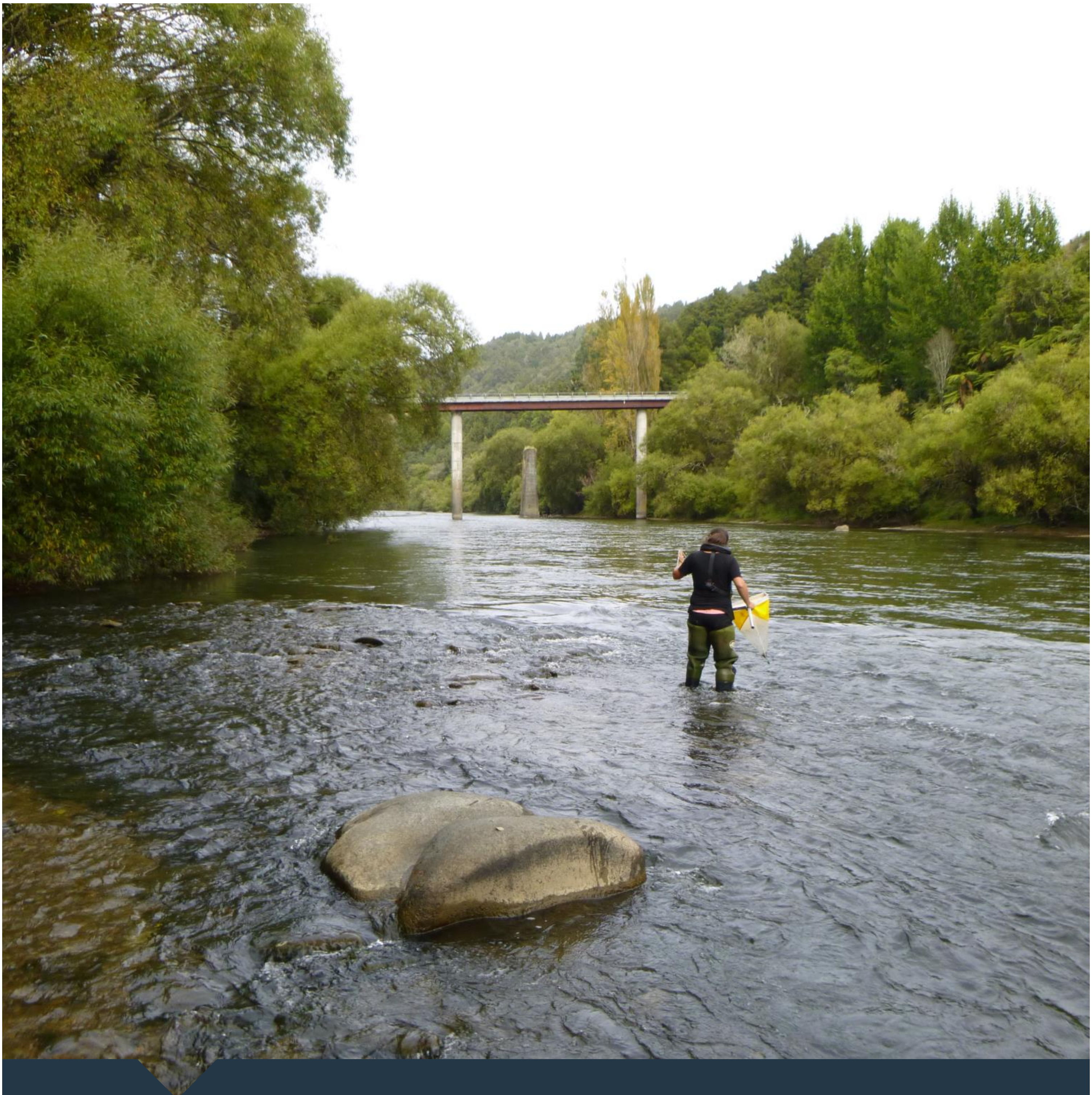

Nutrient losses from Commercial Vegetables in Horowhenua

March 2023

horizons
REGIONAL COUNCIL

Prepared for:

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March 2023
Report No. 2023/INT/1997

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Nutrient losses from Commercial Vegetables in Horowhenua

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Disclaimers and Limitations

This report ('**Report**') has been prepared by WSP exclusively for [Horizons Regional Council] ('**Client**') in relation to the modelling of five different scenarios plus baseline to determine the potential change in nitrogen and phosphorus loading within the Hoki_1a and Hoki_1b Water Management Subzones ('**Purpose**') and in accordance with the short form agreement with the Client dated 8 December 2022. The findings in this Report are based on and are subject to the assumptions specified in the Offer of Service dated 8 December 2022. WSP accepts no liability whatsoever for any reliance on or use of this Report, in whole or in part, for any use or purpose other than the Purpose or any use or reliance on the Report by any third party.

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1 Executive Summary

To support Horizons Regional Council in determining whether commercial vegetable growers in the Hoki_1a and Hoki_1b Water Management Subzones should or should not be exempt from the National Policy Statement Fresh Water regulations, WSP has been engaged to assess the potential reductions that could be achieved for nitrogen and phosphorus losses to water from commercial vegetable systems.

Six scenarios were investigated to determine what scenarios, if any, are likely to result in meeting the required water quality targets for this catchment:

Baseline. Vegetable production in Hoki_1a and Hoki_1b subzones pre-2019.

Scenario 1. Adoption of all GMP/BMP – based on Plan Change 2.

Scenario 2. Scenario 1, plus removal of all other agriculture from the two Water Management Subzones. For this report, only the adoption of GMP/BMP has been addressed; the removal of all other agriculture is out of scope. Therefore, for the purposes of this report, this component is effectively the same as Scenario 1.

Scenario 3. Removal of all vegetables from the two Water Management Subzones and relocating CVG into a neighbouring Water Management Subzone.

Scenario 4. A combined approach to growing vegetables with some in field production and the use of hydroponics/glasshouses.

Scenario 5. Removal of top 25% nitrate leaching crop rotations from the system and replacing with low leaching crop rotations.

OverseerFM has been used to model the baseline year and the five scenarios. The focus of this report is on the contaminants nitrogen and phosphorus. The output data only considers the amount of nitrogen and phosphorus lost from the root zone and does not account for nitrogen and phosphorus entering surface and/or ground water.

Table 1-1 shows that all scenarios within this study reduced nitrogen loss to water, with four out of five scenarios also reducing phosphorus loss to water. Scenario 5 shows no impact on phosphorus losses compared to the baseline. All of the scenarios impacted the volume of vegetables produced in-field from the Hoki_1a and Hoki_1b Water Management Subzones. However, only Scenarios 1 and 2 indicated a direct loss of vegetable production. In Scenarios 3 and 4, vegetable production was moved either outside of the subzones or into glasshouses. Scenario 5 indicated a slight increase in the total volume of vegetables produced (Table 1-2).

Table 1-1: Commercial vegetable in-field leaching of nitrogen and phosphorus (total kg).

	Baseline	Scenarios 1 and 2	Scenario 3	Scenario 4	Scenario 5
Nitrogen (Total kg)	36,370	15,875	6,327	21,400	27,677
% Reduction	n/a	56	83	41	24
Phosphorus (Total kg)	906	544	377	781	906
% Reduction	n/a	40	58	14	0

Table 1-2: Change in vegetable production for each scenario (tonnes).

	Baseline crop tonnage	Post scenario tonnage	Percentage reduction
Scenarios 1 and 2	36,566	24,093	34%
Scenario 3	36,566	36,566	0%
Scenario 4	36,566	36,566	0%
Scenario 5	36,566	37,729	3.2% increase

Of all the scenarios modelled, Scenario 3 shows the greatest potential to improve the outcomes for Lake Horowhenua, while preserving food production. However, this will increase nutrient leaching in the receiving subzone. The direct impact on water bodies in these areas has not been modelled. It should be noted that as Scenario 2 only considered the impact from commercial vegetable production for this report, there may still be potential for Scenario 2 to provide the required water quality outcomes once all other agriculture is removed from the two subzones.

In practice, improving water quality within the Hoki_1a and Hoki_1b Water Management Subzones may best be achieved through an integrated approach adopting parts of each of the scenarios.

2 Introduction

2.1 Background

The National Policy Statement for Freshwater Management 2020 (NPS-FM) requires regional councils to set a target attribute state for all Freshwater Management Units (FMUs) within the region.

However, special provisions for commercial vegetable production in Pukekohe and Horowhenua have been allowed for, as previous modelling has indicated that these areas would not be able to meet the nitrogen national bottom lines without impacting the supply of domestic fresh vegetables (MfE and MPI, 2020). These provisions allow for councils to potentially exempt commercial vegetable growers from the NPS-FM 2020 for a 10-year period from 3rd September 2020. The provisions state that in a FMU that includes all or part of a Specific Vegetable Growing Area (SVGA), decision makers (in this case Horizons Regional Council or 'Horizons') must have regard to:

- The domestic supply of fresh vegetables, and
- Maintaining food security of New Zealanders

The Manawatu region produces significant volumes of vegetables in Horowhenua, however, only the Hoki_1a and Hoki_1b Water Management Subzones fall within the SVGA. In 2018, these two Water Management Subzones had a total vegetable growing area of 503 ha (Figure 2-1). These subzones are impacting the water quality of Lake Horowhenua, particularly through nitrate leaching. However, phosphorus and sediment contamination from commercial vegetable production also contributes to the poor water quality of the lake.

In order to assess whether an exemption is appropriate, Horizons must understand whether achieving the national bottom line for the relevant attributes may compromise the domestic supply of fresh vegetables and the maintenance of food security for New Zealanders. However, Horizons still have the right to set water quality targets for relevant attributes below the national bottom line, if water quality is already below national bottom lines for attributes that are affected by nitrogen.

To support Horizons in determining whether commercial vegetable growers in the Hoki_1a and Hoki_1b subzones should be exempt from the NPS-FM 2020 regulations, WSP has been engaged to explore the potential reductions that could be achieved for nitrogen and phosphorus from commercial vegetable systems in these areas.

2.2 Hoki_1a and Hoki_1b Water Management Subzones

Lake Horowhenua is the largest shallow coastal dune lake within the Horizons region. The LAWA website (LAWA, n.d. (b)) highlights that the lake has a Tropic Level Index of 'very poor' with a continuing trend across the last 10 years of 'very poor'. A ground water monitoring site (352099) located within the Hoki_1a subzone indicates a 5-year median for nitrate nitrogen of 15 mg/L (LAWA, n.d. (a)) (Table 2-1). However, the 10-year trend indicates that nitrate nitrogen is likely to be improving. At the same site, dissolved reactive phosphorus has a 5-year median of 0.06 mg/L P. Both nitrate nitrogen and phosphorus are considered to be high.

There are two streams that drain into the Lake Horowhenua, the Patiki Stream and the Arawhata Stream. Table 2-1 summarises the five-year median total nitrogen and nitrate nitrogen concentrations. The data indicates that these streams are degraded and would not meet the NPS-FM 2020 nitrate toxicity national bottom line.

Table 2-1: Total nitrogen (TN) and nitrate nitrogen (NO_3^--N) concentrations for key waterbodies in the Lake Horowhenua catchment (LAWA, n.d. (b)). Five-year median 2017-2021.

Water body	Five-year median TN (mg/L)	Five-year median NO_3^--N (mg/L)
Lake Horowhenua	2.01	0.454
Patiki Stream	5.87	5.77
Arawhata Stream	10.75	10.55
National bottom line	0.75*	2.4

*750 mg/m^3 as expressed in NPS-FM 2020 (MfE, 2020)

The Hoki_1a and Hoki_1b Water Management Subzones are the two key subzones that encompass Lake Horowhenua (Figure 2-1). Contaminant losses from these two subzones have directly fed into the lake for many years, resulting in significantly degraded water quality as highlighted above. Contaminants including nitrogen, phosphorus, sediment, and E. coli have all contributed to the lakes poor water quality, however, nitrogen is the primary containment.

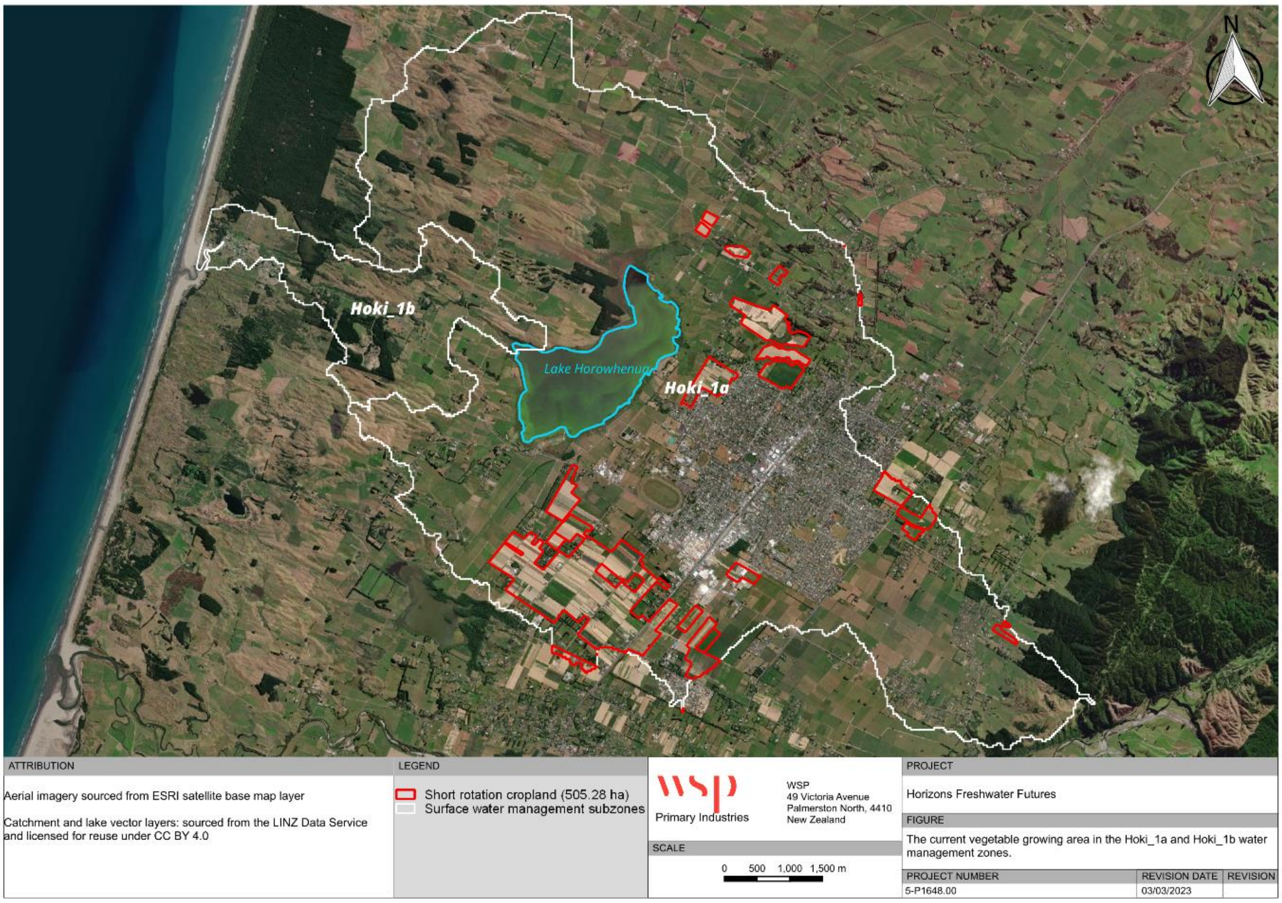

Figure 2-1: The vegetable growing area in the Hoki_1a and Hoki_1b Water Management Subzones in 2018. Data source: LCDB v5.0 (Manaaki Whenua, 2021).

There are a range of land uses within these two subzones, with a mix of both rural and residential uses which all contribute to the poor water quality of the lake. Rural land uses include commercial vegetable growing, sheep and beef, dairy farming, and arable. The productive growing area for commercial vegetables modelled by Bloomer et al (2020) was 377 ha, which covered a titled area of 419 ha (data for this study was collected between 2016 and 2018). It should be noted that data from the Manaaki Whenua Land Cover Data Base (LCDB) v5.0 (Manaaki Whenua, 2021) (Figure 2-1) shows the growing area to be 505 ha. The difference in vegetable growing area between the LCDB data and the Bloomer et al (2020) report is because the LCDB highlights all short-term rotation cropping, not just commercial vegetables. Within the LCDB database a short-term rotation crop is defined as: land regularly cultivated for the production of cereal, root, and seed crops, hops, vegetables, strawberries and field nurseries, often including intervening grassland, fallow land, and other covers not delineated separately (Manaaki Whenua, 2021).

2.3 Nitrogen and phosphorus loss pathways

2.3.1 Primary nitrogen loss pathway

The most common form of nitrogen loss occurs through nitrate leaching, which is a physical process where nitrate is carried by water as it moves through the soil profile. Leaching results when a soil is saturated, resulting in nitrate moving past the root zone, making it unavailable for plant uptake.

Two key conditions are required for leaching to result: a buildup of nitrate in the soil profile, and excess moisture in the soil. Any excess of moisture results in the downward movement of water through the soil profile, known as a drainage event. Nitrate leaching is at greatest risk of occurring during late autumn, winter, and early spring when there is an excess of rainfall over evapotranspiration and the soil is at or near field capacity. During this time of year, plant growth rates are also low, therefore little nitrate is being removed from the soil via plant uptake, allowing a buildup of nitrate in the soil profile over these months. This holds true for commercial vegetable systems. However, vegetables are required to be grown year-round to maintain the supply of fresh vegetables.

Although nitrate leaching is the primary form of nitrogen loss from vegetable systems, for consistency with OverseerFM reporting, nitrate leaching will be referred to a nitrogen leaching or nitrogen loss to water for this report.

2.3.2 Primary phosphorus loss pathway

Unlike nitrogen, the primary loss of phosphorus is through surface runoff which is a physical process where phosphorus is carried across the top of a soil profile by water and transported to nearby surface water bodies. Phosphorus can be transported dissolved in water, in particulate form, or bound to sediment particles. Within agricultural systems, sediment bound transportation is the most common form. Surface runoff of phosphorus is more common during and after heavy rainfall events, soon after phosphorus fertiliser has been applied, or when the soil is bare.

For the context of this report, phosphorus leaching is also important to understand as this is the pathway of loss modelled in OverseerFM. The mechanism of phosphorus leaching is the same of that of nitrate leaching, leading to phosphorus siting below the root zone making it unavailable for plant uptake. The loss of phosphorus through leaching is low in comparison to phosphorus loss through surface runoff.

2.4 Scope of this report

WSP was engaged to provide an economic analysis of the effects of changes in land use practices required in the Hoki_1a and Hoki_1b Water Management Subzones to meet the national bottom lines for the attributes set out in Part 2 of Appendix 5 of the NPS-FM 2020, with a particular focus on the impacts on the domestic supply of fresh vegetables and maintaining food security for New Zealanders.

In order to understand the economic effects on commercial vegetable systems and the flow on impact to the supply of domestic fresh vegetables if growers are required to meet environmental bottom lines, the impacts of potential changes on nitrogen and phosphorus loss from the root zone first need to be determined. This information will indicate which, if any system or land uses changes have potential to meet the national bottom lines (or the water quality attribute targets set by Horizons).

To address this, WSP has undertaken two tasks:

1. Baseline update: The initial task was to replicate and update the baseline modelling in OverseerFM. The initial modelling completed by Page Bloomer Associates in early 2020 (Bloomer, et al., 2020) fed into the water quality models developed by Ton Snelder for Plan Change 2. Replicating this modelling was required because WSP has 'read' access only to this OverseerFM account and the account was now inactive. The outputs from this modelling will be referred to as the baseline year to which all scenario modelling will be compared. This baseline will also be utilised for further scenario modelling.

2: Scenario modelling: Following the replication of the baseline models, five further scenarios were modelled to reflect possible system or land use changes that could achieve the required reductions in nitrogen and phosphorus to meet the required water quality targets. The five agreed scenarios for modelling were:

Scenario 1. Adoption of all GMP/BMP – based on Plan Change 2

Scenario 2. Scenario 1, plus removal of all other agriculture from the two Water Management Subzones. For this report, only the adoption of GMP/BMP has been addressed; the removal of all other agriculture is considered out of scope. Therefore, for the purposes of this report, this component is effectively the same as Scenario 1.

Scenario 3. Removal of all vegetables from the two Water Management Subzones and relocating CVG into a neighbouring Water Management Subzone

Scenario 4. A combined approach to growing vegetables with some in field production and the use of hydroponics/glasshouses

Scenario 5. Removal of top 25% nitrate leaching crop rotations from the system and replacing with low nitrate leaching crop rotations.

