Horticulture Typology Modelling for the FWMT

A technical modelling report

Prepared for

Auckland Council and Horticulture New Zealand

Report prepared by

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Executive Summary

Auckland Council's (AC) Healthy Waters Department has developed a Fresh Water Management Tool (FWMT) which is a continuous, process-based water quality model spanning the entirety of the Auckland region. As part of the continuous improvement of the FWMT, Horticulture New Zealand (HortNZ) and AC are aiming to better understand horticultural farm systems, especially commercial vegetable production (CVP). This work provides more robust information on horticultural land uses in the Auckland region, focusing on understanding baseline environmental and economic footprints for CVP and kiwifruit permanent horticulture for later incorporation into the FWMT. Contaminant yields and profitability assessments are presented as well as the opportunity, effect and cost of on-land interventions to mitigate contaminant losses.

This project received direct input from a small group of CVP growers (members of the Pukekohe Vegetable Growers Association) who provided information and data as well as discussion and review on key assumptions and modelling approaches. The project was also supported by a technical advisory group (TAG) made up of growers, industry, regional and central government representatives as well as technical experts.

The key performance indicators used in this project were contaminant yield and economic performance. Contaminant yield included nitrogen leachate (below the rootzone), total suspended sediment and total phosphorus yield; economic performance included gross margins, annual operating profit (including gross margins and overheads), production and capital costs. The modelling approach adopted was defensibly complex and is shown diagrammatically in Figure 1.

Five CVP crop rotations and one kiwifruit system type were defined (referred to as 'typologies'), to represent major aspects of the horticultural industry in Auckland. After footprint determination, the five CVP rotations were weighted together to create one CVP "impact class" for later incorporation into the FWMT. This weighting was based on an approximate area representation (acknowledging there is no exact data on area for each of the crops modelled) as well as expert and grower advice. Each CVP rotation was based on a five-year rotation comprising of multiple crops. These rotations represent a 1 ha area of land, not a business, which can rotate across different land parcels during the five-year rotation.

To determine nitrogen yields for CVP, each five-year rotation was modelled in APSIM five times over a 25-year simulation period, each with a unique climate window based on actual climate data between 1990 and 2014 for the Pukekohe region. The nitrogen modelling was rotation-specific but not slope specific (as APSIM does not explicitly consider slope) and produced daily results on nitrogen yield below the root zone. For each of the rotations, nitrogen yields were analysed in a variety of ways, including by crop (as averaged across the 25-year simulation period) and by whole rotation (as averaged across each distinct five-year repetition and as an annual average).

To model sediment and phosphorus losses from CVP, Agrilink NZ's Erosion Sediment Calculator (ESC) was used which is independent of crop type but split into two slope categories: high slope and low slope. The low slope class represents land less than or equal to 2° and is based on a modelled slope of 2°. The high slope class represents CVP land greater than 2° and is based on a model slope of 4°.

For the kiwifruit base model Zespri and NZKGI provided baseline nitrogen contaminant loads which were developed in the SPASMO model. The baseline phosphorus yields were based on measured data from Zespri for a Bay of Plenty orchard.

Economic spreadsheet models were developed for each CVP rotation and the kiwifruit orchard. For kiwifruit these were based on data provided by Zespri as well as literature, including annual production, revenue and costs. For CVP rotations economic models were based on production, revenue and crop specific expenses for a five-year period. These data were used to generate crop-specific gross margins which were combined to represent a five-year rotation and then annualised. Following this, annual overheads (which were independent of crop type) were added to generate an annual operating profit. Annual overheads varied by slope and therefore so did operating profit. Annual overheads included land cost, vehicles, repairs and maintenance, irrigation overheads, maintenance of sediment controls, and the cost of vegetated buffer strips and wheel track ripping. For the CVP rotations the gross margin and profit values were weighted across the five CVP rotations to create an overall economic footprint for the CVP impact class.

Mitigations were selected based on literature as well as feedback from technical specialists and growers. The mitigations focused on farm system changes as edge of field mitigations were already included in the FWMT. For sediment and phosphorus losses, sediment control measures were combined and included sediment retention ponds (SRPs) as well as vegetated buffer strips (VBSs). Sediment retention ponds were previously configured as separate devices in the FWMT. The nitrogen mitigations were modelled separately to the phosphorus and sediment mitigations due to the different modelling tools used, however, these can be combined for use within the FWMT.

The mitigations selected for nitrogen included improved irrigation scheduling and reductions in fertiliser input. The improved irrigation meant irrigation application changed from a fixed rate of irrigation over a fixed return period, to a trigger point with a fixed amount of irrigation then applied. Three fertiliser mitigations were considered, one reduced nitrogen by 2% on crops losing more than 0.2 kg N/ha/day (as modelled in APSIM) with no impact on field yield (but with an increased wastage rate), the next reduced fertiliser input by 5% on all crops with an associated reduction in field yield and an increase in wastage, the third reduced fertiliser input by 10% on all crops with an associated reduction in field yield and increase in wastage.

The mitigations for sediment and phosphorus were improved sediment control (increased use of SRPs and VBSs) and wheel track ripping. An assumed rate of adoption for SRPs and VBSs was used for baseline modelling of CVP, as informed by discussions with technical experts and growers. This varied by high and low slope. There is no quantifiable data on the existing, or potential, future adoption of these interventions; as such, discussions with the TAG and growers informed the increased rate of adoption which was assumed for mitigated state modelling.

For kiwifruit, only nitrogen fertiliser reductions were modelled as a mitigation option. There were two reductions in fertiliser considered, both reduced fruit yield. All CVP and kiwifruit mitigations had an associated change in production, revenue, expenses and overheads.

The gross margin for weighted average CVP was $14,384/ha/yr. The annual profit was $3,740/ha/yr for high slope and $3,797/ha/yr for low slope. Annual profits were different between low and high slope categories based on annual maintenance costs and the current assumed adoption percentage of land area treated by VBSs and/or SRPs. The annual earnings before interest and tax (EBIT) for kiwifruit was $44,390/ha/yr.

The base nitrogen yield (as leachate below rootzone) for CVP was 110 kg N/ha/yr and 24 kg N/ha/yr for kiwifruit. Sediment yield for low slope land was 1.8 t/ha/yr compared to 3.3 t/ha/yr for high slope land. Phosphorus loss followed a similar trend to sediment with 3.8 kg P/ha/yr on low slopes and 7.1 kg P/ha/yr on high slopes. These figures compare favourably to other literature, although this comparison is challenging as results are dependent on the full rotation and no other literature has the same combination and order of crops.

The improved irrigation scheduling (IIS) mitigation reduced profit by approximately 17% (low and high slope) and nitrogen yield by 24%. The first fertiliser mitigation (-2% fertiliser on high nitrogen loss crops, combined with IIS) reduced profit by 88% on high slope and 90% on low slope land while nitrogen loss reduced by 31%. The subsequent two mitigations reduced profit by over 100% and generated a 'negative profit'. They also reduced nitrogen loss by 30% (-5% reduction in fertiliser) and 34% (-10% reduction in fertiliser). All the changes in economic performance and contaminant yields as a result of the nitrogen fertiliser mitigations include the impact of the irrigation mitigation.

For low slope, the improved sediment control mitigation reduced annual profit by 12%, annual phosphorus yield by 63% and annual sediment yield by 61%. The improved sediment control mitigation combined with wheel track ripping reduced profit by 19%, phosphorus yield by 68% and sediment yield by 67%. For high slope, the improved sediment control mitigation reduced profit by 5%, phosphorus yield by 68% and sediment yield by 67%. The improved sediment control mitigation combined with wheel track ripping reduced profit by 12%, phosphorus yield by 76% and sediment yield by 27%. There was also a capital cost associated with all the above sediment control mitigations.

There were two kiwifruit mitigations which reduced fertiliser inputs from a baseline of 105 kg N/ha/yr. The first mitigation reduced fertiliser input by 5 kg N/ha/yr; this reduced production by 1%, EBIT by 14% and nitrogen loss by 10%. The second reduced fertiliser input by 10 kg N/ha/yr; this reduced production by 2%, EBIT by 18% and nitrogen loss by 21%.

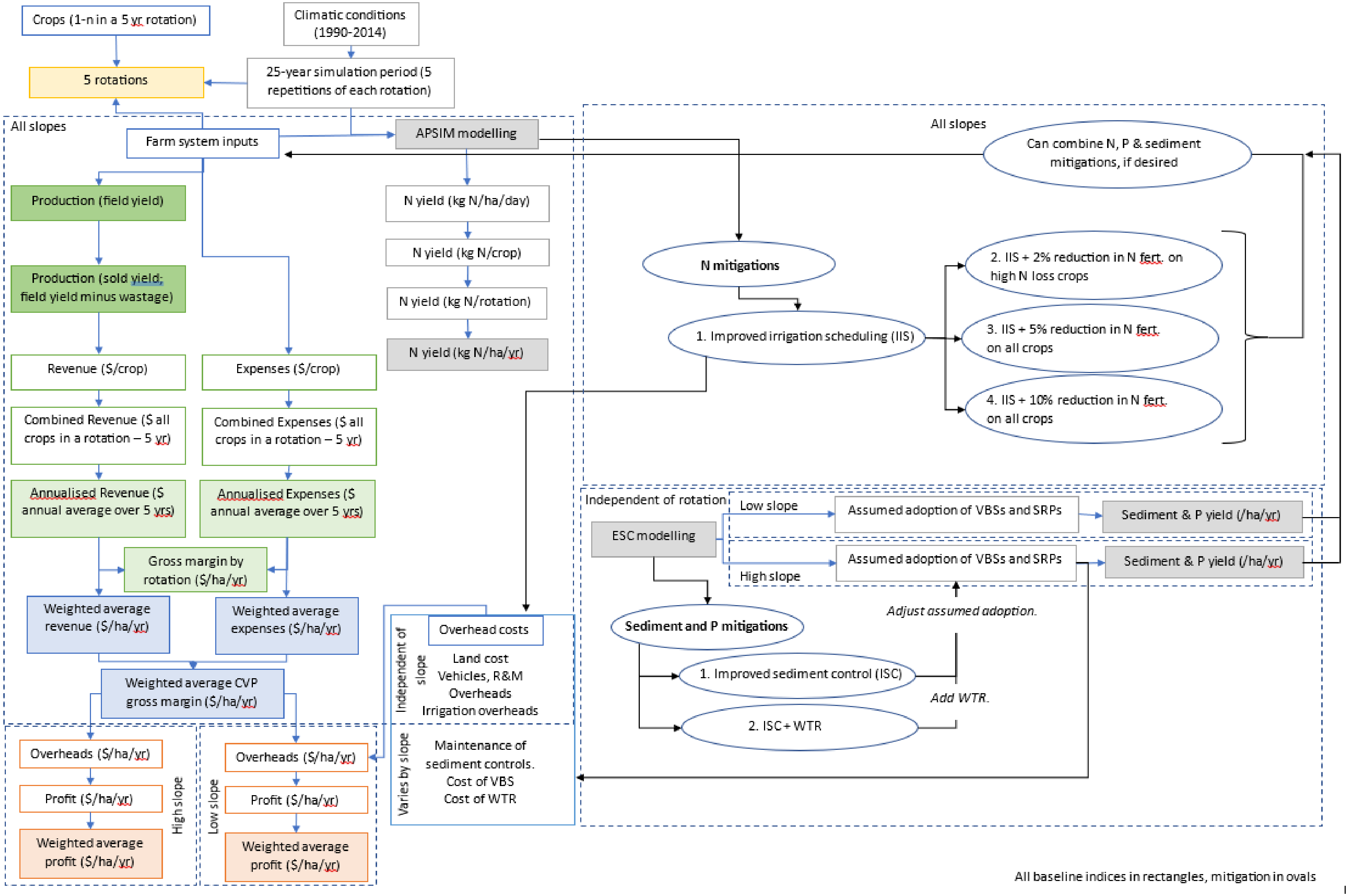
Based on the analysis presented in this report, a recommendation that the FWMT incorporate new horticulture land use groupings is suggested. Currently, the FWMT's (v1.2.) impact classes for horticulture are based on three broad categories, 'low impact,' 'medium impact' and 'high impact.' It is recommended that these categories be changed to 'arable,' 'perennial horticulture' (based on the kiwifruit typology) and CVP (based on the CVP typology presented here).

This work utilises a number of assumptions and therefore carries some limitations. These include:

- The costs are only considered to the farm gate and do not include flow on effects to the quantity of food supplied to consumers, the quality or price of this food, employment or amenity values from changed contaminant losses.
- Contaminant yields are considered at the farm level, i.e., contaminants that leave the rootzone or through overland flow, not necessarily contaminants reaching waterbodies.
- There are more crops grown than those represented in this report, and those crops that have been modelled only represent a specific set of variety, quality and farm input assumptions.
- The gross margins and profitability assessments do not consider factors such processing, noting many CVP entities are vertically integrated to some extent.
- Input and output costs need to be considered on the same basis. Prices were taken as a typical price across the past few seasons where possible.
- The modelling does not capture extreme weather events or climate change.
- Mitigations are constrained by modelling tools.
- To present a static rotation on a per hectare basis is a simplification of reality. In reality, growers are growing a multitude of different crops at a smaller scale than 1 ha.
- The modelling represents a 1 ha parcel of land, not a business, as businesses often change land areas used. The FWMT focuses on those land-use impacts relevant to water quality rather than any individual or segment of businesses.

- The results in this report should be read as relative changes, exact values of price and contaminant loss may vary by different farms or across time.

Key areas for further improvement include quantifying nitrogen mitigations that couldn't be modelled in this work such as residue management and quantifying the current, and future, extent of adoption of SRPs and VBSs as well as other farm practices such as irrigation management practices. In addition, the irrigation application rates need further analysis. Quantifying the weightings of the five rotations would also be beneficial, as the nuances of CVP make it hard to quantify using existing statistics on cropping area when utilising rotations with multiple crops. Despite these areas for improvement, this work represents a significant improvement to how the FWMT considers those dominant horticultural land uses within the Auckland region.



All baseline indices in rectangles, mitigation in ovals

Figure 1: Summary of method

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1 Background

Auckland Council (AC) is developing a Fresh Water Management Tool (FWMT). The FWMT is a continuous, process-based water quality model spanning the entirety of the Auckland region. The FWMT is being developed to support AC with watershed accounting, planning efforts, and implementation programmes to maintain and improve water quality. The FWMT serves operational purposes related to the National Policy Statement for Freshwater Management (NPS-FM) and other regulation affecting water quality as well as responses by AC including Water Quality Targeted Rate (WQTR) decision-making in Auckland. Specifically, this is to fulfil freshwater accounting requirements for objectives and limit-setting decision-making in the (NPS-FM), and implementation requirements for AC as a unitary authority (i.e., regional and district council functions under the RMA and LGA). The FWMT is designed to support both regional policy and planning development across the region, as well as regional infrastructure investment and rural land management. The FWMT helps understand existing and future water quality under alternative farm and catchment action plans – assessing their feasibility, cost and benefit to rural and urban communities.

This project is a joint venture between AC (Healthy Waters) and Horticulture New Zealand (HortNZ). The aim is to better understand horticulture systems, especially commercial vegetable production (CVP) grower systems and those mitigation choices available to CVP growers for improved water quality. The work will provide more robust information on horticultural land uses in the Auckland region focusing on understanding baseline typologies including vegetable rotations, baseline nutrient yield and profitability as well as the opportunity, effects and costs of mitigation choices on-land to prevent contaminant losses.

1.1 Freshwater Management Tool

The development of the FWMT is an iterative process; Stage 1 was focused on initial model development, where data used to calibrate the model was based on existing literature. This restricted how horticulture land uses were amalgamated and the estimates available in the literature for base contaminant footprints and mitigated yields. More information on the Stage 1 build in relation to the rural sector can be found in Muller, et al., (2020a; 2020b) and Muller and Stephens (2020a; 2020b). Stage 2 of the FWMT involves refining key data points that feed into the FWMT. This report centres on refining horticulture data available to support improvement of the FWMT, ensuring that it is more representative of horticulture practices in the region.

The FWMT continuously simulates the baseline or current state of water quality (2013-2017) via process-modelling across the entire Auckland region. The tool enables optimization modelling across intervention types, to identify potential future states and associated management strategies (e.g., choice of intervention, targeted land use type and sub-catchment, prioritised for cost over a 50-year discounted life cycle). For that purpose, pastoral and horticultural hydrologic response units (HRUs), or land use types, require a library of mitigation options. Inclusion of any given mitigation option into the FWMT's mitigation library requires three fundamental logical conditions:

1. Cost – the change in profit (including ongoing maintenance costs), necessary capital outlay associated with a 50-year life cycle of managing a mitigation option;
2. Effect (direct contaminant benefit) – the reduction in contaminant(s) associated with a mitigation option;

3. Opportunity – the conditions (e.g., the HRUs, hydrology, and contaminants) under which a given mitigation is effective, including baseline opportunity (pre-existing adoption) and maximum opportunity (potential).

The FWMT enables both current and future states to be simulated for nutrients (nitrogen, phosphorus), heavy metals (copper, zinc), sediment and faecal indicator bacteria (*E. coli*). The FWMT thereby supports Auckland Council decision-making and management of water quality for existing, future development and climate associated pressures. This report is not an isolated piece of work, but a part of the broader FWMT development process and as such should be read in conjunction with the other ongoing technical work being undertaken by AC, underpinning a decadal model development programme.

Currently the FWMT scope is limited to accounting for six contaminants in varying forms (dissolved, total): nitrogen, phosphorus, copper, zinc, total suspended sediment and *E. coli*. Of these, only total forms are simulated for yields from land whilst instream physicochemical and plant processes are simulated instream to speciate total into dissolved and particulate forms. Given the lack of equivalent enriched heavy metal (copper, zinc) inputs to rural land, both copper and zinc processes on rural HRUs are represented by total suspended sediment losses and transport. Likewise, *E. coli* is not of significant concern for horticulture land uses. Hence, this report focusses only on benefits of rural mitigations for total nitrogen, total phosphorus and total suspended sediment.

1.2 HRU definition

The FWMT simulates hydrology and contaminant response of land to climate and resource use, by classifying the Auckland region into unique biophysical and land use types – so-called Hydrological Response Units (HRU), each representing how hydrological and contaminant processes respond differently to variation in climate across ~490,000 ha of land that makes up the Auckland region.

HRU classes are defined by combinations of land cover, intensity of use, hydrologic soil group and slope. HRU composition of 107 unique classes has been assessed for 5,465 sub-catchments to define a “static” baseline of those landscape factors which control water quality variability within the FWMT. The baseline HRU make-up has been configured to represent the state of land use for the 2013-2017 period, but being static, is generalised over time, even if varying between sub-catchments.

Up to 20 HRUs currently describe the range in land responses to climate for pasture cover, whilst up to 30 HRUs currently characterise horticultural land responses to climate. Each HRU is uniquely parameterised for hydrological and contaminant processes on a regional basis in the FWMT (i.e., land area of equivalent class, under identical climate, are assumed to generate identical contaminant loads via equivalent runoff, interflow or active groundwater pathways). The development of the HRU framework, including all sources of data and transformation is detailed in the Baseline Inputs and Baseline Configuration & Performance reports (see Auckland Council, 2021a; 2021b).

For Stage 1 of the FWMT the HRUs for horticulture were configured based on three key factors: intensity (subgroups of horticulture land use), soil group (based on hydrological soil groups) and slope. These factors are described below and Table 1, which shows how these factors were amalgamated in Stage 1 of the FWMT. These will be refined in this report, specifically the intensity groupings which will be revised based on horticulture rotations and types.

- Intensity:
  - Orchards and idle fallow[1].
  - Arable, citrus, fodder, nuts and viticulture.
  - Berryfruit, flowers, fruit, kiwifruit, nursery, pipfruit, stonefruit, vegetables and greenhouses.

- Hydrological Soil Group (HSG):
  - A+ that are “very high infiltration” soils of “volcanic geology, medium to high soakage”, highest free-draining soil types (free draining).
  - A that are “high infiltration” soils of “sand/loamy sand/sandy loam” (free draining).
  - B that are “moderate infiltration” soils of “silt/silt loam/loam” (moderately draining).
  - C that are “low infiltration” soils of “sandy clay loam” (poorly drained).
  - D that are “very low infiltration” soils of “clay loam/silty clay loam/sandy clay/silty clay/clay” (poorly drained).

- Slope (defined from region-wide LiDAR):
  - Less than 10%, (~6°; flat to rolling).
  - Greater than or equal to 10% (rolling to steep).

Table 1: Summary of horticulture HRUs used in Muller et al. (2020b)

Land cover	Intensity	Soil group	Slope
Horticulture	Low Impact 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
	Medium Impact Horticulture - 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
	High Impact Horticulture - 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

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[1] Noting the terminology is confusing in that “orchards” are accounted for in other impact classes. However, any land identified by LCDB4 as an orchard but lacking AgriBase information to qualify its use as such was then assigned into the idle fallow HRU.

1.3 Life cycle costs

To ensure consistency with the urban mitigation cost modelling (Ira et al., 2020), a lifecycle cost (LCC) modelling approach has been undertaken to assess costs of various rural mitigations for the FWMT. The LCC incorporates the sum of acquisition and ownership costs of an asset over its life cycle from design, manufacturing, usage, and maintenance through to renewal or disestablishment (Figure 2). A "cradle-to-grave" time frame is warranted because future costs associated with a mitigation measure are often greater than the initial acquisition cost and may vary significantly between alternative solutions (e.g., between grey and green infrastructure – Australian National Audit Office, 2001).

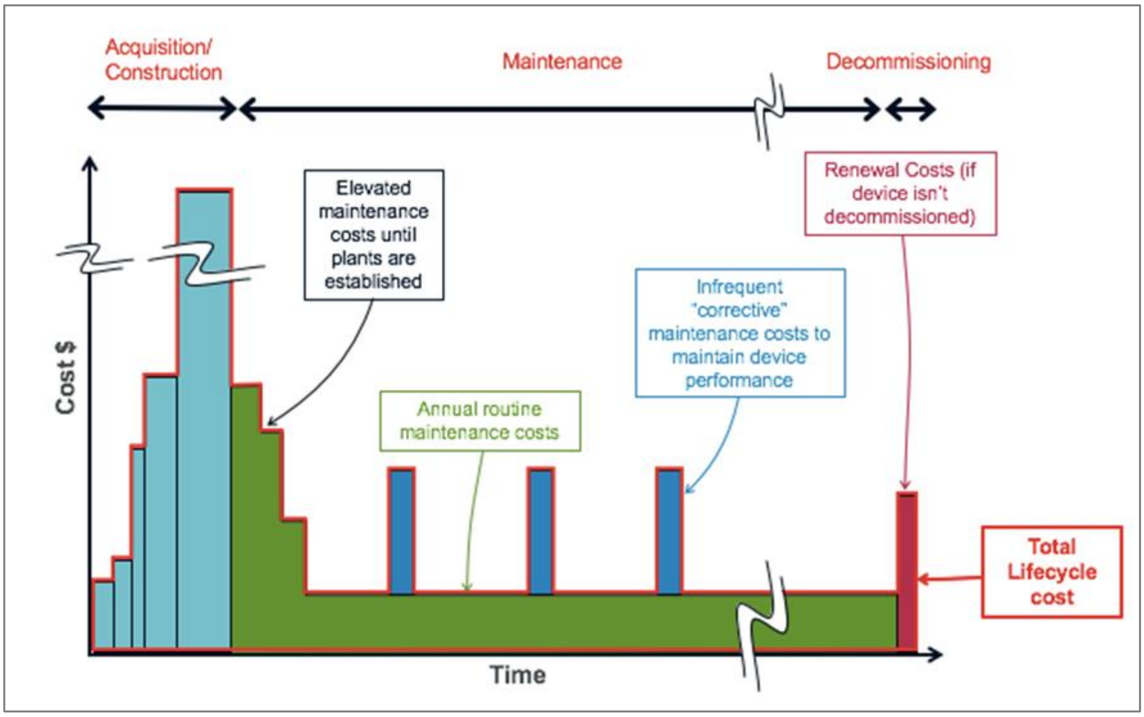

Figure 2: Phases in the life cycle of stormwater interventions and modelled long-term costs (Ira et al., 2020)

A robust LCC model has been developed in general accordance with the Australian/New Zealand Standard (4536:1999) for LCC. The structure of the models is the same for all mitigations and more detail can be found in Ira et al. (2020). Key assumptions include:

- A 50-year life cycle analysis period has been used to provide consistency with the urban intervention LCC costs.
- Interventions have been modelled using a 2%, 4% and 6% discount rate, as recommended by Auckland Council's Chief Economist Unit (Ira et al., 2020).
- Base date for all costing is set to 2019 New Zealand dollars (e.g., capital, maintenance, operating profit, or opportunity cost).
- All costs exclude goods and services tax (GST).
- The total acquisition cost (TAC) includes an overhead and indirect cost factor of 17.5% of the construction cost (this accounts for time needed to plan, consent, or implement potential mitigations, and associated contingencies, and is based on a likely overhead cost for urban interventions of 15% - 20% [Ira and Simcock, 2019]). This is only applied to capital costs incurred in year one, not successive years. TACs are only applied to mitigations that have capital costs.

- Construction costs are allocated in the first year of the model with renewal costs included in future years as applicable, maintenance costs are allocated from years 2 – 50, and either opportunity costs (from retiring land in perpetuity for EOF and land retirement mitigations) or reduced operating profit (from farm system changes in bundled mitigations) is considered annually.
- Where appropriate, full mitigation renewal costs are included in the relevant year(s).

Annualised LCCs generated via the LCC models are indicative estimates intended to enable comparison of various rural intervention scenarios and across rural and urban scenarios – comparative accuracy will be far greater than absolute and intended to support optimisation assessments (i.e., where comparative costing is the means of developing "most efficient" integrated mitigation strategies across both urban and rural contaminant sources). Life cycle costing allows "like for like" comparison of additional costs between interventions, across the full spectrum of costs (e.g., outlay, maintenance, opportunity or profit cost). However, LCC assessments require further assumptions on the feasibility, timing, uptake or optimisation of interventions in specific location(s), or about financing, governance or distributions of costs for particular catchments or activities.

1.4 Previous work

This report builds on the body of work that has supported the FWMT development to date, in particular the following reports:

- Muller at al. (2020a) reviewed rural mitigation literature to provide an indicative set of bundled mitigation options and EOF mitigation options for FWMT Stage 1, across pastoral and horticultural land uses, for total nitrogen (TN), total phosphorus (TP), sediment (total suspended sediment - TSS) and *E. coli.,* identifying a range of cost and benefit estimates from national literature for each. A key finding was the limited available information specific to Auckland climate, landscapes, and farm systems.
- Muller and Stephens (2020a) is an extension to Muller et al. (2020a), providing detailed estimates for riparian management options, including for fence only, fence and setback, setback only, planted and grassed variants. The recommended cost and benefits assigned were limited by the literature for setback options to 1 m and 5 m variants – a test of "reasonable assurance" finding insufficient evidence of how efficacy varies with setback distance, but that costing information was otherwise able to support alternative setback options.
- Muller et al. (2020b) translated literature on rural water quality mitigation into a 50-year LCC. It takes cost and benefit information from Muller et al. (2020a) and Muller and Stephens (2020) and translates it into a suitable format for the FWMT Stage 1. Recommendations extend to the applicability of mitigations across the HRU framework.
- Muller and Stephens (2020b) is a discussion document which summarises the key limitations and areas for refinement from Muller et al. (2020a; 2020b) and Muller and Stephens (2020) as well as issues highlighted as part of initial industry engagement. It developed a roadmap for working with key agricultural sectors to develop refined evidence for the FWMT, of which improvements in the horticulture sectoral data was identified as an area for improvement.
- Muller et al. (2022) which provides an addendum to Muller et al. (2020b) to add some new intervention scenarios as well as revise some of the previous scenarios which needed to be adjusted to fit into the FWMT.
- Auckland Council (2021a; 2021b; 2021c) provide detail on the baseline data and configuration of the FWMT as well as the baseline state assessment for rivers.

1.5 Importance of the Auckland region for the horticulture production

Horticulture is one of the fastest growing sectors of New Zealand's primary industries. In 2021 records were broken with produce exports reaching $6.68 billion and domestic produce reaching $3.52 billion, giving a total industry value of $10.2 billion (Plant & Food, 2021). This compares with a total industry value of only $5.68 billion in 2017 (MPI, 2018).

New Zealanders are fortunate to have most of their fresh vegetables cultivated locally in various growing hubs located around the country. One of New Zealand's key growing hubs is Pukekohe, which comprises highly productive soils straddling the Auckland and Waikato regional boundaries (Deloitte, 2018). Pukekohe's excellent soil types and growing conditions allow for high quality produce, including its rare ability to grow early season potatoes, spring carrots and year-round supply of brassicas. Pukekohe is not a particularly large fruit and vegetable growing hub with the area accounting for 3.80% of New Zealand's total hectares of fruit and vegetable production. However, it punches well above its weight in terms of revenue, generating 26% of New Zealand's total domestic value of vegetable production, and fruit to a lesser extent (Deloitte, 2018).

There are a number for reasons why Auckland's horticultural industry is unique compared to other regions around the country.

- The land within the Pukekohe vegetable growing area largely consists of volcanic, free draining soils which are classed as Land Use Capability (LUC) classes 1 and 2. These LUC classes have the highest ability to sustain agricultural and horticulture production, given its enhanced natural characteristics such as soil, climate and contour.
- The climate is unique as it is generally frost free which allows for year-round supply of certain vegetables.
- It is close to the large Auckland market and is an integral part of the wider horticulture supply chain, providing out of season produce to other parts of New Zealand. There is a range of paths to market for the Pukekohe vegetable growing area including to supermarkets, markets, further processing (e.g., potatoes into frozen chips), international markets, restaurants, and newer food subscription services such as My Food Bag.
- The labour-intensive nature of the crops grown, and the year-round growing systems mean the number of full time equivalent (FTE) employees is high relative to the production area. In 2017 the Pukekohe vegetable growing area employed 1,458 FTE employees which made up 22% of the total FTE employees in the vegetable growing industry, while comprising only 8.90% of the total vegetable growing hectares in New Zealand (Deloitte, 2018).

Despite these advantages, the Pukekohe vegetable growing area faces challenges. The urban sprawl from the Auckland Urban Development area is encroaching on the horticulture land area. The loss of productive land to urbanisation does not just have implications on the vegetable growing area itself but New Zealand's overall domestic food security. Population growth in the Auckland region alone is set to increase by 37% to 2.3 million between 2018 and 2043. This population growth is coupled with changing consumer preferences toward healthier, more plant-based diets, signalling a significant increased demand for horticultural produce (Deloitte, 2018). The Pukekohe vegetable growing area is ideally located to support this increased demand; however, with the continued decrease in productive land due to urbanisation, New Zealand runs the risk of not being able to feed its own population, unless the value and contribution made by this growing region and others around the country is better understood and valued. The importance of the Pukekohe vegetable growing area for domestic food supply has been recognised as a policy challenge with the release of the National Policy Statement for Highly Productive Land (NPS-HPL). The NPS-HPL seeks to preserve the availability of New Zealand's most favourable soils for food and fibre production, now and for future generations. This policy came into effect from mid-October 2022 and requires councils to identify, map and manage highly productive land in-line with the policy statement within three years.

In addition to the NPS-HPL, the Pukekohe region, like all other regions, is subject to resource management rules under the National Policy Statement for Freshwater Management (NPS-FM) which requires councils to consider how they can maintain or improve water quality where degradation has occurred. However, modelling has shown that the Pukekohe vegetable growing area would not meet the national bottom lines for nitrogen – even with extensive land use change (Auckland Council 2021b). Pukekohe (and Horowhenua) therefore has specific provisions for a 'Special Vegetable Growing Area" under the NPS-FM. This provision in the NPS-FM recognises the challenges facing Pukekohe, the water quality challenges and the need to maintain New Zealand's food security and domestic food supply, and the link between domestic vegetable production and human health (MfE, 2020). This provision still requires Auckland Council to set water quality targets and regulate for improvements to water quality.

2 Introduction and overview

This section introduces the project, including its scope and objectives. An overview of the method used for this study at a general level across all rotations is presented. Specific methodology and assumptions are contained in Section 4. A summary of the remainder of the report is also presented to help readers navigate this technical modelling report.

2.1 Project overview

HortNZ and AC (Healthy Waters) have jointly funded this project to better understand horticulture systems, especially CVP grower systems and choices for better water quality across Auckland. The work provides more robust information on horticultural land uses in the Auckland region focusing on understanding baseline typologies (focusing on CVP rotations), baseline nutrient yield and profitability as well as the opportunity, effects and costs of actions to prevent contaminant losses. These estimates support the iterative build and process of continual refinement of the FWMT. In turn, the FWMT will help with planning and implementation programmes to maintain and improve water quality in Auckland.

A better understanding of horticulture farm systems is needed by AC's FWMT to simulate baseline and future water quality (e.g., under mitigation action implementation). The purpose of this project is to better define types of grower systems to the extent the FWMT parameters allow (Auckland Council, 2021c), inclusive of management practice and farm infrastructure as well as biophysical characteristics and baseline nutrient yields (e.g., loads to edge of property by area of effective farmed land) and profitability. The project analyses, for each typology, mitigated contaminant yields (inclusive of cost, benefit [differing reduction by contaminant] and opportunity [differences in the available mix of mitigation choice]). The scope of mitigation actions considered spans both device (e.g., wetlands) and practice-based (bundled good management) choices.

This project received direct input from commercial vegetable growers to better understand vegetable rotations in the Auckland region. It uses grower-system modelling to understand and describe the baseline economic and environmental footprints of the vegetable systems (note: the report offers direction and input for the FWMT but does not extend to include integrated catchment modelling). The baseline models are then used to understand the impact of mitigating contaminant yields from these systems. The project also worked with Zespri and New Zealand Kiwifruit Growers Incorporated (NZKGI) to understand similar economic and environmental data for kiwifruit orchards in the Auckland region.

Specifically, this project:

- Models five CVP rotations, each spanning five years and multiple crops. Each rotation was developed to represent a proportion of CVP land in the Auckland region.
- Models a kiwifruit orchard type, on a steady-state annual basis.
- For each of the six typologies (five CVP and one kiwifruit), determines a baseline contaminant (nitrogen, phosphorus and sediment) yield (loading rate) and baseline profitability.
- For each of the six typologies, determines mitigation options for nitrogen, phosphorus and sediment to assign each option an associated cost (economic) and benefit (reduction in contaminant yield - environmental).
- For each of the six typologies and corresponding options, assigns an opportunity factor, which dictates how readily this mitigation option can be applied across the landscape.

It is acknowledged that this project is predicated on models. As such the answers provided by it are simplifications of reality and they do not nor cannot represent every possible situation or cover every possible scenario. However, they do provide insight into the relative magnitude of the impact of mitigations that can be modelled. As such the work done in this project is a significant step forward in this area of research and ultimately represents an improvement on data which feeds into the FWMT, relative to Muller et al. (2020b).

This project was completed for the purpose of improving the FWMT, as such decisions made on method and assumptions were predicated on this purpose. Any extrapolation or further use of the results presented here, for example in policy development, needs to be cognisant of the assumptions, limitations and methods used in this project for its intended purpose.

2.2 Method overview

This section describes the high-level method across the project. The method and general assumptions that are consistent across all typologies is detailed in Section 3 while rotation and mitigation specific assumptions detailed in the relevant method and assumption sections. Figure 3 provides an overview of the methodology.

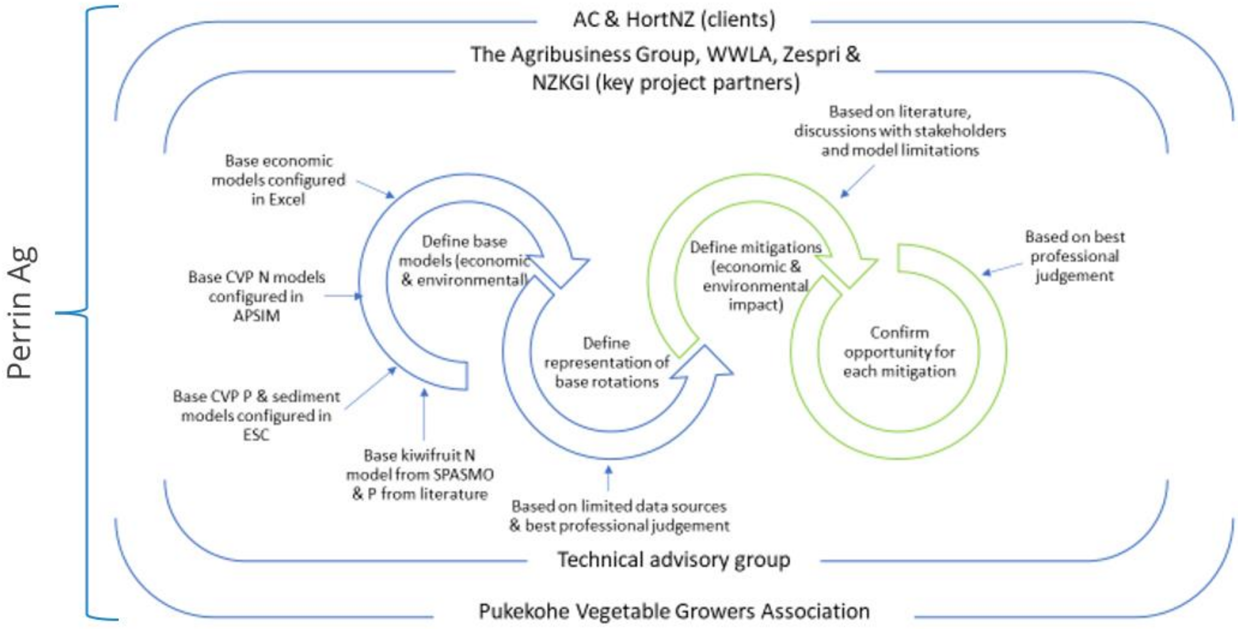

Figure 3: Method overview

This project was funded by AC (Healthy Waters) and HortNZ. The Pukekohe Vegetable Growers Association (PVGA) was a crucial partner who informed the modelling. The AgriBusiness Group, Williamsons Water and Land Advisory (WWLA) were part of the project delivery team. WWLA provided the Agricultural Production Systems Simulator (APSIM) modelling capability while The AgriBusiness Group provided expert advice into the project.

A technical advisory group was established to provide critical review into key parts of the project and linkages to other relevant national work programmes. The technical advisory group consisted of members from the PVGA, AC, HortNZ, MPI, MfE, Plant and Food Research, the FWMT technical review panel and The AgriBusiness Group.

A small group of growers contributed to this work, including providing information and data as well as discussion and review on key aspects. This group included representatives of the Pukekohe Vegetable Growers Association and businesses that spanned national organisations, as well as local based smaller organisations, a range of leasehold and owned land and a range of crops.

The baseline models were defined using various methods and drew on a range of data sources. These are briefly defined in Figure 3 and listed here:

- For the CVP rotations nitrogen is modelled in APSIM and phosphorus and sediment are modelled in the Erosion and Sediment Calculator (ESC).
- Zespri and NZKGI provide the baseline nitrogen contaminant loads for the kiwifruit model which were developed in SPASMO.
- Baseline phosphorus yields for kiwifruit were based on data from Zespri as well as literature.
- Economic models were developed for each vegetable rotation and the kiwifruit orchard.

The mitigation modelling followed from these baseline models. Mitigations were selected from a range of factors, including literature, feedback from technical specialists and growers. Some mitigation selection was constrained by the models used and information available on the impacts of mitigations. There was limited information available on the opportunity for mitigations across the catchment. Mitigations considered include farm system changes as well as edge of field mitigations that were not already included in the FWMT (such as the riparian area and wetland mitigation options).

The key performance indicators that are used in this project are contaminant yield (also referred to as contaminant loss[2]) and economic performance. The metrics used to measure contaminant loss include nitrogen yield or leachate from the rootzone[3] (also referred to as "nitrogen loss") and sediment and phosphorus yield (also referred to as "sediment loss" and "phosphorus loss"). Sediment throughout this report refers to total sediment yields, while phosphorus refers to total phosphorus inclusive of particulate and dissolved reactive phosphorus (based on the models used). The metrics used to assess economic impact include gross margins (the cost and revenue associated with growing specific crops), annual operating profit (the annualised gross margins from all applicable rotations and annual overhead costs to the business), production (volume of saleable produce) and capital costs (upfront investment for mitigations).

2.3 Report structure

There are three key parts to this project. These are shown in Figure 3. Part A is the first two actions (blue arrows) while Part B is based on the second two actions (green arrows). Part C is a summary:

- Part A – Baseline typology modelling. This involves defining the typologies and completing a baseline model for each CVP rotation and the kiwifruit orchard. These models cover nitrogen, phosphorus, sediment and profitability. This also includes assigning a representative areal proportion to each typology.

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[2] While the terms yield refers to contaminant generated from the land activity and loss refers to contaminants entering a receiving environment, they are both used in the context of this work to refer to contaminants lost from a land use beyond the rootzone.

[3] In this modelling, the soil profile was 1 m in depth and nitrogen yield/losses were from the bottom of the soil profile.

- Part B – Mitigation modelling. This involves selecting and modelling appropriate mitigation options for each typology to assess impacts on nitrogen, phosphorus and sediment yields, as well as associated economic impact. The opportunity for each mitigation is also defined to support its integration into the FWMT. Opportunity refers the expected capacity for the mitigation in question to be adopted.
- Part C – Summary.

Part A – Baseline typology modelling

Part A of this report presents the method and results for the baseline models. It focuses on the baseline rotations, contaminant footprints and gross margins for each typology.

The objectives of this section are to resolve the following key questions:

- What do typical CVP rotations in the Auckland region look like?
- What is the baseline nitrogen yields of each CVP rotation as modelled in APSIM?
- What is the baseline sediment and phosphorus yield of each CVP rotation based on the ESC?
- What is the baseline environmental footprint of kiwifruit orchards based on data from NZKGI and Zespri?
- What is the baseline gross margin for each typology?
- What share of CVP in the Auckland region do each of the CVP rotations represent?
- Based on the CVP and kiwifruit models what is the recommended re-configuration of horticulture land in the FWMT HRU framework.

The section starts with a general method which crosses over all rotations, this also includes the results of the sediment and phosphorus modelling for CVP as these are independent of rotation or crop type. A detailed description of each rotation along with nitrogen and gross margin results for each rotation follows. The remaining sections detail the kiwifruit model, the area representation of each typology and a summary of the baseline models.

3 Method

This section provides an overview of the methods used to generate the baseline economic and environmental information for the CVP and kiwifruit land uses. It focuses on methods and assumptions that are consistent across all the CVP land uses. Specific assumptions relating to each typology are detailed in Section 4. This section also includes a discussion on what proportion of CVP land each of the five rotations represents. Figure 1 summarises the method in a diagram.

Five CVP rotations were modelled as part of this work. Each rotation was set up to represent a five-year period with each modelled rotation repeated five times across a 25-year simulation period within APSIM. Figure 4 presents a conceptual view of how a hypothetical rotation was modelled within APSIM over the 25-year simulation period. Outputs from the five 25-year simulations were area weighted to derive a single combined CVP long-term estimate. The rotations are 'closed' and so the final crop in the five-year cycle is then followed by the first crop.

