively built into the OVERSEER model.

6.1.1. GMP

6.1.1.1. Stock exclusion from waterways

Exclusion of stock from waterways prevents direct deposition of dung and urine by cattle and reduces stream bank erosion. A review by Doole (2015) concluded that total P, *E. coli* and sediment loss could be reduced by 10%, 20-25%, and 40-50%, respectively, from mitigating direct dung deposition and streambank erosion from trampling. Furthermore, the inclusion of a five metre grass buffer strip could also reduce total N entering the waterway by 15% through a combination of filtration, deposition and infiltration compared to when cattle had full access to water.

Under the Sustainable Dairying Water Accord 2013 all stock must be excluded from any permanently flowing rivers, streams, drains and springs that are more than a meter wide and 30 cm deep. However, a study by McDowell et al (2017) showed that contaminant loads from low-order streams (streams less than a metre wide and 30 cm deep and in flat catchments dominated by pasture) exempt from fencing regulations accounted for an average of 77% of the national load, varying from 73% for total N to 84% for dissolved reactive P. In New Zealand, fencing of many low-order streams is often considered impractical and too costly and as such other mitigations that reduce delivery of contaminants to small streams may provide a more cost-effective solution (McDowell et al., 2017). The cost of implementing stream fencing has been reported at between $2-45/kg P conserved (McDowell & Nash, 2012).

6.1.1.2. Effluent management

Contamination of waterways by farm dairy effluent (FDE) is highly dependent on soil type and effluent application rate. Soils with a greater susceptibility for preferential flow or rapid drainage as well as those with poor drainage and at higher risk of surface runoff present a high risk for contaminant loss to waterways through the application of FDE (McDowell & Nash, 2012). Deferred irrigation is one mitigation strategy that can be used to reduce FDE loss to waterways by storing effluent and applying low rates (<10 mm/h) only when there is a suitable soil moisture deficit.

Houlbrooke et al (2004) measured the impact of both daily spray irrigation and deferred, low rate irrigation on a poorly drained soil in Manawatu. The total volume of applied effluent lost as drainage was reduced to less than 1% with deferred irrigation compared to 40% under daily spray irrigation. This represented a 90% decrease in N (12 kg N/ha cf. 1.2 kg N/ha) and P lost (2 kg P/ha cf. 0.2 kg P/ha) to water. In contrast, reviews by Doole (2015) and McDowell and Nash (2012) noted a smaller 10-30% reduction in total P loss and likely reflects the range in soil types studied.

The ability to operate a deferred irrigation system will depend on the farm's effluent storage. Doole (2015) stated the annualised cost for a farm requiring greater pond storage would be $10/cow for additional storage, $13/cow to change from a spray to a low rate irrigator and $3/cow for maintenance of the system. McDowell and Nash (2012) on the other hand estimated a saving of $5-35/kg P conserved.

6.1.1.3. Nutrient management

Phosphorus losses from soil are typically driven by soil test Olsen P concentrations (McDowell et al., 2003). Therefore, the most effective way to reduce P loss to water is to ensure that the soil P concentration is maintained within the optimum range for a given farm system and soil type. Soil P concentrations above this range represent an unnecessary source of P loss. McDowell and Nash (2012) reported a 5-20% decrease in total P loss for farms that reduced their soil test P level to within the optimum range, although this was dependent on the existing soil test P concentration. Nutrient budgeting tools, such as OVERSEER, can be used to estimate a farm's P input and outputs which can subsequently be used to create an effective fertiliser regime to maintain optimum soil P. Significant cost savings can be made by maintaining the optimum soil P level at a concentration that minimises P loss and maintains pasture productivity.

The use of less soluble forms of P, such as reactive phosphate rock (RPR), can also be an effective strategy to mitigate P loss, particularly in areas with high rainfall (>800 mm) and a soil pH <6. The lower solubility means there is a smaller soluble P pool available for runoff in high rainfall events. RPR has been shown in field plots grazed by dairy cattle to reduce P loss by approximately one third when compared to superphosphate (McDowell, 2010). Where climatic conditions are not suitable (e.g. <800 mm rainfall and soil pH is >6), there is little economic sense in applying RPR as only a third of the applied P becomes available per annum (McDowell & Nash, 2012). However, under suitable conditions, savings of $0-20/kg P conserved have been reported (McDowell & Nash, 2012).

6.1.2. System changes

6.1.2.1. Grazing management

Grazing management to avoid deposition of urine and dung to pasture can be an effective tool to reduce contaminant loss particularly if implemented when losses through drainage or runoff are likely. Strategic destocking of cows off-farm for three months (late May – late August), as is often practiced on dairy farms, was modelled by de Klein et al (2000) and reduced nitrate leaching by 20-30% compared to a conventional year-round grazing farm applying 0 and 200 kg N/ha, respectively. Extending the destocking period to 5 months with cows full-time on a feedpad increased the nitrate reduction to 35-50%. When trialled on a farmlet in Otago, total nitrate leaching losses to water were reduced by 40% compared to year-round grazing on an average farm stocked at 2.5 cows per hectare (de Klein et al., 2001).

Significant capital costs are required to operate a feedpad system and were reported at $125 per cow for the feedpad plus an additional one-off cost $15,500 for an upgraded effluent system. Annual operating costs of $16,700 including an opportunity cost of $4,100 were also reported in the study (de Klein et al., 2000). Structures that collect effluent are at risk of pollution swapping with increased ammonia and nitrous oxide emissions.

Other studies have looked at destocking for short periods during the day where cows are stood off pasture often on feedpads or standoff pads. Christensen (2013) found that operating a duration-controlled grazing system in which cows were stood off pasture for eight hours per day in two separate events reduced nitrate leaching by an average of 52%. This strategy is particularly effective in late summer/early autumn when the deposition of urine has the greatest influence on the quantity of nitrate leached in winter (Christensen, 2013).

6.1.2.2. Crop management

Many New Zealand dairy farms utilise a winter feed crop as a supplement to the diet when pasture growth is limited, although this practice is expected to be less common in the Auckland region. These crops tend to contribute a disproportionately large part of annual nutrient and sediment losses to the farm system as a result of intensive stock grazing during wet periods. Low cost, good management practices including strip-grazing the paddock from the top to the bottom of the slope leaving a vegetated buffer to uptake nutrient loss, back-fencing every 4-5 days, temporary fencing around critical source areas (CSA) and time-restricted grazing of CSAs once conditions are suitable, are highly effective at reducing contaminant loss to water. Orchiston et al (2013) measured an 82-89% reduction in sediment loss and an 80% reduction in both total P and ammonium-N loss when the above practices were bundled together. It is expected that *E. coli* losses would also be reduced, however this was not quantified.

The use of a catch crop following a winter feed crop can also be used to minimise the loss of contaminants from the farm system. Malcolm et al (2018a) reported an 80-86% reduction in soil mineral-N from oat crops sown in August and July, respectively, compared to plots left in fallow. While Carey et al (2016) measured a 19-49% reduction in actual N leaching compared to fallow treatments. Sowing date and crop sown were the main determinants that impacted on the crops ability to reduce nitrate leaching as these impacted on N uptake and the reduction in drainage volume (Malcolm et al., 2018b).

Cover crops following summer cropping, considered likely to be a more common practice in the Auckland region, can also be effective in mitigating nutrient loss prior to the winter drainage season. Zyskowski et al (2016) modelled a 70 and 80% reduction in nitrate leaching in low and high water holding capacity soils, respectively. Sowing date following the summer crop had a major effect on the cover crops effectiveness with a 10-20% reduction in the ability to reduce nitrate leaching for every month sowing was delayed down to a final 50% reduction in nitrate leaching with a June sown crop.

Restricted grazing of crops is also effective at reducing contaminant loss to water compared with unrestricted access. McDowell and Houlbrooke (2009) measured a 26 and 35% reduction in total P and suspended sediment concentration (mg/l) when cows were restricted to three hours of grazing per day.

6.1.2.3. Dietary manipulation

Pasture diets contain more N than is required by lactating cows and as such excess N, above plant requirements, is excreted. Approximately 50-60% of this N is lost as urine and is highly susceptible to nitrate leaching (Carruthers et al., 1997). Altering the diet by providing low N feeds or supplementing with diuretics (e.g. salt) can reduce nitrate losses from pasture through decreased urine N output or diluted urinary N concentration.

Low N feeds such as maize silage can maintain or increase animal productivity while reducing N leaching. Ledgard et al (2006) measured a 70% decrease in total N content of urine with supplementation of maize silage however no trials to date have measured the impact on N loss from the farm system which is likely to vary depending on the amount and efficiency at which it is fed.

Salt applied as a drench at 200-400 g/day can be used as a diuretic to dilute urinary N concentration and was shown to reduce nitrate leaching losses by 58-69% in a study in Lake Taupo (Ledgard et al., 2007). Uptake of salt as an N mitigation is restricted by its potentially harmful impact on soil structure and animal health. OVERSEER currently does not include salt supplementation as part of its modelling which further restricts its use (McDowell et al., 2013).

Alternative forages such as plantain and diverse pasture mixes are also proving to be effective at reducing urinary N concentration. Box et al (2017) measured a 50-55% and 27-33% decrease in urinary N output for cows fed a 100% and 50% plantain diet compared to those on a conventional ryegrass/white clover pasture without having any negative impact on milk output. A similar trial measured a 74-82% decrease in nitrate losses from pastures containing 20-30% plantain in a perennial ryegrass/white clover sward (Carlton et al., 2019). Diverse pastures containing a mix of several herbs, legumes and pasture species are also effective at reducing N loss. Woodward et al (2013) measured a 50% reduction in urinary N output from cows grazing a diverse pasture mix compared to those on standard pasture. As with salt supplementation, N reductions from alternative forages are yet to be captured in the OVERSEER model.

6.1.2.4. Gibberellic Acid

Gibberellic acid (GA_3) is a plant hormone used by farmers to stimulate dry matter production through increasing stem elongation and leaf expansion (Woods *et al*., 2016). Ghani *et al*. (2014) undertook a trial in the Waikato and found that plant N uptake was significantly lower in plots treated with GA_3 which subsequently resulted in a reduction in pasture N uptake of up to 7.6%. Preliminary modelling through altering pasture N concentration in OVERSEER showed a potential reduction in N leaching of 4-29% depending on the month GA_3 was applied and the subsequent reduction in pasture N concentration. The lowest reduction in N leaching was achieved at a rate of 20 g GA_3/ha applied in April only which reduced pasture N concentration from 3.9 to 3.6%. The 29% reduction was achieved with three GA_3 applications between April and August that replaced N fertiliser (30 kg N/ha) during these times. Dry matter response from substituting urea with gibberellic acid was not statistically different and therefore applying GA_3 in autumn and/or early spring could be an effective option to reduce N leaching while boosting short-term pasture growth.

6.1.2.5. Bundled actions in FEPs

While FEPs do not exclusively consider GMP, they are often heavily focused on GMPs. Kalaugher et al (2019) looked at sustainable milk plans (a FEP equivalent) across the Waipa River catchment and estimated the benefits to N and P losses from implementing the actions described in the sustainable milk plans. Benefits were estimated through the use of OVERSEER and nutrient reduction efficacy rates of each action. Mean reductions in farm nutrient losses following the successful implementation of completed actions were estimated to be 2% for N and 7% for P. These reduction estimates are expected to increase to 4% and 9% respectively, when all actions across all farms are fully implemented. Potential load reductions on individual farms for completed actions ranged from 0 to 14% for N and 0 to 59% for P, depending on the number and combination of actions implemented. This increased to 0-21% for N and 0-74% for P when all actions are fully implemented. Typical actions included nutrient management, effluent management, waterway exclusion and land management including managing of critical source areas. No economic analysis was carried out as part of this study.

6.1.3. De-intensification

DairyNZ has undertaken extensive farm systems modelling across the country looking at the economic impact of reducing N and P losses (Dairy NZ Economics Group 2014; Newman & Muller 2017). These studies follow a typical process for N and P losses which ultimately results in staged de-intensification of the farm system.

6.1.3.1. De-intensification to reduce N losses

For N, autumn N fertiliser applications are reduced and then removed, then spring N fertiliser applications are reduced and then removed, then imported supplements are reduced (up to a 20% reduction from the base) and finally the stocking rate is reduced (up to 20% reduction of cow numbers from the base) and the feed supply and demand balanced. At each point of the modelling feed supply and demand are balanced. Across the Waikato, Waipa and Southland catchments a10% reduction in N caused a reduction in profit of between 2% and 8%, an approximate 20% reduction in N caused a reduction in 6% and 14% and an approximate 25% reduction in nitrogen incurred a 9 to 18% reduction in operating profit. The results from the Waikato and Waipa catchment modelling would provide a reasonable starting point to estimate the potential impacts of reducing nitrogen losses for dairy farms in the Auckland region.

