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MPI SFFF 19079:
What's Coming Out of Tile Drains?

Final Report

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1.0 EXECUTIVE SUMMARY

The SFFF funded "What's Coming out of Tile Drains" project, involved three years of tile drainage and receiving water quality monitoring across horticultural sites on the Heretaunga Plains in Hastings. Tile drainage is important for horticultural crop resilience, due to crops better withstanding flooded and saturated soil conditions, as well as drought conditions. However, tile drainage could also be a critical flow pathway for soil nutrient loss. Consequently, growers wanted to assess the timing, scale, and source of nutrients and sediment in tile drainage discharge from under horticultural crops, and how grower management may impact this.

The project carried out monitoring of 32 tiles from 16 horticultural sites in the Heretaunga Plains, Hastings including 32 surface water locations to represent the receiving water quality. Sites were selected using a range of criteria, including the accessibility of the drain for sampling, the topography, soil types and groundwater interactions of the site, and the ability of the grower to manage the paired drains in the same way. All sites completed the Horticulture New Zealand Environmental Management System (EMS) add on for NZGAP prior to commencement and operated at a minimum of Good Management Practice against this framework throughout the project.

Monitored sites covered a range of soil types, including but not limited to silt loam, clay loam on silt loam, ash on pumice and sandy loam on sand. Natural drainage of the soil types across monitored sites included well drained, imperfect drainage and poor drainage (see Table 1 for more detail).

Visual observation of tile flow behaviour during sampling runs, and flow meter data identified a range of different tile flow behaviours, including permanently flowing tiles, tiles which only flow following sufficient rainfall, and tiles which rarely flowed. Investigation into the monitored tiles at three sites showed permanent flows (suggesting potential groundwater upwelling), however assessment of groundwater nutrients from onsite wells provided a poor nutrient match comparison across Nitrogen species and dissolved reactive Phosphorus (DRP), suggesting that the hydrology systems are complex, and the tile drain nutrient profile is independent of the underlying aquifer at these three sites.

Dry tile conditions were prevalent at numerous locations with seven monitored sites all having extensive dry conditions. As a result, Farm Scale statistical assessment of mean, median, range, and 95th percentile values could not be undertaken at these seven sites.

Throughout the three-year monitoring period, data was captured from a range of conditions including above average rainfall events experienced with the La Nina conditions in 2022 and 2023, and Cyclone Gabrielle event in February 2023. Capturing data across this period reinforced the importance of a multiyear monitoring regime, demonstrating the level of flux and identifying the risks of misrepresentation by over or underreporting outcomes due to single point in time monitoring.

Statistical assessment identified a high degree of variability between individual samples and that nutrient concentrations in tile drains are generally lower than the receiving environment. However, in some instances, tile drain water quality results show elevated levels of nutrients throughout the monitoring period with DRP and Dissolved Inorganic Nitrogen being the primary nutrients of concern. The genesis of these concentrations did not correlate to farm actions or climatic conditions, reinforcing the complexity of the systems. In addition, tile drains stabilise receiving water conditions by reducing variability in conditions such as temperature.

Assessment of potential correlations within the data series including through time, spatial, soil typology, climate, and land management actions (notably fertiliser application) did not identify any discernible significant correlations. Therefore, the origin of these elevations represents an important further learning avenue, particularly for determining their genesis where no notable farm actions could be contributing to their presence. Additionally, the high ranges recorded within tile drain water quality data warrants further assessment to identify what generates the high level of variability identified.

This study has shown that interconnected groundwater aquifer systems, surface run off, and water movement, alongside soil type differences in drainage capability and parent material, all influence water quality outcomes. Project findings therefore reinforce the importance of maintaining and enhancing farm scale mitigations across a catchment utilising the Good Management Practice and Best Management Practice framework of the Horticulture New Zealand Environmental Management System (EMS) add on for NZGAP as a means for mitigating nutrient loss. However, the findings of this study also suggest that that these actions need to be coupled with catchment scale mitigations to realise opportunities for significant, measurable improvements in water quality.

2.0 INTRODUCTION

Subsurface drainage (tile drainage) systems are common under high value horticultural properties as a mechanism for improving effective rooting depth and maximising productivity. The horticulture industry works to continually and proactively understand their impact on the environment, and any mitigations which may be necessary.

The MPI SFFF funded, and AgFirst led 'What's Coming Out of Tile Drains' project, involved three years of water quality monitoring across horticultural sites on the Heretaunga Plains in Hastings. The project was designed to build a dataset of water quality data, alongside data from other external environmental factors, to assess the specific timing, scale, and source of nutrients and sediment in tile drainage discharge from under horticultural crops, and how grower management may impact this.

The project was designed within an adaptive management framework, and the project evolved following initial findings, questions raised, and respective inputs from project partners.

The project's primary sponsor was the Sustainable Food and Fibre Futures fund, with co-funding received from industry partners including Hawke's Bay Regional Council, New Zealand Apples and Pears Inc, Zespri, Vegetable Research and Innovation, Hawke's Bay Fruitgrowers' Association, Horticulture New Zealand, Watties KraftHeinz, Bayley Produce and Hawke's Bay Vegetable Growers Association.

This final report should be read in conjunction with the *Site Set-up* report and the *Year 1 Outcomes* and *Year 2 Outcomes* reports submitted to MPI as part of the project deliverables and are available from AgFirst Consultants upon request.

2.1 What do Tile Drainage Systems do?

Tile drainage is a subsurface system of perforated pipes, which diverts excess moisture from between soil particles, through the drainage system and out to surface water bodies.

Tile drain installations ensure plant roots are not continuously sitting in waterlogged soils, and therefore anoxic conditions, by allowing water to drain from soil pores into the drainage pipe network.

When soils become waterlogged, horticultural crops become susceptible to inhibiting growth and yield, and if sustained water logging occurs, this can result in crop death. Therefore, the installation of sub surface drainage networks is important for crop resilience during wet seasons and flooding events. Additionally, as healthy soil conditions promote root growth at depth, plants can access deeper reserves of soil moisture, which enables greater drought resilience, and reduces the reliance of shallow rooting systems with continual irrigation for survival in drought conditions.

As tile drainage water is discharged into the surface water bodies, horticultural growers want to understand if there is any elevated level of nutrient within this discharge due to land management practices, enabling landowners and industry bodies to make educated decisions about mitigation implementation if necessary.

2.2 Project setup

The project encompassed 16 horticultural farms located within the Ngaruroro, Tukituki, Tūtaekurī and Karamū Catchments in the Hawke's Bay. AgFirst identified 60 different growing locations for potential involvement within the project, analysing physical features via a site visit and a meeting with the landowner to discuss willingness of participation. Site viability was determined using the following attributes:

- Whether the tile drain is accessible and able to be sampled at all flow conditions;
- A comparative and accessible place to take the 'receiving water' measurements;
- The topography, soil types and groundwater interaction of the site;
- A second site to be paired to the first, with similar physical characteristics; and
- Ability of the grower to manage the paired sites in the same way.

Following this list of attributes, 16 sites were chosen trying to use a range of locations and groundwater interaction zones. It was more difficult than expected to find sites that fitted the selection criteria, so the ability to choose soil types was limited.

Within the 16 farms, 8 comprise apple orchards, 4 comprise kiwifruit orchards, and 4 comprise rotational cropping sites.

Monitoring of each horticultural farm was via two paired tiles and two receiving water points above each tile outflow, that samples were collected from throughout the monitoring period of 1 September 2021 to 31 August 2024. Water quality sampling involved:

- Base run grab samples collected from each tile and receiving water location on a fortnightly basis throughout the project;
- Event run grab samples collected from each tile and receiving water location following a rainfall event >15mm in the 24hrs preceding sampling; and
- Proportional run samples collected from 8 farms where permanent monitoring equipment was installed enabling a siphon of a fraction of flow discharge to cover a 2-week monitoring period.

An overview of the monitoring locations and associated site characteristics is set out in Table 1 below.

AgFirst notes Farm A08 was initially included in the project, however it became clear early on that limited useable data would be obtained from this site as despite greater than the 10-year average rainfall, a full soil moisture profile and the tiles cleaned prior to monitoring, no flow was ever recorded, nor was any water present in the receiving water body during sampling runs. As there were other tiles categorised as dry, Farm A08 was consequently superseded by Farm A09, a continuously flowing site, to provide better distribution across the different tile types.

Prior to monitoring, work was completed with all grower participants, to create Farm Environment plans using the Horticulture New Zealand Environmental Management System (EMS) add on, for NZGAP, as a baseline demonstration of compliance. Revisions to the plans were made throughout the project where growers updated their practices. All grower participants were operating at good management practice (GMP) and majority were operating at best management practice (BMP) standard throughout monitoring as assessed against the EMS.

The EMS add on for NZGAP framework, outlines good and best management practices across the following environmental management areas:

- soil quality health and fertility;
- soil erosion and sediment loss;
- nutrient loss (improving uptake and minimising loss);
- water and irrigation use efficiency and minimising nutrient loss; and
- Mahinga Kai and Biodiversity measures to protect and enhance these attributes

Table 1 Summary of site characteristics for the project monitored locations.

