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IMPROVED UNDERSTANDING OF GROWER SYSTEMS WITHIN THE PUKEKOHE AREA TO INFORM THE FRESHWATER MANAGEMENT TOOL

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Introduction

Pukekohe is nationally important for the domestic supply of fresh vegetables and for supporting New Zealand's food security, particularly for Auckland—the country's largest and one of its fastest growing regions by population (Statistics New Zealand, 2022). In 2018, horticultural production and associated spend within the Pukekohe area generated an estimated $261 million of economic activity, focused mainly on the production of potatoes, onions, carrots, leafy greens, brassicas, and tomatoes (Deloitte Touche Tohmatsu Limited, 2018). Commercial vegetable production (CVP) across the wider Pukekohe area provides an important year-round supply of fresh produce to the Auckland market and further afield and is reliant on the area's free-draining, fertile volcanic soils, moderate climate, extensive transport links, and a long history of workforce and technological development (Deloitte Touche Tohmatsu Limited, 2018).

Despite favourable growing conditions, growers face an increasing number of challenges, including urban encroachment and changing environmental expectations from both consumers and policy makers (Deloitte Touche Tohmatsu Limited, 2018; Horticulture New Zealand, 2023). While the National Policy Statement for Highly Productive Land 2022 (NPS-HPL) was introduced to safeguard the country's most fertile soils against encroachment and fragmentation, the National Policy Statement for Freshwater Management 2020 (NPS-FM) tasks regional councils with managing natural capital in a way that prioritises the health and well-being of water bodies and freshwater ecosystems above human consumption and other social, economic, and cultural water uses—including horticultural production (Ministry for the Environment and Ministry for Primary Industries, 2022; Ministry for the Environment, 2020). The forthcoming Natural and Built Environment Act (NBA) and freshwater farm planning regulations are also anticipated to place additional expectations on growers to account for how their activities are manged to avoid or minimise effects on freshwater quality (Ministry for the Environment, 2022; Ministry for the Environment, 2023). The NPS-FM's specified vegetable growing areas provisions require Auckland Council (AC) to have regard to Pukekohe's contribution to the domestic supply of fresh vegetables and the county's overall food security. However, taken together, current policy direction is anticipated to place additional pressure on growers to reduce environmental footprints while maintaining fresh vegetable supply.

As a unitary authority, AC has responsibility for regulating land use activities under the Resource Management Act (RMA) and managing for the protection of water resources under the Local Government Act (LGA) (Department of Internal Affairs, 2002, Ministry for the Environment, 1991). Effective management of water as it moves through the hydrologic cycle is fundamental to integrating both acts and achieving wellbeing outcomes, adapting to climate change, managing urban growth, mitigating the effects of rural land use on freshwater ecosystems, and reversing biodiversity loss. Recent national policy statements, RMA reform, and 3 Waters reform are only adding to the complexity of both management and regulatory decision-making, albeit with Te Mana o te Wai providing a consistent management hierarchy.

To meet this challenge, AC's Healthy Waters Department (HW), in partnership with the wider AC whānau and stakeholders, is developing the Freshwater Management Tool (FWMT) to improve how water is manged across rural and urban Auckland (Nowell *et al.*, 2023). The FWMT enables adaptive planning for stormwater management under Healthy Waters' Network Discharge Consent (NDC), supports both regulatory and non-regulatory decision-making and communication, as well as facilitates the development of water quality investment strategies through the Long-Term Plan (LTP) and other funding sources (e.g., Jobs for Nature).

As a regionwide accounting framework, the FWMT combines process-based (causative) and continuous (high temporal resolution) US-EPA models to generate water quality information and optimised (least-cost) action strategies to achieve water quality objectives on an integrated (catchment by catchment) basis (e.g., action types, locations, scale, costs, and distribution of costs across land-use types to achieve targets). Outputs are generated on a sub-catchment basis (~100 ha) and integrated across the rural-urban divide for numerous contaminants (N, P, sediment, *E.coli*, Cu, Zn).