6.1.3.2. De-intensification to reduce P losses

To reduce P losses, RPR fertilisers are used if suitable, then Olsen P levels above the agronomic optimum (Olsen P 30) are reduced to the agronomic optimum, following this, the key areas of risk that are unlikely to impact significantly on production are identified, and addressed where appropriate, this includes effluent and cropping practices, then the key areas of risk that may impact on production are identified and addressed where appropriate, this includes the use of once a day milking (OAD) for part of the season and decreasing cropping areas and finally the stocking rate is reduced (up to 20% reduction of cow numbers from the base) and the feed supply and demand balanced. At each point of the modelling feed supply and demand are balanced. In the Southland catchments a 5% reduction in P caused a 10% reduction in operating profit, a 10% reduction in P losses caused an 18% reduction in operating profit and a 15% decrease in P losses reduced operating profit by 25%. The Waikato and Waipa catchment study did not explicitly try to reduce P losses and while the Southland catchment study could be used as a starting point the biophysical conditions in Southland are different to those in the Auckland region and there is a likely to be difference in farm systems, including the prevalence of winter cropping.

6.1.4. Bundled mitigations

A number of studies have focused on the impact to contaminant loss and/or business profitability from implementing a select bundle of mitigations. Vibart et al (2015) modelled the impact of three mitigation bundles on N and P loss and farm profitability in Southland. These bundles were based on their cost effectiveness and grouped on capital cost and potential ease of adoption. These bundles could be identified as improved nutrient management (M1), improved animal productivity (M2) and restricted grazing (M3) and were cumulative (i.e. M2 included M1 mitigation, M3 included M1 and M2 mitigations). Each of these bundles were modelled to achieve a 9-24, 18-33 and 34-46% decrease in N leaching, respectively. In terms of P loss, the improvement in nutrient management mitigations achieved the greatest reduction at 30-71%. Further mitigations had little to no effect. Improved nutrient management and animal productivity had little to no effect on farm profit before tax (1- 5% increase), while restricted grazing mitigations (i.e. housing structures) had a 14-17% decrease on farm profit before tax due to high capital costs and operating expenses.

A similar study in the Waikato region (NIWA, 2010) bundled mitigations based on a progressive level of best management practices. These could be broadly identified as good management practices (GMP), edge-of-field mitigations (e.g. nitrification inhibitors, small wetlands) and large-scale devices (e.g. herd shelter). Modelled GMP mitigations, including improved nutrient management, achieved a 16-26% decrease in N leaching, 35-75% decrease in P loss, 7-15% decrease in sediment loss and 45-79% decrease in *E. coli* losses compared to a conventional dairy farm. The addition of edge-of-field mitigations increased N, P, sediment and E. coli loss reductions to 44-62%, 63-89%, 51-77%, 57-93%, respectively. The addition of a herd shelter and restricted grazing to these mitigations had a further impact only on N leaching loss with a final reduction of 50-69%, depending on soil type, compared to a conventional dairy farm. The cost of implementing GMP, edge-of-field, and large-scale device mitigations bundles were estimated to decrease cash profit by 3-20%, 4-19% and 11-13%, respectively.

Daigneault and Elliot (2017) also evaluated the impact of mitigation bundles on contaminant loss and net farm revenue. Their study bundled mitigations cumulatively based also on cost-effectiveness and ease of adoption. M1 bundles were low cost (e.g. optimising fertiliser, stocking rates, effluent management) M2 less-cost-effective and with capital cost or large system changes (e.g. wetlands, feed pads, reduced N fertiliser) and M3 mitigations included either large capital cost mitigations or those that are relatively unproven (e.g. winter off cows, restricted grazing, applying alum, no winter feed crops over 14 t/ha). On average, M1 mitigations had no effect on net revenue and reduced N, P, sediment and *E. coli* losses by 23, 14, 58 and 51%, respectively. M2 mitigations reduced net revenue by 1% and N, P, sediment and *E. coli* by 38, 30, 60 and 51%, respectively. M3 mitigations, as with the other studies, had the greatest bearing on farm profitability with a 22% reduction in net revenue. A 60% N and 34% P reduction was achieved with the M3 mitigations but there were little extra reductions in sediment and *E. coli* with an average reduction compared to a standard dairy farm of 62 and 51%

Based on the above studies we expect that a similar bundling technique of low-cost GMP practices (M1), slightly higher cost and more difficult to implement mitigations (M2), and high-cost, large scale device mitigations (M3) could achieve reductions in N, P, sediment and *E. coli* losses from dairy farms in the Auckland region of 20-60%, 10-35%, 50-60% and 50-60%, respectively. It is expected that M1 mitigations will have little impact on farm profitability, M2 a moderate impact and M3 a significant impact with little additional impact on P, sediment and *E. coli* losses.

6.2. Non-dairy Pastoral (Sheep, Beef and Deer)

The lower N loss footprint of the more extensive sheep, beef and deer grazing systems has resulted in significantly less research focus in the issue of diffuse N pollution relative to the dairy sector. However, the predominance of these farming systems on more marginal land classes with higher risks of sediment loss and typically with livestock access to lower order waterways means risks of sediment, P and *E. coli* contamination to water are potentially significant. Historically, much of the mitigation focus within this sector has been on erosion control, particularly on the fragile hill country of the North Island.

Empirical research within the sector seems to have been focused on edge of field mitigations (largely around erosion control) or around specific high risk practices like winter forage cropping.

Over the last 10 years, more extensive case study work has been undertaken to quantify the environmental and economic impacts of the application of GMP and de-intensification of sheep, beef and deer systems, primarily in catchments/regions of focus such as Southland, Lake Rotorua, the Waikato-Waipa and a number of Bay of Plenty watersheds. Doole (2015) summarised work that considered the efficacy of individual mitigations on Waikato sheep & beef farm case studies and Perrin Ag (2012) provided some guidance on the expected impact of singular practice changes from Rotorua farm case studies. However, studies have largely considered bundles of mitigations rather than singular actions and have been inconsistent in methodology, largely reflecting the individual contexts of the research projects. AgFirst (2009), Perrin Ag (2013 & 2014) considered non-sequential tailored farm specific system change on dry stock farms in the Upper Waikato and Rotorua catchments, with two of those studies allowing for a degree of farm system optimisation. This contrasts with the approach of Vibart et al (2015), Burt et al (2017) and Matheson et al (2018) which considered standardised sequentially applied mitigations to sheep, beef and deer farm systems in Southland (2015 & 2017) and the Bay of Plenty (2018) respectively. Further delineation was provided in Vibart et al (2015) and Matheson et al (2018) with mitigations grouped into specific bundles, with the latter study providing derived abatement curves within each bundle. Monaghan & Quinn (2010) took a similar approach, but their mitigation actions were limited to riparian management (stock exclusion and buffer design). These studies provide the majority of the economic analysis of reducing water contaminants from drystock farm systems and rely heavily on farm systems experts' interpretation of how farm systems would adapt to the adoption of mitigation on farm. While as a collective this analysis is rich and relatively diverse, the complexity and variety of farm systems within the sector makes definitive conclusions often hard to determine, with much of the economic impacts highly dependent on the relatively profitability of alternative stock classes/enterprises

6.2.1. GMP

6.2.1.1. Stock exclusion from waterways

According to Doole (2015), exclusion of sheep, cattle and deer from water ways in conjunction with the use of 5-metre pastoral buffer strip can reduce actual N leaching of about 5% dry stock farms respectively, assuming livestock had access to waterways previously. The same review suggested or P loss reduction the levels are similar to those for N leaching mitigation, in the order of 5% for dry stock farms. Doole estimated the cost of effective stock exclusion in the Waikato on dry stock farms at $3.28/m of stream fenced, annualised over 25yr period at 8% interest. This is substantially lower than the estimate of $14/m of stream fenced by Matheson et al (2018).

Monaghan and Quin (2010) concluded full stock exclusion from streams in the Waikato region would deliver levels of sediment and *E. coli* reduction in the order of 34%-36% and 24%-40%, respectively.

6.2.1.2. Appropriate stock type and stocking rates for land characteristics (e.g. sheep on steeper land)

Treading damage to soils from livestock is recognised to have the potential to increase both the risk of surface run-off and the loss of sediment, P and N in any run-off. This risk is heightened in periods of high soil moisture, which in New Zealand typically coincides with the winter period. Nguyen et al (1998) concluded that intensive winter grazing on hill country pasture is potentially a major source of contaminant runoff to receiving waters. This is more likely to occur with [older] cattle than with sheep, but the lower pasture covers potentially achievable under sheep grazing regimes (albeit not desirable from an animal performance perspective) can expose soil to greater erosion risk. Limiting/excluding cattle older than 18 months from steeper hill slopes during winter is a recommended practice.

The risk of soil erosion from deer pacing fence lines on fragile soils can be significant but can be successfully managed by a combination of sensible fencing solutions (including remedial options for existing farms) and stock management practices (New Zealand Deer Farmers' Association 2012). However, the introduction/expansion of deer onto properties with more fragile soils (i.e. pumice) does need to be considered carefully.

Temporal dynamics are also increasingly recognised as being important, with late summer/autumn urine patches to pasture potentially having more impact that those deposited in the late winter, even with higher underlying soil drainage.

6.2.1.3. Stock water reticulation in lieu of using surface waterbodies

The replacement of natural water sources with reticulated supply for livestock has the potential to improve the profitability of the pastoral operations where it is implemented, although the installation of reticulated supply is likely to require additional co-investment. Journeaux & van Reenan (2017) found in a study of 11 farmers that stock water reticulation can result in the significant internal rate of return of 53% on average. Such mitigation option can reduce *E. coli* and sediment by about 30% and 40% respectively, and with contribution on N leaching and P loss of about 10% depending on livestock type. However, stocking rate tended to increase with the introduction of reticulated stock water in the case study farms, which may in practice, lead to limited (if any) reductions of N loss to water.

6.2.1.4. Appropriate location of stock drinking water trough sites away from waterways

The importance of reducing the hydraulic connectivity of critical source areas from flow paths and waterways has been highlighted by McDowell & Srinivasan (2009). However, to reduce the cost of installation the location of stock facilities (primarily troughs) have often been placed adjacent to stock access ways, which can commonly be in flow paths. The cost of mitigation will depend on the distance required for relocation and whether the reticulation system has sufficient pressure to deliver water to the new location.

6.2.2. System mitigations

6.2.2.1. Change age class of livestock

Doole (2015) specifically considered the impact of replacing older cattle (with a higher maintenance feed intake) with the same equivalent feed demand (measured in stock units) of cattle a whole year younger under a Waikato bull/prime beef finishing system. That analysis suggested annual N loss reductions of up to 20% was achievable when 70% of older cattle were replaced with younger cattle, but this was accompanied by a 60.5% decline in annual profit. While the underlying assumptions were not fully disclosed, it seems likely that margins were significantly lowered by an increasing reliance on selling store cattle at inopportune times relative to their live weight in order to deliver a status quo system.

6.2.2.2. Alter stock class ratios

As a result of urinary dynamics cattle are deemed to have a higher N loss signature than deer or sheep, and female stock a greater N loss signature than males.

The relative profitability of the sheep, cattle and deer enterprises has a significant impact on the likely profitability of using livestock system change to reduce nutrient losses. While increasing the sheep/deer to cattle ratio tends to lower N losses, depending on their positions within their respective commodity cycles, implementing such a change might not lead to an increase in profitability if the lamb price is low in comparison to the beef price. Changes in livestock policies, particularly where breeding stock are involved, often have significant lag periods before increases in profitability are achieved and are not easily reversed once implemented. Altering specie ratios may also present challenges for the management of pasture quality and parasite burden.

For example analysis in Doole (2015) calculated a reduction in N loss to water (below the root zone) of 20% as the sheep to cattle ratio on a hill country farm lifted from 20%:80% to 70%:30%. In this study, annual profit increased by 91%, a significant lift. However, this change would be highly dependent on the relative productivity of the respective livestock systems (growth rates, reproductive performance) and the relative product prices, neither of which were disclosed.

By way of comparison, Matheson et al (2018) considered a 10% lift in the sheep:cattle ratio in two of their case studies to a maximum of 60%:40%, with a 2-3% reduction in N loss to water considered achievable but with an 8-9% reduction in annual profit from the comparative scenario. In this study, this mitigation was considered at the latter end of a bundle where some N loss reduction had already been achieved.