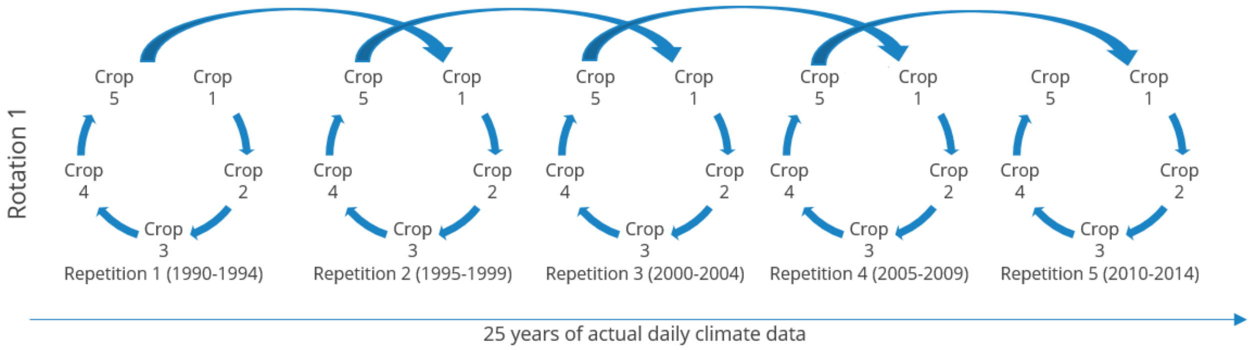

Figure 4: Example of CVP rotation setup

The reasons that crops must be modelled as a typical rotation is that the nutrient cycles are influenced by the proceeding crops (and their nutrient inputs, removal and losses). This is often, for example, why cover crops are used to support uptake of nutrients between vegetable crops to ensure nutrients and soil are not lost through leachate and overland flow. A crop can have the same growing window and same inputs but if there was more nitrogen residue in the soil than the crop can use from the proceeding crop it will result in a different environmental outcome compared to a crop that left less residue nitrogen. Five years was used as the rotation length as some key crops can only be grown once in a five-year period on the same patch of ground. Additionally, five repetitions were used to capture a range of climate influences on the outcomes.

Each rotation is for a hypothetical 1 ha area of land reflecting the FWMT's use of information on yields and mitigated yields, on a HRU or land type basis. This approach recognises the differing crops on a land parcel rotating, but the corresponding economic measures are then also relative to the land parcel rather than a business, which might only grow certain crops in a rotation thereby moving between different parcels of land in a leasehold exercise. While it is accepted that CVP businesses make decisions at smaller scales than 1 ha, this is a unit which is easily comparable to other rural activities and can be easily integrated into the FWMT.

3.1 Physical data collection

3.1.1 Commercial vegetable production rotations and physical data

Collecting data on CVP rotations focused on two key aspects - first, defining the rotations based on an understanding of the major crops grown across the Pukekohe vegetable growing area and then second, collating sufficient physical data on these rotations to model their baseline footprints in APSIM and the ESC. Five CVP rotations were chosen as a balance between capturing key crops grown in the area, notable likely variation in environmental (contaminant yield), and economic behaviour (i.e., representing the common CVP rotations within Pukekohe).

To understand the typical and most prevalent rotations in Pukekohe three data collection processes were used - a literature review, a review of statistical data and discussions with growers (through the PVGA). These are discussed below.

- Literature review.

There is limited information on CVP rotations typical of Auckland (Pukekohe) in the literature. This is largely due to the complex nature of CVP and the fact that there is often no such thing as a “typical” rotation. In addition, growers in the Pukekohe vegetable growing area can differ to other vegetable growing areas around New Zealand in terms of growing patterns. As such, each reviewed study was predicated on different assumptions and objectives making extrapolating to other regions, let alone comparably across studies, difficult. Despite this, the limited literature offers some use in drafting initial CVP rotations and in discussions with growers.

In the following key studies, and in the modelling used for this project, each rotation is assumed to be a ‘closed’ rotation. A closed rotation is when each rotation as listed repeats, e.g., following the last crop in the rotation, the rotation begins again with the first crop. This also simulates what happens in reality where crops are not continuously grown on an area of land and instead other crops rotate through that area before the first crop is grown again. It is also helpful to simplify the modelling process.

The first key study is The AgriBusiness Group (2014). This study modelled three rotations in the Lower Waikato area, which is adjacent to the Auckland region, and part of the Pukekohe vegetable growing area. The three rotations were classed as extensive, intensive and market garden and are described in Table 2. The extensive rotation was assumed by the authors to cover approximately 50% of the land area in the study area (Lower Waikato and Pukekohe), the intensive rotation assumed to cover 45% and the traditional market garden assumed to cover 5% (The Agribusiness Group, 2014).

Table 2: Rotations utilised in The AgriBusiness Group (2014)

Rotation	Crop rotation
Extensive	Potato (summer) → Onions → Carrots → Squash → Oats and Rye → Barley (grain) → Oats and Rye
Intensive	Squash → Broccoli → Oats and Rye → Lettuce (summer) → Mustard → Onions → Oats and Rye → Potato (winter)
Traditional Market Gardens	Broccoli → Mustard → Lettuce → Cabbage → Mustard → Spinach → Cauliflower → Cabbage → Mustard

The AgriBusiness Group (2014) study was also utilised by MPI in the Whangamarie study (MPI, 2022). In the Whangamarie stream catchment (Pukekohe), MPI assumed that the extensive rotation from The AgriBusiness Group (2014) research covered 48% of the catchment area, the intensive rotation covered 43%, the traditional market garden covered 5%, and the remaining 4% was in orchards. Latter areal weightings were based on information from the LCDB version 4.

Welton et al. (2021) looked at arable and vegetable crops in Auckland and considered five rotations that each covered two years. The rotations used in Welton et al. (2021) are shown in Table 3 (no area weighting was utilised).

Table 3: Rotations utilised in Welton et al. (2021)

Rotation	Crop rotation
1	Oats → Potato → Oats → Onions
2	Onions → Potatoes → Oats
3	Potatoes → Oats → Lettuce → Spinach → Cabbage → Lettuce
4	Lettuce → Spinach → Cabbage → Lettuce → Potatoes → Oats
5	Lettuce → Potatoes → Oats → Broccoli → Pumpkin → Oats

- Statistical review.

This step identified quantitative data on crops grown in the Auckland area (the majority of which is in Pukekohe). The Pukekohe vegetable growing area is approximately 4,359 ha according to Deloitte (2018). This compares favourably to the approximately 3,919 ha of short rotation crops and vegetables in the Manukau area in the FWMT (version 1.2; Auckland Council 2021a[4]).

The challenge with statistical data is that it is often presented on an annual basis and in the case of CVP, multiple crops are grown in one year and crops often rotate over a multi-year basis (e.g., failing to resolve temporal or climate-driven variation). In addition, statistics are often on a per hectare basis that may not represent the area of cropping and associated costing (i.e., costs require relation back to rows of crop rather than hectares to correctly estimate yield and costs/returns). Weather conditions and market demand also play a big part in determining the area of a certain crop planted on a year-to-year basis, hence the need for growers to retain flexibility and autonomy in which crops are grown in what sequential order (e.g., to protect against pathogens), what seasonal window and over what particular area and density. Collectively, this makes extrapolation from other studies particularly challenging for CVP in Auckland.

Often there are more than one crop grown in a year, resulting in the totals in Table 4 and Table 5 adding up to over 100% of the total land area. This reiterates the challenge of using statistical data to design rotations. The statistical data reviewed shows there is a wide range in the area of commonly grown crops grown in the Auckland region. The differences in the year the data was collected in, how data was collected, and the source of data has a large impact on the ranges presented. Although the range of data makes it difficult to assign an exact area grown of a particular crop, it does still allow conclusions to be drawn between the most commonly grown crops and the least commonly grown crops. This data informs why the certain crops were chosen and how many rotations these crops were included for this project. For example, crops such as

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[4] Noting that the Manukau area I the FWMT (version 1.2; Auckland Council 2021a) is derived from representative data for period 2013-2017 and exclusive of the Waikato region but former including northern part of Waikato,

potatoes and onions which are shown to be the most commonly grown crops have been included in four of the five rotations.

However, statistical data is useful in ensuring rotations capture all the key crops grown and in determining how rotations are weighted toward more common crops. Statistical data that was accessed included data gathered by HortNZ and Statistics NZ for the 2021 year.

Table 4 shows the area of CVP crops grown in the Auckland region according to the data provided by HortNZ which was sourced from their New Zealand Good Agricultural Practices (NZGAP) program. It should be noted that there are two key limitations to the accuracy of this data. Firstly, not all reported area is necessarily in the Auckland region as growers report area as an enterprise area (i.e., will include areas in Waikato etc., especially for large growers). Secondly, the NZGAP program isn't compulsory for growers, meaning data may not fully represent the sector and it may include hectares being actively cropped at any one time and so may be less than the total area set aside for CVP.

Table 4: NZGAP data showing area of CVP crops grown in the Auckland region (Pers. Comm. Damien Farrelly, 2022).

Crop	Crop area (ha/yr)	Notes
Asian greens	113	Includes Chinese cabbage
Brassicas	293	Broccoli/cabbage not specified
Broccoli	103	
Cabbage	490	
Carrots	455	
Cauliflower	192	
Leek	23	
Lettuce	880	
Onion	2,340	
Potato	3,200	
Pumpkin	1,898	Includes squash
Silverbeet	49	
Spinach	306	
Spring onion	88	
Total Area	**10,428**	

HortNZ and Plant and Food Research (2021a) produce an industry publication called 'Fresh Facts.' This publication includes data for the planted area of some CVP crops grown in the Auckland region and is summarised in Table 5. This data is sourced from Statistics NZ Agricultural Production Census as of June 2017.

Table 5: Planted crop areas for CVP crops grown in the Auckland region (HortNZ and Plant and Food Research, 2021a).

Crop	Crop area (ha/yr)
Broccoli, cabbage, cauliflower	1,111
Carrots	225
Peas & beans	51
Lettuce	625
Onions	1,919
Potatoes	2,242
Squash	300
Sweet corn	29
Other vegetable	1,400
Total area	**7,933**

Statistics NZ (2021) data for the area of some CVP crops grown in the Auckland region can be found in Table 6. This data is from the June 2020 final Agricultural Production Census Statistics, which is an update on the 2017 data as presented in 2021's Fresh Facts. The Agricultural Production Statistics only provide data on limited crop types.

Table 6: Crop areas for CVP crops grown in the Auckland region (Statistics NZ, 2021)

Crop	Crop area (ha/yr)
Onions	1,710
Potatoes	1,940
Squash	20
Sweet corn	20
Peas	20
Total area	**3,710**

- Discussions with growers.

This comprised online workshops supported by data provision and discussion with individual growers. During these workshops, growers were asked for information on key crops as well as typical patterns for cropping. From this, rules were identified around mixing crops, what crops could and could not follow each other (e.g., due to the presence of pathogens etc.) and what prevalent crops were in the vegetable growing area. This was an iterative process with growers commenting on the draft rotations, subsequent revisions, and further reviews. In addition to the discussions with growers the draft rotations were also presented to the technical advisory group (TAG) for feedback.

Following these three iterative steps the five baseline CVP rotations were created, which are shown in Table 7 (for detailed information on each rotation see Section 4). The CVP rotations offer a framework for revising the highest-impact horticultural HRU classes in the FWMT. A detailed revision of the FWMT HRUs is provided in Section 10.4. Each rotation spans five years and is designed as a 'closed' rotation. This means each five years is designed to be repeated and the crop grown at the end of year five is the opening crop for year one.

Table 7: Overview of CVP rotations

Rotation	Crops[1, 2, 3]
1	Cabbage (summer) → Barley (cereal and incorporated) → Onions → Oats (incorporated) → Potatoes → Phaecelia (incorporated) → Carrots → Silverbeet → Cabbage (winter) → Barley (cereal and incorporated)
2	Fallow 1 → Onions → Fallow 2 → Potatoes → Oats (incorporated) → Carrot → Fallow 3 → Lettuce (winter) → Fallow 4 → Broccoli (winter) → Fallow 5 → Broccoli (summer) → Fallow 6 → Barley (cereal and incorporated)
3	Lettuce (winter) → Fallow 1 → Asian Greens (Shanghai pak choy) → Fallow 2 → Spinach → Fallow 3 → Cauliflower → Fallow 4 → Spring onions → Fallow 5 → Onions → Oats (incorporated) → Potatoes → Phaecelia (incorporated) → Lettuce (winter) → Fallow 6 → Asian Greens (Shanghai pak choy) → Fallow 7
4	Lettuce (summer) → Fallow 1 → Broccoli (winter) → Oats (incorporated) → Broccoli (winter) → Fallow 2 → Barley (cereal and incorporated) → Lettuce (summer) → Fallow 3 → Broccoli (winter) → Fallow 4 → Barley (cereal and incorporated)
5	Onions → Potatoes → Lettuce (summer) → Rye Grass (incorporated) → Pumpkin → Barley (cereal and incorporated) → Broccoli (summer) → Pumpkin

1. In this case summer and winter crops are based on the predominant growing period and the associated growing requirements such as fertiliser and required growing days.

2. As only a finite number of crops could be modelled in this process, crops listed in this table represent a range of varieties, e.g., Asian Greens represent a broad spectrum of these vegetables such as bok choy not just Shanghai pak choy. Pumpkin also represents squash and cabbage also represents Chinese cabbage.

3. Days in each crop and fallow period are detailed in Section 4.

To present a static rotation on a per hectare basis is a simplification of reality. In reality, growers are growing a multitude of different crops and planting single rows of one plant type and planting and harvesting on a weekly basis. In addition, there are a multitude of crop varieties within one crop type, for example, different potato types aimed at different markets with different management practices, planting and harvesting dates etc. However, modelling inherently simplifies reality and this holds true of the rotations chosen for this analysis. We note the rotations presented here are a marked improvement in the way CVP is currently resolved and then generalised for the FWMT.

CVP rotations are flexible and the five rotations described here are subject to change in reality due to differing climatic and economic situations. There is also no way of currently knowing or mapping where different CVP crops are grown (currently and historically) within the Auckland region. There was also no evidence to suggest the contaminant processes or mitigation options were significantly different across the five rotations. Therefore, it was decided it was most appropriate to weight the results from each of the five CVP rotations into one CVP land use impact class for the FWMT.

To combine the five CVP rotations detailed in this report into one land use impact class for the FWMT, a representative factor needed to be assigned to each CVP rotation. This factor was based on the approximate area of CVP production under each of the five rotations. Table 8 shows the relative proportion each defined rotation makes up of the CVP land use as determined for this project. There was limited information available to definitively quantify the proportion of each rotation across the Pukekohe vegetable growing area. As such these weightings were based on the statistics presented in this section alongside growers' knowledge and the authors' best professional judgement.

Table 8: Assigned proportion that each rotation makes up of the CVP land use

Rotation	Main crops rotation is based on	Relative proportion
Rotation 1	Potatoes & onions	25%
Rotation 2	Potatoes & onions	25%
Rotation 3	Asian greens & brassicas	5%
Rotation 4	Lettuce & brassicas	25%
Rotation 5	Pumpkin	20%
Total		**100%**

Following the selection of the five CVP rotations, a data sheet of all the data required for the APSIM and ESC models was created. This data was predicated on a 'typical' crop variety in a 'typical' year (e.g., lettuce is based on a standard type such as iceberg sold to supermarkets rather than the extensive combinations of alternative sale routes and varieties). Data collected included:

- Cultivation practices
- Sowing dates and methods
- Irrigation practices (millimetres applied each month)
- Fertiliser use (quantity, type, application dates and methods)
- Harvest dates and methods
- Crop yield (both in field and sold, and therefore wastage)

Requisite data was provided to The AgriBusiness Group and WWLA to configure the APSIM baseline models. Where data was not available from the growers' expert opinion, model defaults were used (from the relevant SCRUM models, see Section 3.2). This process was again iterative with draft results assessed and reviewed by the project team, growers and the technical advisory group in various forms and changes made based on feedback.

Some data that would have aided rotation model development was not available, for example the nutrient content in the crops, wastage and residue. Data like this is the subject of further research (e.g., in the Sustainable Vegetable Systems Research Project [Plant and Food Research, 2021b]) and could be used in the future to improve the data in the FWMT. In addition, other data such as specific paddock soil tests were not used as the models are designed to represent typical rotations and not specific paddocks.

3.1.2 Kiwifruit model

Three sources provided kiwifruit data. The physical data for nitrogen yields was provided by Zespri and NZKGI and was based on SPASMO model results. The financial data was sourced from a variety of sources including literature, previous gross margin analysis, expert opinion and from Zespri and NZKGI. Data on phosphorus yields was based on literature estimates and supported by data provided by Zespri and NZKGI, who also provided information on sediment and copper yields. No information was available on *E. coli* yields from kiwifruit; however, due to the nature of the orchards they are not expected to be a source of high amounts of faecal bacteria.

3.2 Nitrogen modelling (APSIM) assumptions

3.2.1 APSIM Background

APSIM is a modelling framework comprising a system model configured from component modules (McCown et al., 1996). The model was developed by an initiative comprised of various scientific research and government agencies across Australia, New Zealand, and the United States (APSIM, 2023). As such, the model is internationally recognised, used, and continuously being formally developed as a tool to evaluate management strategies for agricultural and horticulture production systems and the consequences for the soil resource and the environment[5]. APSIM is a process-based model which contains a suite of modules that enable the simulation of systems for a diverse range of plant, animal, soil, climate, and management interactions (McCown et al., 1996, Keating et al., 2003). This modular framework allows for the source code and algorithms to be adjusted, distributed and interrogated among research practitioners, in response to validated research initiatives. This facilitates communication and co-learning between modellers and various stakeholders.

Plant and Food Research have developed a model to be used in conjunction with APSIM to provide baseline assumptions for a range of New Zealand horticulture crops. The Simple Crop Resource Uptake Model (SCRUM, Brown and Zyskowski, n.d)[6] was used in this project to generate the baseline assumptions for the rotations which were then supplemented with management factors provided by the growers in Auckland to simulate typical rotations. SCRUM has been built using the Plant Modelling Framework (PMF) of Brown et al. (2014) to simulate a range of different crops in situations where water and nitrogen balance are of interest, but a fully mechanistic plant model is not needed or is not available (Brown and Zyskowski, n.d). More information on SCRUM can be found in Brown and Zyskowski (n.d).

APSIM is increasingly being used to estimate nitrogen leaching from arable and horticulture systems in New Zealand (Cichota et al., 2010; Vogerler et al., 2013; Hume et al., 2015). The efficacy of SCRUM-APSIM has been evaluated against OVERSEER®[7] (Overseer) modelling and experimental field trial practices (Vibart et al., 2015; Khaemhan et al., 2015, Khaemhah and Brown, 2016). Typically, APSIM has been found to provide comparable long-term results to measured data, while also providing greater flexibility in modelling management compared to Overseer. Khaembah and Brown (2016) compared APSIM estimates of nitrogen leaching with measured nitrogen leaching data under two three-year horticulture and arable crop rotations near Lincoln and found that there was a strong correlation (R^2=0.88) between measured leaching rates and APSIM-estimated leaching rates. This is considerably higher confidence than the lack of "…confidence in Overseer outputs from modelling cropping, horticultural or commercial vegetable enterprises" (Science Advisory Panel, 2021, p.72). However, other researchers (Sharp et al., 2011) have found that APSIM may underestimate the rate of nitrogen mineralisation in the soil profile for a potato crop grown in Lincoln, and that it has higher nitrogen yields than Overseer under an intensive cropping regime, due to the higher crop nitrogen uptake and denitrification in Overseer (Sharp et al., 2011). While APSIM has demonstrated higher accuracy at modelling crop rotations, numerous input data and parameters, as well as a high level of user expertise, is needed to ensure reliable results are produced. Therefore, APSIM modelling is not suited to widespread [grower and industry] use and is more typically used by research and consulting organisations.

Crop rotations are dynamic, with significant differences over a year in the timing and extent of crop status (nitrogen uptake pattern, root depth and soil cover) and farm management events (cultivation, fertiliser, and irrigation). A key feature of APSIM is its daily-time step modules which allow continuous stimulation of temporal soil water and nitrogen dynamics in response to climatic, management, and

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[5] While APSIM is being continually developed the version used in this work was APSIM NextGen Version 2022.11.7127.0

[6] While there is no specific SCRUM version number available, the SCRUM model that was current in 2022/23 was used.

[7] Overseer is an agricultural management tool which assists farmers and their advisers to examine nutrient use and movements within a farm to optimise production and environmental outcomes. https://www.overseer.org.nz/

crop status variations. APSIM utilises daily climate inputs (rainfall, evaporation, daily minimum and maximum temperature) to produce daily fluxes of water and nutrients, as well as crop production indicators. In the context of vegetable cropping systems, this is important as these factors can vary immensely within a single month due to intensive management, which can have a critical influence on the nutrient balance. APSIM does not explicitly consider slope.

3.2.2 APSIM assumptions

APSIM utilises daily climate inputs (rainfall, evaporation, daily minimum and maximum temperature) to produce daily fluxes of water and nutrients, as well as crop production indicators. The APSIM models developed for this project cover the time period 01/01/1990 – 31/12/2014. Data was sourced from NIWA's Virtual Climate Station Network (VCSN) located at Pukekohe VCSN node 30746 (Figure 5). Notably, VCSN data from this node is used in conjunction with other virtual and gauged stations in the FWMT Stage 1. It was concluded that VCSN site 30746 which is in the middle of the CVP land around Pukekohe would give the most applicable climate data. While this report does not assess if this time period is representative of current or expected future weather, having five climate periods modelled for each rotation helps ensure the overall results in this report cover a range of weather conditions.

Figure 5: Virtual Climate Station Network node 30746 used in APSIM

Information on soils were based on literature for the predominant soils in the area. The soil type of Morrinsville_8a.1 (Landcare, 2022) which was previously known as Patumahoe or Pukekohe, was used as it was the dominant soil type CVP occurred on in the Auckland region (Figure 6). This soil type also had the required soil information needed for APSIM modelling. More information on the soil can be found in Martindale et al. (2018) and Landcare Research (2022). Table 9 and Table 10 specify the general assumptions used in the APSIM model relating to soils. Where data was not able to be provided from literature, expert opinion from The AgriBusiness Group and WWLA was used to inform the parameters.

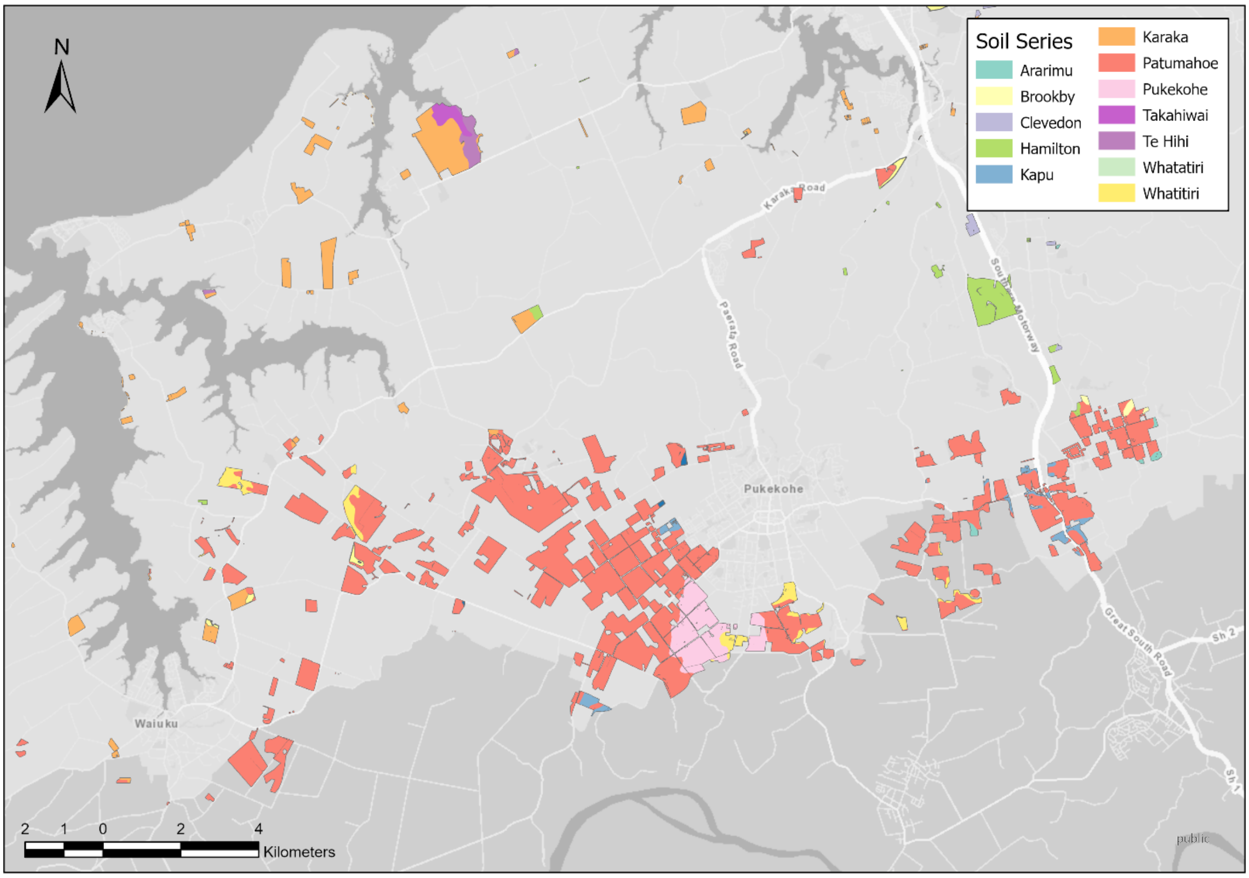

Figure 6: Soil types in Pukekohe for those parcels identified within the FWMT as having a land use of "short rotation cropland."

Table 9: General APSIM parameters

Category	Parameter	General	Notes / Reference
Surface Organic Matter	Type of initial residue pool	Pasture	
	Mass of initial surface residue (kg/ha)	40	Dalgliesh et al., 2016
	Standing fraction (0-1)	0	Dalgliesh et al., 2016
	C:P ratio	1	Sparling et al., 2008
	C:N ratio	14	Sparling et al., 2008
Interception	Multiplier on rainfall to calculate interception losses	0.2	Estimate based on prior work (WWLA, 2019; 2020, Zhao & Legarth 2020.) and calibration
	Power on rainfall to calculate interception losses	1	
	Constant value to add to calculate interception losses	0.5	
	Fraction of solar radiation reaching the soil surface that results in soil heating	0.4	Estimate based on prior work (WWLA, 2019; 2020, Zhao & Legarth 2020.)
	Minimum height difference between canopies	2	
	Fraction of intercepted rainfall that evaporates at night	0.5	
Soil Water	Summer start date for soil water evaporation	1-Oct	Estimate based on prior work (WWLA, 2019; 2020, Zhao & Legarth 2020.)
	Cumulative soil water evaporation to the end of stage 1 soil water evaporation in summer	12	Estimate based on prior work (WWLA, 2019; 2020, Zhao & Legarth 2020.) and calibration
	Cumulative soil water evaporation to the end of stage 1 soil water evaporation in winter	10	Estimate based on prior work (WWLA, 2019; 2020, Zhao & Legarth 2020.)
	Winter start date for soil water evaporation	1-May	
	Drying coefficient for stage 2 soil water evaporation in winter	8	Estimate based on prior work (WWLA, 2019; 2020, Zhao & Legarth 2020.) and calibration
	Drying coefficient for stage 2 soil water evaporation in summer	8	
	Constant in soil water diffusivity calculation	80	Estimate based on prior work (WWLA, 2019; 2020, Zhao & Legarth 2020.) and Dalgliesh et al., 2016
	Effect of soil water storage above the lower limit on soil water diffusivity	30	
	Fraction of incoming radiation reflected from bare soil	0.2	Estimate based on prior work (WWLA, 2019; 2020, Zhao & Legarth 2020.)
	Runoff curve number for bare soil with average moisture	62	Dalgliesh et al., 2016 and calibration
	Max reduction in curve number due to cover	22	Estimate based on prior work (WWLA, 2019; 2020, Zhao & Legarth 2020.)
	Cover for max curve number reduction	0.9	

Table 10: APSIM soil parameters

Category	Parameter	Layers / Depth (cm)			Description	Notes / References
		0-20	20-70	70-100		
Soil Chemical	NO3N (ppm)	20	40	4		Estimate
	NH4N (ppm)	0.6	0.7	0.5		Estimate
	pH	6	5.6	5		Martindale et al., 2018
Soil Physical	BD (g/cm3)	0.96	0.92	0.78	Bulk density	Martindale et al., 2018
	AirDry (mm3/mm3)	0.05	0.05	0.05		Dalgliesh et al., 2015
	LL15 (mm3/mm3)	0.06	0.06	0.06	Volumetric water content corresponding to a soil potential of 15 bar	Landcare Research. 2022
	DUL (mm3 /mm3)	0.08	0.08	0.08	Drained upper limit	Calibration parameter / Landcare Research. 2022
	SAT (mm3 /mm3)	1	1	0.48	Saturation	Martindale et al., 2018
	KS (mm/day)	155	65	15	Millimetres per day that is allowed to drain from the layer when the soil water is above saturation	Calibration parameter / Landcare Research. 2022
	LL (mm/mm)	0.8	0.8	0.8	Drainage Lower Limit	Varies by crop
	KL (/day)	0.1	0.1	0.1	Fraction of PAW able to be extracted/day from a particular soil layer	Varies by crop
	XF (0-1)	1	1	1	Root exploration factor	Varies by crop
	PAWC (mm/mm)	50	50	50	Plant Available water constant	Varies by crop
Soil water	SWCON (/day)	0.5	0.15	0.1	Saturated flow - proportion of water above DUL which will drain to adjacent soil layers/day	Calibration parameter
	KLAT (mm/day)				Lateral conductivity (mm/day)	Calibration parameter
Soil Organic	Carbon (Total %)	5	4	3.3		Martindale et al., 2018
	Soil C:N Ratio (g/g)	14	14	14		Dalgliesh et al., 2016
	Fbiom (0-1)	0.04	0.03	0.02	Proportion of non-inert C in the microbial biomass pool	Calibration parameter / Dalgliesh et al., 2016
	Finert (0-1)	0.5	0.6	0.9	Proportion of initial organic C assumed to be inert	Calibration parameter / Dalgliesh et al., 2016
	FOM (kg/ha)	1,000	800	200	Fresh organic matter	Dalgliesh et al., 2016

Table 11 details the SCRUM model used, the sowing depth, row spacing and plant density for each of the vegetable crops. Of note are the following proxy crops used (as per advice from Hamish Brown [Pers. comm. 2022]):

- Silverbeet was entered as lettuce as there was no SCRUM silverbeet model.
- Asian greens were entered as spinach as there was no SCRUM Asian green model.
- The mature spring onion crop was entered as spring onion seed as there was no mature spring onion model in SCRUM.
- Cabbage was entered as a brassica SCRUM model.

Revising these models to better represent the actual vegetable crops is an area of suggested refinement but is beyond the scope of this project and will likely need additional, specialist research.

Table 11: APSIM assumptions by crop

Crop	Rotation	SRCUM model	Sowing depth (mm)	Row spacing (mm)	Plant (plants/m^2)
Carrots	1, 2	Carrot	20	150	18
Onions	1, 5	Onions spring	6	100	80
Onions	2, 3	Onions autumn	6	100	80
Potatoes	1, 2, 3, 5	Potatoes medium	150	250	8
Pumpkin	5	Squash	20	900	1
Spinach	3	Spinach	10	300	16
Oats (incorporated)	1, 2, 3	Oats spring	10	150	250
Oats (incorporated)	4	Oats autumn	10	150	250
Phacelia (incorporated)	1, 3	Phacelia	10	50	56
Ryegrass (incorporated)	5	Ryegrass	5	120	300
Barley (grain & incorporated)	1	Barley spring	40	200	120
Barley (grain & incorporated)	2, 4, 5	Barley autumn	40	200	120
Silverbeet	1	Lettuce	25	500	6
Cabbage (summer)	1	Brassica	10	150	30
Cabbage (winter)	1	Brassica	10	150	30
Cauliflower	3	Cauliflower	8	60	29
Spring onion	3	Spring onion seed	100	150	20
Asian Greens	3	Spinach	10	300	16
Broccoli (summer)	2, 5	Broccoli spring	10	200	29
Broccoli (winter)	2, 4	Broccoli winter	10	200	29
Lettuce (summer)	4	Lettuce	3	300	16
Lettuce (winter)	2, 3	Lettuce	3	300	16

3.3 Sediment and phosphorus modelling assumptions

The sediment and phosphorus yields were calculated based on the Erosion and Sediment Calculator (Vegetable Research and Innovation, n.d.). This model and its key assumptions are detailed in the background report Agrilink (2020). The ESC uses a modified version of the Revised Universal Soil Loss Equation (RUSLE). This is an updated version of the Universal Soil Loss Equation (USLE) first developed by Wischmeier and Smith (1978).

Table 13 lists the key baseline input factors for the ESC. It highlights what the baseline assumptions are in the ESC and what was utilised in the baseline for this research. **Error! Reference source not found.** s ummarises the key input parameters for the ESC that are consistent across all baseline and mitigation scenarios. Vegetated buffer strips (VBSs) and sediment retention ponds (SRPs) are discussed in section 3.3.3 and 3.3.4.

Table 12: Summary of baseline ESC parameters

Inputs	<2° (low slope)	>2° (high slope)
Soil type	Clay Loam	Clay Loam
Slope (°)	2	4
Length of slope (m)	200	200
Soil cover	Cropping	Cropping
Location	Pukekohe	Pukekohe
Cover crop	Yes	Yes
Cultivation method	Conventional cultivation	Conventional cultivation

Table 13: Erosion sediment calculator assumptions

Criteria	ESC baseline assumption	Input parameter for this research
Crop type	The ESC model is independent of crop type.	Independent, therefore, the results are the same across all rotations and results are all annualised.
Slope length	Uses the RUSLE equation detailed in Basher (2016).	Length of slope used in the baseline model was 200m. See section 3.3.1 for more detail on how this was calculated.
Steepness	Uses the RUSLE equation detailed in Basher (2016).	Two slope classes were modelled which represents the typography of CVP land in the Auckland region. These were <2º (low slope) based on 2º modelled slope and >2º (high slope) based on 4º modelled slope. See section 3.3.2 for more detail on how this was calculated.
Soil type (K-factor)	Soil type effects the erodibility factor which is known as the K-factor from soil texture classes (12 classes with K-factors ranging from 0.02 to 0.38) (Barber et al., 2019a).	The soil type used in the ESC is clay loam, which is the dominant soil type in the Pukekohe region formally known as a Morrinsville_8a.1 (Morr_8a.1) which was previously known as Patumahoe or Pukekohe soil (Martindale et al., 2018).
Rainfall factor (R-factor)	The ESC obtains a rainfall erosivity factor (R-factor) from Klik et al. (2015). The baseline ESC model has R-factors for 600 weather stations across the entirety of New Zealand, location coordinates then enable the model to triangulate a localised R-factor based on the nearest three stations.	This research used a set of location coordinates for the middle of the CVP growing area in Pukekohe as the model is not meant to represent a specific paddock, but more generalised CVP areas.
Ground soil cover (C-factor)	The ESC had only two options; pasture or cropping. The C-factor for pasture was set to 0.02, whilst for cropping it is set to 0.33 (Basher et al., 2016). The ESC only has these two options to avoid a large degree of complexity.	In this research the C-factor was set to cropping.
Cultivation	Cultivation practice was split into minimum and conventional cultivation. The ESC assumes a 50% erosion reduction during one third of the year for minimum cultivation over a baseline of conventional cultivation (Barber et al., 2019a).	Baseline cultivation was conventional. It was concluded after conversations with PVGA members, there is limited opportunity for CVP growers to use minimum cultivation practices because of the nature of crops grown, and level of ground preparation need to establish a successful crop.
Cover crops	Cover crops in the ESC reduces erosion by 60% during one third of the year which equates to a 20% erosion reduction annually.	Cover crops are used in the baseline model as they are used in the rotations provided by growers wherever growers feel they are practical. During discussions with local horticultural consultants, they confirmed that growers use cover crops to good effect.
Wheel track ripping (WTR)	Wheel track ripping in the ESC reduces erosion by 90% during a third of the erosion period, which equates to a 30% erosion reduction annually.	It was assumed that the rotations did not use WTR in the baseline model.

3.3.1 Slope length assumptions in the baseline ESC

Length of slope used in the baseline model was based on analysis from AC using LINZ parcel data (Table 14). It should be noted that a horticultural parcel doesn't represent a single field as several fields may occupy a single parcel, which is likely inflating length overall. With this taken into consideration, the data was analysed and sense checked by growers and horticultural advisors. Through those discussions it was agreed that it would be appropriate to set the representative slope length for CVP land in the Auckland region to 200 meters.

Table 14: Parcel length data used to help determine slope length

Horticultural parcel length (longest side, m)	Number of parcels
100 – 142	727
142 – 184	566
184 – 226	488
226 – 268	378
268 – 310	395
310 – 352	290
352 – 394	227
394 – 436	193
436 – 478	107
478 – 520	86
520 – 562	67
562 – 604	93
604 – 646	92
646 – 688	26

3.3.2 Slope steepness assumptions in the ESC

The slope data in the Auckland and Waikato region used to help define the slope to model in the ESC was derived from LENZ slope layer (Landcare Research, 2011). The LENZ slope layer was overlayed with horticultural land use layers from the LCDB version 5 database and HortNZ's CVP land use layer. Table 15 summarises the results from the two different horticultural land use layers[8] intersected with LENZ slope data. It should be noted the CVP slope data was based on a sub-set of vegetable growing area that is registered in the NZGAP Environment Management System (EMS) add-on and has been mapped for the Auckland and northern Waikato regions. The LCDB version 5 horticulture land use layer includes orchard, vineyard, other perennial crops and short-rotation cropland land use classes.

After sense checking this information with the TAG, it was agreed that the percentage of land represented by 2° and 4° slopes was sufficient to use for areal weighting overall CVP in the ESC. The low slope class represents CVP on land less than or equal to 2° and is based on a modelled slope of 2°. The high slope class represents all land greater than 2° and is based on a model slope of 4° (which is in turn based on an approximate midpoint of the land between 2 and 17°).

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[8] The HortNZ layer was analysed twice: once for all CVP land around Pukekohe and again for only the CVP land area occurring within the Auckland region.

Table 15: Percentage of land in each slope from different land use layers

Slope data source	Percentage of land ≤ 2°	Percentage of land 2 - 4°	Percentage of land 4 - 6°	Percentage of land 6 - 8°	Percentage of land 8 - 17°	Total area (ha)
LENZ slope CVP Auckland	71	17	7	2	3	2,162
LENZ slope CVP Auckland & Waikato	61	23	10	3	3	7,023
LENZ slope LCDB version 5 Pukekohe area	79	14	5	1	1	7,248

3.3.3 Vegetated buffer strips

Vegetative buffer strips (VBSs) often referred to as buffers or buffer strips are strips of vegetation in or alongside cultivated land. These can be situated in riparian areas at the edge of watercourses and/or drains, at the baseline of paddocks on cultivated land or in cultivated paddocks. They are distinct to riparian areas which are modelled separately (see Muller and Stephens, 2020a). Their primary role is to slow runoff water and trap sediment through filtering and increasing infiltration.

The ESC calculates the impact of VBSs on sediment yield rates (Barber & Stenning, 2021). The baseline ESC has a simple "yes" or "no" input for VBSs, with the width of the buffer strip and slope of buffer strip also needing to be defined when these are used. For this work two widths of VBSs were used, 3 m and 5 m. It was assumed that in 1 ha of CVP land there would be 100 m of VBS, or an area of 300 m^2 for 3 m VBSs and 500 m^2 for 5 m VBSs.

Modified equations from Zhang et al. (2010) were used to predict efficiency of the VBSs in the ESC:

- Buffer slopes ≤10%: Removal efficiency = $21.7 + (2.0 * \text{Slope}) + 61.0 * (1 - e^{-0.35*\text{buffer width}})$
- Buffer slopes >10%: Removal efficiency = $79.7 - (3.8 * \text{Slope}) + 61.3 * (1 - e^{-0.35*\text{buffer width}})$

The ESC does not directly account for the effects of channelisation or bunding causing bypass of the strip as it would have added significant complexity to the model (Barber & Stenning, 2021). Therefore, a simple 'channelisation factor' was developed and added to the calculator to help address some of the effects caused by this common issue. In the absence of robust predictive equations to account for runoff bypass this factor is a simple user-selected percentage that accounts for the proportion of the strip that is encountering sheet flow runoff (Barber & Stenning, 2021). For example, 80% is the default percentage that indicates 20% of the VBS is not encountering sheet flow runoff (e.g., 100% equates to a VBS receiving only sheet flow and having no channelisation) (Barber & Stenning, 2021). This channelisation factor needs to be user defined as detailed in section 3.3.5 and Table 17.

The way growers use VBSs in their CVP systems varies. Some will establish a VBS permanently and keep it maintained, some will establish a VBS once a year, and others establish a VBS multiple times a year (one VBS with each crop grown in that year). When considering the cost to establish VBSs three costs were estimated to reflect how often VBSs are established (low, medium and high). The use of these was then based on the crops grown in each rotation as well as discussions with growers. The costs and assumption used to estimate these costs is further explained in section 3.4.3.

3.3.4 Sediment retention ponds

The use of SRPs in the construction industry is very widespread, with years of research and design guidelines, such as Auckland Regional Council (1999). In the construction industry the minimum SRP size is 2% of catchment area (equating to 200 m^3 storage per hectare of catchment area), rising to 3% when the slope is >18°.

The horticulture industry has previously modelled and demonstrated that in the case of CVP, SRP size can be reduced while achieving the same environmental outcome as a larger SRP in the construction sector (Barber et al., 2019a). This is due to the lower runoff coefficient and larger aggregate sizes which result in quicker settling (Barber et al., 2019a). The estimated efficiency of SRPs in the ESC is determined from a study by Barber et al. (2019a). Results from Barber et al. (2019a) showing the effectiveness of different size SRPs at trapping all sediment and suspended sediment (fine particles which phosphorus typically binds to) is presented in Table 16.

Table 16: SRP efficiency at different trap sizes for all sediment and suspended sediment derived from Barber et al. (2019a)

SRP size (proportion of catchment area)	SRP efficiency (proportion of sediment reduced)	
	All sediment	Suspended sediment
2%	0.999%	0.95%
1%	0.997%	0.93%
0.50%	0.993%	0.88%
0.25%	0.991%	0.73%

3.3.5 Adoption of sediment retention ponds and vegetated buffer strips in the baseline model

The approach to the use of SRPs and VBSs in the baseline model was different to the other key input factors that feed into the ESC model. As VBSs and SRPs are key mitigation measures that significantly reduce the yield of sediment and phosphorus it was important that the baseline modelling best represented the current[9] use of mitigations amongst CVP growers in the Auckland region, albeit with limited quantifiable information to ascertain how widespread these options are utilised.

SRPs aren't as effective at low slopes and therefore are typically used less on low slopes compared to high slopes. Lower treatment efficacy on low slopes is partly due to the lesser velocity of runoff mobilising lesser contaminant and limited preferential flow path to the devices, which makes their ability to intercept loads more challenging (Barber et al., 2019b). In contrast, VBSs are more effective on low slopes where lesser proportions of flow will be preferential (e.g., more delivered as sheet flow). VBS act to slow runoff water and trap sediment through filtering and increased infiltration (Barber & Stenning, 2021). A study by Dillaha et al. (1989) found that VBSs on flatter land showed significant portions of runoff entered the strips as shallow uniform flow, underpinning their greater effectiveness in these areas. They were ineffective in hilly areas, however, due to the concentrated flows in higher rainfall events inundating and bypassing the strips. In the ESC modelling this concept was reflected by decreases in the channelisation factor between low slope (80% channelisation) and high slope (60% channelisation). The decrease in the channelisation factor means more of the VBS is encountering

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[9] While the baseline period in the FWMT is 2013-2017, there is limited quantifiable data on use of SRPs and VBS currently (i.e., 2022) let alone in this baseline period and so current use is based on best professional judgement in the use of these mitigations in 2022.

sheet flow runoff. For example, a VBS with a 60% channelisation factor (high slopes) is less effective than one with 80% channelisation factor (low slopes).