Site ID	Landuse	Age	Tile Drain Flow Behaviour	Receiving Water Character	Soil Description	Natural Drainage	Tile Material
A01	Apples	Mature	T1 – Event T2 – Event	Always flowing	Silt loam on clay	Imperfect	Clay
A02	Apples	Mature	T1 – Event T2 – Event	Always flowing	Clay loam on silt loam	Imperfect	Novaflow
A03	Apples	2015	T1 – Event T2 – Event	Dry, occasional stagnant water	Clay loam on silt loam	Poor	Novaflow
A04	Apples	2019	T1 – Dry T2 – Dry	Always flowing	Sandy loam on sand	Good	Novaflow
A05	Apples	Mature	T1 – Event / Seasonal T2 – Event / Seasonal	Always flowing	Silt/sandy loam on stones	Imperfect	Novaflow
A06	Apples	Mature	T1 – Event / Seasonal T2 – Event / Seasonal	Always flowing, natural spring	Silt loam on clay	Imperfect	Novaflow
A07	Apples	2021	T1 – Continuous T2 – Event / Seasonal	Always flowing	Clay loam on silt loam	Poor	Novaflow
A08	Apples	Mature	T1 – Dry T2 – Dry	Dry	Silt loam on sand	Imperfect	Clay
A09	Apples	Mature	T1 – Continuous T2 – Continuous	Always Flowing	Sand/silt loam on old topsoil	Imperfect	Novaflow
C01	Cropping	N/A	T1 – Dry T2 – Dry	Dry	Silt loam on sand	Imperfect	Novaflow
C02	Cropping	N/A	T1 – Dry T2 – Dry	Always present, occasionally stagnant	Ash on pumice	Poor	Novaflow
C03	Cropping	N/A	T1 – Event T2 – Event	Stagnant water	Silt on gravel/pumice	Imperfect	Novaflow
C04	Cropping	N/A	T1 – Continuous T2 – Continuous	Always flowing	Silt loam on shelly sandy loam	Poor	Novaflow
K01	Kiwifruit	Mature	T1 – Dry T2 – Dry	Dry	Silt loam	Good	Novaflow
K02	Kiwifruit	Mature	T1 – Dry T2 – Dry	Stagnant water	Silt loam on clay	Imperfect	Clay
K03	Kiwifruit	Mature	T1 – Continuous T2 – Continuous	Always present, occasionally stagnant	Silt loam	Imperfect/poor	Combination
K04	Kiwifruit	Mature	T1 – Event T2 – Event	Dry	Silt loam on clay	Imperfect	Clay

3.0 PROJECT OBJECTIVES

The project's primary objective was to assess water quality from within selected tile drainage systems across the Heretaunga Plains, comparing to the receiving water system in each of the monitored locations, to build a dataset demonstrating water quality that is coming out of tile drains.

Secondary to this assessment, the project intended to collect data to inform the following objectives:

- Understand the representativeness of tile drain water quality within a whole of Catchment context;
- Deliver additional understanding within industry of losses of Nitrogen, phosphorous, sediment, and E. Coli from within tile drainage systems;
- Determine how any identified losses are impacted by crop system, soil type, land management practices, and weather / climatic factors; and
- Understand what mitigation options could be implemented to improve sustainability and water quality within these systems should water quality monitoring data identify mitigation is necessary.

4.0 PROJECT OBJECTIVE INVESTIGATION AVENUES

Little published information on water quality from horticultural tile drainage system discharges in New Zealand, and little understanding of their contribution to catchment water quality was held at the genesis of this project. The horticultural industry felt that findings from this project would be important for social license and regulation going forward, and thus forming a strong baseline of data over time was a significant component of the project.

To assess the timing, scale and sources of nutrient and sediment the primary media sampled was water. Secondary assessment of soil parameters was undertaken to determine whether changes to soil are correlated to water quality. Assessment of soil included measurement of soil moisture via permanent soil moisture probes and nutrient assessment of topsoil to inform whether horticultural farm management actions (i.e. fertiliser loading) are correlated to drainage water quality. Soil moisture monitoring was undertaken throughout the monitoring years with nutrients assessed in topsoil each winter using repeat composite core samples across the tile drain area.

Data collected over the three-year monitoring period to create the project dataset included tile drain & receiving water quality parameters, climatic conditions, and farm management actions.

Water quality data collection included a grab sample protocol on a fortnightly schedule (referred to as "base runs"), alongside Event sampling runs, which were enacted following a 15mm rainfall event with a 24 hour period. During the base or event runs, a grab water sample and flow measurement from each paired tile drain exit and receiving water point is taken. Data collected from the water sample included:

- Temperature (ProQuatro Handheld Meter);
- pH (ProQuatro Handheld Meter);
- dissolved oxygen (ProQuatro Handheld Meter);

- conductivity (ProQuatro Handheld Meter);
- ammonical nitrogen (lab analysis);
- nitrite-nitrogen (lab analysis);
- nitrate/nitrite-nitrogen (lab analysis);
- Total Kjedahl Nitrogen (lab analysis);
- Dissolved Reactive Phosphorus (lab analysis);
- Total Phosphorus (lab analysis), and;
- Total Suspended solids (lab analysis).

4.1 Climate Summary

The three years of monitoring for this project captured some significant rainfall events, including the above average rainfall experienced with the La Nina conditions in 2022 and 2023, and Cyclone Gabrielle event in February 2023.

Weather data from stations associated with the monitored sites was captured for site specific insights, however for reference, Table 2 outlines weather data over the monitoring period for the Twyford weather station.

Year 1: 2021/22

For the monitoring period September 2021-August 2022, rainfall throughout spring and summer was below the long-term rolling average. However, the La Nina conditions of autumn 2022 presented higher than average rainfall in July and August 2022. A total of 1,023 mm was recorded for 2021/22, 32.5% above the 12 year rolling average, with February, March and April well above rolling averages.

Evapotranspiration (ET) in November, December and January (2021-2022) was higher than the long term average, as was the mean maximum temperature in these months, resulting in slightly above average ET and temperature conditions. Consequently, many monitored sites were dry and not flowing during monitoring visits through the 2021/2022 summer.

Year 2: 2022/23

For the monitoring period September 2022-August 2023, La Nina conditions continued, meaning rainfall of 1,234 mm was received in this period, well in excess of the long term average of 773mm (60% more than the average). Additionally, on the 14th February 2023, Cyclone Gabrielle brought significant wet windy conditions, and resulting in significant flooding, and silt deposition across areas of the Heretaunga Plains. Rainfall recorded in February 2023 was 3.8 times more than the 12 year rolling average, and 34% of the total average annual rainfall. ET was lower than average throughout the summer months, otherwise close to the 12-year average for most of Year 2 monitoring.

The mean maximum temperatures were close to the 12-year average except over December and January when it was 2 degrees lower. The mean minimum temperature tended to be slightly above the 12-year average except in March, July and August where it was slightly lower.

The monitored sites saw soil moisture levels well above field capacity during spring, late summer, autumn and winter which when coupled with low ET levels meant plant transpiration demand was not significant.

Year 3: 2023/24

Rainfall experienced throughout the September 2023-August 2024 monitoring period was back on the previous two extreme seasons, and aside from January and June 2024, was more aligned to the long-term average. More sites saw periods of no flow in this monitoring period, however groundwater levels were still high, with event tiles only needing a little rainfall to induce flow.

Monthly mean minimum and maximum temperatures were more similar to the long-term averages, and ET had the highest annual total of 789mm from the three monitored years.

4.1.1 Cyclone Gabrielle

On 14 February 2023, Cyclone Gabrielle hit the East Coast of the North Island, and significantly impacted Hawke's Bay. A range of impacts were felt by the horticultural sector, from minimal damage to complete orchard destruction, and consequently, the project monitoring sites sustained varying levels of damage.

Post-cyclone, a health and safety risk assessment was carried out for each site. and. Damage sustained to sites included warped flow equipment, flooded and corroded flow meter control boxes, flooded in ground "POD" flowmeter installations, repairs required on all battery terminals, erosion of stream banks, collapsed kiwifruit and apple canopy structures and at some sites, silt deposits restricting access. Sampling was able to continue across 15 of the sites once safe access was available, and 14 of the 16 flow meters were able to be repaired or replaced. However, site A05 was retired from monitoring following Cyclone Gabrielle, due to irreparable damage to the two installed flow meters, significant silt deposits inhibiting access to the drain, and damage to the orchard site resulting in removal of the monitored pipfruit block.

Flow meter data from during the event was also able to be captured from a number of lesser effected sites, allowing for visibility of flow peaks and lag times across these sites.
Cyclone Gabrielle resulted in significant passive project extension, with discussion across growers, industry and the wider community around sub surface drainage systems, crop resilience and resulting productivity and learnings regarding silt deposits, flooding and root health. Being able to capture monitoring data following the cyclone was therefore a valuable addition to the project dataset.

Table 2 Hawke's Bay Climate Data for the monitoring years, compared to the 12 year Rolling Average. Sourced from Twyford, HortPlus, MetWatch.