6.2.2.3. Diverse pastures

Voegler et al (2017) considered the adoption of diverse pastures into a dry stock farming system. This analysis was largely focused on the impacts that the seasonal distribution of feed supply from swards with alternative species had on the farm system, along with the assumption of a lower N content in the diverse pasture mix arising from a lower legume component. Assuming 50% of the farm area was sown in diverse pasture, it was estimates that up to a 35% reduction in N leaching was achievable in an average pasture growth year based on APSIM measurements. The equivalent OVERSEER assessment assessed only 9% reduction. Their inclusion was estimated to deliver increases in farm net profit before tax of 16% in average growth year, essentially linked to sales of surplus [summer] pasture. Any potential diuretic effect from pasture components was not considered.

6.2.3. De-intensification

6.2.3.1. Reducing cropping area

Doole (2015) considered the reduction of cash cropping from drystock farm systems, with that analysis indicating moderate reductions in N loss with commensurate reductions in profitability, no doubt due to the higher relative profitability of the affected maize growing enterprise within that farm system.

In contrast, Burt et al (2017) considered a suite of forage cropping changes in Southland, whereby the cropping footprint was minimised by identifying high risk cropping areas, growing higher yielding crops, lowering the area cropped and refilling any resulting feed deficit [with alternative supplement]. This indicated a 4%-13% in whole farm N losses for essentially no loss of profitability.

6.2.3.2. Reducing N fertiliser use

The use of nitrogenous fertiliser, even when applied in line with best management practices has a contributory impact on increasing N losses from the farm system. This occurs through both increasing the quantity of N cycling through the farm system and typically allowing higher stock intensities to be farmed, normally through the higher risk winter leaching period. In dry stock systems where the returns per kg DM eaten are typically lower than the cost per kg DM of imported feed, it is typically more profitable to lower feed demand (i.e. reduce stock numbers) than increase feed supply (i.e. purchase more feed).

Analysis in the Upper Waikato Drystock Nutrient Study (Perrin Ag, 2013) found that the cessation of fertiliser N usage, typically accompanied by a reduction in stocking rate, generally led to a reduction in system N losses with no reduction in EBIT. This was typically due to the marginal cost of the N fertiliser exceeding the return from the feed reduced.

Burt et al (2017) also considered the impact of reducing N fertiliser use in Southland sheep & beef and deer systems, although this was bundled with eliminating [luxury] P fertiliser applications that likely had little impact on pasture production. They estimated reductions of between 0-4.5kg N/ha/year with a commensurate increase in farm profitability of $40-$55/ha).

Matheson et al (2018) considered the impacts of eliminating N applied to drystock farms for different purposes, differentiating between applications effectively supporting capital (breeding) livestock and that supporting trading livestock. In all cases N losses to water were reduced through reduced N fertiliser use, but the elimination of N fertiliser that was deemed to support capital livestock lowered overall profitability in each of the three times it was implemented, even though crude marginal analysis (like that identified in Perrin Ag 2013) would suggest this not to be the case. Part of the reason for this was considered to be the stickiness of some farm costs, primarily labour and fixed overheads. Conversely, removal of N fertiliser to support (higher value?) trading livestock tended result in improved profit, suggesting the modelled farm systems were not using this tool optimally.

6.2.3.3. Reducing stocking rate

All things being equal, higher stocking rates will generate higher N loss to water as a result of higher quantities of N cycling through the farm system and more N therefore subject to the inefficient return via the urine patch.

Reducing stocking rate can be considered on its own or as a result of other land use practices that necessarily result in a reduction in livestock numbers as result of reduced feed supply.

The former was analysed in Doole (2015), which identified a 19% reduction in N loss to water when stocking rate (a mix of sheep and cattle) reduced by 25% for a Waikato finishing operation. This was accompanied by a 36% decline in estimated farm profit. It is unclear whether any allowance was made for increased productivity (associated with higher feed allocation to residual livestock). In this instance, given the reported decline in profit it seems as if it didn't or was assumed couldn't occur. Burt et al (2017) also considered lower stocking rates (-10%) in Southland, but bundled with changes in livestock distribution across the landscape and sex ratios. They estimated a 0-10kg N/ha reduction in annual N leaching for a -$110/ha-$124/ha reduction in annual profit.

6.2.3.4. Planting steepland in trees

Doole (2015) specifically considered the targeted afforestation of steepland within a Waikato hill country farm, finding planting up to 10% of the farm area resulted in a 4% reduction in annual N loss (associated with destocking) and a 16% reduction in P loss with only a 4% reduction in annual profit.

It is not clear if long-term revenue was assigned to the established forest, if carbon was sold nor if the cost of forest establishment was considered.

However, Matheson et al (2018) suggested the efficacy of forestry as a mitigation on steeper soils is more dependent on the "income" assigned the forested area rather than the cost of afforestation itself. Using a figure close to the equivalent annuity associated with forestry land use as a proxy for long term forestry revenue has a significant impact on lowering the cost of mitigation (27% improvement) where moderate areas of tree planting is potentially required, illustrating the opportunity forestry has to be a cost-effective tool for improving water quality where a longer-term view of returns can be made.

6.2.3.5. Management of gorse

From a fundamental point of view, the eradication of gorse and conversion to alternative ground covers is likely to result in a reduction in N loss to water. Magesan & Wang (2008) calculated N losses to water from mature gorse stands in the Rotorua catchment at 36kg N/ha and 40kg N/ha, which would be equivalent to losses from either intensive dairy support activity or extensive dairy farm systems in the same area. However, there is insufficient information in the literature on the effect of gorse on P losses, sediment and *E. coli*.

Matheson et al (2018) suggested an additional $30/ha in annual weed & pest expenditure would be incurred by accelerated gorse control on easy and steep contoured land affected by gorse.

6.2.4. Bundled mitigations

As for the dairy sector, a number of studies have considered the bundling mitigations for dry stock operations that are likely to be introduced on farm at the same time (Daigneault 2017).

Vibart et al (2015) considered three bundles in their Southland analysis of five farm systems, comprising M1 (RPR, fenced wetland establishment), M2 (full stock exclusion from streams, improved productivity via reproduction) and M3 (riparian margins, loafing pad for beef cows). Their analysis indicated reductions in N and P losses in the order of -30%N and -30% P for M1; -30% N,-40% P for M2 and -34% N, -40% P for M3,.all from baseline losses. The impact on net profit after tax was assessed at an average of -4% for M1, -2.6% for M2 and -20% for M3. In summary, significant improvements in nutrient loss reduction were made for relatively limited financial impact

Matheson et al (2018) also looked at three bundles of mitigations across four BOP sheep, beef and deer farm systems, but with the bundles comprising significantly more mitigations. In contrast to the Vibart study, on average across the four drystock farm systems analysed, implementation of M1 lowered profitability by $95/ha (-43%, M2 by a further $80/ha and M3 by an additional $51/ha. The aggregate impact on N losses were assessed at a cumulative average of -1%, -15% and -23% from baseline and for P at a cumulative reduction of -23%, -24% and -24% at each bundle.

While both of these studies indicated that the cumulative "cost" of adoption increased as contaminant load reduction increased, the inclusion of certain mitigations in a specific bundle can have a significant impact on the shape of any derived abatement curve. The inclusion of productivity improvements allowed for in Vibart et al (2015) potentially confounded the "cost" associated with the bundle and didn't account for the "cost' of upskilling – advisory, time lag etc. However, both studies the M1 bundle could broadly be considered to comprise GMP mitigations, while subsequent bundles included edge of filed mitigation and de-intensification actions, aggregated by [the perceived] relative cost and/or efficacy. This approach is broadly mirrored in Daigneault 2017.

If a similar approach was adopted for the Auckland region, we would expect that a similar bundling technique of low-cost GMP practices [M1], slightly higher cost and more difficult to implement mitigations (limited de-intensification, small scale EOF mitigation) [M2], and high-cost (significant de-intensification) and large scale device mitigations [M3] could achieve reductions in N, P, sediment and *E. coli* losses from dry stock farms in the region of 10-30%, 20-30%, 30-40% and 30-40%, respectively. Overall, it would be expected that M1 mitigations will have little impact on farm profitability, M2 a moderate impact and M3 a significant impact. However, selection of specific mitigations within the bundles would be critical to ensure this and regional specific modelling would be needed to evaluate the likely costs.

6.3. Horticulture and arable

Horticultural activity primarily consists of arable-based land uses that are based around a rotation of multiple crop types (vegetable crops, grain), either at "field" (arable) or market garden scale, and so-called permanent horticulture, primarily tree crops (orchards) and soft fruits.

Horticulture faces considerable challenges and risks from the natural environment, increasing environmental expectations and regulations, and social expectations (Bloomer et al. 2019). The latter can be counter-productive: while consumers now want year-round supply of vegetable varieties which are difficult to produce in winter and can result in increased leaching, consumers also want these produced with fewer environmental impacts. Growers are also more exposed to climatic and disease risks that agriculture is more likely to be able to withstand: for example, excess rain can result in disease damage that destroys a crop or makes it unsaleable, hail can result in crops being of little or any value, and climatic events such as drought and floods can destroy a crop and possibly result in considerable soil loss (Bloomer et al. 2019).

It is recognised horticultural production can have a significant environmental impact (Bloomer et al 2019). Environmental regulation and environmental limits set by regional and national government are increasing. These can be inconsistent across regions, and in some cases are difficult if not impossible to achieve (Bloomer et al. 2019).

The literature in this sector is comparatively sparse compared with the pastoral sector, both from a contaminant measurement perspective and economic analysis. The limited empirical research on contaminant loads from horticultural activity, particularly with regard to diffuse nutrient losses, has limited the availability of models to evaluate system change with and likely limited confidence in the outputs of those models that exist. Furthermore, many of the studies undertaken have used modelling approaches and models not designed or developed for horticulture or arable, and widely recognised as not being particularly effective in modelling. The OVERSEER model is notable in this respect and shortcomings will be described further later. Another challenge in assessing the impact of horticulture is that crops are usually grown in rotation over a number of years, sometimes with more than one crop per year, so an assessment of the impact of horticulture on water quality needs to consider the operation holistically rather than considering individual crops e.g. timing, crops, rotation lengths, what happens between crops.

There has been a moderate amount of work done to define and quantify field level erosion control mitigations, primarily the work of Barber (2014) which was summarised in Doole (2015). Additionally, many horticultural growers have been adhering to certified standards and best management practices / good agricultural practice determined by their grower organisations for many years. Over 65% of growers (Dolan, 2016) belong to the at least one of the NZGAP gap programmes scheme for food safety, environmental, social practice and traceability standards (NZGAP, 2017), while others belong to GLOBALGAP programmes. In the horticultural industry, these QA schemes have been in place for 20 years or more with strong participation, enabling growers to be certified as meeting regulatory and market (local and international) requirements, including environmental standards.

Analysis on the economic impact of strategies to lower diffuse nutrient loss has been limited. A series of reports by The Agribusiness Group (2014, 2015 & 2016) prepared for HortNZ and MPI provide the most widely referred to analysis in this area. Their 2014 analysis for the Lower Waikato provides the most appropriate comparator for the Auckland region, albeit only three horticultural rotations were considered and the nutrient loss estimates generated by OVERSEER should be treated with caution, particularly those for P.

This general dearth of studies on horticultural impacts on water quality has been recognised with recent and future work planned in this area e.g. plans to look at testing for precise fertiliser prescription, precise application, reducing leaching, and recapturing nitrates (LandWISE, 2018), Foundation for Arable Research (2018) plan to measure diffuse nutrient losses from arable and vegetable systems, Horizon's recent RFI call for work on horticulture and water quality and related work, and Barber's (2018) recently published work on mitigation using sediment retention ponds (SRPs).

The proposed treatment of vegetable production under the NES Freshwater and the parallel NES for Highly Productive Soils would appear to demonstrate recognition by central government about the tensions between the [potentially negative] environmental footprint of intensive horticulture, a lack of good information and the importance of the industry for food security. This could be interpreted by AC as strong signal about how to treat this sector in water quality settings

6.3.1. GMP

6.3.1.1. No tillage/low impact cultivation (e.g. along contours, appropriate for season, strip tillage, direct drilling)

It is generally accepted that the establishment of crops using conventional "full" cultivation methods result in greater rates of mineralisation of N in soil organic matter than no-till alternatives. However, the impact that this has on actual N loss on soil drainage can be variable. Carran (1990) found that a similar amount of nitrate was present in the sub-soil in mid-winter after establishment of spring sown wheat crops out of established pasture irrespective of tillage method. However, research to date in the FRNL project found that compared with conventional tillage, direct drilling autumn-sown forage crops reduced the compaction that results from winter grazing, leading to as much as a 20% improvement in the yield of a subsequent cereal [catch] crop, which in turn increases N uptake from the soil. According to Daigneault and Elliot (2017), eliminating crop disturbance from tilling can also reduce P loss and sediment along with N leaching but reduce EBIT of arable crops by 10%.