Given the nature of the VBSs and SRPs and the fact that growers often use one of the two measures or both depending on the paddock area and contour, the adoption of SRPs and VBSs in the baseline model was determined using a weighting matrix. This approach was done for both baseline model slope classes (low and high slope) shown in Table 18 and Table 19, respectively, where weightings (percentage) for assumed adoption of VBSs and SRPs for each slope class were generated based on interviews with growers and local consultants. This approach allows for greater adoption of SRPs and VBSs in the later mitigation modelling; however, as no measured data was available to quantify these weightings, this is a key area for further improvement of this modelling.

To generate the adoption matrix for VBSs and SRPs three types of SRPs and VBSs were described (Table 17) in a matrix to represent all the combinations of the SRP and VBS types. Each cell in this table has a unique ESC result. These unique results are then weighted together to give one result. The weightings are based on the assumed adoption rates which equate to the assumed land area treated by each of the SRP and VBS combinations. The VBS channelisation parameters differ by low and high slope land.

Table 17: Description of SRPs and VBSs weighting matrix

Input parameter in the ESC		SRP size (proportion of catchment area)		
		None	0.25%	0.50%
VBS parameters (Low slope)	None	No SRP No VBS	SRP is 0.25% of catchment area No VBS	SRP is 0.50% of catchment area No VBS
	3 m wide	No SRP VBS that is 3 m wide, with 80% channelisation & 2° slope	SRP is 0.25% of catchment area VBS that is 3 m wide, with 80% channelisation & 2° slope	SRP is 0.50% of catchment area VBS is 3 m wide, with 80% channelisation & 2° slope
	5 m wide	No SRP VBS that is 5 m wide, with 80% channelisation & 2° slope	SRP is 0.25% of catchment area VBS that is 5 m wide, with 80% channelisation & 2° slope	SRP is 0.50% of catchment area VBS is 5 m wide, with 80% channelisation & 2° slope
VBS parameters (High slope)	None	No SRP No VBS	SRP is 0.25% of catchment area No VBS	SRP is 0.50% of catchment area No VBS
	3 m wide	No SRP VBS that is 3 m wide, with 60% channelisation & 2° slope	SRP is 0.25% of catchment area VBS that is 3 m wide, with 60% channelisation & 2° slope	SRP is 0.50% of catchment area VBS is 3 m wide, with 60% channelisation & 2° slope
	5 m wide	No SRP VBS that is 5 m wide, with 60% channelisation & 2° slope	SRP is 0.25% of catchment area VBS that is 5 m wide, with 60% channelisation & 2° slope	SRP is 0.50% of catchment area VBS that is 5 m wide, with 60% channelisation & 2° slope

The SRP option was split into three types, namely, none (or no SRP in place), 0.25% and 0.50% of catchment area. Studies have found that SRPs sized at 0.50% of the catchment area are the most efficient size of SRP which remove nearly all bedload, 88% of suspended sediment and are not cost prohibitive to install (Barber, 2012; Barber, 2014; Barber, et al., 2019a).

The VBS typses were described as none (or no VBS in place), 3 m and 5 m width. For low slope land, the 3 m VBS was modelled off a 3 m wide VBS with 80% channelisation factor and VBS slope of 2° while the

5 m was modelled off a 5 m wide VBS with a channelisation factor of 80% and slope of 2°. In baseline modelling for high slope land, VBS inputs into the ESC changed slightly due to the increase in slope, namely the channelisation factor decreased to 60%. The decreasing channelisation factor accounts for the increase speed at which water will be travelling down slopes greater than 2°. Faster moving water decreases the effectiveness of the VBS, which the modelling is accounting for through the decrease in channelisation factor. It should be noted that the slope the VBSs are modelled on doesn't change despite the slope of the land changing from 2° to 4° in the low and high slope model. It is assumed that the VBSs are established on low slope land regardless of the slope of the contributing hillslope. If there is no low-slope land at the bottom of a hillslope of greater than 2° then best practice would be to use a SRP instead.

Table 18 and Table 19 present the assumed baseline adoption of SRPs and VBSs for low and high slope land respectively. For example, for low slope land, 3% of land area is treated by both a 5 m wide VBS and an SRP that is sized to 0.50% of the catchment area. These estimates are based on best professional judgement. This is a key area that needs further refinement to better understand the amount of CVP land that is treated by VBSs and/or SRPs and the type of VBSs and SRPs (i.e., size) used.

Table 18: Assumed baseline adoption of land area treated by SRPs and VBSs for low slope land

Low slope land		SRP		
		None	0.25% of catchment area	0.50% of catchment area
VBS	None	35%	15%	5%
	3 m wide	10%	15%	7%
	5 m wide	5%	5%	3%

Table 19: Assumed baseline adoption of land area treated by SRPs and VBSs for high slope land

High slope land		SRP		
		None	0.25% of catchment area	0.50% of catchment area
VBS	None	20%	30%	20%
	3 m wide	3%	10%	10%
	5 m wide	2%	3%	2%

3.4 Gross margin modelling assumptions

3.4.1 Commercial vegetable rotation gross margins

Collating data on the CVP gross margins followed a similar process to collecting the physical data and focused on iterative data provision from growers as well as data collection from external sources where possible. Gross margins were developed for each crop that then formed part of an annual profit margin for each rotation. The greatest scrutiny was placed on those cost categories that might change as a result of adopting modelled mitigations (as detailed in section 5) as the focus of this research is on the relativities between baseline and mitigation scenarios rather than the specific gross margin of any specific crop or rotation.

To generate the revenue for the gross margins, the crop yields from the APSIM model were taken (both field and sold yields, accounting for losses and wastage between field, processing and sale) and multiplied by income per unit (either per hectare or per head). While it is acknowledged there is a huge amount of variation in both yields and income per unit and across years, rotations and growers, the overall revenue for each crop was reviewed by a panel of growers and adjusted where necessary until settling on the final figures as presented in Table 20.

Costs for the gross margins were calculated based on one of the following approaches:

- APSIM input data was matched with input prices to generate a cost. For example, fertiliser inputs from the APSIM data were matched with fertiliser prices to generate a fertiliser cost; similarly irrigation amounts were extracted from APSIM and matched with a cost per unit of water applied based on literature estimates.
- Some costs were 'built' from the ground up. Cost estimates for practices such as cultivation and harvesting were based on hours of labour and estimated machinery costs, including fuel, repairs and maintenance. These estimates were supported by estimates from Horticultural Gross Margin Budgets (2013), an online resource from Department of Primary Industries (DPI) New South Wales, Australia. This resource was useful for providing estimates for values such as hours spent on a task which could then be matched with expected New Zealand-based labour costs to build expenses.
- Costs such as those for spraying weeds and seeds were provided by growers for some crops.
- Some costs were calculated based on a known formula where applicable, this was particularly the case for levies.
- Costs that were not able to be calculated or estimated from one of the above methods were based on literature, including those costs found in The AgriBusiness Group (2014), Lincoln University (2022) and Askin and Askin (2018). All costs sourced from the literature were adjusted for inflation (using the Farm Expense Price Index[10] for the appropriate period depending on the source data).
- Where costs were unavailable for some crops, costs were estimated by matching to other, similar crops.

All costs were then compiled into the gross margins for each crop which were then reviewed by growers and adjusted to mirror a likely typical gross margin for each crop.

It should be noted that these are arbitrary gross margins; they cannot represent any single grower or CVP business rotating across multiple parcels of land but instead, they correspond to the area of ground from a modelling perspective (i.e., to better align with the brief to guide HRU classification in the FWMT). For example, the gross margins estimated here do not consider land swapping, which is a common practice between businesses to maximise crop yields, minimise pest and diseases and to maintain soil sustainability. They also do not represent the full diversity of vegetables grown (e.g., different types of potatoes) or the range in prices received from varying markets or seasonality of delivery.

One of the key challenges in estimating gross margins was the selection of input and output costs to use (i.e., revenue and expenses) as these need to be considered on the same basis. For example, if spot prices for inputs are used, spot prices should also be used for costs, rather than long term averages. The challenge was dealing with the current period of high inflation especially for fertiliser, fuel and labour costs. The output prices were taken more as a typical price across the past few seasons and as such, input prices were matched to this where possible. Although limitations on data availability restricted this "like-for-like" approach being applied consistently, for example when literature was used to determine prices, the method used in the literature determined if these prices were spot prices or long-term averages.

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[10] https://infoshare.stats.govt.nz/

Following the creation of the crop gross margins, relevant gross margins were applied to each rotation and a total gross margin for the five-year crop cycle was generated. This was then annualised as a simple average over the five years of the rotation.

Table 20 sets out the yield, wastage and price information for each crop. Broccoli was treated slightly differently with the price determined based on both supermarket and trimmed grade two broccoli. In addition, wastage refers to both weight of the plant left in the paddock such as stalks and leaves (residue) as well as parts of the plant removed in processing and product discarded due to not meeting market specifications.

Table 20: Crop yield, wastage and price information

Crop	Field yield (unit per ha)	Sold yield (unit per ha)	Wastage (%)	Weight per head (gm)	Revenue ($ per unit)	Revenue ($ per ha)
Spinach	12 tonnes	11 tonnes	10	NA	4,500/tonne	49,500
Carrot	65 tonnes	55 tonnes	15	NA	600/tonne	33,000
Onion	65 tonnes	40 tonnes	38	NA	550/tonne	22,000
Potato	50 tonnes	45 tonnes	10	NA	520/tonne	23,400
Pumpkin	40 tonnes	20 tonnes	50	NA	750/tonne	15,000
Oats	Incorporated					0
Phaecelia	Incorporated					0
Ryegrass	Incorporated					0
Barley (grain)		7.5 tonnes	*		500/tonne	3,750
Cabbage (summer and winter)	22,500 heads	18,000 heads	20	900	1.50/head	27,000
Silverbeet	30,000 heads	24,000 heads	20	750	1.25/head	30,000
Cauliflower	22,500 heads	21,300 heads	5	600	1.50/head	31,950
Asian green	309,000 plants	293,550 plants	5	200	0.50/head	146,775
Spring onion	907,000 plants	816,300 plants	10	40	0.07/head	57,141
Lettuce (summer)	50 tonnes	28,600 heads	51	850	1.00/head	28,600
Lettuce (winter)	44 tonnes	23,400 heads	60	750	1.20/head	28,080
Broccoli (summer)	35 tonnes	19,727 heads	73	1,130	[1]	19,053
Broccoli (winter)	33.5 tonnes	24,583 heads	72	870	[2]	28,660

* *There was no wastage in the barley yield as it is not processed separately for sale like vegetables for human consumption so there was no difference recorded for field and sold yield.*

1.Summer broccoli was $1/head for supermarket grade and $0.60/head for grade two with approximately 90% of heads of supermarket quality.

2. Winter broccoli was $1.20/head for supermarket grade and $0.80/head for grade two with approximately 90% of heads of supermarket quality.

Irrigation values were based on a cost per millimetre of water applied, sourced from Muller, Srinivasan and Neal (2021), who noted that on average, irrigation was $1.55/mm of water applied when labour, repairs and maintenance and electricity were included. Because this was based on a study in Canterbury where pivot irrigation is common, unlike in Pukekohe, additional labour cost was added and the value of $2/mm of water applied was used. Because of the way irrigation was specified in the APSIM model the amount of irrigation applied to each crop varies each year. To simplify the gross margins for each crop, the irrigation amount was averaged for each crop in each rotation. It was also averaged across the rotations by crop to populate the gross margin by crops. Irrigation costs are summarised in Table 21.

Irrigation volumes, and therefore costs, are derived from the APSIM modelling and the specified irrigation rules. The volume of irrigation used will depend on the climatic conditions in each of the five repetitions of a rotation in APSIM and a crop that appears once in a rotation will have five different volumes of irrigation applied over the full APSIM scenario period. To incorporate irrigation costs the following approaches were used:

- To generate a crop gross margin separate to those of the specific rotations (i.e., the gross margins in Table 22 and Table 23) the irrigation applied to each crop in a rotation was averaged across the five repetitions and then averaged across the rotations. For example, onions appear once in rotation 1 and therefore five times across the five repetitions over the model simulation period for rotation 1, so the five different irrigation volumes (due to climatic differences) were averaged to get 413 mm/ha applied on average to the onion crop in rotation 1. This process was repeated for all rotations with onions (e.g., rotations 2, 3, and 5) and the four resulting irrigation values were averaged to get a representative irrigation applied to all onion crops (369mm/ha in Table 21).
- To generate a gross margin for each rotation the irrigation applied to each crop in a rotation was averaged across the five repetitions. For example, in the onion example, the value of 431 mm/ha was used in the gross margin for rotation 1, while 336mm/ha was used in the gross margin for rotation 2.

Table 22 and Table 23 present crop specific gross margins. These exclude the business overhead costs and therefore are not the operating profit metrics which are discussed in the next section. They only include the costs and revenue associated with each crop. Appendix 1 presents the specific assumptions and sources for each cost category by crop type.

Table 21: Crop irrigation mm and costs

Crop	Average by rotations										Average across all crops and rotations	
	Rotation 1		Rotation 2		Rotation 3		Rotation 4		Rotation 5			
	mm/ha	$/ha	mm/ha	$/ha	mm/ha	$/ha	mm/ha	$/ha	mm/ha	$/ha	mm/ha	$/ha
Spinach	NA		NA		294	588	NA		NA		294	588
Carrot	112	224	0	0	NA		NA		NA		56	112
Onion	413	826	336	672	427	854	NA		301	602	369	739
Potato	308	616	196	392	329	658	NA		168	336	250	501
Pumpkin	NA		NA		NA		NA		431	861	431	861
Oats	224	448	469	938	231	462	413	826	NA		334	669
Phaecelia	350	700	NA		336	672	NA		NA		343	686
Ryegrass	NA		NA		NA		NA		0	0	0	0
Barley (grain)	448	896	455	910	NA		522	1,043	0	0	356	712
Cabbage (S)	217	434	NA		NA		NA		NA		217	434
Cabbage (W)	0	0	NA		NA		NA		NA		0	0
Silverbeet	553	1,106	NA		NA		NA		NA		553	1,106
Cauliflower	NA		NA		0	0	NA		NA		0	0
Asian green	NA		NA		200	400	NA		NA		200	400
Spring onion	NA		NA		630	1,260	NA		NA		630	1,260
Lettuce (S)	NA		NA		NA		168	336	210	420	189	378
Lettuce (W)	NA		112	224	46	91	NA		NA		79	158
Broccoli (S)	NA		224	448	NA		NA		217	434	221	441
Broccoli (W)	NA		245	490	NA		119	238	NA		182	364

Note, if a crop is in a rotation but no irrigation is applied it is recorded as zero (and contributes to the average), if it is not in a rotation NA is recorded (and it does not contribute to the average).

Table 22: Gross margin analysis for crops sold per tonne ($/ha)

Crop^	Carrots	Carrots	Onions	Onions	Potatoes	Potatoes	Pumpkin	Spinach	Oats	Phaecelia	Ryegrass	Barley (grain & incorp.)
Rotation	**1**	**2**	**1, 3**	**2, 5**	**1, 3**	**2, 5**	**5**	**3**	**1, 2, 3, 4**	**1, 3**	**5**	**1, 2, 4, 5**
Revenue												
Sold yield (t/ha)	55	55	40	40	45	45	20	11	Incorp.*	Incorp.	Incorp.	7.5
Price ($/t)	600	600	550	550	520	520	750	4,500	-	-	-	500
Revenue ($/ha)	**33,000**	**33,000**	**22,000**	**22,000**	**23,400**	**23,400**	**15,000**	**49,500**	**-**	**-**	**-**	**3,750**
Expenses												
Seed	2,900	2,900	2,000	2,000	7,450	7,450	1,199	2,920	300	200	200	200
Cultivation	935	935	988	988	355	355	606	1,752	220	220	220	220
Fertiliser	1,832	1,221	2,436	2,216	3,928	2,928	1,029	1,322	-	-	-	288
Agri-chemicals	1,150	1,150	2,200	2,200	1,587	1,587	448	1,191	-	-	-	294
Irrigation	224	-	840	637	637	364	861	588	669	686	-	712
Harvesting	1,440	1,440	3,269	3,269	2,316	2,316	5,026	7,592	-	-	-	460
Grading	7,150	7,150	2,900	2,900	1,875	1,875	-	4,976	-	-	-	-
Packing	2,634	2,634	3,504	3,504	2,523	2,523	700	1,368	-	-	-	-
Freight	1,650	1,650	1,000	1,000	1,125	1,125	1,300	880	-	-	-	240
Levies	162	162	100	100	232	232	74	243	-	-	-	-
Total expenses ($/ha)	**20,077**	**19,242**	**19,236**	**18,813**	**22,027**	**20,754**	**11,242**	**22,832**	**1,189**	**1,106**	**420**	**2,414**
Gross margin ($/ha)	**12,923**	**13,758**	**2,764**	**3,187**	**1,373**	**2,646**	**3,758**	**26,668**	**-1,189**	**-1,106**	**-420**	**1,336**

*Incorp. = incorporated

^The multiple types of carrots, onions and potatoes reflect different growing windows and fertiliser use.

Table 23: Gross margin analysis for crops sold per head ($/ha)

Crop	Silverbeet	Cabbage (summer)	Cabbage (winter)	Cauliflower	Spring onion	Asian Greens	Broccoli (summer)	Broccoli (winter)	Lettuce (summer)	Lettuce (winter)
Rotation	1	1	1	3	3	3	2, 5	2, 4	4	2, 3
Revenue										
Sold yield (heads/ha)	24,000	18,000	18,000	21,300	816,300	293,550	19,727	24,583	28,600	23,400
Price ($/head)	1.25	1.50	1.50	1.50	0.07	0.50	See Table 20		1.00	1.20
Revenue ($/ha)	**30,000**	**27,000**	**27,000**	**31,950**	**57,141**	**146,775**	**19,053**	**28,660**	**28,600**	**28,080**
Expenses										
Seed	1,132	3,212	3,212	3,212	1,700	2,600	800	1,000	1,200	1,200
Cultivation	1,378	1,378	1,378	2,102	1,752	1,050	2,000	2,200	5,267	5,267
Fertiliser	1,423	796	820	1,604	945	718	809	1,204	744	1,075
Agri-chemicals	502	502	502	876	2,000	1,600	888	1,000	1,500	1,753
Irrigation	1,106	434	-	-	1,260	400	441	364	378	158
Harvesting	3,180	3,180	3,180	4,088	9,110	13,856	1,700	1,700	5,740	5,740
Grading	-	-	-	-	5,971	20,331	701	701	-	-
Packing	-	-	-	-	1,500	4,000	-	-	2,044	2,044
Freight	1,440	2,592	2,592	3,067	2,612	3,669	1,862	1,862	1,216	878
Levies	147	132	132	157	280	719	93	140	140	138
Total expenses ($/ha)	**10,308**	**12,266**	**11,816**	**15,106**	**27,130**	**48,943**	**9,294**	**10,171**	**18,229**	**18,253**
Gross margin ($/ha)	**19,693**	**14,774**	**15,184**	**16,844**	**30,011**	**97,832**	**9,759**	**18,489**	**10,371**	**9,827**

3.4.2 Commercial vegetable rotation annual overheads

Additional annual overhead costs were then added to each annualised rotation gross margin. This was to incorporate costs that are not crop specific but would change as a result of the mitigation scenarios, for example, repairs and maintenance of sediment traps. Key overheads were included to generate an operating profit figure which was more aligned with the profit analysis structure of other rural enterprises; these overhead costs remain constant across each rotation.

Table 24 and Table 25 show the fixed annual business costs that apply to each business depending on what rotation of crops is grown for both slope classes. The annual business overheads varied by slope because different slope classes were assigned different levels of sediment control measures (VBSs and SRPs) and therefore sediment maintenance costs varied by slope. It should be noted that the annual cost for maintenance of sediment control is predicated on the same cost for both low and high slope (although it varies by size of SRP). However, because there are different levels of assumed adoption of VBS and SRPs for the two different slope classes, the annual overhead cost is higher for maintaining sediment control measures for the high slope land.

As with SRP, the base costs used to establish a VBS is the same regardless of the slope. However, because at a low slope it is assumed there is more land treated by VBS than on high slope, the weighted average cost of establishing a VBS appear higher for lower slopes. For example, it was estimated that 45% of land is treated by a 3 m or 5 m VBS on low slope land compared to 30% on high slope land (Table 18 and Table 19).

Vegetated buffer strip costs change between rotations. This is because they cause a loss of productive area, and each rotation has a different annual profit. In addition, some rotations have fewer crops in them and as such a VBS once established can be used for longer and less VBSs are needed annually. This is a key cost to consider for growers and has therefore been calculated based on the annual profit for each rotation divided by the area lost on a per year basis. The annual maintenance costs of SRPs and VBSs are discussed in following section 0.

In addition, the overhead costs for vehicles, repairs and maintenance, insurance, administration and staff costs were based on grower survey information. Repairs and maintenance are lower for crops with less mechanistic harvesting. As such rotation 1 and 2 have higher repairs and maintenance, rotation 4 has the lowest repairs and maintenance while rotations 5 and 3 are somewhere between the two. These differences are largely based on the proportion of root vegetable crops which can be harvested by machine. Land lease costs were also included as while it is acknowledged that some growers own land, some lease all their land and some have a combination of owned and leased land. These costs were generalised to encapsulate an average cost of accessing land for CVP rotations. The annual cost of irrigation scheduling costs and wheel track ripping (WTR) are not included in the baseline but are included in mitigation modelling. This is because it is assumed that no WTR or irrigation scheduling equipment (e.g., soil moisture sensors) is used in the base.

Table 24: Fixed business costs for each rotation on low slopes at base

Cost category	Low slope ($/ha/yr)				
	Rotation 1	Rotation 2	Rotation 3	Rotation 4	Rotation 5
Land cost	3,500	3,500	3,500	3,500	3,500
Vehicles and repairs and maintenance	2,000	2,000	1,500	1,000	1,500
Overhead insurance, admin. and staff	5,000	5,000	5,000	5,000	5,000
Maintenance of sediment control measures	288	288	288	288	288
Cost of VBS	216	184	937	249	113
Cost of WTR	*Not included in the baseline – for use in mitigations*				
Irrigation overheads (e.g., moisture sensors)	*Not included in the baseline – for use in mitigations*				
Total overhead costs	**11,004**	**10,972**	**11,225**	**10,037**	**10,401**

Table 25: Fixed business costs for each rotation on high slopes at base

Cost category	High slope ($/ha/yr)				
	Rotation 1	Rotation 2	Rotation 3	Rotation 4	Rotation 5
Rates	3,500	3,500	3,500	3,500	3,500
Vehicles and repairs and maintenance	2,000	2,000	1,500	1,000	1,500
Overhead insurance, admin. and staff	5,000	5,000	5,000	5,000	5,000
Maintenance of sediment control measures	306	306	306	306	306
Cost of VBS	139	124	605	161	103
Cost of WTR	*Not included in the baseline – for use in mitigations*				
Irrigation overheads (e.g., moisture sensors)	*Not included in the baseline – for use in mitigations*				
Total overhead costs	**10,945**	**10,930**	**10,911**	**9,967**	**10,409**

Annual maintenance costs for SRPs and VBSs

Table 27 shows the annual maintenance costs for each combination of VBSs and SRPs mitigation across both slope classes.

Sediment retention pond maintenance costs were based on the machinery required to clean out the ponds and then spread the topsoil back on the paddocks. The time taken and charge-out rates for the machinery (including labour) were obtained from a local contractor and then sense checked with growers. It was assumed that ponds were cleaned out once a year, typically in the summer when they are dry.

Vegetative buffer strip maintenance costs were split into a cost for establishment and a cost to maintain. The costs to establish a VBS were based on the time taken of 0.5 hr/ha to install a 5 m VBS and 0.3 hr/ha to install a 3 m VBS. Seed costs were based on the area of the VBS while machinery and labour costs were calculated on the time to establish each sized VBS. The annual costs to maintain a VBS assumed they were of 45% of the establishment cost (this only applied to the low-cost scenario). Three costs were calculated to account for the different way growers use VBSs:

- **Low cost –** this was based on a permanent VBS where an establishment cost in year 1 of $330/ha/yr and $275/ha/yr for 5 m and 3 m VBSs, with an ongoing maintenance cost of $150/ha/yr and $125/ha/yr for 5 m and 3 m VBSs for years 2-5.
- **Medium cost –** this was based on one VBS being established each year to imitate a VBS being established with one crop at a cost of $330/ha/yr and $275/ha/yr for 5 m and 3 m VBSs over 5 years.

- **High cost –** this was based on two VBSs being established each year to imitate a VBS being established with every crop planted in a year on the same piece of land. This was at a cost of $660/ha/yr and $550/ha/yr for 5m and 3m VBSs over 5 years.

Each of the cost scenarios (low, medium and high) were added up over the five-year period and then simply averaged to give the final cost of $392/ha/yr and $327/ha/yr for 5 m and 3 m VSBs (Table 26). It was assumed that each option was split evenly across CVP land in Auckland (simple average).

The nature of VBSs means they are planted within the productive area of a paddock. Although at the edge of the paddock, the crop in rotation could in theory be planted on this land. The loss in productive cropping area needs to be accounted as a cost for establishing this mitigation. This 'opportunity cost' varies between crops and, therefore, rotations as some crops are more or less profitable than others.

The annual average profit per hectare for each rotation was used to reflect the profit that could have been achieved by the grower on the piece of land that is now unproductive. This annual average per hectare profit for each rotation was taken and an annual average profit per square metre was calculated. The profit per square metre was then multiplied by the number of square metres per hectare the VBS would take up (300 m^2 for 3 m VBSs and 500 m^2 for 5 m VBSs) to get the cost of lost production for each rotation (Table 26). The cost for each rotation was then multiplied by the baseline weighting for VBS adoption by growers at low and high slopes (Table 18, Table 19). Table 24 and Table 25 summarise the costs of loss of productive area for each rotation (these costs are the same across both low and high slopes).

Table 26: Cost of loss in productive cropping area for VBSs planted at 3 m and 5 m widths based on the average annual gross margins for each rotation

Rotation	Average annual gross margin ($/ha/yr)	Cost of unproductive VBS area (ha/yr)	
		3 m VBS	5 m VBS
Rotation 1	13,392	$402	$670
Rotation 2	11,417	$343	571
Rotation 3	58,200	$1,746	$2,910
Rotation 4	15,467	$464	$773
Rotation 5	7,027	$211	$351

Table 27: Annual maintenance cost of each option for both low and high slopes ($/ha/yr)

		SRP		
		None	0.25% of catchment area	0.50% of catchment area
VBS	None	-	$250	$300
	3 m wide	$327	$577	$627
	5 m wide	$392	$642	$692

The individual and combined annual maintenance costs for SRPs and VBSs needed to be weighted by the baseline level of adoption by growers for each possible combination. The weighting percentages for each combination presented in Table 18 and Table 19 were multiplied by the annual costs above (Table 27). The annual adoption-weighted maintenance costs for sediment control measures currently estimated to be used by growers was $288/ha/yr for low slopes and $306/ha/yr for high slopes.

4 Baseline Models

This section summarises the baseline models, environmental and economic, for all five CVP rotations and the kiwifruit model. Each CVP rotation is described in terms of physical parameters, nitrogen yield estimates (nitrogen leachate beyond the rootzone) and gross margin results. Following this, the baseline erosion and sediment models are described, and the results are summarised including the annual profitability (gross margins and annual overheads). Finally, the kiwifruit model is described.

The description tables for each rotation note sowing and harvest months, the sowing date was assumed to coincide with the first day of each month while harvest dates coincide with the last day of each month. All fertiliser is assumed to be surface applied unless noted for specific crops in each rotation. There is also an assumption that no fertiliser is applied when rainfall is occurring at a rate of more than 10 mm per day and is instead deferred to the next day where daily rainfall is less than 10 mm/day. Section 3.2 contains information on the SCRUM model, sowing depth, row spacing and plant density by crops.

The APSIM models were configured with a set of irrigation rules at the base. The baseline irrigation was configured to apply 35 mm of irrigation every 7 days, except in the following circumstances:

- Where more than 20 mm of rainfall had occurred in the previous 7 days.
- Where more than 20 mm of rainfall occurred in the next 2 days (assuming this observed rainfall is a proxy for utilising rainfall forecasts).
- It is outside of the irrigation season (October to April).
- There is bare ground.

The tables below detail the total mm of irrigation applied to each crop. This is the average irrigation applied to that crop over the five repetitions when the aforementioned irrigation parameters are used in APSIM with the climate periods used in this modelling (1/01/1990 to 31/12/2014). The gross margins presented for each rotation utilise this value of irrigation application to determine an irrigation cost per hectare. The gross margin for each crop in each rotation is slightly different to the gross margins presented in Section 3.4 which provide an average gross margin for each crop across all rotations (i.e. they average the irrigation volumes across all rotations, whereas the crops in each rotation in this section have a unique irrigation cost).

Crops with a ‘S’ next to them are considered ‘summer’ crops and those with a ‘W’ are considered ‘winter’ crops. This is based on the predominant growing period and the associated growing requirements such as fertiliser and required growing days.

All nitrogen yield results represent nitrogen loss below the soil profile in APSIM, which was 1 m. This is not directly equivalent to nitrogen entering waterways.

Given that rainfall is a key driver of nitrogen losses below the rootzone, the rainfall volumes used in APSIM (from VSCN data point 30746 for the period 1/01/1990 to 31/12/2014) are summarised in Table 28.

Table 28: Rainfall volumes from VSCN data point 30746 for the period 1/01/1990 to 31/12/2014

	Total rainfall (mm)	Average annual rainfall (mm/yr)	Maximum annual rainfall (mm/yr)	Minimum annual rainfall (mm/yr)
Repetition 1 (1990-1994)	6,619	1,324	1,022	1,530
Repetition 2 (1995-1999)	7,287	1,457	1,241	1,730
Repetition 3 (2000-2004)	6,185	1,237	1,099	1,435
Repetition 4 (2005-2009)	6,156	1,231	1,124	1,394
Repetition 5 (2010-2014)	6,593	1,319	1,197	1,664
Full 25 years (1990-2014)	32,839	1,314	1,022	1,730

4.1 Rotation 1

4.1.1 Rotation 1 – Description

Table 29 details the physical details for rotation 1. All fertiliser is surface applied except for the first application of fertiliser to onions which is incorporated at 50 mm and the first application of fertiliser to potatoes which is incorporated at 100 mm.

Table 29: Rotation 1 physical details

Year	Month	Crop	Crop yield (unit/ha)	Total irrigation applied (mm/ha)	N Fert. (kg N/ha)	P Fert. (kg P/ha)
1	Feb.	Cabbage (S)	20.25 t (field) 22,500 heads (field) 18,000 heads (sold)	217	58	128
	Mar.				31	0
	Apr.				31	0
	May					
	June					
	July					
	Aug.	Barley	7.5 t (field) Grain harvest and residue incorporated	497	46	0
	Sep.				46	0
	Oct.					
	Nov.					
	Dec.					
2	Jan.					
	Feb.					
	Mar.					
	Apr.					
	May					
	June	Onions	65 t (field) 40 t (sold)	413	0	60
	July				53	70
	Aug.				45	25
	Sep.				38	19
	Oct.				28	7
	Nov.				17	4
	Dec.					
3	Jan.					
	Feb.	Oats	4 t DM (field) Incorporated	224		
	Mar.					
	Apr.					
	May					
	June				0	0
	July	Potatoes	50 t (field) 45 t (sold)	308	160	160
	Aug.				81	0
	Sep.				65	13

	Oct.					
	Nov.					
	Dec.					
4	Jan.	Phacelia	4 t DM Incorporated	350		
	Feb.					
	Mar.					
	Apr.	Carrots	65 t (field) 55 t (sold)	112	42	88
	May				41	23
	June				38	9
	July				38	9
	Aug.					
	Sep.					
	Oct.					
	Nov.	Silverbeet	22.5 t (field) 30,000 heads (field) 24,000 heads (sold)	553	75	35
	Dec.				68	0
5	Jan.				68	0
	Feb.					
	Mar.					
	Apr.	Cabbage (W)	20.25 t (field) 22,500 heads (field) 18,000 heads (sold)	0	74	128
	May				23	0
	June				23	0
	July					
	Aug,					
	Sep.					
	Oct.	Barley	7.5 t (field) Grain harvest and residue incorporated	399	46	0
	Nov.				46	0
	Dec.					
6/1	Jan.					

4.1.2 Rotation 1 – Nitrogen results

Table 30 summarises the baseline nitrogen results for rotation 1. It includes nitrogen yield per hectare and daily nitrogen yield for each crop averaged across each of the five repetitions in the simulation period and days in crop. Table 31 summarises the descriptive statistics for nitrogen yield for the full five-year rotation across the five repetitions of the rotation.

Table 30: Baseline nitrogen results for Rotation 1 by crop (APSIM)

Year	Month	Crop	Average N yield (kg N/ha)	Daily average N yield (kg N/ha/day)	Days in crop
1	Feb - Jul	Cabbage (S)	25.77	0.14	181
1-2	Aug - May	Barley	44.74	0.15	304
2-3	Jun - Jan	Onions	96.43	0.39	245
3	Feb - Jun	Oats	16.16	0.11	150
3	Jul - Dec	Potatoes	91.14	0.50	184
4	Jan - Mar	Phacelia	5.85	0.06	90
4	Apr - Oct	Carrots	94.00	0.44	214
4-5	Nov - Mar	Silverbeet	105.93	0.70	151
5	Apr - Sep	Cabbage (W)	56.65	0.31	183
5-6/1	Oct - Jan	Barley	17.70	0.14	123

Table 31: Descriptive statistics for nitrogen results for Rotation 1 (APSIM)

		Sum of N yield (kg N/ha)	Average annual N yield (kg N/ha/yr)	Average daily N yield (kg N/ha/day)
Results by repetition	Repetition 1 (1990-1994)	572	114	0.31
	Repetition 2 (1995-1999)	607	121	0.33
	Repetition 3 (2000-2004)	528	106	0.29
	Repetition 4 (2005-2009)	531	106	0.29
	Repetition 5 (2010-2014)	533	107	0.29
Average N yield across all repetitions		544	111	0.30
Max. N yield across repetitions		607	121	3.12
Min. N yield across repetitions		528	106	0
Standard deviation				0.37
Note the max. and min. daily N yield is based on all days modelled (i.e., the full 1,826 days) not the daily N yield averaged by repetition.				

4.1.3 Rotation 1 – Gross margin

Table 32 summarises the specific crop gross margins for rotation 1.

Table 32: Specific crop gross margins for rotation 1

Crop	Cabbage (S)	Barley	Onions	Oats	Potatoes	Phacelia	Carrots	Silverbeet	Cabbage (W)	Barley
Revenue										
Sold yield (units/ha)	18,000 heads	7.5 tonnes	40 tonnes	Incorp.	45 tonnes	Incorp.	55 tonnes	24,000 heads	18,000 heads	7.5 tonnes
Price ($/unit)	1.50/head	500/tonne	550/tonne	-	520/tonne	-	600/tonne	1.25/head	1.50/head	500/tonne
Revenue ($/ha)	**27,000**	**3,750**	**22,000**	**-**	**23,400**	**-**	**33,000**	**30,000**	**27,000**	**3,750**
Expenses ($/ha)										
Seed	3,212	200	2,000	300	7,450	200	2,900	1,132	3,212	200
Cultivation	1,378	220	988	220	355	220	935	1,378	1,378	220
Fertiliser	796	288	2,436	-	3,928	-	1,832	1,423	820	288
Agri-chemicals	502	294	2,200	-	1,587	-	1,150	502	502	294
Irrigation	434	994	826	448	616	700	224	1,106	-	798
Harvesting	3,180	460	3,269	-	2,316	-	1,440	3,180	3,180	460
Grading	-	-	2,900	-	1,875	-	7,150	-	-	-
Packing	-	-	3,504	-	2,523	-	2,634	-	-	-
Freight	2,592	240	1,000	-	1,125	-	1,650	1,440	2,592	240
Levies	132	-	100	-	232	-	162	147	132	-
Total expenses ($/ha)	**12,226**	**2,696**	**19,222**	**968**	**22,006**	**1,120**	**20,077**	**10,307**	**11,816**	**2,500**
Gross margin ($/ha)	**14,774**	**1,054**	**2,778**	**-968**	**1,394**	**-1,120**	**12,923**	**19,693**	**15,184**	**1,250**

4.2 Rotation 2

4.2.1 Rotation 2 – Description

Table 33 details the physical details for rotation 2. All fertiliser is surface applied except for the first application of fertiliser to onions which is incorporated at 50 mm and the first application of fertiliser to potatoes which is incorporated at 100 mm.

Table 33: Rotation 2 physical details

Year	Month	Crop	Crop yield (unit/ha)	Total irrigation applied (mm/ha)	N Fert. (kg N/ha)	P Fert. (kg P/ha)
1	Feb.	Fallow 1		0		
	Mar.					
	Apr.				48	66
	May					
	June	Onions	65 t (field) 40 t (sold)	336	42	39
	July				27	5
	Aug.				37	
	Sep.				54	
	Oct.					
	Nov.					
	Dec.					
2	Jan.	Fallow 2		0		
	Feb.					
	Mar.					
	Apr.					
	May	Potatoes	50 t (field) 45 t (sold)	196	210	175
	June					
	July				37	
	Aug.				37	
	Sep.				37	
	Oct.					
	Nov.					
	Dec.	Oats	4 t DM (field) Incorporated	469		
3	Jan.					
	Feb.					
	Mar.					
	Apr.					
	May	Carrots	65 t (field) 55 t (sold)	0	49	28
	June					
	July				37	
	Aug.				37	
	Sep.				37	
	Oct.					
	Nov.					
	Dec.					
4	Jan.	Fallow 3		0		
	Feb.					
	Mar.	Lettuce (W)	44.1 t (field) 17.6 t (sold)	112	75	
	Apr.				41	
	May				41	
	June	Fallow 4		0		
	July					
	Aug.					
	Sep.		33.6 t (field)	245	75	

	Oct.	Broccoli (W)	9.3 t (sold)		54	
	Nov.				54	
	Dec.	Fallow 5		0		
5	Jan.					
	Feb.	Broccoli (S)	35 t (field) 9.3 t (sold)	224	60	
	Mar.				54	
	Apr.	Fallow 6		0		
	May	Barley	7.5 t (field) Grain harvested and residue incorporated	455	46	
	June				46	
	July					
	Aug,					
	Sep.					
	Oct.					
	Nov.					
	Dec.					
6/1	Jan.					

4.2.2 Rotation 2 – Nitrogen results

Table 34 summarises the baseline nitrogen results for rotation 2. It includes nitrogen yield per hectare and daily nitrogen yield for each crop averaged across each of the five repetitions in the simulation period and days in crop. Table 35 summarises the descriptive statistics for nitrogen yield for the full five-year rotation across the five repetitions of the rotation.

Table 34: Baseline nitrogen results for Rotation 2 by crop (APSIM)

Year	Month	Crop	Average N yield (kg N/ha/crop)	Daily average N yield (kg/N/ha)	Days in crop
1	Feb - May	Fallow 1	4.91	0.04	120
1	Jun - Dec	Onions	104.47	0.49	214
2	Jan - Apr	Fallow 2	5.31	0.04	120
2	May - Nov	Potatoes	131.36	0.61	214
2-3	Dec - Apr	Oats	10.50	0.07	151
3	May - Dec	Carrots	13.08	0.05	245
4	Jan - Feb	Fallow 3	0.70	0.01	59
4	Mar - May	Lettuce (w)	27.33	0.30	92
4	Jun - Aug	Fallow 4	73.39	0.80	92
4	Sep - Nov	Broccoli (w)	64.29	0.71	91
4-5	Dec - Jan	Fallow 5	11.30	0.18	62
5	Feb - Mar	Broccoli 2 (s)	25.73	0.43	59
5	Apr	Fallow 6	8.45	0.28	30
5-6/1	May - Jan	Barley	80.92	0.29	276

Table 35: Descriptive statistics for nitrogen results for Rotation 2 (APSIM)

		Sum of N yield (kg N/ha)	Average annual N yield (kg N/ha/yr)	Average daily N yield (kg N/ha/day)
Results by repetition	Repetition 1 (1990-1994)	607	121	0.33
	Repetition 2 (1995-1999)	613	123	0.34
	Repetition 3 (2000-2004)	502	100	0.27
	Repetition 4 (2005-2009)	552	110	0.30
	Repetition 5 (2010-2014)	560	112	0.31
Average N yield across all repetitions		567	113	0.31
Max. N yield across repetitions		613	123	2.83
Min. N yield across repetitions		502	100	0
Standard deviation				0.44

Note the max. and min. daily N yield is based on all days modelled (i.e., the full 1,826 days) not the daily N yield averaged by repetition.

4.2.3 Rotation 2 – Gross margin

Table 36 summarises the specific crop gross margins for rotation 2.

Table 36: Specific crop gross margins for rotation 2

Crop	Onions	Potato	Oats	Carrot	Lettuce (W)	Broccoli (W)	Broccoli (S)	Barley
Revenue								
Sold yield (units/ha)	40 tonnes	45 tonnes	Incorp.	55 tonnes	23,400 heads	24,583 heads	19,727 heads	7.5 tonnes
Price ($/unit)	550/tonnes	520/tonnes	-	600/tonnes	1.20/heads	*See Table 20*		500/tonnes
Revenue ($/ha)	**22,000**	**23,400**	**-**	**33,000**	**28,080**	**28,660**	**19,053**	**3,750**
Expenses ($/ha)								
Seed	2,000	7,450	300	2,900	1,200	1,000	800	200
Cultivation/planting	988	355	220	935	5,267	2,200	2,000	220
Fertiliser	2,216	2,928	-	1,221	1,075	1,204	809	288
Agri-chemicals	2,200	1,587	-	1,150	1,753	1,000	888	294
Irrigation	672	392	938	-	224	490	448	910
Harvesting	3,269	2,316	-	1,440	5,740	1,700	1,700	460
Grading	2,900	1,875	-	7,150	-	701	701	-
Packing	3,504	2,523	-	2,634	2,044	-	-	-
Freight	1,000	1,125	-	1,650	878	1,862	1,862	240
Levies	100	232	-	162	138	140	93	-
Total expenses ($/ha)	**18,848**	**20,782**	**1,458**	**19,242**	**18,319**	**10,297**	**9,301**	**2,612**
Gross margin ($/ha)	**3,152**	**2,618**	**-1,458**	**13,758**	**9,761**	**18,363**	**9,752**	**1,138**

4.3 Rotation 3

4.3.1 Rotation 3 – Description

Table 37 details the physical details for rotation 3. All fertiliser is surface applied except for the first application of fertiliser to onions which is incorporated at 50 mm and the first application of fertiliser to potatoes which is incorporated at 100 mm.

Table 37: Rotation 3 physical details

Year	Month	Crop	Crop yield (unit/ha)	Total irrigation applied (mm/ha)	N Fert. (kg N/ha)	P Fert. (kg P/ha)
1	Mar.	Lettuce (W)	44.1 t (field) 17.6 t (sold)	91	75	11
	Apr.				41	
	May				41	
	June					
	July	Fallow 1		0		
	Aug.					
	Sep.	Asian Greens	61.8 t (field) 309,000 heads (field) 293,550 heads (sold)	217	64	38
	Oct.				23	
	Nov.				23	
	Dec.	Fallow 2		0		
2	Jan.	Spinach	12 t (field) 11 t (sold)	294		61
	Feb.				48	20
	Mar.				54	
	Apr.	Fallow 3		0		
	May	Cauliflower	13.5 t (field) 22,500 heads (field) 21,300 heads (sold)	0	184	128
	June				23	
	July				23	
	Aug.					
	Sep.	Fallow 4		0		
	Oct.	Spring Onions	36.28 t (field) 907,000 heads (field) 816,300 heads (sold)	630		38
	Nov.				41	
	Dec.				23	
3	Jan.				23	
	Feb.				15	
	Mar.					
	Apr.					
	May	Fallow 5		0		
	June	Onions	65 t (field) 40 t (sold)	427		60
	July				52	70
	Aug.				45	25
	Sep.				38	19
	Oct.				28	7
	Nov.				17	4
	Dec.					
4	Jan.					
	Feb.	Oats	4 t DM (field) Incorporated	231		
	Mar.					
	Apr.					
	May					
	June					
	July	Potatoes	50 t (field) 45 t (sold)	329	160	160
	Aug.				81	
	Sep.				65	13
	Oct.					