Freshwater Management Tool outputs include region-wide information on contaminant yield (from land) and in-stream concentrations across 106 distinct 'land types.' Each land type represents key geophysiochemical (e.g., soils, slope, climate, land cover) and anthropogenic (e.g., imperviousness, land use) factors that influence variation in water quality across the Auckland region (grouped into 'hydrologic response units,' or HRUs).

A robust evidence base underpins the tool's predictive current and future water quality and catchment action planning abilities (Brown *et al.,* 2021a). Information on land use 'impacts' help to inform baseline water quality predictions and provides users with detail, objective information on 'catchment context.' Likewise, estimates of generalised environmental benefit, detailed economic costs, as well as adoption opportunity estimates for a range of source controls and edge-of-field devices, inform the suite of mitigations available within the FWMT. Feasible action plans are explicitly mapped and optimised for their footprint (cost) and effect (benefit)—whether within or between catchments (urban and rural)—providing valuable information to inform stormwater management planning, development applications, and freshwater farm planning.

In the first stage of the FWMT's development, an approach of 'defensible simplicity' was taken to adopt increasing model complexity only where required and supported by thorough evidence. This approach was endorsed by the FWMT's expert peer-review team (PRT; Hamilton *et al.,* 2021). Both the PRT and Stephens and Muller (2021a) acknowledged the categorisation of some HRUs, including horticultural land use types, should be improved—principally the diverse CVP rotational systems common around Pukekohe.

Improved modelling of horticulture land uses will help the FWMT better capture the variability in contaminant yields associated with differing vegetable crop rotations, including feasibility, effects, and costs on those of differing management practices. Ultimately, this work will help Pukekohe's CVP growers and AC better account for management actions taken to lessen environmental impact and demonstrate progress to meeting current and future water quality objectives.

Purpose

This paper explores how HW and Horticulture New Zealand partnered with the Pukekohe Vegetable Growers Association (PVGA) to better characterise CVP for water quality yields including variation therein over differing rotations (i.e., crop types) and the feasibility, costs, and effect of practice-based management choices. Outputs include detailed rotational typologies for CVP, contaminant yield information, and economic gross margins.

While this paper doesn't detail ameliorative actions, the next stage of this work will lead to an improved understanding of the cost, effect, and opportunity for mitigation choices relevant to CVP to achieve water quality outcomes—including both management practice and edge-of-field devices. Evidence detailing mitigation performance will support better decision making via improved optimised catchment action planning for water quality, including the provision of catchment context and action planning guidance to support freshwater farm planning.

FWMT land use impacts

The original land use categories spanning horticultural activities in the FWMT were broadly grouped into three 'impact' classes ('low, medium, and high'; Brown *et al.*, 2021b)[1]. Figure 1 conceptualises how impact classes were revised as a result of this work and the data used to inform these revisions. This paper focuses on the 'cultivated horticulture' land use impact class.

See Muller and Innes (2023, in preparation) for a full accounting of how land use impact classes have been revised during this project.