3 Methodology

3.1 Modelling approach

In keeping with the approach taken for all on-farm modelling during Horizons Plan Change 2, OverseerFM has been used to model the baseline year plus the five scenarios that could potentially be implemented to improve water quality within the Hoki_1a and Hoki_1b Water Management Subzones. The focus of this report is on the contaminants nitrogen and phosphorus.

OverseerFM is an imperfect tool for estimating both nitrogen and phosphorus losses from commercial vegetable systems, due to limitations of the model, particularly in relation to data availability and parameterisation of the model for the wide range of vegetable crops and systems. However, it is a useful tool to estimate the relative change in nitrate leaching for comparable systems in different scenarios.

3.2 Baseline data transfer

As part of their Plan Change 2 process, Horizons Regional Council contracted Page Bloomer Associates to model nitrogen losses from commercial vegetable systems located within the Hoki_1a and Hoki_1b Water Management Subzones (Bloomer, et al., 2020). Overseer v6.2.3 was used to modelled vegetable systems pre-2019, using grower data from between 2016 and 2018.

As part of the Bloomer et al (2020) approach, commercial vegetable operations were grouped into three production systems: potatoes and onions; brassica dominant; and intensive vegetables. Intensive vegetables were the dominant system in the subzones, followed by potatoes and onions, and then brassica dominant (Table 3-1).

Table 3-1: Vegetable growing systems within the Hoki_1a and Hoki_1b Water Management Subzones 2018 (Bloomer, et al., 2020).

Vegetable system	Percentage of growing area
Potatoes and Onions	27
Brassica dominant	11
Intensive Vegetables	62

This approach took into consideration the extreme variability within vegetable growing operations. This includes differences within paddocks, between paddock to paddock and changes seasonally and annually. This is no different for the commercial vegetable growing operations within the Hoki_1a and Hoki_1b Water Management Subzones.

For this study, the baseline has first been updated by transferring all 62 crop rotations across the three vegetable systems (potatoes and onion, brassica dominant, and intensive vegetables) through from the Bloomer report into a new OverseerFM account v6.5.0.

All crop data was copied like for like and became the baseline data for this report. The only difference between the models was a change in soil name (Mokotua_2a.1 to Mokotua_19a.1) as Smap updated the database. Any differences in data outputs between the Bloomer et al. (2020) models and the baseline models within this report is solely the result of differences between OverseerFM versions. Differences in subzone outputs are also evident, due to differences in scaling the data from crop rotation outputs up to catchment scale outputs. The differences in approach are explained in Section 3.9.

3.3 Scenario 1: Adoption of good and best management practices

Scenario 1 took a similar approach to the Plan Change 2 study (Jolly, et al., 2020), modelling the adoption of a range of good management practice (GMP) and best management practices (BMP) using OverseerFM. Jolly et al. (2020) took a more in-depth look at the impact of a range of GMP and BMP compared to Bloomer et al. (2020). The modelling approach is summarised below:

- All fertiliser data drawn from Bloomer et al. (2020).
- All vegetable crops apart from potato and onions were required to adopt minimum till cultivation techniques,
- All catch crops were required to adopt direct drill cultivation techniques,
- To reduce fallow periods, where the fallow was three or more months, a catch crop was required (apart from where the three-month period covers the months of June to August due to winter conditions making sowing and harvest to difficult).
- All forage catch crops were required to be cut and carried and livestock were not included in the system.
- The implementation of the practice of controlled trafficking, which has been shown to reduce the growing area by 16% (Bloomer & Hosking, 2006) . Where growing area reduces as the result of GMP and BMP adoption, no additional sourcing of land area has been modelled.

For this scenario, the default level of practice change modelled was BMP. However, not all practices had an associated BMP, and in these cases GMP was modelled. Table 3-2 highlights all practice changed modelled as part of this scenario.

Table 3-2: GMP and BMP modelled as part of Scenario 1.

Good management practices
Minimise soil tillage as much as practicable
Minimise fallow periods between crops
Planting catch crops in between vegetable rotations
Planting of buffer strips down the side of each paddock (1.5 m)
Matching soil testing results to plant requirements
Split fertiliser application
Best management practices
Planting of buffer strips at the bottom of each paddock (6 m)
Use controlled trafficking where appropriate
Soil testing for base fertiliser every year
Soil testing for nitrogen before each side dressing for fertiliser using quick N test

The approach taken for defining GMP and BMP for Plan Change 2 is explained in Jolly et al. (2020).

3.4 Scenario 2: The adoption of practice change, plus removal of other agriculture

Scenario 2, like Scenario 1 included the adoption of all GMP and BMP highlighted in Table 3-2. The second part of the scenario is the removal of all other forms of agriculture from the two Water Management Subzones. However, removal of other forms of agriculture was out of scope for this report, which only addresses the vegetable component of the scenario, replicating Scenario 1.

3.5 Scenario 3: Removal of vegetable production from Hoki_1a and Hoki_1b subzones

In this scenario, all commercial vegetable production is moved to a neighbouring subzone to reduce the impact of nitrogen and phosphorus loss on Lake Horowhenua. The land use within the Hoki_1a and Hoki_1b subzones would change from commercial vegetables to extensive sheep and beef. For this purpose, Horizons has provided WSP with nitrogen and phosphorus loss data for the sheep and beef systems, sourced from the Our Land and Water typologies.

A spatial analysis using ArcGIS was completed to determine which neighbouring subzones had sufficient LUC class 1 land to grow the required volume of vegetable crops. The LCDB database v5.0 (Manaaki Whenua, 2021) is the most current land cover data available and was used to identify where vegetables were currently not grown within neighbouring subzones. The Land Use Capability 2021 (Manaaki Whenua, 2023b) was used to identify the location of LUC class 1 land.

Two subzones: Ohua_1b to the south of Hoki_1a and Hoki_1b subzones; and Mana_13e to the north of Hoki_1a and Hoki_1b subzones, were identified as having sufficient suitable land for the transfer of commercial vegetables. Using OverseerFM, a modelling exercise was carried out using the baseline data to determine the impact of transferring commercial vegetable operations into either of these subzones.

3.5.1 Moving to Ohau_1b Water Management Subzone

All commercial vegetable crops were assumed to be moved to areas that are mapped LUC class 1 (Figure 3-1). The predominant soil sibling was identified by combining Smap (Manaaki Whenua, 2023a) with the New Zealand Land Resource Inventory Land Use Capability data (Manaaki Whenua, 2023b) as well as Manaaki Whenua's highly productive land (Manaaki Whenua, 2023c). To remain consistent with earlier modelling, any potato and onion rotations were grown in brown soil, while all brassica and intensive vegetable rotations were grown in a recent soil when modelled in OverseerFM.

These were the Oronoko_233a.1 sibling (brown) and the Selwyn_131a.1 sibling (recent) (Table 3-3).

The new climate information for the Ohau_1b subzone (Figure 3-1) was tested against the OverseerFM defaults of the Hoki_1a and Hoki_1b subzones. The difference in climate information was very small, and any effect on nutrient transfer was therefore assumed to be negligible.

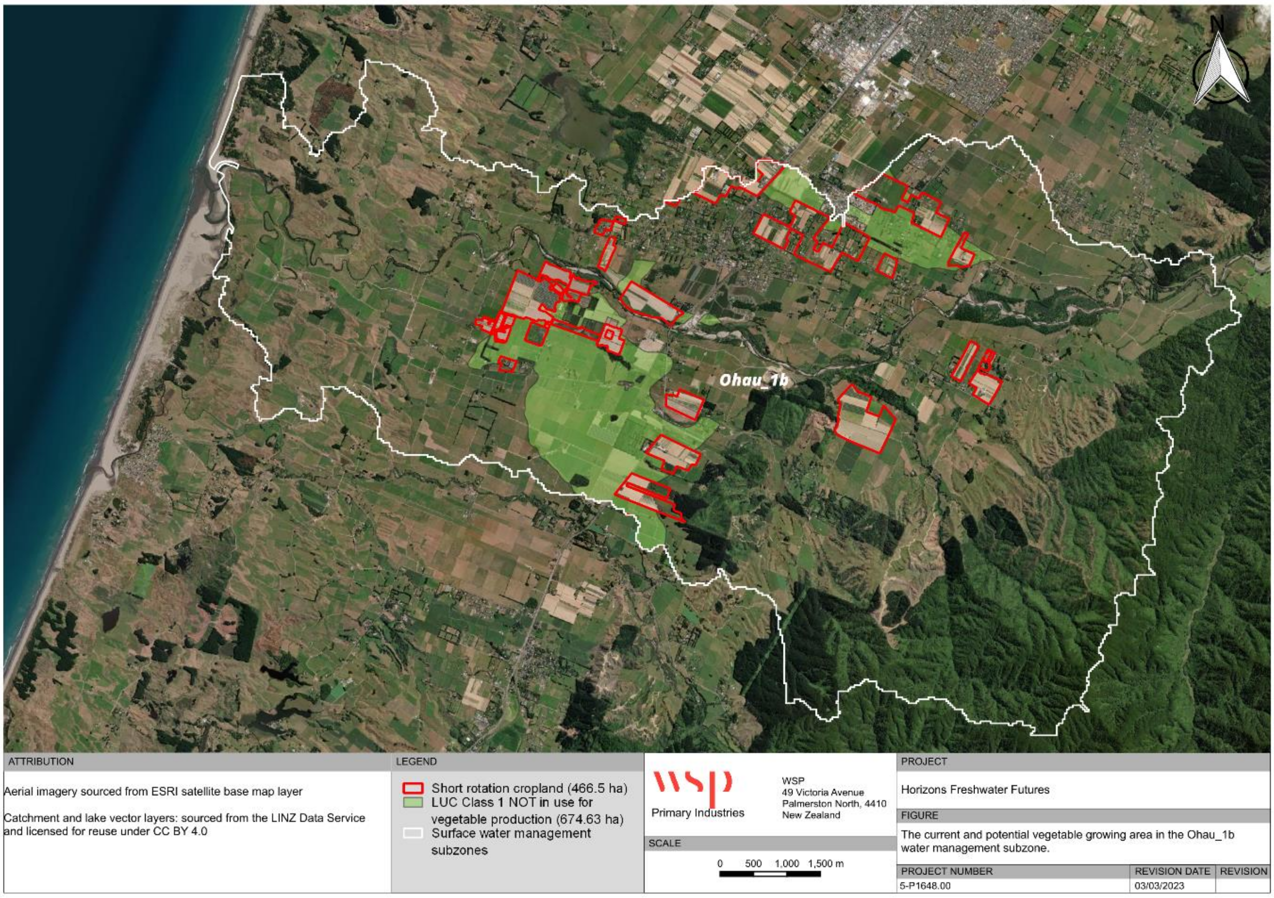

Figure 3-1: Ohua_1b Water Management Subzone potential vegetable growing areas.

3.5.2 Moving to Mana_13e Water Management Subzone

As for the Ohua_1b subzone, using Smap and highly productive land layers in combination, the predominant soils siblings of LUC class 1 land in the Mana_13e subzone (Figure 3-2) were identified. Brown soil siblings made up the clear majority (approximately 90%) of the subzone thus all crop rotations were modelled using the Gladstone_127a.2 sibling (Table 3-3), as this was the most predominant and only minor differences in soil chemical characteristics are expected between the most popular siblings by are, which were all brown by order.

New climate information was tested against the original catchment using OverseerFM defaults, and the difference was very minor, and any impacts therefore also assumed to be negligible. No steps were taken to manually override block climate for each rotation.

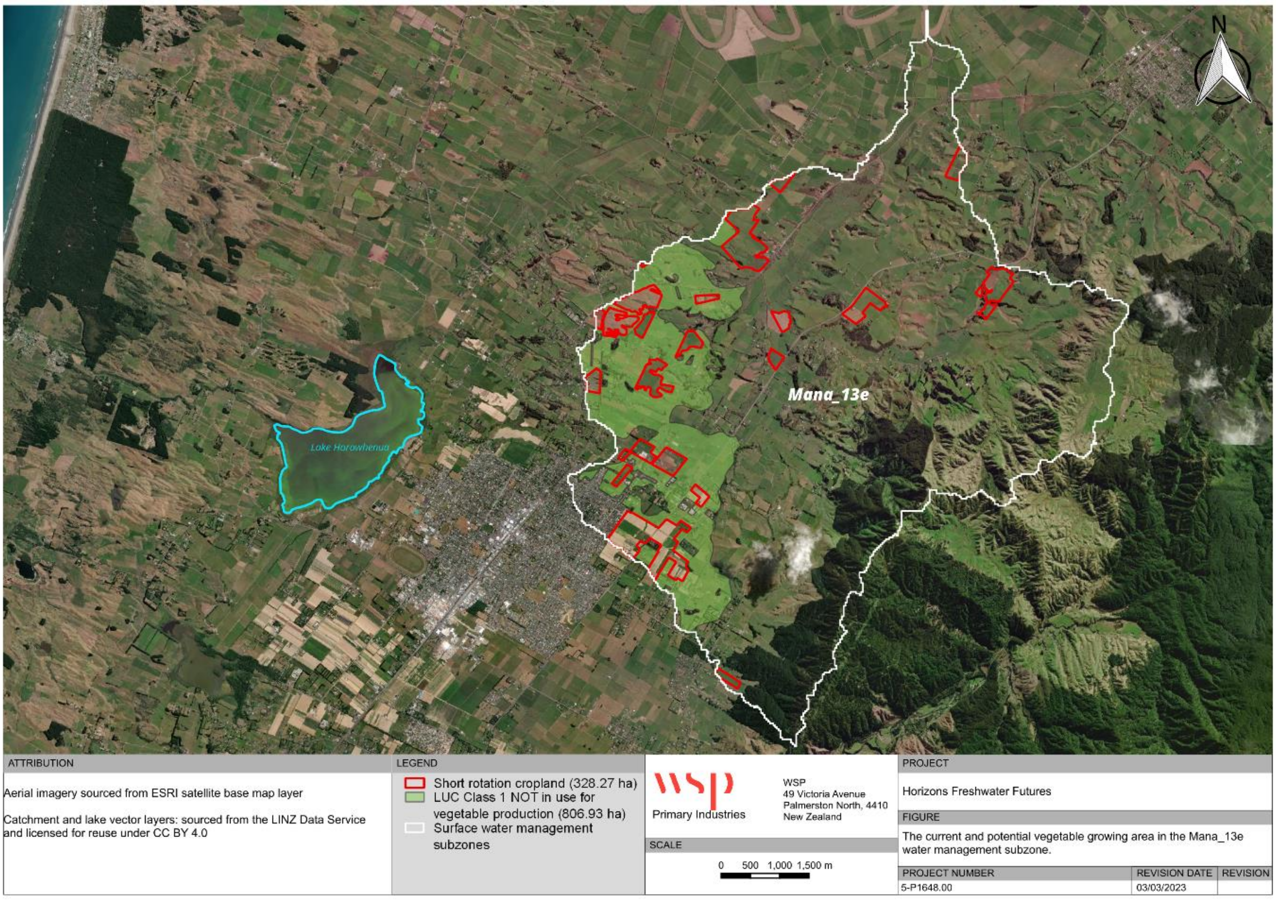

Figure 3-2: Mana_13e Water Management Subzone potential vegetable growing areas.

Table 3-3: Key soil characteristics across the different subzones. (Manaaki Whenua, 2023a).

Soil	Origin	Texture	Drainage class	Permeability	P retention
Selwyn_131a.1 (Ohau_1b)	Alluvium	Loam over sand	Well drained	Moderate over rapid	19%
Oronoko_233a.1 (Ohau_1b)	Loess on alluvium	Silt	Well drained	Moderate	36%
Gladstone_127a.2 (Mana_13e)	Loess	Silt	Moderately well drained	Moderate	36%
Pahua_29a.1 (Hoki_1a)	Loess	Silt	Imperfectly drained	Moderate over slow	19%
Mokotua_a.1 (Hoki_1a)	Loess	Silt	Imperfectly drained	Moderate over slow	36%

3.6 Scenario 4: The use of glasshouses

Scenario 4 is a mixed model approach to growing vegetables. While most crops would continue to be grown in-field, certain crops would be required to be grown in enclosed glasshouses in the future. Through a literature review completed as part of the wider project (Appendix C) it has been identified that lettuce, spinach, and parsley are all suitable crops for glasshouse production that are currently being grown in the Hoki_1a and Hoki_1b Water Management Subzones. Based on this information, the OverseerFM baseline data was modified to remove all plantings of either lettuce, spinach, or parsley in the two subzones and replace these with pasture. The pasture crop was treated as a cut and carry crop, with the number of silage cuts varying depending on the length in time the crop was grown. All harvested silage was export off farm and fertiliser were applied at maintenance levels to support suitable pasture growth rates. Appendix B provides additional detail on how the pastoral crops were modelled in OverseerFM.

The above approach is different to the planned approach of simply removing land out of the commercial vegetable growing area where lettuce, spinach, or parsley was grown. However, removing the land area for only these vegetables was impractical to model in the context of the different rotations. Therefore for simplicity, removed vegetables were substituted for pasture modelled as a cut and carry silage crop within the affected crop rotations.

The use of enclosed glasshouses to grow vegetables also has a potential environmental impact where hydroponic waste nutrient solution (wastewater) is discharged to land. One high level OverseerFM model has been developed to provide an indication of the potential impact of applying wastewater to land within the Hoki_1a or Hoki_1b Water Management Subzones.

Key concepts and principals for growing in enclosed glasshouses are explained in more detail in the literature review. Each glasshouse is a fully enclosed hydroponic system, with no loss of nutrients and water through leaching or to the atmosphere. The glasshouses are used for producing vegetables year-round, featuring a recirculating nutrient system. The discharge of nutrient solution from greenhouse operations provides quality fertiliser for irrigating on to pasture. However, like any pastoral system, there is a risk of nitrate leaching from the root zone.

Appendix B highlights the assumptions made when modelling glasshouse wastewater to land within OverseerFM. Key parameters for the modelling included a nitrogen loading of 364 mg N/L in 2,325 m^3 of wastewater (van Ruijven, et al., 2019).

3.7 Scenario 5: Removal of top 25% nitrate leaching crop rotations

Scenario 5 addresses the impact of removing the highest 25% nitrate leaching crop rotations and replacing those crop rotations with low nitrate leaching crops rotations (Table 3-4). Based on the baseline data sorted for greatest nitrate leaching to lowest nitrate leaching rotations, the highest and lowest nitrate leaching crop rotations were identified.

The highest nitrate leaching rotations come from either brassica dominant rotations or intensive vegetable rotations. In comparison, the low nitrate leaching crop rotations are present in all three vegetable systems, with a high presence of potatoes and onions rotations. When determining the low nitrate leaching crop rotations, consideration was also given to the diversity of the type of vegetables grown in these rotations. For this reason, no high leaching crop rotations were replaced with potato- or onion-only crop rotations. This avoided the issue of over-supply of potatoes or onions, which would potentially impact the supply of leafy green crops in a greater capacity to the impact already seen when removing the greatest 25% nitrate leaching rotations.

The cropping area of each rotation was also considered when replacing crop rotations. The approach taken matches a high nitrate leaching crop rotation with a low nitrate leaching crop rotation. The low leaching crop rotations adopted the growing area of the high leaching crop rotations, thus keeping the total growing area across the subzones the same.

This approach for this scenario was focused on reducing nitrogen losses to water, and did not consider the impact on phosphorus losses to water.

Table 3-4: The highest nitrate leaching crop rotations from baseline year and their low nitrate leaching replacement crop rotations.

Top 25% leaching rotations removed	Replaced with lowest nitrate leaching rotations
Cabbage Lettuce Spinach	Spring Onion Lettuce Spinach Melon Cabbage
Red Cabbage Parsley	Kale Spinach
Pumpkin Red Cabbage	Parsley Pumpkins Beets
Lettuce Cabbage Spinach	Spring Onion Lettuce Spinach Melon Cabbage
Squash Cauliflower Broccoli Lettuce	Lettuce Cauliflower Pumpkin Cabbage
Spring Onion Cabbage Lettuce Spinach	Spring Onion Cabbage Melon
Lettuce Cabbage Broccoli Cauliflower	Cauliflower Potato Cauliflower
Red Cabbage Leek Spinach	Coriander White Pak Choi Spring Onion Spinach
Cabbage Cauliflower Lettuce	Lettuce Cauliflower Pumpkin Cabbage
Parsley Spinach Lettuce Wong Bok Beets	Spinach Radish Fennel Spring Onion Wong Bok
Radish Cabbage Fennel	Radish Coriander Lettuce Shanghai Spring Onion
Celery Spring Onion Spinach 2	Melon Spring Onion
Lettuce Broccoli Lettuce Onion	Celery Cabbage Broccoli
Cauliflower Broccoli Lettuce Broccoli	Celery Cabbage Broccoli

3.8 Extrapolating OverseerFM data

To estimate subzone impacts, we applied the OverseerFM outputs for each scenario, including the baseline year, on a pro rata basis according to cropped areas outlined in the Bloomer et al (2020) report (Table 3-1).