	Nov.					
	Dec.					
5	Jan.	Phacelia	4 t DM Incorporated	336		
	Feb.					
	Mar.					
	Apr.					
	May	Lettuce (W)	44.1 t (field) 17.6 t (sold)	0	75	11
	June				41	
	July				41	
	Aug,	Fallow 6		0		
	Sep.	Asian Greens	61.8 t (field) 309,000 heads (field) 293,550 heads (sold)	182	64	38
	Oct.				23	
	Nov.				23	
	Dec.	Fallow 7		0		
6/1	Jan.					
	Feb.					

4.3.2 Rotation 3 – Nitrogen results

Table 38 summarises the baseline nitrogen results for rotation 3. It includes nitrogen yield per hectare and daily nitrogen yield for each crop averaged across each of the five repetitions in the simulation period and days in crop. Table 38 summarises the descriptive statistics for nitrogen yield for the full five-year rotation across the five repetitions of the rotation.

Table 38: Baseline nitrogen results for Rotation 3 by crop (APSIM)

Year	Month	Crop	Average N yield (kg N/ha/crop)	Daily average N yield (kg/N/ha)	Days in crop
1	Mar - Jun	Lettuce (w)	93.15	0.76	122
1	Jul – Aug	Fallow 1	91.30	1.47	62
1	Sep - Nov	Asian Greens	77.97	0.86	91
1	Dec	Fallow 2	9.73	0.31	31
2	Jan – Mar	Spinach	46.17	0.51	90
2	Apr	Fallow 3	24.43	0.81	30
2	May - Aug	Cauliflower	178.83	1.45	123
2	Sep	Fallow 4	18.99	0.63	30
2-3	Oct - Apr	Spring Onion	60.82	0.29	212
3	May	Fallow 5	0.35	0.01	31
3-4	Jun - Jan	Onions	60.10	0.25	245
4	Feb - Jun	Oats	12.37	0.08	150
4	Jul - Dec	Potatoes	76.63	0.42	184
5	Jan – Apr	Phaecelia	7.78	0.06	120
5	May – Jul	Lettuce (w)	38.38	0.42	92
5	Aug	Fallow 6	21.54	0.69	31
5	Sep – Nov	Asian Greens 2	83.06	0.91	91
5-6/1	Dec - Feb	Fallow 7	8.75	0.10	90

Table 39: Descriptive statistics for nitrogen results for Rotation 3 (APSIM)

		Sum of N yield (kg N/ha)	Average annual N yield (kg N/ha/yr)	Average daily N yield (kg N/ha/day)
Results by repetition	Repetition 1 (1990-1994)	937	187	0.51
	Repetition 2 (1995-1999)	931	186	0.51
	Repetition 3 (2000-2004)	858	172	0.47
	Repetition 4 (2005-2009)	954	191	0.52
	Repetition 5 (2010-2014)	872	174	0.48
Average N yield across all repetitions		910	182	0.50
Max. N yield across repetitions		954	191	3.86
Min. N yield across repetitions		858	172	0
Standard deviation				0.64

Note the max. and min. daily N yield is based on all days modelled (i.e., the full 1,826 days) not the daily N yield averaged by repetition.

4.3.3 Rotation 3 – Gross margin

Table 40 summarises the specific crop gross margins for rotation 3.

Table 40: Specific crop gross margins for rotation 3

Crop	Lettuce (W)	Asian Greens	Spinach	Cauliflower	Spring Onion	Onions	Oats	Potatoes	Phacelia	Lettuce (W)	Asian Greens
Revenue											
Sold yield (units/ha)	23,400 heads	293,550 heads	11 tonnes	21,300 heads	816,300 heads	40 tonnes	Incorp.	45 tonnes	Incorp.	23,400 heads	293,550 heads
Price ($/unit)	1.20/head	0.50/head	4,500/tonne	1.50/head	0.07/head	550/tonne	-	520/tonne	-	1.20/head	0.50/head
Revenue ($/ha)	**28,080**	**146,775**	**49,500**	**31,950**	**57,141**	**22,000**	**-**	**23,400**	**-**	**28,080**	**146,775**
Expenses ($/ha)											
Seed	1,200	2,600	2,920	3,212	1,700	2,000	300	7,450	200	1,200	2,600
Cultivation	5,267	1,050	1,752	2,102	1,752	988	220	355	220	5,267	1,050
Fertiliser	1,075	718	1,322	1,604	945	2,216	-	3,928	-	1,075	718
Agri-chemicals	1,753	1,600	1,191	876	2,000	2,200	-	1,587	-	1,753	1,600
Irrigation	182	434	588	-	1,260	854	462	658	672	-	364
Harvesting	5,740	13,856	7,592	4,088	9,110	3,269	-	2,316	-	5,740	13,856
Grading	-	20,331	4,976	-	5,971	2,900	-	1,875	-	-	20,331
Packing	2,044	4,000	1,368	-	1,500	3,504	-	2,523	-	2,044	4,000
Freight	878	3,669	880	3,067	2,612	1,000	-	1,125	-	878	3,669
Levies	138	719	243	157	280	100	-	232	-	138	719
Total expenses ($/ha)	**18,277**	**48,978**	**22,832**	**15,106**	**27,130**	**19,250**	**982**	**22,048**	**1,092**	**18,095**	**48,908**
Gross margin ($/ha)	**9,803**	**97,797**	**26,668**	**16,844**	**30,011**	**2,750**	**-982**	**1,352**	**-1,092**	**9,985**	**97,867**

4.4 Rotation 4

4.4.1 Rotation 4 – Description

Table 41 details the physical details for rotation 4. All fertiliser is surface applied except for the first application of fertiliser to broccoli which was incorporated to 50 mm.

Table 41: Rotation 4 physical details

Year	Month	Crop	Crop yield (unit/ha)	Total irrigation applied (mm/ha)	N Fert. (kg N/ha)	P Fert. (kg P/ha)
1	Feb.	Lettuce (S)	50.0 t (field)	217	60	8.8
	Mar.		24.3 t (sold)		41	
	Apr.	Fallow 1		0		
	May					
	June					
	July					
	Aug.					
	Sep.	Broccoli (W)	33.6 t (field)	217	75	11
	Oct.		9.3 t (sold)		54	
	Nov.				54	
	Dec.	Oats	4 t DM (field)	413		
2	Jan.		Incorporated			
	Feb.					
	Mar.					
	Apr.					
	May					
	June	Broccoli (W)	33.6 t (field)	0	75	11
	July		9.3 t (sold)		54	
	Aug.				54	
	Sep.					
	Oct.	Fallow 2		0		
	Nov.					
	Dec.					
3	Jan.					
	Feb.					
	Mar.					
	Apr.	Barley	7.5 t (field)	462	46	
	May		Grain harvested and		46	
	June		residue incorporated			
	July					
	Aug.					
	Sep.					
	Oct.					
	Nov.					
	Dec.					
4	Jan.					
	Feb.	Lettuce (S)	50.0 t (field)	119	60	8.8
	Mar.		24.3 t (sold)		41	
	Apr.	Fallow 3		0		
	May					
	June					
	July					
	Aug.	Broccoli (W)	33.6 t (field)	140	75	11
	Sep.		9.3 t (sold)		54	
	Oct.				54	

	Nov.	Fallow 4		0		
	Dec.					
5	Jan.					
	Feb.					
5	Mar.	Barley	7.5 t (field) Grain harvested and residue incorporated	581	46	
	Apr.				46	
	May					
	June					
	July					
	Aug,					
	Sep.					
	Oct.					
	Nov.					
	Dec.					
6/1	Jan.					

4.4.2 Rotation 4 – Nitrogen results

Table 42 summarises the baseline nitrogen results for rotation 4. It includes nitrogen yield per hectare and daily nitrogen yield for each crop averaged across each of the five repetitions in the simulation period and days in crop. Table 43 summarises the descriptive statistics for nitrogen yield for the full five-year rotation across the five repetitions of the rotation.

Table 42: Baseline nitrogen results for Rotation 4 by crop (APSIM)

Year	Month	Crop	Average N yield (kg N/ha/crop)	Daily average N yeild (kg/N/ha)	Days in crop
1	Feb – Mar	Lettuce (s)	11.04	0.19	59
1	Apr – Aug	Fallow 1	64.43	0.42	153
1	Sep - Nov	Broccoli (w)	46.89	0.52	91
1-2	Dec – May	Oats	43.83	0.24	182
2	June – Sep	Broccoli 2 (w)	45.01	0.37	122
2-3	Oct – Mar	Fallow 2	7.47	0.04	182
3-4	Apr – Jan	Barley	74.88	0.24	306
4	Feb – Mar	Lettuce 2 (s)	6.17	0.10	59
4	Apr – Jul	Fallow 3	46.22	0.38	122
4	Aug – Oct	Broccoli 3 (w)	47.84	0.52	92
4-5	Nov – Feb	Fallow 4	17.83	0.15	120
5-6/1	Mar – Jan	Barley 2	62.80	0.19	337

Table 43: Descriptive statistics for nitrogen results for Rotation 4 (APSIM)

		Sum of N yield (kg N/ha)	Average annual N yield (kg N/ha/yr)	Average daily N yield (kg N/ha/day)
Results by repetition	Repetition 1 (1990-1994)	517	103	0.28
	Repetition 2 (1995-1999)	497	99	0.27
	Repetition 3 (2000-2004)	435	87	0.24
	Repetition 4 (2005-2009)	454	91	0.25
	Repetition 5 (2010-2014)	469	94	0.26
Average N yield across all repetitions		474	95	0.26
Max. N yield across repetitions		517	103	2.04
Min. N yield across repetitions		435	87	0
Standard deviation				0.33
Note the max. and min. daily N yield is based on all days modelled (i.e., the full 1,826 days) not the daily N yield averaged by repetition.				

4.4.3 Rotation 4 – Gross margin

Table 44 summarises the specific crop gross margins for rotation 4.

Table 44: Specific crop gross margins for rotation 4

Crop	Lettuce (S)	Broccoli (W)	Oats	Broccoli (W)	Barley	Lettuce (S)	Broccoli (W)	Barley
Revenue								
Sold yield (units/ha)	23,400 heads	24,583 heads	Incorp.	24,583 heads	7.5 tonnes	28,600 heads	24,583/heads	7.5 tonnes
Price ($/unit)	1.20/head	*See Table 20*	-	*See Table 20*	500/tonne	1.00/head	*See Table 20*	500/tonne
Revenue ($/ha)	**28,080**	**28,660**	**-**	**28,660**	**3,750**	**28,600**	**28,660**	**3,750**
Expenses ($/ha)								
Seed	1,200	1,000	300	1,000	200	1,200	1,000	200
Cultivation/planting	5,267	2,200	220	2,200	220	5,267	2,200	220
Fertiliser	744	1,204	-	1,204	288	744	1,204	288
Agri-chemicals	1,500	1,000	-	1,000	294	1,500	1,000	294
Irrigation	434	434	826	-	924	238	280	1,162
Harvesting	5,740	1,700	-	1,700	460	5,740	1,700	460
Grading	-	701	-	701	-	-	701	-
Packing	2,044	-	-	-	-	2,044	-	-
Freight	1,216	1,862	-	1,862	240	1,216	1,862	240
Levies	140	140	-	140	-	140	140	-
Total expenses ($/ha)	**18,286**	**10,241**	**1,346**	**9,807**	**2,626**	**18,090**	**10,087**	**2,864**
Gross margin ($/ha)	**10,314**	**18,419**	**-1,346**	**18,853**	**1,124**	**10,510**	**18,753**	**886**

4.5 Rotation 5

4.5.1 Rotation 5 – Description

Table 45 details the physical details for rotation 5. All fertiliser is surface applied except for the first application of fertiliser to onions which is incorporated at 50 mm and the first application of fertiliser to potatoes which is incorporated at 100 mm.

Table 45: Rotation 5 physical details

Year	Month	Crop	Crop yield (/ha)	Total irrigation applied (mm/ha)	N Fert. (kg N/ha)	P Fert. (kg P/ha)
1	Feb.	Fallow 1		0		
	Mar.					
	Apr.				48	66
	May					
	June	Onions	65 t (field) 55 t (sold)	301	42	39
	July				27	5
	Aug.				37	
	Sep.				54	
	Oct.					
	Nov.					
	Dec.					
2	Jan.	Fallow 2		0		
	Feb.					
	Mar.					
	Apr.					
	May	Potatoes	50 t (field) 45 t (sold)	168	210	175
	June					
	July				37	
	Aug.				37	
	Sep.				37	
	Oct.					
	Nov.					
	Dec.	Fallow 3		0		
3	Jan.					
	Feb.	Lettuce (S)	50.0 t (field) 24.3 t (sold)	210	60	9
	Mar.				41	
	Apr.	Ryegrass	4 t Incorporated	0		
	May					
	June					
	July					
	Aug.					
	Sep.	Pumpkin	40 t (field) 20 t (sold)	427	59	47
	Oct.				34	
	Nov.				16	13
	Dec.					
4	Jan.					
	Feb.	Fallow 4		0		
	Mar.					
	Apr.	Barley	7.5 t (field) Grain harvested and residue incorporated	0	46	
	May				46	
	June					
	July					
	Aug.					
	Sep.					

	Oct.					
	Nov.					
	Dec.					
5	Jan.					
	Feb.	Broccoli (S)	35 t (field)	217	60	
	Mar.		9.3 t (sold)		54	
	Apr.	Fallow 5		0		
	May					
	June					
	July					
	Aug.					
	Sep.	Pumpkin	40 t (field)	434	59	47
	Oct.		20 t (sold)		34	
	Nov.				16	13
	Dec.					
6/1	Jan.					

4.5.2 Rotation 5 – Nitrogen results

Table 46 summarises the baseline nitrogen results for rotation 5. It includes nitrogen yield per hectare and daily nitrogen yield for each crop averaged across each of the five repetitions in the simulation period and days in crop. Table 47 summarises the descriptive statistics for nitrogen yield for the full five-year rotation across the five repetitions of the rotation.

Table 46: Baseline nitrogen results for Rotation 5 by crop (APSIM)

Year	Month	Crop	Average N yield (kg N/ha/crop)	Daily average N yield (kg/N/ha)	Days in crop
1	Feb – May	Fallow 1	4.55	0.04	120
1	Jun – Dec	Onions	84.00	0.39	214
2	Jan – Apr	Fallow 2	3.83	0.03	120
2	May – Nov	Potatoes	132.33	0.62	214
2-3	Dec – Jan	Fallow 3	1.64	0.03	62
3	Feb – Mar	Lettuce (s)	19.81	0.33	59
3	Apr – Aug	Ryegrass	32.93	0.22	153
3-4	Sep - Jan	Pumpkin	44.75	0.29	153
4	Feb – Mar	Fallow 4	0.74	0.01	59
4 -5	Apr – Jan	Barley	45.29	0.15	306
5	Feb - Mar	Broccoli (s)	27.41	0.46	59
5	Apr – Aug	Fallow 5	63.02	0.41	153
5-6/1	Sep – Jan	Pumpkin 2	65.80	0.43	153

Table 47: Descriptive statistics for nitrogen results for Rotation 5 (APSIM)

		Sum of N yield (kg N/ha)	Average annual N yield (kg N/ha/yr)	Average daily N yield (kg N/ha/day)
Results by repetition	Repetition 1 (1990-1994)	557	111	0.31
	Repetition 2 (1995-1999)	574	115	0.31
	Repetition 3 (2000-2004)	487	97	0.27
	Repetition 4 (2005-2009)	502	100	0.28
	Repetition 5 (2010-2014)	510	102	0.28
Average N yield across all repetitions		526	105	0.29
Max. N yield across repetitions		574	115	2.79
Min. N yield across repetitions		487	97	0
Standard deviation				0.37
Note the max. and min. daily N yield is based on all days modelled (i.e., the full 1,826 days) not the daily N yield averaged by repetition.				

4.5.3 Rotation 5 – Gross margin

Table 48 summarises the specific crop gross margins for rotation 5.

Table 48: Specific crop gross margin for rotation 5

Crop	Onions	Potatoes	Lettuce (S)	Ryegrass	Pumpkin	Barley	Broccoli (S)	Pumpkin
Revenue								
Sold yield (units/ha)	40 tonnes	45 tonnes	28,600 heads	Incorporated	20 tonnes	7.5 tonnes	19,727 heads	20 tonnes
Price ($/unit)	550/tonne	520/tonne	1.00/head	-	750/tonne	500/tonne	*See Table 20*	750/tonne
Revenue ($/ha)	**22,000**	**23,400**	**28,600**	**-**	**15,000**	**3,750**	**19,053**	**15,000**
Expenses ($/ha)								
Seed	2,000	7,450	1,200	200	1,199	200	800	1,199
Cultivation	988	355	5,267	220	606	220	2,000	606
Fertiliser	2,216	2,928	744	-	1,029	288	809	1,029
Agri-chemicals	2,200	1,587	1,500	-	448	294	888	448
Irrigation	602	336	420	-	854	-	434	868
Harvesting	3,269	2,316	5,740	-	5,026	460	1,700	5,026
Grading	2,900	1,875	-	-	-	-	701	-
Packing	3,504	2,523	2,044	-	700	-	-	700
Freight	1,000	1,125	1,216	-	1,300	240	1,862	1,300
Levies	100	232	140	-	74	-	93	74
Total expenses ($/ha)	**18,778**	**20,726**	**18,272**	**420**	**11,235**	**1,702**	**9,287**	**11,249**
Gross margin ($/ha)	**3,222**	**2,674**	**10,328**	**-420**	**3,765**	**2,048**	**9,766**	**3,751**

4.6 Summary of baseline nitrogen footprints - CVP

Table 49 provides a summary of nitrogen yield results for each rotation. These are provided on an average annual basis, i.e., they take the average of all the yearly data in APSIM as well as an average across all crops within each five-year CVP rotation. All results in this section relate to long-term (generalised) nitrogen losses below the rootzone (1 meter deep in APSIM) across repeated rotations and multiple crop types. The weighted results are based on the weightings presented in Table 8.

Table 49: Baseline nitrogen results by year (APSIM)

Average annual summaries *(determined as an average of five repetitions)*	**Rotation 1**	**Rotation 2**	**Rotation 3**	**Rotation 4**	**Rotation 5**	**Weighted average**
Average fertiliser use for a full rotation (kg N/ha/ 5 years)	1,281	1,235	1,454	935	1,053	1,146
Average fertiliser use per year (kg N/ha/year)	256	247	291	187	211	229
Rainfall (mm/yr)	1,314	1,314	1,314	1,314	1,314	1,314
Irrigation (mm/yr)	615	407	547	430	351	461
Average N yield for a full rotation (kg N/5 years)	554	567	910	474	526	549
Average N yield per year (kg N/ha/yr)	111	113	182	95	105	110
Average N yield per day (kg N/ha/yr)	0.30	0.31	0.50	0.26	0.29	0.30

The nitrogen yield (loss) for each crop within a rotation depends on the management of that crop (including fertiliser applications) and how these management events coincide with climate conditions (including rainfall as well as conditions which depress plant growth and therefore nutrient uptake). The nitrogen yield is also significantly impacted by the nitrogen already in the soil profile, especially the soil organic matter and mineral nitrogen. These are both impacted by the crops grown beforehand, including the nitrogen used or left in the soil, the nitrogen content of any residues left in the field and again, the climate and within soil processes. As such, while the modelling can have two crops such as carrots treated the same from a management perspective, they may have different nitrogen loss rates based on the climate across different repetitions within a rotation and may also differ across rotations even if the climate is the same due to the preceding crops.

4.7 Summary of baseline gross margins and profitability – CVP

Table 50 provides a summary of the gross margins, overheads and profit for each rotation. Results are provided on an average annual basis, i.e., they are averaged across each crop to get a total gross margin and then divided by the five-year period prior to averaging across five rotations. Annual overheads are then added on. The results that are independent of slope type are listed first, with slope-specific variation in annual overheads and annual profit then listed. The latter differ little economically across slope classes but are noted separately given the differing sediment and phosphorus mitigation responses (i.e., that will generate markedly different cost-benefit for equivalent management) (see Section 3.4.2 and 0).

Table 50: Average annual gross margins and profitability for low and high slope

Slope	Average annual summaries ($/ha/yr)	Rotation 1	Rotation 2	Rotation 3	Rotation 4	Rotation 5	Weighted average
Independent	Average annual revenue	33,980	31,589	106,740	30,136	25,361	34,335
	Average annual expenses	20,588	20,172	48,540	14,669	18,334	19,951
	Average annual gross margins	13,392	11,417	58,200	15,467	7,027	14,384
Low	Average annual overheads	11,004	10,972	11,225	10,037	10,401	10,645
	Average annual profit (low slope)	**2,388**	**445**	**46,975**	**5,430**	**-3,374**	**3,740**
High	Average annual overheads	10,945	10,930	10,911	9,967	10,409	10,588
	Average annual profit (high slope)	**2,447**	**487**	**47,289**	**5,500**	**-3,382**	**3,797**

It is worth noting is that the high slope land low slope land has approximately the same profitability (1.5% difference). The high slope land appears marginally higher given the assumed adoption of sediment control measures (VBSs and SRPs, see Section 3.3.5) meaning the overhead costs of sediment control is higher on low slope land and therefore the profit is lower. The difference in profitability for the and slopes is solely due to overheads as the gross margins are consistent across slope. This also shows that there is more scope to adopt sediment control mitigations on high slope land.

4.8 Summary of baseline sediment and phosphorus footprints – CVP

Table 51 summarises the ESC sediment and phosphorus results for baseline sediment control adoption for both low slope and high slope land. Appendix 2 presents detailed results for each of the possible combinations of sediment control that were then combined and weighted by the adoption rates presented in Table 17 for low slope land. Appendix 3 presents similar outputs for high slope land (as combined and weighted by the adoption rates presented in Table 18).

Additional metrics were calculated and included to the following table compared with what the ESC produced to help interpretation and understanding. Namely, the following additional results were calculated:

- “Mitigated by measure (t/ha/yr)” which is calculated as “baseline erosion” minus “not mitigated by measure”.
- “Not mitigated soil yield (mm/ha/yr)” which is calculated by “not mitigated by measure” divided by 1.2*10. Where 1.2 is the assumed density of the topsoil (1.2 t/m^3).

Table 51: Baseline sediment and phosphorus modelled results for weighted average baseline results

Rate of soil erosion	Low slope	High slope
SRP size and VBS width	Varies with assumed adoption (See Table 18 and Table 19)	
Baseline erosion (t/ha/yr)	5.2	17.3
Treatment (%)	66%	81%
Mitigated by measure (t/ha/yr)	3.4	14.0
Not mitigated by measure (t/ha/yr)	1.8	3.3
Not mitigated soil yield (mm/ha/yr)	0.15	0.28
P yield (kg P/ha/yr)	3.8	7.1
Reduction of suspended sediment by SRP	38.75%	59.60%

In terms of the results shown in Table 51 (and Appendix 2 and 3) the baseline erosion was 5.2 and 17.3 t/ha/yr for low and high slopes, respectively. The difference in this modelling can be explained by the change in slope, given as slope increased the baseline erosion also increased. All other factors that influence erosion remained constant between the two slope models.

The sediment treatment percentage varied across the different options within each slope model depending on the mitigation that was applied. The results changed between slope models as well, indicating slope has an effect of the efficiency of mitigations. As expected, the combined model of SRPs at 0.50% of catchment area and 5 m VBSs showed the highest reduction of 99.8% and 99.7% for low and high slope models, respectively (Appendix 2 and 3).

The sediment treatment percentage changed most markedly between low and high slope for VBSs modelled individually. VBSs that were 3 m wide and 5 m wide changed from 55% and 71% in the low slope model to 41% and 58% in the high slope model (Appendix 2 and 3). This change is driven by the difference in slope which changes the channelisation factor of the VBS. The channelisation factor was set at 80% for the low slope and 60% for the high slope.

The baseline combined ESC results represent the best understanding of the current level of sediment and phosphorus yield occurring on CVP systems for each slope class (Table 51). The sediment treatment percentage is lower 66% for the low slope class compared to 81% for the high slope class. However, the total amount of sediment lost (i.e., not mitigated by measures) on the high slope class is 3.3 t/ha/yr (0.28 mm/ha/yr) compared with 1.8 t/ha/yr (0.15 mm/ha/yr) on the low slope class – essentially due to greater total amount of erosion. Phosphorus yield followed the same pattern as with sediment, with 7.1 kg P/ha/yr and 3.8 kg P/ha/yr for high and low slope classes, respectively.

Overall, the baseline erosion level ultimately drives the total amount of sediment and phosphorus that is mitigated and the corresponding amount lost – both of which are directly impacted by slope. The results show that baseline erosion is much lower on the low slope class; therefore, the amount of sediment and phosphorus yields are less compared with the high slope class, even though the amount of sediment intercepted before it leaves the farm on a percent basis is lower for low slope land.

4.9 Kiwifruit

4.9.1 Kiwifruit – baseline nitrogen footprint

In 2016, on behalf of Zespri, Plant and Food Research (PFR) started a research programme to measure and model nitrogen yields from kiwifruit orchards. The study included eight measurement sites within the Bay of Plenty, and the results were used to inform and calibrate a SPASMO[11] model. SPASMO (Soil Plant Atmosphere System Model) models the transport of water, microbes and solutes (e.g., nitrogen and dissolved phosphorus) through soils integrating variables such as climate, soil, water uptake by plants in relation to farm and orchard practices, and other factors affecting environmental process and plant production. A soil water balance is calculated by considering the inputs (rainfall and irrigation) and losses (plant uptake, evaporation, runoff and drainage) of water from the soil profile. The model includes components to predict the carbon, nitrogen and phosphorus budget of the soil. These components allow for a calculation of plant growth and uptake of both nitrogen and phosphorus, various exchange and transformation processes that occur in the soil and aerial environment, recycling of nutrients and organic material to the soil biomass, and the addition of surface applied fertiliser and effluent to the land.

The 2022 SPASMO model nitrogen results from this work and subsequently presented below are predicated on a range of assumptions, namely:

- Two locations were modelled, one in Pukekohe and one in Kumeu.
- Two average annual rainfall amounts of 1,220 mm (Pukekohe) and 1,287 mm (Kumeu). These are based on the average rainfall for 30-years between 1990 and 2020.
- An average nitrogen fertiliser application of 105 kg N/ha/yr.
- Eight soil types were modelled, five in Pukekohe and three in Kumeu.
- Both green (Hayward) and gold (Gold 3) kiwifruit varieties were modelled (for each soil type).
- For the green kiwifruit variety, a mean regional productivity of 8,700 tray equivalent (TE)/ha, dry matter of 17.3% and tray weight of 3.6 kg/TE were modelled.
- For the gold kiwifruit variety, a mean regional productivity of 13,100 TE/ha, dry matter of 18.6 % and tray weight of 3.3 kg/TE were modelled.
- Average results were weighted by the amount of producing green (237) and gold (286) hectares in Auckland region in 2022. The overall average value assumes the same proportion of hectares on each soil type; it is not known if this is the case or not.

Table 52 summarises the modelled nitrogen yields for kiwifruit in Auckland, based on SPASMO modelling. The same orchard system was modelled across the soil, rainfall and fertiliser factors. The only orchard system variable that changes across the green and gold variety is yield. This means that the differences in nitrogen losses below the rootzone are driven by soil, rainfall and fruit yield. Maximum values are significantly elevated for the soil type “Patumhoe silt loam” which might be an outlier and is under ongoing investigation. Kumeu soils are described as ‘poorly characterised’ and are due to be refined.

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[11] http://tools.envirolink.govt.nz/dsss/soil-plant-atmosphere-system-model/

Table 52: Modelled nitrogen yields for kiwifruit in Auckland

Location (rainfall)	Soil type	Green (kg N/ha/yr)	Gold 3 (kg N/ha/yr)	Weighted by variety hectares (kg N/ha/yr)
Pukekohe (1,220 mm)	Karaka silt loam	22.2	16.1	18.8
	Kiripaka silt loam	18.0	12.7	15.1
	Patumahoe silt loam	46.4	41.5	43.7
	Waitomokia silt loam	17.7	15.4	16.4
	Weymouth clay loam	31.6	27.3	29.2
Kumeu (1,287 mm)	Karaka silt loam	21.3	17.1	19.0
	Kiripaka silt loam	15.7	12.9	14.1
	Otao silt loam	38.3	33.5	35.7
Average		26.4	22.0	24.0

4.9.2 Kiwifruit – baseline phosphorus, copper and sediment footprints

Zespri has measured phosphorus and copper yields from kiwifruit orchards in the Bay of Plenty. These were separately collected for both leachate and runoff.

4.9.2.1 Contaminants in leachate

Phosphorus yields were measured on six kiwifruit orchards, while copper was measured on two, between August 2016 and September 2020, all in leachate samples at 120 cm depth. Phosphorus yields were measured as dissolved reactive phosphorus (DRP) filtered at 20 microns and total phosphorus. While these were measured on multiple orchards, these measurements were concentrations and loads are required for the FWMT. Contaminant loads were provided for one Bay of Plenty orchard for DRP, total phosphorus and copper. These were provided on a cumulative basis for the period from August 2016 to September 2020 and adjusted to an annual value. Table 53 shows the annual contaminant yields in leachate for one Bay of Plenty kiwifruit orchard.

Table 53: Average leachate yields for one Bay of Plenty kiwifruit orchard

Contaminant	Cumulative total (kg/ha; 48 months)	Annual average (kg/ha)
Total phosphorus	0.38	0.10
Total copper	0.19	0.05
Dissolved reactive phosphorus	0.18	0.05

4.9.2.2 Contaminants in runoff

In addition to collecting data on leachate, four orchard sites in the Bay of Plenty were set up to collect water and nutrient samples generated via runoff events from the orchard. These runoff samples were focused on sediment, phosphorus, copper and nitrogen. Soil types covered an allophanic and a pumice soil.

These samples were collected between March 2018 and February 2022. These were collected in an open channel sediment trap. Table 54 shows the contaminant yields in runoff water in these Bay of Plenty kiwifruit orchards. These have been adjusted to show an average across the four trial sites and the cumulative total of contaminant yield is averaged to an annual basis.

Table 54: Average contaminant yields in runoff water in four Bay of Plenty kiwifruit orchards

Contaminant	Cumulative total (kg/ha; Mar. 2018 to Feb. 2022)	Annual average (kg/ha)
Total mass (total suspended sediment)	775	194
Total mineral nitrogen	0.0725	0.018
Total phosphorus	2.025	0.506
Total copper	0.145	0.036

4.9.2.3 Literature estimates

There is limited additional information on phosphorus yields from kiwifruit orchards in the literature, largely because these are expected to be minor given the relative low slope of kiwifruit orchards, as well as the permanent ground cover. There are three key modelled data sources which estimate phosphorus yields from kiwifruit orchards:

- Matheson et al. (2018) estimated phosphorus yields for Bay of Plenty kiwifruit orchards using Overseer. They estimated a phosphorus yield of 0.5 kg P/ha/yr across green and gold orchards.
- Archer and Brookes (2018) estimated an average phosphorus yield of 0.16 kg P/ha/yr for Hawkes Bay kiwifruit orchards. This study was based on SPASMO modelling and the Hawkes Bay climate is different to Auckland.
- McIntosh (2009) used measurement sites in the Bay of Plenty alongside the SPASMO model and estimated that phosphorus yields from a kiwifruit farm in Maketu was on average 0.35 kg P/ha/yr with a range from 0.27 kg P/ha/yr to 0.42 kg P/ha/yr.

In terms of nitrogen losses in the literature included:

- Matheson et al. (2018) estimated nitrogen yields for Bay of Plenty kiwifruit orchards using Overseer. They estimated a nitrogen yield of 19 kg N/ha/yr for green orchards and 23 kg N/ha/yr for gold orchards.
- Archer and Brookes (2018) estimated an average nitrogen yield of 13 kg N/ha/yr for Hawkes Bay kiwifruit orchards. The results ranged from 9 to 23 kg N/ha/yr.
- McIntosh (2009) used measurement sites in the Bay of Plenty alongside the SPASMO model and estimated that nitrogen yields from a kiwifruit farm in Maketu was on average 7.5 kg N/ha/yr with a range from 5.8 kg N/ha/yr to 9.2 kg N/ha/yr.

4.9.3 Kiwifruit – baseline gross margin

The baseline profitability model is based on a range of data sources. This includes matching the Zespri and KGI SPASMO modelled fruit yield information with the Zespri orchard gate return to provide revenue. The expense information was based on data provided by Zespri based on a data set of 714 gold hectares and 598 green (conventional) hectares across the country for the 2022 season[12] (Zespri, 2022). The combined figures are based on a weighted average of 45% Hayward variety and 55% Gold 3 variety based on the relative area in each variety in Auckland. Table 55 provides a modelled profitability assessment for use in the FWMT.

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[12] The data provided by Zespri is subject to their legal disclaimer relating to the accuracy and reliance on this information.

Table 55: Modelled annual profitability for kiwifruit orchards

	Green ($/ha)	Gold 3 ($/ha)	Weighted by variety ($/ha)
Tray equivalent/ha (TE/ha)	8,700	13,100	11,106
Orchard Gate Return ($/TE)	6.35	11.51	9.17
Orchard Gate Return/ha ($/ha)	55,245	150,781	107,488
Orchard working expenses ($/ha)			
Pruning	18,258	19,692	19,042
Thinning	5,083	10,321	7,947
Fertiliser (and application)	2,387	2,907	2,671
Pollination (including artificial pollination and hive hire)	4,122	3,850	3,973
Plant health (including Hi Cane, plant health, PSA management, irrigation, spraying and girdling.)	7,377	9,348	8,455
Orchard care (including mowing, shelter maintenance and weed spraying)	1,907	2,397	2,175
Repairs and maintenance	1,517	2,775	2,205
Admin (including accounting, consulting, legal, insurance, rates, other admin, levies, subscriptions and ACC)	4,338	4,577	4,469
Harvesting costs	7,531	9,550	8,635
Management salaries or contract management fees	2,683	4,227	3,527
Total orchard working expenses ($/ha)	55,201	69,645	63,099
EBITDA ($/ha)	44	81,136	44,389

4.9.4 Kiwifruit – summary

Table 56 provides a summary for the baseline gross margin for kiwifruit orchards as well as expected baseline environmental footprint. The contaminants are based on the measured data provided by Zespri for all contaminants except for nitrogen in leachate, which is based on SPASMO modelling. The economic indicators and nitrogen in leachate are weighted by variety hectares while the environmental indicators were only available for green kiwifruit so are not weighted.

Table 56: Summary of baseline kiwifruit model

	Results	Weighted or not
Tray equivalent/ha (TE/ha)	11,106	Weighted by variety hectares
Orchard Gate Return/ha ($/ha)	107,490	
Total orchard working expenses ($/ha)	63,099	
EBIT ($/ha)	**44,389**	
Contaminants in runoff		
Total suspended sediment (kg/ha/yr)	194	Based on measured data on green kiwifruit in BOP
Total mineral nitrogen (kg/ha/yr)	0.018	
Total phosphorus (kg/ha/yr)	0.506	
Total copper (kg/ha/yr)	0.036	
Contaminants in leachate		
Total nitrogen (kg/ha/yr)	24	Weighted by variety hectares
Total phosphorus (kg/ha/yr)	0.10	Based on measured data on green kiwifruit in BOP
DRP (kg/ha/yr)	0.05	
Total copper (kg/ha/yr)	0.05	

4.10 Summary – Baseline models

Table 57 provides a summary of key results for CVP. These are separated by slope type where appropriate and by rotation. The weighted results are based on the weightings presented in Table 8.

Table 57: Summary of average annual footprints for CVP rotations

Slope	Average annual summaries	Rotation					Weighted average
		1	2	3	4	5	
Low	Gross margins ($/ha/yr)	13,392	11,417	58,200	15,467	7,027	14,384
	Profit ($/ha/yr)	2,388	445	46,975	5,430	-3,374	3,740
	P yield (kg P/ha/yr)	3.8					3.8
	Sediment yield not mitigated (t/ha/yr)	1.8					1.8
High	Gross margins ($/ha/yr)	13,392	11,417	58,200	15,467	7,027	14,384
	Profit ($/ha/yr)	2,447	487	47,289	5,500	-3,382	3,797
	P yield (kg P/ha/yr)	7.1					7.1
	Sediment yield not mitigated (t/ha/yr)	3.3					3.3
Independent	N yield (kg N/ha/yr)	111	112	182	95	105	110
	N fertiliser use (kg N/ha/yr)	256	247	291	187	211	229
	Weighting (%)	25	25	5	25	20	100

Table 58 provides the key baseline footprint information for CVP as a whole by slope, weighted by the area of each rotation (Table 8), alongside the key kiwifruit results. For the kiwifruit results, the economic indicators and nitrogen in leachate are weighted by variety hectares while the other environmental indicators were only available for green kiwifruit so are not weighted.

Table 58: Summary of weighted average annual baseline footprints for CVP and kiwifruit

Average annual summaries	CVP	
	Low slope	High slope
Average annual gross margins ($/ha/yr)	14,384	14,384
Average annual profit ($/ha/yr)	3,740	3,797
P yield (kg P/ha/yr)	3.8	7.1
Sediment yield not mitigated (t/ha/yr)	1.8	3.3
Average N yield per year (kg N/ha/yr)	110	110
	Kiwifruit	
EBIT ($/ha/yr)	44,389	
Total suspended sediment in runoff (kg/ha/yr)	194	
Total mineral N in runoff (kg/ha/yr)	0.018	
Total nitrogen in leachate (kg/ha/yr)	24	
Total P yield in runoff and leachate (kg/ha/yr)	0.556	
Total copper in runoff and leachate (kg/ha/yr)	0.086	
Total DRP in leachate (kg/ha/yr)	0.05	

Part B – Mitigation Modelling

Part B of this report models selected actions to mitigate the water quality impacts from kiwifruit and CVP.

The objectives of this section are to resolve the following key questions:

- What mitigation options are available for horticulture land uses, focusing on CVP and kiwifruit?
- What mitigation options can be modelled in this project for CVP and kiwifruit?
- For the selected mitigation options, what is their lifecycle cost (over 50-years) including impact on profitability as well as any capital and maintenance costs?
- For the selected mitigation options what is their generalised efficacy (over 50-years) on the applicable contaminants?
- For the selected mitigation options what is the opportunity to apply them over the horticulture land uses detailed in this report?
- What are the limitations of any mitigation modelling in this report?

The section starts with a discussion on mitigation selection, then outlines the mitigation options selected to mitigate nitrogen yields from CVP, including how they were modelled, their cost, efficacy and the opportunity to apply them to the CVP typology. It then discusses the options to mitigate phosphorus and sediment yields for CVP, including how they were modelled, their cost, efficacy and the opportunity to apply them to the CVP typology. Opportunity refers the expected capacity for the mitigation in question to be adopted. Kiwifruit mitigation options are also discussed.

5 Mitigation selection

This section summarises the mitigation selection process. It focuses on the three contaminants this project focuses on, namely, nitrogen, sediment and phosphorus.

To begin, literature was reviewed and discussions with growers and industry experts were undertaken to generate a long list of mitigations that considered those used or available to all horticultural systems. This list was then refined to mitigations that were sensible for CVP systems in the Auckland region and that could be modelled in the modelling tools used in this project. This refinement was based on discussion with growers and experts.

5.1 Mitigations considered

There is limited information available on nitrogen mitigations for CVP relating to New Zealand especially in a modelling context. In a practical context there are two important documents designed to guide improved nutrient management on farms, namely, Reid and Morton (2019) “Nutrient Management for Vegetable Crops in New Zealand” and HortNZ (2014) “Code of Practice for Nutrient Management”. However, sediment and phosphorus mitigations have been widely studied in the CVP sector in the Auckland region. The key studies used to create the original list of mitigations are noted below.

The first key study is Thomas et al. (2021). This work conducted a worldwide literature review to assess and analyse mitigation methods used to achieve reductions in nitrogen leaching in vegetable production systems. It provided expert opinion on each mitigations suitability to New Zealand CVP systems and the cost to implement each of the technologies. The second key study was the work done by Barber (2014). This work is based around erosion, sediment and phosphorus mitigations and gives detailed trial information on the efficiency of each mitigation at controlling sediment and phosphorus. Muller et al. (2020a) also reviewed mitigations for nitrogen, phosphorus and sediment for horticulture land uses for early inclusion in the FWMT, this included looking at good management practices and deintensification options.

Table 59 lists all the mitigations for nitrogen, sediment and phosphorus that were extracted from the above literature sources and put to growers and experts for feedback. The table further details what contaminant the mitigation is targeted at and why the mitigation was or wasn’t selected for modelling.

Table 59: Long list of considered mitigations (sed. = sediment)

Mitigation	Contaminant(s)	Selected (yes = √)	Discussion
Fertiliser type (slow release, nitrification inhibitors)	N and P	X	No slow-release fertiliser on the market that are suited to CVP in Pukekohe. Trial work has been done by growers and fertiliser companies to show this. It is an area of further research. There are concerns with some nitrification inhibitors due to food residue, they are also variable in their impact due to soil and residue N so are challenging to model and not widely used by growers.
Timing of fertiliser application	N	X	While this is realistic in practice, modelling is designed to represent a simplification of the CVP system and this mitigation is too precise to model at a generic level.
Fertiliser application method	N	X	APSIM can only differentiate between fertiliser being incorporated and surface applied (broadcast). The APSIM models used did not differentiate between fertiliser that is surface applied via different methods e.g., foliar sprays. As such while this may have benefits in practice it was at a too refined resolution for this research.
Fertiliser volume and rate	N	√	This is a typical nitrogen mitigation that can be modelled. There is the need to be really clear on associated yield impacts which is difficult in a model and there is limited research that brings together differences in fertiliser use and yield for the specific conditions and crops in the models set up in the base. In addition, growers felt that no one uses excess fertiliser due to the cost of fertiliser and so reducing fertiliser volumes has a negative impact on both field yield (crops grown) and sold yield (wastage increases). More research is needed to further refine the fertiliser and yield relationship in models and the current application practices to confirm grower beliefs.
Herbage/plant testing	N	X	Hard to capture the impact of this. Further discussions with growers concluded that testing is done to reinforce a decision rather than to make a decision, largely due to the time it takes for test results to get back and the correlation between N level in root vs leaf. While this mitigation may have benefits in practice it was at a too refined resolution for the models in this research.
Soil N quick tests	N	X	This mitigation only measures nitrate levels and doesn't consider ammonium levels so doesn't give overall N content in soil. Growers noted difficulty in sampling clay soils. In addition, because our modelling is based on typical soil tests and modelling defaults this mitigation is too refined for use in this research which is based on typical growing systems.
Irrigation application rate	N	√	This can be modelled and is a good option to model. It does need to be cognisant of infrastructure limitations e.g., water availability and type of irrigator (pivots often can't be used in the Pukekohe area due to paddock size and shape).
Soil moisture monitoring for irrigation scheduling	N	√	This can be modelled by using a change of irrigation scheduling rules as a proxy. For example, changing from using a set rate and return period to using soil moisture trigger points.