Month	Rainfall (mm)				Evapotranspiration (mm)				Mean Maximum Temperature (°C)				Mean Minimum Temperature (°C)			
	2021/22	2022/23	2023/24	12 year Rolling Average	2021/22	2022/23	2023/24	12 year Rolling Average	2021/22	2022/23	2023/24	12 year Rolling Average	2021/22	2022/23	2023/24	12 year Rolling Average
September	62	156	60	73	60	48	68	54	18	17	19	17	5	8	7	6
October	61	71	45	55	83	78	90	79	20	18	20	20	9	7	7	7
November	68	77	81	61	105	106	88	96	23	22	20	22	12	11	9	10
December	113	108	31	54	121	88	109	102	26	22	24	24	14	13	13	12
January	18	186	102	55	128	80	114	114	26	22	25	25	13	14	14	13
February	163	258	20	68	79	78	103	85	24	23	25	24	14	14	12	13
March	181	48	24	66	63	76	84	68	22	23	22	23	12	10	8	11
April	27	45	33	64	44	41	47	39	21	20	21	21	8	10	6	8
May	57	27	81	47	24	25	25	26	19	19	16	18	5	6	3	5
June	53	183	138	90	20	15	15	17	16	15	16	15	5	6	4	4
July	128	64	85	79	22	24	18	21	15	15	14	14	4	2	3	3
August	92	13	43	60	33	36	28	32	16	15	15	15	5	2	2	4
Total	**1,023**	**1,234**	**742**	**773**	**780**	**694**	**789**	**735**								

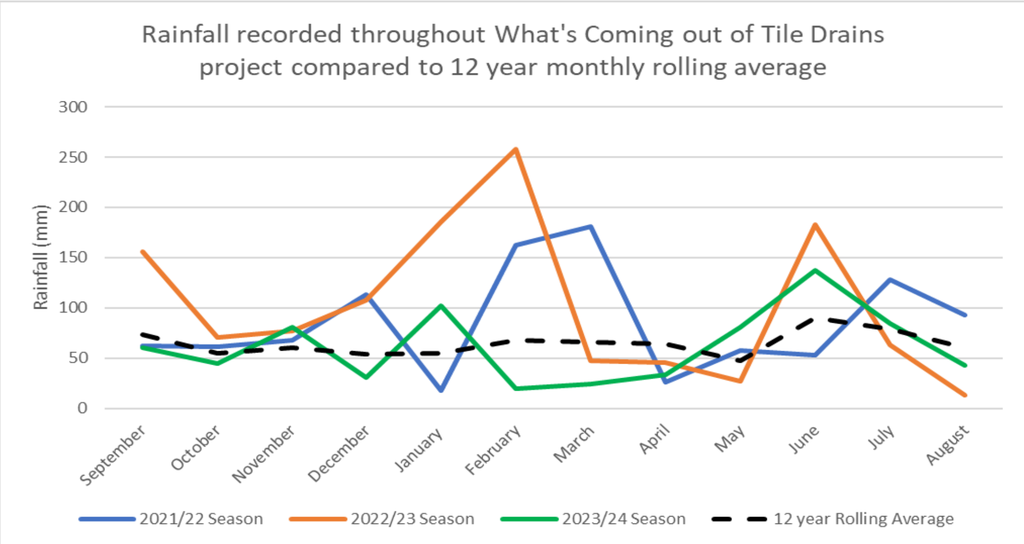

Figure 1 Hawke's Bay Rainfall Data for the monitoring years, compared to the 12 year Rolling Average. Sourced from Twyford, HortPlus, MetWatch

5.0 WHAT WE LEARNT

The project data collected under a robust and regular monitoring regime formed a three-year data set, and enabled assessments of water quality parameters for both the tile drain discharge and receiving water environments. In addition, there was investigation into what correlations may exist regarding farm management practices such as irrigation or fertiliser application, climate, and other factors that may influence tile drain and receiving water quality.

An important learning highlighted within the first year of monitoring, and then reinforced throughout the subsequent project years, was the unique nature of each tile drain. Many different factors influence the flow behaviour and discharge water quality of each tile drain, including but not limited to the crop type planted in the block being drained, soil type, water holding capacity, aquifer/hydraulic pressure, groundwater influence, grower management strategy and wider catchment interactions. Additionally, horticultural tile drains themselves are not standardised systems. The shape, direction, grid spacing, installation depth and material all vary. Consequently, the introduction of any "one size fits all" policy would not be suited to these systems, due to all the different contributing factors influencing each tile drain.

Despite the finding of the unique nature of each tile, the project learnings will be beneficial and applicable to other horticultural regions across New Zealand. The project team encourages monitoring in other regions to confirm findings where the environmental setting (soil type, rainfall pattern, groundwater table height and fluctuation) may differ, as this project has learnt that across the Heretaunga Plains, tile behaviour can differ even down to a site level.

Specific learnings will be outlined in more detail below.

5.1 Benefits of tile drainage systems

As outlined in section 2.1 of this report, tile drainage systems allow for improved crop resilience, due to crops better withstanding flooded and saturated soil conditions, as well as drought conditions.

Drowned root systems growing in anoxic conditions results in significant plant stress and root death. Death of deeper root systems means resilience in drought conditions is also compromised as plants are unable to access deep soil moisture reserves. Consequently, increased grower inputs are required for plant survival and crop production.

Within the 3-year period of this project, above long-term average rainfall was experienced for two seasons, along with a significant flooding event from rainfall during Cyclone Gabrielle. Following the cyclone, New Zealand Apples and Pears, Plant and Food Research, Fruition Horticulture and Agfirst, completed further work into the root system resilience of crops and tolerance to wet feet. This work was adjacent to the What's Coming out of Tile Drains? project and demonstrated the importance tile drains play with plant recovery, health and yield outcome differences very notable between those blocks which had drainage system installations and those without.

Research on Cyclone Gabreille impacts also highlighted the importance of removing excess water regarding Phytophthora management. Phytophthora is a fungus like organism which swims through soil water to infect roots and cause root rot. A variety of crops are susceptible to Phytophthora infection, including all those involved in this Tile Drains monitoring project.

The success of horticultural crops relies on growers getting the first principles correct, including soil drainage, irrigation, frost and hail control, market access and labour capability. Tile drainage installation enhances naturally poorly drained soils, improving productivity and development of this land. Thus, tile drainage systems provide growers reassurance that drainage is not a limiting factor to success, when investing in permanent horticulture production systems such as pipfruit or kiwifruit, or high value crops such as onions.

5.1.1 Economic Benefits

Horticulture and the related processing industry was identified in 2023 as having contributed "$558 million to Hawke's Bay economy, supported 6,868 jobs and generated an estimated $321 million of exports" (Martin Jenkins, 2024).[1] In addition, in MPI's December 2024 Situation and Outlook of the Primary Industries report (SOPI), New Zealand's horticultural export revenue is forecast to reach $8billion in the year to 30th June 2025, driven by kiwifruit and pipfruit sector growth, of which Hawke's Bay is an integral region for these sectors. Improved productivity, ongoing crop resilience and development of new horticultural land is vital to maintaining current productivity and regional economy support, as well as achieving future industry export revenue targets.

As outlined in section 5.1, tile drainage systems improve productivity and resilience of horticultural crops. Using E. Griffiths' *Soils of the Heretaunga Plains; a guide to their management*, approximately 75% of the Heretaunga is classified as having less than "good" natural drainage levels (i.e. moderate, imperfect, poor or very poor). Thus, across the 20,000ha land area on Heretaunga Plains[2] dedicated to horticulture, tile drainage installations (both existing and new) will result in improved crop outcomes for around 15,000ha, contributing economic benefits to the local community, as well as contributing to the export income goals for New Zealand.

As this project has demonstrated that grower on farm management did not correlate to elevated levels of nutrient in tile drainage discharge, horticultural practices of installing tile drainage systems in newly developed blocks and maintaining and utilising existing drainage networks can continue. Marketers can have confidence to continue to tell customers that crops are produced in a sustainable manner on the Heretaunga Plains.

Within the monitoring sites of this project, site K04 is an example of a block with inadequate drainage for its soil type. This site has an imperfectly draining silt loam on clay soil, with a high-water table, and although a clay tile drainage was installed at this site in 1974, the drainage grid pattern is inadequate for the soil type. Thus, during the wet seasons in 2021/2022 and 2022/2023, this site suffered significantly from flooded soils and the kiwifruit crop experienced

[1] Martin Jenkins. (December 2024). *Understanding Opportunities and Challenges for the Hawke's Bay Economy*. Accessed via: https://static1.squarespace.com/static/6705ff37bcaead61a88c1126/t/67bbe039f04d7948fd1390bf/1740365900225/VERSION+6+HBREDA+Low+res.pdf

[2] Hawke's Bay Regional Council (2021) *Hawke's Bay Regional Land Transport Plan.* Accessed via https://www.hbrc.govt.nz/assets/Document-Library/Plans/Regional-Land-Transport-Plan-2021-2031.pdf

poor vine health from drowned root systems, vine mortality, and consequently a loss in productivity and revenue.