In practice, there is little difference in the cost of establishment of crops using no-till techniques, with greater weed and pest control often required. However, irrespective of the impact on freshwater and water contaminants reduction, direct drilling or strip tillage will lower the risk of run-off and soil loss and represent a useful practice change on farm.

6.3.1.2. Grass buffer strips around cropping paddocks

Grassed swales used for controlling overland flow through ephemeral flow paths amongst arable cropping activity should be at a minimum 3m wide shaped into a flat shallow saucer about 0.3m deep (Barber 2014). Grass buffer strips of this width or greater are particularly effective in reducing sediment loss and *E. coli* (Wilcock et al., 2009; Barber 2014; Low et al., 2017).

The appropriateness of grass buffer strips of 2m in width is essentially limited in application where there is little risk of surface run-off and they are essentially in place to deliver livestock exclusion from flow paths or stream channels (McKergow et al., 2007). In a cropping context, such width strips are best used for the exclusion of stock from critical source areas whilst grazing forage crops.

6.3.1.3. Cover crops between cultivation cycles

Cover crops are usually grown to be ploughed into the soil, but not harvested or grazed, in order to improve soil quality. Cover crops stabilise soil, accumulate nutrients left from previous land uses, improve drainage and soil structure, and can fix N (for some cover crops). Such cropping practices are suitable for all farm land use practices (Low et al., 2017). The N leaching reduction from cover ranges depending on crop and season and can be about 70-80% reduction from the baseline for cover crop sown in March, and about 25% reduction for cover crop sown in June. The cost of cover crop cultivation is approximately $80/ha, depending on cover crop. However, this land use has some limitations as it might lead to substantial reduction in N leaching for some crops, e.g. barely, while have meagre effect on the whole farm outcomes (Low et al., 2017).

6.3.1.4. Earth decanting bunds for intensive cultivation

An earth decanting bund for intensive cultivation is a temporary berm of compacted soil to create a damming area where ponding can occur (Low et al., 2017). Earth decanting is established along the flat contours at the bottom of paddocks. The paddock can hold the runoff to drop out the sediment by moving the headland further up the paddock (Low et al., 2017). According to Doole (2015) the efficacy in sediment reduction of earth decanting bunds in the Lower Waikato region is 87.5% and its cost is $130/ha.

6.3.1.5. Manage risk from contouring/landscaping

Tillage practices and cultivation on slope ridges can increase erosion. Contour strip cropping can be used and includes strip of pasture or small grain alternation with a strip of row crops. Ridges in contour strip cropping reduce the possibility of erosion. Contour strip cropping can reduce soil erosion by as much as 50% as comparing to farming up and down hills (USDA, 2013).

Cover crops are cultivated often solely to manage erosion. Planting cover crops can lead to the seasonal reduction in surface erosion in contour farming by planting legumes, cereal rye, clover and other crops in horticultural farms. According to Keenan (2013), erosion reduction effectiveness of cover crops is 40% from baseline erosion, which can cost $82/ha in an arable situation.

6.3.2. De-intensification

6.3.2.1. Reducing N fertiliser use

The Agribusiness Group's 2014 analysis primarily focussed on the impact of de-intensification of arable and market garden activity through reducing N fertiliser use – initially through limiting individual application rates and then with progressively total reductions in annual application. For all three of their assumed production systems (two arable, one market garden), limiting N fertiliser reduced N losses to water (as estimated by OVERSEER) but with progressively reduced profitability through loss of crop yield (and revenue). In fact, in all three examples, reductions in total N applications by a factor of between 20%-30% was determined to result in full erosion of profitability for reductions in N leaching of between 11% and 31% from baseline losses. Accepting that there is considerable scepticism about the accuracy of OVERSEER in determining N loss estimates from complex cropping activity, this analysis suggests that the sensitivity of plant yields to N fertiliser is such that lowering the diffuse N footprint from these activities via this pathway is likely to be costly, if not prohibitive.

Mathers (2017) and Ford and Halliday (2017) considered de-intensification as a mitigation for N losses from arable and horticulture (vegetable and flower) crops. In arable, Mathers (2017) modelled de-intensification as a reduction in nitrogen fertiliser and therefore reduced yields. This arable mitigation was applied to feed wheat, milling wheat and barley crops within a hypothetical farm located in Southland on well-drained soils receiving approximately 840 mm of rainfall a year. Modelling was undertaken in OVERSEER. The hypothetical arable farm had a base N loss of 18kg/ha/yr and a base operating profit of $3,692/effective ha. Reducing N fertiliser had little impact on N losses (maximum 6% reduction or from 18 to 17 kgN/ha/yr) and a considerable impact on operating profit (varied between a 35% and 80% reduction, depending on how much fertiliser was removed. These results indicated that in this example restricting N inputs did not necessarily reduce N losses and could have a significant impact on operating profit.

Ford and Halliday (2017) considered de-intensification as a mitigation for N losses from horticulture (vegetable and flower) crops. As with Mathers (2017) arable example, nitrogen fertiliser was the primary leaver used to de-intensify. Three different crop rotations were considered; a carrot rotation (total length 12 years including 9 in pasture), a parsnip rotation (total length 12 years including 9 in pasture) and a tulip rotation (total length 13 years including 12 in pasture. The tulip crop was modelled through the use of onions in OVERSEER as tulips are not a crop in OVERSEER and onions were thought to be the best proxy, based on expert advice.

The crop rotations were modelled using a whole farm system approach to show the impact of a crop over its entire rotation on a piece of land, rather than the losses of one crop in one year. This approach is consistent with OVERSEER modelling for horticulture in other regions. The size of the farm used in the representative file was driven by the size a farm would be required for the crops to adequately rotate around the property and includes pastoral areas. The financial performance and N loss both account for the crop and pastoral enterprises. As with the arable scenario, de-intensifying the cropping regime (primarily through fertiliser) has limited impact on total N loss from the enterprise given the dilution effect of the pastoral area (where no mitigations were applied). At most the mitigations applied reduced N loss by 1kgN/ha/yr (across pastoral and crop blocks) while profitability reduced by between 19 and 65% (carrot rotation), 13 and 34% (parsnip rotation) and 9 and 35% (tulip rotation) across the three levels of de-intensification modelled.

Both Mathers (2017) and Ford and Halliday (2017) raise a key question for AC in how to model multiple year horticultural rotations in their FWMT and in any associated mitigation modelling. In addition, this modelling only considers N losses not sediment or P losses.

6.3.3. Bundled mitigations

There has been very limited consideration of bundled mitigations for horticulture in the literature. Matheson et al (2018) considered a limited suite of bundle mitigations to a field horticulture (arable) system in the Bay of Plenty, concluding that forgoing yield in lieu of reducing N losses accounted for 70% of the cost of the bundle implementation. They also noted that ten of the thirteen mitigations considered for the arable farm system were entirely designed to deal with reducing sediment losses but that impact was unable analysed in this study, as there is no possibility to estimate reductions in sediment losses with OVERSEER. The farm system modelled was based around maize silage and ryegrass crops (both grazed and baled). Initial mitigations reduced N loss by 9% and EBIT by 7%, the second mitigation bundle included reducing N fertiliser which actually increased N losses. When all three mitigation bundles were modelled N loss reduced by 7%, P loss by 4% and EBIT by 45%.

Matheson et al (2018) modelled (in OVERSEER) the impact of bundled mitigations on green and gold kiwifruit orchards in the Kaituna area of the Bay of Plenty. Mitigations (M1) included; protection of existing wetlands, maintaining optimal Olsen P levels, efficient fertiliser and irrigation practices, grass swards under canopy, minimising bare ground, laneway run-off diversions and vegetated buffers around waterways. M2 mitigations included all the M1 mitigations and detention bunds. As not all of these mitigations can be included in OVERSEER there was no difference between M1 and M2 mitigations recorded in OVERSEER results and no changes in P were observed due to the limitations in OVERSEER. N mitigations contributed to an approximate 7% reduction in N loss (across green and gold) and a negligible GHG change (approximately 1-2% reduction). However, there was a reduction in EBIT of approximately 6%.

6.4. Forestry

Forestry includes plantation forestry, indigenous forestry and farm forestry. Often forestry is used on other land use types as a mitigation, however, there is still mitigations to reduce water quality impacts from forestry. Forestry can be used for timber, carbon credits, mānuka honey production as well as a permanent offset for water quality impacts. Given the long time horizons to realise income from plantation forestry and the variations in costs and benefits over time, estimations of costs and benefits are often best done in a cost benefit framework. Studies estimating the impact of changes to water quality policy under the NPSFM often focus on N and P and therefore, often forestry is not included in modelling as its primary impact is on sediment (for example Moran et al., 2017).

6.4.1. GMP

The National Environmental Standard for Plantation Forestry (NES PF) provides a set of conditions which plantation foresters must meet. These are focused on eight separate activities that cover the life cycle of plantation forestry: mechanical land preparation, afforestation (the establishment of a stand of trees), earthworks, forest quarrying, river crossings, pruning/thinning to waste, harvesting, and replanting phases of operations. These activities have a set of practices within them which foresters must undertake (e.g. riparian setbacks) or they must seek resource consent.

Some of the conditions in the NES PF which can be considered mitigations for plantation forestry include; setbacks from waterbodies, submitting a harvest plan, install and maintain storm water and sediment control measures and spoil cannot be deposited where it can enter, or deliver sediment to, a waterbody. Some estimates of the costs and benefits of these activities were completed as part of the policy process, however limited quantifiable detail was provided on the costs and benefits of specific activities such as installing and maintaining sediment control measures.

The use of mitigations such as wetlands (natural or constructed), riparian buffers, sediment traps, or retention bunds to capture sediment are applicable for forestry as they are for pastoral land uses. These mitigations can be costed based on assumptions such as size and type of construction, however, estimates of benefits vary based on catchment characteristics.

There is a growing body of literature which references practices that can be undertaken within plantation forestry as potential options to reduce the impact of forestry, particularly harvesting on water quality (Bloomberg et al., 2011). These include actions such as species types, staggered harvesting, planting density and harvesting types. However, while these are often suggested as having potential there is no comprehensive analysis of the environmental benefits of such activities, nor the economic impacts for businesses. While estimating the economic impacts could be undertaken through consultation with forestry businesses, the quantification of the potential benefits is likely to be harder and further consideration should be given as to how this gap is managed.

However, if ACs desire is to estimate the economic and environmental impacts of changes based on implementing the NPS FM then it could be argued that the mitigations contained in the NES PF are not relevant as these would be double counted based on the analysis already conducted for the NES PF (e.g. as was argued in Moran et al., 2017). If AC wants to increase the requirements for forestry then these could be included, but the counterfactual scenario should be based on the NES PF which is currently operative. This means only the costs and benefits of changes over and above the NES PF should be considered. If this is the case, then there is limited literature on the costs and benefits of these additional mitigations and it would be recommended that these were estimated in conjunction with industry.

6.4.1.1. Setbacks

Setbacks were included as a requirement in the NES PF and the potential costs of these were estimated by NZIER (2016). In this work the cost was based on an opportunity cost of not planting setbacks and was estimated at $8,500 per hectare for slopes under a 7% gradient and $5,000 per hectare for slopes between 7% and 15%. Slopes over 15% were not been valued as it is expected that under the status quo these would have setbacks at least ten metres to reflect forestry practicalities. No estimates of effectiveness were provided. These estimates could be revised for a specific context based on expected annualised income.

One study which uses expert opinion to estimate the potential benefits of setbacks on sedimentation caused by plantation forestry NIWA (2010). This Waikato based study used expert elicitation to estimate the benefits of setbacks and gross margin analysis to estimate the economic impact. NIWA (2010) looked at 5 metre wide setbacks and assumed there was 60 meters of stream bank per hectare, half of the setback width was assumed to be harvestable area. They estimated a 20% reduction in sediment yields, a 10% reduction in N yields and a 15% reduction in P yields as well as benefits through stream shading and habitat protection. Economic impacts were considered to be a 3% reduction in harvestable area and a gross margin of $773 per hectare per year was used (26 year time period with a stumpage value of approximately $27,000 per hectare).