Table 59 cont.: Long list of considered mitigations (sed. = sediment)

Mitigation	Contaminant(s)	Selected	Discussion
Catch/cover crops	N, P and sed.	X	Widely adopted by growers already and they are included in the baseline rotations where possible. Very little to no scope to add more cover crops into the cropping systems/rotations without the loss of productive vegetable crops. Further, change in crop rotation would alter a multitude of variables, making it very difficult to attribute core reasons for changes in results.
Cross contour (deep) ripping across slopes	P and sed.	X	Not a very common practice in Pukekohe and hard to model as this is not an option in the ESC.
Altering crop rotations	N	X	The is little scope to alter rotations as there has been a lot of work go into setting them up in a way that reflects what growers do and have to do from a soil health, pest and disease management and maximising yields perspective. Also, there is likely to be a natural variation in rotations across growers and time, therefore using variations of crop rotations is unlikely to be a useful mitigation.
Low impact cultivation	P and sed.	X	There is very little scope for this mitigation to be modelled because of the nature of the crops grown and soils found in the Pukekohe area.
Residue management	N	X	There have been limited residue management trials and there is no scope in this project to do the trial work needed to quantify the effect this mitigation would have on N leaching. It is an area where ongoing research and trials would inform future mitigation modelling.
Reduce fallow periods between crops	N	X	There is little to no scope to further reduce fallow periods in the modelled rotations based on the growers CVPs in Pukekohe.
Constructed wetlands	N	X	Both facilitated and large rural constructed wetlands are modelled in the FWMT separately to this project, as a catchment (rather than farm-scale) mitigation.
Headland management	P and sed.	X	This typically relates to planting headlands. No ability to model this in the ESC. There would be a loss of productive area that needs to be considered if headlands were planted in grass and excluded from cropping area. Weed burden of headland management is an issue growers noted. Some growers have looked to start trails on this. This is likely to be only suitable on very low sloped land as turning on grassed headlands on narrow crop tyres on a slope when wet can create a health and safety issue.
Increased vegetative buffer strips	P and sed.	√	Need to be cognisant of the loss of productive area VBS will take up. This will be easier in some crops than others depending on planting and harvest methods. Some will be able to be established and maintained through multiple crops others will need to be redone regularly. These strips could be at the edge of fields, mid field or alongside drains etc. Some growers currently use VBSs.
Riparian buffer strips around waterways	N, P and sed.	X	Both planted and grassed riparian areas of varying widths are modelled in the FWMT separately to this project.
Increased sediment retention ponds	P and sed.	√	Ideally need to quantify the current use of SRPs and what sizes are currently used by growers. This mitigation can be modelled in the ESC and is an important mitigation in Pukekohe.

Table 59 cont.: Long list of considered mitigations (sed. = sediment)

Mitigation	Contaminant(s)	Selected	Discussion
Interceptor drains	P and sed.	X	Difficult to model as not included in the ESC.
Adding organic matter and/or biochar, zeolite etc.	N	X	These additions to soil are designed to amend soil, for example, biochar is designed with nitrate absorbing properties which can reduce N yield, likewise zeolite binds ammonium so acts like a slow-release N fertiliser. These are difficult to model as there is limited data on how they work across a range of CVP systems. This is a mitigation for further consideration.
Bioreactors	N	X	This technology does not reduce nitrate leaching per se but does reduce the concentration of nitrate in drainage water that enters the reactor before it is discharged to waterways. However, the ability to be able to model this would be difficult especially as these are an edge of field mitigation focused on nitrogen and it is difficult to understand where and how frequently they need to appear in the landscape especially because their effectiveness is tied to the drainage system flowing into the bioreactor. Quantifying the opportunity, cost and benefit of this mitigation in the Pukekohe context would be challenging.
Stacked cover cropping	N, P and sed.	X	The idea behind this option is to reduce periods of fallow land by always having a crop grown, with certain crops grown direct into cover crops that have been sprayed out. However, this is relatively unproven and would require specific machinery.
Wheel track ripping (WTR)	P and sed.	√	There are some growers who utilise this in Pukekohe and there was consideration that it could be further used. However, the quanta of current and potential use are unclear. It is able to be modelled in the ESC. This would likely require additional machinery to be purchased. In addition, consideration needs to be given to the additional compaction that wheel track ripping can cause and the potential for this mitigation to fail in high intensity rainfall events and create preferential flow paths that then create additional loss of soil (and sediment and phosphorus).
Wheel track dyking	P and sed.	X	Very similar to WTR, growers felt that ripping is easier and works better in the Pukekohe context. It can be modelled in the ESC. In addition, once dykes fill up the flow of water increases and the mitigation isn't effective anymore.

5.2 Selected mitigations

Mitigations for each sediment and phosphorus mitigation option were cumulative, i.e., WTR was applied in addition to the impact of improved sediment control. This was also the case for nitrogen mitigations. Nitrogen mitigations were modelled separately to sediment and phosphorus mitigations (although they can be combined post modelling if desired). More detail on the mitigations and how they were modelled are included in section 6 and 7.

5.2.1 Sediment and phosphorus

Improved sediment control measures (combined increase in use and construction of SRPs and VBSs) and wheel track ripping were selected for mitigating sediment and phosphorus yields.

Improved sediment control consists of a combination of two mitigations VBSs and SRPs. It was agreed to combine the two mitigations as they act to control sediment and phosphorus in a similar way by intercepting soil particles but are not always used in the same environments. VBSs are typically more effective when contours are less than or equal to 2°, whereas SRPs are used when slopes are greater than 2°. Both SRP and VBS were applied in the baseline model; however, the level of adoption was set below 100% (see Table 18 and Table 19). In the mitigation model, the adoption and design of the SRPs and VBSs are improved.

Sediment retention ponds are a very effective mitigation method which are well suited to the CVP land around the Auckland region due to the steeper contours. This mitigation has been used by some growers since the 1990s; however, growers and experts indicated there is still room for further adoption, or if they were already used, there is room to increase the sizing of SRPs in relation to their contributing catchments.

Vegetative buffer strips are a common mitigation method which are effective at reducing sediment and phosphorus yield and are well adopted in other regions around New Zealand. The adoption of VBSs by growers in the Auckland region seemed to be low after having discussions with experts and growers. The reason for this was because of the steeper contours CVP occurred on. This presented an opportunity to assess the slope of land which CVP used in the Auckland region. It was apparent that there were significant areas of CVP land that took place on slope below 2° (suitable for VBS to be used, see Section 3.3.2). It was concluded that an opportunity was available for VBSs to be adopted by growers and to increase the size of VBSs to the recommended size if they already existed in the Auckland region.

Wheel track ripping was also selected as a mitigation. This mitigation targets the point of sediment and phosphorus yield rather than capturing it once erosion has occurred. This mitigation is suited to sloping land which CVP commonly occurs on in the Auckland region. After discussions with growers and experts it was apparent that there was additional opportunity for growers to adopt WTR.

5.2.2 Nitrogen

For nitrogen, the first mitigation selected was improved irrigation practices, this included an assumption that soil moisture sensors were able to be adopted by growers not already using these. These were modelled by altering the irrigation rules that were assumed in the baseline model. In particular, there was a move from a set rate and return period to rules based on soil moisture levels.

The second nitrogen mitigation was based on identifying crops with high nitrogen yields and then reducing fertiliser input to those specific crops by 2%. Following this mitigation, all crops had fertiliser reduced by 5% and then finally all crops had fertiliser reduced by 10% (these mitigations were applied sequentially and were not cumulative). Each mitigation has an associated change in field yield and wastage (and therefore sold yield).

5.3 Mitigations with future opportunity

Table 60 details mitigations that weren't selected for this project but have been identified as having future opportunity to be explored for use in modelling and/or in practice. These are expanded on from the comments in Table 59 above.

Table 60: Mitigations that have opportunity to be further explored in other work

Mitigation	Discussion
Fertiliser type	Slow-release fertilisers have been trialled by a number of growers who found the nitrogen wasn't released when the crop needed it or prills were washed away in rainfall events. Discussions with Ballance fertiliser representatives confirmed this. It was concluded further work needed to be done on slow-release fertiliser for them to be practical for adoption by CVP growers.
Fertiliser application method	Opportunity here for more accurate application and placement of fertiliser post planting. Currently broadcast is the only method available to growers to apply fertiliser after planting. There is no machine currently available to deliver fertiliser on top of the bed while staying in spray lines, apart from incorporating fertilisers pre planting. Wastage going into the wheel tracks and between rows. It was estimated by growers that a 15% saving in fertiliser could be achieved if fertiliser could be applied onto of the bed and not broadcast. Good opportunity for significant environmental and economic benefits for certain crops.
Soil quick N tests	Opportunity to develop a test that can give nitrate and ammonium nitrate levels quickly and accurately to better inform growers of the current nitrogen levels in the soil. These are still challenging to incorporate into a modelling exercise given that models often average across a range of locations. However, there is possibly further scope to utilise improved technologies in this space.
Residue management	Opportunity to reduce N leaching by not incorporating crop residues directly after harvesting. Waiting to incorporate residues closer to the planting of the next crop so when nitrogen is released it can be untaken by the next crop and not leached. Research is needed to understand the benefits this can provide environmentally and economically as well as on nutrient content in residues to enable this to be modelled.
Stacked cover cropping	The idea behind this option is to reduce periods of fallow land by always having a crop grown, with certain crops grown direct into cover crops that have been sprayed out. However, this is relatively unproven and would require specific machinery. In addition, some crops are not suited to this in Pukekohe where bed preparation and planting are often timed to accommodate local weather conditions and for example, prepare beds in advance so that there is minimal working of soil in wet conditions which is detrimental to not only soil compaction but can also lead to further soil loss.
Cross contour (deep) ripping across slopes	Cross contour ripping may be an effective option in some places to slope water flow down slopes. However, the timing of this mitigation would need to be considered carefully in Pukekohe given the occurrence of relatively high intensity rainfall events and how cross contour ripping behaves in these episodic events which is hard to model. The rationale behind this concept is to slow the flow of water down slope so that sediment and phosphorus drops out. Therefore, doesn't end up at the bottom of the paddock where it then needs to be transported manually back up the hill at a greater cost financially.

6 Phosphorus and sediment mitigation

6.1 Introduction

As described in Section 5, improved sediment control (mitigation one) and wheel track ripping (mitigation two) were the two mitigations selected for sediment and phosphorus mitigation modelling. This section summarises the sediment and phosphorus mitigation modelling method, cost of the mitigation, modelling results (impact mitigation has on sediment and phosphorus yield) and opportunity for the mitigation to be implemented by growers in the Auckland region. These mitigations were modelled through the ESC - details of the ESC and the basic assumptions used are detailed in Section 3.

Initially it was thought that VBSs and SRPs would be modelled separately however, following discussions with experts it was clear that there was a range of use of both of these mitigations presently (at base). There was also a difference in what type of land was suitable for each and hence they were combined into a base level of adoption and into the 'improved sediment control' mitigation.

6.2 Mitigation 1 – Improved sediment control

6.2.1 Method

The method for modelling the improved sediment control mitigation was essentially the same as the baseline modelling found in Section 3.3. Namely each of the nine combinations of SRPs and VBSs levels were modelled in the ESC and weighted by the assumed level of adoption (which equates to what proportion of land is treated by the sediment control measures). However, it was assumed that more land was treated by VBS and SRPs in the improved sediment control mitigation option than at the base.

Figure 7 demonstrates how the improved sediment control mitigation was modelled for low slope. It shows 9 blocks of colour for both the baseline and the improved sediment control scenarios, each block represents an assumed level of adoption of a combination of VBS and SRPs. The assumed adoption changes from the baseline to the mitigated scenario, for example in the baseline it was assumed 35% of the land area on low slope land was not treated by SRP or VBSs, this decreases to 5% in the improved mitigation scenario. The changes in assumed adoption levels is shown in Table 61 and Table 62 for low and high slopes (with the baseline adoption shown in parenthesis).

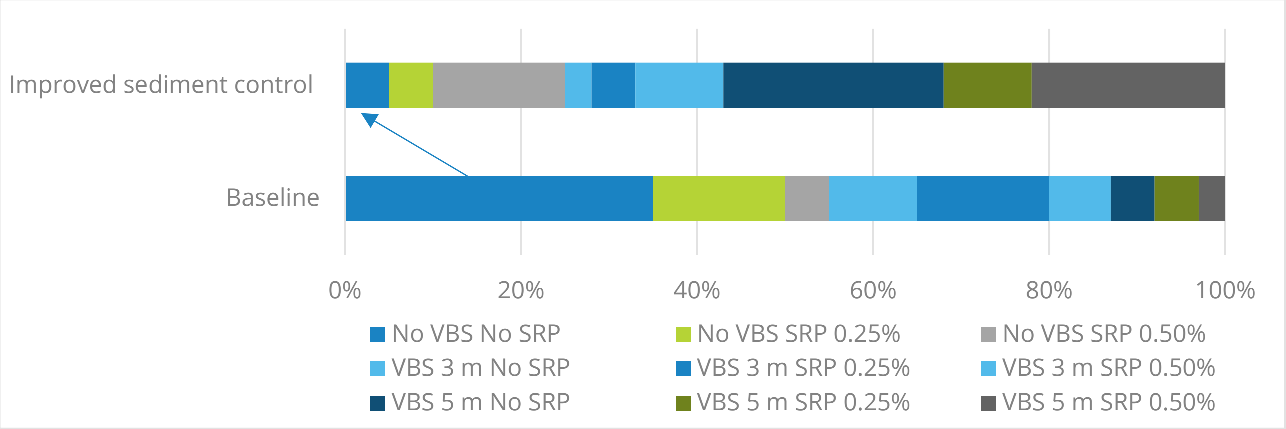

Figure 7: Diagram of improved sediment control method (proportion of land area treated by VBSs and SRPs)

The ESC provides a unique result for each combination of VBS and SRPs, i.e., each coloured block on Figure 7. These results do not change between the baseline models and the improved sediment control scenario. What is changed is the weighting (assumed adoption) of each unique ESC result. Each unique ESC result can be found in Appendix 2 (Table 100) for low slope and Appendix 3 (Table 101) for high slopes.

Table 61: Assumed adoption of SRPs and VBSs for low slope land for the improved sediment control mitigation (and baseline adoption rate in brackets)

Low slope land		SRP		
		None	0.25% of catchment area	0.50% of catchment area
VBS	None	5% (35%)	5% (15%)	15% (5%)
	3 m wide	3% (10%)	5% (15%)	10% (7%)
	5 m wide	25% (5%)	10% (5%)	22% (3%)

The assumed baseline adoption rate is presented in brackets

Table 62: Assumed adoption of SRPs and VBSs for high slope land for the improved sediment control mitigation (and baseline adoption rate in brackets)

High slope land		SRP		
		None	0.25% of catchment area	0.50% of catchment area
VBS	None	3% (20%)	15% (30%)	40% (20%)
	3 m wide	2% (3%)	5% (10%)	10% (10%)
	5 m wide	5% (2%)	7% (3%)	13% (2%)

The assumed baseline adoption rate is presented in brackets

6.2.2 Cost

The annual maintenance costs for SRPs and VBSs individually and combined, as well as the assumptions used to calculate these costs are detailed above in section 3.4.2 and

Table 27.

Low slope annual maintenance cost increased from $288/ha/yr at the baseline to $473/ha/yr, a mitigated annualised cost difference of $185/ha/yr. The high slope annual maintenance cost increased from $306/ha/yr at the baseline to $410/ha/yr, an annualised cost difference of $104/ha/yr. All mitigated costs increased reflecting the assumed greater adoption of SRP and VBS than at baseline. Low slope annualised costs increased by a larger relative amount reflecting greater adoption of more expensive SRP and VBS options.

The other costs which relate to VBSs (not SRPs) is the loss of productive area. The method and costs for estimating this loss of productive area for 3 m and 5 m VBSs are detailed in section 3.4.2 and Table 26. The same principles for calculating the cost for loss of productive area were applied here for the weightings (Table 61 and Table 62) for low and high slope with improved sediment control. Namely the cost takes the loss annual average profitability and removes this from the annual gross margin (as part of the annual overheads).

The maintenance of SRPs and the cost of the VBSs are both annual costs and were applied as annual overheads. The annual weighted maintenance costs for baseline and mitigated improved sediment control are detailed in in Table 65 (low slope) and Table 66 (high slope). The weighted results are based on the weightings presented in Table 8.

In addition to the additional annual costs of the improved sediment control measures, there is an additional capital cost of implementing SRPs. In order to generate an additional capital cost for SRPs assumptions need to be made about the relative change for the proportion that moves from no SRP to one that is 0.25% of the catchment area or to 0.50% of the catchment area, or from 0.25% of the catchment area to 0.50% of the catchment area. To do this some general rules were generated and then these were applied to get to the final proportions in each of the nine combinations of VBSs and SRPs. The two rules assumed that no change went 'backwards' e.g., from a larger SRP to a smaller one, and moving from no SRP to a 0.50% catchment area was prioritised over moving from no SRP to 0.25%, the idea was that if someone was going to construct a SRP where one didn't originally exist it would likely be sized more accurately to the recommended limit of 0.50%.

The capital cost of moving from no SRP to one that was 0.50% of catchment area was assumed to be $1,000 and the cost of moving from no SRP to one that was 0.25% of catchment area was assumed to be $700. These were based on discussions with experts and assumptions of earthwork equipment and use.

The weighted capital cost for improved sediment control for low slope land was $859 (per hectare of catchment area). The weighted capital cost for improved sediment control for high slope land was $845 (per hectare of catchment area). It is assumed that this has a 50-year life span.

6.2.3 Efficacy

Table 63 summarises the mitigated sediment and phosphorus results for the weighted average options for low slope and high slope land. Appendix 2 has detailed results for each of the options that was combined for the weighted average for the low slope options and Appendix 3 provides details for high slope land.

Table 63: Weighted average improved sediment control mitigation results

Rate of soil erosion	Low slope	High slope
SRP size and VBS width	Varies with assumed adoption (See Table 61Table 18 and Table 62)	
Baseline erosion (t/ha/yr)	5.2	17.3
Treatment %	87%	94%
Mitigated by measure (t/ha/yr)	4.5	16.2
Not mitigated by measure (t/ha/yr)	0.7	1.1
Not mitigated soil yield (mm/ha/yr)	0.05	0.09
P yield (kg P/ha/yr)	1.4	2.3
Reduction of suspended sediment by SRP	56.0%	75.2%

As mentioned above the individual and combination modelling results remained the same for the mitigation modelling. The greater treatment percentages for both slope classes under mitigation scenarios simply reflects greater adoption of sediment control measures than at baseline and is explored in section 6.2.4 below.

6.2.4 Opportunity

Opportunity refers to the expected capacity for improved sediment control to be adopted. The uptake of improved sediment control mitigation has been reflected in the change from the assumed baseline adoption percentages in each of the nine VBS and SRP combinations (e.g., the improved sediment control mitigation). Changes in sediment control mitigation adoption are summarised in Table 61 and Table 62.

In Table 61 the assumed adoption percentages demonstrate more uptake of more demanding combinations of mitigation and lesser extent of CVP land being treated by no SRP or VBS combination. The most notable assumption regarding increased sediment control measures on low slope CVP adoption, is that considerably more growing area is treated by a 5m VBS and no SRP (e.g., good practice recommendations in literature reflecting lesser preferential flow paths and more sheet flow).

The assume adoption percentages in Table 62 (high slope) also shift to reflect fewer CVP area adopting "none" (e.g., more area being treated). Notable increases in adoption occur in no VBS and 0.50% SRP. SRPs were more widely adopted on high slope land at baseline than VBS or a combination, but the important point is the shift from 0.25% SRP to favouring 0.50% SRP (e.g., increased SRP treatment volumes per catchment area of high slope CVP land)0.

The results of the improved sediment control option for both low and high slope are weighted by proportion of land assumed to be treated by sediment control measures. This means the final adoption-weighted results can be applied to all CVP land (e.g., as a single HRU comprised of the x9 alternative levels of treatment on each of low and high slope CVP areas).

In terms of the opportunity there is very little literature supporting the percentages chosen at either baseline or for the improved sediment control mitigation. The main drivers behind the weighing percentages are from conversations with growers and industry experts, and literature on the effectiveness of VBSs and SRPs at different slopes. There has been no literature found relating to VBSs use in the Auckland region and only one non verified or audited data set on SRPs in the Auckland region, from the Survey of Rural Decision Makers (MWLR, 2018). Improving evidence on the opportunity of mitigation measures at baseline and after mitigation is a key area for further improvement beyond this report. If this evidence becomes available, then the weighting percentages can be updated and the results re-run.

In terms of baseline adoption, no peer-reviewed or independently audited dataset exists for detainment bunds or SRPs in horticulture, nationally or in the Auckland region. The only dataset available is that from the Survey of Rural Decision Makers (MWLR, 2018). The latter is not verified or audited, and as above, might not represent sectoral activity in the Auckland region. Nonetheless, responses in 2017 (with 2019 equivalent responses in brackets) indicate only 1 in 4 farmers possessed a sediment trap. Among those respondents managing erosion, 5% (17%) maintain sediment traps to a "low" extent, 9% (34%) to a "medium" extent, 7% (33%) to a "high" extent and 4% (16%) to the "fullest" extent possible – noting the lack of definition and therefore consistency about low, medium, high or fullest forms of maintenance. Respondents are not segregated into pastoral or horticultural farmers, nor too is the area of farm treated understood (e.g., unclear what area of farm is upstream and how to modify recommended benefits here to reflect the four tiers of sediment trap management).

6.3 Mitigation 2 – Wheel track ripping

Heavy machinery is typically used in the process of planting and establishing CVP crops which creates compaction of the soil wherever the machine has gone. The compacted soil in the wheel tracks which run parallel (up and down) to the slope act as a channel for water to run during rainfall events as it can't infiltrate and drain through the soil. Once water starts to run down a slope, undermining of the adjoining crop beds occurs leading to extensive crop and soil loss (Barber, 2014). Ripping the wheel tracks leads to increased rainfall infiltration rates and significantly decreases soil movement. This happens as water is allowed to percolate into the soil rather than flow down the wheel track (Barber, 2014).

Wheel track ripping (WTR) should be carried out as soon as possible after planting. A shallow tined implement pulled behind a tractor is used for this purpose. The tines typically have double leg subsoiler shanks with small wing bases to help water to flow under the soil surface (Barber, 2014).

6.3.1 Method

Wheel track ripping was applied following the improved sediment control mitigation (i.e., in addition to this mitigation). As such all results for the WTR mitigation are inclusive of the improved sediment control costs and benefits. It was modelled by selecting this as an option in the ESC which then assumes that WTR reduces erosion by 90% during a third of the erosion period, which equates to a 30% erosion reduction annually.

For mitigation modelling, the assumed potential for WTR was 50% of low slope and 80% of high slope land. It should be noted that there are no data sets or studies to show the current adoption of WTR by growers. Best professional judgment, discussion with growers and industry experts have helped to give insight into how many growers might be using WTR as a mitigation option and what level of adoption might be realistic and achievable for this mitigation. It was assumed there was higher adoption potential ("opportunity" for the mitigation) on the high slope land as this is where the mitigation would be most cost-effective.

6.3.2 Cost

There are two cost groups associated with WTR, capital costs and an ongoing cost to implement this mitigation option. These also incorporate the costs of the improved sediment control mitigation. The weighted results are based on the weightings presented in Table 8. These are summarised in Table 65 (low slope) and Table 66 (high slope).

The capital cost is consistent across all rotations and is based on estimates of the additional machinery required. It is assumed there is a capital cost of $5,000 and this machinery has a life span of 25 years. It was assumed one cost of $5,000 would cover 10 ha.

The annual cost varies based on the number of crops in a rotation. The more crops and cultivation that occurs in a rotation the more the WTR is implemented. The cost for WTR assumed to be $120/ha/crop for the labour and fuel. Because this cost was per crop each annual cost of WTR was individualised by rotation to account for the difference number of crops grown[13]. In addition to this, there was a cost of $40/ha/yr for extra repairs and maintenance on the machinery. This cost is shown on a per hectare basis, as one ripper is assumed to cover 10 ha, this cost is $400/yr for each ripper. This cost doesn't by rotation. The costs do not vary by slope; however, the results are presented different due to the different profitability of low and high slope (due to other overhead costs). Because it was assumed that WTR was not used in the base, there is no cost for WTR included in the baseline or the improved sediment control mitigation results (i.e., mitigation 1).

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[13] Rotation 1 grew 10 crops in 5 years, rotation 2 grew 8 crops in 5 years, rotation 3 grew 11 crops in 5 years, rotation 4 grew 8 crops in 5 years and rotation 5 grew 8 crops in 5 years.

6.3.3 Efficacy

Table 64 summarises the results with and without WTR and weighted results for low and high slopes.

Table 64: Weighted average wheel track ripping mitigation results

Inputs	Low slope	High slope
WTR	Weighted (50% with WTR)	Weighted (80% with WTR)
SRP size	See weighted Table 61	See weighted Table 62**Error! Reference source not found.**
VBS details		
Results (rate of soil erosion)		
Baseline erosion (t/ha/yr)	5.2	17.3
Treatment (%)	89%	95.5%
Mitigated by measure (t/ha/yr)	4.6	16.5
Not mitigated by measure (t/ha/yr)	0.6	0.8
Not mitigated soil yield (mm/ha/yr)	0.05	0.07
P yield (kg P/ha/yr)	1.2	1.7
Reduction of suspended sediment by SRP	56.0%	75.2%

6.3.4 Opportunity

As previously discussed, it was assumed that there was opportunity for WTR to be adopted by 50% of the low slope horticulture land and 80% of the high slope land. As with the improved sediment control mitigation there is no quantifiable evidence to base this assumption on. It is based on discussions with growers and experts. This is a key area for further refinement.

6.4 Phosphorus and sediment mitigation summary

Two sediment and phosphorus mitigations were sequentially applied in this modelling. The first one was based on improved sediment control and the second one was based on WTR, these were cumulative (i.e., the costs and benefit of the WTR scenario also include those from the improved sediment control mitigation). The improved sediment control mitigation was based on increasing the adoption of VBSs and SRPs from baseline adoption rates, whilst WTR assumed there was no existing adoption of WTR but there was limited the total opportunity of 50% of low slope and 80% of high slope land. Quantifying the baseline and mitigation opportunity is crucial for future research. Because the results are weighted by opportunity the final weighted results can be applied to all CVP land.

There is a capital cost for both the improved sediment control and WTR mitigation. There is also an additional annual overhead cost for WTR and increased annual overhead cost for the improved sediment control mitigation. These are summarised in Table 65 and Table 66, where the weighted results are based on the weightings presented in Table 8.

Table 65: Summary of the cost of sediment and phosphorus mitigations for low slopes

Average annual costs ($/ha/yr)		Low slope ($/ha/yr)						Additional capital cost
		Rotation 1	Rotation 2	Rotation 3	Rotation 4	Rotation 5	Weighted average	
Base	Maintenance of sediment control measures	288	288	288	288	288	288	NA
	Cost of VBS	216	184	937	249	113	232	
	Total overhead costs	11,004	10,972	11,225	10,037	10,401	10,645	
	Average annual profit	2,389	445	46,975	5,430	-3,374	3,740	
Improved sediment	Maintenance of sediment control measures	473	473	473	473	473	473	$859 50-yr lifespan
	Cost of VBS	454	387	1,973	524	238	488	
	Total overhead costs	11,427	11,360	12,446	10,498	10,711	11,086	
	Average annual profit	1,965	57	45,754	4,969	-3,685	3,298	
WTR	Cost of WTR	280	232	304	232	232	248	$5,000 25-yr lifespan for 10 ha
	Total overhead costs	11,762	11,714	11,286	10,714	11,214	11,354	
	Average annual profit	1,631	-297	46,915	4,753	-4,187	3,030	

Table 66: Summary of the cost of sediment and phosphorus mitigations for high slopes

Average annual costs ($/ha/yr)		High slope ($/ha/yr)						Additional capital cost
		Rotation 1	Rotation 2	Rotation 3	Rotation 4	Rotation 5	Weighted average	
Base	Maintenance of sediment control measures	306	306	306	306	306	306	NA
	Cost of VBS	139	124	605	161	103	157	
	Total overhead costs	10,945	10,930	10,911	9,967	10,409	10,588	
	Average annual profit	2,447	487	47,289	5,500	-3,382	3,796	
Improved sediment control	Maintenance of sediment control measures	410	410	410	410	410	410	$845 50-yr lifespan
	Cost of VBS	236	201	1,024	272	124	253	
	Total overhead costs	11,146	11,111	11,434	10,182	10,534	10,788	
	Average annual profit	2,247	306	46,766	5,248	-3,507	3,587	
WTR	Cost of WTR	280	232	304	232	232	248	$5,000 25-yr lifespan for 10 ha
	Total overhead costs	11,454	11,406	10,978	10,406	10,906	11,047	
	Average annual profit	1,938	11	47,222	5,061	-3,879	3,338	

In terms of efficacy, the weighted average results for the base, improved sediment control and WTR mitigations are summarised in Table 67 for low and high slope. Figure 8 graphically summarises the sediment and phosphorus mitigation results by slope, but excludes capital costs.

Table 67: Summary of sediment and phosphorus yield mitigation efficacy

	Low slope			High slope		
Rate of soil erosion	Base	Improved sediment control	WTR	Base	Improved sediment control	WTR
SRP size and VBS width	See assumed adoption in Table 61			See assumed adoption in Table 62		
Baseline erosion (t/ha/yr)	5.2	5.2	5.2	17.3	17.3	17.3
Treatment (%)	66%	87%	89%	81.0%	94%	95.5%
Mitigated by measure (t/ha/yr)	3.4	4.5	4.6	14.0	16.2	16.5
Not mitigated by measure (t/ha/yr)	1.8	0.7	0.6	3.3	1.1	0.8
Not mitigated soil yield (mm/ha/yr)	0.15	0.05	0.05	0.28	0.09	0.07
P yield (kg P/ha/yr)	3.8	1.4	1.2	7.1	2.3	1.7
Reduction of suspended sediment by SRP	38.75%	56.0%	56.0%	59.6%	75.2%	75.2%

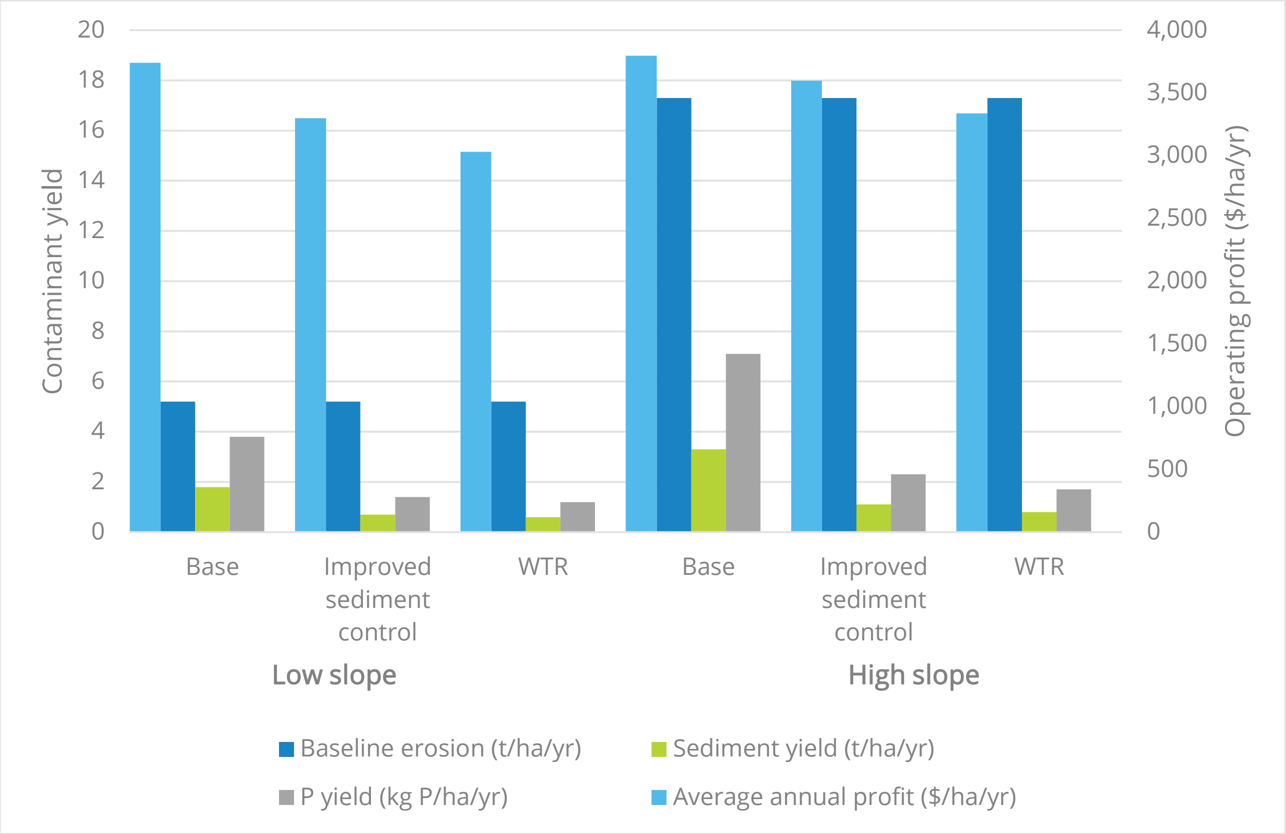

Figure 8: Sediment and phosphorus mitigation results by slope (note that capital costs are excluded from this figure)

7 Nitrogen mitigation

7.1 Introduction

As described in Section 5, improved irrigation practices and fertiliser reductions were selected for nitrogen mitigation modelling of CVP. This section summarises the nitrogen mitigation modelling method, cost of the mitigation, modelling results and opportunity for the mitigation to be implemented by growers in the Auckland region. These mitigations were modelled through APSIM, with details of APSIM and the basic assumptions used are reported in Section 3. Nitrogen mitigations were modelled separately from sediment and phosphorus modelling but were also sequential. The fertiliser mitigations all include the improved irrigation scheduling mitigations, but the fertiliser mitigations themselves are not additive (i.e., the 5% reduction in N fertiliser is not additional to the 2% reduction, but instead of, therefore the total is only a 5% reduction, not at 7% reduction).

7.2 Mitigation 1 – improved irrigation scheduling

For nitrogen the first mitigation selected was improved irrigation practices. This included an assumption that soil moisture sensors were able to be adopted by growers not using these. These were modelled by altering the irrigation rules that were assumed in the base modelling. In particular, there was a move from a set rate and return period to rules based on soil moisture levels. While some growers already use soil moisture sensors (anecdotally) it was assumed more growers could use these based on discussion with growers and horticultural consultants.

The irrigation rules used in the baseline APSIM models were set to apply 35 mm of irrigation every 7 days (see section 4 for more detail). The average irrigation applied at baseline over the five repetitions for each crop in a rotation is detailed in the relevant descriptor tables in Section 4. Table 21 summarises the average irrigation by crop for each rotation and a simple average across rotations.

To model improved irrigation practices the irrigation rules in APSIM were altered, the change in rules was used as proxy to demonstrate an improvement in irrigation practices based. The changes to rules were based on discussions with experts, growers and with consideration to industry accepted good management practices.

The revised irrigation rules were:

- Apply 25mm of irrigation when soil meets specified soil moisture trigger levels (50% of plant available water) with a rule for ensuring a minimum 7- day return period.
- Cease irrigation when soil meets specified target levels (90% of plant available water).
- Irrigation was only applied within the irrigation season (October to April).
- No irrigation was applied to bare ground.

The baseline rules about rainfall preceding irrigation were removed as this was addressed through the target soil moisture levels. Likewise, the soil moisture target level also enables headroom to cope with reasonable forecast rainfall in the following days while balancing plant requirements.

7.2.1 Cost

Irrigation values were based on a cost per millimetre of water applied, sourced from Muller, Srinivasan and Neal (2021) with an additional amount to allow for more labour-intensive irrigation systems that are common in Pukekohe. As noted in Section 3.4.1 a cost of $2/mm/ha was used for irrigation cost.

With the revised irrigation application, the revised irritation amount applied to each crop changes the cost of irrigation and therefore the gross margin. The irrigation amounts and costs by rotation are summarised in Table 68 (with the associated change in the rotation gross margins presented in Appendix 6) and the relevant change in annual profitability are shown in Table 69 (low slope) and Table 70 (high slope) by rotation and weighted average.

It was assumed that based on Muller, Srinivasan and Neal (2021), repairs and maintenance was approximately 28% of the irrigation cost per mm applied. Even though less irrigation was applied in the irrigation mitigation scenario it was assumed that this component was unlikely to change and the change was more likely to relate to lower electricity costs and lower labour costs (less shifting and setting up of irrigators, with additional labour relating to implementing the new system counted as part of the overhead costs described below). As such, the 28% of the base case irrigation per crop that was assumed to be repairs and maintenance was retained, while the remainder of the cost per crop was based on the revised volume of application and the remaining component of the price per mm. There are, therefore, some crops no longer receiving irrigation but still contributing the same proportion of repairs and maintenance cost as in the base.

In addition to the change in irrigation expenses by crop, and therefore gross margins, there is also additional overheads associated with operating and maintaining irrigation soil moisture sensors and a capital cost for the initial purchase (assumed to have a 10-year lifespan). It is assumed than there is one sensor required per hectare; this is an assumption and not based on evidence. The additional annual overhead for irrigation was $1,365/ha. This was based on $660/ha as an annual cost for sensors, including additional labour to implement the revised irrigation scheduling methodology as well as an annual cost of $205/ha for the software for irrigation scheduling and the annualised capital cost of the sensor. The capital cost is assumed at $5,000 per sensor, with one sensor per hectare and a 10-year lifespan. Due to the frequency of this capital cost it has been annualised and included as part of the overheads.

It is important to note that with less irrigation applied and therefore less cost for irrigation application the gross margins per crop look more profitable. Especially because there was assumed no change in field or sold yield as it was assumed there was no plant stress due to the use of trigger points; however, this strategy may present some risk to growers as applying only just enough irrigation to meet plant demand means there is no buffer for human error or incorrect forecasting and commercial vegetable crops are very sensitive to accessing water at required times to ensure desired yield. The additional overheads from the costs to implement the revised irrigation management more than offset these marginal gains and lower the overall profit at the rotation level.

Overall, the gross margins increased by 5%, the annual overheads increased by 13% and annual profit decreased by 17% for both low and high slope CVP systems.

Table 68: Crop irrigation mm and costs for irrigation mitigation scenario

Crop	Average by rotations										Average across all crops and rotations	
	Rotation 1		Rotation 2		Rotation 3		Rotation 4		Rotation 5			
	mm/ha	$/ha	mm/ha	$/ha	mm/ha	$/ha	mm/ha	$/ha	mm/ha	$/ha	mm/ha	$/ha
Spinach	NA		NA		0	82	NA		NA		0	82
Carrot	50	117	0	0	NA		NA		NA		25	59
Onion	20	150	30	146	45	197	NA		25	127	25	146
Potato	50	172	5	63	60	195	NA		0	47	29	119
Pumpkin	NA		NA		NA		NA		0	121	0	121
Oats	0	63	160	407	0	65	0	116	NA		40	162
Phaecelia	0	98	NA		0	94	NA		NA		0	96
Ryegrass	NA		NA		NA		NA		0	0	0	0
Barley (grain)	103	303	0	127	NA		0	146	0	0	26	144
Cabbage (S)	50	147	NA		NA		NA		NA		50	147
Cabbage (W)	10	17	NA		NA		NA		NA		10	17
Silverbeet	125	370	NA		NA		NA		NA		125	370
Cauliflower	NA		NA		0	0	NA		NA		0	0
Asian green	NA		NA		0	56	NA		NA		0	56
Spring onion	NA		NA		0	176	NA		NA		0	176
Lettuce (S)	NA		NA		NA		28	95	0	59	14	77
Lettuce (W)	NA		0	31	20	47	NA		NA		10	39
Broccoli (S)	NA		35	123	NA		NA		10	78	20	96
Broccoli (W)	NA		5	77	NA		0	33	NA		3	55

Note, if a crop is in a rotation but no irrigation is applied it is recorded as zero, if it is not in a rotation NA is recorded

Table 69: Economic impact of the irrigation mitigation scenario for low slope

Average annual summaries ($/ha/yr)	Rotation 1	Rotation 2	Rotation 3	Rotation 4	Rotation 5	Weighted average
Average annual revenue	33,980 (0%)	31,589 (0%)	106,740 (0%)	30,136 (0%)	25,361 (0%)	34,335 (0%)
Average annual expenses	19,690 (-4%)	19,552 (-3%)	47,648 (-2%)	13,943 (-5%)	17,756 (-3%)	19,230 (-4%)
Average annual gross margins	14,290 (7%)	12,037 (5%)	59,092 (2%)	16,193 (5%)	7,605 (8%)	15,105 (5%)
Average annual overheads	12,369 (12%)	12,337 (12%)	12,590 (12%)	11,402 (14%)	11,766 (13%)	12,010 (13%)
Average annual profit	**1,921 (-20%)**	**-300 (-167%)**	**46,502 (-1%)**	**4,791 (-12%)**	**-4,161 (-23%)**	**3,096 (-17%)**
Numbers in parentheses is percentage change from base						

Table 70: Economic impact of the irrigation mitigation scenario high slope

Average annual summaries ($/ha/yr)	Rotation 1	Rotation 2	Rotation 3	Rotation 4	Rotation 5	Weighted average
Average annual revenue	33,980 (0%)	31,589 (0%)	106,740 (0%)	30,136 (0%)	25,361 (0%)	34,335 (0%)
Average annual expenses	19,690 (-4%)	19,552 (-3%)	47,648 (-2%)	13,943 (-5%)	17,756 (-3%)	19,230 (-4%)
Average annual gross margins	14,290 (7%)	12,037 (5%)	59,092 (2%)	16,193 (5%)	7,605 (8%)	15,105 (5%)
Average annual overheads	12,310 (12%)	12,295 (12%)	12,276 (13%)	11,332 (14%)	11,774 (13%)	11,953 (13%)
Average annual profit	**1,979 (-19%)**	**-258 (-153%)**	**46,816 (-1%)**	**4,861 (-12%)**	**-4,169 (-23%)**	**3,153 (-17%)**
Numbers in parentheses is percentage change from base						

The irrigation mitigation scenario had no impact on annual revenue based on the cost assumptions that yield was unchanged. The expenses slightly (4%) decreased based on lower irrigation application volumes. As a result of these assumptions the gross margins, which were the same between low and high slope, were increased by 5%. The annual overheads have increased based on the cost assumptions (by 13%). With these assumptions the annual profit at a weighted average level decreased by 17%. This was not equal across all rotations due to the large variation in base profit across the rotations. While the differences in percentage change are large (from -1% to -167%) the absolute value only ranges from a reduction of $468/ha/yr (rotation 1) to $787/ha/yr (rotation 5). Rotation 2 in particular has a significant percentage reduction in profit, however the base profit was only $445/ha/yr.

7.2.2 Efficacy

The results for the irrigation mitigation scenario are detailed by rotation in Appendix 8. The summary of results is presented in Table 71. Overall nitrogen yield decreased by 24% for the five-year weighted average CVP model.

Table 71: Irrigation mitigation scenario nitrogen results by year (APSIM)

Average annual summaries	Rotation 1	Rotation 2	Rotation 3	Rotation 4	Rotation 5	Weighted average
Irrigation (mm/yr)	100 (-84%)	47 (-88%)	29 (-95%)	11 (-97%)	7 (-98%)	42 (-91%)
Average N yield for a full rotation (kg N/5 years)	343 (-38%)	436 (-23%)	814 (-11%)	385 (-19%)	439 (-17%)	420 (-24%)
Average N yield per year (kg N/ha/yr)	69 (-38%)	87 (-23%)	163 (-10%)	77 (-19%)	88 (-16%)	84 (-24%)
Average N yield per day (kg N/ha/yr)	0.19 (-37%)	0.24 (-23%)	0.45 (-10%)	0.21 (-19%)	0.24 (-17%)	0.23 (-23%)

Numbers in parentheses is percentage change from base

It is acknowledged that the decrease (91%) in irrigation volume applied seems unrealistic. The volume of irrigation applied at the base is likely too high and the volume applied in the improved irrigation scenario are too low. However, the irrigation rules are logical (and agreed as realistic by the TAG and growers) and applied correctly in the APSIM model, these rules, combined with the soil properties as specified in APSIM dictate how much irrigation is applied. The irrigation volumes are concerning and warrant further investigation. This would ideally include further analysis to understand why the base irrigation volumes are so high and then they are so low in the improved irrigation scheduling mitigation. The irrigation rules and soil properties are based on the best possible information; however, there has been no on-site calibration and it is not clear if the results are accurate. While the irrigation application volumes seem unrealistic the magnitude of change in nitrogen yield (23% reduction) seems within the realms of possibility.