This site has 1.6 canopy hectares of Hayward kiwifruit, a crop which over the last four seasons returned an average value of $7.29 per tray orchard gate return (OGR). An estimate of the production actuals and losses because of vine death attributed to wet feet in the 2022, 2023 and 2024 harvest seasons is outlined in Table 3. Prior to the drainage issues, this block was achieving a yield of 6,900 trays per hectare. However, this then dropped to 4,444 trays/ha in 2022, 3,836/ha in 2023 and decreased even further to 1,357/ha in the 2024 season.

This loss of yield potential equates to an OGR value loss of almost $10,000/ha in 2022, $11,000/ha in 2023 and $88,231/ha in 2024, using the relevant returns per tray in each season. The installation of additional tile drainage, alongside ongoing maintenance of the established system, would mitigate the impacts flooded soils had on productivity and therefore the value loss this grower sustained.

Across the Heretaunga Plains, perennial horticulture encompasses 8,143 ha[3]. Extrapolating the returns used in the case study, poor drainage may result in yield losses across the Plains to a value in the range of $10,000 and $88,231 per hectare, suggesting tile drainage could contribute an economic benefit of between $81M and $718M in yield alone. Wider benefits in certainty of production, savings in replant costs, and redevelopment costs are also accrued.

This case study of Site K04 demonstrates the importance of the tile drainage network on those Heretaunga Plains soils with a less than "good" natural drainage classification. The findings from this project also provide reassurance to growers and marketers that under a good management practice framework, horticultural tile drainage systems are not a direct conduit of nutrient discharge, changing negative perceptions of the industries impacts on waterways with this drainage method. Growers can confidently install and improve existing tile drainage networks, to realise the improved productivity and therefore profitability this enables. This then has a positive economic benefit to the Hawke's Bay community.

[3] United Fresh (2024). *Fresh Facts 2024: New Zealand's Fresh Fruit and Vegetable Industry.*

Table 3 Case Study of loss due to inadequate drainage for monitored site K04.

Harvest Season	Canopy Area	Zespri Returns per tray (OGR)	Trays per hectare harvested	Returns/ha	Trays lost from 6,900/ha target	Returns/ha not realised	Comments
2022	1.6	$6.35	4,444	$28,218	2,456	$9,748	
2023	1.6	$5.78	3,836	$22,170	3,064	$11,070	
2024	0.6	$9.55	1,357	$12,956	5,543	$88,231	Canopy area reduced as a result of vine death

5.2 Importance of multiyear datasets

Throughout the three-year project monitoring period, a range of different climatic factors were encountered. This enabled monitoring of the differences in flow patterns of monitored tile drains, as well as the ability to capture data from months with above or below long-term average rainfall. Monitoring also included data capture from the extreme event of Cyclone Gabrielle.

The varying climatic conditions which monitoring captured, reinforces the importance of sampling over a three-year period, to ensure data capture of climatic differences and resulting discharge patterns. Across the monitoring period, there was significant flux within discharge concentrations, alongside unexplained nutrient concentration peaks, troughs and outliers within the dataset, which did not correlate to a farm management practice.

Consequently, a learning from this project is the importance of a monitoring regime which enables visibility of flux, to prevent misrepresentation by over or underreporting outcomes due to single point in time monitoring.

5.3 Grower Engagement and site selection

Grower engagement over a long-term monitoring period and multiple monitoring sites can be challenging, particularly when working with non-owner operators, where management and staffing changes within the business can mean new managers not understanding the project or its participation requirements.

Maintaining motivation and engagement for a project over multiple years was crucial to ensure ongoing data capture and provide continued site access.

Grower participation and therefore monitoring site selection is likely to be biased to those better engaged, and performers, or growers who have a more environmental focus and are motivated to continually improve their performance, as opposed to poor performers. Additionally, all grower participants were operating at Good or Best Management Practice, allowing reconfirmation that these growing within these compliance frameworks provide neutral or positive environmental outcomes.

5.4 Tile Flow Behaviour

Tile drainage flow information was collected both with a recorded visual observation, and continuously monitored through the installation of a flow meter at selected sites. A range of different tile flow behaviours was identified, including permanently flowing tiles, tiles which only flow following a rainfall event over a trigger point, and tiles which rarely flowed.

Identified differences in tile drainage flow behaviour may influence the extent of any environmental impact nutrient discharge may have, dependent on the time of year or regularity of flow.

Tile drain flow recorded for some sites (e.g. A09) significantly exceeds all rainfall and irrigation inputs recorded for the site, confirming that vertical and lateral water movements within the soil profile are linked into tile drainage outflows.

5.4.1 Sampling visit Flow observations

During each monitoring visit, a range of tile flow conditions were encountered and recorded, including whether:

- A sample could be collected in accordance with sampling protocols;
- Tile drains and / or receiving water were dry;
- Tile drain outflow was submerged and a sample could not be collected;
- Tile drain outflow was insufficient for a representative sample to be collected, but not completely dry; or
- Access is compromised and personnel cannot safely access the monitoring point.

Figure 2 shows that across all sampling runs, 45% of all tile drain exits were classified as dry, 26% were classified as "sample taken" meaning the tile was flowing, and 4% were classified as "dripping", meaning there the flow was insufficient for a sample to be taken, but was not completely dry.

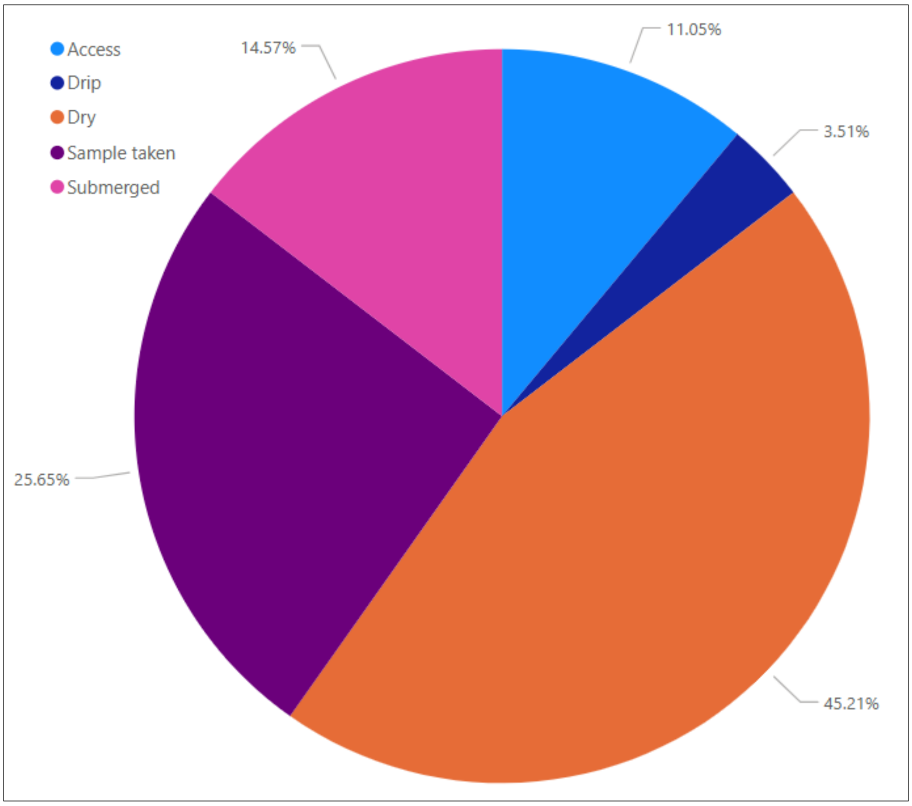

Figure 2 Visual observation of tile drain flow behaviour, for all tile drain samples taken across all sites.

Understanding that some tile exits are often dry and not flowing, while others may flow continuously is a significant finding for the project. When tiles are not flowing, they are not contributing nutrient loading through discharge into the receiving water body. This finding suggests timings of discharges can play an important role in risk mitigation of total catchment loadings.

5.4.2 Flow meter observations

At the start of year two monitoring, flow meters were installed on the tile exits of selected sites, for further quantification of flow behaviour and to incorporate a continuous monitoring element into the project.

Massey University assisted with the design, installation and ongoing maintenance of the equipment (Figures 2 and 3), creating an app to download the SD card data, and transform the text files into tile flow graphs (Figure 4).

This data allowed a more granular comparison of tile drainage flow behaviour within and between sites, and assessment of base flow, response to rainfall, peak flow and dry periods. This also reinforced the finding of the range in tile drainage flow behaviours from Year 1 monitoring.

In the instance where the receiving water submerges the tile exit, the flow meters provided visibility of the tile exit flow behaviour, in a situation where otherwise no data could be collected. Additionally, the continuous flow monitoring element helped with reaffirming or contradicting flow observation data, and improved flow visibility of drier tiles where there might be a short period of fast flow that has gone by the time of the monitoring visit, or whether in fact they are dry tiles with little to no flow.

Flow meter data showed that from installation in spring 2022, generally all metered tiles flowed more regularly throughout the Year 2 monitoring period (spring 2022 to winter 2023), and most tiles had lesser flow, or periods of no flow throughout the Year 3 monitoring period (spring 2023 to date).