6.5. Other land uses

Other rural land uses that could have a potential impact on the AC FWMT are lifestyle blocks and commercial equine blocks. Nationally, limited work has been done on these land uses due to the focus on land uses with significantly more scale and mitigation options. Indeed, many regions have excluded land parcels below certain thresholds (such as land area, stocking rates and/or cropping areas) from meeting certain regulations relating to contaminant losses (e.g. Horizons, Bay of Plenty and Waikato Regional Councils). However, given the influence of Auckland city across land use within the greater Auckland region, it is potentially important to consider if, and how, these land uses could be incorporated into the FWMT. The first consideration should be based on the scale of these land uses relative to other rural land uses. After that, additional consideration needs to be given to:

- Their relative intensity (stocking rates, use of feed and fertiliser inputs);
- Potential crossover into other sectors (lifestyle land utilised informally by neighbouring commercial operators);
- Adequacy of modelling tools to capture systems accurately – this is particularly important for equine farming operations, where horses may be stabled nightly for 10 hours, spend the rest of the day on pasture and receive a ration imported supplement, none of which can be accurately modelled in OVERSEER under its provision for equids.
- Assumptions around soil fertility;
- Complexity of applying EOF mitigations in environments that may cross-over into peri-urban areas that have some storm water engineering

Assumptions of lifestyle properties being farmed below potential with limited inputs may well be incorrect and would need to be evaluated. Standard abatement curves may also be unhelpful on the basis such property owners may not meet the definition of being rational economic actors. Hence preparedness or otherwise to adopt mitigations may well be different and the economic consequences of any adoption atypical relative to what might be assumed for commercial land owners. Depending on the scale of this land use within the region or specific sub-catchments, adoption of mitigations on these properties might be integral to achievement of community water catchment targets and thus good information will be critical.

7. Edge of field mitigations

7.1. Detainment bunds

Detainment bunds are a relatively new tool designed specifically to remove P and sediment from large volumes of surface runoff. These bunds temporarily catch and store runoff behind an earth bund for a maximum of three days. During this period, suspended sediment and P particles are able to settle on pasture while the water slowly drains through an outlet or down through the soil profile (Clarke, 2013). Trials in the Rotorua catchment showed that the quantity of sediment and P retained was dependent on the influent load in the ephemeral stream. Published data on the performance of the bunds to reduce P and sediment loss is not yet available. An early study by Brown et al. (1981) of a similar sediment-retention pond system in America quantified the reduction in total P and sediment loss as 25-33% and 65-76%, respectively, which may give an indication of the effectiveness of detainment bunds.

Clarke (2013) found that detainment bunds were more effective at attenuating particulate P compared with dissolved P. On the other hand, wetlands are more effective at attenuating dissolved P and N (Tanner et al., 2005) and less effective at dealing with large inflows of water. As such, implementing a combination of synergistic nutrient mitigations, such as those described above, may provide better overall contaminant reduction that just one mitigation on its own.

7.2. Dung beetles

Early research in New Zealand indicated that the introduction of dung beetles can reduce surface runoff volume from pastoral soils (Forgie et al., 2013). Later studies in the Auckland region have quantified this effect with a 49-81% reduction in surface runoff when 25 and 53 mm rainfall occurred over a 10 minute period, respectively. Sediment loss was, however, only reduced under the more common and less extreme rainfall event with the decrease ranging from 73-100% depending on soil type (Forgie et al., 2018). As P loss is strongly linked to sediment loss, similarly high levels of reductions in P loss are also expected. The effect of dung beetles on *E. coli* loss was studied in a trial by Dymond (2016) in the Wairarapa with a 35% reduction modelled. This assumed the beetles removed all dung on the pasture/soil surface preventing it from being caught up in overland flow. Along with reduced contaminant losses, dung beetles may also be able to reduce GHG emissions with an overseas outdoor grazing trial quantifying a 7% decrease in GHG emissions at the pat scale but only a 0.05-0.13% reduction in the whole lifecycle of milk or beef production given that only a limited fraction of cow dung ends up on pasture (Slade et al., 2016).

7.3. Soil amendments

Aluminium sulphate (alum) is effective at mitigating P loss from topsoil by sorbing P to the soil surface and reducing the available P that can be lost to runoff or drainage. At 20 kg alum per hectare, total P can be reduced by 29% (McDowell & Houlbrooke, 2009) without impairing pasture growth or animal performance (McDowell & Nash, 2012). The cost-effectiveness of applying alum has been reported at USD$157-830/kg P conserved at 25 kg Al/ha. Applying alum to critical source areas for P loss or after grazing forage crops is likely to be more cost-effective than large-scale application to pasture (McDowell & Norris, 2014).

7.4. Nitrification Inhibitors

Dicyandiamide (DCD) is an effective nitrification inhibitor that can be applied to reduce nitrate leaching by slowing down the conversion of ammonium-N to nitrate-N. Currently unavailable in New Zealand dairy systems due to milk quality compliance issues, DCD is able to reduce nitrate leaching by an average of 59%, with greater reductions possible in autumn (76%) compared to spring (42%). DCD is also extremely effective at reducing nitrous oxide emissions from cow urine patches, with reductions of 82% reported (Di & Cameron, 2005). Pasture production is increased with the use of DCD as there is a greater opportunity for the plants to utilise the ammonium before it is converted to nitrate and lost through the soil profile. Nitrate leaching losses from winter forage crops can also be reduced with use of DCD. Shepherd et al. (2012) quantified a 20-27% reduction in N leached when applied within two days of grazing and again at six weeks post-grazing.

Other nitrification inhibitors are available, including nitropyrin, however these are typically more expensive, have a low water solubility, are more volatile and therefore are less suitable for use with solid fertilisers. Importantly, DCD unlike other inhibitors is able to break down completely in the soil into ammonium and carbon dioxide (Di and Cameron, 2005).

Emerging technology such as Spikey, developed by Pastoral Robotics Ltd, may present an alternative method of nitrification inhibition. Spikey is able to detect and treat individual urine patches with a nitrification inhibitor. Initial results indicate a potential 30% reduction in both nitrate leaching and nitrous oxide volatilisation (Bates et al., 2015).

7.5. Spaced planting of poplars or willows on land use capability class 4-6 (steep erodible) land

The space-planting poles on erosion prone hill country has long been accepted as an effective means of reducing erosion (Hawley & Dymond 1988, Hicks 1995. Daigneault and Elliot (2017) quantified a 20% and 70% reduction in P loss and sediment loss, respectively, with space-planting of trees on slopes. However, the economic imperative for it is not great. Analysis by Parminter et al (2001) concluded that the productivity gain from soil retention was typically less than the suppression effect from shading on pasture dry matter production and that only on highly erodible soils and where [sheep & beef] farmers were happy with low returns on the investment from planting was the cost-benefit positive for the landowner. This analysis excluded the potential public good benefit from reducing soil erosion.

7.6. Riparian buffer management

Effective stock exclusion and riparian fencing with planted buffer includes vegetation around rivers, streams and lakes. Meta-analysis by Zhang et al (2010) found that buffer width alone accounted for 37%, 44% and 35% of the variance in removal efficacy for sediment, N & P respectively. A summary of the existing literature by Doole (2015) also suggested that the width of the buffer does have an impact on the extent of N loss reduction, but whether this is due to a greater interception area or a reduction in pastoral area (with a commensurate reduction in stocking rate) is unclear. We also note that much of the literature reviewed by Zhang considered N losses in overland flow or run-off, which in NZ pastoral systems is unlikely to be the primary pathway of nonpoint-source N loss to water.

There is a concern that nutrient cycling within the riparian areas can act as an indirect source of N and P loss if planted vegetation is not regularly cut and removed (Collier et al., 2013). However, based on estimates of Keenan (2013), Daigneault et al (2017a) showed that it is possible to reduce 40% of sediment with grass buffer strips. However, Zhang et al (2010) found that buffers composed of trees have higher N and P removal efficacy than buffers composed of grasses or mixtures of grasses and trees. The cost of establishing riparian vegetation strip is around $255/ha for horticulture (Keenan, 2013), but this will vary depending on the choice of any planted vegetation. BOPRC advise that a native sedge vegetation riparian planting strip could be established at an average cost of $20 per lineal metre of waterway planted, assuming both sides of the waterway were planted), with annual weed control costs of $130/ha retired (De Monchy 2018, pers. comm).

To date, most of the regulation and voluntary practice change around riparian management has been centred on high order water bodies and lowland drains. However, McDowell et al (2017) found that 77% of national contaminant load was coming from lower-order streams that are not currently required to be fenced. With P being the primary nutrient entering water ways from overland flow and direct [stock] deposition, the fencing of low-order streams in areas of high P load may be extremely effective in reducing pollution.

7.7. Wetlands

Nitrogen removal in natural wetlands is variable and estimates are based on a range of study types across a range of wetland characteristics. McKergow et al (2017) undertook a review of N removal in wetlands, they found a wide range of N removal rates (30 to 8,100 mg $N/m^2/day$) which is in accord with the overseas work (Dooley 2019). The efficiency of wetlands in removing N depends on many factors including (but not limited to) the type of wetland (seepage, constructed etc.), catchment area and riparian plantings. The wetland module in OVERSEER can be used to estimate the efficacy of wetlands, however, they do require quite significant assumptions in how the wetland is set up in the model. Costs of wetlands also vary considerably based on the assumptions made but can be estimated using information on input costs (such as fencing etc.).

7.8. Housing infrastructure

DairyNZ undertook an analysis of wintering barns including analysing both the economic and environmental impact of barns (Journeaux & Newman 2015). This study used real case studies and analysed both them pre and post barn state, including estimating the environmental (N, P and greenhouse gasses) impact of the barn. The changes in N leaching varied based on how the barn was incorporated into the farming system. Four of the farms recorded a significant increase (greater than 10%) in N leaching, six recorded relatively neutral N leaching results (varying from -4 to +10%), while four farms recorded reduced N leaching (of greater than 10%) post barn. Typically, the farms intensified and changes in wintering practices along with effluent management influenced the N loss post the barns. DairyNZ did conclude that a barn could reduce the N loss from dairy farms provided there was no associated intensification of the farming system. The barn systems tended to have a negative impact on P losses even without intensification which appeared to be mainly driven by changes in effluent management and cropping practices.

8. Land-use change

Land use change to less intensive activities can substantially change the nutrient leaching, erosion and *E. coli* levels. However, currently, such practice can have limited appeal for landowners. This is typically a result of the following factors:

- Cost of transition can be high i.e. cost of orchard development ($220,000/ha for kiwifruit pergolas and shelter), deer fencing (>$20/m) and handling facilities, and these costs need to financed at the start of conversions;
- Existing land uses might mask long-term future land use plans (conversion to housing) and be considered necessary to meet significant short to medium term holding costs;
- Barriers to entry to the supply chain of lower intensity alternatives with profitable returns i.e. licences for crop varietals (G3 kiwifruit licence), supplier shares (i.e. Dairy Goat Co-op milk supply rights), limited markets for supply (sheep milk);
- Potential loss of capital value with "permanent" land use change including potentially low salvage value of prior investment (i.e. dairy land being planted in radiata pine), and restricted opportunities for further change in the future;
- Perceived or real loss of profitability and annual cash flow, particularly where existing businesses are moderately or highly geared (pasture land converting to forestry);
- A desire to prevent the "stranding of assets" that have not yet reached the end of their economic life i.e. milking parlours, feed pads etc.;
- Inadequate landowner knowledge of the alternative land uses;
- Personal preference.

9. Recommendations

Cognisant of this review forming part of the preliminary work stream for accounting for rural productive HRU mitigation options within the FWMT, a number of key recommendations are made below having been informed by the literature review.

The objective for this review has been to collate earlier investigations of mitigation efficacy for rural land uses, simulated by the FWMT. That review is largely reliant on data outside of the Auckland region, but has been compiled into a matrix bundle defined by HRU factors (e.g., slope, soil type, land cover and intensity of use).

Use of the recommended costing and efficacy information for rural options (M1 to M3, deintensification, bush reversion) within the tool will require assumptions about the baseline functional state (e.g., what level of those bundles is already ongoing during the 2013-17 baseline modelling period from which effects of their targeted adoption will be simulated in scenarios).

It is also important to recognise that operating profits presented in Table 3 are broadly accurate for pastoral and horticultural intensity classes of HRU but not individual HRU's (i.e. these have not been resolved to slope or hydrological soil group classes of HRU).

Having reviewed earlier mitigation studies, the uppermost recommendation is to ensure awareness of limitations in those studies, by directing research into case-studies of Auckland-specific farm types configured in the FWMT (e.g., of HRUs).

The priority for the next stage of this work is, at a minimum, being able to fill key information gaps associated with the contaminants for which bundles have no national, let alone regional, data available (i.e. the blank cells in Tables 6-11).

9.1. Key focus areas

It is recommended that in order to fill these key information gaps and to test applicability of transferring existing work to the Auckland region, AC will need to undertake some farm systems modelling. Key areas to focus on are:

- Horticulture and arable mitigations, including GMP, EOF and de-intensification. There is very limited literature that quantifies costs and benefits of mitigations on horticulture and arable farms. While there is one study which provides a starting point (The AgriBusiness Group, 2014) it covers limited crop rotations and it is not clear if the crop rotations considered are applicable to the Auckland region. In addition, the use of OVERSEER for horticulture and arable land uses has been criticised, especially as it does not estimate the impact of mitigations for sediment. It is likely that AC will need to consider if it is feasible to fill this key literature gap and if so, how this could be done (e.g. through alternative modelling software, or empirical research).
- While there is some information on N and P mitigation on non-dairy pastoral systems, given the wide range in farm system types within this land use class it is challenging to transfer estimates from other studies to the Auckland region. It is recommended that AC analyses the types of farming systems across the region in this land use class and then it is recommended that farm systems modelling is undertaken to estimate the impacts of reducing N and P from these farms.