7.2.3 Opportunity

Opportunity refers the expected capacity for improved irrigation scheduling to be adopted. There is no accessible quantified information on the irrigation practices used across horticulture land uses in Auckland. The baseline assumption was that all land uses were using the same irrigation practices at the baseline and then all CVP land can move to the improved irrigation practices i.e., it is assumed 100% of CVP land can adopt this mitigation. However, as in the preceding section, there is concern over the quantum of irrigation being applied in the base and under this improved irrigation mitigation. Better understanding grower practices and irrigation system constraints in a quantifiable manner is important for future research and improvements to the FWMT.

7.3 Mitigation 2, 3 and 4 – fertiliser reductions

The second, third and fourth nitrogen mitigations were all related to reducing fertiliser (and associated field and sold yields). The mitigations were:

- The second nitrogen mitigation was based on identifying crops with high nitrogen yields and then reducing fertiliser (by 2%), there was no change in field yield, but wastage increased by 5% (e.g., as more produce was not at saleable quality due to colour, size or blemishes, which reduces sold yield). In this case high N loss crops were those which had a N loss of at least 0.20 kg N/ha/day based on the APSIM modelling (irrigation scenario).
- The third nitrogen mitigation was reducing all fertiliser applications by 5% on all crops. Field yield was reduced by 5% and wastage was also increased by 5%.
- The fourth nitrogen mitigation was reducing all fertiliser applications by 10% on all crops. Field yield was reduced by 10% and wastage was also increased by 10%.

In all fertiliser mitigations for all barley crops, all fertiliser was removed as this was a cover crop and of less economic importance. This includes for the mitigation which targeted high N yield crops.

These mitigations were sequential not additive i.e., the fourth mitigation was a 10% reduction from the improved irrigation scenario, not from the preceding fertiliser mitigation. It should be noted a reduction in fertiliser for a crop means that all applications (i.e., base and side dressings) were reduced by the same proportion.

7.3.1 Limitations on modelling fertiliser reductions

There has been work on understanding at a farm level the impact of nutrient management on a range of horticulture crops (Reid and Morton, 2019). This work however is largely built on knowing available nitrogen in the soil, which while being available for specific paddocks through soil tests it is more complicated in a modelling context. APSIM provides daily concentrations of nitrate and ammonium in the soil layers; however, in a generalised modelling context it is difficult to convert this to available nitrogen and as such the recommendations in Reid and Morton (2019) are difficult to translate to changes in fertiliser in the APSIM models. Figure 9 demonstrates the different types of soil nitrogen.

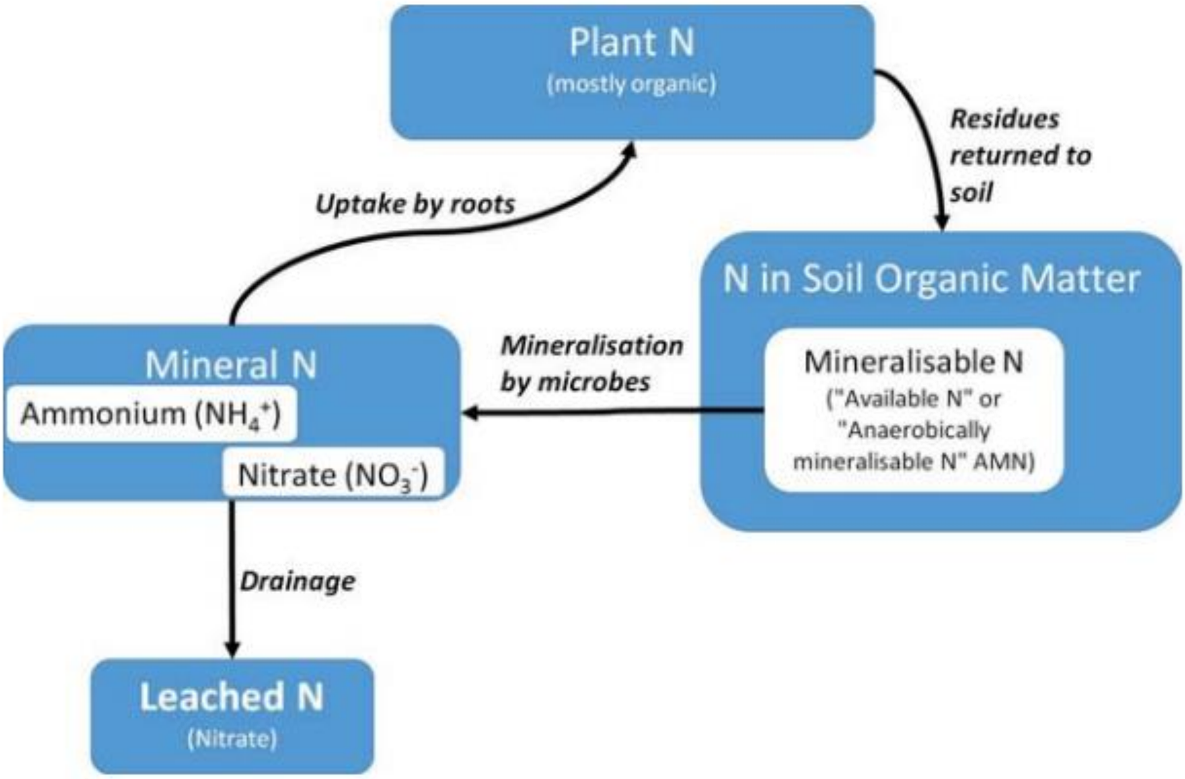

Figure 9: Soil nitrogen (Reid and Morton, 2019)

Mineral nitrogen measures the nitrate and ammonium content of freshly collected soil. It represents the N immediately available to plants and does not account for what may be mineralised from soil organic matter over the coming weeks and months. It can be converted to kilograms of nitrogen per hectare if the sampling depth and bulk density of the soil are known (which they are in APSIM). Mineral nitrogen is the only form of nitrogen that is taken up by plants or lost by leaching. The amount in the soil varies during the year in relation to its nitrogen inputs, rate of production and rate of removal by plants and through leaching.

Available nitrogen is a measure of nitrogen mineralised under specific laboratory conditions (anaerobic incubation at 40°C for 7 days). It represents an estimate of nitrogen that will be potentially mineralised in the field through the season. It does not include the immediately plant-available component of soil nitrogen (mineral nitrogen). Available nitrogen is the small portion of the organic nitrogen that is broken down each year to mineral nitrogen by the action of soil microbes. The mineralisable nitrogen is replenished each year, mainly by freshly returned plant residues.

Soil nitrogen tests enable a grower to understand the nitrogen content in their soils and plan their fertiliser applications accordingly. Without knowing the available nitrogen content, it is difficult to align the change in yields because of the change in fertiliser in Reid and Morton (2019) to the generalised crop modelling in APSIM. In addition, because the model is already presenting generalised yields (both field and sold yields) it is difficult to capture the nuances that may exist in the impact of changing fertiliser yield across growers, crops and rotations.

It is recognised that this is currently a significant limitation for CVP modelling but also an area where there may be economic and environmental impacts from changing practices at an individual grower, crop and paddock level. As such, there is a relevant research program currently underway ("*Sustainable Vegetable Systems", SVS).* This programme aims to help minimise nitrogen yields from vegetable crops and rotations. They note that "to minimise losses, such as leaching, a simple approach is to better match nitrogen supply to the demand by the crop. In practice, this is not straightforward, because of the difficulty in quantifying and predicting all the different components that contribute to crop nitrogen uptake and soil nitrogen supply" (Searle et al., 2022). As part of this project, alongside research trials and monitoring, a farmer-facing tool "N-sight" is being developed to help farmers and growers better match nitrogen supply and demand to specific crops. While this tool will not model nitrogen leaching, it will focus on better understanding and optimising tactical nitrogen use. This will hopefully lead to better environmental outcomes in practice, but at this stage does not help with the complexities of modelling long-term changes in nitrogen fertiliser in a generalised modelling context and the associated economic and environmental impacts.

In summary, the cost and efficacy results presented for nitrogen fertiliser mitigations are a key area for further improvements. The results presented in this section should therefore be treated with caution. While they represent the best available information now, notwithstanding the limitations outlined, it is likely they will need to be improved further as more information and tools are available.

7.3.2 Cost and efficacy

Table 72, Table 73 and Table 74 provide a summary of the cost and efficacy of the fertiliser recommendations. Detailed results on fertiliser, revenue, expenses, gross margins, profit, production and nitrogen yield per crop are in Appendix 9. In the summary table expenses, revenue, gross margins and nitrogen yield are independent of slope type, while overheads and profits are dependent on slope type.

Table 72: Summary of cost and efficacy of reducing fertiliser on high nitrogen loss crops by 2%

Slope	Average annual summaries ($/ha/yr)	Rotation 1	Rotation 2	Rotation 3	Rotation 4	Rotation 5	Weighted average
Independent	Average annual revenue	31,835 (-6%)	28,823 (-9%)	101,642 (-5%)	26,003 (-14%)	24,043 (-5%)	31,556 (-8%)
	Average annual expenses	19,564 (-5%)	19,473 (-3%)	47,627 (-2%)	13,821 (-6%)	17,790 (-3%)	19,154 (-4%)
	Average annual gross margins	12,271 (-8%)	9,350 (-18%)	54,015 (-7%)	60,911 (-21%)	6,253 (-11%)	24,584 (-14%)
Low slope	Average annual overheads	12,369 (12%)	12,337 (12%)	12,590 (12%)	11,402 (14%)	11,766 (13%)	12,010 (13%)
	Average annual profit	**-98 (-104%)**	**-2,987 (-771%)**	**41,425 (-12%)**	**780 (-86%)**	**-5,513 (-63%)**	**392 (-90%)**
High slope	Average annual overheads	12,310 (12%)	12,295 (12%)	12,276 (13%)	11,332 (14%)	11,774 (13%)	11,953 (13%)
	Average annual profit	**-40 (-102%)**	**-2,945 (-705%)**	**41,739 (-12%)**	**850 (-85%)**	**-5,521 (-63%)**	**449 (-88%)**
Independent	Average N yield for full rotation (kg N/5 years)	284 (-49%)	382 (-33%)	805 (-12%)	358 (-24%)	431 (-18%)	382 (-30%)
	Average N yield per year (kg N/ha/yr)	57 (-49%)	76 (-33%)	161 (-12%)	72 (-24%)	86 (-18%)	76 (-31%)
	Average N yield per day (kg N/ha/yr)	0.16 (-47%)	0.21 (-32%)	0.44 (-12%)	0.20 (-23%)	0.24 (-18%)	0.21 (-30%)

Numbers in parentheses are percentage change from base

Table 73: Summary of cost and efficacy of reducing fertiliser on all crops by 5%

Slope	Average annual summaries ($/ha/yr)	Rotation 1	Rotation 2	Rotation 3	Rotation 4	Rotation 5	Weighted average
Independent	Average annual revenue	29,601 (-13%)	26,080 (-17%)	95,104 (-11%)	23,844 (-21%)	21,335 (-16%)	28,904 (-16%)
	Average annual expenses	19,110 (-7%)	17,604 (-13%)	47,564 (-2%)	13,776 (-6%)	17,541 (-4%)	18,509 (-7%)
	Average annual gross margins	10,491 (-22%)	8,476 (-26%)	47,540 (-18%)	10,068 (-35%)	3,794 (-46%)	10,395 (-28%)
Low slope	Average annual overheads	12,369 (12%)	12,337 (12%)	12,590 (12%)	11,402 (14%)	11,766 (13%)	12,010 (13%)
	Average annual profit	**-1,877 (-179%)**	**-3,860 (-968%)**	**34,950 (-26%)**	**-1,334 (-125%)**	**-7,972 (-136%)**	**-1,615 (-143%)**
High slope	Average annual overheads	12,310 (12%)	12,295 (12%)	12,276 (13%)	11,332 (14%)	11,774 (13%)	11,953 (13%)
	Average annual profit	**-1,819 (-174%)**	**-3,818 (-884%)**	**35,264 (-25%)**	**-1,264 (-123%)**	**-7,980 (-136%)**	**-1,558 (-141%)**
Independent	Average N yield for full rotation (kg N/5 years)	281 (-49%)	406 (-28%)	785 (-14%)	348 (-27%)	432 (-18%)	384 (-30%)
	Average N yield per year (kg N/ha/yr)	56 (-50%)	81 (-28%)	157 (-14%)	70 (-26%)	86 (-18%)	77 (-30%)
	Average N yield per day (kg N/ha/yr)	0.15 (-50%)	0.22 (-29%)	0.43 (-14%)	0.19 (-27%)	0.24 (-17%)	0.21 (-30%)

Numbers in parentheses are percentage change from base

Table 74: Summary of cost and efficacy of reducing fertiliser on all crops by 10%

Slope	Average annual summaries ($/ha/yr)	Rotation 1	Rotation 2	Rotation 3	Rotation 4	Rotation 5	Weighted average
Independent	Average annual revenue	26,229 (-23%)	22,510 (-29%)	85,401 (-20%)	21,002 (-30%)	19,290 (-24%)	25,563 (-26%)
	Average annual expenses	19,114 (-7%)	19,342 (-4%)	47,451 (-2%)	13,733 (-6%)	17,472 (-5%)	18,914 (-5%)
	Average annual gross margins	7,114 (-47%)	3,168 (-72%)	37,950 (-35%)	7,269 (-53%)	1,817 (-74%)	6,649 (-54%)
Low slope	Average annual overheads	12,369 (12%)	12,337 (12%)	12,590 (12%)	11,402 (14%)	11,766 (13%)	12,010 (13%)
	Average annual profit	**-5,255 (-320%)**	**-9,169 (-2,161%)**	**25,359 (-46%)**	**-4,133 (-176%)**	**-9,949 (-195%)**	**-5,361 (-243%)**
High slope	Average annual overheads	12,310 (12%)	12,295 (12%)	12,276 (13%)	11,332 (14%)	11,774 (13%)	11,953 (13%)
	Average annual profit	**-5,196 (-312%)**	**-9,127 (-1,974%)**	**25,673 (46%)**	**-4,062 (-174%)**	**-9,956 (-194%)**	**-5,304 (-240%)**
Independent	Average N yield for full rotation (kg N/5 years)	272 (-51%)	365 (-36%)	757 (-17%)	338 (-29%)	415 (-21%)	365 (-34%)
	Average N yield per year (kg N/ha/yr)	54 (-51%)	73 (-35%)	151 (-17%)	68 (-28%)	83 (-21%)	73 (-34%)
	Average N yield per day (kg N/ha/yr)	0.15 (-50%)	0.20 (-35%)	0.41 (-18%)	0.19 (-27%)	0.23 (-21%)	0.20 (-33%)

Numbers in parentheses are percentage change from base

7.3.3 Opportunity

Opportunity refers the expected capacity for the three reduced fertiliser mitigations to be adopted. There is no quantifiable information on the range of fertiliser practices across all CVP operations. As with bundled farm system mitigations in the equivalent pastoral report it is assumed that these practices and mitigations represent an average and there are applied to all CVP operations in this modelling context. This is because the base models are predicated on typical crops and inputs, as such there will be both 'unders' and 'overs' at the base and at the mitigation. Because of the use of averages this mitigation can be applied to all hectares growing crops. However, some growers will be able to undertake mitigations at a lower cost and others at a higher cost and at best this modelling is a simplification of reality and an average.

7.4 Nitrogen mitigation summary

Table 75 summarises the cost and efficacy of nitrogen mitigations for CVP, including the weighted average results. Figure 10 summarises the key economic and nitrogen results for the weighted average CVP scenario.

Table 75: Summary of cost and efficacy of nitrogen mitigations for CVP

Slope	Average annual summaries	Rotation					Weighted average
		1	2	3	4	5	
		Baseline					
Independent	Gross margins ($/ha/yr)	13,392	11,417	58,200	15,467	7,027	14,384
	N yield (kg N/ha/yr)	111	113	182	95	105	110
Low slope	Profit ($/ha/yr)	2,389	445	46,975	5,430	-3,374	3,740
High slope	Profit ($/ha/yr)	2,447	487	47,289	5,500	-3,382	3,796
		Improved irrigation scheduling					
Independent	Gross margins ($/ha/yr)	14,290 (7%)	12,037 (5%)	59,092 (2%)	16,193 (5%)	7,605 (8%)	15,105 (5%)
	N yield (kg N/ha/yr)	69 (-38%)	87 (-23%)	163 (-10%)	77 (-19%)	88 (-16%)	84 (-24%)
Low slope	Profit ($/ha/yr)	1,921 (-20%)	-300 (-167%)	46,502 (-1%)	4,791 (-12%)	-4,161 (-23%)	3,096 (-17%)
High slope	Profit ($/ha/yr)	1,979 (-19%)	-258 (-153%)	46,816 (-1%)	4,861 (-12%)	-4,169 (-23%)	3,153 (-17%)
		Improved irrigation scheduling & reduce fertiliser on high nitrogen loss crops by 2%					
Independent	Gross margins ($/ha/yr)	12,271 (-8%)	9,350 (-18%)	54,015 (-7%)	12,182 (-21%)	6,253 (-11%)	12,402 (-14%)
	N yield (kg N/ha/yr)	57 (-49%)	76 (-33%)	161 (-12%)	72 (-24%)	86 (-18%)	76 (-31%)
Low slope	Profit ($/ha/yr)	-98 (-104%)	-2,987 (-771%)	41,425 (-12%)	780 (-86%)	-5,513 (-63%)	392 (-90%)
High slope	Profit ($/ha/yr)	-40 (-102%)	-2,945 (-705%)	41,739 (-12%)	850 (-85%)	-5,521 (-63%)	449 (-88%)
		Improved irrigation scheduling & reduce fertiliser on all crops by 5%					
Independent	Gross margins ($/ha/yr)	10,491 (-22%)	8,476 (-26%)	47,540 (-18%)	10,068 (-35%)	3,794 (-46%)	10,395 (-28%)
	N yield (kg N/ha/yr)	56 (-50%)	81 (-28%)	157 (-14%)	70 (-26%)	86 (-18%)	77 (-30%)
Low slope	Profit ($/ha/yr)	-1877 (-179%)	-3,860 (-967%)	34,950 (-26%)	-1,334 (-125%)	-7,972 (-136%)	-1,615 (-143%)
High slope	Profit ($/ha/yr)	-1819 (-174%)	-3,818 (-884%)	35,264 (-25%)	-1,264 (-123%)	-7,980 (-136%)	-1,558 (-141%)
		Improved irrigation scheduling & reduce fertiliser on all crops by 10%					
Independent	Gross margins ($/ha/yr)	7,114 (-47%)	3,168 (-72%)	37,950 (-35%)	7,269 (-53%)	1,817 (-74%)	6,649 (-54%)
	N yield (kg N/ha/yr)	54 (-51%)	73 (-35%)	151 (-17%)	68 (-28%)	83 (-21%)	73 (-34%)
Low slope	Profit ($/ha/yr)	-5,255 (-320%)	-9,169 (-2,160%)	25,359 (-46%)	-4,133 (-176%)	-9,949 (-195%)	-5,361 (-243%)
High slope	Profit ($/ha/yr)	-5,196 (-312%)	-9,127 (-1,974%)	25,673 (-46%)	-4,062 (-174%)	-9,956 (-195%)	-5,304 (-240%)

Numbers in parentheses are percentage change from base

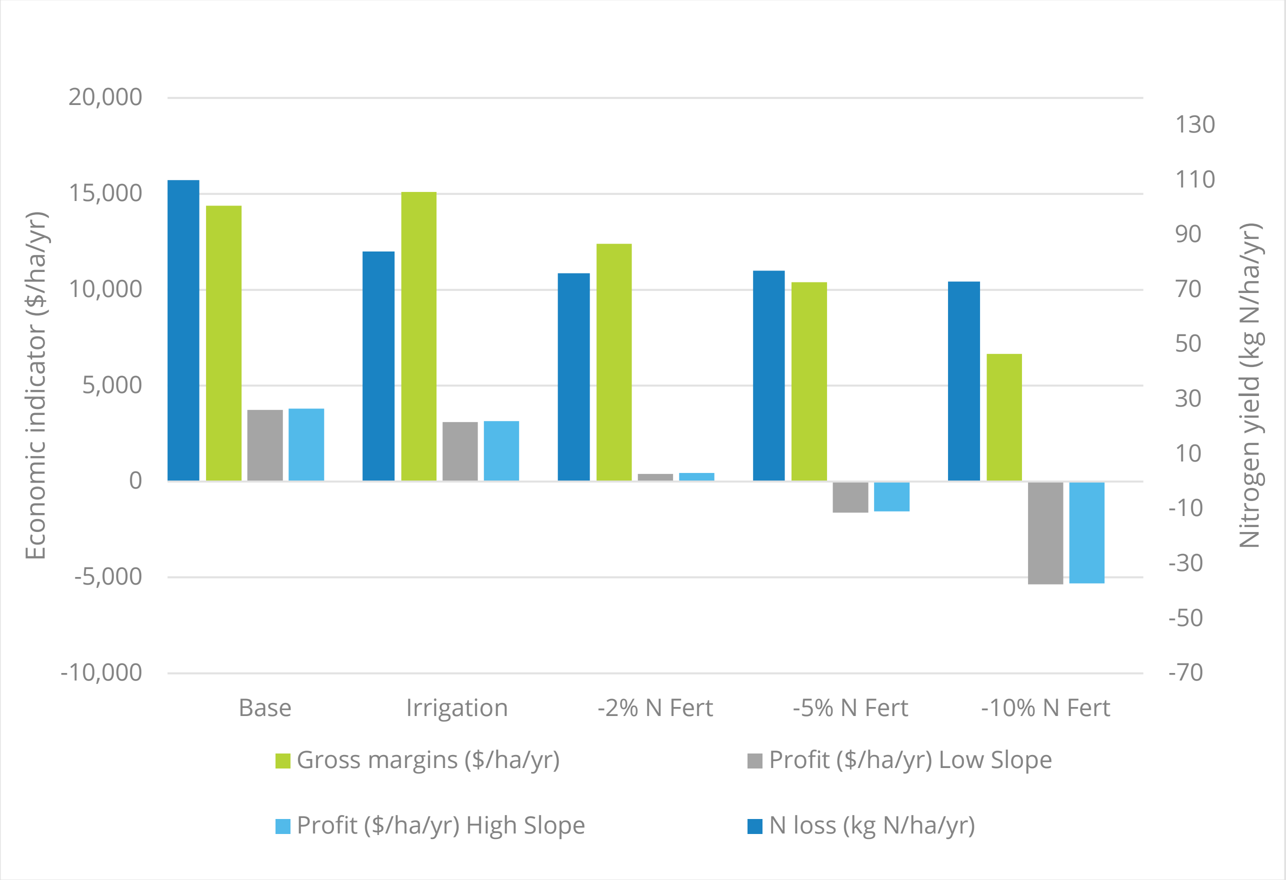

Figure 10: Weighted average nitrogen mitigation results

The results for the nitrogen mitigation show that between the base and the improved irrigation scenario there is an increase in gross margins (due to lower irrigation expenses), and a decrease in profit and nitrogen yield. The decrease in nitrogen yield (-24%) from the irrigation scenario is a much larger change than from subsequent fertiliser mitigations. This is likely because the significant reduction in irrigation applied reduced drainage and as such subsequent mitigations may have lower effectiveness (relative to their impact without the reduced irrigation). The fertiliser mitigations all decreased the gross margins as well as the profit and nitrogen yield relative to the base. Both the 5% reduction and 10% reduction in all nitrogen fertiliser led to negative profits (losses), while reducing nitrogen fertiliser by 2% on the high nitrogen loss targets had a positive profit, albeit very small, and would significantly impact the financial resilience of these businesses.

It is important to note that the 2% reduction of nitrogen fertiliser on high nitrogen loss crops was cheaper than the reduction of all nitrogen fertiliser by 5%, however the nitrogen yield was marginally (1 kg N/ha/yr) higher for the 5% reduction. However, this difference is only 1.3% and so is a very similar level of nitrogen yield. The results of these mitigations means that the FWMT will never choose the 5% reduction in fertiliser option if the model is left to optimise as it is less effective and more costly. This occurs because field yield is not reduced in the 2% reduction (sold yield is), however, the 5% reduction reduced field yield and so there is less crop available to utilise nitrogen in the soil meaning more is available to be lost. This result suggests that focused reductions in fertiliser change on high nitrogen loss crops are likely to be more efficient than blanket reductions which significantly impact production (both field and sold yields). However, it is clear that this will only achieve a limited reduction in nitrogen losses before more expensive mitigations are required.

8 Combining nitrogen, sediment and phosphorus mitigations

The mitigations for sediment and phosphorus are presented throughout this report as largely independent from nitrogen. This is due to the different models used to calculate the different contaminants. However, there is no reason these cannot be combined in any desirable combination. Table 76 presents these results by low and high slope as well as a weighted average (weighted based on proportions in Table 8).

Table 76: Combined mitigation results for 2% reduction in high N loss crops and WTR (inclusive of improved irrigation scheduling and improved sediment control)

		Rotation					Weighted average
		1	2	3	4	5	
		Baseline					
Independent	Gross margins ($/ha/yr)	13,392	11,417	58,200	15,467	7,027	14,384
	N yield (kg N/ha/yr)	111	113	182	95	105	110
Low slope	Overheads ($/ha/yr)	11,004	10,972	11,225	10,037	10,401	10,645
	Profit ($/ha/yr)	2,389	445	46,975	5,430	-3,374	3,740
	P yield (kg P/ha/yr)						3.8
	Sediment yield (t/ha/yr)						1.8
High slope	Overheads ($/ha/yr)	10,945	10,930	10,911	9,967	10,409	10,588
	Profit ($/ha/yr)	2,447	487	47,289	5,500	-3,382	3,796
	P yield (kg P/ha/yr)						7.1
	Sediment yield (t/ha/yr)						3.3
		Combined 2% reduction in high N loss crops and WTR (inclusive of improved irrigation scheduling and improved sediment control)					
Independent	Gross margins ($/ha/yr)	13,392	11,417	58,200	15,467	7,027	14,384 (-14%)
	N yield (kg N/ha/yr)	111	113	182	95	105	110 (-31%)
Low slope	Overheads ($/ha/yr)	13,126	13,079	12,650	12,079	12,579	12,010 (13%)
	Profit ($/ha/yr)	-855	-3,729	41,365	103	-6,326	392 (-90%)
	P yield (kg P/ha/yr)						1.2 (-68%)
	Sediment yield (t/ha/yr)						0.6 (-67%)
	Additional capital cost	$859/catchment area (50-yr life) and $5,000 (10 ha, 25-yr life)					
High slope	Overheads ($/ha/yr)	12,819	12,771	12,343	11,771	12,271	11,953 (13%)
	Profit ($/ha/yr)	-548	-3,421	41,672	411	-6,018	449 (-88%)
	P yield (kg P/ha/yr)						1.7 (-76%)
	Sediment yield (t/ha/yr)						0.8 (-76%)
	Additional capital cost	$845/catchment area (50-yr life) and $5,000 (10 ha, 25-yr life)					

Numbers in parentheses are percentage change from base

9 Kiwifruit mitigations

9.1 Introduction

The physical modelling for kiwifruit was completed by Zespri in SPASMO. As this research did not have access to this SPAMSO modelling, the mitigation modelling for kiwifruit is based on first principles and some empirical relationships where published (e.g., the nitrogen content of kiwifruit at different fertiliser application rates). This is a key area for future refinement in the FWMT. The only mitigation option that was considered was reducing the nitrogen applied to the kiwifruit orchard. Two simple options were considered; a 5 kg N/ha reduction in nitrogen application (100 kg N/ha/yr applied) and a further 10 kg N/ha reduction in fertiliser (90 kg N/ha/yr applied).

9.2 Method

The mitigation modelling for kiwifruit is based on an assumed relationship between fertiliser use and nitrogen yield. Nitrogen was the only contaminant that was reduced in this analysis. The application method and type of nitrogen (e.g., fertiliser versus compost) was not considered. The nitrogen mitigation was based on two relationships; the relationship between fertiliser application and fruit yield for green and gold kiwifruit and the relationship between fertiliser application and nitrogen yield. The relationship between fertiliser application and fruit yield was based on information provided by Zespri and NZKGI (as shown in Figure 11).

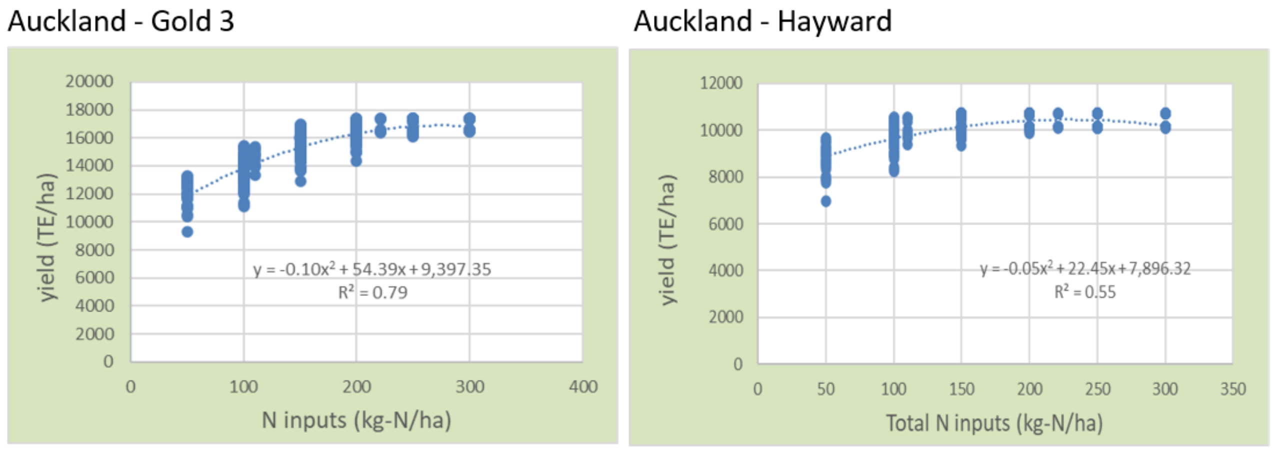

Figure 11: Kiwifruit fertiliser and yield relationship (Zespri and NZKGI, Pers. Comm)

The fruit yield information used for this project is based on a yield of 8,700 TE/ha for green and 13,100 TE/ha for gold kiwifruit in Auckland with 105 kg N/ha of fertiliser applied. When this fertiliser value is put into the relationship in Figure 11 the predicted yield for green kiwifruit is 9,702 TE/ha and 14,006 TE/ha for gold kiwifruit. The difference in the SPASMO yield and those shown in Figure 11 needs to be accounted for when assessing differences in yields for different fertiliser application rates This was done by shifting the fruit yield and fertiliser input curve down to fit in with the provided results for the Auckland region (from SPASMO). The expected fruit yield under different fertiliser application rates and the method used to calculate these are summarised in Table 77. The change in yield for mitigation 1 and 2 are based on the relationship in Figure 11 with an adjustment which shifts the curve down to meet the SPASMO yield data (base yield).

Table 77: Kiwifruit yield and fertiliser applications

Mitigation scenario	Green (TE/ha)	Gold (TE/ha)	Method
Baseline (105 kg N/ha)	8,700	13,100	Provided from SPASMO
Figure 11 baseline (105 kg N/ha)	9,702	14,006	Calculated from SPASMO fertiliser and yield from the original Figure 11 trendline equation
Mitigation 1 (100 kg N/ha)	8,639	12,931	Calculated based on revising the curve in Figure 11 down to fit the SPASMO yield/fertiliser relationship
Mitigation 2 (90 kg N/ha)	8,510	12,756	Calculated based on revising the curve in Figure 11 down to fit the SPASMO yield/fertiliser relationship

9.2.1 Efficacy

Ideally the change in nitrogen yield from varying yield and fertiliser applications would be calculated in the SPASMO model. However, this was beyond the scope of this study. With the need to estimate losses, a less precise method, such a numerical relationship, is required on which to base the associated nitrogen yield rate from different fertiliser and fruit yield combinations. In order to calculate the nitrogen yield relationship, the following steps were taken:

1. For the baseline scenario (105 kg N/ha/yr of fertiliser applied), the modelled nitrogen yield from SPASMO (26 kg N/ha/yr green, 22 kg N/ha/yr gold, and 24 kg N/ha/yr weighted) were removed from the fertiliser applied. This left a volume of nitrogen applied not lost to water. On the basis of a mass balance approach, it was assumed that this value was the nitrogen removed in product.
2. This nitrogen that was assumed to be removed in product was divided by the production (in trays equivalent) to establish a nitrogen removed per tray equivalent that could then be varied based on the production levels as a result of fertiliser use (Table 77). This was cross checked using an assumed rate of 280 trays per tonne and an average of 1.265 kg N/tonne of product removed from Journeaux et al. (2019). Carey et al. (2009) and Morton (2013) also noted that for Hayward (green) kiwifruit between 27 and 40 kg N/ha is removed in product. Based on our calculations for green kiwifruit there was approximately 39 kg N/ha being removed in product. There was no data to validate gold kiwifruit which was higher based on the same calculations for our work (59 kg N/ha/yr removed as product).
3. Mills et al. (2008) tested the nitrogen concentration in green kiwifruit under different nitrogen fertiliser treatments (0, 145 and 295 kg N/ha/yr) on a pumice orchard in Te Puke and noted that the higher the nitrogen fertiliser applied the higher the nitrogen content in each fruit. The inverse of this relationship is that as fertiliser is reduced the content of nitrogen in each fruit (or TE) also reduces. As such, there was an assumption made that the nitrogen content in the kiwifruit reduced by 2% in each TE for every 5 kg N/ha/yr that was removed from the orchard. It is acknowledged that this increase in the nitrogen content is arbitrary; however, any larger percentage change altered the nitrogen yield and fertiliser use curve to a relationship where the less fertiliser that was applied increased the nitrogen yield which is illogical based on first principles of nitrogen cycling.
4. The above steps allowed the amount of nitrogen removed in product to be calculated for each mitigation run and the associated yield. This amount was then removed from the nitrogen fertiliser applied and the remainder was the assumed nitrogen yield rate.

The results are summarised in Table 78. Because these have not been modelled in SPASMO they should be used with some caution as they are a very simplified process and do not account for factors such as changes in soil organic matter. Ideally further SPAMSO modelling would be completed to validate the nitrogen yield estimates but was beyond the scope of this contract.

Table 78: Estimated change in kiwifruit fertiliser and nitrogen yield

	Green (kg N yield /ha)	Gold (kg N yield /ha)	Weighted by variety (kg N yield/ha)
Baseline (105 kg N/ha)	26.4	22	24
Mitigation 1 (100 kg N/ha)	23.5	19.7	21.5
Mitigation 2 (90 kg N/ha)	20.6	17.4	18.9

9.2.2 Cost

The costs associated with the proposed kiwifruit mitigations are assumed to be the change in yield (and therefore income) and the change in fertiliser use. The change in yield and income is directly calculated through the difference in tray equivalent produced. The fertiliser costs in the gross margin are not based on the quantum of fertiliser but on the information provided from Zespri and NZKGI, this is assumed to be reduced proportionally to the change in fertiliser. This is a simplification of reality as the fertiliser costs in the gross margin also include application, and these costs will likely remain fixed even if less fertiliser is applied. However, given the information available it was assumed that this simplification was appropriate. These costs are summarised in Table 79.

Table 79: Costs and benefits of kiwifruit mitigation modelling (only impacted categories included)

	Baseline – 105 kg N/ha ($/ha)			Mitigation 1 – 100 kg N/ha ($/ha)			Mitigation 2 – 90 kg N/ha ($/ha)		
	Green	Gold	Weighted by variety	Green	Gold	Weighted by variety	Green	Gold	Weighted by variety
Tray equivalent/ha (TE/ha)	8,700	13,100	11,106	8,639	12,931	10,986	8,510	12,756	10,832
Orchard Gate Return ($/TE)	6.35	11.51	9.17	6.35	11.51	9.17	6.35	11.51	9.17
Orchard Gate Return/ha ($/ha)	55,245	150,781	107,488	54,858	148,836	100,742	54,039	146,822	99,329
Orchard working expenses ($/ha)									
Fertiliser (and application)	2,387	2,907	2,671	2,273	2,769	2,544	2,046	2,492	2,290
Total orchard working expenses ($/ha)	55,201	69,645	63,099	57,858	66,737	62,713	54,862	69,229	62,718
EBITDA ($/ha)	44	81,136	44,389	-3,000	82,099	38,029	-824	77,593	36,610

9.2.3 Opportunity

Because the fertiliser and production data are based on averages this mitigation is assumed to apply to 100% of this HRU. There was no available information on the range of fertiliser use on orchards in Auckland, though this could be an area for further research.

9.3 Kiwifruit mitigation summary

Table 80 summarises the key results for the nitrogen mitigation scenarios. All results are based a weighted average by hectares in green and gold kiwifruit in the Auckland region.

Table 80: Summary for nitrogen mitigations for kiwifruit (all weighted by hectares)

	Baseline	Mitigation 1	Mitigation 2
N fertiliser use (kg N/ha)	105	100	90
Production (TE/ha)	11,106	10,986	10,832
Orchard Gate Return/ha ($/ha)	107,488	100,742	99,329
Total orchard working expenses ($/ha)	63,099	62,713	62,718
EBITDA ($/ha)	44,389	38,029	36,610
N yield (kg N/ha)	24	21.5	18.9

Part C – Summary

This section presents the summary of results for use in the FWMT. It includes the baseline economic and environmental footprints for the CVP typology (i.e., the weighted CVP rotation) and the kiwifruit typology which is the proxy for the permanent horticulture crop in the FWMT. It also summarises the mitigation and opportunity results. This section concludes with a summary of key modelling assumptions and areas for further improvement for modelling horticulture in the FWMT.

10 Conclusions

10.1 Baseline footprints for CVP and kiwifruit

Table 81 presents a summary of baseline environmental and economic results for CVP (weighted by expected area in each rotation in the Pukekohe vegetable growing area, see Table 8) and kiwifruit. These are provided on an average annualised basis for nitrogen yield (nitrogen loss) (i.e., they take the average of all the yearly data in APSIM as well as an average across all crops within each five-year CVP rotation). The ESC results are annual, and the economic impacts are on an average annualised basis. Sediment and phosphorus yield are independent of crop type but differ by slope, while nitrogen yield is independent of slope type and differs by rotation.

Table 81: Summary of weighted baseline contaminant yields from CVP and kiwifruit

Average annual summaries	CVP	
	Low slope	High slope
Average annual gross margins ($/ha/yr)	14,384	14,384
Average annual profit ($/ha/yr)	3,740	3,797
P yield (kg P/ha/yr)	3.8	7.1
Sediment yield (t/ha/yr)	1.8	3.3
Average N yield (kg N/ha/yr)	110	110
	Kiwifruit	
EBIT ($/ha/yr)	44,389	
Total suspended sediment in runoff (kg/ha/yr)	194	
Total N in leachate (kg/ha/yr)	24	
Total mineral N in runoff (kg/ha/yr)	0.018	
Total P yield in runoff and leachate (kg/ha/yr)	0.556	
Total copper in runoff and leachate (kg/ha/yr)	0.086	
DRP in leachate (kg/ha/yr)	0.05	

One observation of note of the baseline results (and mitigation results) is that the profitability of high slope land is higher than the low slope land. The reason for this is that there is a higher assumed existing adoption of sediment control measures (VBSs and SRPs) at low slope land (see Section 3.3.5) meaning the overhead costs of sediment control is higher and therefore the profit is lower. The difference in profitability for the low and high and slopes is solely due to overheads as the gross margins are consistent across slope. This also shows that there is more scope to adopt sediment control mitigations on high slope land.

10.2 Mitigation results for CVP

Table 82 summarises the cost and efficacy of the sediment and phosphorus mitigations, namely improved sediment control and WTR. These are separated into two slope classes, the low slope class represents land on land less than or equal to 2° and is based on a modelled slope of 2°. The high slope class represents all land greater than 2° and is based on a model slope of 4° based on an approximate midpoint of the land between 2 and 17°. The values in Table 86 account for varying adoption and potential opportunities between low and high slope land for SRPs and VBSs (i.e., they can be applied directly to all CVP land in the applicable slope class in the FWMT). Alternatively, these slope classes could be weighted together based on the weights in Section 3.3.2.

Table 82: Summary of sediment and phosphorus yield mitigation output on Auckland CVP (WTR is inclusive of improved sediment control mitigation)

	Low slope			High slope		
	Base	**Improved sediment control**	**+ WTR**	**Base**	**Improved sediment control**	**+ WTR**
Average annual profit ($/ha/yr)	3,740	3,298 (-12%)	3,030 (-19%)	3,796	3,587 (-5%)	3,338 (-12%)
Additional capital cost ($)	0	$859/ha of catchment area (50-yr life)	$5,000 25-yr lifespan for 10 ha	0	$845/ha of catchment area (50-yr life)	$5,000 25-yr lifespan for 10 ha
P yield (kg P/ha/yr)	3.8	1.4 (-63%)	1.2 (-68%)	7.1	2.3 (-68%)	1.7 (-76%)
Sediment yield (t/ha/yr)	1.8	0.7 (-61%)	0.6 (-67%)	3.3	1.1 (-67%)	0.8 (-27%)

Numbers in parentheses are percentage change from base

Table 83 summarises the cost and efficacy of the nitrogen mitigations for CVP, namely improved irrigation scheduling and three independent fertiliser reductions. These are area-weighted by the five CVP rotations and their corresponding unique contaminant response and costs (see Table 8) i.e., are relevant to all of CVP as a single rotation-independent whole and can be applied directly to a combined CVP HRU in the FWMT). There are no additional capital costs included separately to the profitability impacts. All nitrogen mitigation results are sequential not additive (i.e., read left to right, include the prior mitigation's effects and costs), as such the maximum fertiliser reduction was 10% not 17%.

Table 83: Summary of cost and efficacy of nitrogen mitigations for Auckland CVP (note the fertiliser mitigations all include the improved irrigation scheduling mitigation but are not themselves additive)

Slope	Average annual summaries	Base	Improved irrigation scheduling (IIS)	IIS + Reduce N fertiliser on high N yield crops by 2%	IIS + Reduce N fertiliser on all crops by 5%	IIS + Reduce N fertiliser on all crops by 10%
Low slope	Profit ($/ha/yr)	3,740	3,096 (-17%)	392 (-90%)	-1,615 (-143%)	-5,361 (-243%)
High slope	Profit ($/ha/yr)	3,796	3,153 (-17%)	449 (-88%)	-1,558 (-141%)	-5,304 (-240%)
Independent	N loss (kg N/ha/yr)	110	84 (-24%)	76 (-31%)	77 (-30%)	73 (-34%)

Numbers in parentheses are percentage change from base

The 2% reduction in fertiliser on high nitrogen loss crops reduced nitrogen yield by 31%, while the 5% reduction of fertiliser across all crops reduced nitrogen yield by 30%. The 2% reduction in fertiliser on high nitrogen loss crops was also less costly. This occurs because field yield is not reduced in the 2% reduction (sold yield is), however, a 5% reduction reduced field yield and so there is less crop available to utilise nitrogen in the soil meaning more is available to be lost. Essentially these mitigations are not significantly different in terms of efficiency and show that targeting crops that are high nitrogen loss risk and making changes which minimise the impact on yield is more effective than targeting all crops where the impact on yield starts to reduce the efficiency of that mitigation.