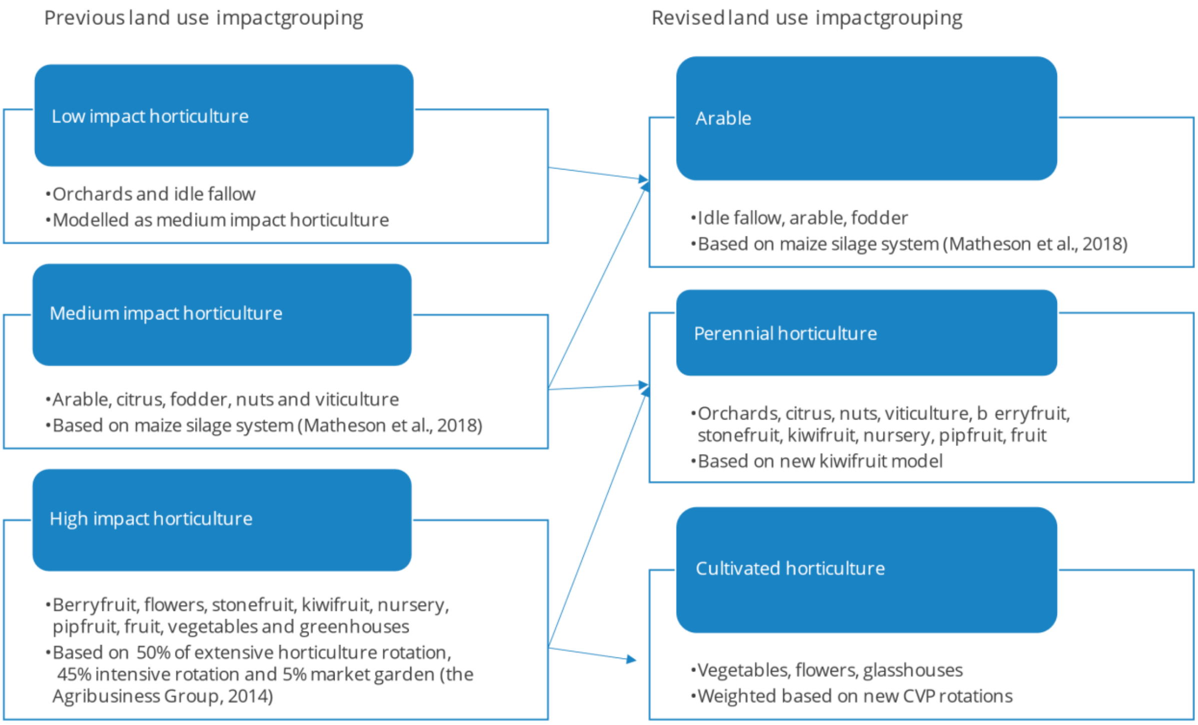

Figure 1: Original and revised land use impact classes, or groupings, for horticulture in the FWMT.

Methodology

Five characteristic crop rotations spanning a 5-year time period were created based on literature, statistics, and direct conversations with growers. For each rotation, environmental footprint (yield) estimates were determined for nitrogen, phosphorus, and sediment using both APSIM (for nitrogen) and the Erosion and Sediment Rate Calculator (ESC; for phosphorus and sediment; Agrilink NZ Limited, 2019; Holzworth *et al.* 2018). Table 1 summarises the five CVP rotations used in this modelling. Each of the rotations was given a weighting criterion based on the area cropped as all rotations were combined into a single land use impact class for later incorporation into the FWMT (Figure 1). These weightings were based on statistics, grower discussions, and best professional judgment of the area in each crop—a complex assessment given factors such as crop growth period, land swapping practices among growers, and the range and variety of crops grown.

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[1]Impact is one of three major factors, alongside soil and slope, creating up to thirty unique horticultural types (HRUs) within the FWMT. The term refers to impact on land processes rather than on waterway state, permitting the unique process-representation of rainfall–land activity interaction within the tool.

Table 1: Commercial vegetable production rotations for the Pukekohe area

Rotation	Area weighting	Crops (5-year rotation)
1	25%	Cabbage (summer) → Barley (cereal and incorporated) → Onions → Oats (incorporated) → Potatoes → Phaecelia (incorporated) → Carrots → Silverbeet → Cabbage (winter) → Barley (cereal and incorporated)
2	25%	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	5%	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	25%	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	20%	Fallow 1 → Onions → Fallow 2 → Potatoes → Fallow 3 → Lettuce (summer) → Rye Grass (incorporated) → Pumpkin → Barley (cereal and incorporated) → Broccoli (summer) → Fallow 4 → Pumpkin

The APSIM and ESC models were parametrised based on data from growers, literature, and expert opinion. The APSIM models used SCRUM crop models and were adjusted where more accurate information was provided by growers (Brown and Zyskowski, n.d). Each 5-year rotation was modelled in APSIM 5 times over the time period 01/01/1990–31/12/2014. Meteorological data was sourced from NIWA's Virtual Climate Station Network (VCSN) located at Pukekohe VCSN site 30746. Soil input information was based on literature describing the predominant soils in in the area as determined from S-map and the Fundamental Soil Layer (FSL; Manaaki Whenua – Landcare Research, 2023a; Manaaki Whenua – Landcare Research, 2023b). The soil type of Morrinsville_8a.1 (S-map), equivalent to Patumahoe (FSL), a clay loam, was used as it was the dominant soil type on which CVP occurred within the Pukekohe area.