- There is a strong evidence base for estimating the impact of N and P mitigation options on dairy farms. While none of the existing research is in the Auckland region, it may be possible to transfer some of the estimates (based on similar farm system types and biophysical characteristics) however, these should be validated with some Auckland specific examples. In order to transfer any estimates AC will need to ensure they are comfortable with the underlying assumptions of studies chosen especially for bundled mitigation studies.
- For both dairy and non-dairy pastoral land uses there is limited research on sediment and E. coli mitigations. However, the biggest constraining factor on this has been tools available and AC will have to consider these model limitations when incorporating mitigation options.
- The land use change and diversification mitigation options are not extensively modelled due to the assumptions that are required. However, it is possible to undertake an estimate where future possible land use change is analysed alongside typical performance (environmental and economic) of the changing land uses. This would first require an understanding of potential future land use and typical performance across the Auckland region.
- There is reasonable literature on some EOF mitigations, however, others are emerging or not well researched. Some of these (e.g. riparian areas, wetlands and stock exclusion) could be included in modelling for the AC based on existing research and tools available. For others, it is likely that there would be limited additional benefit in redoing modelling (e.g. housing) and instead utilising existing research would be the most appropriate way forward. For some (e.g. N inhibitors, soil amendments and dung beetles) it is recommended that these are not included in modelling due to the limited empirical research available.

9.2. Additional considerations

9.2.1. Base land use information

There is potential to improve the base understanding of the spatial distribution of existing land use across the region. Within land use classes there is a wide range of system types, for example, the rotation type on horticulture and arable land, the ratio of stock types in non-dairy pastoral and the intensity of the system in dairy. While there is no comprehensive database of systems within each land use class, understanding the predominant system types within each land use is important in transferring cost and benefit values from existing literature and selecting case studies specific to the Auckland region to incorporate into the FWMT. While AC can utilise some existing databases to spatially consider land use classes across the region, this should be refined with industry who can also provide information on system types typical to the region within each land use class, especially for horticulture and arable.

9.2.2. Defining the counterfactual scenario

There is a wide range of policies that impact on freshwater, AC needs to consider what is to be included in any economic analysis through the FWMT and what is already incorporated into the 'base-state' or counterfactual scenario. For example, the NES PF is operative and therefore, plantation forestry should already be incorporating the actions required through this and the costs and benefits of the NES PF do not need to be considered in the FWMT. In addition, given the current proposals relating to a new NPSFM, a new national environmental standards for freshwater and stock exclusion regulations under Section 360 or the RMA, AC should consider how the modelling undertaken in the FWMT can answer questions relating to these proposed policies as well as the current NPSFM.

9.2.3. Good management practice

GMP have been defined in a range of ways throughout farm system modelling studies. Given the strong emergence of FEPs in both the Auckland region (Kaipara Harbour programme) and nationally (in the proposed NPSFM) it would be logical for AC to consider both GMP and actions within a FEP. While an FEP is not necessarily limited to GMPs estimating the costs and benefits of moving to GMP across a range of land uses and farm types would provide a starting point to also estimating the costs and benefits of using FEPs. Two key challenges exist in quantifying FEP efficacy: understanding how much GMP has been implemented already during the baseline simulation period of the FWMT (from which any further effect is assigned in scenarios to full adoption of GMP) and understanding what GMPs can be modelled (e.g., in OVERSEER and Farmax).

There are various ways to estimate GMP costs and benefits. One option is to use estimates from the literature. While this provides a useful starting point, the literature is limited. GMP definitions and the actions considered in FEPs (or equivalents) vary widely and studies often consider the costs or the benefits (rather than both), or are land use specific. For example, much of the research by DairyNZ quantifies the benefits (changes in N and P loss) of implementing the actions contained within a Sustainable Milk Plan (a similar tool to an FEP), and while these benefits provide a useful estimate which could be included in AC's FWMT, they do not have estimated costs and the study is limited to dairy farms only (outside of the Auckland region). New tools, such as MitAgator, may help overcome this in future modelling exercises, provided the required input data is available.

A second option is to select a range of GMPs and use a cost benefit framework for inputs to the FWMT. One challenge with this option is that the costs and benefits are highly farm specific and using a cost benefit framework would require numerous case studies to generate regional variation. Another key challenge is this provides no context as to where current farms sit in relation to the defined GMPs. This could be overcome through for example a survey or discussions with industry.

A third option is to use farm systems experts to quantify the costs and benefits of moving to GMP on specific and representative case study farms and then engage with sector and industry groups to (qualitatively) assess to what extent have these practices are adopted within the sector. This can provide more robust cost benefit estimates and provides valuable information on where farm practices sit relative to GMPs. Within this option, it is recommended that AC uses the Industry-agreed GMPs as a starting point to define GMP and work with industry groups to refine and confirm these. Using farm systems expertise, the final GMPs can then be modelled on case study farms. Modelling using OVERSEER and Farmax will provide estimates for costs and benefits (N and P) while actions not able to be captured in OVERSEER and actions which benefit sediment and *E. coli* can be considered using estimates from literature and combined with the modelling results. This would provide AC with an indication of what the costs and benefits are of moving from current practice to GMP, it would present this as a bundled estimate rather than of specific GMPs on each farm.

9.2.4. De-intensification

There has been a range of work undertaken to analyse the impact of de-intensification mitigations, from empirical studies to numerous modelling studies. However, this work is varied across sectors with the most work undertaken in relation to dairy farming and N, with some work on dairy farms and P, non-dairy pastoral (N and P) and very limited work in relation to horticulture and arable farm systems (for N, P, sediment nor E.coli). In addition, these studies are often bundled (by nature of needing to have a balanced farm system) and so are often hard to directly compare. However, there is enough of an evidence base to use as a starting point to estimate the impact of de-intensification on dairy and non-dairy pastoral land uses on N and P losses. AC would be able to verify some of these results on a few case studies in the Auckland region to ensure that the existing relationships hold in relation to the biophysical characteristics of the Auckland region, but would not need to start from scratch. However, in relation to other land uses, primarily horticulture (across a range of crop rotations and types) and arable, AC will need to undertake a more detailed analysis of the impact of de-intensification due to the comparatively low existing evidence base. If AC did want to utilise work from existing studies, they would need to ensure they are comfortable with the assumptions made in the relevant studies and would need to utilise spatial data and information on current farm systems to ensure that extrapolating the results would be appropriate.

9.2.5. Diversification

Incorporating diversification as a mitigation strategy can be considered, however, it is recommended that this is done separately to de-intensification. Diversification is often not as simple as scaling back one enterprise and increasing (or incorporating) another. It is likely to have fundamental implications for how a farm system is run and should be considered separately to de-intensification to ensure de-intensification is still a necessary (and suitable) requirement. Depending on the nature of diversification suggested some of the impacts will be able to be considered in OVERSEER and Farmax. However, others such as the impact of the diversification on sediment and *E. coli* will need to be considered alongside output from such models. It is hard to assess how large changes such as diversification will be incorporated into a farming system and therefore, the number of assumptions required in modelling mitigations such as this increases. For example, the impact of the diversification will need to be based on averages (e.g. average performance of the new enterprise) as there would be no information to understand how one land manager may perform in the new land use relative to another. This does not mean they cannot be considered, but that the assumptions used need to be consider carefully and fully documented and the extent to which these options can be extrapolated across the region should be restricted.

9.2.6. Edge of field mitigations

The impact of some EOF mitigations (such as the use of barns on dairy farms and wetlands) are relatively well considered in literature and others are less well researched. Often these mitigation strategies are considered separate to de-intensification options. It is recommended that AC also considers these separately to de-intensification, this is primarily because often EOF mitigations often have a significant impact on the overall farm system and therefore, it is useful to consider these first and then consider if de-intensification is still an necessary (and suitable) requirement. Further consideration needs to be given to what specific mitigations AC wants to consider in this category.

While analysing these types of mitigations is possible, often they need to be considered in both farm systems modelling software (OVERSEER and Farmax) and a spreadsheet-based cost benefit analysis to incorporate both costs and benefits not in OVERSEER and Farmax. The big challenge with modelling these mitigations is that due to their often significant impact on a farm system it is often hard to assess how they will be incorporated into a farming system and therefore, the number of assumptions required increases. This does not mean they cannot be considered, but that the assumptions used need to be consider carefully and fully documented and the extent to which these options can be extrapolated across the region should be restricted.

9.2.7. Total land use change

In order to understand the impact of land use change the potential for land use change needs to be considered. This includes understanding where it is possible and likely for land uses to change and what they may change to. This includes biophysical factors such as climate, soil and slope information as well as anthropogenic factors such as policy or access restrictions. Once the potential scope of land use change is understood then considering the impact of land use change can be estimated using a cost benefit framework with key indicators (such as changes in contaminant levels and profit, as well as potential social changes such as employment). Understanding the potential for land use change should incorporate industry knowledge.

9.3. Sediment and *E. coli*

The challenge with using OVERSEER and Farmax to undertake farm systems modelling is that they do not consider the impact of changes on sediment and *E. coli.* Based on this, the best option is to consider the impact of mitigations on sediment and *E. coli* in a cost-benefit framework. For example, where mitigations are expected to impact sediment and/or *E. coli* (such as fencing waterways or detainment bunds) the impact of these options will be estimated using literature (benefits) and expert knowledge (costs) and reported alongside estimates from farm system modelling. In addition, specific mitigations targeting sediment and *E. coli* could be considered at a farm or catchment level if they were of particular interest for AC providing the required input information is available. For example, if AC has information on stock exclusion still required at a catchment level (including land use type and amounting of fencing required) then a cost benefit analysis could be undertaken for this specific mitigation.

9.4. General assumptions

Regardless of what specifics are modelled and incorporated into the FWMT there will need to be a suite of general assumptions and decisions that will need to be made. These wherever possible should be made in consultation with key stakeholders (such as industry) before the modelling occurs. This includes the use of case study farms rather than an average farm in order to understand the range of potential implications. Key assumptions include (but are not limited to); how to treat input and output prices (e.g. specific years or averages), if farm data is 'smoothed' (e.g. to represent a specific year and if so what year, or smoothed across years), what metrics to consider (e.g. operating profit, interest, tax, depreciation etc.), how to deal with seasons (e.g. annual results for dairy versus the length of rotation across horticulture rotations), the baseline level of farm/orchard efficacy and if farm level system optimisation can occur beyond this frontier (and if so at what cost), what can and cannot be modelled and/or estimated and appropriateness of extrapolating results. The extent of pre-existing adoption across sectors of mitigation strategies is also a critical component to validating existing standards of water quality and an important factor to include in stakeholder engagement strategies.

PERRIN AG CONSULTANTS LTD

10. References

AgFirst Waikato. 2009. Upper Waikato Nutrient Efficiency Study. Final report to Environment Waikato. 104p.

Archer, L. & Brookes, J. (2018). Modelling Water Restrictions and Nutrient Losses for Horticulture in the TANK Catchment – An Economic Analysis. Prepared for Hawkes Bay Regional Council. https://www.hbrc.govt.nz/assets/Document-Library/TANK/TANK-Key-Reports/Modelling-Water-Restrictions-and-Nutrient-Losses-for-Horticulture-AgFirst-2018.pdf

Barber, A. 2014. *Erosion and sediment control guidelines for vegetable production.* A report for Horticulture New Zealand.

Barber, A. 2019, June. Outdoor vegetable production - joining the dots on soil erosion and sediment control. *The Journal (The Official Publication of the New Zealand Institute of Primary Industry Management)*, 23(2), 8-11.

Barber, A., Smith, S., Wharfe, L., & Hodgson, V. 2017. *Vegetable washwater - Literature and council policy review.* A report for Horticulture New Zealand.

Barber. A., Stenning, H., Allen, J., Journeaux, P., Hunt, J., & Lucock, D. 2018. *Overseer – Valuation of the benefits*. A report for Overseer.

Basher, L.R. & Ross, C.W. 2002. Soil erosion under intensive vegetable production on clay loam, strongly structured soils at Pukekohe, New Zealand. *Australian Journal of Soil Research*, 40, 947-961.