First, the OverseerFM output data for nitrogen and phosphorus were divided into each of the three vegetable systems. Total nitrogen and total phosphorus for each of the three systems was then multiplied by their respective total growing area: 27% for potato and onions; 11% for brassica dominant; and the remaining 62% for intensive vegetables. The resulting information gave the total kilograms of nitrogen and total kilograms of phosphorus loss to water for each of the scenarios. To determine the equivalent kilograms of nitrogen leached per hectare, the total kilograms nitrogen was divided by either the productive area or the titled area. The same was completed for the phosphorus data.

4 Results

4.1 Summary of results

Table 4-1 provides the nitrogen leaching results for in-field vegetables only, on a per hectare basis for each of the modelled scenarios, compared against the baseline values. Scenario 3 effectively results in no nitrogen loss to water from commercial vegetables for the two Water Management Subzones, as this scenario modelled the removal of all vegetable production from these subzones (and replacement with sheep and beef). Scenarios 1 and 2 provide the next greatest reduction in nitrogen leaching. These scenarios model the adoption of all GMP and BMP for the vegetable production operations and highlight the significant impact that GMP/BMP can have on reducing nitrogen losses for the subzones.

Table 4-1: Summary of nitrogen leaching rates per hectare across baseline and scenarios for in field commercial vegetable.

	Average kg N/ha	Max kg N/ha/yr	Min kg N/ha/yr
Baseline	96	251	21
Scenarios 1 and 2	42	112	5
Scenario 3	0	0	0
Scenario 4*	54	224	5
Scenario 5	73	127	21

*Information for in field crops only

Phosphorus leaching rates for the different scenarios (Table 4-2) are ranked similarly to nitrogen in order of reduction except for Scenario 5 which had no impact. This is largely unsurprising as the approach for Scenario 5 was targeted to address nitrate leaching.

Table 4-2: Summary of phosphorus leaching rates per hectare across baseline and scenarios for in field commercial vegetable.

	Average kg P/ha	Max kg P/ha/yr	Min kg P/ha/yr
Baseline	2.4	7.6	0.4
Scenarios 1 and 2	1.4	4.3	0.3
Scenario 3	0	0	0
Scenario 4*	1.7	6.5	0.4
Scenario 5	2.4	7.6	0.4

*Information for in-field crops only

Table 4-3 shows the total amounts of nitrogen and phosphorous leached for each scenario alongside the percentage reductions. This includes the sheep and beef component of Scenario 3, and wastewater applied to land in Scenario 4. However, it does not include the removal of all agriculture in Scenario 2. All scenarios within this study reduced nitrogen loss to water, with four out of five scenarios also reducing phosphorus loss to water. Scenario 5 shows no impact on phosphorus losses compared to the baseline.

*Table 4-3: Summary of nitrogen and phosphorus leaching for each scenario (total kg). **

	Baseline	Scenarios 1 and 2	Scenario 3	Scenario 4	Scenario 5
Nitrogen (kg)	36,370	15,875	6,327	21,400	27,677
% Reduction	n/a	56	83	41	24
Phosphorus (kg)	906	544	377	781	906
% Reduction	n/a	40	58	14	0

*Does not take into consideration land use change for Scenario 2, however includes sheep and beef data for Scenario 3.

The change in vegetable production for each scenario compared against the baseline production is shown in Table 4-4. Although Scenario 3 shows a total removal of all vegetable production (100% reduction compared with baseline), this will not impact on Horowhenua's total vegetable production as these vegetable rotations are simply moved into a neighbouring subzone. Estimates of the impacts on the receiving subzones are provided in Section 4.4 below. For Scenario 4, there is a 32% reduction in tonnage of vegetables produced in-field, however this production is moved into glasshouses and therefore there is no overall loss.

Although Scenarios 1 and 2 demonstrate a high reduction in nitrogen and phosphorus leaching, these scenarios also have a large reduction in crop tonnage (34%). Scenario 5 shows a small increase in tonnage (3.2% higher). This is the result of the replacement crop rotations including crops with higher yields per hectare. However, Scenario 5 is the only scenario that potentially has an uneven influence on the vegetable tonnage across rotations. For dark green leafy vegetables, there is an overall reduction under this scenario. The highest 25% nitrate leaching crop rotations produced 1,018 tonnes of dark leafy green vegetables. When these crops are substituted out for low leaching crop rotations, the tonnage reduces by 7% to 944 tonnes.

Table 4-4: Change in vegetable in-field tonnage for each scenario (tonnes).

	Baseline crop tonnage	Post scenario tonnage	Percentage reduction
Scenarios 1 and 2	36,566	24,093	34%
Scenario 3	36,566	36,566	0%
Scenario 4	36,566	36,566	0%
Scenario 5	36,566	37,729	3.2% increase

*Information for in field crops only

4.2 Baseline

Baseline data is summarised in Table 4-5. This shows the total and per hectare nitrogen and phosphorus loss for both the productive area and the titled area. These numbers differ from the outputs in the Bloomer et al. (2020) report, as the OverseerFM version used is different and this analysis uses a different data summary approach, as highlighted in the methodology.

Table 4-5: Commercial vegetable baseline year results 2018.

	N loss kg N/ha	N loss kg N	P loss kg P/ha	P loss kg P	Area ha
Productive area	96	36,370	2.4	906	377
Titled area	87	36,370	2.2	906	419

Figure 4-1 shows an example of the total for different nitrogen pools and change in these nitrogen pools across an example baseline crop rotation (celery, lettuce, spinach, cabbage, and spinach). Across the crop rotation there are greater amounts of soil inorganic nitrogen compared to plant nitrogen uptake. Winter nitrate leaching is evident across both growing periods as the result of fallow periods. It also highlights the disparity between nitrogen fertiliser applications (in light blue) and crop demand across the rotation.

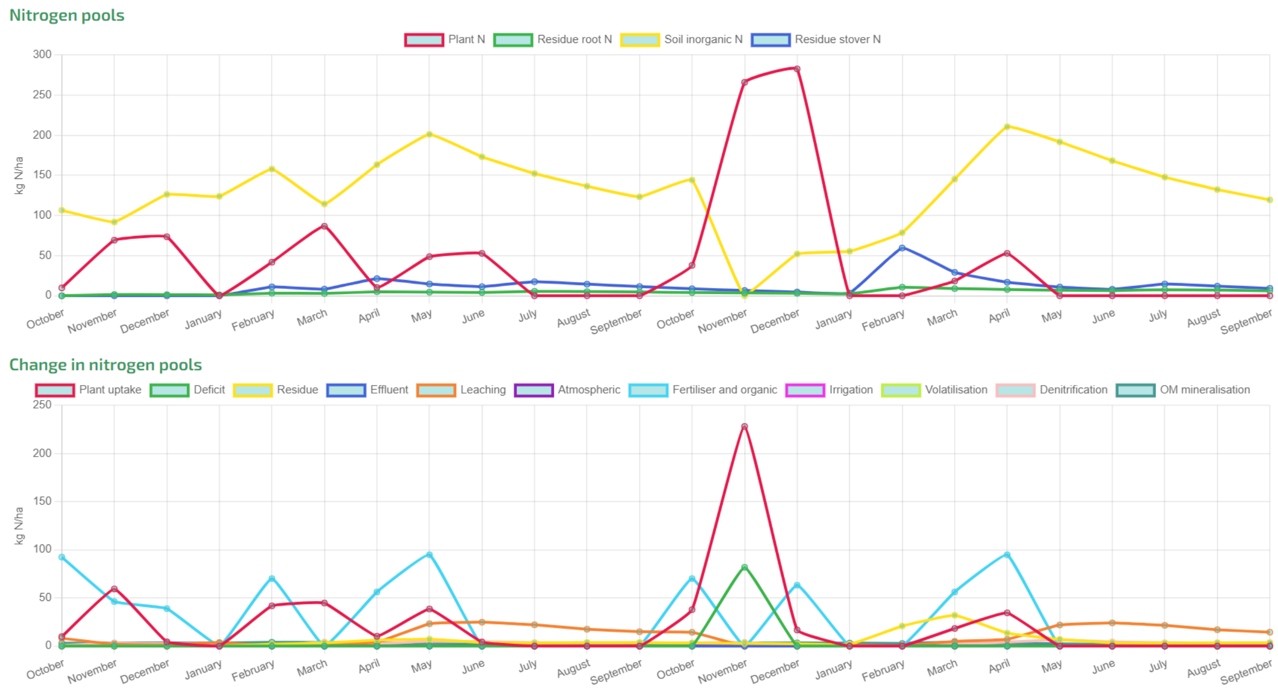

Figure 4-1: An example of the change in nitrogen pools for the baseline model. Crop rotation shown is celery, lettuce, spinach, cabbage, and spinach.

4.3 Scenarios 1 and 2: Adoption of practice change

The nitrogen and phosphorus losses for Scenarios 1 and 2 (adoption of GMP/BMP), for both productive and title area, are shown in Table 4-6. Although the modelled adoption of BMP and GMP results in a 56% reduction in nitrogen leached and removes of 20,461 kg of nitrogen compared with the baseline, this scenario also results in 12,473 tonnes less of vegetables being grown and harvested from the Hoki_1a and Hoki_1b subzones (Table 4-4). This is a 34% reduction in the total volume of vegetable production from these subzones. The tonnage of vegetables produced from Scenario 1 (and 2) is reduced as the result of some BMP reducing the growing area. These practices include the introduction of buffer zones and controlled trafficking.

Table 4-6: Commercial vegetable adoption of best and good management practices.

	N loss kg N/ha	N loss kg N	P loss kg P/ha	P loss kg P	Area ha
Productive area	42	15,909	1.5	548	377
Titled area	38	15,909	1.3	548	419

Figure 4-2 shows the different nitrogen pools and change in nitrogen pools across the crop rotation when BMP and GMP are undertaken, for the same example crop rotation shown above. Across the crop rotation, soil inorganic nitrogen levels vary compared to plant nitrogen with significantly higher soil inorganic nitrogen only resulting at the end of the rotation when a catch crop is present. Winter nitrate leaching is minimal across both growing periods as the result of forage oats growing over this period. Nitrogen fertiliser applications (in light blue) are shown to better match crop demand across the rotation.

When comparing the baseline nitrogen pool graphs (Figure 4-1) to Scenario 1 nitrogen pool graphs (Figure 4-2) it is observed that the baseline model has more inorganic soil nitrogen available compared to Scenario 1 (and 2). The source of the additional nitrogen in the baseline model is a result of higher nitrogen fertiliser applications, and nitrogen fertiliser applications not being matched to crop demand. The adoption of nitrogen fertiliser BMP and GMP still do not result in the complete match of supply to crop demand.

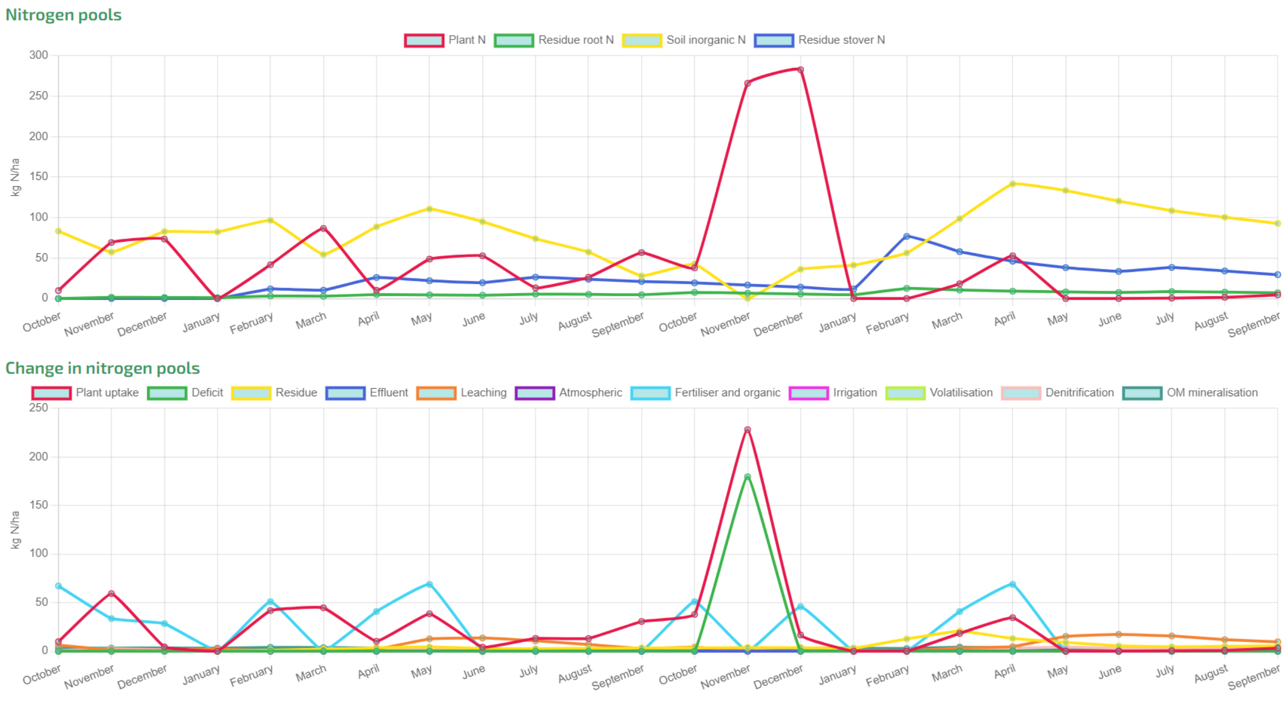

Figure 4-2: An example of the change in nitrogen pools for the GMP/BMP model. Crop rotation celery, lettuce, spinach, cabbage, and spinach.

Although the BMP and GMP modelled in Scenario 1 are targeted at reducing nitrogen loss from the subzones, the modelling highlighted an additional benefit for reducing phosphorus loss, with phosphorus losses reduced by 40%. The BMP and GMP that impacted this reduction were the adoption of buffer zones, annual base soil testing, the introduction of controlled trafficking, and the adoption of minimum till.

4.4 Scenario 3: Removal of vegetable production from Hoki_1a and Hoki_1b subzones

For Scenario 3, the removal of vegetables would result in the in-field nitrogen and phosphorus loss from the Hoki_1a and Hoki_1b subzones equalling zone (Tables 4-1 and 4-2.) The tonnage of vegetables produced from the subzones would also equate to zero (Table 4-4).

Although the removal of vegetable production from the Hoki_1a and Hoki_1b subzones will reduce the vegetable impact on nitrogen and phosphorus losses to zero, the replacement of this land use with sheep and beef farming will still have an impact on the water quality of Lake Horowhenua.

Table 4-7 outlines the difference in nitrogen and phosphorus losses within these subzones under commercial vegetable production compared with sheep and beef farming. Replacement with sheep and beef farming has a modelled reduction in nitrogen losses of 84% and phosphorus losses of 58%.

Table 4-7: The impact on the Hoki_1a and Hoki_1b Water Management Subzones when commercial vegetables are replaced with sheep and beef farming.

	N loss kg N/ha	N loss kg N	P loss kg P/ha	P loss kg P	Area ha
Vegetable baseline	96	36,370	2.4	906	377
Sheep and beef	15	5,693	1	377	377
Percentage reduction	n/a	84	n/a	58	n/a

For this scenario, two neighbouring subzones Ohau_1b and Mana_13e were modelled as alternative locations for producing the total volume of vegetables currently grown in Hoki_1a and Hoki_1b subzones. The impact on nitrogen and phosphorus losses for these are shown in Tables 4-8 and 4-9. Table 4-8 shows a greater amount of nitrogen being lost from commercial vegetables when located within the Ohau_1b subzone, with a minimal difference in phosphorus loss to water observed. Table 4-9 shows slightly lower amounts of nitrogen being lost from commercial vegetables when located within the Mana_13e subzone. However, phosphorus losses reduced significantly by 60%.

Within these subzones, enough LUC class 1 land currently in non-vegetable production has been identified allowing 377 ha of commercial vegetables removed from the Hoki_1a and Hoki_1b subzones to be grown (Figures 3-1 and 3-2).

Table 4-8: The additional impact on the Ohau_1b Water Management Subzone with the inclusion of an additional 377 ha of commercial vegetables.

	N loss kg N/ha	N loss kg N	P loss kg P/ha	P loss kg P	Area Ha
Productive area	107	40,171	2.4	903	377
Titled area	96	40,171	2.2	903	419

Table 4-9: The additional impact on the Mana_13e Water Management Subzone with the inclusion of an additional 377 ha of commercial vegetables.

	N loss kg N/ha	N loss kg N	P loss kg P/ha	P loss kg P	Area Ha
Productive area	94	35,441	0.7	275	377
Titled area	85	35,441	0.7	275	419

The alternative subzones have different soil types modelled to those modelled for Hoki_1a and Hoki_1b subzones (Table 3-3). Therefore, the impacts in nitrogen and phosphorus losses due to vegetable growing in these areas will be different compared to the current subzones.

Within the Ohau_1b subzone the brassica dominant and intensive vegetables crop rotations are located on the recent soil of Selwyn_131a.1, which has an alluvium origin and loam over sand texture with moderate over rapid permeability. The potato and onion crop rotations are located on the brown soil of Oronoko_233a.1, which is formed on loess over alluvium. The texture is silt with a moderate permeability. Both soils within the Ohau_1b subzone are well drained, thus these soils are more freely drained compared to the soils modelled within the Hoki_1a and Hoki_1b subzones, which were both imperfectly drained (Table 3-3). Therefore, nitrogen loss to water is higher when growing vegetables within the Ohau_1b subzone. This has been shown with the Ohau_1b subzone modelling 107 kg N/ha (productive area) compared to the Hoki_1a and Hoki_1b subzones modelling a 96 kg N/ha (productive area) (Table 4-5 and Table 4-8).

The Mana_13e subzone has all crop rotations located on the brown soil of Gladstone_127a.2, which is formed on loess. The texture is silt with a moderate permeability. The drainage class is moderately well drained. Within this subzone the phosphorus loss at water was significantly lower (0.7 kg P/ha productive area; Table 4-9) than the baseline year for Hoki_1a and Hoki_1b subzones (2.6 kg P/ha productive area; Table 4-5). This difference is driven by the soil type and different phosphorus retentions. Gladstone_127a.2 has a phosphorus retention of 36% (medium), the same as Mokotua_19a.1 which is present over 27% of the modelled area in the Hoki_1a and Hoki_1b subzones. However, the Pahau_29a.1 soil which covers 73% of the modelled area has a much lower phosphorus retention 19% (low) which increases the leaching potential in the Hoki_1a and Hoki_1b subzones relative to the Mana_13e subzones.

4.5 Scenario 4: Hydroponic growing in glasshouses

For Scenario 4, three crops (lettuce, spinach, and parsley) were removed from in-field production in the Hoki_1a and Hoki_1b subzones, and instead grown using hydroponics in a glasshouse. These crops were selected as they are all currently grown hydroponically in New Zealand in a commercial setting. In addition, information is available within the literature to support the modelling inputs. Further background information for this scenario is provided in the literature review in Appendix C.

Table 4-10 highlights the resulting nitrogen and phosphorus losses after removal of these three crops from being grown in-field within the two subzones. Compared to the baseline, there was a 44% reduction in nitrogen loss, and a 29% reduction in phosphorus loss when lettuce, spinach, and parsley were removed from in-field production within the Hoki_1a and Hoki_1b subzones.

Table 4-10: Removal of all lettuce, spinach, and parsley crops from the Hoki_1a and Hoki_1b Water Management Subzones.

	N loss kg N/ha	N loss kg N	P loss kg P/ha	P loss kg P	Area Ha
Productive area	54	20,506	1.7	645	377
Titled area	49	20,506	1.5	645	419

Table 4-4 shows that there is a 32% reduction in in-field vegetable tonnage for this scenario. However, as the result of transferring the three selected crops to glasshouses there is no overall loss of vegetables produced within two subzones. It should be noted that this shift in production method will come at a financial cost.

The removal of lettuce, spinach, and parsley from in-field production will significantly impact the nitrogen and phosphorus leaching from the intensive vegetable rotations. There is a lesser impact on the brassica dominant rotations. The potato and onion rotations are not impacted, as lettuce, spinach, nor parsley crops are not included in this vegetable system (Table 4-11).

Table 4-11: Comparison of nitrogen and phosphorus leaching for the three different vegetable systems before and after the removal of lettuce, spinach, and parsley.