Sediment and phosphorus losses were calculated based on the ESC. This model and its key assumptions are detailed in Agrilink (2020). The ESC uses a modified version of the Revised Universal Soil Loss Equation (RUSLE). Two ESC models were created, one for land less than 2^o ('low slope') and one more than 2^o ('high slope'). The models are agnostic of crop type and are parameterised similarly across the five rotations (Table 2).

Table 2: Summary of base ESC parameters

Inputs	Low slope	High slope
Soil type	Clay Loam	Clay Loam
Slope (º)	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

Gross margins were developed for each crop (and rotation) based on a range of data sources, including direct grower guidance. To generate revenue for the gross margins, the 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 across years, rotations, and growers, the overall 'typical' revenue for a crop was reviewed and approved by a panel of growers. Expenses were based on APSIM data (e.g., fertiliser inputs), data provided by growers (e.g., spraying and weeds), literature, or built up from more basic components (e.g., fuel and harvesting). Where costs were unavailable some crops were matched to other, similar, crops.

It should be noted that these are arbitrary gross margins, representative of specific crop rotations (as detailed in Table 1) occurring on a single patch of land rather than a gross margin attributable to any specific vegetable growing business. The gross margins 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 exclude variants of vegetables grown (e.g., different types of potatoes) and varying prices (e.g., fluctuation in markets, timing of sale).

Crop gross margins were applied to each corresponding crop throughout the 5-year combined rotation length to estimate a total rotation gross margin. Total gross margins are annualised as a simple average annual gross margin (i.e., taking the 5-year rotational gross margin and dividing by 5). Additional annual costs were then added to each annualised gross margin. This was done to incorporate costs that are not crop specific (e.g., land costs, repairs and maintenance of sediment traps, and administration). Final economic outputs for CVP representation in the FWMT consisted of an annual overhead cost and an annual profit (gross margin minus overheads). This annual profit figure excludes the cost of capital, tax and depreciation.

Base footprints

Environmental

Table 3 provides a summary of nitrogen losses from the rootzone for each of the five CVP rotations as well as their area-weighted combined average (weights from Table 1). These are provided on an average full rotation basis (where kg N yield was averaged across the five repetitions of each rotation during the 25-year APSIM simulation time period). Those average rotation N yields were then annualised and are also presented on a per day basis.

Table 3: Base nitrogen results (APSIM)

Average annual summaries	Rotation 1	Rotation 2	Rotation 3	Rotation 4	Rotation 5	Weighted average
Average N yield for a full rotation (kg N/5 year rotation)	554	567	910	474	526	549
Average rotation N yield per year (kg N/ha/yr)	111	113	182	95	105	110
Average rotation N yield per day (kg N/ha/day)	0.30	0.31	0.50	0.26	0.29	0.30

The approach to the use of sediment retention ponds (SRPs) and vegetated buffer strips (VBSs) in the base model was different to the other key input factors that feed into the ESC model. Both VBSs and SRPs are key mitigation measures that significantly reduce the loss of sediment and phosphorus. As such, capturing the effect of current mitigation uptake amongst growers in the Auckland region was important to FWMT baseline and scenario modelling (i.e., ensuring spread in impact types represented differing contaminant yield and mitigation potential as well as cost-effectiveness on current yield). A weighting approach was used to help assign the current use of SRPs and VBSs by growers which assumes that growers often use a combination of the two. Assignment of SRPs and VBSs was done for the two slope-based base models as shown in Table 4 and Table 5[2]. The weightings (i.e., percentage adoption) were assumptions based on conversations with growers and local CVP advisor recommendations. Quantifying the use of these mitigation measures across the model domain is a key consideration for improving future CVP modelling in the FWMT.