Bates, G., Quin, B., & Bishop, P. 2015. Low-cost detection and treatment of fresh cow urine patches. In: Moving farm systems to improved attenuation. (Eds L.D. Currie and L.L Burkitt). Occasional Report No. 28. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 12 pages. Beef + Lamb NZ. (2019) Sheep and beef farm survey https://beeflambnz.com/industry-data/farm-data-and-industry-production/sheep-beef-farm-survey

Bloomberg, M., Davies, T., Visser, R. & Morgenroth, J. 2011. Erosion Susceptibility Classification and Analysis of Erosion Risks for Plantation Forestry. Report prepared for Ministry for the Environment.

Bloomer, D. McVeagh, P., & O'Brien, G. 2019. Environmental challenges facing intensive horticulture. In: *Nutrient loss mitigations for compliance in agriculture*. (Eds L.D. Currie and C.L. Christensen). Occasional Report No. 32. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. https://flrc.massey.ac.nz/workshops/19/Manuscripts/Paper_Bloomer_2019.pdf 8 pages.

Brown, M.J., Bondurat, J.A., & Brockway, C.E. 1981. Ponding surface drainage water for sediment and phosphorus removal. Transactions of the ASAE 24(6): 1478-1481.

Box, L., Edwards, R., & Bryant, R. 2017. Milk production and urinary nitrogen excretion of dairy cows grazing plantain in early and late lactation. New Zealand Journal of Agricultural Research 60(4): 470-482

Burt, A., Sluys, C. & Fung, L. 2017. Part C: Farm Case Studies- Drystock (Sheep, Beef Cattle and Deer). In: The Southland Economic Project: Agriculture and Forestry. (Eds.: Moran, E., Pearson, L., Couldrey, M., and Eyre, K.) Technical Report. Publication no. 201904. Environment Southland, Invercargill, New Zealand.

Carey, P.L., Cameron, K.C., Di, H.J., Edwards, G.R., & Chapman, D.F. 2016. Sowing a winter catch crop can reduce nitrate leaching losses from winter-applied urine under simulated forage grazing: a lysimeter study. Soil Use and Management 32(3): 329-337.

Carlton, A., Cameron, K.C., Di, H., Edwards, G.R., & Clough, T.J. 2019. Nitrate leaching losses are lower from ryegrass/white clover forages containing plantain than from ryegrass/white clover forages under different irrigation. New Zealand Journal of Agricultural Research 62(2): 150-172.

Carran, R.A. 1990. Dynamics of soil and plant nitrogen in cultivated and no-till spring wheat systems following old pasture. New Zealand Journal of Crop and Horticultural Science Vol. 18: 5-9.

Carruthers, V.R., Adrewes, W.G.K., & Sedcole, J.R. 1997. Effect of altering the non structural:structural carbohydrate ration in a pasture diet on milk production and ruminal metabolites in cows in early and late lactation. Animal Science 64: 393-402.

Cichota, R., Brown, H., Snow, V.O., Wheeler, D.M., Hedderley, D., Zyskowski, R., & Thomas, S. 2010. A nitrogen balance model for environmental accountability in cropping systems. *New Zealand Journal of Crop and Horticultural Science,* 38(3), 189-207. DOI:10.1080/01140671.2010.498401

Christensen, C.L. 2013. Duration-controlled grazing of dairy cows: Impacts on pasture production and losses of nutrients and faecal microbes to water. PhD Thesis, Massey University.

Clarke, D., Paterson, J., Hamilton, D., Abell, J., Scarsbrook, M., Thompson, K., Moore, R., & Bruere, A. 2013. Overview of using detainment bunds for mitigating diffuse-source phosphorus and soil losses from pastoral farmland. In: Accurate and efficient use of nutrients on farms. (Eds L.D. Currie and C L. Christensen).
https://www.massey.ac.nz/~flrc/workshops/13/Manuscripts/Paper_Clarke_2013.pdf.
Occasional Report No.
26. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 9 pages.

Daigneault, A., & Elliot, S. 2017. Land-use contaminant loads and mitigation costs. A Technical Paper. Motu Economic and Public Policy Research.

Daigneault, A., Elliott, S., Greenhalgh, S., Kerr, S., Lou, E., Murphy, L., & Wadhwa, S. 2017. *Modelling the potential impact of New Zealand's freshwater reforms on land-based greenhouse gas emissions*. MPI Technical Paper No: 2017/22. A report for MPI SLMACC.

DairyNZ. (2018).Economic survey 2017-18. https://www.dairynz.co.nz/resources/resource-list/dairynz-economic-survey-2018-19/

DairyNZ & LIC. (2018). Dairy Statistics. https://www.dairynz.co.nz/resources/resource-list/dairynz-economic-survey-2018-19/

DairyNZ Economics Group. 2014. Waikato Dairy Farm Nitrogen Mitigation Impacts: Analysis of Waipa-Franklin and Upper Waikato Dairy Farms. Retrievedfrom

http://waikatocivildefence.govt.nz/assets/WRC/Council/Policy-and-Plans/HR/S32/C/3231728.pdf de Klein, C.A.M. & Ledgard, S.F. 2001. An analysis of environmental and economic implications of nil and restricted grazing systems designed to reduce nitrate leaching from New Zealand dairy farms. I. Nitrogen losses. New Zealand Journal of Agricultural Research 44: 201-215

de Klein, C., Paton, J., & Ledgard, S. 2000. An evaluation of a strategic de-stocking regime for dairying to improve nitrogen efficiency and reduce nitrate leaching from dairy farms in nitrate-sensitive areas. Proceedings of the New Zealand Grassland Association 62: 105-110.

Di, H.J., & Cameron, K.C. 2005. Reducing environmental impacts of agriculture by using a fine particle suspension nitrification inhibitor to decrease nitrate leaching from grazed pastures. Agriculture, Ecosystems and Environment 109: 202–212.

Dolan, M. 2016. *The environmental benefits of NZGAP as a third part quality assurance scheme.* Retrieved from https://www.waikatocivildefence.govt.nz/assets/WRC/Council/Policy-and-Plans/HR/S32/E3/8726653.pdf

Doole, G. 2015. Description of mitigation options defined within the economic model for Healthy Rivers Wai Ora Project. Report No. HR/TLG/2015-2016/4.6

Dooley, E. 2019. Assimilated Capacity of Constructed Wetlands in New Zealand: Literature Review *in* Pukehina Eco-Village Development; Diffuse Nitrogen and Phosphorous losses, wetland literature review and land versatility assessment. Perrin Ag Consultants Ltd 2019. Prepared for the Property 7 Group in support of Western Bay District Council RMA Hearing for RC11154S.

Dunbier, M., Brown, H., Edmeades, D., Hill, R., Metherell, A., Rahn, C., Thorburn, P., Williams, R., Shepherd, M., & Wheeler, D. 2013. *A peer review of Overseer in relation to modelling nutrient flows in arable crops.* A report for The Foundation for Arable Research.

Dymond, J., Serezat, D., Ausseil, A., & Muirhead, R. 2016. Mapping of Escherichia coli sources connected to waterways in the Ruamahanga Catchment, New Zealand. Environmental Science and Technology 50(4): 1897-1905.

ECAN. 2019. Farm Environment Plans. Accessed 27 Nov. 2019 https://www.ecan.govt.nz/your-region/farmers-hub/farming-plans-and-consenting/farm-environment-plans

Everest, M. 2013. Hinds catchment nutrient and on-farm economic modelling, Sub report – Economic assessment excluding outside of OVERSEER mitigations. Version 1. Macfarlane Rural Business Limited, Ashburton, 14 August 2014. C14C/157099

FAR. 2013. A peer review of OVERSEER® in relation to modelling nutrient flows in arable crops. https://assets.far.org.nz/uploads/FAR_OVERSEER_REVIEW_-_final.pdf

Ford, S. 2015. *Discussion on the treatment of vegetable production in the EW healthy rivers planning process*. Retrieved from https://www.waikatoregion.govt.nz/

Ford, S.J. 2015a, September. *Statement of evidence on behalf of Horticulture New Zealand in the matter of the Environmental Canterbury [Temporary Commissioners and Improved Water Management] Act 20110.*

Ford, S.J. 2016, November. *Statement of evidence on behalf of Horticulture New Zealand in the matter of the hearing of submissions on the proposed Gisborne regional freshwater plan.*

Ford, S.J. 2017, June. *Statement of evidence on behalf of Horticulture New Zealand in the matter of the hearing of submissions on the proposed Plan Change 85, 85A-85D to the Whangarei District plan.*

Ford, S.J. 2019, May. *Statement of evidence on behalf of Horticulture New Zealand in the matter of submissions on proposed Waikato regional plan change 1 – Waikato and Waipa river catchments.*

Ford S. & Halliday A. 2017. Part C: Farm Case Studies- Horticulture. In: The Southland Economic Project: Agriculture and Forestry. (Eds.: Moran, E., Pearson, L., Couldrey, M., and Eyre, K.) Technical Report. Publication no. 201904. Environment Southland, Invercargill, New Zealand.

Forgie S.A., Paynter Q., Zhao Z., Flowers C., & Fowler S.V. 2013. The impact of tunnelling and dung burial by new exotic dung beetles (Coloptera: Scarabaeinae) on surface run-off, survivorship of a cattle helminth, and pasture foliage biomass in New Zealand pastures. Prepared by Landcare Research. Prepared for the Dung Beetle Technical Advisory Group.

Forgie, S.A., Paynter, Q., Zhao Z., Flowers C., & Fowler S.V. 2018. Newly released non-native dung beetle species provide enhanced ecosystem services in New Zealand pastures. Ecological Entomology doi:10.1111/een.12513.

Foundation for Arable Research. 2018, June. *Fluxmeter news – the latest from the fluxmeter network. Edition 1 – June 2018. Search* https://www.forestandbird.org.nz/

Franklin Sustainability Project. No date. *Soil and drainage management guide.* Retrieved from http://agrilink.co.nz/wp-content/uploads/2016/10/SoilDrainageMgmtGuide_PrinterFriendly.pdf

Gentile, R., Green, S., Mason, K., van den Dijssel, C., Johnstone, P., & Clothier, B. 2014. *Land management practices and nutrient losses from farms on the Poverty Bay Flats.* A report for Gisborne District Council.

Ghani, A., Ledgard, S., Wyatt, J., & Catto, W. 2016. Agronomic assessment of gibberellic acid and cytokinin plant growth regulators with nitrogen fertiliser application for increasing dry matter production and reducing the environmental footprint. *Proceedings of the New Zealand Grassland Association 76*: 177-182.

Grinter, J. & White, J. 2016. National Stock Exclusion Study: Analysis of the costs and benefits of excluding stock from New Zealand waterways. MPI Technical Report No: 2016/55

HBRC. 2015. Plan Change 6 to Hawke's Bay Regional Resource Management Plan Tukituki River Catchment. https://www.hbrc.govt.nz/assets/Document-Library/Tukituki/Tukituki-Plan-Change-6.pdf

Halliday, A.P. 2015, September. *Statement of evidence on behalf of Horticulture New Zealand in the matter of the hearing of submissions on Variation 3 of the proposed Land and water regional plan (Environment Canterbury).*

Harris, S., & Doole, G. 2017. *Te Awarua o Porirua collaborative modelling project. Work brief 11 RM. Assessment of rural economics and mitigation costs*. A report for LWP.

Hawley, J.G.; Dymond, J.R. 1988. How much do trees reduce landsliding? Journal of Soil and Water Conservation 43: 495–498.

Houlbrooke, D.J., Horne, D.J., Hedley, M.J., Hanly, J.A., Scotter, D.R., & Snow, V.O. 2004. Minimising surface water pollution resulting from farm-dairy effluent application to mole-pipe drained soils. I. An evaluation of the deferred irrigation system for sustainable land treatment in the Manawatu. New Zealand Journal of Agricultural Research 47(4): 405-415

Journeaux, P. & Newman, M. 2015. Economic & Environmental Analysis of Dairy Farms with Barns: Cost Benefit Analysis of 14 NZ Dairy Farms with Barns. DairyNZ Ltd and AgFirst Waikato, 63p.

Journeaux, P. & van Reenan, E. 2017. Economic evaluation of stock water reticulation on hill country. A report prepared for the Ministry for Primary Industries and Beef + Lamb New Zealand. AgFirst.

Kalaugher, E., Burger, D. & Bramley, M. 2019. Potential reductions in farm nutrient loads resulting from farmer practice change in the Waipā catchment: SMP Final Call analysis. DairyNZ; Hamilton.

Keenan, C. 2013. Sustainable practice development, and the Horticulture industry in NZ: The development of GAP and Good Management Practice. Presentation in ECAN hearing group 2-23 May, 2013. https://potatoesnz.co.nz

Keenan, C.M. 2016, October. *Statement of evidence in the matter of the hearing of submissions on the proposed Gisborne regional freshwater plan.*

Khaembah, E.N., & Horrocks, A. 2018. A modelling approach to assessment and improvement of nitrogen management on New Zealand arable farms: a case study. *Agronomy New Zealand,* 48, 1-11.