5.4.3 Four categories of Tile flow behaviour

Following flow observations, AgFirst categorised the tile flow behaviour into the four different categories evident across monitoring sites:

- Dry, or very few flow events recorded during our sampling runs;
- Event- Only show flow following a rainfall event of over 15mm;
- Seasonal- Flow during Spring, Autumn and Winter, but are summer dry; and,
- Continuous Flow- Regular, continuous flow recorded.

Soil moisture monitoring using a Diviner 2000 probe was undertaken across all sites, measuring soil moisture relative to full point from surface to 700mm at all sites. These readings demonstrated that continuous flow tiles were dominated by upwelling or lateral movement of water at depths below 700mm while event tiles in particular, relied on sufficient rainfall to recharge the soil profile above full point. Seasonal flow tiles represent a combination of these relationships while dry tiles require further determination on water movements.

The graphs in figure 5 illustrate a range of flow behaviours evident across selected sites.

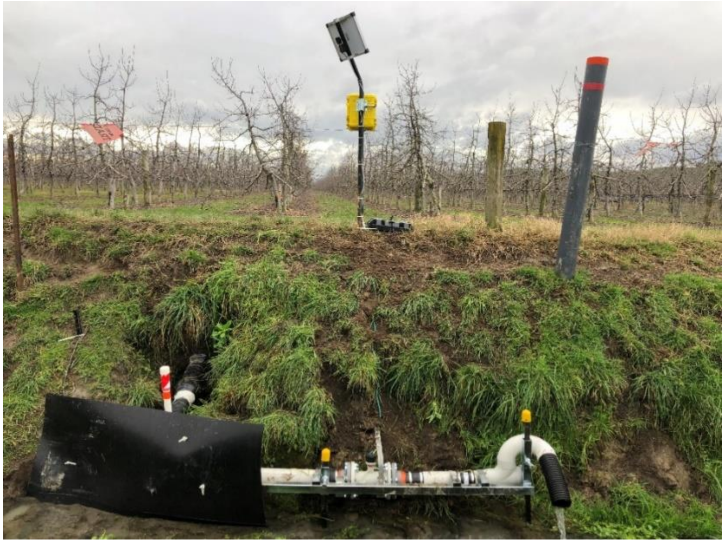

Figure 3: Tile drainage flow meter equipment, installed at a monitoring site, allowing for continuous flow data capture

Figure 4: Installed tile drainage flow meters enabled flow data capture on sites where the receiving water body regularly submerged the tile exit, therefore inhibiting manual flow data collection during monitoring runs. This allowed more regular data capture at these sites.

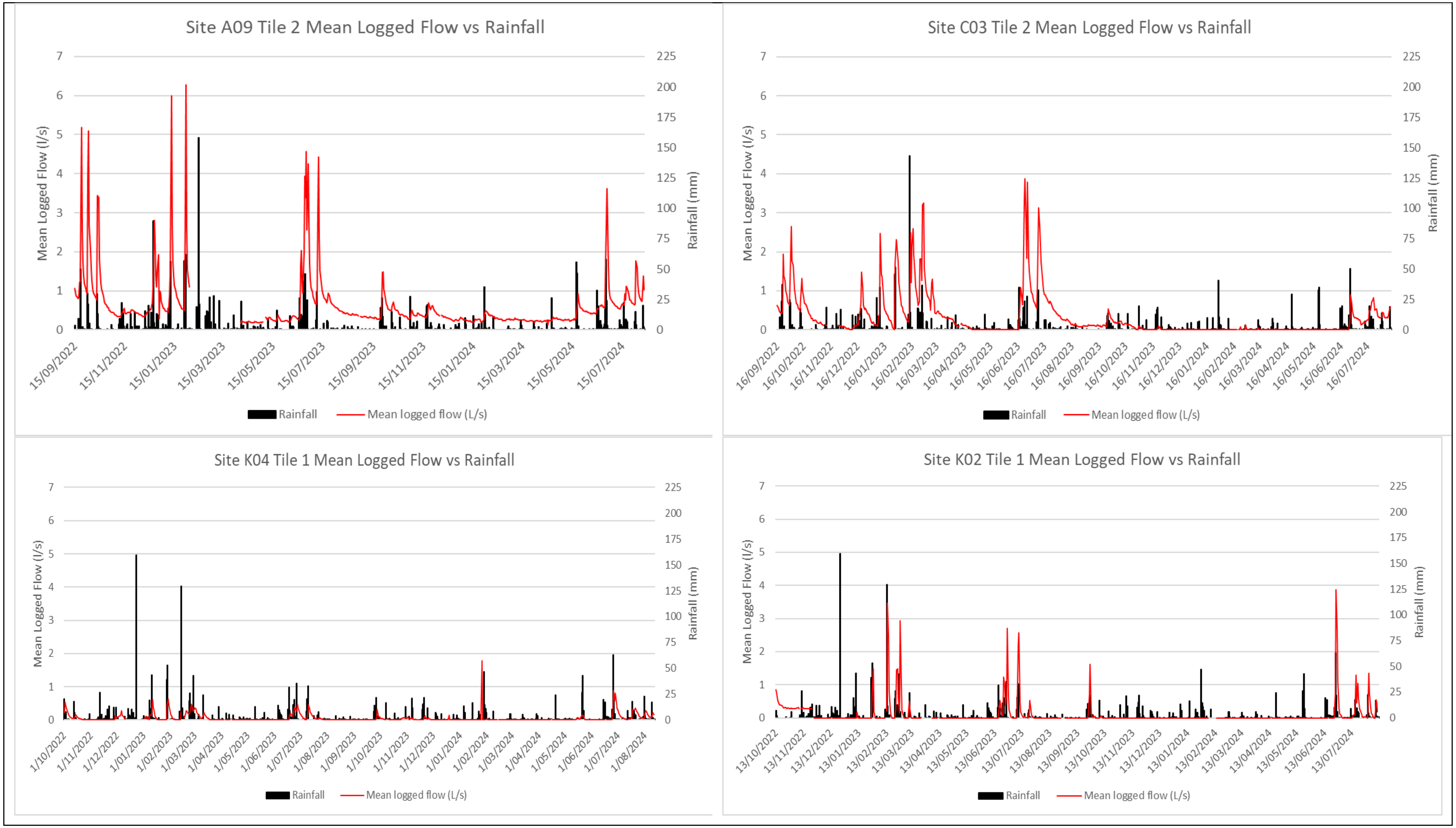

Figure 5: Tile drainage flow graphs from sites A09 Tile 2, C03 Tile 2, K04 Tile 1 and K02 Tile 1, illustrating the range of mean logged flow registered by the flow meter equipment installations, against rainfall from that site.

5.4.4 Groundwater Linkages

Tile drains within sites A09, C04, and K03 were all identified as having continuously flowing tiles regardless of climatic conditions, suggesting that either upwelling, horizontal water movement, or a shallow perched groundwater table was present and dominating the tile drainage flow relationship. Assessment of the groundwater nutrient profiles was undertaken from the installed irrigation bores within these three sites to compare the nutrient profiles between tile drainage and underlying irrigation water.

Farm A09 presented the closest nutrient profile match of groundwater to tile drain discharge, with identical or close matches for all field assessment parameters and three of the Nitrogen species (Ammoniacal Nitrogen, Nitrite Nitrogen and total Kjedahl Nitrogen), however large variations in DRP and Total P were evident. The comparisons confirm that upwelling is highly unlikely to be the contributing factor to tile drainage flow at Farm A09, and that more complex lateral movements are occurring.

Both C04 and K03 presented poor nutrient match comparisons when assessed against the groundwater wells on site again confirming upwelling is not the dominant hydrological relationship and suggests lateral water movement within the sphere of influence of the tile drain is driving flow. The proximity of C04 to coastal conditions also suggests that tidal fluctuations could also be influencing the patterns observed.

5.5 Nutrient and Water Quality Data

All data series collected underwent statistical assessment in accordance with the Project Sample and Analysis Plan (SAP), dated 08 July 2024. Statistical Assessment completed included:

- Mean
- Median
- Range
- 95^{th} Percentile (Hazen Method)
- 95% Upper Confidence Limit[4] (UCL) for:
    - Nitrate Nitrogen
    - Nitrite Nitrogen
    - Ammoniacal Nitrogen
    - Dissolved Inorganic Nitrogen (calculated)
    - Total Nitrogen;
    - Dissolved Reactive Phosphorous; and
    - Total Phosphorous.

To determine what these statistical parameters show in the context of the project objectives, statistical data have been evaluated as follows:

[4] Processing of 95% Upper Confidence Limits completed using the United States of America Environmental Protection Agency (US EPA) software package Pro-UCL and will include Shapiro-Wilk Normality tests to determine whether data series are normally distributed.

- Base run grab sample data collected for all monitoring locations across the life of the project have been processed to compare tile drain series results to the corresponding receiving water series results;
- Event series grab sample data collected for all monitoring locations across the life of the project have been processed to compare tile drain series results to the corresponding receiving water series results;
- Proportional water sample[5] data collected for the 8 monitoring locations following equipment installation have been processed to compare tile drain results to the corresponding receiving water series results;
- Base, event, and proportional data have been assessed spatially within sub-catchments to identify whether any downstream trends are evident;
- Apple, kiwifruit, and cropping production systems have been evaluated to determine any specific trends within and between systems;
- Land management actions have been assessed against tile drainage results;
- Base, Event, & Proportional data series have been evaluated against climatic and soil data;
- Base, Event, & Proportional data series have been evaluated against Regional and National Water Quality Objectives;
- All data has been evaluated at individual farm scale; and
- Potential losses have been modelled through OverseerFM and compared against Base data.

