Appendix C

Process wastewater nutrient memorandum

TECHNICAL MEMORANDUM

INVESTIGATION	Nutrient Balance Model Summary	**PROJECT**	Takapau Plant Wastewater Irrigation Consenting
CLIENT	**Silver Fern Farms Management Limited**	**PROJECT NO**	A02164500
		PREPARED BY	Alana Bowmar and Daryl Irvine
		SIGNATURE	FINAL
		DATE	19 June 2018

Introduction

This technical memorandum has been prepared by Pattle Delamore Partners Limited (PDP) on behalf of Silver Fern Farms Management Limited (Silver Fern Farms) to summarise the investigations into the existing wastewater irrigation to land system at the Silver Fern Farms Takapau Plant. All wastewater generated from the Takapau plant, including Animal Assembly, Primary Butchery, Secondary Butchery and other processing areas is treated in a non-chemical Dissolved Air Flotation (DAF) treatment device and then irrigated to company owned land surrounding the plant. Irrigation of process wastewater is conducted under Resource Consent DP981043Ld & DP981044Ad, issued by Hawkes Bay Regional Council, which is due to expire on 31 December 2018. PDP has been engaged by Silver Fern Farms to assist with applying for a replacement consent and as part of the consent application process, PDP has conducted a review of the existing process wastewater irrigation system.

The assessment of the process wastewater irrigation system includes:

- A visual assessment of the soil conditions within the irrigation areas;
- An assessment of soil monitoring;
- An assessment of soil permeability;
- A nutrient model of the land holdings system, utilising the Overseer Nutrient Modelling programme.

Irrigation System Description

The wastewater irrigation system consists of 218 ha of irrigable area, which is utilised for cut and carry of pasture or lucerne as silage or hay. The irrigation blocks are divided into 5 main blocks, being Blocks A, B, C, D and E. The land holdings also consist of Blocks F, G, S1 and S2 which are utilised for disposal of stock yards solids. This soils assessment is focussed on the wastewater irrigation block only.

Several different soil types are identified by Landcare's S-map online soil database within the wastewater irrigation areas; however, many of these soil types are relatively similar. The process wastewater irrigation blocks can be categorised into two main soil order and drainage characteristic, being:

- Well to moderately well drained: Allophanic and Orthic Brown soils (Blocks A, B, C, D and part of E)
- Poorly drained: Perch-gley Pallic soils (part of Block E)

Wastewater is preferentially irrigated to the moderately well drained and well drained soils throughout the year and only to the poorly drained soils during dry periods.

The wastewater is irrigated utilising traveling rotary irrigators, of which six of the twelve irrigators are equipped with GPS tracking systems. Cropping of the pasture and lucerne across all irrigated blocks yields an average of 9.3 tonne DM/ha/yr (based on 2015/16 data).

Annual irrigation loading rates are summarised in Table 1.

Table 1: Wastewater Loading Rates

Parameter	Block				
	A	B	C	D	E
Hydraulic (mm/yr)	441	281	384	371	193
Nitrogen (kg/ha/yr)	382	243	333	321	167
Phosphorus (kg/ha/yr)	61	39	53	52	27
Sodium (kg/ha/yr)	401	255	349	337	175
Potassium (kg/ha/yr)	367	233	319	308	160
Calcium (kg/ha/yr)	158	101	138	133	69
Magnesium (kg/ha/yr)	36	23	32	30	16

Note:

1. *Based on the blocks average wastewater loading rates from January 2012 – August 2017*
2. *Block E has received an overall lower wastewater loading rate. This is due to areas of poorly drained soils and lower pipe pressure that restricted the number of irrigators until recent installation of booster pump.*
3. *Hydraulic and nutrient loads have been averaged across the block areas excluding the control block C3.*
4. *Nitrogen is measured as TKN.*

Visual Soil Assessment

The visual soil assessment was undertaken on all blocks irrigated with wastewater to assess the general condition of the soil, assessing against the "Soil Indicator" criteria in the Visual Soil Assessment Guideline developed by Landcare Research (Shepherd, 2009)[1]. The visual soil assessment is utilised to assess whether there is an obvious degradation of the soil condition as a result of the irrigation activity. The assessment considers:

- Soil structure and consistency;
- Soil porosity;
- Soil colour;
- Soil mottling;
- Earthworm numbers; and
- Surface relief (treading damage etc.)

A visual soil assessment was conducted for all irrigated blocks and Block G, as a control block (un-irrigated). Block G was selected over Block C for visual soil assessment, as Block G has had no known historical irrigation and has the same gley soils as parts of Block E. Because gley soils would generally score lower under a visual soil assessment, a gley soil control block was selected for comparison with Block E, to assess whether or not wastewater irrigation was contributing to the lower scoring of Block E or whether it was solely associated with soil type. Table 2 provides a summary of the visual assessment results.