10.3 Mitigation results for kiwifruit

Table 84 summarises the profit and nitrogen yield for the nitrogen mitigation scenarios for kiwifruit. All results are based a weighted average by hectares in green and gold kiwifruit in the Auckland region. Nitrogen is the only contaminant that had mitigations modelled.

Table 84: Summary for nitrogen mitigations for kiwifruit (all weighted by hectares)

	Base (105 kg N/ha/yr)	Mitigation 1 (100 kg N/ha/yr)	Mitigation 2 (90 kg N/ha/yr)
Production (TE/ha)	11,106	10,986 (-1%)	10,832 (-2%)
EBITDA ($/ha)	44,389	38,029 (-14%)	36,610 (-18%)
N yield (kg N/ha)	24	21.5 (-10%)	18.9 (-21%)
Numbers in parentheses are percentage change from base			

10.4 Representation

As discussed in Section 1.2 the published HRU framework within the FWMT Stage 1 (v1.0) split horticultural land use impact groups into ‘Low impact’, ‘Medium impact’ and ‘High impact’. Based on the revised analysis in this report it is recommended that this is altered to better reflect the improved data on baseline footprints, including the contaminant pathways, and land use management options for the differing land uses.

The recommended changes are summarised in Figure 12. This shows that idle fallow land, arable and fodder land are grouped together and represented by an arable land use grouping. This land use grouping is represented by the maize silage system modelled for the ‘Medium impact’ horticulture typology in Muller et al. (2020b). Orchards based on perennial tree crops are grouped together and are represented by the kiwifruit land use modelled as part of this report. Commercial vegetable production land uses are grouped together and are based on the CVP rotations modelled in this report. As above, these groupings are not solely linked to environmental impact, but are based on contaminant pathways, baseline footprints (economic and environmental) and applicable mitigation options.

A significant change in the HRU groupings is separating out CVP and perennial horticulture (e.g., kiwifruit) as these land uses have different contaminant processes, footprints and mitigation options. The other significant change proposed is to separate out crops based on a more annual cycle and integrated with pasture (e.g., arable cropping) and CVP which includes much more frequent cultivation and different crop types.

While this report only modelled CVP and kiwifruit (previously both in the ‘High impact’ grouping) it was clear that these land uses should be separated based on the baseline footprints and contaminant processes identified in this research (especially across different types of contaminants, e.g., sediment in CVP is not an issue for kiwifruit/perennial horticulture). Muller et al. (2020b) considered other types of horticulture and recommended that the ‘Low impact’ and ‘Medium impact’ groupings were combined (largely due to uncertainty in what constituted ‘Low impact’ land separate to the other two groupings). In addition, they recommended that these land uses were based on an arable model derived from the maize silage system modelled in Matheson et al. (2018). Because this work has not reconsidered arable crops there is no reason to remove this model from the revised HRU groupings and land not suited to CVP or the perennial horticulture model were assigned to this arable model.

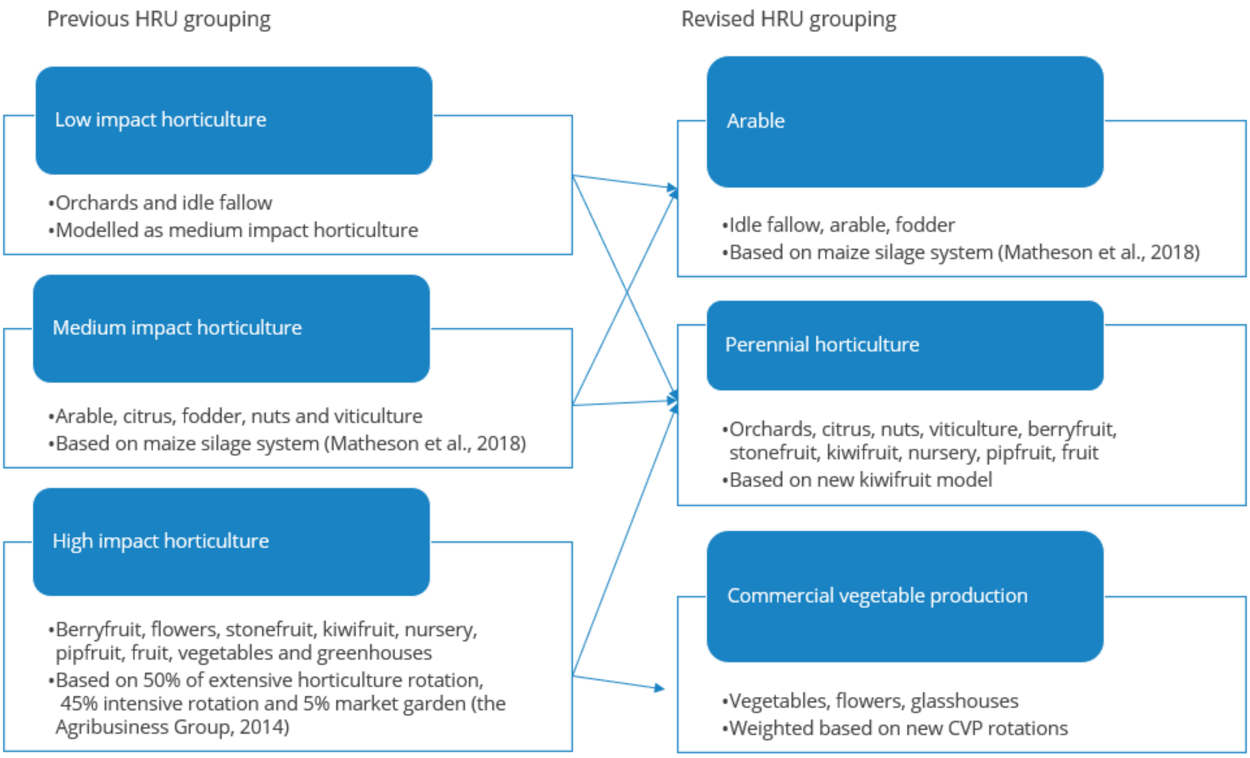

Figure 12: Revised land use impact classes for horticulture

In order to combine the CVP rotations detailed in this report into one land use impact class for the FWMT, a representative factor was assigned to each CVP rotation. This was done as because there was no way to map these land uses separately. In addition, while there is variation in footprints and profit across the five rotations, the contaminant processes and applicable mitigation options were consistent across the five rotations. Table 8 summarises the weightings for the five CVP rotations in this work.

Table 85 provides a summary of the recommended revised HRU framework for the FWMT based on the analysis in this report. At this stage there is no differentiation between soil types across the revised HRUs. That being said the, CVP HRU is modelled on the CVP rotations detailed in this report which are based on a Morrinsville_8a.1 soil from Landcare (2022), a moderately well drained soil. In addition, there is no information at this stage to differentiate slope type for arable and perennial horticulture. The cultivated horticulture HRU is only typed for flat to rolling slope, this category in the FWMT is defined from region-wide LiDAR at less than 10% (approximately 6°). The CVP models in this report are based on low and high slope (with low slope based on 2° and high slope based on a 4° model). Given the proportion of CVP land on flat to rolling land (see Table 15) it is felt that this is only applicable to flat to rolling land slopes in the FWMT.

Table 85: Summary of the recommended horticulture HRUs

Land cover	Intensity	Soil group	Slope
Horticulture	**Arable** - Idle fallow, arable, fodder Based on maize silage system (Matheson et al., 2018)	Free draining	Flat to rolling
			Rolling to steep
		Moderately draining	Flat to rolling
			Rolling to steep
		Poorly drained	Flat to rolling
			Rolling to steep
	Perennial horticulture - Orchards, citrus, nuts, viticulture, berryfruit, stonefruit, kiwifruit, nursery, pipfruit, fruit Based on new kiwifruit model	Free draining	Flat to rolling
			Rolling to steep
		Moderately draining	Flat to rolling
			Rolling to steep
		Poorly drained	Flat to rolling
			Rolling to steep
	Cultivated horticulture - Flowers, vegetables & greenhouses Based on new CVP model	Free draining	Flat to rolling
		Moderately draining	Flat to rolling
		Poorly drained	Flat to rolling

10.5 Key modelling assumptions and limitations

Modelling inherently relies on assumption and has limitations. While these have been discussed where relevant throughout the report it is necessary to highlight the key ones in this summary. The key assumptions and limitations for this modelling are:

- The costs in this report are only considered to the farm gate and do not include flow on effects to the quantity of food supplied to consumers, the quality or price of this food. Equally it does not include flow on considerations such as changes in employment because of changes behind the farm gate.
- Contaminant yields are considered at the farm level, i.e., nitrogen yields are nitrogen that leaves the root zone, not nitrogen necessarily reaching waterbodies. Sediment and phosphorus are also considered in a similar manner, namely yields from a farm, but not necessarily to water.
- This work does not consider the impact of the changing water quality e.g., on amenity values, nor the impact of the access and availability of fresh fruit and vegetables to communities.
- The five CVP rotations and kiwifruit are assumed to represent all cultivated and perennial horticulture. In reality there are many more crops that are grown, a wide range of practices and growing systems and rotations and a wide range of cost and income profiles. For example, even for potatoes there are many varieties, methods of growing and timings, costs and revenues that can be combined for different growers and different seasons.
- The CVP rotations have been weighted to get a combined average, these weightings need to be further quantified.
- The gross margins and profitability assessments do not consider factors such processing and many CVP entities are vertically integrated to some extent. As such, these are very much an arbitrary construct and simplification of a CVP business.

- Input and output costs need to be considered on the same basis. The current period of high inflation is a challenge for setting prices. Output prices were taken more as a typical price across the past few seasons and as such, input prices were matched to this where possible. Although limitations on data availability restricted this being applied consistently, e.g., where literature estimates were used, these were adjusted using inflation rather than being an average of the last few years.
- The modelling does not capture extreme weather events and the associated response, nor any potential future changes to the Auckland weather systems as a result of climate change.
- Mitigations that are modelled are not all those that could be used in reality and there is significant uncertainty in the impact of the mitigations.
- To present a static rotation on a per hectare basis is a simplification of reality. In reality, growers are growing a multitude of different crops and planting single rows of one plant type and constantly planting and harvesting. In addition, there are a multitude of crop varieties within one crop type, for example, different potato types aimed at different markets with different management practices, planting and harvesting dates etc. However, modelling inherently simplifies reality and the rotations modelled are likewise a simplification of reality.

In addition to these assumptions, the results in this report should be read as relative changes. While the exact values of price and contaminant loss may vary in reality, by different farms or across time, the relative results are considered more robust.

10.5.1 Considerations for integration into the FWMT

When integrating these results into the FWMT a few key considerations need to be noted:

- The CVP land in this work has been separated into low and high slope. This distinction could be retained in the FWMT, or alternatively these could be weighted together based on the weights in Section 3.3.2.
- While the mitigations for sediment and phosphorus are presented throughout this report as largely independent from nitrogen, there is no reason these cannot be combined as desired. This was demonstrated in Section 8.
- The improved sediment control mitigation (and therefore the WTR mitigation, as these are cumulative) includes a combination of SRPs and VBSs. Currently the SRP is also a device separately parameterised in the FWMT. The sediment and phosphorus mitigations in this research if combined with a separate SRP device will lead to duplication of effect and opportunity. Instead, only one should be used. It is recommended that the results in this work are preferred for CVP land given that this work has used the ESC directly for Pukekohe CVP land and the inputs into this and the economic impact have been reviewed by the TAG and growers. In addition, this work considers, albeit qualitatively, how much land is already treated by SRPs and the likely interaction between SRPs and VBSs when growers are treating sediment loss. While other practice-based mitigations for sediment and phosphorus were discussed with growers it was felt that SRPs and VBSs are the key mitigation currently used and likely to be the preferred option into the future.
- The capital costs for the improved sediment control, WTR and improved irrigation scheduling mitigations need to be integrated with caution as they are all in different units. The improved irrigation scheduling and WTR capital costs are based on the hectares treated. However, the improved sediment control capital costs are based on the catchment area that is being drained to that device.

- The metrics used in this work to measure contaminant loss include nitrogen yield or leachate from the rootzone and sediment and phosphorus yield. Sediment through this report refers to total sediment yields, while phosphorus refers total phosphorus inclusive of particulate and dissolved reactive phosphorus (based on the models used). This needs to be considered when integrating the work into the FWMT.
- Based on the 2% and 5% reductions in fertiliser results, the optimisation process in FWMT will never select the 5% reduction of fertiliser across all crops. Essentially these mitigations are not significantly different in terms of efficiency but the 5% reduction in fertiliser is more costly. This is discussed in more detail in Section 7.3. As such, only one of these mitigations should be included in the FWMT at one time.

10.6 Key areas for improvement

During this project there were clear areas identified for further research. There are three key areas which should be improved for further iterations of the FWMT and/or for further horticulture modelling.

- Nitrogen yields from CVP (baseline and mitigations)

Modelling nitrogen yields from CVP has been a challenging exercise as there is a lot of variation in rotations, practices, annual variation and the impact of changed practices is hard to generalise and quantify. There have been some significant criticisms of using Overseer for modelling CVP (e.g., Keenan, 2019; Ford, 2019) and as such this work chose to use APSIM which has been more accepted as it can better model the nuances and timescales associated with CVP.

As discussed in Section 7.3 there is considerable uncertainty around the cost and efficacy of the nitrogen fertiliser mitigations presented in this work. Modelling the expected nitrogen yields from CVP crops is extremely complex. The APSIM models represent generalised crop yields, fertiliser practices, residue management, irrigation management and soil nitrogen levels and as such there is limited data on which to estimate the yield (both field and sold) impacts. As a results, the nitrogen mitigation results presented here need to be used with caution and this is a key area for further improvements to the FWMT and horticulture modelling more generally.

In addition to this, there were limited mitigations that could be included in a generalised modelling context and mitigations which may be useful in individual contexts such as residue management, fertiliser placement and types, where not able to be modelled in this work with any confidence.

Understanding how to reduce nitrogen yields from CVP is a key area that needs further support. There are limited options available especially options which are not cost prohibitive (both from input cost and change in yield). It is an area that needs to be supported further beyond the FWMT and in conjunction with existing and ongoing research (e.g., the Sustainable Vegetable Systems research) and with growers.

- Opportunity of mitigations

There is no quantifiable information on the current extent of environmental practices across horticulture in Auckland, nor of the opportunity to adopt further mitigations. The baseline period in the FWMT is 2013-2017 and there is also no quantifiable data on use of SRPs and VBS in this baseline period either. Using best professional estimates on the current levels of adoption (2022) of SRPs and VBSs possibly overestimates their use compared to the baseline period in the FWMT.

One key limitation for the CVP rotations in this sense is that the rotations modelled here are hypothetical so even if the area that drained into SRPs was known, it would be complex to then assign these to the rotations. While some of this data is likely captured in the horticulture operations that have an NZGAP EMS accreditation, it is not readily available across all the horticulture land in Auckland. In the way the modelling has been conducted in this report, this lack of data on use of environmental mitigation is of particular relevance to the assumptions for the sediment and phosphorus mitigation modelling. The way the results are calculated, it would be possible to update them if data on the use of SRPs, VBSs and WTR was able to be quantified. Until this data is quantified it is a key are of weakness when using the modelling results here in the FWMT. While the current estimates are based on best professional judgement and talking with experts and growers, quantifiable data is important to validate this. This affects the baseline sediment and phosphorus yields as well as the mitigations.

- Kiwifruit nitrogen mitigation modelling

The physical modelling for the baseline environmental footprint of kiwifruit was completed by Zespri in SPASMO and measured data (albeit in the Bay of plenty). This means the baseline footprints are this research are considered robust. However, because this work did not have access to the baseline SPASMO models nor the scope to commission further SPASMO modelling, the mitigation runs for nitrogen for kiwifruit were not based on modelled output and instead based on simplified relationships between, fertiliser use, yield and assumptions on the nitrogen content in the fruit. This means the nitrogen yields results for the kiwifruit typology are not as robust as the baseline footprints and this is an area for further development as this typology represents all permanent horticulture in Auckland.

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Appendices

1. Crop gross margin assumptions- at base

Table 86: Carrot gross margin assumptions

Crop	Carrots	Carrots	Notes and sources
Rotation	**1**	**2**	
Revenue			
Sold yield (t/ha)	55	55	See Table 20 for yield and wastage information. Based on grower survey.
Price ($/t)	600	600	
Revenue ($/ha)	**33,000**	**33,000**	
Expenses			
Seed	2,900	2,900	Based on grower survey.
Cultivation/planting	935	935	Based on a fuel price of $2.80/litre and labour cost of $34/hr. Quantity of fuel and hours of labour came from DPI. (2013).
Fertiliser	1,832	1,221	Grower survey supplied typical rates and types of fertilisers. Fertiliser prices came from price lists effective from April 2022 from commercial fertiliser suppliers.
Agri-chemicals	1,150	1,150	Based on grower survey.
Irrigation	224	0	Millimetres of water applied per month came from APSIM based on water assumptions. The price for per mm of water was $2/mm applied which came from Muller et al. (2021).
Harvesting	1,440	1,440	Based on a fuel price of $2.80/ litre and labour cost of $34/hr for machine operators and $26/hr for casual labour. Quantity of fuel and hours of labour came from DPI. (2013).
Grading	7,150	7,150	Based on grower survey.
Packing	2,634	2,634	$41/t from The AgriBusiness Group (2014) which was inflation adjusted to $48/t.
Freight	1,650	1,650	$30/t sourced from growers' survey and The AgriBusiness Group (2014).
Levies	162	162	Levy information as at February 2021 provided by HortNZ
Total expenses	**20,077**	**19,242**	
Gross margin	**12,923**	**13,758**	

Table 87: Onion gross margin assumptions

Crop	Onions	Onions	Notes and sources
Rotation	**1, 3**	**2, 5**	
Revenue			
Sold yield (t/ha)	40	40	See Table 20 for yield and wastage information. Based on grower survey.
Price ($/t)	550	550	
Revenue ($/ha)	22,000	22,000	
Expenses			
Seed	2,000	2,000	Based on grower survey.
Cultivation/planting	988	988	Based on a fuel price of $2.80/litre and labour cost of $34/hr. Quantity of fuel and hours of labour came from DPI. (2013).
Fertiliser	2,436	2,216	Grower survey supplied typical rates and types of fertilisers. Fertiliser prices came from price lists effective from April 2022 from commercial fertiliser suppliers.
Agri-chemicals	2,200	2,200	Based on grower survey.
Irrigation	840	637	Millimetres of water applied per month came from APSIM based on water assumptions. The price for per mm of water was $2 / mm applied which came from Muller et al. (2021).
Harvesting	3,269	3,269	Based on grower survey.
Grading	2,900	2,900	Based on DPI. (2013) updated with current labour costs.
Packing	3,504	3,504	$75/t from The AgriBusiness Group (2014) which was inflation adjusted to $88/t.
Freight	1,000	1,000	$25/t sourced from growers' survey and The AgriBusiness Group (2014).
Levies	100	100	Levy information as at February 2021 provided by HortNZ
Total expenses	**19,236**	**18,813**	
Gross margin	**2,764**	**3,187**	

Table 88: Potato gross margin assumptions

Crop	Potatoes	Potatoes	Notes and sources
Rotation	**1, 3**	**2, 5**	
Revenue			
Sold yield (t/ha)	45	45	See Table 20 for yield and wastage information. Based on grower survey.
Price ($/t)	520	520	
Revenue ($/ha)	23,400	23,400	
Expenses			
Seed	7,450	7,450	Based on grower survey.
Cultivation/planting	355	355	Based on a fuel price of $2.80/litre and labour cost of $34/hr. Quantity of fuel and hours of labour came from DPI. (2013).
Fertiliser	3,928	2,928	Grower survey supplied typical rates and types of fertilisers. Fertiliser prices came from price lists effective from April 2022 from commercial fertiliser suppliers.
Agri-chemicals	1,587	1,587	Based on Lincoln University (2022).
Irrigation	637	364	Millimetres of water applied per month came from APSIM based on water assumptions. The price for per mm of water was $2/mm applied which came from Muller et al. (2021).
Harvesting	2,316	2,316	Based on DPI. (2013) updated with current costs from grower survey.
Grading	1,875	1,875	Based on DPI. (2013) updated with current costs from grower survey.
Packing	2,523	2,523	$46/t from The AgriBusiness Group (2014) which was inflation adjusted to $56/t.
Freight	1,125	1,125	$25/t sourced from grower survey and The AgriBusiness Group (2014).
Levies	232	232	Levy information as at February 2021 provided by HortNZ
Total expenses	**22,027**	**20,754**	
Gross margin	**1,373**	**2,646**	

Table 89: Pumpkin gross margin assumptions

Crop	Pumpkin	Notes and sources
Rotation	**5**	
Revenue		
Sold yield (t/ha)	20	See Table 20 for yield and wastage information. Based on grower survey.
Price ($/t)	750	
Revenue ($/ha)	15,000	
Expenses		
Seed	1,199	Based on DPI. (2013).
Cultivation/planting	606	Based on a fuel price of $2.80/litre and labour cost of $34/hr. Quantity of fuel and hours of labour came from DPI. (2013) butternut gross margin.
Fertiliser	1,029	Grower survey supplied typical rates and types of fertilisers. Fertiliser prices came from price lists effective from April 2022 from commercial fertiliser suppliers.
Agri-chemicals	448	Based on DPI. (2013) then inflation and exchange rate adjusted.
Irrigation	861	Millimetres of water applied per month came from APSIM based on water assumptions. The price for per mm of water was $2/mm applied which came from Muller et al. (2021).
Harvesting	5,026	Based on DPI. (2013) updated with current labour costs.
Grading	-	Included in harvesting cost.
Packing	700	$30/t from The AgriBusiness Group (2014) which was inflation adjusted to $35/t.
Freight	1,300	$65/t sourced from grower survey and The AgriBusiness Group (2014).
Levies	74	Levy information as at February 2021 provided by HortNZ
Total expenses	11,242	
Gross margin	3,758	

Table 90: Spinach gross margin assumptions

Crop	Spinach	Notes and sources
Rotation	**3**	
Revenue		
Sold yield (t/ha)	11	See Table 20 for yield and wastage information. Based on grower survey.
Price ($/t)	4,500	
Revenue ($/ha)	49,500	
Expenses		
Seed	2,920	Based on The AgriBusiness Group (2014) then inflation adjusted.
Cultivation/planting	1,752	Based on The AgriBusiness Group (2014) then inflation adjusted.
Fertiliser	1,322	Grower survey supplied typical rates and types of fertilisers. Fertiliser prices came from price lists effective from April 2022 from commercial fertiliser suppliers.
Agri-chemicals	1,191	Based on The AgriBusiness Group (2014) then inflation adjusted.
Irrigation	588	Millimetres of water applied per month came from APSIM based on water assumptions. The price for per mm of water was $2/mm applied which came from Muller et al. (2021).
Harvesting	7,592	Based on The AgriBusiness Group (2014) then inflation adjusted.
Grading	4,976	Based on The AgriBusiness Group (2014) then inflation adjusted.
Packing	1,368	$107/t from The AgriBusiness Group (2014) which was inflation adjusted to $124/t.
Freight	880	$80/t sourced from The AgriBusiness Group (2014) which was inflation adjusted.
Levies	243	Levy information as at February 2021 provided by HortNZ
Total expenses	22,832	
Gross margin	26,668	

Table 91: Oat, Phaecelia and Ryegrass gross margin assumptions

Crop	Oats	Phaecelia	Ryegrass	Notes and sources
Rotation	**1, 2, 3, 4**	**1, 3**	**5**	
Revenue				
Sold yield (t/ha)	Incorporated	Incorporated	Incorporated	
Price ($/t)	-	-	-	
Revenue ($/ha)	-	-	-	
Expenses				
Seed	300	200	200	Based on Askin and Askin (2018). Oat seed price from commercial seed suppliers price list.
Cultivation/planting	220	220	220	Based on Askin and Askin (2018)
Fertiliser	-	-	-	
Agri-chemicals	-	-	-	
Irrigation	669	686	-	
Harvesting	-	-	-	
Grading	-	-	-	
Packing	-	-	-	
Freight	-	-	-	
Levies	-	-	-	
Total expenses	1,189	1,106	420	
Gross margin	-1,189	-1,106	-420	

Table 92: Barley gross margin assumptions

Crop	Barley (grain & incorporated)	Notes and sources
Rotation	**1, 2, 4, 5**	
Revenue		
Sold yield (t/ha)	7.5	Based on grower survey.
Price ($/t)	500	Based on and Lincoln University (2022).
Revenue ($/ha)	3,750	
Expenses		
Seed	200	Based on Askin and Askin (2018).
Cultivation/planting	220	Based on Askin and Askin (2018) and Lincoln University (2022).
Fertiliser	288	Grower survey supplied typical rates and types of fertilisers. Fertiliser prices came from price lists effective from April 2022 from commercial fertiliser suppliers.
Agri-chemicals	294	Based on Askin and Askin (2018) and Lincoln University (2022).
Irrigation	712	Millimetres of water applied per month came from APSIM based on water assumptions. The price for per mm of water was $2/mm applied which came from Muller et al. (2021).
Harvesting	460	Based on Askin and Askin (2018) and Lincoln University (2022).
Grading	-	
Packing	-	
Freight	240	$27/t sourced from The AgriBusiness Group (2014) which was inflation adjusted to $32/t.
Levies	-	
Total expenses	2,414	
Gross margin	1,336	

Table 93: Cabbage gross margin assumptions

Crop	Cabbage (summer)	Cabbage (winter)	Notes and sources
Rotation	**1**	**1**	
Revenue			
Sold yield (t/ha)	18,000	18,000	See Table 20 for yield and wastage information. Based on grower survey.
Price ($/t)	1.50	1.50	
Revenue ($/ha)	27,000	27,000	
Expenses			
Seed	3,212	3,212	Based on The AgriBusiness Group (2014) which was inflation adjusted.
Cultivation/planting	1,378	1,378	Based on a fuel price of $2.80/litre and labour cost of $34/hr. Quantity of fuel and hours of labour came from DPI. (2013) butternut gross margin.
Fertiliser	796	820	Grower survey supplied typical rates and types of fertilisers. Fertiliser prices came from price lists effective from April 2022 from commercial fertiliser suppliers.
Agri-chemicals	502	502	Based on DPI. (2013) then inflation and exchange rate adjusted.
Irrigation	434	-	Millimetres of water applied per month came from APSIM based on water assumptions. The price for per mm of water was $2/mm applied which came from Muller et al. (2021).
Harvesting	3,180	3,180	Based on DPI. (2013) updated with current labour costs.
Grading	-	-	No figures available
Packing	-	-	No figures available
Freight	2,592	2,592	Based on The AgriBusiness Group (2014) which was inflation adjusted
Levies	132	132	Levy information as at February 2021 provided by HortNZ
Total expenses	12,266	11,816	
Gross margin	14,774	15,184	

Table 94: Silverbeet gross margin assumptions

Crop	Silverbeet	Notes and sources
Rotation	**1**	
Revenue		
Sold yield (t/ha)	24,000	See Table 20 for yield and wastage information. Based on grower survey.
Price ($/t)	1.25	
Revenue ($/ha)	30,000	
Expenses		
Seed	1,132	Price from commercial seed suppliers price list. Rate from DPI. (2013).
Cultivation/planting	1,378	Based on cabbage gross margin.
Fertiliser	1,423	Grower survey supplied typical rates and types of fertilisers. Fertiliser prices came from price lists effective from April 2022 from commercial fertiliser suppliers.
Agri-chemicals	502	Based on cabbage gross margin.
Irrigation	1,106	Millimetres of water applied per month came from APSIM based on water assumptions. The price for per mm of water was $2/mm applied which came from Muller et al. (2021).
Harvesting	3,180	Based on cabbage gross margin.
Grading	-	No figures available
Packing	-	No figures available
Freight	1,440	Based on spinach freight cost
Levies	147	Levy information as at February 2021 provided by HortNZ
Total expenses	10,308	
Gross margin	19,693	

Table 95: Cauliflower gross margin assumptions

Crop	Cauliflower	Notes and sources
Rotation	**3**	
Revenue		
Sold yield (t/ha)	21,300	See Table 20 for yield and wastage information. Based on grower survey.
Price ($/t)	1.50	
Revenue ($/ha)	31,950	
Expenses		
Seed	3,212	Based on The AgriBusiness Group (2014) which was inflation adjusted.
Cultivation/planting	2,102	Based on The AgriBusiness Group (2014) which was inflation adjusted.
Fertiliser	1,604	Grower survey supplied typical rates and types of fertilisers. Fertiliser prices came from price lists effective from April 2022 from commercial fertiliser suppliers.
Agri-chemicals	876	Based on The AgriBusiness Group (2014) which was inflation adjusted.
Irrigation	-	Millimetres of water applied per month came from APSIM based on water assumptions. The price for per mm of water was $2/mm applied which came from Muller et al. (2021).
Harvesting	4,088	Based on The AgriBusiness Group (2014) which was inflation adjusted.
Grading	-	No figures available
Packing	-	No figures available
Freight	3,067	Based on The AgriBusiness Group (2014) which was inflation adjusted
Levies	157	Levy information as at February 2021 provided by HortNZ
Total expenses	15,106	
Gross margin	16,844	

Table 96: Spring onion gross margin assumptions

Crop	Spring onion	Notes and sources
Rotation	**3**	
Revenue		
Sold yield (t/ha)	816,300	See Table 20 for yield and wastage information. Based on grower survey.
Price ($/t)	0.07	
Revenue ($/ha)	57,141	
Expenses		
Seed	1,700	Based on Askin and Askin (2018).
Cultivation/planting	1,752	Based on spinach gross margin.
Fertiliser	945	Grower survey supplied typical rates and types of fertilisers. Fertiliser prices came from price lists effective from April 2022 from commercial fertiliser suppliers.
Agri-chemicals	2,000	Based on grower survey.
Irrigation	1,260	Millimetres of water applied per month came from APSIM based on water assumptions. The price for per mm of water was $2/mm applied which came from Muller et al. (2021).
Harvesting	9,110	Based on grower survey and spinach gross margin
Grading	5,971	Based on grower survey and spinach gross margin
Packing	1,500	Based on grower survey and spinach gross margin
Freight	2,612	Based on spinach gross margin
Levies	280	Levy information as at February 2021 provided by HortNZ
Total expenses	27,130	
Gross margin	30,011	

Table 97: Asian greens gross margin assumptions

Crop	Asian Greens	Notes and sources
Rotation	**3**	
Revenue		
Sold yield (t/ha)	293,550	See Table 20 for yield and wastage information. Based on grower survey.
Price ($/t)	0.50	
Revenue ($/ha)	146,775	
Expenses		
Seed	2,600	Based on grower survey
Cultivation/planting	1,050	Based on grower survey
Fertiliser	718	Grower survey supplied typical rates and types of fertilisers. Fertiliser prices came from price lists effective from April 2022 from commercial fertiliser suppliers.
Agri-chemicals	1,600	Based on grower survey.
Irrigation	400	Millimetres of water applied per month came from APSIM based on water assumptions. The price for per mm of water was $2/mm applied which came from Muller et al. (2021).
Harvesting	13,856	Based on grower survey
Grading	20,331	Based on grower survey
Packing	4,000	Based on grower survey
Freight	3,669	Based on lettuce freight cost $50/t
Levies	719	Levy information as at February 2021 provided by HortNZ
Total expenses	**48,943**	
Gross margin	**97,832**	

Table 98: Broccoli summer and winter gross margin assumptions

Crop	Broccoli (summer)	Broccoli (winter)	Notes and sources
Rotation	**2, 5**	**2, 4**	
Revenue			
Sold yield (t/ha)	19,727	24,583	See Table 20 for yield and wastage information. Based on grower survey.
Price ($/t)			
Revenue ($/ha)	19,053	28,660	
Expenses			
Seed	800	1,000	Based on grower survey
Cultivation/planting	2,000	2,200	Based on grower survey
Fertiliser	809	1,204	Grower survey supplied typical rates and types of fertilisers. Fertiliser prices came from price lists effective from April 2022 from commercial fertiliser suppliers.
Agri-chemicals	888	1,000	Based on grower survey.
Irrigation	441	364	Millimetres of water applied per month came from APSIM based on water assumptions. The price for per mm of water was $2/mm applied which came from Muller et al. (2021).
Harvesting	1,700	1,700	Based on grower survey
Grading	701	701	Based on grower survey
Packing	-	-	Based on grower survey
Freight	1,862	1,862	Based on The AgriBusiness Group (2014) which was inflation adjusted
Levies	93	140	Levy information as at February 2021 provided by HortNZ
Total expenses	**9,294**	**10,171**	
Gross margin	**9,759**	**18,489**	

Table 99: Lettuce summer and winter gross margin assumptions

Crop	Lettuce (summer)	Lettuce (winter)	Notes and sources
Rotation	**4**	**2, 3**	
Revenue			
Sold yield (t/ha)	28,600	23,400	See Table 20 for yield and wastage information. Based on grower survey.
Price ($/t)	1.00	1.20	
Revenue ($/ha)	28,600	28,080	
Expenses			
Seed	1,200	1,200	Based on grower survey
Cultivation/planting	5,267	5,267	Based on grower survey
Fertiliser	744	1,075	Grower survey supplied typical rates and types of fertilisers. Fertiliser prices came from price lists effective from April 2022 from commercial fertiliser suppliers.
Agri-chemicals	1,500	1,753	Based on grower survey and DPI. (2013) where figures were inflation and exchange rate adjusted.
Irrigation	378	158	Millimetres of water applied per month came from APSIM based on water assumptions. The price for per mm of water was $2/mm applied which came from Muller et al. (2021).
Harvesting	5,740	5,740	Based on grower survey and DPI. (2013) where figures were inflation and exchange rate adjusted.
Grading	-	-	
Packing	2,044	2,044	Based on The AgriBusiness Group (2014) which was inflation adjusted
Freight	1,216	878	Based on The AgriBusiness Group (2014) which was inflation adjusted
Levies	140	138	Levy information as at February 2021 provided by HortNZ
Total expenses	**18,229**	**18,253**	
Gross margin	**10,371**	**9,827**	

2. ESC results for all combinations of sediment controls for low slope land

Table 100: Baseline and mitigated (improved sediment control) sediment and phosphorus modelling results for individual and combined options for low slope land

Low slope land	None	SRP 0.25%	SRP 0.50%	VBS 3 m	VBS 5 m	SRP 0.25% & VBS 3 m	VBS 3 m & SRP 0.50%	SRP 0.25% & VBS 5 m	VBS 5 m & SRP 0.50%	Baseline weighted	Mitigated weighted
Inputs											
SRP size	0.00%	0.25%	0.50%	0.00%	0.00%	0.25%	0.50%	0.25%	0.50%	Table 18	Table 61
VBS details	No	No	No	3m	5m	3m	3m	5m	5m		
Results (rate of soil erosion)											
Baseline erosion (t/ha/yr)	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2
Treatment (%)	20.0%	99.3%	99.4%	54.7%	70.6%	99.6%	99.7%	99.7%	99.8%	66%	87.0%
Mitigated by measure (t/ha/yr)	1.0	5.2	5.2	2.8	3.7	5.2	5.2	5.2	5.2	3.4	4.5
Not mitigated by measure (t/ha/yr)	4.2	0.0	0.0	2.4	1.5	0.0	0.0	0.0	0.0	1.8	0.7
Not mitigated soil yield (mm/ha/yr)	0.35	0.00	0.00	0.20	0.13	0.00	0.00	0.00	0.00	0.15	0.05
P yield (kg P/ha/yr)	9.0	0.1	0.1	5.1	3.3	0.0	0.0	0.0	0.0	3.8	1.4
Reduction of suspended sediment by SRP	0.0%	73.0%	88.0%	0.0%	0.0%	73.0%	88.0%	73.0%	88%	38.75%	56.0%

3. ESC results for all combinations of sediment controls for high slope land

Table 101: Baseline and mitigated (improved sediment control) sediment and phosphorus modelling results for individual and combined options for high slope land

High slope land	None	SRP 0.25%	SRP 0.50%	VBS 3 m	VBS 5 m	SRP 0.25% & VBS 3 m	VBS 3 m & SRP 0.50%	SRP 0.25% & VBS 5 m	VBS 5 m & SRP 0.50%	Baseline weighted	Mitigated weighted
Inputs											
SRP size	0.00%	0.25%	0.50%	0.00%	0.00%	0.25%	0.50%	0.25%	0.50%	Table 19	Table 62
VBS details	No	No	No	3m	5m	3m	3m	5m	5m		
Results (rate of soil erosion)											
Baseline erosion (t/ha/yr)	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3
Treatment (%)	20.0%	99.3%	99.4%	41.0%	58.0%	99.6%	99.7%	99.6%	99.7%	81.0%	94%
Mitigated by measure (t/ha/yr)	3.4	17.2	17.2	7.1	10.0	17.2	17.2	17.2	17.2	14.0	16.2
Not mitigated by measure (t/ha/yr)	13.9	0.1	0.1	10.2	7.3	0.1	0.1	0.1	0.1	3.3	1.1
Not mitigated soil yield (mm/ha/yr)	1.16	0.01	0.01	0.85	0.61	0.01	0.01	0.01	0.01	0.28	0.09
P yield (kg P/ha/yr)	30.0	0.3	0.2	22.2	15.8	0.2	0.1	0.1	0.1	7.1	2.3
Reduction of suspended sediment by SRP	0.0%	73.0%	88.0%	0.0%	0.0%	73.0%	88.0%	73.0%	88.00%	59.6%	75.2%

4. ESC results for all combinations of sediment controls with WTR on low slope land

Table 102: Wheel track ripping mitigation applied for 50% of growers with improved sediment control mitigation for low slope land

Low slope land	None	SRP 0.25%	SRP 0.50%	VBS 3 m	VBS 5 m	SRP 0.25% & VBS 3 m	VBS 3 m & SRP 0.50%	SRP 0.25%& VBS 5 m	VBS 5 m & SRP 0.50%	WTR mitigation	Weighted average
Weighting											50:50
Inputs											
WTR	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
SRP size	0.00%	0.25%	0.50%	0.00%	0.00%	0.25%	0.50%	0.25%	0.50%	Table 61	Table 61
VBS details	No	No	No	3m	5m	3m	3m	5m	5m		
Results (rate of soil erosion)											
Baseline erosion (t/ha/yr)	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2
Treatment (%)	44.0%	99.5%	99.6%	74.6%	79.4%	99.8%	99.8%	99.8%	99.9%	91.1%	89%
Mitigated by measure (t/ha/yr)	2.3	5.2	5.2	3.9	4.1	5.2	5.2	5.2	5.2	4.7	4.6
Not mitigated by measure (t/ha/yr)	2.9	0.0	0.0	1.3	1.1	0.0	0.0	0.0	0.0	0.5	0.6
Not mitigated soil yield (mm/ha/yr)	0.24	0.00	0.00	0.11	0.09	0.00	0.00	0.00	0.00	0.04	0.05
P yield (kg P/ha/yr)	6.3	0.1	0.0	2.9	2.3	0.0	0.0	0.0	0.0	1.0	1.2
Reduction of suspended sediment by SRP	0.0%	73.0%	88.0%	0.0%	0.0%	73.0%	88.0%	73.0%	88.0%	56.0%	56.0%

5. ESC results for all combinations of sediment controls with WTR on high slope land

Table 103: Wheel track ripping mitigation applied for 80% of growers with improved sediment control mitigation for high slope land

High slope land	None	SRP 0.25%	SRP 0.50%	VBS 3 m	VBS 5 m	SRP 0.25% & VBS 3 m	VBS 3 m & SRP 0.50%	SRP 0.25%& VBS 5 m	VBS 5 m & SRP 0.50%	WTR mitigation	Weighted average
Weighting											20:80
Inputs											
WTR	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
SRP size	0.00%	0.25%	0.50%	0.00%	0.00%	0.25%	0.50%	0.25%	0.50%	Table 62	Table 62
VBS details	No	No	No	3m	5m	3m	3m	5m	5m		
Results (rate of soil erosion)											
Baseline erosion (t/ha/yr)	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3
Treatment (%)	44.0%	99.5%	99.6%	67.0%	70.6%	99.7%	99.8%	99.7%	99.8%	95.9%	95.5%
Mitigated by measure (t/ha/yr)	7.6	17.2	17.2	11.6	12.2	17.2	17.3	17.3	17.3	16.6	16.5
Not mitigated by measure (t/ha/yr)	9.7	0.1	0.1	5.7	5.1	0.1	0.0	0.0	0.0	0.7	0.8
Not mitigated soil yield (mm/ha/yr)	0.81	0.01	0.01	0.48	0.43	0.01	0.00	0.00	0.00	0.06	0.07
P yield (kg P/ha/yr)	21.0	0.2	0.1	12.4	11.1	0.1	0.1	0.1	0.1	1.5	1.7
Reduction of suspended sediment by SRP	0.0%	73.0%	88.0%	0.0%	0.0%	73.0%	88.0%	73.0%	88.0%	75.2%	75.2%

6. Gross margins by rotation for irrigation mitigation scenario

Table 104: Gross margin for rotation 1 by crop for irrigation mitigation scenario

Crop	Cabbage (S)	Barley	Onions	Oats	Potatoes	Phacelia	Carrots	Silverbeet	Cabbage (W)	Barley
Revenue										
Sold yield (units/ha)	18,000 heads	7.5 tonnes	40 tonnes	Incorp.	45 tonnes	Incorp.	55 tonnes	24,000 heads	18,000 heads	7.5 tonnes
Price ($/unit)	1.50/head	500/tonne	550/tonne	-	520/tonne	-	600/tonne	1.25/head	1.50/head	500/tonne
Revenue ($/ha)	**27,000**	**3,750**	**22,000**	**-**	**23,400**	**-**	**33,000**	**30,000**	**27,000**	**3,750**
Expenses										
Seed	3,212	200	2,000	300	7,450	200	2,900	1,132	3,212	200
Cultivation/planting	1,378	220	988	220	355	220	935	1,378	1,378	220
Fertiliser	796	288	2,436	-	3,928	-	1,832	1,423	820	288
Agri-chemicals	502	294	2,200	-	1,587	-	1,150	502	502	294
Irrigation	147	164	150	63	172	98	117	370	17	361
Harvesting	3,180	460	3,269	-	2,316	-	1,440	3,180	3,180	460
Grading	-	-	2,900	-	1,875	-	7,150	-	-	-
Packing	-	-	3,504	-	2,523	-	2,634	-	-	-
Freight	2,592	240	1,000	-	1,125	-	1,650	1,440	2,592	240
Levies	132	-	100	-	232	-	162	147	132	-
Total expenses	**11,939**	**1,866**	**18,546**	**583**	**21,562**	**518**	**19,971**	**9,571**	**11,833**	**2,063**
Gross margin	**15,061**	**1,884**	**3,454**	**-583**	**1,838**	**-518**	**13,029**	**20,429**	**15,167**	**1,687**

Table 105: Gross margin for rotation 2 by crop for irrigation mitigation scenario

Crop	Onions	Potato	Oats	Carrot	Lettuce (W)	Broccoli (W)	Broccoli (S)	Barley
Revenue								
Sold yield (units/ha)	40 tonnes	45 tonnes	Incorp.	55 tonnes	23,400 heads	24,583 heads	19,727 heads	7.5 tonnes
Price ($/unit)	550/tonnes	520/tonnes	-	600/tonnes	1.20/heads	*See Table 20*		500/tonnes
Revenue ($/ha)	**22,000**	**23,400**	**-**	**33,000**	**28,080**	**28,660**	**19,053**	**3,750**
Expenses								
Seed	2,000	7,450	300	2,900	1,200	1,000	800	200
Cultivation/planting	988	355	220	935	5,267	2,200	2,000	220
Fertiliser	2,216	2,928	-	1,221	1,075	1,204	809	288
Agri-chemicals	2,200	1,587	-	1,150	1,753	1,000	888	294
Irrigation	146	63	407	-	31	77	123	127
Harvesting	3,269	2,316	-	1,440	5,740	1,700	1,700	460
Grading	2,900	1,875	-	7,150	-	701	701	-
Packing	3,504	2,523	-	2,634	2,044	-	-	-
Freight	1,000	1,125	-	1,650	878	1,862	1,862	240
Levies	100	232	-	162	138	140	93	-
Total expenses	**18,322**	**20,453**	**927**	**19,242**	**18,126**	**9,885**	**8,976**	**1,829**
Gross margin	**3,678**	**2,947**	**-927**	**13,758**	**9,954**	**18,775**	**10,077**	**1,921**