	Potato and onion	Brassica dominant	Intensive vegetables
Baseline nitrogen kg N/ha/yr	74.7	101.8	105
Removal of crops kg N/ha/yr	74.7	74.4	42
Baseline phosphorus kg P/ha/yr	0.6	3.9	2.9
Removal of crops kg P/ha/yr	0.6	2.9	2.0

Although the removal of lettuce, spinach, and parsley from in-field production within Hoki_1a and Hoki_1b subzones results in a reduction of nitrogen losses, the production of waste nutrient solution (wastewater) from hydroponic production will result in additional nitrogen loading if this wastewater is applied to land (best practice). Table 4-12 shows the potential impact of applying glasshouse wastewater to land. In a pastoral cut and carry setting, the potential impact to water quality from applying glasshouse wastewater to land would be minimal.

Table 4-12: Summary of applying glasshouse wastewater to land.

N loss kg N/ha	N loss kg N	P loss kg P/ha	P loss kg P	Area ha
7	894	0.9	136	27.1

The impact of additional nitrogen loading (from glasshouse wastewater) has seen the overall nitrogen loss reduce from 20,506 kg N when lettuce, spinach, and parsley are removed from in-field production to 21,400 kg N when these crops are transferred to glasshouse production with wastewater being applied to land (Tables 4-10 and 4-13). This equates to an overall nitrogen reduction of 83% from the baseline (Table 4-3).

The establishment of glasshouses means that hydroponic wastewater will need to be disposed of. If not disposed to land, it is commonly directly discharged into local waterways, with the resulting environmental impact being greater.

Table 4-13: Impact of the removing all lettuce, spinach, and parsley crops from the Hoki_1a and Hoki_1b Water Management Subzones and growing these crops in glasshouses.

	N loss kg N/ha	N loss kg N	P loss kg P/ha	P loss kg P	Area ha
Productive area	48	21,400	1.7	781	446

Figure 4-3 highlights an example of the nitrogen pool and change in nitrogen pools for the example crop rotation. When lettuce and spinach are removed from the crop rotation, it shows that their removal significantly reduces soil inorganic nitrogen compared with the baseline (Figure 4-1). This is because there is less nitrogen fertiliser being inputted into the system and less residual nitrogen within the soil (as the result of less vegetables crops within the rotation). There are also no fallow periods within the rotation, as the result of ryegrass pastures replacing any spinach, lettuce, or fallow period within the crop rotation. Nitrate leaching is minimal across the entire crop rotation as soil inorganic nitrogen levels are low during periods when nitrate is at risk of being leached.

The trends in nitrogen pools observed when comparing the baseline and Scenario 4 (Figures 4-1 and 4-3) is also observed across the other crop rotations that had either lettuce, spinach, or parsley removed from the crop rotation.

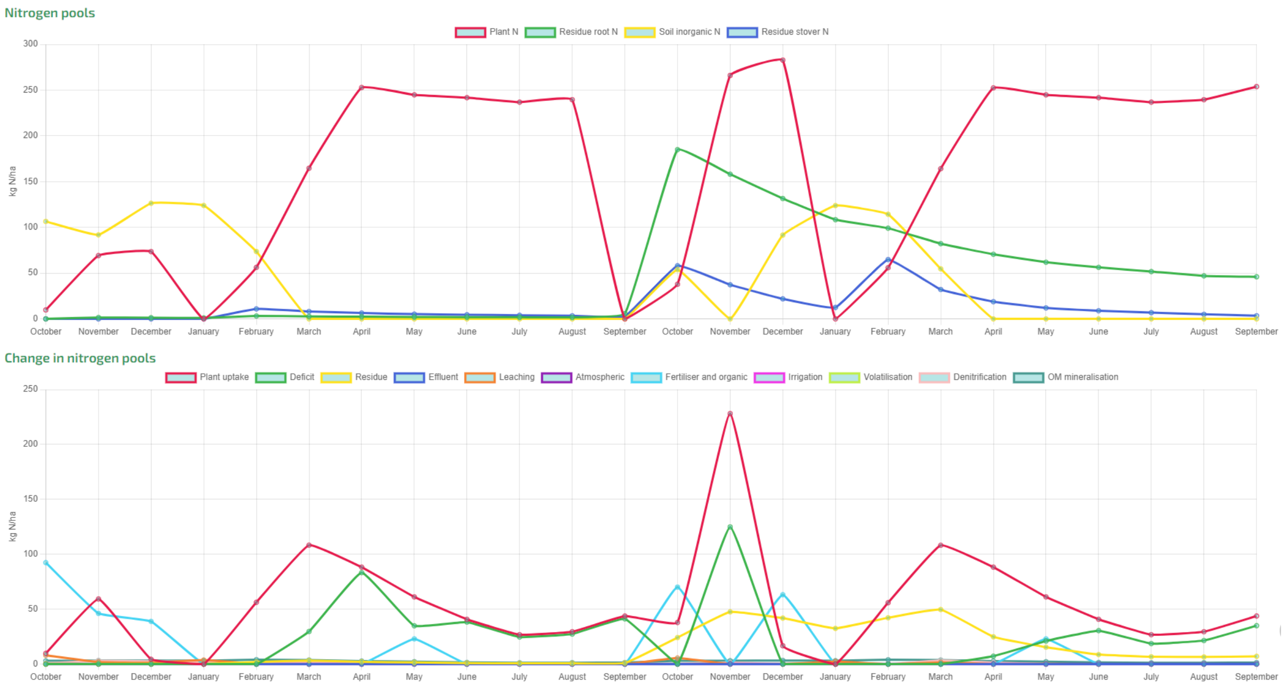

Figure 4-3: An example of the change in nitrogen pools for the removal of lettuce, spinach, and parsley from growing in-field. Original crop rotation: celery, lettuce, spinach, cabbage, and spinach. New crop rotation: celery, rye grass, cabbage, ryegrass.

4.6 Scenario 5: Removal of the top 25% nitrate leaching crop rotations

The resulting nitrogen and phosphorus leaching rates for the productive and titled area of this modelled scenario are shown in Table 4-14. By substituting high nitrate leaching crop rotations for low nitrate leaching rotations a 24% reduction in nitrogen loss was observed. There was no impact on the amount of phosphorus loss to water, as the approach for this scenario was targeted at reducing nitrate leaching and did not take phosphorus leaching into consideration.

It was observed that no potato and onion rotations were present within the highest nitrogen loss to water crop rotations, while 5 out of 12 of the brassica dominant crops were present, with the remainder being intensive vegetable crop rotations. There were 14 rotation crops in the top 25% nitrogen loss to water crop rotations. In comparison, when solely looking at the lowest 25% nitrogen loss to water crop rotations, there was a higher presence of potatoes and onions (10 out of 14 crop rotations).

Table 4-14: The impact of the removal of the 25% highest nitrate leaching crops rotations from the Hoki_1a and Hoki_1b Water Management Subzones and replaced with low nitrate leaching crops rotations.

	N loss kg N/ha	N loss kg N	P loss kg P/ha	P loss kg P	Area ha
Productive area	73	27,677	2.4	906	377
Titled area	66	27,677	2.2	906	419

5 Discussion and Conclusions

5.1 Drivers of nitrogen leaching in a commercial vegetable setting

There are multiple drivers of nitrate leaching within a commercial vegetable growing operation. From the baseline data, the crop rotations that have the greater nitrogen leaching do so for similar reasons:

- Winter fallow during reporting year – high soil inorganic nitrogen levels coinciding with no plant uptake of nitrogen.
- High residual nitrogen following previous crop. The previous crop is commonly a brassica.
- Poor timing of nitrogen fertiliser applications. These were either applied too early or too late resulting in low plant nitrogen uptake, and therefore high levels of nitrogen available for nitrate leaching during drainage events.
- Nitrogen fertiliser applications above crop requirements at the time of application.
- Long fallow periods with no opportunity for nitrogen removal before drainage events.

These drivers include a mixture of grower practices and the crop type present within the rotations. Reducing the rate of nitrogen loss when high losses are driven by crop type is more difficult to change. However as observed in Scenario 1, improved management practices can reduce nitrogen loss significantly.

Due to the requirement for year-round fresh vegetable supply, there are also practical challenges with implementing some of the most effective practices. It is difficult to avoid nitrogen fertiliser applications during the months of May to August (at-risk months for nitrate leaching) because crops require adequate nutrient inputs during these times for key plant growth stages. There are also reasons why early and late application occur, such as the very short growing length of lettuce resulting in upfront nitrogen fertiliser. Late nitrogen fertiliser applications are not usually planned, but rather applied as needed when soil nitrogen levels are low (which can result in the yellowing of leafy green vegetables if not corrected). Rather than removing nitrogen fertiliser applications at at-risk times from the system, it may be more effective to adopt management tools such as the use of soil testing and nitrogen balance/budgets so that informed decisions on fertiliser applications can be made.

This study also considered the reasons why the lowest nitrogen loss crop rotations had low nitrate leaching:

- The use of catch crops which decrease the levels of inorganic nitrogen.
- No or short fallow periods between crops.
- Low previous crop residuals.
- Long rotation crops are present. These crops result in longer periods of nitrogen uptake and less fallow periods compared to other crop rotations.

These factors are driven by the crops present within each of the rotations and the order those crops appear within the rotation, rather than the adoption of improved management practices. This is confirmed through the Scenario 1 modelling, where the low leaching crop rotations remain low leaching when ranked after the adoption of BMP and GMP across all crop rotations. The adoption of BMP and GMP simply results in lower nitrogen losses from each individual crop rotation.

5.2 Summarising the impact of the scenarios

Ranking the scenarios from the most effective at improving the water quality of Lake Horowhenua to the less effective, Scenario 3 (moving vegetable growing out of the Hoki_1a and Hoki_1b Water Management Subzones) will have the greatest impact for both nitrogen (83% reduction) and phosphorus (58% reduction). This scenario will also preserve the supply of fresh vegetables grown from the wider Horowhenua region. However, there is the potential of decreasing the water quality of the receiving subzone (either Mana_13e or Ohau_1b). The nitrogen and phosphorus loss values when moving vegetables into either of these subzones has been provided for potential future water quality modelling (Tables 4.8 and 4.9). The difference in nitrogen and phosphorus loss to water across the different subzones is attributed to soil type and associated parent material. For soil types where loess is present, there is a lower connectivity to water bodies. As the loess layer slows down the movement of water through the subsoil it provides a greater opportunity to reduce nitrogen entering water bodies. Therefore, the Mana_13e subzone has a lower risk of nitrate entering nearby water bodies compared to the soils within the Ohau_1b subzone, which have a greater connectivity to water bodies. Similarly, the Mana_13e subzone has a medium phosphorous retention level while the dominant soil of the Ohau_1b subzone have low phosphorous retention levels. Therefore, phosphorous loss to water from the Mana_13e subzone is lower.

Scenario 1 (the adoption of BMP/GMP) and Scenario 2 (adoption of BMP/GMP and removal of all other agriculture) have the next greatest impact for both nitrogen (56% reduction) and phosphorus (40% reduction). However, Scenario 2 will overall have a greater reduction in nitrogen and phosphorus loss to water when the removal of agriculture is taken into consideration. Both scenarios will have the same negative impact on the supply of fresh vegetables grown from the Horowhenua region, with a 34% reduction in tonnage observed through the adoption of BMP and GMP. Although the cost of either of these scenarios has not been quantified to date, the adoption of BMP and GMP will have financial implications on growers. These costs will include less income as the result of lower tonnage of vegetables being produced, and may include additional capital costs through the need to invest in new machinery or technology (e.g. GPS tractors and controlled-application fertiliser bins).

Scenario 4 (the use of glasshouses) indicates the next most beneficial scenario for improving water quality with nitrogen reducing by 41% and phosphorus 14%. This scenario will also preserve the supply of fresh vegetables in the Horowhenua region. However, transitioning some crops into glasshouses will add significant costs to vegetable production within the Horowhenua region. This cost has not been quantified to date.

Scenario 5 (removal of top 25% nitrate leaching crop rotations) was modelled as the least effective at improving the water quality of Lake Horowhenua. There were no improvements from the baseline for phosphorus loss to water while nitrogen loss to water saw a 24% reduction. The key benefit of this scenario was a 3.2% increase in the total tonnage of vegetable grown. The increase in vegetable production occurred as the vegetables present within the crop rotations replacing the high nitrate leaching crops had higher yields per hectare compared to the crops they replaced.

5.3 Potential for a mixed scenario approach

Improving the water quality of Lake Horowhenua to the level required to meet water quality targets set out by Horizons may not be achieved in practice by adopting a single scenario. Each of the scenarios present their own challenges: The reduced environmental impact of commercial vegetable growing in Scenarios 1 and 2 resulted in a significant loss in vegetables grown however there is a substantial environmental benefit. Simply moving all commercial vegetable growing to another location (Scenario 3) would have the highest environmental benefit to the Hoki_1a and Hoki_1b Water Management Subzones without losing vegetable production. However, this is effectively pollution-swapping and does not consider the considerable cost to growers of acquiring new land and relocating operations. Moving the production of some vegetables to glasshouses (Scenario 4) provided substantial reductions in nitrogen loss to water with no change to vegetable production. Though significant capital investment would be required for a subset of growers. Changing the crops grown by replacing higher nitrate leaching rotations with more environmentally friendly ones (Scenario 5) reduced nitrogen loss to water. There was no change in phosphorus losses and a slight increase in overall tonnage in vegetables produced. The economic and social impacts of reducing production of some vegetables and increasing others was not considered.

The best way to improve water quality within the Hoki_1a and Hoki_1b Water Management Subzones, potentially achieving the required water quality targets, may be to adopt parts of each of the proposed scenarios.

Although no OverseerFM modelling has been completed for a mixed scenario approach, this approach could have the potential of being more successful in achieving water quality targets while having a minimal effect on the volume of vegetable produced and economic impact on growers. A mixed scenario approach could also prevent pollution swapping (improving water quality in one subzone at the expense of another).

Jolly et al. (2020) found that the BMP and GMP that are most effective at reducing nitrogen loss to water are those practices associated with nitrogen fertiliser applications, such as frequent nitrogen soil testing, split fertiliser applications and completing a nitrogen balance/budget for each crop rotation. This has also been observed within the current study. Improving nitrogen fertiliser practices in-field also do not influence the volume of vegetables grown, thus preventing reduced grower income. Combining the adoption of nitrogen fertiliser BMP/GMP with the removal of high leaching crops (substituting low nitrate leaching crops) in addition to all other agriculture, and the transfer of some suitable crops into glasshouses, may be a suitable mixed approach. The cost of establishing glasshouse systems will remain high, however, it will drive growers to improve management practices without impacting yield. This scenario would also prevent pollution swapping.

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Appendix A - Crop Rotations

The original crop rotations

Table A - 1: Potatoes and onions baseline crop rotations

<table>
<tr><th></th><th>Potato 1</th><th>Potato 1</th><th>Potato 1</th><th>Potato 2</th><th>Potato 3</th><th>Potato 3</th><th>Potato 3</th><th>Potato 4</th><th>Onions (Early)</th><th>Onions (Mid)</th><th>Onions (Main)</th><th>Beetroot</th></tr>
<tr><td>Oct</td><td rowspan="6">Potato 1 Early</td><td></td><td></td><td rowspan="7">Potato 2</td><td rowspan="6">Potato 3 Early</td><td rowspan="8">Potato 3 Mid</td><td></td><td></td><td rowspan="5"></td><td rowspan="6"></td><td rowspan="6"></td><td rowspan="11"></td></tr>
<tr><td>Nov</td><td rowspan="7">Potato 1 Mid</td><td rowspan="10">Potato 1 Late</td><td rowspan="10">Potato 3 Late</td><td rowspan="6">Potato 4</td></tr>
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<tr><td>Mar</td><td rowspan="3">Annual Ryegrass Autumn</td></tr>
<tr><td>Apr</td><td rowspan="6">Annual Ryegrass Autumn</td><td rowspan="6">Annual Ryegrass Autumn</td><td rowspan="3">Annual Ryegrass Autumn</td><td rowspan="3">Annual Ryegrass Autumn</td></tr>
<tr><td>May</td><td rowspan="5"></td><td rowspan="6"></td></tr>
<tr><td>Jun</td><td rowspan="5"></td><td rowspan="4"></td><td rowspan="9">Early</td></tr>
<tr><td>Jul</td><td rowspan="9">Mid</td><td rowspan="11">Main</td></tr>
<tr><td>Aug</td></tr>
<tr><td>Sep</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="7">Beetroot</td></tr>
<tr><td>Oct</td><td rowspan="6">Potato 1 Early</td><td rowspan="7">Potato 2</td><td rowspan="6">Potato 3 Early</td><td rowspan="8">Potato 3 Mid</td></tr>
<tr><td>Nov</td><td rowspan="7">Potato 1 Mid</td><td rowspan="10">Potato 1 Late</td><td rowspan="10">Potato 3 Late</td><td rowspan="6">Potato 4</td></tr>
<tr><td>Dec</td></tr>
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<tr><td>May</td><td rowspan="5"></td><td rowspan="5"></td></tr>
<tr><td>Jun</td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4">Early</td><td rowspan="3">Annual Ryegrass Autumn</td></tr>
<tr><td>Jul</td><td rowspan="3">Mid</td></tr>
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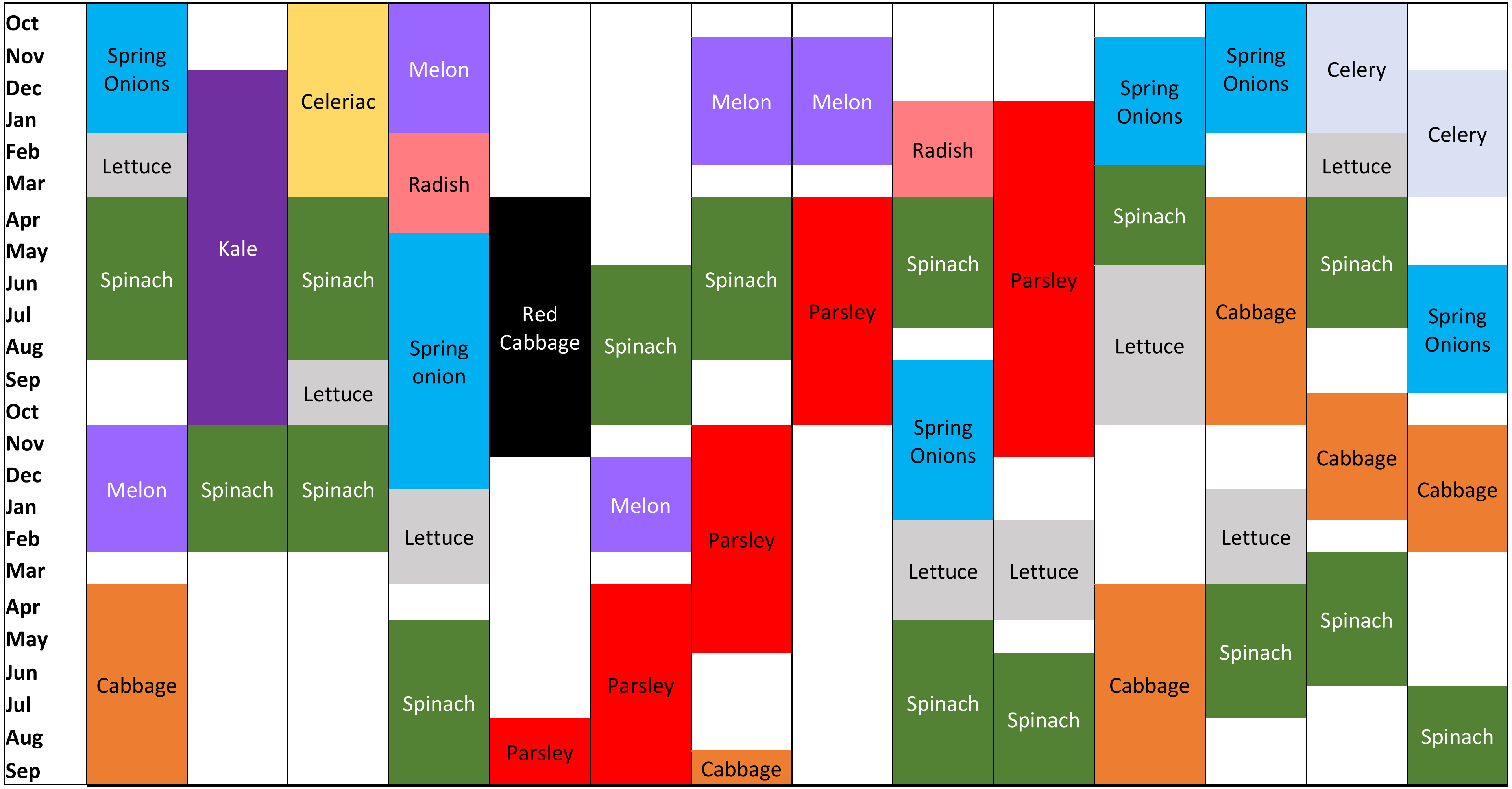
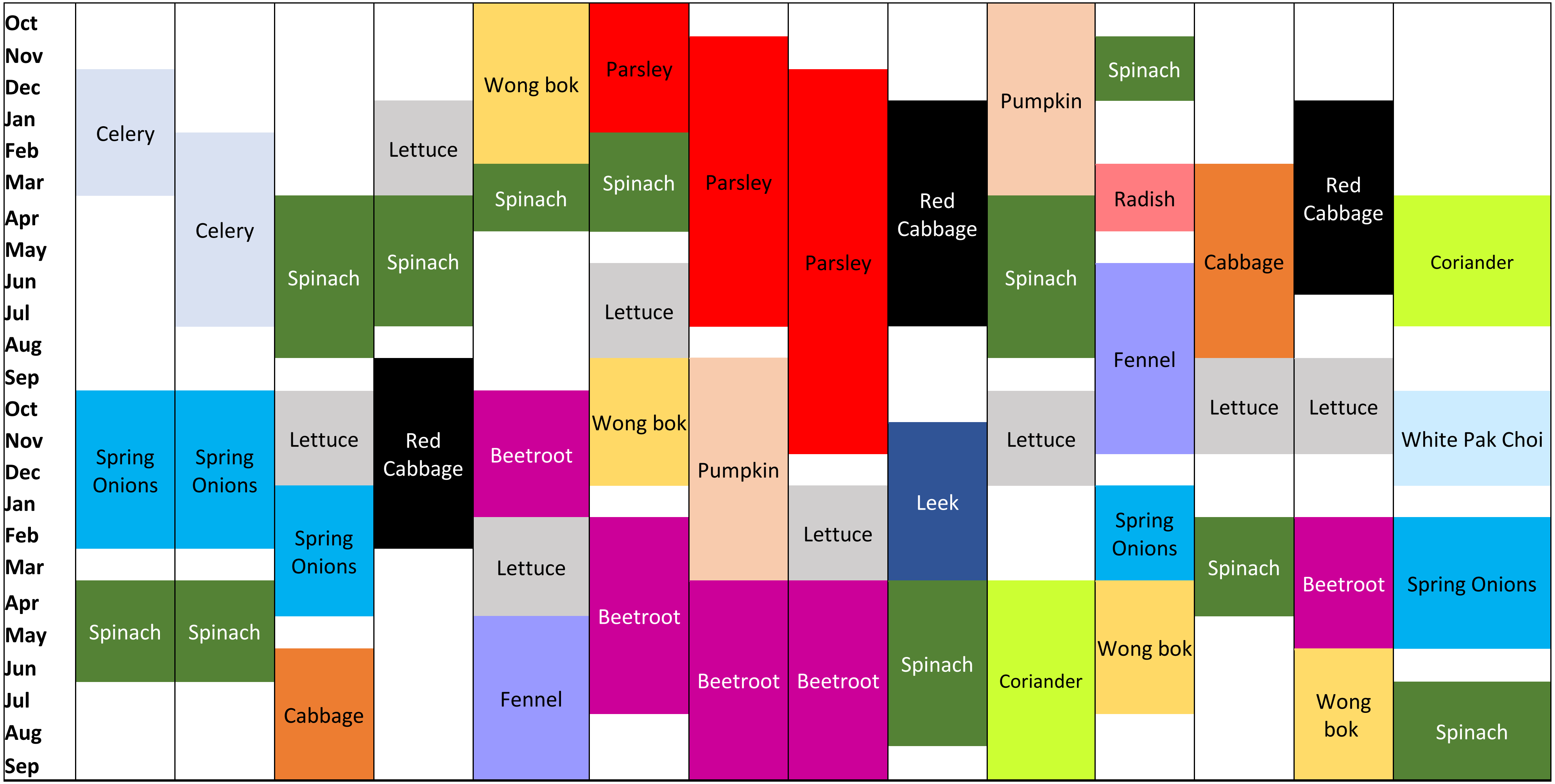
<tr><td>Sep</td><td></td><td></td><td>Main</td><td>Beetroot</td></tr>
</table>