5.5.1 Data completeness

Data collected under this project has produced a completeness level of 86.6%, split into:

- 88% Apples;
- 87.9% Kiwifruit;
- 83.2% cropping.

While a completeness goal of 90% useable data was sought for the three-year data series, access constraints represented the biggest obstacle in meeting this threshold. This included block spraying during sampling time, flooded tracks and unsafe drain edges particularly during monitoring in winter, but also as a result of Cyclone Gabrielle. These issues were unavoidable as the safety of personnel is paramount, and no alternative options were available that would have addressed this issue. Further details on data completeness are included in the Project Sample and Analysis Plan, available upon request from AgFirst.

A high degree of completeness has been obtained, and the level of completeness is considered robust for the assessments made.

5.5.2 Distribution

Statistical assessment of Base, Event, & Proportional data series for both tile drainage and receiving waters did not identify any discernible distribution. Assessment confirmed data was not normal at 1% significance level. Consequently, 95% UCL assessment has been completed using non-parametric parameters.

[5] Refer to limitations section regarding robustness of Proportional Data Series.

5.5.3 Base Run Series

Statistical analysis of Base Run data identifies:

- Data ranges within the Base Run series show a high degree of variation between individual sample results;
- Apart from Dissolved Reactive Phosphorous and Total Phosphorous, nutrient concentrations in tile discharges are lower than the receiving water environments, ranging from 1.5 to five times lower at mean values and up to 15 times lower at 95th percentile;
- Mean values of Tile Drains discharges meet the NPS Attribute A threshold for Ammoniacal Nitrogen and Nitrate with 95th percentile values within Attribute B;
- DRP and Total P concentrations were generally high, exceeding the Attribute D and ANZECC thresholds respectively;
- No discernible correlation over time, against climatic event, or against land use actions is present for any nutrient parameters;
- A cyclical seasonal change in temperature and Dissolved Oxygen is observed as a result of climatic influence;

5.5.4 Event Run Series

Statistical analysis of Event Run data identifies consistent findings with Base Run data when compared against receiving waters including:

- Data ranges within the series show a high degree of variation between individual sample results;
- Tile discharge concentrations were lower than the receiving water environments, including for DRP;
- DRP and Total P concentrations were above the NPS Attribute D Band and ANZECC Trigger levels in both tile and receiving flows;
- Mean values for Nitrate and ammonia within Tile Drains discharges meet the NPS Attribute A & B thresholds, however 95th percentile values decrease attribute states;
- No discernible correlation over time is present for any nutrient parameters; and
- A cyclical change in temperature and Dissolved Oxygen is observed as a result of climatic influence;

5.5.5 Proportional Series

Statistical analysis of Proportional Series data identifies contrasting results to the base and event grab samples, including:

- Tile discharges generally had lower DRP and Total P concentrations than receiving environment samples;
- Proportional samples have elevated Total Nitrogen, Nitrate, and Dissolved Inorganic Nitrogen levels compared to Base and Event Run receiving water;
- Sample temperature of Proportional Tile samples is closer to receiving water values than Base and Event tile flows; and
- Total suspended solids values within proportional samples are higher than the Base run results, but lower than Event discharges.

Analytical results from the proportional data series must be considered in light of the limitations set out in Section 5.10.

5.5.6 Base, Event, & Proportional Sample Comparison

When compared against the Base Run data series, Event Run data reveals:

- Limited differences in Temperature, pH, Dissolved Oxygen and conductivity statistical results;
- Increased E.Coli values for mean, median, and range occur during Event run sampling, however insufficient data is available for 95th percentile comparisons;
- Total Suspended Solid mean values reduce during events, however range and 95th percentile values remain consistent within tile flows;
- Discernible increases in Nitrate-Nitrogen, Total Nitrogen and Dissolved Inorganic Nitrogen are observed within Event run tile flows compared to base run data, however event run tile flows remain lower than Event run receiving water;
- While mean DRP concentrations are unchanged, an increase in the range is observed alongside a significant reduction in the 95th percentile values; and
- Mean values of total phosphate increase within the Event Run data series compared to Base run, alongside an increase in the range, however 95th percentile values decrease significantly.

When compared against the Base & Event Run data series, the Proportional Data Series Reveals:

- Higher levels of Nitrogen are present within the Proportional samples when assessed as mean and Hazen 95th percentile values;
- Maximum values of Total Nitrogen and Nitrate are similar across all three data series;
- Proportional samples had notably higher maximum values for Ammoniacal Nitrogen, Nitrite-Nitrogen and Total Kjeldahl Nitrogen, ranging from 2 to 4 times greater those recorded in base and event samples;
- 95th percentile total suspended solids was markedly increased within Proportional samples;
- DRP and Total P were notably reduced in Proportional sample mean and 95th percentile values. Maximum (and therefore range) of DRP and Total P is also notably reduced;
- Sample temperatures are elevated with a 95th percentile of 19.435 °C recorded in comparison to 17.9 °C within Base run and 17.92 °C within Event run samples; and
- pH values are close in value between Proportional, Base, & Event run samples.

Limitations within the proportional series data are set out in Section 5.10 below.

5.5.7 Spatial Assessment

Within the project, three sets of farms are located within the same reaches of drains and waterways. Within these three systems, spatial assessment is able to be made on two of the three groupings within K03, A09 and A04 located within one and A01 and K04 located within one. AgFirst notes C01 and K01 are also located within one sub catchment but the prevalence of dry tiles within these systems makes meaningful comparison impossible.

With respect to Farms K03, A09, and A04 these flow from upstream (K03) to downstream (A04) providing an upper and mid value, however as A04 comprises predominantly dry tiles, no lower value is available. Assessment of data between these two sites reveals:

- Higher nutrient loadings are present within K03 compared to A09 lower in the catchment with total Nitrogen, DRP and Total P, Nitrate-Nitrogen and Dissolved Inorganic Nitrogen all approximately twice the values in K03 compared to A09 despite being higher in the catchment;
- Temperature values from A09 are 1.2 degrees lower at the 95th percentile while dissolved oxygen is almost identical;
- Ammoniacal-Nitrogen and Nitrite-Nitrogen values are both very low, with limited significant differences present between the sites; and
- Total suspended solids within A09 flows are 4 times lower than K03 at the 95th percentile;

The remaining pair of farms, A01 and K04 provide an upper and lower comparison. Assessment of data between these two sites reveals:

- Mean values for all nutrient parameters show limited difference. Dissolved reactive phosphorous and total phosphorous have a greater difference, with K04 presenting lower values for both these parameters; and
- K04 also exhibits a much greater range for all parameters assessed and this is reflected in the 95th percentile values for K04 exceeding A01 for all nutrients assessed except for Nitrite-Nitrogen;

5.5.8 Production System Evaluation

Analysis of Base Run, Event Run and Proportional data series for the three different production systems has identified:

- Limited differences in pH, temperature, and dissolved oxygen are present between systems;
- Conductivity is notably higher within cropping tile discharges, but this is likely a result of tidal influences and locational constraints;
- Apples & kiwifruit systems assessed have lower tile drain Nitrogen discharges than cropping systems;
- Kiwifruit tiles have the lowest N discharges, however the dry nature of tiles within two of the four kiwifruit blocks will have contributed to skewed statistical assessment; and
- Cropping systems generally have a greater range recorded within the tiles and receiving water series compared to apples and kiwifruit;

5.5.9 Land Management Evaluations

Evaluation of land management practices identified a range of actions being undertaken within the different production systems including fertiliser application, cultivation, harvest, root ripping and irrigation. Assessment of management actions identified:

- Within apple production systems, three sites applied phosphorous fertiliser applications throughout the three-year data period while 6 sites did not. Insufficient data is available for two of these systems due to dry tiles, however evaluation of the remaining shows that all five apple systems that did not apply any phosphorous fertilisers have higher DRP values at the 95th percentile than the system that did apply DRP;

- Comparison assessment of Total Suspended Solids (TSS) 95th percentile values and 95th percentile DRP values at a Farm scale identifies that the farm with the lowest DRP value has a TSS value in the middle of the range of TSS values recorded. This suggests DRP issues are not directly associated with sediment loss;
- Peak discharges of nutrients recorded do not correlate in timing to farm management actions. In example, the highest peak discharge of DRP at Farm A01 occurred on 27 July 2022, which does not correlate to any known management action recorded, with fertiliser applied in November 2023 and the next action recorded being harvest in late March. Similarly, the highest Nitrate-Nitrogen peak for Farm A01 was recorded 08 March 2023, with the only corresponding farm actions being harvest of the crop during this time;
- Physical augmentation actions (ripping, cultivation & harrowing) have not provided a clear action for peak discharge of Nitrogen in any of the farming systems. For example, Farm C04 routinely rips and harrows in October and March, however the highest Nitrate-Nitrogen discharge occurs in August and the highest DRP occurs in late November;

5.5.10 Climatic & Soil Influences

Assessment of climate and soil data associated with the monitored sites reveals:

- Peak discharge events do not directly correlate with rainfall events. For example, the peak Nitrate-Nitrogen concentration in Farm A01 tile drainage identified above on 08 March 2023 occurred during a period of no rainfall and within base monitoring event. In contrast, peak Nitrate discharge in A09 occurred on 26 June 2023 during a rainfall event where 35.3mm of rain was recorded. However, on 17 June 2023, rainfall of 31.8mm was recorded, however no corresponding peak discharge was identified. As similar patterns occur in all monitored farms, no significant correlation in rainfall and peak discharge is present within the data series;
- Climatic cycles have been captured within the 3 year data series for average and above average rainfall events alongside a period of extended dry conditions. Any influence these have had on tile discharges does not show in correlations assessed; and
- A variety of drainage and soil types are encompassed within the monitoring programme, however no clear correlations are noted as to the influences on nutrient discharges.