Table 4: Baseline weighting (percentage adoption) of SRPs and VBSs for low slope land (<2º slope)

Land < 2º		**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 5: Baseline weighting (adoption) of SRPs and VBSs for high slope land (>2º slope)

Land > 2º		**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%

Table 6 summarises the base sediment and phosphorus results for the weighted average SPR/VBS uptake for low slope and high slope land.

[2] As the ESC is agnostic of crop type, the parameterisation of the model was the same across each of the five rotations as shown in Table 2.

Table 6: Base sediment and phosphorus modelled results for weighted average base results.

	Low slope	High slope
Inputs		
SRP size	See Table 4	See Table 5
VBS width		
Results (rate of soil erosion)		
Baseline erosion (t/ha/yr)	5.2	17.3
Reduction	66%	81%
Mitigated erosion (t/ha/yr)	3.4	14.0
Unmitigated erosion (t/ha/yr)	1.8	3.3
Unmitigated soil loss (mm/ha/yr)	0.15	0.28
P yield (kg P/ha/yr)	3.8	7.1
Reduction of suspended sediment yield by SRP	38.75%	59.60%

Economic

Table 7 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 calculated for each crop to get a total gross margin over the 5-year period, prior to annualisation). Because the annual maintenance costs for SRPs and VBSs are different across the two slope types, they are presented by low (< 2^{o}) and high slope (> 2^{o}) in tables Table 7 and Table 8, respectively.

Table 7: Average gross margins and profit for low slope (annualised over 5-year rotation)

Average annual summaries ($/ha/yr)	Rotation 1	Rotation 2	Rotation 3	Rotation 4	Rotation 5	Weighted average
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
Average annual overheads	11,004	10,972	11,225	10,037	10,401	10,645
Average annual profit	2,388	445	46,975	5,430	-3,374	3,740

Table 8: Average gross margins and profit for high slope (annualised over 5-year rotation)

Average annual summaries ($/ha/yr)	Rotation 1	Rotation 2	Rotation 3	Rotation 4	Rotation 5	Weighted average
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
Average annual overheads	10,945	10,930	10,911	9,967	10,409	10,588
Average annual profit	2,447	487	47,289	5,500	-3,382	3,797

It is important to stress that the gross margins presented do not represent a CVP business but rather the annualised average economics for all crops grown on a 1 ha patch of land representing each of the five rotations. They exclude land-swapping (where growers grow some vegetables in a rotation which are in their speciality such as root vegetables and then land-swaps with a colleague who grows leafy greens on the same patch and vice-versa) as well as vertical integration where growers process vegetables into higher value products themselves. While rotation 3's average annual profit is substantially higher than the other rotations, the crop represents a small area of land and many crops in this rotation are sold into higher value produce markets. Similarly, rotation 5's negative profit is driven partly by overheads which may not incurred by all growers with that rotation and it doesn't consider the ability to recoup some losses by further processing some products into this rotation for example for higher income post farm gate (by a vertically integrated business). In addition, for rotation 5 businesses may also only grow part of that rotation and then land-swap with another grower, however the FWMT is focused on a 1 ha piece of land not a business and as such this does not suggest that a grower continually grows a full rotation that is providing a negative return. The weighted average results is the key base result which will be used further in the FWMT.

Next steps

Completion of mitigation modelling is a key focus for this project in the short-term. Mitigation modelling will build off the existing mitigation assessment work that informs the FWMT and is considered robust (e.g., for wetlands and riparian areas; Stephens and Muller, 2021b; Stephens *et al.,* 2021). Updated opportunity costs will be based on the new CVP rotations (incorporating the gross margin information described above). Mitigations not currently characterised for the FWMT will be modelled, including improved sediment and phosphorus control, as well as irrigation improvements and reductions in nitrogen fertiliser use. These mitigations will be modelled by rotation with annualised cost and generalised benefit (e.g., contaminant yield reduction on rotation baselines reported here), and grouped into bundles of 'good growing practice' for inclusion into the FWMT.

In addition to the five CVP rotations above, a new horticultural impact type and corresponding mitigation information is in development for kiwifruit, with industry input (Zespri and NZKGI).