Table 106: Gross margin for rotation 3 by crop for irrigation mitigation scenario

Crop	Lettuce (W)	Asian Greens	Spinach	Cauliflower	Spring Onion	Onions	Oats	Potatoes	Phacelia	Lettuce (W)	Asian Greens
Revenue											
Sold yield (units/ha)	23,400 heads	293,550 heads	11 tonnes	21,300 heads	816,300 heads	40 tonnes	Incorp.	45 tonnes	Incorp.	23,400 heads	293,550 heads
Price ($/unit)	1.20/head	0.50/head	4,500/tonne	1.50/head	0.07/head	550/tonne	-	520/tonne	-	1.20/head	0.50/head
Revenue ($/ha)	**28,080**	**146,775**	**49,500**	**31,950**	**57,141**	**22,000**	**-**	**23,400**	**-**	**28,080**	**146,775**
Expenses											
Seed	1,200	2,600	2,920	3,212	1,700	2,000	300	7,450	200	1,200	2,600
Cultivation/planting	5,267	1,050	1,752	2,102	1,752	988	220	355	220	5,267	1,050
Fertiliser	1,075	718	1,322	1,604	945	2,216	-	3,928	-	1,075	718
Agri-chemicals	1,753	1,600	1,191	876	2,000	2,200	-	1,587	-	1,753	1,600
Irrigation	94	61	82	-	176	197	65	195	94	-	51
Harvesting	5,740	13,856	7,592	4,088	9,110	3,269	-	2,316	-	5,740	13,856
Grading	-	20,331	4,976	-	5,971	2,900	-	1,875	-	-	20,331
Packing	2,044	4,000	1,368	-	1,500	3,504	-	2,523	-	2,044	4,000
Freight	878	3,669	880	3,067	2,612	1,000	-	1,125	-	878	3,669
Levies	138	719	243	157	280	100	-	232	-	138	719
Total expenses	**18,189**	**48,605**	**22,326**	**15,106**	**26,047**	**18,593**	**585**	**21,585**	**514**	**18,095**	**48,595**
Gross margin	**9,891**	**98,170**	**27,174**	**16,844**	**31,094**	**3,407**	**-585**	**1,815**	**-514**	**9,985**	**98,180**

Table 107: Gross margin for rotation 4 by crop for irrigation mitigation scenario

Crop	Lettuce (S)	Broccoli (W)	Oats	Broccoli (W)	`Barley	Lettuce (S)	Broccoli (W)	Barley
Revenue								
Sold yield (units/ha)	23,400 heads	24,583 heads	Incorporated	24,583 heads	7.5 tonnes	28,600 heads	24,583/heads	7.5 tonnes
Price ($/unit)	1.20/head	*See Table 20*	-	*See Table 20*	500/tonne	1.00/head	*See Table 20*	500/tonne
Revenue ($/ha)	**28,080**	**28,660**	**-**	**28,660**	**3,750**	**28,600**	**28,660**	**3,750**
Expenses								
Seed	1,200	1,000	300	1,000	200	1,200	1,000	200
Cultivation/planting	5,267	2,200	220	2,200	220	5,267	2,200	220
Fertiliser	744	1,204	-	1,204	288	744	1,204	288
Agri-chemicals	1,500	1,000	-	1,000	294	1,500	1,000	294
Irrigation	95	25	116	34	129	77	26	163
Harvesting	5,740	1,700	-	1,700	460	5,740	1,700	460
Grading	-	701	-	701	-	-	701	-
Packing	2,044	-	-	-	-	2,044	-	-
Freight	1,216	1,862	-	1,862	240	1,216	1,862	240
Levies	140	140	-	140	-	140	140	-
Total expenses	**17,947**	**9,833**	**636**	**9,842**	**1,831**	**17,928**	**9,833**	**1,864**
Gross margin	**10,653**	**18,827**	**-636**	**18,818**	**1,919**	**10,672**	**18,827**	**1,886**

Table 108: Gross margin for rotation 5 by crop for irrigation mitigation scenario

Crop	Onions	Potatoes	Lettuce (S)	Ryegrass	Pumpkin	Barley	Broccoli (S)	Pumpkin
Revenue								
Sold yield (units/ha)	40 tonnes	45 tonnes	28,600 heads	Incorporated	20 tonnes	7.5 tonnes	19,727 heads	20 tonnes
Price ($/unit)	550/tonne	520/tonne	1.00/head	-	750/tonne	500/tonne	*See Table 20*	750/tonne
Revenue ($/ha)	**22,000**	**23,400**	**28,600**	**-**	**15,000**	**3,750**	**19,053**	**15,000**
Expenses								
Seed	2,000	7,450	1,200	200	1,199	200	800	1,199
Cultivation/planting	988	355	5,267	220	606	220	2,000	606
Fertiliser	2,216	2,928	744	-	1,029	288	809	1,029
Agri-chemicals	2,200	1,587	1,500	-	448	294	888	448
Irrigation	127	119	59	-	120	-	78	122
Harvesting	3,269	2,316	5,740	-	5,026	460	1,700	5,026
Grading	2,900	1,875	-	-	-	-	701	-
Packing	3,504	2,523	2,044	-	700	-	-	700
Freight	1,000	1,125	1,216	-	1,300	240	1,862	1,300
Levies	100	232	140	-	74	-	93	74
Total expenses	**18,304**	**20,509**	**17,911**	**420**	**10,501**	**1,702**	**8,931**	**10,503**
Gross margin	**3,696**	**2,891**	**10,689**	**-420**	**4,499**	**2,048**	**10,122**	**4,497**

8. Efficacy results by rotation for irrigation mitigation scenario

Table 109: Irrigation mitigation scenario nitrogen results for rotation 1 by crop (APSIM)

Year	Month	Crop	Days in crop	Baseline scenario			Irrigation mitigation scenario		
				Irrigation applied (mm/crop)	Average N yield (kg N/ha/crop)	Daily average N yield (kg/N/ha)	Irrigation applied (mm/crop)	Average N yield (kg N/ha/crop)	Daily average N yield (kg/N/ha)
1	Feb - Jul	Cabbage (S)	181	217	25.77	0.14	50	10.63	0.06
1-2	Aug - May	Barley	304	497	44.74	0.15	145	19.29	0.06
2-3	Jun - Jan	Onions	245	413	96.43	0.39	20	60.24	0.25
3	Feb - Jun	Oats	150	224	16.16	0.11	0	1.40	0.01
3	Jul - Dec	Potatoes	184	308	91.14	0.50	50	98.63	0.54
4	Jan - Mar	Phacelia	90	350	5.85	0.06	0	0.00	0.00
4	Apr - Oct	Carrots	214	112	94.00	0.44	40	91.66	0.43
4-5	Nov - Mar	Silverbeet	151	553	105.93	0.70	125	22.27	0.15
5	Apr - Sep	Cabbage (W)	183	0	56.65	0.31	10	36.59	0.20
5-6/1	Oct - Jan	Barley	123	399	17.70	0.14	60	2.12	0.02

Table 110: Irrigation mitigation scenario descriptive statistics for nitrogen results for rotation 1 (APSIM)

		Baseline scenario			Irrigation mitigation scenario		
		Sum of N yield (kg N/ha)	Average annual N yield (kg N/ha/yr)	Average daily N yield (kg N/ha/day)	Sum of N yield (kg N/ha)	Average annual N yield (kg N/ha/yr)	Average daily N yield (kg N/ha/day)
Results by repetition	Repetition 1 (1990-1994)	572	114	0.31	342	68	0.19
	Repetition 2 (1995-1999)	607	121	0.33	402	80	0.22
	Repetition 3 (2000-2004)	528	106	0.29	316	63	0.17
	Repetition 4 (2005-2009)	531	106	0.29	334	67	0.18
	Repetition 5 (2010-2014)	533	107	0.29	321	64	0.18
Average N yield across all repetitions		554	111	0.30	343	69	0.19
Max. N yield across repetitions		607	121	3.12	402	80	3.05
Min. N yield across repetitions		528	106	0.00	316	63	0.00
Standard deviation				0.37			0.40

Note the max. and min. daily N yield is based on all days modelled (i.e., the full 1,826 days) not the daily N yield averaged by repetition.

Table 111: Irrigation mitigation scenario nitrogen results for rotation 2 by crop (APSIM)

Year	Month	Crop	Days in crop	Baseline scenario			Irrigation mitigation scenario		
				Irrigation applied (mm/crop)	Average N yield (kg N/ha/crop)	Daily average N yield (kg/N/ha)	Irrigation applied (mm/crop)	Average N yield (kg N/ha/crop)	Daily average N yield (kg/N/ha)
1	Feb - May	Fallow 1	120	0	4.91	0.04	0	0.00	0.00
1	Jun - Dec	Onions	214	336	104.47	0.49	30	75.88	0.35
2	Jan - Apr	Fallow 2	120	0	5.31	0.04	0	4.71	0.04
2	May - Nov	Potatoes	214	196	131.36	0.61	5	142.58	0.67
2-3	Dec - Apr	Oats	151	469	10.50	0.07	160	0.67	0.00
3	May - Dec	Carrots	245	0	13.08	0.05	0	19.47	0.08
4	Jan - Feb	Fallow 3	59	0	0.70	0.01	0	1.27	0.02
4	Mar - May	Lettuce (w)	92	112	27.33	0.30	0	11.23	0.12
4	Jun - Aug	Fallow 4	92	0	73.39	0.80	0	70.94	0.77
4	Sep - Nov	Broccoli (w)	91	245	64.29	0.71	5	13.31	0.15
4-5	Dec - Jan	Fallow 5	62	0	11.30	0.18	0	0.67	0.01
5	Feb - Mar	Broccoli 2 (s)	59	224	25.73	0.43	35	4.61	0.08
5	Apr	Fallow 6	30	0	8.45	0.28	0	0.17	0.01
5-6/1	May - Jan	Barley	276	455	80.92	0.29	0	87.17	0.32

Table 112: Irrigation mitigation scenario descriptive statistics for nitrogen results for rotation 2 (APSIM)

		Baseline scenario			Irrigation mitigation scenario		
		Sum of N yield (kg N/ha)	Average annual N yield (kg N/ha/yr)	Average daily N yield (kg N/ha/day)	Sum of N yield (kg N/ha)	Average annual N yield (kg N/ha/yr)	Average daily N yield (kg N/ha/day)
Results by repetition	Repetition 1 (1990-1994)	607	121	0.33	459	92	0.25
	Repetition 2 (1995-1999)	613	123	0.34	494	99	0.27
	Repetition 3 (2000-2004)	502	100	0.27	349	70	0.19
	Repetition 4 (2005-2009)	552	110	0.30	437	87	0.24
	Repetition 5 (2010-2014)	560	112	0.31	443	89	0.24
Average N yield across all repetitions		567	113	0.31	436	87	0.24
Max. N yield across repetitions		613	123	2.83	437	87	3.28
Min. N yield across repetitions		502	100	0.00	349	70	0.00
Standard deviation				0.44			0.47

Note the max. and min. daily N yield is based on all days modelled (i.e., the full 1,826 days) not the daily N yield averaged by repetition.

Table 113: Irrigation mitigation scenario nitrogen results for rotation 3 by crop (APSIM)

Year	Month	Crop	Days in crop	Baseline scenario			Irrigation mitigation scenario		
				Irrigation applied (mm/crop)	Average N yield (kg N/ha/crop)	Daily average N yield (kg/N/ha)	Irrigation applied (mm/crop)	Average N yield (kg N/ha/crop)	Daily average N yield (kg/N/ha)
1	Mar - Jun	Lettuce (w)	122	91	93.15	0.76	40	83.92	0.69
1	Jul – Aug	Fallow 1	62	0	91.30	1.47	0	139.31	2.25
1	Sep - Nov	Asian Greens	91	217	77.97	0.86	0	56.61	0.62
1	Dec	Fallow 2	31	0	9.73	0.31	0	1.01	0.03
2	Jan – Mar	Spinach	90	294	46.17	0.51	0	1.72	0.02
2	Apr	Fallow 3	30	0	24.43	0.81	0	4.63	0.15
2	May - Aug	Cauliflower	123	0	178.83	1.45	0	277.12	2.25
2	Sep	Fallow 4	30	0	18.99	0.63	0	31.42	1.05
2-3	Oct - Apr	Spring Onion	212	630	60.82	0.29	0	25.22	0.12
3	May	Fallow 5	31	0	0.35	0.01	0	0.00	0.00
3-4	Jun - Jan	Onions	245	427	60.10	0.25	45	31.49	0.13
4	Feb - Jun	Oats	150	231	12.37	0.08	0	2.82	0.02
4	Jul - Dec	Potatoes	184	329	76.63	0.42	60	65.41	0.36
5	Jan – Apr	Phaecelia	120	336	7.78	0.06	0	0.49	0.00
5	May – Jul	Lettuce (w)	92	0	38.38	0.42	0	29.35	0.32
5	Aug	Fallow 6	31	0	21.54	0.69	0	26.12	0.84
5	Sep – Nov	Asian Greens 2	91	182	83.06	0.91	0	36.69	0.40
5-6/1	Dec - Feb	Fallow 7	90	0	8.75	0.10	0	0.82	0.01

Table 114: Irrigation mitigation scenario descriptive statistics for nitrogen results for rotation 3 (APSIM)

		Baseline scenario			Irrigation mitigation scenario		
		Sum of N yield (kg N/ha)	Average annual N yield (kg N/ha/yr)	Average daily N yield (kg N/ha/day)	Sum of N yield (kg N/ha)	Average annual N yield (kg N/ha/yr)	Average daily N yield (kg N/ha/day)
Results by repetition	Repetition 1 (1990-1994)	937	187	0.51	884	177	0.48
	Repetition 2 (1995-1999)	931	186	0.51	842	168	0.46
	Repetition 3 (2000-2004)	858	172	0.47	723	145	0.40
	Repetition 4 (2005-2009)	954	191	0.52	833	167	0.46
	Repetition 5 (2010-2014)	872	174	0.48	789	158	0.43
Average N yield across all repetitions		910	182	0.50	814	162.83	0.45
Max. N yield across repetitions		954	191	3.86	884	177	6.47
Min. N yield across repetitions		858	172	0.00	789	158	0.00
Standard deviation				0.64			0.92

Note the max. and min. daily N yield is based on all days modelled (i.e., the full 1,826 days) not the daily N yield averaged by repetition.

Table 115: Irrigation mitigation scenario nitrogen results for rotation 4 by crop (APSIM)

Year	Month	Crop	Days in crop	Baseline scenario			Irrigation mitigation scenario		
				Irrigation applied (mm/crop)	Average N yield (kg N/ha/crop)	Daily average N yield (kg/N/ha)	Irrigation applied (mm/crop)	Average N yield (kg N/ha/crop)	Daily average N yield (kg/N/ha)
1	Feb – Mar	Lettuce (s)	59	217	11.04	0.19	20	0.04	0.00
1	Apr – Aug	Fallow 1	153	0	64.43	0.42	0	70.21	0.46
1	Sep - Nov	Broccoli (w)	91	217	46.89	0.52	0	26.23	0.29
1-2	Dec – May	Oats	182	413	43.83	0.24	0	11.91	0.07
2	June – Sep	Broccoli 2 (w)	122	0	45.01	0.37	0	61.37	0.50
2-3	Oct – Mar	Fallow 2	182	0	7.47	0.04	0	8.59	0.05
3-4	Apr – Jan	Barley	306	462	74.88	0.24	0	74.07	0.24
4	Feb – Mar	Lettuce 2 (s)	59	119	6.17	0.10	35	0.00	0.00
4	Apr – Jul	Fallow 3	122	0	46.22	0.38	0	41.20	0.34
4	Aug – Oct	Broccoli 3 (w)	92	140	47.84	0.52	0	33.59	0.37
4-5	Nov – Feb	Fallow 4	120	0	17.83	0.15	0	3.54	0.03
5-6/1	Mar – Jan	Barley 2	337	581	62.80	0.19	0	53.81	0.16

Table 116: Irrigation mitigation scenario descriptive statistics for nitrogen results for rotation 4 (APSIM)

		Baseline scenario			Irrigation mitigation scenario		
		Sum of N yield (kg N/ha)	Average annual N yield (kg N/ha/yr)	Average daily N yield (kg N/ha/day)	Sum of N yield (kg N/ha)	Average annual N yield (kg N/ha/yr)	Average daily N yield (kg N/ha/day)
Results by repetition	Repetition 1 (1990-1994)	517	103	0.28	413	83	0.23
	Repetition 2 (1995-1999)	497	99	0.27	410	82	0.22
	Repetition 3 (2000-2004)	435	87	0.24	322	64	0.18
	Repetition 4 (2005-2009)	454	91	0.25	412	82	0.23
	Repetition 5 (2010-2014)	469	94	0.26	366	73	0.20
Average N yield across all repetitions		474	95	0.26	385	77	0.21
Max. N yield across repetitions		517	103	2.04	412	82	2.36
Min. N yield across repetitions		435	87	0.00	322	64	0.00
Standard deviation				0.33			0.37

Note the max. and min. daily N yield is based on all days modelled (i.e., the full 1,826 days) not the daily N yield averaged by repetition.

Table 117: Irrigation mitigation scenario nitrogen results for rotation 5 by crop (APSIM)

Year	Month	Crop	Days in crop	Baseline scenario			Irrigation mitigation scenario		
				Irrigation applied (mm/crop)	Average N yield (kg N/ha/crop)	Daily average N yield (kg/N/ha)	Irrigation applied (mm/crop)	Average N yield (kg N/ha/crop)	Daily average N yield (kg/N/ha)
1	Feb – May	Fallow 1	120	0	4.55	0.04	0	0.03	0.00
1	Jun – Dec	Onions	214	301	84.00	0.39	25	97.29	0.45
2	Jan – Apr	Fallow 2	120	0	3.83	0.03	0	4.17	0.03
2	May – Nov	Potatoes	214	168	132.33	0.62	0	146.99	0.69
2-3	Dec – Jan	Fallow 3	62	0	1.64	0.03	0	0.55	0.01
3	Feb – Mar	Lettuce (s)	59	210	19.81	0.33	0	0.49	0.01
3	Apr – Aug	Ryegrass	153	0	32.93	0.22	0	26.57	0.17
3-4	Sep - Jan	Pumpkin	153	427	44.75	0.29	0	17.07	0.11
4	Feb – Mar	Fallow 4	59	0	0.74	0.01	0	0.11	0.00
4 -5	Apr – Jan	Barley	306	0	45.29	0.15	0	42.12	0.14
5	Feb - Mar	Broccoli (s)	59	217	27.41	0.46	10	7.72	0.13
5	Apr – Aug	Fallow 5	153	0	63.02	0.41	0	65.64	0.43
5-6/1	Sep – Jan	Pumpkin 2	153	434	65.80	0.43	0	30.45	0.20

Table 118: Irrigation mitigation scenario descriptive statistics for nitrogen results for rotation 5 (APSIM)

		Baseline scenario			Irrigation mitigation scenario		
		Sum of N yield (kg N/ha)	Average annual N yield (kg N/ha/yr)	Average daily N yield (kg N/ha/day)	Sum of N yield (kg N/ha)	Average annual N yield (kg N/ha/yr)	Average daily N yield (kg N/ha/day)
Results by repetition	Repetition 1 (1990-1994)	557	111	0.31	486	97	0.27
	Repetition 2 (1995-1999)	574	115	0.31	491	98	0.27
	Repetition 3 (2000-2004)	487	97	0.27	368	74	0.20
	Repetition 4 (2005-2009)	502	100	0.28	437	87	0.24
	Repetition 5 (2010-2014)	510	102	0.28	414	83	0.23
Average N yield across all repetitions		526	105	0.29	439	88	0.24
Max. N yield across repetitions		574	115	2.79	437	87	3.19
Min. N yield across repetitions		487	97	0.00	368	74	0.00
Standard deviation				0.37			0.45

Note the max. and min. daily N yield is based on all days modelled (i.e., the full 1,826 days) not the daily N yield averaged by repetition.

9. Cost and efficacy results by rotation for fertiliser mitigation scenarios

Table 119: Fertiliser mitigations for rotation 1 by crop (APSIM) (note red text equals fertiliser changes in high N yield mitigation)

	Year	Month	Crop	Units (/ha)	N use (total) kg N/ha/yr	Field yield	Sold yield	Revenue $/ha/yr	Expenses $/ha/yr	Gross margin $/ha/yr	Average N yield (kg N/ha/crop)
Fertiliser mitigation (high N yield crops -2% fertiliser)	1	Feb - Jul	Cabbage (S)	Heads	120			27,000	11,939	15,061	7.74
	1-2	Aug - May	Barley	Tonnes	0	3.5	3.5	1,750	1,578	172	9.02
	2-3	Jun - Jan	Onions	Tonnes	177	65	37	20,213	18,526	1,687	52.81
	3	Feb - Jun	Oats	Incorp.	0			0	-583	-583	0.53
	3	Jul - Dec	Potatoes	Tonnes	300	50	43	22,100	21,515	585	77.02
	4	Jan - Mar	Phacelia	Incorp.	0			0	-518	-518	0.00
	4	Apr - Oct	Carrots	Tonnes	156	65	52	31,050	19,940	11,110	80.43
	4-5	Nov - Mar	Silverbeet	Heads	211	30,000	24,000	30,000	9,616	20,384	20.67
	5	Apr - Sep	Cabbage (W)	Heads	120			25,313	11,833	13,479	34.36
	5-6/1	Oct - Jan	Barley	Tonnes	0	3.5	3.5	1,750	1,775	-25	1.74
Fertiliser mitigation (all crops -5% fertiliser)	1	Feb - Jul	Cabbage (S)	Heads	114	21,375	16,031	24,047	11,898	12,149	7.72
	1-2	Aug - May	Barley	Tonnes	0	3.5	3.5	1,750	1,578	172	9.00
	2-3	Jun - Jan	Onions	Tonnes	172	62	35	19,202	18,488	714	52.19
	3	Feb - Jun	Oats	Incorp.	0	0	0	0	583	-583	0.54
	3	Jul - Dec	Potatoes	Tonnes	291	48	40	20,995	21,449	-454	75.81
	4	Jan - Mar	Phacelia	Incorp.	0	0	0	0	518	-518	0.00
	4	Apr - Oct	Carrots	Tonnes	151	62	49	29,498	19,343	10,155	79.76
	4-5	Nov - Mar	Silverbeet	Heads	200	28,500	21,375	26,719	8,128	18,590	20.25
	5	Apr - Sep	Cabbage (W)	Heads	114	21,375	16,031	24,047	11,791	12,256	33.96
	5-6/1	Oct - Jan	Barley	Tonnes	0	3.5	3.5	1,750	1,775	-25	1.73

Table 123 cont.: Fertiliser mitigations for rotation 1 by crop (APSIM) (note red text equals fertiliser changes in high N yield mitigation)

	Year	Month	Crop	Units (/ha)	N use (total) kg N/ha/yr	Field yield	Sold yield	Revenue $/ha/yr	Expenses $/ha/yr	Gross margin $/ha/yr	Average N yield (kg N/ha/crop)
Fertiliser mitigation (all crops -10% fertiliser)	1	Feb - Jul	Cabbage (S)	Heads	108	20,250	14,175	21,263	11,875	9,406	7.69
	1-2	Aug - May	Barley	Tonnes	0	3.5	3.5	1,750	1,578	172	8.97
	2-3	Jun - Jan	Onions	Tonnes	163	59	30	16,583	18,372	-1,789	51.26
	3	Feb - Jun	Oats	Incorp.	0	0	0	0	583	-583	0.52
	3	Jul - Dec	Potatoes	Tonnes	275	45	36	18,720	21,294	-2,574	72.02
	4	Jan - Mar	Phacelia	Incorp.	0	0	0	0	518	-518	0.00
	4	Apr - Oct	Carrots	Tonnes	143	59	44	26,190	19,784	6,406	77.30
	4-5	Nov - Mar	Silverbeet	Heads	190	27,000	18,900	23,625	8,061	15,564	19.54
	5	Apr - Sep	Cabbage (W)	Heads	108	20,250	14,175	21,263	11,750	9,512	33.19
	5-6/1	Oct - Jan	Barley	Tonnes	0	3.5	3.5	1,750	1,775	-25	1.71

Table 120: Fertiliser mitigations for rotation 2 by crop (APSIM) (note red text equals fertiliser changes in high N yield mitigation)

	Year	Month	Crop	Units (/ha)	N use (total) kg N/ha/yr	Field yield	Sold yield	Revenue $/ha/yr	Expenses $/ha/yr	Gross margin $/ha/yr	Average N yield (kg N/ha/crop)
Fertiliser mitigation (high N yield crops -2% fertiliser)	1	Feb - May	Fallow 1		47						0.00
	1	Jun - Dec	Onions	Tonnes	157	65	37	20,213	18,275	1,937	60.48
	2	Jan - Apr	Fallow 2								4.19
	2	May - Nov	Potatoes	Tonnes	315	50	43	22,100	20,393	1,707	133.84
	2-3	Dec - Apr	Oats	Incorp.	0			-	927	-927	0.51
	3	May - Dec	Carrots	Tonnes	160	65	55	33,000	19,242	13,758	16.40
	4	Jan - Feb	Fallow 3								1.18
	4	Mar - May	Lettuce (w)	Kilograms	157	44,084	17,550	28,080	18,126	9,954	11.07
	4	Jun - Aug	Fallow 4								71.14
	4	Sep - Nov	Broccoli (w)	Kilograms	183	33,552	9,312	23,497	9,885	13,612	13.42
	4-5	Dec - Jan	Fallow 5								0.67
	5	Feb - Mar	Broccoli 2 (s)	Kilograms	114	33,552	9,312	15,475	8,976	6,500	4.54
	5	Apr	Fallow 6								0.17
	5-6/1	May - Jan	Barley	Tonnes	0	3.5	3.5	1,750	1,541	209	59.26
Fertiliser mitigation (all crops -5% fertiliser)	1	Feb - May	Fallow 1		46						0.00
	1	Jun - Dec	Onions	Tonnes	152	62	35	16,583	16,106	476	81.37
	2	Jan - Apr	Fallow 2								4.60
	2	May - Nov	Potatoes	Tonnes	305	48	40	20,995	17,525	3,470	139.35
	2-3	Dec - Apr	Oats	Incorp.				-	927	-927	0.65
	3	May - Dec	Carrots	Tonnes	152	62	49	29,498	18,021	11,477	18.53
	4	Jan - Feb	Fallow 3								1.22
	4	Mar - May	Lettuce (w)	Kilograms	149	41,880	14,579	24,553	17,051	7,502	10.76
	4	Jun - Aug	Fallow 4								68.03
	4	Sep - Nov	Broccoli (w)	Kilograms	174	31,874	7,253	22,322	8,681	13,641	12.79
	4-5	Dec - Jan	Fallow 5								0.65
	5	Feb - Mar	Broccoli 2 (s)	Kilograms	108	33,222	7,185	14,702	8,167	6,534	4.41
	5	Apr	Fallow 6								0.16
	5-6/1	May - Jan	Barley	Tonnes	0	3.5	3.5	1,750	1,541	209	58.26

Table 124 cont.: Fertiliser mitigations for rotation 2 by crop (APSIM) (note red text equals fertiliser changes in high N yield mitigation)

	Year	Month	Crop	Units (/ha)	N use (total) kg N/ha/yr	Field yield	Sold yield	Revenue $/ha/yr	Expenses $/ha/yr	Gross margin $/ha/yr	Average N yield (kg N/ha/crop)
Fertiliser mitigation (all crops -10% fertiliser)	1	Feb - May	Fallow 1		43						0.00
	1	Jun - Dec	Onions	Tonnes	144	59	30	16,583	18,138	-1,555	58.34
	2	Jan - Apr	Fallow 2								4.09
	2	May - Nov	Potatoes	Tonnes	289	45	36	18,720	20,200	-1,480	128.70
	2-3	Dec - Apr	Oats	Incorp.				-	927	-927	0.58
	3	May - Dec	Carrots	Tonnes	144	59	44	26,190	19,199	6,991	17.37
	4	Jan - Feb	Fallow 3								1.21
	4	Mar - May	Lettuce (w)	Kilograms	141	39,676	11,827	22,098	18,033	4,065	10.52
	4	Jun - Aug	Fallow 4								64.74
	4	Sep - Nov	Broccoli (w)	Kilograms	165	30,197	5,361	16,500	9,774	6,726	12.14
	4-5	Dec - Jan	Fallow 5								0.63
	5	Feb - Mar	Broccoli 2 (s)	Kilograms	103	31,474	5,233	10,708	8,899	1,809	4.28
	5	Apr	Fallow 6								0.16
	5-6/1	May - Jan	Barley	Tonnes	0	3.5	3.5	1,750	1,541	209	57.51

Table 121: Fertiliser mitigations for rotation 3 by crop (APSIM) (note red text equals fertiliser changes in high N yield mitigation)

	Year	Month	Crop	Units (/ha)	N use (total) kg N/ha/yr	Field yield	Sold yield	Revenue $/ha/yr	Expenses $/ha/yr	Gross margin $/ha/yr	Average N yield (kg N/ha/crop)
Fertiliser mitigation (high N yield crops -2% fertiliser)	1	Mar - Jun	Lettuce (w)	Kilograms	154	44,084	15,346	24,553	18,174	6,379	83.01
	1	Jul – Aug	Fallow 1								137.64
	1	Sep - Nov	Asian Greens	Heads	108	309,000	278,100	139,050	48,602	90,448	55.93
	1	Dec	Fallow 2								1.00
	2	Jan – Mar	Spinach	Tonnes	102	12	11	49,500	22,326	27,174	1.70
	2	Apr	Fallow 3								4.60
	2	May - Aug	Cauliflower	Heads	225	22,500	20,175	30,263	15,081	15,181	274.24
	2	Sep	Fallow 4								31.07
	2-3	Oct - Apr	Spring Onion	Tonnes	102	907,000	816,300	57,141	26,047	31,094	24.95
	3	May	Fallow 5								0.00
	3-4	Jun - Jan	Onions	Tonnes	180	65	40	22,000	18,593	3,407	31.49
	4	Feb - Jun	Oats	Incorp.	0			0	585	-585	2.82
	4	Jul - Dec	Potatoes	Tonnes	300	50	43	22,100	21,538	562	64.24
	5	Jan – Apr	Phaecelia	Incorp.	0			0	514	-514	0.50
	5	May – Jul	Lettuce (w)	Kilograms	157	44,084	17,550	24,553	18,080	6,473	29.16
	5	Aug	Fallow 6								25.90
	5	Sep – Nov	Asian Greens 2	Heads	108	309,000	278,100	139,050	48,593	90,457	36.31
	5-6/1	Dec - Feb	Fallow 7								0.81
Fertiliser mitigation (all crops -5% fertiliser)	1	Mar - Jun	Lettuce (w)	Kilograms	149	41,880	14,579	23,326	18,139	5,186	81.06
	1	Jul – Aug	Fallow 1								134.56
	1	Sep - Nov	Asian Greens	Heads	105	293,550	264,195	132,098	48,587	83,511	54.70
	1	Dec	Fallow 2								0.97
	2	Jan – Mar	Spinach	Tonnes	97	11.4	9.9	44,460	22,290	22,170	1.67
	2	Apr	Fallow 3								4.49
	2	May - Aug	Cauliflower	Heads	219	21,375	19,166	28,749	15,052	13,697	267.05
	2	Sep	Fallow 4								30.25
	2-3	Oct - Apr	Spring Onion	Tonnes	97	861,650	732,403	51,268	26,023	25,245	24.32
	3	May	Fallow 5								0.00
	3-4	Jun - Jan	Onions	Tonnes	171	62	35	19,202	18,535	667	30.52
	4	Feb - Jun	Oats	Incorp.				0	585	-585	2.70

Table 125 cont.: Fertiliser mitigations for rotation 3 by crop (APSIM) (note red text equals fertiliser changes in high N yield mitigation)

	Year	Month	Crop	Units (/ha)	N use (total) kg N/ha/yr	Field yield	Sold yield	Revenue $/ha/yr	Expenses $/ha/yr	Gross margin $/ha/yr	Average N yield (kg N/ha/crop)
	4	Jul - Dec	Potatoes	Tonnes	291	48	40	20,995	21,472	-477	62.20
	5	Jan – Apr	Phaecelia	Incorp.				0	514	-514	0.49
	5	May – Jul	Lettuce (w)	Kilograms	149	41,880	14,579	23,326	18,045	5,281	28.39
	5	Aug	Fallow 6								25.19
	5	Sep – Nov	Asian Greens 2	Heads	105	293,550	264,195	132,098	48,577	83,520	35.32
	5-6/1	Dec - Feb	Fallow 7								0.79
Fertiliser mitigation (all crops -10% fertiliser)	1	Mar - Jun	Lettuce (w)	Kilograms	141	39,676	11,827	22,098	18,096	4,002	78.48
	1	Jul – Aug	Fallow 1								130.28
	1	Sep - Nov	Asian Greens	Heads	99	278,100	236,385	118,193	48,561	69,632	52.95
	1	Dec	Fallow 2								0.94
	2	Jan – Mar	Spinach	Tonnes	92	10.8	8.8	39,690	22,239	17,451	1.61
	2	Apr	Fallow 3								4.36
	2	May - Aug	Cauliflower	Heads	207	20,250	17,145	25,718	14,973	10,744	257.15
	2	Sep	Fallow 4								29.10
	2-3	Oct - Apr	Spring Onion	Tonnes	92	816,300	653,040	45,713	25,999	19,714	23.43
	3	May	Fallow 5								0.00
	3-4	Jun - Jan	Onions	Tonnes	162	59	30	16,583	18,419	-1,836	29.80
	4	Feb - Jun	Oats	Incorp.				0	585	-585	2.56
	4	Jul - Dec	Potatoes	Tonnes	275	45	36	18,720	21,317	-2,597	59.03
	5	Jan – Apr	Phaecelia	Incorp.				0	514	-514	0.49
	5	May – Jul	Lettuce (w)	Kilograms	141	39,676	11,827	22,098	18,002	4,096	27.58
	5	Aug	Fallow 6								24.40
	5	Sep – Nov	Asian Greens 2	Heads	99	278,100	236,385	118,193	48,551	69,642	34.11
	5-6/1	Dec - Feb	Fallow 7								0.76

Table 122: Fertiliser mitigations for rotation 4 by crop (APSIM) (note red text equals fertiliser changes in high N yield mitigation)

	Year	Month	Crop	Units (/ha)	N use (total) kg N/ha/yr	Field yield	Sold yield	Revenue $/ha/yr	Expenses $/ha/yr	Gross margin $/ha/yr	Average N yield (kg N/ha/crop)
Fertiliser mitigation (high N yield crops -2% fertiliser)	1	Feb – Mar	Lettuce (s)	Kilograms	101	49,962	24,310	28,600	17,947	10,653	0.05
	1	Apr – Aug	Fallow 1								76.77
	1	Sep - Nov	Broccoli (w)	Kilograms	183	33,552	9,312	23,497	9,833	13,664	27.93
	1-2	Dec – May	Oats	Incorp.				0	636	-636	11.89
	2	June – Sep	Broccoli 2 (w)	Kilograms	179	33,552	7,634	23,497	9,824	13,672	60.30
	2-3	Oct – Mar	Fallow 2								8.34
	3-4	Apr – Jan	Barley	Tonnes	0	3.5	3.5	1,750	1,543	207	45.46
	4	Feb – Mar	Lettuce 2 (s)	Kilograms	101	49,962	24,310	28,600	17,928	10,672	0.00
	4	Apr – Jul	Fallow 3								43.81
	4	Aug – Oct	Broccoli 3 (w)	Kilograms	179	33,552	7,634	22,322	9,816	12,506	35.38
	4-5	Nov – Feb	Fallow 4								3.60
	5-6/1	Mar – Jan	Barley 2	Kilograms	0	3.5	3.5	1,750	1,577	173	44.22
Fertiliser mitigation (all crops -5% fertiliser)	1	Feb – Mar	Lettuce (s)	Kilograms	96	47,464	20,721	24,387	17,913	6,465	0.05
	1	Apr – Aug	Fallow 1								74.56
	1	Sep - Nov	Broccoli (w)	Kilograms	174	31,874	7,253	22,322	9,770	12,552	27.05
	1-2	Dec – May	Oats	Incorp.				0	636	-636	11.59
	2	June – Sep	Broccoli 2 (w)	Kilograms	174	31,874	7,253	22,322	9,779	12,543	58.62
	2-3	Oct – Mar	Fallow 2								8.13
	3-4	Apr – Jan	Barley	Tonnes	0	3.5	3.5	1,750	1,543	207	44.81
	4	Feb – Mar	Lettuce 2 (s)	Kilograms	96	47,464	20,721	24,378	17,894	6,484	0.00
	4	Apr – Jul	Fallow 3								42.35
	4	Aug – Oct	Broccoli 3 (w)	Kilograms	174	31,874	7,253	22,322	9,770	12,551	34.19
	4-5	Nov – Feb	Fallow 4								3.51
	5-6/1	Mar – Jan	Barley 2	Kilograms	0	3.5	3.5	1,750	1,577	173	43.16

Table 126 cont.: Fertiliser mitigations for rotation 4 by crop (APSIM) (note red text equals fertiliser changes in high N yield mitigation)

	Year	Month	Crop	Units (/ha)	N use (total) kg N/ha/yr	Field yield	Sold yield	Revenue $/ha/yr	Expenses $/ha/yr	Gross margin $/ha/yr	Average N yield (kg N/ha/crop)
Fertiliser mitigation (all crops -10% fertiliser)	1	Feb – Mar	Lettuce (s)	Kilograms	91	44,966	17,382	23,095	17,876	5,219	0.05
	1	Apr – Aug	Fallow 1								72.34
	1	Sep - Nov	Broccoli (w)	Kilograms	165	30,197	5,361	16,500	9,722	6,778	26.24
	1-2	Dec – May	Oats	Incorp.				0	636	-636	11.32
	2	June – Sep	Broccoli 2 (w)	Kilograms	165	30,197	5,361	23,322	9,731	12,591	57.00
	2-3	Oct – Mar	Fallow 2								7.92
	3-4	Apr – Jan	Barley	Tonnes	0	3.5	3.5	1750	1,543	207	44.18
	4	Feb – Mar	Lettuce 2 (s)	Kilograms	91	44,966	17,382	23,095	17,858	5,237	0.00
	4	Apr – Jul	Fallow 3								40.91
	4	Aug – Oct	Broccoli 3 (w)	Kilograms	165	30,197	5,361	16,500	9,722	6,778	33.01
	4-5	Nov – Feb	Fallow 4								3.42
	5-6/1	Mar – Jan	Barley 2	Kilograms	0	3.5	3.5	1,750	1,577	173	42.10

Table 123: Fertiliser mitigations for rotation 5 by crop (APSIM) (note red text equals fertiliser changes in high N yield mitigation)

	Year	Month	Crop	Units (/ha)	N use (total) kg N/ha/yr	Field yield	Sold yield	Revenue $/ha/yr	Expenses $/ha/yr	Gross margin $/ha/yr	Average N yield (kg N/ha/crop)
Fertiliser mitigation (high N yield crops -2% fertiliser)	1	Feb – May	Fallow 1		47						0.03
	1	Jun – Dec	Onions	Tonnes	157	65	37	20,213	18,2575	1,956	95.00
	2	Jan – Apr	Fallow 2								4.08
	2	May – Nov	Potatoes	Tonnes	315	50	43	22,100	20,449	1,651	142.89
	2-3	Dec – Jan	Fallow 3								0.48
	3	Feb – Mar	Lettuce (s)	Kilograms	101	49,962	24,310	28,600	17,911	10,689	0.45
	3	Apr – Aug	Ryegrass	Tonnes	0	4	4	0	420	-420	25.49
	3-4	Sep - Jan	Pumpkin	Tonnes	109	40	20	15,000	10,501	4,499	16.92
	4	Feb – Mar	Fallow 4								0.11
	4 -5	Apr – Jan	Barley	Tonnes	0	3.5	3.5	1,750	1,414	336	41.98
	5	Feb - Mar	Broccoli (s)	Kilograms	114	34,971	9,312	19,053	8,931	10,122	7.68
	5	Apr – Aug	Fallow 5								65.39
	5-6/1	Sep – Jan	Pumpkin 2	Tonnes	107	40	18	13,500	11,068	2,432	30.28
Fertiliser mitigation (all crops -5% fertiliser)	1	Feb – May	Fallow 1		46						0.03
	1	Jun – Dec	Onions	Tonnes	152	62	35	19,202	18,242	960	97.16
	2	Jan – Apr	Fallow 2								4.14
	2	May – Nov	Potatoes	Tonnes	305	48	40	20,995	20,413	582	142.48
	2-3	Dec – Jan	Fallow 3								0.52
	3	Feb – Mar	Lettuce (s)	Kilograms	96	47,464	20,721	24,378	17,877	6,501	0.47
	3	Apr – Aug	Ryegrass	Tonnes	0	4	4	0	420	-420	25.38
	3-4	Sep - Jan	Pumpkin	Tonnes	104	38	17	12,825	10,449	2,376	16.19
	4	Feb – Mar	Fallow 4								0.11
	4 -5	Apr – Jan	Barley	Tonnes	0	3.5	3.5	1,750	1,414	336	41.49
	5	Feb - Mar	Broccoli (s)	Kilograms	108	32,222	7,185	14,702	8,889	5,812	7.63
	5	Apr – Aug	Fallow 5								66.15
	5-6/1	Sep – Jan	Pumpkin 2	Tonnes	104	38	17	12,825	10,003	2,822	30.53

Table 127 cont.: Fertiliser mitigations for rotation 5 by crop (APSIM) (note red text equals fertiliser changes in high N yield mitigation)

	Year	Month	Crop	Units (/ha)	N use (total) kg N/ha/yr	Field yield	Sold yield	Revenue $/ha/yr	Expenses $/ha/yr	Gross margin $/ha/yr	Average N yield (kg N/ha/crop)
Fertiliser mitigation (all crops -10% fertiliser)	1	Feb – May	Fallow 1		43						0.03
	1	Jun – Dec	Onions	Tonnes	144	59	30	16,583	18,119	-1,537	89.06
	2	Jan – Apr	Fallow 2								4.01
	2	May – Nov	Potatoes	Tonnes	289	45	36	18,720	20,256	-1,536	136.43
	2-3	Dec – Jan	Fallow 3								0.53
	3	Feb – Mar	Lettuce (s)	Kilograms	91	44,966	17,382	23,095	17,840	5,255	0.48
	3	Apr – Aug	Ryegrass	Tonnes	0	4	4	0	420	-420	24.73
	3-4	Sep - Jan	Pumpkin	Tonnes	98	36	14	10,800	10,501	299	15.46
	4	Feb – Mar	Fallow 4								0.10
	4 -5	Apr – Jan	Barley	Tonnes	0	3.5	3.5	1,750	1,414	336	40.97
	5	Feb - Mar	Broccoli (s)	Kilograms	103	31,474	5,233	14,702	8,854	5,848	7.55
	5	Apr – Aug	Fallow 5								65.54
	5-6/1	Sep – Jan	Pumpkin 2	Tonnes	98	36	14	10,800	9,959	841	30.06