5.5.11 Regional and National Water Quality Thresholds

With respect to water quality guidelines, assessment of results has identified:

- All Nitrite-Nitrogen concentrations are compliant with the Drinking Water Standards as an appropriately conservative threshold;
- 95th percentile values for Tile Drain Ammoniacal Nitrogen within the Base Run series meet the Attribute B thresholds of the NPS FW, however Event and Proportional are within Attribute C criteria. Receiving water is within the Attribute C band;
- 95th percentile values for Tile Drain Nitrate-Nitrogen within the Base Run series are within the Attribute B band while Event falls within the Attribute C band and Proportional within the Attribute D band. Receiving waters are within Attribute C band;
- All three Tile Drain data series exceed the DIN threshold for lowland tributaries within the ANZECC Guidelines, however receiving water 95th percentile values are approximately 25% more than tile drainage values; and

- DRP values all fall within the Attribute D band.

5.5.12 Farm Scale Evaluation

When evaluating data from the 17 farms that were selected to participate in this trial, the following key learnings have been identified:

- Conditions within Farms A04, A05, A08, C01, C02, K01 and K02 did not provide enough data to be able to undertake individual statistical assessment in accordance with the Sample and Analysis Plan;
- Average tile flow temperatures between all farms are close in value, ranging from 14.09 to 15.1 °C;
- Average Ammoniacal Nitrogen values at the farm scale comply with the Attribute A levels in all but one site which is within the Attribute B scale;
- Farm scale DRP values are variable, ranging from Attribute B to Attribute D;
- At the farm scale, all but one site complies with the Attribute A levels for mean Nitrate-Nitrogen;
- Dissolved inorganic Nitrogen mean levels are variable at the farm scale, ranging from 0.059 to 2.76 mg/L;
- Assessed using the Hazen 95th percentile values:
    - 3 sites are within the Attribute B band for Ammoniacal Nitrogen with all remaining sites within the Attribute A;
    - 1 site is within the Attribute A Band and 1 Site is within the Attribute B band while all remaining sites are within the Attribute D band for DRP;
    - 2 sites meet the lowland tributary threshold for dissolved inorganic Nitrogen band while all remaining exceed this threshold;
    - No individual farm had sufficient data for assessing E.Coli using the Hazen method; and
- The range of data recorded across all parameters is high (e.g. 20.2 mg/L for Nitrate-Nitrogen & DIN, 34 mg/L for phosphate, 32 mg/L for DRP) and this significant variability is contributing to the 95th percentile values exceeding the water quality thresholds. Further work is needed to:
    - evaluate whether these outliers are true and correct data points; and
    - determine what generates these high levels of variability and what mechanisms can be employed to reduce their occurrences.

5.5.13 Overseer Nutrient Loss Modelling

As a mechanism to investigate whether modelled nutrient losses from the OverseerFM farm modelling system correlate with assessed tile drainage values, AgFirst set up three modelled farms under OverseerFM for A09, C04, and K03 using the specific collected farm data for the 2021 – 2022 and 2022 – 2023 seasons. Modelling identified:

- A range of potential Nitrogen (N) and Phosphorous (P) losses within the three farming systems with N surplus ranging from 88kg/ha/yr in C04, to -13 kg/ha/yr in K03;
- Modelled total N in drainage of 2, 7, and 2 mg/L was calculated for Farms A09, C04, and K03 respectively;
- Comparison of modelled N in drainage values against the Hazen 95th percentile values correlated to 54%, 56.9%, and 145.3% of the OverseerFM modelled values, identifying that significant dilution is occurring within two of the systems between the recorded

drainage output position and the modelled N loss below the root system. It is unclear why OverseerFM has underestimated K03;

- A significant dilution factor was expected as it has been identified in work completed by Clothier & Green in 2016 where up to 90% dilution of N was recorded underneath vineyards within Marlborough, alongside a lag time of 185 days for Nitrogen leaching from the rootzone into shallow groundwater; and
- As OverseerFM does not provide a modelled P in drainage, a direct comparison could not be made. AgFirst notes that Overseer models an expected loss of 0.3 and 0.4 kg/ha of P for all farming systems and that this value does not alter significantly regardless of the amount of fertilise input into the system, suggesting dynamic processes are at play. Further work is required to compare the DRP concentrations with modelled total P losses.

5.5.14 Rainfall Water Quality

Assessment of the nutrient profile within rainwater was undertaken in Spring 2023 and Summer 2024 to explore what additional influences may be linked to tile drain out flows due to the lack of discernible correlations at completion of assessment of the Year 2 data series. Four sampling events of rainwater were undertaken, identifying:

- Rainfall is contributing Nitrogen loading into the systems with Ammoniacal Nitrogen being the dominant Nitrogen species measured within rainfall;
- When assessed as Dissolved Inorganic Nitrogen, rainfall concentrations provide between 32% and 70% of the ANZECC threshold (0.444 mg/L) for receiving waters in Hawke's Bay.

Currently, rainfall is not accounted for within nutrient budgets and its contribution will further increase the dynamics of the Nitrogen cycle.

5.6 Soil Quality Assessment

Annual soil sampling has been undertaken across each tile as part of the project. Assessment of soil quality data captured a range in nutrient states and conditions and reveals:

- Nutrients are variable across the sites with data ranges of 83 µg/mL for Olsen P and 204 mg/kg of potentially mineralizable N;
- Base Saturation values ranged from 65.2% to 98.3%;
- Calcium base saturation ranged from 46.3 to 87.1%;
- Organic matter ranged from 1.9% to 11.9%
- Total Carbon ranged from 1.11 to 6.9%;
- Cation exchange capacity ranges from 8 to 34 me/100g with an average of 15.01 me/100g;
- The highest Olsen-P value recorded was 92 µg/mL, however this represents a site with dry tile conditions. The second highest value is 87 µg/mL which represents a site where the Hazen 95th percentile value is in the middle of the range of values recorded; and
- The maximum potentially mineralizable Nitrogen value similarly represents a site with dry tiles. When comparing these values against the site with the highest Nitrate-Nitrogen and DIN values recorded in tile drainage, potentially mineralizable Nitrogen

recorded is less than half the maximum values recorded in other sites with lower tile drainage Nitrate-Nitrogen and DIN.

5.7 Regression Assessments

Data assessment has not identified any clear correlations for on farm actions and associated discharges. Focussing on Nitrate and DRP as the two key contaminants of concern, regression analysis notes:

- No clear relationship between DRP mean and 95th percentile concentrations in Tile Drains and Olsen-P concentrations in soil (e.g. Base run R^2 = 0.008);
- Analysis of mean and 95th percentile DRP concentrations against mean and 95th percentile TSS values does not provide a significant correlation (e.g. 95th percentile Base run R2 = 0.076)
- Assessment of total phosphorous application across the full 3 years (kg/ha) against Tile Drain DRP concentrations shows a potentially significant correlation (R^2 = 0.91), this value however is skewed by one single farming system. When this one farm is removed, the R^2 value drops to 0.04. Similarly, when phosphorous applications are assessed as kg/ha per year, the R^2 value is <0.1. It is noted that this site is also influence by outlier data (discussed in Section 5.10 below), further limiting the robustness of this potential correlation;
- Assessment of total Nitrogen application (kg/ha & Total kg) against mean and 95th percentile DIN and Nitrate Tile Drain values does not identify any significant correlation (R^2's of 0.03 and 0.02 respectively);
- No correlation between Tile Drain DRP concentrations and total base saturation or Cation Exchange Capacity exists (R^2 values of 0.065 and 0.064 respectively); and
- A weak correlation between mineralizable N (kg/ha) and Tile Drain Nitrate concentrations is observed (R^2 = 0.267).

5.8 Grower Farm Environmental Plans and Good Management Practices

Prior to the commencement of monitoring, all grower participants completed the NZGAP EMS add-on, to provide a baseline of compliance. All grower participants were operating at Good Management Practice (GMP) and majority were operating at Best Management Practice (BMP).

NZGAP is an assurance programme within which growers are certified as operating within a safe and sustainable set of practices in the areas of food safety, environment and social practice. GMPs are defined under a standardised framework within NZGAP, which align with regulatory standards and market requirements.