LandWISE. 2018. *Future Proofing Vegetable Production.* Retrieved from http://www.landwise.org.nz/projects/future-proofing-vegetable-production/

Ledgard, S. 2006. Nitrogen management – why is it important and what can we do about it? In: D.F. Chapman; D.A. Clark; K.L. Macmillan; D.P. Nation, Eds. 'Meeting the challenges for pasture based dairying' Proceedings of the 3rd Dairy Science Symposium. University of Melbourne, Victoria, Australia (National Dairy Alliance). Pp. 23-31.

Ledgard, S.F., Welten, B.G., Menneer, J.C., Betteridge, K., Crush, J.R., & Barton, M.D. 2007. New nitrogen mitigation technologies for evaluation in the Lake Taupo catchment. Proceedings of the New Zealand Grassland Association 69: 117-121.

Low, H; McNab, I; Brennan, J. 2017. Mitigating nutrient loss from pastoral and crop farms: A review of New Zealand literature. Horizons Regional Council. 39p.

Macintosh, K.A., Mayer, B.K., McDowell, R.W., Powers, S.M.,Baker, L.A., Boyer, T.H. & Rittmann, B.E. 2018. Managing Diffuse Phosphorus at the Source versus at the Sink. *Environmental Science and Technology* 52(21), 11995-12009. DOI: 10.1021/acs.est.8b01143

Magesan, G; Wang, H. 2008. Nitrogen leaching from gorse – Final Report to the Bay of Plenty Regional Council. 39p.

Malcolm, B., Teixeira, E., Johnstone, P., Maley, S., de Ruiter, J., & Chakwizira, E. 2018a. Catch crops after winter grazing for production and environmental benefits. Agronomy New Zealand 46 99-108.

Malcolm, B.J., Carey, P.L., Teixeira, E.I., Johnstone, P.R., Maley, S.C., & de Ruiter, J.M. 2018b. Potential of catch crops to reduce nitrogen leaching in New Zealand winter grazing systems. Journal of New Zealand Grasslands 80: 207-214.

Mathers, D. 2015. Rootzone reality - A network of fluxmeters measuring nutrient losses under cropping rotations. In: *Moving farm systems to improved attenuation*. (Eds L.D. Currie and L.L Burkitt). http://flrc.massey.ac.nz/workshops/15/Manuscripts/Paper_Mathers_2015.pdf Occasional Report No. 28. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 3 pages.

Mathers D. 2017. Part C: Farm Case Studies- Arable. In: The Southland Economic Project: Agriculture and Forestry. (Eds.: Moran, E., Pearson, L., Couldrey, M., and Eyre, K.) Technical Report. Publication no. 201904. Environment Southland, Invercargill, New Zealand.

Matheson, L; Djanibekov, U; Bird, B; Greenhalgh, S. 2018. Economic and contaminant loss impacts on farm and orchard systems of mitigation bundles to address sediment and other freshwater contaminants in the Rangitāiki and Kaituna-Pongakawa-Waitahanui water management areas. Final report, forming delivery for Milestone 2A, 2B, 2C & 2D. Version 1.3. 109 pages;

McDowell, R.W. 2010. Evaluation of two management options to improve the water quality of Lake Brunner, New Zealand. New Zealand Journal of Agricultural Research 53(1): 59-69.

McDowell, R.W., & Houlbrooke, D.J. 2009. Management options to decrease phosphorus and sediment losses from irrigated cropland grazed by cattle and sheep. Soil Use and Management 25: 224-233.

McDowell, R.W., & Nash, D. 2012. A review of the cost-effectiveness and suitability of mitigation strategies to prevent phosphorus loss from dairy farms in New Zealand and Australia. Journal of Environmental Quality 41: 680–693.

McDowell, R.W, & Norris, M. 2014. The use of alum to decrease phosphorus losses in runoff from grassland soils. Journal of environmental quality 43: 1635-1643.

McDowell, R.W., Cox, N., & Snelder, T.H. 2017. Assessing the yield and load of contaminants with stream order: would policy requiring livestock to be fenced out of high-order streams decrease catchment contaminant loads? Journal of Environmental Quality 46: 1038-1047.

McDowell, R.W., Monaghan, R.M., & Morton, J. 2003. Soil phosphorus concentrations to minimise potential P loss to surface waters in Southland. New Zealand Journal of Agricultural Research 46(3): 239-253.

McDowell, R.W., Wilcock, B., & Hamilton, D.P. 2013. Assessment of strategies to mitigate the impact or loss of contaminants from agricultural land to fresh waters. Report prepared for MfE. RE500/2013/066

Mckergow, L., Hughes, A. & Rutherford, K. 2017. Seepage wetland protection review. Report prepared for DairyNZ. NIWA Client Report 2016048HN.

Monaghan, R.M., Quinn, J. 2010. Appendix 9: Farms, in: National Institute of Water and Atmospheric Research (NIWA), Waikato River Independent Scoping Study, NIWA, Hamilton. HAM2010-032

Moran, E., Pearson, L., Couldrey, M., and Eyre, K. 2017. The Southland Economic Project: Agriculture and Forestry. Technical Report. Publication no. 2019-04. Environment Southland, Invercargill, New Zealand. 340pp

MPI. (2017). Carbon Look-up Tables for Forestry in the Emissions Trading Scheme. https://www.mpi.govt.nz/forestry/forestry-in-the-emissions-trading-scheme/emissions-returns-and-carbon-units-nzus-for-forestry/calculating-the-amount-of-carbon-in-your-forest-land/carbon-tables-for-calculating-carbon

MPI, FANZ & AgResearch. 2015. Facts about OVERSEER®.

Muller, C. 2017. Modelling dairy farm systems: processes, predicaments and possibilities. In Science and policy: nutrient management challenges for the next generation. Proceedings of the Fertilizer and Lime Research Centre Annual Workshop.

Newman, M. & Muller, C. 2017. Part C: Farm Case Studies- Dairy. In: The Southland Economic Project: Agriculture and Forestry. (Eds.: Moran, E., Pearson, L., Couldrey, M., and Eyre, K.) Technical Report. Publication no. 201904. Environment Southland, Invercargill, New Zealand.

NIWA. 2010. Waikato River Independent Scoping Study. NIWA, Hamilton, HAM2010-032

Norris, M., Johnstone, P., Green, S., Clemens, G., van den Dijssel, C., Wright, P., Clark, G., Thomas, S., Mathers, D. and Halliday, A. 2016. Rootzone reality – A network of fluxmeters measuring nutrient losses under cropping rotations. In: *Integrated nutrient and water management for sustainable farming.* (Eds L. D. Currie and R. Singh). https://www.massey.ac.nz/~flrc/workshops/13/Manuscripts/Paper_Orchison_2013.pdf Occasional Report No. 29. Fertiliser and Lime Research Centre, Massey University, Palmerston North, New Zealand. 11 pages.

NZIER. 2016. Plantation forestry economic analysis Revisions with new information on proposed National Environmental Standards. MPI Technical Paper No: 2017/05

Orchiston, T.S., Monaghan, R.M., & Laurenson, S. 2013. Reducing overland flow and sediment losses from winter forage crop paddocks grazed by dairy cows. In: Accurate and efficient use of nutrients on farms. (Eds L.D. Currie and C L. Christensen). http://flrc.massey.ac.nz /publications.html. Occasional Report No. 26. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 7 pages.

Parsons, O., Doole, G., Romera, A. 2015. On-farm effects of diverse allocation mechanisms in the Lake Rotorua catchment. Report for the Rotorua Stakeholder Advisory Group, August 2015.

Perrin Ag Consultants Ltd. 2012: Farmer Solutions Project. Final report to Bay of Plenty Regional Council. 66p.

Perrin Ag Consultants Ltd. 2014: NDA Impact Analysis. Final report to Bay of Plenty Regional Council. 147p.

Perrin Ag Consultants Ltd. 2013. Upper Waikato Drystock Nutrient Study. Final report to Waikato Regional Council. 89p.

Reid, J.B., & Morton, J.D. 2019. *Nutrient management for vegetable crops in New Zealand.* A report for Horticulture New Zealand.

Reid, J.B., Searle, B.P., Hunt, A., Johnstone, P.R., & Morton, J. 2019. *Nutrient management for vegetable crops in NZ – recommendations and supporting information*. Plant & Food Research Internal Report.

Shepherd, M., Stafford, A., & Smeaton, D. 2012. The use of a nitrification inhibitor (DCn™) to reduce nitrate leaching under a winter-grazed forage crop in the Central Plateau. Proceedings of the New Zealand Grassland Association 74: 103-108.

Slade, E., Riutta, T., Roslin, T., & Tuomisto, H. 2016. The role of dung beetles in reducing greenhouse gas emissions from cattle farming. Scientific reports, 6, 18140. doi:10.1038/srep18140

The AgriBusiness Group. 2016. Ministry for Primary Industries Stock Exclusion Costs Report. MPI Technical Paper No: 2017/11.

The Agribusiness Group. 2014. *Nutrient performance and financial analysis of horticultural systems in the Horizons Region.* A report for HortNZ and MPI.

The Agribusiness Group. 2014. *Nutrient performance and financial analysis of Lower Waikato horticultural growers.* A report for HortNZ and MPI.

The Agribusiness Group. 2015. *Waimea Plains nutrient performance and financial analysis of horticultural systems.* A report for HortNZ and MPI.

The Agribusiness Group. 2016. *Hawkes Bay nutrient performance and financial benchmarking.* A report for HortNZ and MPI.

The AgriBusiness Group. 2014. Nutrient Performance and Financial Analysis of Lower Waikato Horticulture Growers. Prepared for Waikato Regional Council, Ministry of Primary Industries and HortNZ. Retrieved from https://www.hortnz.co.nz/assets/Environment/National-Env-Policy/JR-Reference-Documents-/Agribusiness-2014.-nutrient-performance-and-financial-analysis-of-lower-waikato-horticulture.pdf

USDA. 2013. Intro to Soils – York county, Pennsylvania. Web Soil Survey. National Cooperative Soil Survey. 61p.

Vibart, R. Vegeler, I. Dennis, S. Kaye-Blake, W. Monaghan, R. Burggraaf, V. Beautrais, J. and Mackay, A. 2015. A regional assessment of the cost and effectiveness of mitigation measures for reducing nutrient losses to water and greenhouse gas emissions to air from pastoral farms. Journal of Environmental Management 156, 276-289.

Vogeler, I., Vibart, R., & Cichota, R. 2017. Potential benefits of diverse pasture swards for sheep and beef farming. Agricultural Systems, 154, 78-89.

Wilcock, B., Elliot, S., Hudson, N., Parkyn, S., & Quinn, J. 2008. *Climate change mitigation measures: Water quality benefits and costs.* A report for ministry for the Environment.

Wilcock, R.J., Betteridge, K., Shearman, D., Fowles, C.R., Scarsbrook, M.R., Thorrold, B.S., Costall, D. (2009). Riparian protection and on-farm best management practices for restoration of a lowland stream in an intensive dairy farming catchment: a case study. New Zealand Journal of Marine and Freshwater Research, 43(3), 803-818. doi: https://www.tandfonline.com/doi/pdf/10.1080/00288330909510042

Woods, R.R., Cameron, K.C., Edwards, G.R., Di, H.J., & Clough, T.J. 2016. Does gibberellic acid reduce nitrate leaching losses from animal urine patches? *In: Integrated nutrient and water* *management for sustainable farming*. (Eds L.D. Currie and R.Singh). https://flrc.massey.ac.nz/workshops/16/Manuscripts/Paper_Woods_2016.pdf Occasional Report No. 29. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 5 pages.

Woods, R., Bidwell, V., Clothier, B., Green, S., B., Elliot, S., Shankar, U., … & Wheeler, D. 2006. *The CLUES project: Predicting the effects of land-use on water quality – Stage II.* A report for the Ministry of Agriculture and Forestry.

Woodward, S.L., Waugh, C.D., Roach, C.G., Fynn, D., & Phillips, J. (2013). Are diverse species mixtures better pastures for dairy farming? Proceedings of the New Zealand Grassland Association 75: 79-84.

Zespri. (2017). Zespri Group Limited and Subsidiaries Annual Report for the year ended 31 March 2017. https://www.zespri.com/en-NZ/publications/annualreports

Zyskowski, R.F., Teixeira, E.I., Malcolm, B.J., Johnstone, P.R., & de Ruiter, J.M. 2016. Effectiveness of winter cover crops to reduce nitrogen leaching losses in cropping systems in Waikato, New Zealand. *Agronomy New Zealand 46*: 109-119.

Find out more: fwmt@aucklandcouncil.govt.nz