Table A - 2: Brassica dominant baseline crop rotations

Oct		Cauliflower									Pumpkin	
Nov												Cabbage
Dec							Broccoli			Lettuce		
Jan				Cabbage		Lettuce			Cauliflower			
Feb	Broccoli											
Mar			Lettuce		Cabbage			Celery		Cauliflower		
Apr		Broccoli										
May						Cabbage					Cauliflower	
Jun												
Jul			Broccoli				Onion					
Aug												Cauliflower
Sep	Lettuce								Potato			
Oct				Cauliflower						Pumpkin		
Nov												
Dec		Lettuce			Cauliflower	Broccoli		Cabbage				
Jan	Cabbage										Broccoli	
Feb			Lettuce									
Mar		Broccoli					Cauliflower					Leek
Apr				Lettuce								
May									Cauliflower	Cabbage		
Jun					Lettuce							
Jul			Onion								Lettuce	
Aug						Cauliflower		Broccoli				
Sep	Potato			Cabbage								

Table A - 3: Intensive vegetables baseline crop rotations

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Celery
Spring Onions
Spinach
Celery
Spring Onions
Spinach
Spinach
Lettuce
Spring Onions
Cabbage
Lettuce
Spinach
Red Cabbage
Wong bok
Spinach
Beetroot
Lettuce
Fennel
Parsley
Spinach
Lettuce
Wong bok
Beetroot
Parsley
Pumpkin
Beetroot
Parsley
Lettuce
Beetroot
Red Cabbage
Leek
Spinach
Pumpkin
Spinach
Lettuce
Coriander
Spinach
Radish
Fennel
Spring Onions
Wong bok
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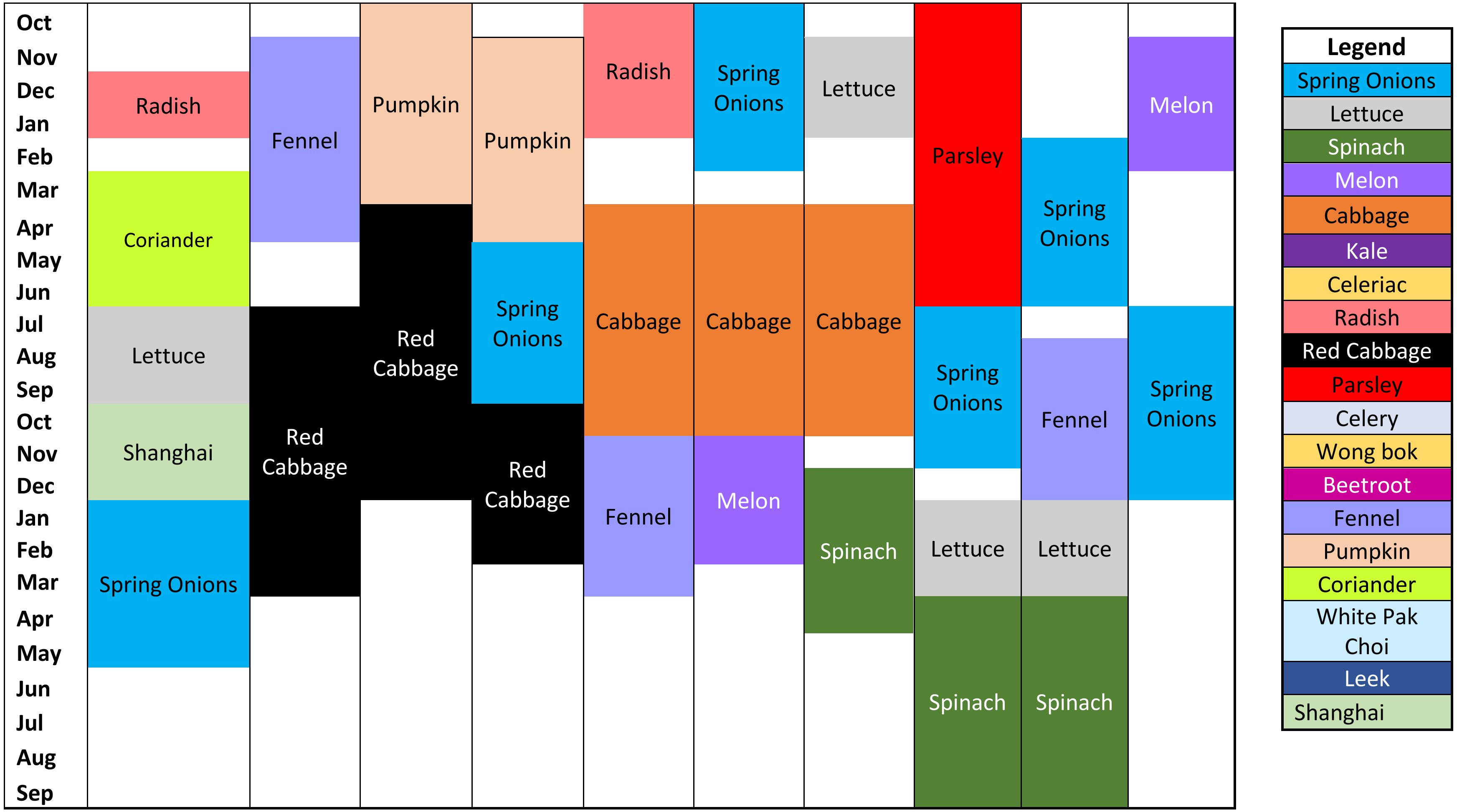
Red Cabbage
Lettuce
Beetroot
Wong bok
Coriander
White Pak Choi
Spring Onions
Spinach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Aug
Sep
Radish
Coriander
Lettuce
Shanghai
Spring Onions
Fennel
Red Cabbage
Pumpkin
Red Cabbage
Pumpkin
Spring Onions
Red Cabbage
Radish
Cabbage
Fennel
Spring Onions
Cabbage
Melon
Lettuce
Cabbage
Spinach
Parsley
Spring Onions
Lettuce
Spinach
Spring Onions
Fennel
Lettuce
Spinach
Melon
Spring Onions
Legend
Spring Onions
Lettuce
Spinach
Melon
Cabbage
Kale
Celeriac
Radish
Red Cabbage
Parsley
Celery
Wong bok
Beetroot
Fennel
Pumpkin
Coriander
White Pak Choi
Leek
Shanghai

The crop rotations after catch crops were added to the rotations

Table A - 4: Potato and onion crop rotations with the adoption of catch crops.

<table>
<tr><th></th><th>Potato 1</th><th>Potato 1</th><th>Potato 1</th><th>Potato 2</th><th>Potato 3</th><th>Potato 3</th><th>Potato 3</th><th>Potato 4</th><th>Onions (Early)</th><th>Onions (Mid)</th><th>Onions (Main)</th><th>Beetroot</th></tr>
<tr><td>Oct</td><td rowspan="6">Potato 1 Early</td><td></td><td></td><td rowspan="7">Potato 2</td><td rowspan="6">Potato 3 Early</td><td rowspan="8">Potato 3 Mid</td><td></td><td></td><td rowspan="5"></td><td rowspan="6"></td><td rowspan="6"></td><td rowspan="11"></td></tr>
<tr><td>Nov</td><td rowspan="7">Potato 1 Mid</td><td rowspan="10">Potato 1 Late</td><td rowspan="10">Potato 3 Late</td><td rowspan="6">Potato 4</td></tr>
<tr><td>Dec</td></tr>
<tr><td>Jan</td></tr>
<tr><td>Feb</td></tr>
<tr><td>Mar</td><td rowspan="3">Annual Ryegrass Autumn</td></tr>
<tr><td>Apr</td><td rowspan="6">Annual Ryegrass Autumn</td><td rowspan="6">Annual Ryegrass Autumn</td><td rowspan="3">Annual Ryegrass Autumn</td><td rowspan="3">Annual Ryegrass Autumn</td></tr>
<tr><td>May</td><td rowspan="5">Annual Ryegrass Autumn</td><td rowspan="6">Annual Ryegrass Autumn</td></tr>
<tr><td>Jun</td><td rowspan="5">Annual Ryegrass Autumn</td><td rowspan="4">Annual Ryegrass Autumn</td><td rowspan="9">Early</td></tr>
<tr><td>Jul</td><td rowspan="9">Mid</td><td rowspan="11">Main</td></tr>
<tr><td>Aug</td></tr>
<tr><td>Sep</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="7">Beetroot</td></tr>
<tr><td>Oct</td><td rowspan="6">Potato 1 Early</td><td rowspan="7">Potato 2</td><td rowspan="6">Potato 3 Early</td><td rowspan="8">Potato 3 Mid</td></tr>
<tr><td>Nov</td><td rowspan="7">Potato 1 Mid</td><td rowspan="10">Potato 1 Late</td><td rowspan="10">Potato 3 Late</td><td rowspan="6">Potato 4</td></tr>
<tr><td>Dec</td></tr>
<tr><td>Jan</td></tr>
<tr><td>Feb</td></tr>
<tr><td>Mar</td><td rowspan="3">Annual Ryegrass Autumn</td></tr>
<tr><td>Apr</td><td rowspan="6">Annual Ryegrass Autumn</td><td rowspan="6">Annual Ryegrass Autumn</td><td rowspan="3">Annual Ryegrass Autumn</td><td rowspan="5">Annual Ryegrass Autumn</td></tr>
<tr><td>May</td><td rowspan="5">Annual Ryegrass Autumn</td><td rowspan="5">Annual Ryegrass Autumn</td></tr>
<tr><td>Jun</td><td rowspan="4">Annual Ryegrass Autumn</td><td rowspan="4">Annual Ryegrass Autumn</td><td rowspan="4">Early</td><td rowspan="3">Annual Ryegrass Autumn</td></tr>
<tr><td>Jul</td><td rowspan="3">Mid</td></tr>
<tr><td>Aug</td></tr>
<tr><td>Sep</td><td></td><td></td><td>Main</td><td>Beetroot</td></tr>
</table>

Table A - 5: Brassica dominant crop rotations with the adoption of catch crops.

Oct		Cauliflower									Pumpkin	
Nov												Cabbage
Dec							Broccoli			Lettuce		
Jan				Cabbage		Lettuce			Cauliflower			
Feb	Broccoli											
Mar			Lettuce		Cabbage			Celery		Cauliflower		
Apr		Broccoli					Annual Ryegrass					Annual Ryegrass
May						Cabbage					Cauliflower	
Jun												
Jul			Broccoli	Annual Ryegrass			Onion					
Aug												Cauliflower
Sep	Lettuce	Annual Ryegrass			Annual Ryegrass			Annual Ryegrass	Potato			
Oct				Cauliflower						Pumpkin		
Nov												
Dec		Lettuce			Cauliflower	Broccoli		Cabbage				
Jan	Cabbage										Broccoli	
Feb			Lettuce						Annual Ryegrass			
Mar		Broccoli					Cauliflower					Leek
Apr			Annual Ryegrass	Lettuce								
May						Annual Ryegrass		Annual Ryegrass	Cauliflower	Cabbage		
Jun					Lettuce							
Jul			Onion								Lettuce	
Aug						Cauliflower		Broccoli				
Sep	Potato			Cabbage								

Table A - 6: Intensive vegetables crop rotations with the adoption of catch crops.

Oct	Spring Onions		Celeriac	Melon			Maize					Forage oats	Celery	
Nov	Spring Onions		Celeriac	Melon			Maize	Melon			Spring Onions	Forage oats	Celery	
Dec	Spring Onions	Kale	Celeriac	Melon			Maize	Melon			Spring Onions	Forage oats	Celery	Celery
Jan	Spring Onions	Kale	Celeriac	Melon			Maize	Melon	Radish	Parsley	Spring Onions	Forage oats	Celery	Celery
Feb	Lettuce	Kale	Celeriac	Radish			Maize	Melon	Radish	Parsley	Spring Onions	Forage oats	Lettuce	Celery
Mar	Lettuce	Kale	Celeriac	Radish					Radish	Parsley	Spinach	Forage oats	Lettuce	Celery
Apr	Spinach	Kale	Spinach	Radish	Red Cabbage		Forage oats	Parsley	Spinach	Parsley	Spinach	Cabbage	Spinach	
May	Spinach	Kale	Spinach	Spring onion	Red Cabbage		Forage oats	Parsley	Spinach	Parsley	Spinach	Cabbage	Spinach	Forage oats
Jun	Spinach	Kale	Spinach	Spring onion	Red Cabbage	Forage oats	Forage oats	Parsley	Spinach	Parsley	Lettuce	Cabbage	Spinach	Forage oats
Jul	Spinach	Kale	Forage oats	Spring onion	Red Cabbage	Forage oats	Forage oats	Parsley	Spinach	Parsley	Lettuce	Cabbage	Forage oats	Forage oats
Aug	Spinach	Kale	Forage oats	Spring onion	Red Cabbage	Forage oats	Forage oats	Parsley		Parsley	Lettuce	Cabbage	Forage oats	Forage oats
Sep		Kale	Forage oats	Spring onion	Red Cabbage	Forage oats	Forage oats	Parsley	Spring Onions	Parsley	Lettuce	Cabbage	Forage oats	Forage oats
Oct		Kale	Forage oats	Spring onion	Red Cabbage	Forage oats		Parsley	Spring Onions	Parsley	Lettuce	Cabbage	Cabbage	Forage oats
Nov	Maize	Spinach	Spinach	Spring onion	Red Cabbage		Parsley	Maize	Spring Onions	Parsley	Maize		Cabbage	Cabbage
Dec	Maize	Spinach	Spinach	Spring onion	Forage oats	Melon	Parsley	Maize	Spring Onions		Maize		Cabbage	Cabbage
Jan	Maize	Spinach	Spinach	Lettuce	Forage oats	Melon	Parsley	Maize	Spring Onions		Maize	Lettuce	Cabbage	Cabbage
Feb	Maize	Spinach	Forage oats	Lettuce	Forage oats	Melon	Parsley	Maize	Lettuce	Lettuce	Maize	Lettuce		Cabbage
Mar	Maize	Forage oats	Forage oats	Lettuce	Forage oats		Parsley	Maize	Lettuce	Lettuce	Maize	Lettuce	Spinach	
Apr	Cabbage	Forage oats	Forage oats		Forage oats	Parsley	Parsley	Maize	Lettuce	Lettuce	Cabbage	Spinach	Spinach	
May	Cabbage	Forage oats	Forage oats	Spinach	Forage oats	Parsley	Parsley		Spinach		Cabbage	Spinach	Spinach	Forage oats
Jun	Cabbage	Forage oats	Forage oats	Spinach	Forage oats	Parsley			Spinach	Spinach	Cabbage	Spinach	Spinach	Forage oats
Jul	Cabbage	Forage oats	Forage oats	Spinach		Parsley			Spinach	Spinach	Cabbage	Spinach	Forage oats	Forage oats
Aug	Cabbage	Forage oats	Forage oats	Spinach	Parsley	Parsley			Spinach	Spinach	Cabbage	Forage oats	Forage oats	Forage oats
Sep	Cabbage		Forage oats	Spinach	Parsley	Parsley	Cabbage		Spinach	Spinach	Cabbage	Forage oats	Forage oats	Forage oats