Therefore, an important project finding, is that there is no correlation between growers who are operating at GMP and farm practices contributing to an elevated level of nutrient discharge. Additionally, as all findings reported in this project were from monitored sites operated at GMP level or above, growers are reminded that they should continue to operate at GMP level and stay updated with any changes to this framework as best practice.

This is encouraging information for grower participants and stakeholders, as growers can continue to operate at GMP, with reassurance that for nutrient and irrigation management decision-making, this an appropriate mitigation for lowering overall catchment loadings. The recorded elevations of nutrient flow still warrant further investigation to clarify their relationship and causations.

5.9 Mitigation

An initial project objective was to consider what mitigation options could be implemented to improve sustainability and water quality within these systems should water quality monitoring data identify mitigation is necessary.

Following considerable research involving literature reviews, consultation with science advisors, grower participants and the governance group regarding potential mitigation concepts, an important learning for this project is that edge-of-field and land based 'mitigation options' to the monitored sites have various limitations to their applicability and suitability.

Within the mitigation option research process, grower participants surveyed discussed their readiness to make changes, should these be proven to have positive impact. However, growers also reiterated that current NZGAP and GLOBALGAP practices around nutrient and water usage on farm/orchard, require nutrient impact mitigation measures already, such as applications of fertiliser based on a nutrient budget, and informed by soil and leaf testing and crop requirements, split fertiliser applications and weather monitoring.

Evaluation of a range of land based and edge of field mitigation options was undertaken to determine the feasibility of these schemes within permanent horticultural enterprise. It was noted that these options are not feasible within the HBRC Drainage Network and considerable assessment of flood displacement risk would be needed. Additionally, data collected did not identify any significant correlation of any on farm actions to measured water quality outcomes, reinforcing that GMP and BMP measures represents suitable farm scale mitigation measures for reducing catchment loading.

This study has shown that interconnected groundwater aquifer systems, surface run off, and water movement, alongside soil type differences in drainage capability and parent material, all influence water quality outcomes. Therefore, catchment scale mitigations operating in conjunction with GMP and BMP measures appear the most likely opportunity for significant, measurable improvements in water quality. Mitigation measures need to be applied throughout the whole catchment headwaters to the coastal receiving waterbody. As drains act as a conduit, these are considered an important opportunity to mitigate contaminants before they enter more ecologically significant water bodies and further work to overcome barriers with their primary flood mitigation function to enable treatment is an important pathway to improved water quality.

As an alternative mitigation option, instead of treating the point source discharge at the exit point, or changing grower input practice, we investigated the potential to alter the drainage media surrounding the tile. Benchtop assessment confirmed fine lime chip as a viable option and generated a significant relative percentage reduction in DRP concentrations. Based on the benchtop assessment, options are being considered to undertake a full field scale trial.

5.10 Limitations, Issues, and Potential for Bias

In evaluating the performance of this project and associated learnings, AgFirst notes the following identified limitations, issues, and potential bias:

- Assessing tile drain discharges against the National Policy Statement for Freshwater Management 2020 (NPS Freshwater, updated February 2023) and associated wider guideline values provides catchment context only. The NPS recommends that a minimum of a monthly monitoring regime be undertaken for 5 years for grading water quality. This SFFF project only encompasses three years of tile drains and receiving water monitoring at the study farms;
- Willingness of growers to participate in the project lends itself to higher performing and early adopter candidates. This is confirmed through the GMP & BMP assessment where limited change to grower practices was required to bring operations into GMP and BMP.
- Wider research within the water quality sphere (notably the *Linking Legacies to Wai)* project identified an average lag time between land use change and increased Nitrate loading of 4.5 years. As a result, any changes in land management such as fertiliser application practices, induced by project participation are unlikely to be revealed within tile drainage water quality data as this project only encompasses 3 years;
- Tile drain outlets are an open conduit and readily inundated during weather events. As a result, E.coli levels should be considered carefully as the potential for cross contamination cannot be avoided;
- Proportional sampling methodologies do not meet the accredited withholding times for analysis and as a result do not meet QA/QC requirements. While recommendations from the laboratory were followed, no accreditation is provided;
- Proportional sampling equipment was regularly inundated and flooded, requiring repeated flushing for generating samples. A risk of cross contamination of the proportional samples is also present due to this;
- Proportional sample results show notable differences to grab sampling and in light of variability, lack of accreditation and potential cross contamination, further assessment on the significance of these differences is required;
- Saltwater intrusion into tiles has been identified within at least one location and the variability of these results has likely skewed the data series; and
- Notable outliers are present within the data collected and these will also have skewed the statistical assessment. For example, we have a sample recording a Total Nitrogen value of 6.8 mg/L but recorded Nitrate and DIN of 20.2 mg/L. When queried with the laboratory, they have noted QA/QC processes have passed for sample analysis and cannot provide any additional insight into these data values, suggesting they are erroneous.

6.0 EXTENSION ACTIVITIES UNDERTAKEN

Project extension has been completed throughout the lifetime of the project, in a range of ways to capture a broad audience with representation from each targeted group. Extension activities undertaken include:

- Presentations
  - In person and virtual
  - With smaller groups or people such as workshops as well as with larger groups at conferences
  - Inclusion of iwi groups, students, growers, policy providers, industry services etc.
- Short Videos
  - These have been distributed through AgFirst New Zealand's YouTube, Facebook and LinkedIn, and are available for public viewing.
- Discussion/Q&A Panels
- Meetings
- Email enquiries
- Short form articles in "In Brief" e-newsletter
- Manuscript and published abstract
- Magazine articles
- Newspaper article
- Report distribution
- Conversations
- Webinar discussion of learnings.

A full extension log has been maintained throughout the project, and extension within each milestone has been reported.

Extension has been focused both on nutrient quality findings, but also what tile drainage systems are, how we have undertaken monitoring, their role in crop resilience, and findings of the different flow characteristics.

7.0 FURTHER LEARNING AVENUES IDENTIFIED

There was little research available on tile drainage under horticultural systems in New Zealand at the genesis of this project. KE Deuss confirms this in their 2022 thesis, stating that there are "significant gaps in our understanding of the hydroclimatic drivers of runoff and deep drainage responses, especially in mole and tile-drained soils with fragipans. Quantification of water flow pathways has been identified as a major challenge…. therefore, one of the major limitations in understanding contaminant fluxes from agricultural landscapes[6]". There is significant lateral and vertical movement of water across the Heretaunga Plains, with the dynamic water system of rainfall, river flows, groundwater and aquifer systems, influencing both tile drainage flow behaviours, and discharge concentrations. Deuss (2022) notes that tile drainage systems exist in a "hydrologically sensitive landscape that demonstrates a highly non-linear response to

[6] KE Duess. 2022. *A study of the soil pattern, properties and hydrology of a mole and tile-drained, loess-mantled downland in Southland, New Zealand [Doctoral Thesis, Lincoln University]. Accessed via file:///C:/Users/User/Downloads/Deuss_PhD%20(1).pdf*

variations in precipitation intensity"[7]. These findings reinforce the different flow behaviours observed and measured across the monitored sites of this project. Additionally, as this project found elevated nutrient concentrations in tile drain discharge did not correlate to grower inputs, there may be a catchment wide influence on the tile drainage discharge nutrient concentrations, with mitigation likely to require a catchment wide approach. Thus, quantification of the different flow behaviours of the tile drainage systems across the Heretaunga Plains, would be beneficial to assist with further understanding of hydrology patterns, catchment implications, and environmental outcomes given the adverse effects of cumulative loading.

This project has found grower on farm management to not correlate to elevated levels of nutrient in tile drainage levels. This aligns with findings from the Plant and Food Research led SFFF20122 project *Future orchard planting systems*, where nitrogen leaching concentrations from the planar cordon and tall spindle pipfruit growing systems was "extremely low"[8].
However, there are elevated levels of nutrient which have been found throughout the monitoring period, thus investigation into the origin of these would be an important future learning avenue. Of particular interest is the elevated levels of dissolved reactive Phosphorus and total Phosphorus, which were found at sites where Phosphorus applications had not taken place, soil Phosphorus levels were not unusually elevated, and total suspended solids within the samples were within an acceptable range. Test pits were dug to determine whether volcanic deposition or volcanically derived soils may be the contributing factor of elevated levels at a particular monitoring site. However, Olsen-P concentrations were found to rapidly attenuate to be within the expected medium range for subsoils, and therefore other factors are more likely to be contributing to the elevated DRP concentrations in tile drainage discharge.

A field scale trial of alternate drainage media is considered a good option for positively contributing to water quality at a catchment scale where DRP is elevated. Regardless of the sources of DRP, this would assist in lowering DRP loadings, and when coupled with other environmental enhancement methods (i.e. riparian planting, wetlands, and harvestable plants) that could provide overarching benefits.

[7] KE Duess. 2022. *A study of the soil pattern, properties and hydrology of a mole and tile-drained, loess-mantled downland in Southland, New Zealand [Doctoral Thesis, Lincoln University]. Accessed via file:///C:/Users/User/Downloads/Deuss_PhD%20(1).pdf*

[8] Plant and Food Research. 2024. *Future orchard planting systems: to double productivity, improve environmental outcomes and transform labour practices – progress report December 2024.*

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