Finally, updated land use impact classes (as presented in Figure 1) and those mitigations feasible for CVP and kiwifruit growing will be integrated into the FWMT Stage 2—for improved freshwater accounting and optimised water quality management strategies. Both improved input information and industry engagement with the FWMT is a core objective for the ongoing FWMT programme. Outcomes then can include more effective management of nitrogen losses from horticulture amidst complex regulatory changes in Auckland.

Industry collaboration

Beyond this program of work, the FWMT development programme is committed to investing in long-term partnerships across the primary industries to develop robust information for freshwater management (e.g., more accurate representation of farm system types within the FWMT; better feasibility and cost-effectiveness of mitigation options; improved decision-making across AC, primary industries, and farmers and growers). Continuous improvement in FWMT capabilities will also assure farmers and growers of better credit for actions and impacts taken to improve water quality—improving the design of regulatory responses to policy and ensuring greater accountability for both landholder and public investment.

Key FWMT programme priorities moving forward include:

- Modelling pastoral land use impacts across Auckland and the mitigation choices available to the sheep and beef and dairy sectors to advance the FWMT's representation of these land uses.
- Sharing detailed, objective modelled outputs on catchment state and risk (i.e., catchment context).
- Making mitigation feasibility models more widely available to support on-farm action selection and siting.
- Producing optimised (lowest-cost) action plans to further guide on-land action to achieve water quality objectives for a given investment.
- Accounting for actions already taken and their associated effect (across catchments or by sector group).
- Trialling mitigations within the Auckland region to assess feasibility, effectiveness, and full lifecycle costs and providing demonstration sites to drive adoption of feasible, cost-effective solutions for water quality improvement.

The FWMT team encourages collaboration and would like to hear from you at fwmt@aukclandcouncil.govt.nz.

Key modelling limitations

Modelling inherently relies on assumption and has limitations—good modelling is always for a defined purpose. In this instance, modelling was undertaken for better classification of CVP activities in the Auckland region for their existing contaminant footprint (yield) and mitigation choices (feasibility, lifecycle cost, contaminant yield reduction).

Muller & Inness (2023, in preparation) discuss key assumptions and limitations associated with the modelling, including:

- Costs (lifecycle) generated are direct and to the farm gate; costs excluded flow on effects to the quantity of food supplied to consumers, the quality or price of this food. Indirect costs such as changes in in employment and associated costs are excluded (e.g., behind the farm gate).

- Contaminant losses are considered at the farm scale (i.e., nitrogen yields are from root zone, not necessarily reaching waterbodies—the broader functions of the FWMT enable loads to waterways and through waterways (i.e. in-stream processes) to be modelled). Sediment and phosphorus are also considered in a similar manner, namely losses from a farm, but not necessarily losses to water.
- The five CVP rotations are assumed indicative of the broader cultivated and perennial horticulture in the Auckland region. Each rotation is a simplification albeit a reasonable, evidence-based simplification of the true diversity of grower activities. For example, crops have numerous varieties, methods of growing and timings, costs and revenues that combine to create variation within each CVP rotational type—the full diversity of which was not captured in this modelling exercise.
- The five CVP rotations have been weighted based on crop prevalence and expert opinion to generate one CVP model that can be used in the FWMT for cultivated horticulture.
- The gross margins and profitability assessments do not consider factors such as land swapping, nor do they consider factors such as processing, as many CVP entities are vertically integrated to some extent. As such they are not representative of a CVP business structure.
- The modelling is presented on a one-hectare block basis which is an arbitrary modelling construct with many growers continually planting and harvesting one or several rows at a time. For example, each week another row of brassicas are planted and there can be are multiple type of leafy greens all within one paddock. This way there are continual planting and harvesting activities across a horticulture business to suit demand and conditions.
- Input and output costs need to be considered on the same basis, for example if spot prices for inputs are used, costs should be on the same basis, rather than long term averages. The challenge is the current period of high inflation especially for fertiliser, fuel, and labour. It was felt that using long term input prices was likely to be significantly lower than current input prices and current high prices, especially labour, were unlikely to reduce again. 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 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.

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