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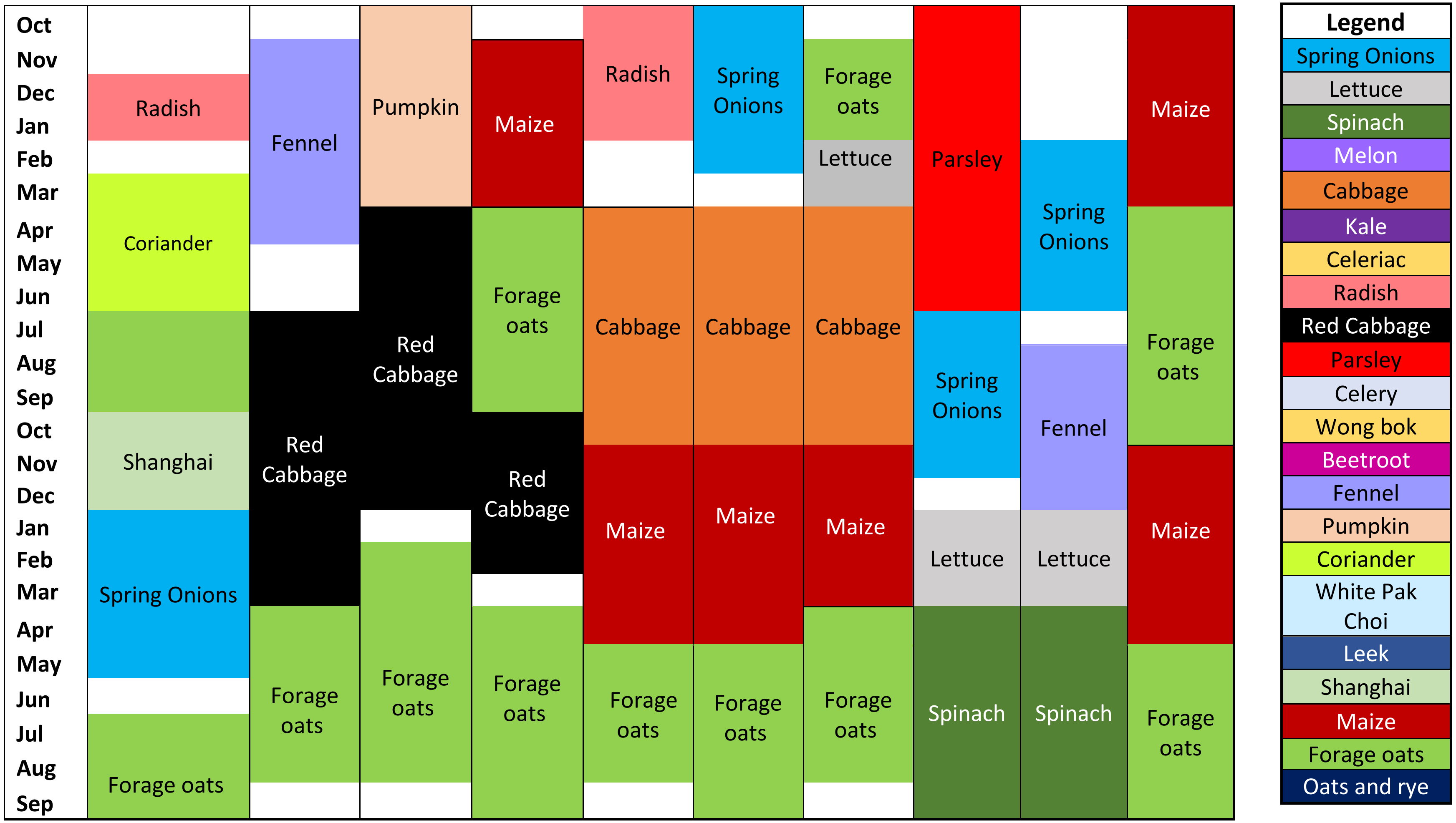
Celery
Forage oats
Spring Onions
Spinach
Forage oats
Celery
Spring Onions
Spinach
Forage oats
Spinach
Lettuce
Spring Onions
Forage oats
Lettuce
Spinach
Forage oats
Maize
Wong bok
Spinach
Oats and rye
Beetroot
Lettuce
Fennel
Parsley
Spinach
Lettuce
Wong bok
Beetroot
Parsley
Pumpkin
Beetroot
Parsley
Lettuce
Beetroot
Forage oats
Red Cabbage
Oats and rye
Leek
Spinach
Pumpkin
Spinach
Forage oats
Lettuce
Forage oats
Coriander
Spinach
Radish
Fennel
Spring Onions
Wong bok
Maize
Cabbage
Lettuce
Spinach
Oats and rye
Forage oats
Red Cabbage
Lettuce
Beetroot
Oats and rye
Coriander
White Pak Choi
Spring Onions
Forage oats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Coriander
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Spring Onions
Forage oats
Fennel
Red Cabbage
Forage oats
Pumpkin
Red Cabbage
Forage oats
Maize
Forage oats
Red Cabbage
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Maize
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Maize
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Parsley
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Spring Onions
Fennel
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Maize
Forage oats
Maize
Forage oats
Legend
Spring Onions
Lettuce
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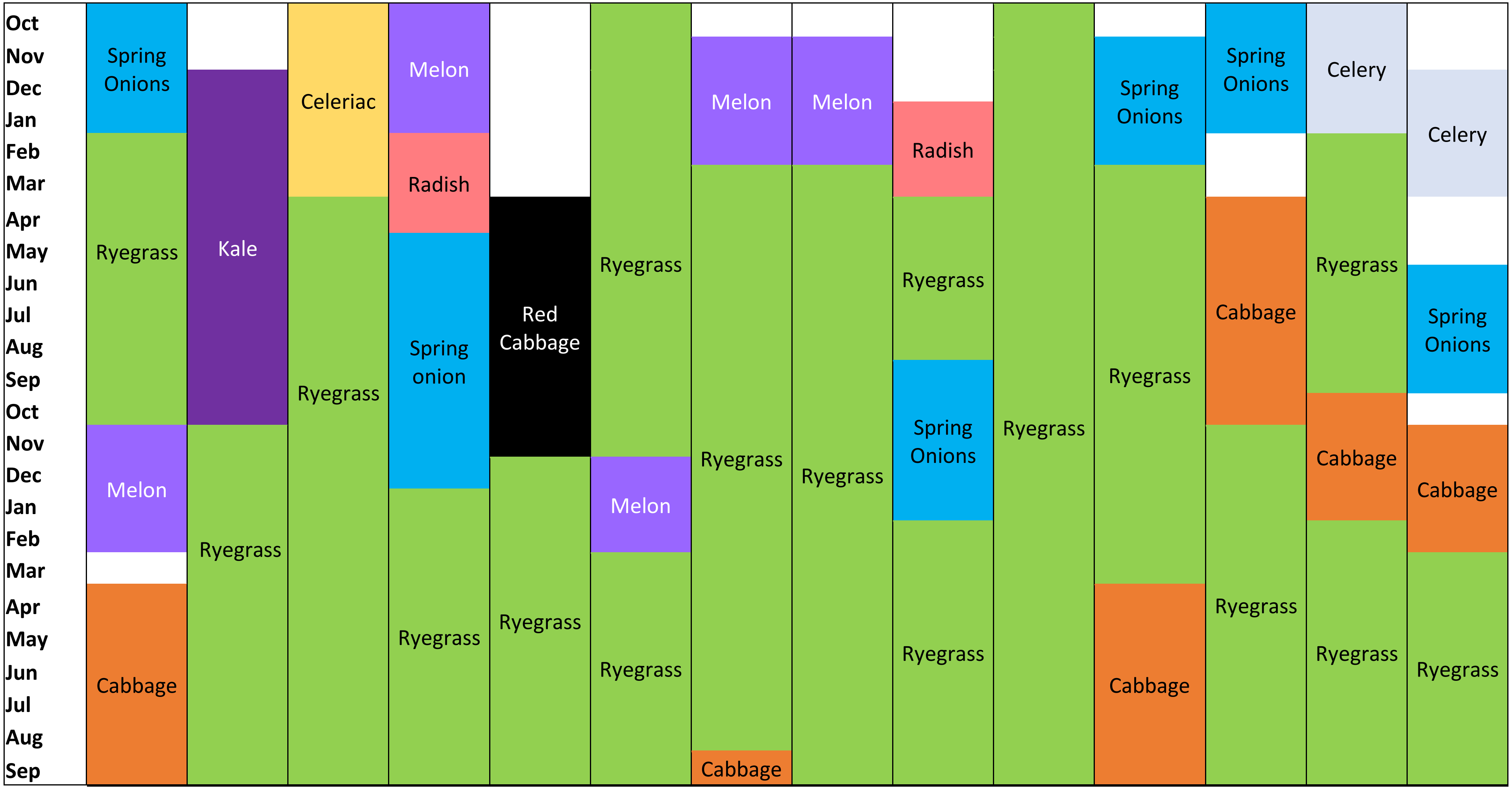
Kale
Celeriac
Radish
Red Cabbage
Parsley
Celery
Wong bok
Beetroot
Fennel
Pumpkin
Coriander
White Pak Choi
Leek
Shanghai
Maize
Forage oats
Oats and rye

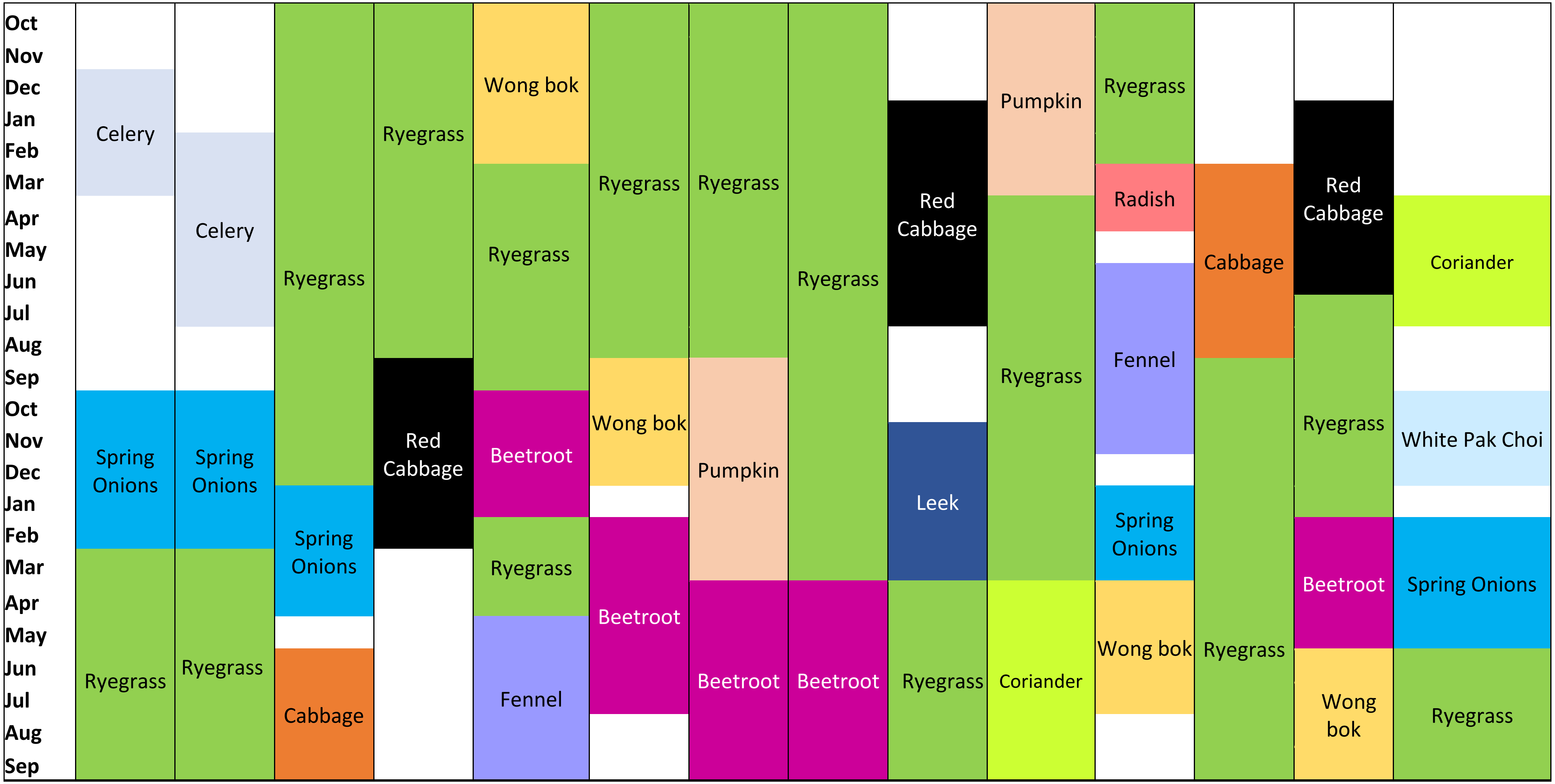
The crop rotations after lettuce, spinach and parsley were removed

Table A - 7: Brassica dominant with the removal of lettuce.

Oct		Cauliflower									Pumpkin	
Nov												Cabbage
Dec							Broccoli			Ryegrass		
Jan				Cabbage		Ryegrass			Cauliflower			
Feb	Broccoli											
Mar			Ryegrass		Cabbage			Celery		Cauliflower		
Apr		Broccoli										
May						Cabbage					Cauliflower	
Jun												
Jul			Broccoli				Onion					
Aug												Cauliflower
Sep	Ryegrass								Potato			
Oct		Ryegrass		Cauliflower						Pumpkin		
Nov												
Dec					Cauliflower	Broccoli		Cabbage				
Jan	Cabbage										Broccoli	
Feb			Ryegrass									
Mar		Broccoli					Cauliflower					Leek
Apr				Ryegrass								
May									Cauliflower	Cabbage		
Jun					Ryegrass							
Jul			Onion								Ryegrass	
Aug						Cauliflower		Broccoli				
Sep	Potato			Cabbage								

Table A - 8: Intensive vegetables with the removal of lettuce, spinach, and parsley.

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Spring Onions
Ryegrass
Ryegrass
Spring Onions
Cabbage
Ryegrass
Red Cabbage
Wong bok
Ryegrass
Beetroot
Ryegrass
Fennel
Ryegrass
Wong bok
Beetroot
Ryegrass
Pumpkin
Beetroot
Ryegrass
Beetroot
Red Cabbage
Leek
Ryegrass
Pumpkin
Ryegrass
Coriander
Ryegrass
Radish
Fennel
Spring Onions
Wong bok
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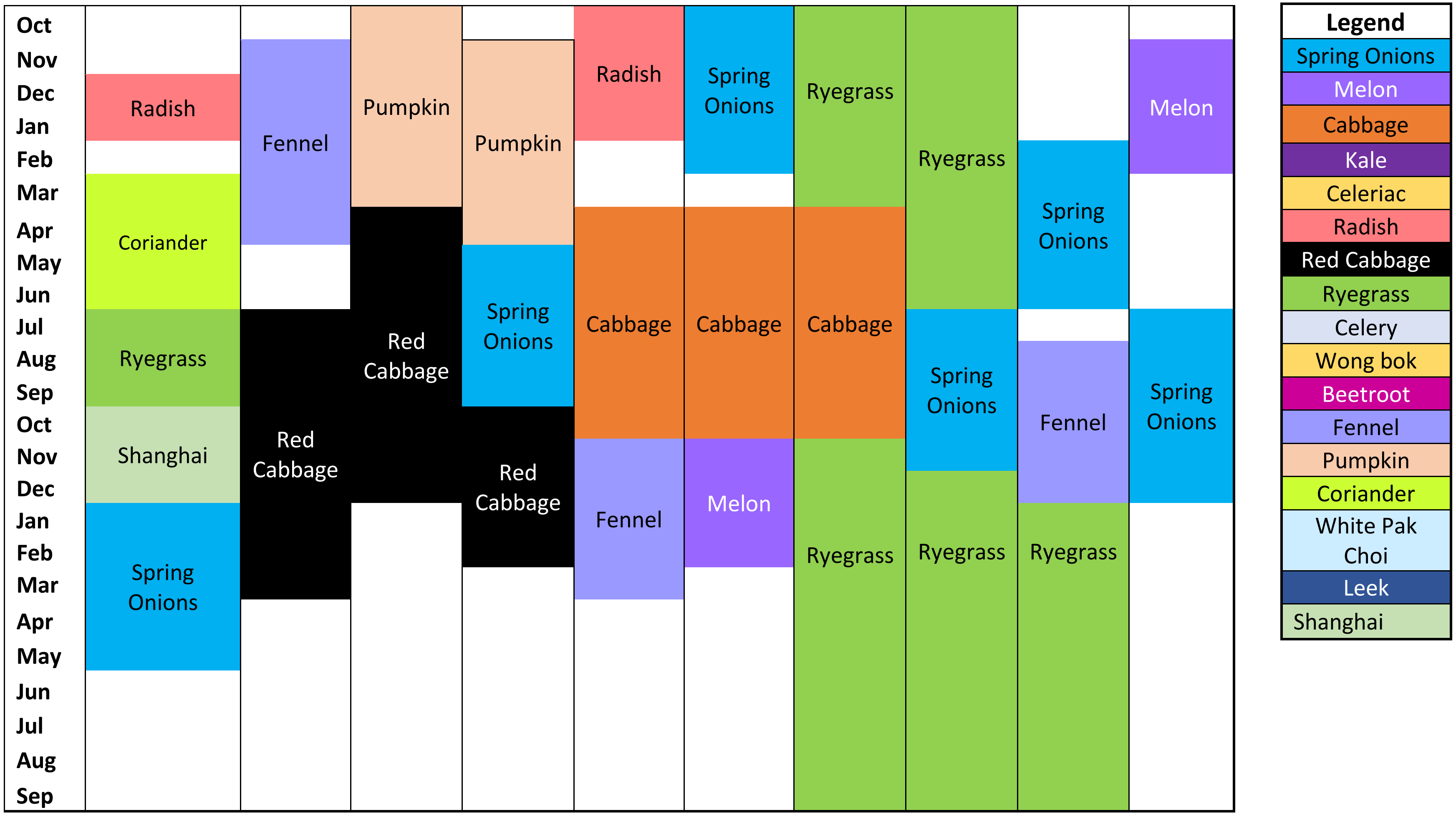
Red Cabbage
Ryegrass
Beetroot
Wong bok
Coriander
White Pak Choi
Spring Onions
Ryegrass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Aug
Sep
Radish
Coriander
Ryegrass
Shanghai
Spring Onions
Fennel
Red Cabbage
Pumpkin
Red Cabbage
Pumpkin
Spring Onions
Red Cabbage
Radish
Cabbage
Fennel
Spring Onions
Cabbage
Melon
Ryegrass
Cabbage
Ryegrass
Ryegrass
Spring Onions
Ryegrass
Spring Onions
Fennel
Ryegrass
Melon
Spring Onions
Legend
Spring Onions
Melon
Cabbage
Kale
Celeriac
Radish
Red Cabbage
Ryegrass
Celery
Wong bok
Beetroot
Fennel
Pumpkin
Coriander
White Pak Choi
Leek
Shanghai

Appendix B - Assumptions in OverseerFM Modelling

Baseline assumptions

- All assumptions were the same as Bloomer et al. (2020).

Scenario one assumptions

- Assumptions the same as Jolly et al. (2020),
- Grass was modelled as oats and, therefore, has been referred as oats through the report,
- No maize or grass/oats fertiliser was used,
- All brassica dominant and intensive vegetable paddocks were 200 m by 50 m in size and running lengthways towards waterways,
- All potatoes and onions paddocks were 400 m by 25 m in size and running widthways towards waterways,
- The main onions paddocks (60 ha) were spilt into three 20 ha blocks,
- Grass buffers were present at one end along waterways,
- The paddock sizes all remained the same through the adoption of GMP and BMP. Where cropping is reduced, the reduction was applied through reducing the cultivated area,
- Maize and forage oats were grown when fallow period was three or more months but not during the winter months,
- Maize and forage oats were harvested and sold,
- All livestock were removed from potato and onion systems with forage crops being exported,
- Fertiliser for BMP came from Bloomer et al. (2020) OverseerFM models,
- All yields came from Bloomer et al. (2020) OverseerFM models.

Scenario four assumptions – In rotation pastoral cut and carry

- All lettuce, spinach, and parsley crops were removed from the in-field rotations
- It was assumed that permanent pasture can be drilled any time of year.
- Add permanent pasture (category), pasture (crop type), direct drilled (cultivation practise at sowing), cut/carry only (defoliation management).
- Pasture growth rates are based on Massey University Dairy 1 provided by Diary NZ (2020) as they have the most similar growing environment to the Horowhenua district.
- From harvest Table A – 9 (below) was used to determine monthly growing potential and hence when pasture covers were likely to have reached the target of 4,000 kg DM.
- When covers of 4,000 kg DM were reached, silage was cut at around 2,500 kg DM leaving a 1,500 kg DM residual. All silage was exported off farm.
- It is assumed it is not possible to physically cut lower than 1,000 kg DM residual for the final harvest.
- If at the conclusion of the rotation, covers are less than 2,000 kg DM, it was assumed that the value of silage does not cover the cost of harvest and therefore is non-economic. In this instance it was assumed that herbage is worked into the ground with the next crop, returning organic matter to the soil.
- After each silage cut (except the final cut) fertiliser was surface applied in the form of 100 kg/ha Serpentine super 15K and 20kg/ha SustaiN per 1,000 kg DM removed. This is to replace 100% P and 85% K with enough nitrogen to ensure an economic yield and match inputs from pasture growth data.

Table A - 9: Pasture production data (DairyNZ, 2020).

Month	Daily growth rate (kg DM/ha/day)	Number of days in month	Monthly pasture grown (kg DM)	Total accumulated pasture grown (kg DM)
January	30	31	930	930
February	33	28	924	1,854
March	31	31	961	2,815
April	31	30	930	3,745
May	32	31	992	4,737
June	20	30	600	5,337
July	18	31	558	5,895
August	24	31	744	6,639
September	42	30	1,260	7,899
October	49	31	1,519	9,418
November	48	30	1,440	10,858
December	46	31	1,426	12,284

Scenario four assumptions – Greenhouse wastewater

- Irrigation block is 5 ha cut and carry
- Pasture is ryegrass only
- Pasture growth rates are based off Massey University Dairy 1 provided by Dairy NZ as they have the most similar growing environment to the Horowhenua district. Monthly growing potential is defined in Table A – 9.
- From harvest Table A – 9 used to determine when covers are likely to have reached 3,000-4,000 kg DM. When this is reached, silage cut of around 1,800-3,000 kg DM leaving a target of 1,500 kg DM residual.
- Supplement is cut as silage, actual weight as dry matter, all supplement is sent off farm.
- As per industry standard, this removed 61 kg P/ha. So as not to mine fertility a single application of 200 kg/ha (19 kg P/ha) Superten is applied to the pastoral area in October to complement the 42 kg P/ha being applied via irrigation (assuming 100% replacement rate).
- Silage also removes 244 kg K/ha. So not to mine fertility, two applications of 110 kg/ha muriate of potash was applied to the pastoral area in October and February to complement the 84 kg K/ha being applied via irrigation (assuming 80% replacement rate).
- 200 kg/ha good quality lime is applied every December, does not dissolve within a year.
- No extra nitrogen is applied above what is supplied from irrigation (and fertiliser topping up irrigation to correct total N applied) as it is assumed that the applications of 21 kg N/ha from September to April is sufficient to stimulate growth to the level at which supplement is cut.
- Irrigation is through a lateral pivot over 5 ha.
- Irrigation is applied in all months except May, June, July & August.
- Irrigation is based on 'Fixed depth and return period'. Override management default to apply 5 mm/application every 32 days.

- Nutrient source is block specific and the maximum value was selected for all nutrients (see below). As the selected nitrogen value of 364 mg/L (van Ruijven, et al., 2019) was already above the maximum value available in Overseer, this was assumed to be the case for each nutrient

N	P	K	S	CA	MG	NA	UNITS
200	100	200	100	100	100	100	mg/l

- As nitrogen concentrations in the greenhouse wastewater were estimated to be 364 mg/L, but the maximum that can be represented in OverseerFM is 200 mg/L, additional Nitrogen is “applied” in the model as fertiliser to represent the application of 364 mg/L through 2,325,000 L to the total block.
- 2,325,000 L at a concentration of 364 mg/L is the equivalent of 846.3 kg N. Therefore, it was calculated that an extra 367.9 kg N needs to be applied to pasture to represent the estimated nitrogen applied from greenhouse wastewater. This is applied as 8x applications of 20 kg/ha of SustaiN surface applied during months of irrigation.
- Low nitrogen loading rates taken into consideration: 30 kg N/ha/month and 200 kg N/ha/yr (Horticulture New Zealand, 2007).
- Phosphorus concentration was the only other nutrient data available for greenhouse wastewater. For this 100 mg/L was used, as it was this highest value in any of the reported literature (Kwon, et al., 2021).

Appendix C – Glasshouse Literature Review

Memorandum

To	Charlotte Almond
Copy	
From	Lisa Arnold
Office	Palmerston North
Date	18 March 2023
File/Ref	5-P1648.00 Horizons Our Freshwater Future
Subject	Literature review – Horowhenua CVG - suitable hydroponic glasshouse crops

1 Introduction

The Horizons region has a significant area of commercial vegetable production in Horowhenua district which is important for New Zealand's domestic food supply. The National Policy Statement for Freshwater Management 2020 (NPS-FM) requires regional councils to set target attribute states in all Freshwater Management Units (FMUs) for their relevant attributes. Within the NPS-FM there are two specified vegetable growing areas in Horowhenua, the Hoki_1a and Hoki_1b subzones, in which Horizons Regional Council (Horizons) may set target attribute states below national bottom lines. The land uses within these subzones are impacting the water quality of Lake Horowhenua (particularly due to the result of nitrogen (N) losses, but also sediment and sediment-carried phosphorus (P)). The NPS-FM also states that the regional council must 'have regard to the importance of the contribution of the specified growing area to the domestic supply of fresh vegetables and maintaining food security for New Zealanders' (Section 3.33 of the NPS-FM).

To assist Horizons with determining whether it should set target attribute states in the Hoki_1a and Hoki_1b subzones which are below the national bottom lines in the NPS-FM, several scenarios are being investigated. The goal of these scenarios is to determine if national water quality bottom lines within the two subzones can be met. One of these scenarios is to assume that a portion of the Hoki_1a and Hoki_1b subzones will convert from traditional in-field horticulture to hydroponic glasshouse-based horticulture. As of 2020 there were approximately 310 ha of glasshouse crops grown in New Zealand, most of which are grown using hydroponics (email comm. Horticulture NZ, 2023).

Hydroponics is defined as the cultivation of plants using a nutrient solution in an enclosed environment, rather than a soil-based media. As the nutrient solution is enclosed and captured within these systems, the discharge of the waste nutrients can be controlled. Depending on how the waste nutrient solution is managed, the potential impacts of nutrients on water quality in the catchment may be reduced.

The aim of this memo is to review and summarise the available literature on the hydroponic glasshouse scenario, with particular focus on answering the following questions:

- Which commercial vegetable crops that are currently grown in Horowhenua are suitable for growing in a hydroponic glasshouse system?
- What are the differences in yield of these crops when grown hydroponically compared to in-field production?
- To produce the current yield of each crop, how many hectares of glasshouses would be needed?
- What are the pros and cons (including environmental and crop quality) for hydroponic glasshouse growing compared to in-field production?
- How do hydroponic glasshouse growing systems work and what are the key points of differences for growing the selected crops?
- Apart from growing hydroponically in glasshouses, are there any other suitable out-of-field systems to grow commercial vegetables?
- What area of land currently in commercial vegetable production (in-field systems) could be transferred out of vegetables and into another land use or into glasshouses?
- If certain vegetable crops are transferred out of in-field vegetable production and into glasshouses, what is the change to the amount of nitrate leached within the subzones as a result? This question is not addressed within this memo, but has been answered using OverseerFM modelling in the main report

2 Identification of crops

Of the 23 commercial vegetable crops grown in Horowhenua (outlined in Bloomer et al. 2020), three were identified as potentially suitable for commercially growing hydroponically within glasshouses for further investigation within this literature review:

- lettuce
- spinach
- parsley

These three leafy green crops have been demonstrated to grow successfully in hydroponic systems (Sharma, et al., 2018). Lettuce, spinach, and parsley are grown in New Zealand in commercial settings and are well suited to a hydroponic system as they do not require structural support and do not develop an extensive root system. They also have a short growing cycle allowing for multiple crops to be grown per year.

Celery was also considered as a potential crop that could be grown hydroponically as globally it is grown on a commercial scale. However, this crop is not grown hydroponically in New Zealand on a commercial scale and there is limited data available in the literature regarding its hydroponic production. From what could be gathered, celery is less ideally suited to hydroponic systems than the three crops above as it has a heavier stalk and leaf mass and requires some structural support, and it has a longer growing cycle than these crops allowing for less crop rotations per year.

Leek, radish, and spring onions are crops also potentially suitable for growing hydroponically. However, like celery, these crops are not grown hydroponically in New Zealand on a commercial scale and there is limited data available in the literature regarding their hydroponic production.

See Appendix Table A-1 for a list of all Horowhenua vegetable crops considered for hydroponic suitability. There are other crops within this list that have been identified as suitable for hydroponics, but these have been excluded due to the current volume of crop grown being relatively small. Most crops can be grown using hydroponics, however there are several factors which determine whether a crop is viable to grow commercially, at a large scale, using hydroponics. Commercially viable crops should have a high value relative to the cost of hydroponic production (compared with in field production), have a higher yield or quality when grown under hydroponics, or be able to be produced off-season using hydroponics (Lecuona, 2013). Some of the crops listed in Appendix Table A-1 are deemed unsuitable (or less suitable) for commercial hydroponic production, particularly those that require a large amount of space for their root systems (e.g., potatoes) or for above ground vegetational growth (e.g., vine crops and certain cucurbits e.g., squash and pumpkin) (Brio Hydroponics, 2022). It should also be noted that different crop varieties of similar families may be better suited to hydroponics. For example, with lettuce, fancy lettuce grows well under hydroponics, however iceberg lettuces (a type of crisphead lettuce) are difficult to grow hydroponically due to their morphology and therefore are typically grown in soil (CropKing, 2013; Cultivators, 2021). A supply of fancy lettuces produced hydroponically will not necessarily be able replace a supply of crisphead lettuces such as iceberg, as the different types of lettuce have different culinary uses, flavour, texture and storage abilities.

3 Production data

Hydroponic systems typically generate a higher yield of crops (Hussain, et al., 2014) while utilising a smaller land area compared to in-field growing. For many crops, a hydroponic system protected within a glasshouse environment allows for continuous year-round production under carefully controlled environmental conditions, and shorter harvest cycles hence multiple crop rotations throughout the year (Lages Barbosa, et al., 2015).

The current in-field production of lettuce, spinach, and parsley in Horowhenua have been compared with the potential yield from a hydroponic system (Table 3-1). 'Current' production figures are based on pre-2019 data which has been used for the analysis in Bloomer et al. 2020. Available data from the literature suggests that lettuce production is 8.2 times higher in a hydroponic system (Lages Barbosa, et al., 2015), and spinach production is 7.4 times higher (Acharya, et al., 2021). Although specific data is unavailable for hydroponic parsley crop, an estimated average of 6.6 times higher yield has been used based on an average magnitude difference of a range of crops (Hussain, et al., 2014). To produce the current yield of these three crops (from 86.6 hectares of land), 27.1 hectares of glasshouse productive area would be required (approximately 40.4 hectares of total glasshouse area). Using the pre-2019 data to produce the tonnage highlighted in Table 3-1, 75.8 ha of land was required during the year due to crop rotations.

Table 3-1. Comparison of yield from in-field vs. hydroponic systems.

<table>
<tr><th rowspan="2"></th><th colspan="2">In-field production (Horowhenua)</th><th colspan="2">Production figures from literature</th><th rowspan="2">Hydroponic difference in yield</th><th rowspan="2">Glasshouse area* to produce equivalent field crop</th></tr>
<tr><th>Total crop</th><th>Per ha</th><th>In-field</th><th>Hydroponic</th></tr>
<tr><td>Lettuce</td><td>Total crop (pre 2019 [a]) 1,245 tonne over 24.9 ha</td><td>50 t/ha/crop</td><td>36.9 – 41.1 t/ha/yr[b]

10.4 – 12 t/ha/crop[c]</td><td>349 - 471 t/ha/yr[b]

21.5 – 32 t/ha/crop[c]</td><td>8.5 – 12.8 x higher

1.8 – 3.1 x higher

(Average 7.3 x higher)</td><td>3.4 ha</td></tr>
<tr><td>Spinach</td><td>Total crop (pre 2019 [a]) 1,139 tonne over 40.7 ha</td><td>28 t/ha/crop</td><td>11.3 – 12.7 t/ha/crop [c]

4.9 t/ha/crop[d]</td><td>25.3 – 36.6 t/ha/crop[c]

9.3 t/ha/crop[d]</td><td>2.0 – 3.2 x higher

2.3 x higher

(Average 2.6 x higher)</td><td>15.6 ha</td></tr>
<tr><td>Parsley</td><td>Total crop (pre 2019 [a]) 567 tonne over 21 ha</td><td>27 t/ha/crop</td><td>Data unavailable – use available figures for spinach</td><td>Data unavailable – use available figures for spinach</td><td>2.0 – 3.2 x higher

(Average 2.6 x higher)</td><td>8.1 ha</td></tr>
</table>

**Note: glasshouse productive area given, this is typically 67% of the total glasshouse area*

[a] *Pre-2019 is an average of 2016-2018 data* (Bloomer, et al., 2020); [b] (Lages Barbosa, et al., 2015) – *hydroponic based on 12 crops per year* [c]; (Acharya, et al., 2021); [d] (Ranawade, et al., 2017)

4 Comparison of hydroponics vs. field production

Hydroponic systems can offer several benefits over conventional in-field production (Table 4-1). Besides a typically higher yield and the ability to grow multiple crops year round, recirculating hydroponic systems use 5 – 20 x less water when compared with an irrigated in field system (AlShrouf, 2017; Lages Barbosa, et al., 2015) and less fertiliser (80-85% less for recirculating/closed hydroponic systems) (AlShrouf, 2017), have low or nil pest, disease and weed pressure (Hussain, et al., 2014), and require lower labour inputs (Hussain, et al., 2014; Sharma, et al., 2018).

However, hydroponic systems are energy intensive, requiring 82 times more energy (Lages Barbosa, et al., 2015). They require a consistent high quality water supply – water should be analysed before use and if the mineral content is high then it may need to be treated, for example high sodium, heavy metals or pathogens (Stocker Horticulture and Hydroponic Supplies Ltd, n.d.). These systems are also expensive to establish (Hassall & Associates Pty Ltd, 2001). Although water use is typically a lot lower for hydroponic systems vs. irrigated in field crops, greenhouse crops are not exposed to rainfall and therefore this source of water is not utilised within the system unless captured. Although labour inputs are typically lower for a hydroponic system, experienced technical management staff are critical to ensure the system is operated correctly (Hussain, et al., 2014; Hassall & Associates Pty Ltd, 2001). The system must also be frequently monitored for pH, electrical conductivity (of nutrient solution) and for electrical failures (Richa, et al., 2020). Although pest and disease pressures are typically lower in a hydroponic system, waterborne diseases can rapidly spread between plants (Hassall & Associates Pty Ltd, 2001).

Studies on crop quality parameters usually focus on specific components of quality such as size, dry matter, nutritional content, and taste. Two studies were found which provide reviews of the literature comparing quality parameters of crops grown hydroponically vs. in-field (Gruda, 2009; Aires, 2018). These two reviews both discuss a range of different quality parameters and show that there are studies stating no difference and some stating a higher or lower quality reported for in-field grown produce vs. hydroponic produce. For example, Buchanan and Omaye (2013) found that levels of ascorbic acid (Vitamin C) and alpha-tocopherol (a type of Vitamin E) were higher for hydroponically grown lettuce compared with soil grown lettuce. In contrast, Kimura and Rodriguez-Amaya (2003) found that the level of carotenoids were lower for hydroponic lettuce compared with those grown in soil.

As there is potentially less damage to crop from environmental exposure and pest/disease damage within a hydroponic system, this is likely to resulting in a lower percentage of reject produce and higher pack-outs. However, no literature was found to support this.

There is no opportunity to add value through certified organic marketing for a hydroponic system, as a soil-based media is required to achieve organic certification in New Zealand (and in most cases globally) (Huggins, 2022). Hydroponically grown produce is not typically marketed as "hydroponic" to the consumer and a price premium is more likely to be achieved based on a higher quality product, marketing strategies and and out of season supply (Hassall & Associates Pty Ltd, 2001).

Typical enclosed conditions within a glasshouse environment create a period of insufficient CO_2 availability during daytime hours, even with ventilation (Wang, et al., 2022). To mitigate this, CO_2 must be added to the glasshouse to maintain crop yield and quality. Of key concern for glasshouse production in New Zealand is that the industry is currently facing domestic supply issues for CO_2, following the closure of the Marsden Point refinery and recent shutdown of the Todd Energy Plant in January 2023 (Lewis, 2022; Olley, 2023). CO_2 can be imported from overseas, but this comes at a significant cost to customers.

Table 4-1. Pros and cons of hydroponic vs. in-field systems. Pros are highlighted in green, Cons in red and neutral factors are in orange.

	Hydroponics (glasshouse)	In-field (uncovered)
Yield	• Can produce significantly higher yields; shorter growing time – multiple crop rotations per year; all year round production possible for some crops.	• Generally lower yields, longer growing time and limited seasonal production for some crops.
Land requirements	• A smaller area of land is required to produce the same amount of crop • Does not rely on soil therefore can be established on poorer soils	• A larger land area is required to produce the same yield • Relies on suitable soil type and fertility to grow
	• Requires flat land and should avoid waterlogged areas	
Nutrient management	• Recirculating systems have reduced fertiliser use • Waste nutrient solution may be applied to field crops as a fertiliser	• Current issues with nutrient leaching and freshwater quality from vegetable production
Erosion and soil loss	• No direct impact on soil loss	• Soil loss from cultivation • Soil loss when vegetables are washed pre-packing
Crop quality	• Potentially less damage to crop from environmental exposure and pest/disease damage, resulting in less reject produce	• Damage to crop from environmental exposure and pest/disease, expected higher % of reject produce
	• For a range of quality parameters the literature findings vary. Some studies report no differences and some report higher quality parameters for hydroponic or soil-based systems.	
Water use	• For recirculating systems significantly less water is required compared with an irrigated in-field system • No irrigation system required as water is provided through the hydroponic medium • Drainage water may be recycled back into a crop production system	• Higher water requirements • Irrigation systems are typically employed
	• A consistent high quality of water supply is required.	• Water quality is of less importance
Energy and fuel use	• Considerably more energy is required • Recent fuel supply issues in New Zealand with natural gas and CO_2 – increased cost for imported alternatives	• Fuel use for tractors and machinery – comparatively lower fuel use than glasshouse fuel requirements.
	• Opportunity to use alternative fuels such as biomass for energy	
Climate	• Protection from environmental extremes, allows for crop growth in	• Exposed to climatic extremes which may damage crops or limit crop growth

	Hydroponics (glasshouse)	In-field (uncovered)
	winter where cold temperatures are a limitation	
Pest, disease and weeds	• Lower pest and disease pressure – typically no spraying required • Effectively no weeding • Water borne root diseases may spread easily between plants.	• Generally higher pest and disease pressures, requirement to spray pesticides and fungicides regularly • Weed control typically a big issue requiring herbicide, machinery or manual weed control methods.
Labour	• Less manual labour is required due to automation of processes, and essentially no requirement for weeding, spraying or tilling • A high degree of technical expertise and experience is required from management and operational staff to ensure the system is operated correctly. • The system must be frequently monitored for pH, electrical conductivity (of nutrient solution) and for electrical failures.	• High labour requirements for operational activities – cultivation, spraying, weeding, irrigation management • As with hydroponics, a high degree of technical expertise and experience is required from management; both systems require general horticultural knowledge but operational skill sets are different
Establishment and operational costs	• A significantly high cost to establish which typically limits these systems to high value crops only • High operational costs due to heating and CO_2 requirements	• Comparatively low cost to establish • Comparatively low operational costs
Value-add products	• Unable to achieve organic certification as this requires a soil-based medium • Value-add through out of season supply, marketing terms such as "vine-ripened" for tomatoes	• Able to achieve organic certification if desired

5 Glasshouse production systems

5.1 Establishment requirements

Glasshouses for vegetable or herb production in New Zealand range in size from 0.05 ha up to 34 ha (Te Puni Kōkiri, n.d.) and most range from 1 to 10 ha (pers. comm. S McNally 2023). Within a glasshouse the productive area usually takes up about 2/3 of the total floor area. There may also be specialised seedling production areas if seedlings are grown on site rather than sourced from a supplier. The total land area required for a glasshouse operation will also need to factor in space for waste collection (vegetative waste but also collection of waste nutrient solution if tanks or ponds are used), packing and cool storage areas, offices and areas for vehicle and machinery movement. The Horowhenua commercial vegetable industry is already well established and therefore existing packing and cool storage facilities in the area may be utilised.

A glasshouse operation requires flat land, and it is best to avoid waterlogged areas (Te Puni Kōkiri, n.d.). A site that is not perfectly flat may still be suitable as earthworks can be used to level the site (pers. comm. S McNally 2023). Typically a glasshouse is constructed with a slanted floor so that water can drain.

When considering a potential site, it is important to consider the daylight hours, light intensity and temperature throughout the season. Areas with summer temperatures above 30°C for long periods are not recommended as most summer crops grow in the range of 18-22°C. Areas that experience very harsh cold winters are also not recommended as considerable energy will be required for heating; winter temperatures in the glasshouse should be kept at 16-19°C (Te Puni Kōkiri, n.d.). Aspect is also important so that the glasshouse receives sunlight but is not shaded. Although the climate can be controlled within a glasshouse, this is primarily influenced by the outside climate. Internal climate is manipulated using heating, cooling and lighting; however, these require energy and the correct technology and expertise to operate to maintain a favourable environment for the crop. Protection in the form of shelterbelts is required for more exposed sites, to protect the glasshouse panels from strong winds, but it is important that these do not shade the glasshouse (pers. comm. S McNally 2023). Stormwater management is also an important consideration for a large glasshouse due to the large roof area. There is potential to collect rainwater from the roof and use this for irrigation of field crops, or if treated to the required water quality standard this could be used within the hydroponic system.

Glasshouse systems in New Zealand are typically specialised and set up to produce a single crop, i.e. a monoculture. If other crops are produced in the same operation then they are typically produced in a separate area or separate glasshouse which is set up specifically for that crop. There is potential for different leafy green crops such as lettuces or herbs to be grown in the same area in a rotation if the plant spacing and size is similar (pers. comm. S McNally 2023).

The most commonly employed hydroponic systems in the New Zealand commercial setting are the nutrient film technique (NFT) and drip systems. Drip systems are the most commonly used system for vine crops such as tomatoes, capsicums and cucumbers whereas NFT is the most commonly used system for lettuce, leafy green and herb production (pers. comm. S Vogrincic 2023; Pure Hydroponics, n.d.).

An overview of these two systems is provided below.

5.2 Drip systems

A water reservoir delivers a slow feed of nutrient solution to plant roots via a pump (Figure 5-1; (Sharma, et al., 2018)). Each plant is individually fed the solution via a drip-line micro-emitter. As this system is commonly used for larger plants such as tomatoes or cucumbers, each plant is typically grown in a supporting absorbent medium such as perlite or coconut coir. The unused nutrient solution that drains from the plant roots is then collected and can be either recirculated and returned to the reservoir (i.e., a closed system) or collected as a waste solution for disposal.

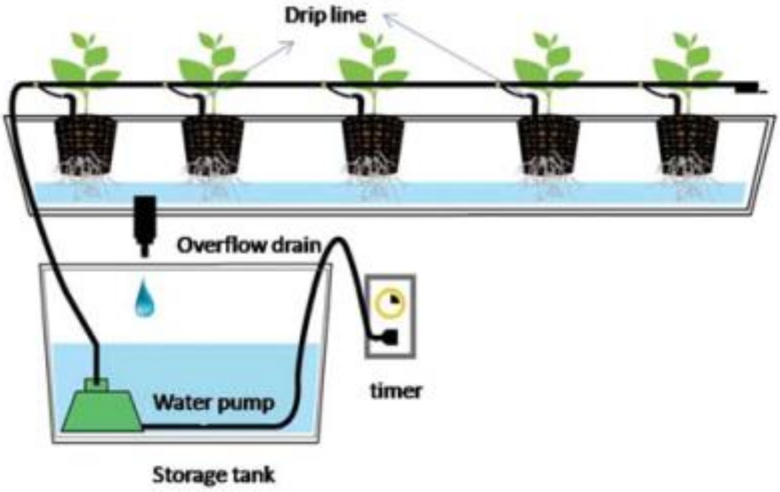

Figure 5-1. Representation of a drip system. Image from Sharma et al. 2018.

5.3 Nutrient film technique (NFT) systems

In an NFT system, nutrient solution from a reservoir is pumped through a series of pipes within which the plant roots are suspended, to continuously provide a supply of nutrients and water to the plants (Figure 5-2; Sharma, et al., 2018). The nutrient solution is recirculated through the system (i.e., a closed system) until a maximum time period is reached or the concentrations of different nutrients reach a certain trigger point at which then the solution is removed as waste and replaced. Regular chemical analysis and adjustment of the nutrient concentrations in solution is needed for this system (Hassall & Associates Pty Ltd, 2001). These systems only provide structural support to the plant in the form of a plastic tubing and therefore larger vine plants are less well suited to these systems as opposed to smaller leafy green crops such as lettuces. As there is no absorbent growing medium involved, a pump failure can quickly result in the drying out of the plant roots.

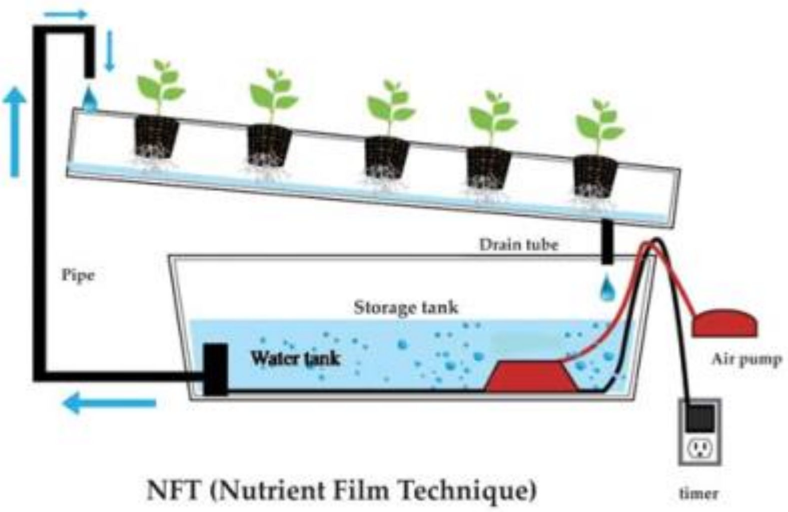

Figure 5-2. Representation of a NFT system. Image from Sharma, et al., 2018.

5.4 Crop comparison

All three of the crops selected for this literature review are most commonly grown in a NFT system and therefore the overall hydroponic set up is similar. There are however some key differences between the crops which will influence the composition of the nutrient solution required and create different operational requirements. These differences are summarised in Table 5-1.

For lettuces they are typically harvested only once in the form of the whole plant. For spinach and parsley, two harvests of fresh leaf are carried out within the growing cycle before the plant is replaced. Lettuces have the shortest growth cycle in a hydroponic system, reaching harvest between 30 to 40 days after transplant. Spinach and parsley take longer, typically reaching first harvest at 45 days from transplant and second harvest at 60 days, allowing for about 6 crops per year.

Besides temperature and light, the nutrient solution is the key driver of crop growth within a hydroponic system. Two critical factors of the nutrient solution are electrical conductivity (EC) and pH, which must be tailored for the crop (Sharma, et al., 2018; Hussain, et al., 2014). Electrical conductivity is a measure of the concentration of nutrients in solution and pH is a measure of acidity which influences the availability of nutrients to the plants. Both factors must be within a certain range to support optimal crop growth. Spinach and parsley have a similar EC requirement whereas lettuce has a lower EC requirement. All three of these crops require a similar pH range (slightly acidic to neutral).

A limitation with measuring the EC of a nutrient solution is that this does not measure the concentration of the specific nutrients required but rather the total ions in solution. However, specific nutrients can be measured using separate sensors.

Table 5-1. Key crop differences influencing the hydroponic system set up and operation. pH and EC values from (Sharma, et al., 2018).

Crop	Days to harvest (from transplanting)	Approximate number of crops per year	pH requirement	EC (dSm^{-1})
Lettuce	30 - 40	9 - 12	6.0 – 7.0	1.2 – 1.8
Spinach	45, 60 (two harvests)	6	6.0 – 7.0	1.8 – 2.3
Parsley	45, 60 (two harvests)	6	6.0 – 6.5	1.8 – 2.2

6 Nutrient management considerations for glasshouse production

Two basic types of commercial hydroponic systems have been identified (Hassall & Associates Pty Ltd, 2001):

- Open systems – where nutrient solution is 'run to waste'
- Closed systems – where nutrient solution is recirculated (and eventually replaced)

Open systems generate a significant amount of waste nutrient solution as a fresh batch of solution is applied to the plants each time. Closed systems are more commonly used commercially both globally and in the New Zealand setting. These systems use 80-85% less fertiliser compared with a conventional in-field system (AlShrouf, 2017). Closed systems generate waste nutrient solution but to a much lesser degree than an open system, as the nutrient solution in a closed system is recirculated through the system over time before eventually being replaced with a new batch. Management of the recirculated solution (addition of nutrients, water, and careful maintenance of EC and pH) is important to ensure that plant needs are met and to extend the time period of the solution batch before it needs replacing (i.e., to save cost and reduce the amount of waste solution produced). Nutrient management of recirculating hydroponic solutions is discussed in depth by Bugbee (2003).

Both open and closed hydroponic systems allow for the capture of the waste nutrient solution compared with an in-field system where fertiliser is applied to the soil and excess nutrients are susceptible to either leaching through the soil profile or runoff over the soil. However, the management of waste nutrient solution from hydroponic systems can be problematic as it can have high concentrations of nutrients and discharges to the environment (particularly those directly into waterways) can cause pollution (Kumar & Cho, 2014; Richa, et al., 2020). Treatment methods such as denitrification, constructed wetlands and microalgae-based treatments have been shown to be effective at removing nitrogen and phosphorus from hydroponic wastewater (particularly from open systems) so that discharge can occur with minimal impact to the environment (Richa, et al., 2020).

There is the potential to treat and re-use hydroponic waste nutrient solution within the same system. Filtration methods and UV treatment can be effectively used to remove bacteria and recover nutrients, and activated carbon to remove toxic root exudates, so that the solution is suitable for re-use (Richa, et al., 2020).

Hydroponic waste nutrient solution can also be applied to in-field crops, and this can reduce fertiliser inputs and potable water use (Grewal, et al., 2011; Choi, et al., 2011). It is common practice for glasshouse operations in New Zealand to apply hydroponic waste nutrient solution to land, similar to how municipal wastewater is discharged. An example of this is Turners and Growers who discharge waste nutrient solution to land from their hydroponic tomato production.

If unable to discharge to land, other disposal options can be considered, for example:

- Discharge through denitrification /filter beds
- Discharge to a sewer (requiring consent)
- Discharge to surface water (requiring consent and not considered good practice)
- Transport away for alternative disposal

(Horticulture NZ, 2020)

The concentrations of nitrogen, phosphorus and other nutrients in hydroponic waste nutrient solution vary and will depend on a range of factors such as the concentration of supplied nutrients, the crop type and growth stage, whether the hydroponic waste system is open or closed and if closed how frequently the nutrient solution is replaced. Limited data is available in the literature to suggest a range of N and P concentrations in waste nutrient solution. Saxena and Bassi (2012) report concentrations of N ranging from 200–300 mg/L and P 30–100 mg/L. Park et al. (2008) recorded nitrogen concentrations of >300 mg/L from New Zealand glasshouses growing tomato and cucumber. Kwon et al. (2021) found that waste nutrient concentrations from tomato, capsicum and strawberry hydroponic production in Korea ranged from 48 – 494 mg/L for N and 12.7 – 96.9 mg/L for P. Another study from Sweden found that glasshouse waste nutrient solution had an N range of 34.7 – 73.7 mg/L and a P range of 15.4 – 15.9 mg/L (Hultberg, et al., 2013). No specific data for leafy green systems in New Zealand was found during this review.

Good management practices for discharging waste nutrient solution to land are summarised in a checklist format for growers in the Horticulture NZ publication: 'Greenhouse Nutrient Solution Discharge - The requirements for achieving Good Practice' (Horticulture NZ, 2020). This publication is based on the New Zealand 'Code of Practice for The Management of Greenhouse Nutrient Discharges' (Horticulture NZ, 2007), and provides a good practice guideline for nitrogen loading to grazed pasture of either a limit of 30 kg N/ha/month and less than 150 kg N/ha/year on sites underlain by sand and volcanic soils, or; a limit of 50 kg N/ha/month and less than 200 kg N/ha/year on sites underlain by soils other than sand and volcanic soils. These are based on Auckland Council limits and these requirements may differ for other regional councils.

7 Other out of field systems

Vertical farming

While the standard hydroponic method is set up as a horizontal system, a vertical hydroponic system consists of stacked layers of plants vertically. A vertical hydroponic system can produce a greater crop yield from a smaller area (Touliatos, et al., 2016). Artificial lighting is required to supply enough light for the stacked layers, which are not exposed to sufficient sunlight. Removal of sunlight from the system reduces the need for cooling and therefore may in fact lower the overall energy requirements for the system. Other than these factors, vertical hydroponic farming will have similar pros and cons as for a horizontal system, as outlined in Table 4-1.

A vertical hydroponic system may be well suited to an urban or factory environment where space is of premium. Current vertical farming examples in New Zealand cities include leafy greens (lettuce, kale, basil and spinach) production at Greengrower in Hamilton, and microgreen production at Shoots Microgreens in Wellington.

Aeroponics

An aeroponic system is similar to a hydroponic system however there is no medium used; plant roots are suspended in air in an enclosed chamber and continually or intermittently misted with a nutrient solution (AlShrouf, 2017). An aeroponic system has an advantage over hydroponics in that waterborne diseases cannot spread between plants. Water and nutrient use efficiency are higher than a hydroponic system, but these systems require a high level of maintenance and technical expertise to operate (Niu & Masabni, 2021). As considerably less water is used, there is minimal wastewater to handle compared with a hydroponic system.

Whether aeroponic production systems are currently used commercially in New Zealand could not be confirmed within the scope of this review.

8 Transition from field to glasshouses

The Bloomer et al. (2020) report outlines that, pre-2019, there were 377 ha of commercial vegetable production within the study area. The three selected crops (lettuce, spinach and parsley) are grown on 75.8 ha of land as part of the 377 ha. Sometimes these crops are in rotation with each other, while in other rotations only one of the three crops is present.

Due to the nature of the rotational vegetable cropping, transitioning the total production of these three crops to glasshouses could reduce the total area by 75.8 ha based off the pre-2019 crop rotations. However, removing 75.8 ha of land would result in additional crops also being removed from production due to the specific crop rotation rarely only having lettuce, spinach, and parsley (Appendix Table A-2). Therefore, with the glasshouse scenario it is recommended that rather than removing a percentage of land, all crop rotations remain in play however where lettuce, spinach, and parsley are present they must be replaced with an annual rye grass. This will provide an indication of the nitrogen loading impact that these selected crops are having on the sub-catchments' nitrogen loading.

Additionally, it must not be assumed that the total area of the three crops that are currently grown in-field are potentially able to be grown under a glasshouse system, as there may be certain varieties (for example, iceberg lettuces) which are not suitable to grow commercially using hydroponics. Specificity of crop type cannot be modelled in Overseer therefore from Bloomer et al. (2020) it is difficult to ascertain total areas of each crop type.

Although there are many crops currently grown in Horowhenua which are not suitable, or not likely to be suitable, for commercial hydroponic production, some of these may be nutritionally similar to crops that can be produced with hydroponics and therefore may be substituted. Curran-Cournane and Rush (2021) found that the volume of vegetables classified by the FAO and FHI 360 (2016) as "dark-green-leafy vegetables" produced in New Zealand is inadequate to meet the diverse dietary need of the total New Zealand population, only producing enough to provide 0.03 servings of vegetables per day per New Zealand person; 5 servings a day are recommended. To meet the dietary needs of New Zealand's population, the production of dark-green-leafy vegetables such as spinach could be increased and grown in a hydroponic setting, potentially substituting the production of other vegetables which are only suitable for in-field production, for example cabbage and iceberg lettuces.

Removal of any area of soil-based commercial vegetable production will reduce fertiliser inputs applied directly to the soil and therefore N and P loading in the catchment. Additionally, the area of soil cultivation will be reduced resulting in lower soil loss and erosion.

As a hydroponic glasshouse system does not rely on soil as a growing medium, glasshouses may be established on land with soils that are poor or deemed less suitable for cropping, as long as these areas are flat (or able to be made flat) and not subject to waterlogging. Therefore, in Horowhenua there may be areas of poorer soils not currently suitable for in-field vegetable production which may be suitable for glasshouse production.

9 Summary

Three vegetable crops that are extensively grown in Horowhenua have been identified as suitable for commercially growing hydroponically within glasshouses: lettuce, spinach, and parsley. These three crops are currently grown commercially in NZ within hydroponic systems.

Globally these crops are reported to produce a higher yield when grown in a hydroponic system, by a magnitude of 7.3x for lettuce and 2.6x for spinach and parsley. Based on these global findings, the expected hectares of glasshouse production required to produce the same volume of crop currently grown in the Horowhenua area outlined in Bloomer et al. (2020) is 3.4, 15.6 and 8.1 ha for lettuce, spinach, and parsley respectively. Removal of these three crops from the field rotation will not necessarily reduce the amount of land required for in-field vegetable production but will reduce nutrient loading and soil loss within the catchment. There is the potential for increased production of lettuce and spinach (classified as dark-leafy-green vegetables) in hydroponic systems as a substitute for other in-field crops, to help meet New Zealand's diverse dietary requirement for this category of vegetables.

Besides a higher yield, hydroponic growing systems offer several benefits compared to in-field production. These systems allow for a greater number of crop cycles per year, use less water (compared with an irrigated in field system) and less fertiliser, have reduced pest, disease and weed pressures and typically have a lower labour requirement. However, hydroponic systems are energy intensive and expensive to establish. They require a high level of staff technical expertise to operate and require regular monitoring. A consistent, high quality of water supply is needed and there is the potential for waterborne diseases to spread rapidly across the whole crop. The literature is unclear as to whether quality of produce is higher for a hydroponic system. A current concern for glasshouse production in New Zealand is that the industry is facing domestic supply issues for CO_2 which is required for these systems.

Most commercial glasshouses in NZ are between 1 – 10 ha in size. As hydroponics do not rely on soil media, glasshouses can be established in areas with poorer soil if the site is flat or made flat through excavation. The climate for the site must not be excessively hot in summer or very cold in winter as the internal environment will need to be kept at controlled temperature to meet crop requirements (generally between 16 - 22°C).

Hydroponic systems in NZ are typically set up for a single crop. Lettuces have a very short growing cycle (30-40 days) and up to 12 crops may be grown per year. Spinach and parsley have a slightly longer growing cycle (45-60 days) and each crop is typically harvested twice, allowing for around 6 crops per year. All three crops have a similar pH requirement, and EC requirements are similar except lettuce requires a lower EC.

The hydroponic system most used in NZ for the production of leafy green and herb crops is nutrient film technique. This is a recirculating (closed) system whereby the nutrient solution is recycled through the system, although a waste nutrient solution is still created when this is replaced. This waste solution may contain high levels of N and P although these concentrations will vary depending on several factors. Typical waste nutrient concentrations for hydroponic leafy green production in NZ were not available although in general hydroponic concentrations may range from 35 to >300 mg/L for N and 12 to 100 mg/L for P. Good practice guidelines for management of greenhouse nutrient discharges recommend 30—50 kg N/ha/month and 150-200 kg N/ha/year for nitrogen loading (Horticulture NZ, 2020).

Vertical hydroponic farming and aeroponics are other out-of-field systems without a soil-based media, which could be suitable for leafy green production. However, vertical farming systems are currently not as well established in New Zealand and the extent of aeroponic production (if any) in New Zealand is not known.

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Appendix

Table A-1. Horowhenua vegetable crops considered for hydroponic suitability.

Horowhenua vegetable crop	Horowhenua production (pre-2019) tonnes	Suitable for hydroponic production	Reasoning included/excluded
lettuce	**1,245**	**yes**	**common glasshouse crop grown in NZ and globally, with good information available in the literature**
spinach	**1,139**	**yes**	
parsley	**567**	**yes**	
celery	431	yes	common hydroponic crop grown globally however there is a lack of data available in the literature to include these within the review
leek	280	yes	
radish	556	yes	
spring onion	756	yes	
coriander	44	yes	grown hydroponically either in New Zealand or globally, however relatively small volume grown in Horowhenua therefore excluded due to the limited extent of this review.
fennel	199	yes	
kale	12	yes	
shanghai	70	yes	
white pak choi	70	yes	
celeriac	62	not likely	large root component
beetroot	1,055	not likely	large root component
onion	6,090	not likely	large root component
potato	3,273	not likely	large root component
broccoli	64	not likely	above-ground large head development
cauliflower	199	not likely	above-ground large head development
cabbage	2566	not likely	above-ground large head development
red cabbage	299	not likely	above-ground large head development
wong bok	190	not likely	above-ground large head development
melon	1,288	not likely	space consuming, large vine requires support, heavy fruit
pumpkin	113	not likely	space consuming, large vine requires support, heavy fruit

Table A-2. Horowhenua vegetable crop rotation impacted by the in-field removal of lettuce, spinach, or parsley.

Horowhenua vegetable crop rotations	Area (ha)
Total area	**75.8**
Broccoli Lettuce Cabbage	1
Cabbage Cauliflower Lettuce	1
Cabbage Cauliflower Lettuce Cabbage	1
Cabbage Lettuce Spinach	3.3
Cauliflower Broccoli Lettuce Broccoli	1
Celeriac Spinach Lettuce Spinach	1.4
Celery Lettuce Spinach Cabbage Spinach	3
Celery Spring Onion Spinach	2
Celery Spring Onion Spinach 2	3
Kale Spinach	1
Lettuce Broccoli Lettuce Onion	1
Lettuce Cabbage Spinach	4.2
Melon Parsley	7.3
Melon Radish Spring Onion Lettuce Spinach	2
Melon Spinach Parsley Cabbage	4
Parsley Lettuce Beets	2
Parsley Lettuce Spinach	2.5
Parsley Spring Onion Lettuce Spinach	1.5
Pumpkin Spinach Lettuce Coriander	2
Radish Spinach Spring Onion Lettuce Spinach	1.5
Red Cabbage Leek Spinach	2
Red Cabbage Lettuce Beets Wong Bok	2.8
Spinach Lettuce Spring Onion Cabbage	2.8
Spinach Melon Parsley	8.5
Spring Onion Cabbage Lettuce Spinach	4.9
Spring Onion Fennel Lettuce Spinach	2.7
Spring Onion Spinach Lettuce Cabbage	4.9
Wong Bok Spinach Beets Lettuce Fennel	1.5

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