The wastewater irrigation blocks on allophanic/brown soils, generally scored well on the visual soil assessment,

[1] Shepherd TG, (2009) *Visual Soil Assessment. Volume 1. Field Guide for Pastoral Grazing and Cropping on Flat to Rolling Country. 2nd edition,* Horizons Regional Council. 119p.

with moderate to good soil conditions. This included Blocks A, B, C, D and E3. Blocks E6, G1 and G2, contain gley soils and experience poor drainage resulting in anoxic conditions (as described above, Landcare's S-map identifies Block E and G as containing gley soils, which was confirmed on site). These soils all scored poorly with Poor to Moderate conditions. The soil conditions are therefore more affected by the soil type rather than the irrigation activity. While Block D scored as moderate, it was only marginally lower than the "Good" range, mainly due to earthworm count.

Table 2: Visual Soil Assessment Results

Irrigation Site	Ranking Score		
	Poor (<10)	Moderate (10 – 20)	Good (>20)
Block A North			22
Block A South			22
Block B3			22
Block C1			22
Block C2			25
Block D1		19	
Block D2			22
Block E3			28
Block E6	9		
Block G1 (Control)		11	
Block G2 (Control)	8		

Aside from the standard visual assessment, the appearance of the soils in the well-drained areas is good and they appear well managed. Very wet conditions were observed in the areas of Block E that contain poorly drained soils but this was also observed in the un-irrigated Block G. At the time of the visual assessment (spring) the poorly drained areas of Block E had not received wastewater irrigation since the previous summer/autumn; therefore, the wet conditions were attributed to rainfall.

Pasture cover was good for all blocks, with the exception of Block A where the pasture was clumpy, likely as a result of extended years of cropping without grazing or resowing and/or the grass height being allowed to grow too long between cropping events. It is recommended that Block A is resown for better pasture distribution. Consideration could also be given to grazing of residuals, which involves periodically grazing stock on the pasture to encourage lower level pasture removal and scuffing of soil surfaces. Sufficient stand-down time between wastewater application, grazing and stock processing would be required.

Soil Monitoring

Monitoring of soil nutrient levels is conducted by Silver Fern Farms on a regular basis. The last soil sampling event provided to us was undertaken on 30 August 2017, with the average results summarised in Table 3. Monitoring has been conducted to a depth of 75 mm. Block C3 is utilised as a control block and this is appropriate for comparison of nutrient levels as irrigation has not occurred on this block for a number of years.

Monitoring data indicates elevated Olsen P levels (plant available phosphorus) in the main irrigated blocks, A, B, C and D. The optimum Olsen P level for the land use is 30 – 40 mg/L (DairyNZ, 2012). As outlined in Table 6, based on the average cropping rate for the 2015/16 season of 9.3 T DM/ha/yr, the average phosphorus loading rates (19 kg/ha/yr balanced across the land holdings area) are slightly in excess of crop uptake rates (averaged at 15 kg TP/ha/yr, as balanced across the land holdings area). Therefore, it is expected that the Olsen P levels in the top soil layers will be elevated.

Sodium levels are elevated for all irrigated blocks, in comparison to the control block; however, the exchangeable sodium percentages remain relatively low. At the monitored ESP levels, it is not expected that the soils will be experiencing impaired permeability as a result of elevated sodium. The ESP levels will require on going monitoring identifying if there is an increasing trend and if lime or gypsum addition is required to offset sodium addition. pH levels in the soil remain at optimum levels (DairyNZ, 2012).

Table 3: Soil Monitoring Results

Monitoring Parameter	Block					
	A	B	C	D	E	Control (C3)
pH	6.4	5.7	6.4	6.2	6.3	5.9
Olsen P (mg/L)	81	98	94	83	30	14
Sodium (me/100g)	0.41	0.39	0.45	0.43	0.34	0.10
Potassium (me/100g)	1.7	1.4	1.7	1.4	0.6	0.6
Calcium (me/100g)	11	6	12	7	10	9
Magnesium (me/100g)	1.5	1.0	1.6	1.4	1.3	0.7
CEC (me/100g) [3]	18	14	21	15	16	17
ESP (%) [3]	2.3	2.3	2.7	2.9	2.2	0.6
ASC [3 4]	45	32	54	41	29	82
TOC (% w/w) [3 4]	4.4	3.6	4.9	4.0	3.6	9.0

Notes:

1. *Based on the blocks average of soil monitoring results from 30 August 2017 sampling event.*
2. *Control block C3 is not irrigated with wastewater but is harvested similar to the main irrigation blocks.*
3. *CEC = cation exchange capacity, ESP = exchangeable sodium percentage, ASC = anion storage capacity, TOC = total organic carbon.*
4. *Results not available for the 30 August 2017 sampling event, so the block average 29 July 2016 sampling event results were used.*

Soil samples for heavy metal analysis were also collected during our 18 October 2017 site visit from Blocks A and D for assessment against a selected control site, Block G, which has received no historic irrigation. Due to the accumulative nature of heavy metals, Block G was considered to be more appropriate as a control block. Table 4 summarises the soil heavy metal results from the samples collected on 18 October 2017. Monitoring of the irrigation blocks indicates that there is minimal increase in heavy metal concentrations in comparison to the background levels and all results are well below guideline limits. There may be a slight increase in zinc concentrations in comparison to the background levels, however, given the number of years that irrigation has been occurring at the site, the rate of increase is negligible.

Table 4: Heavy Metal Testing

Soil Parameter	Block A	Block D	Block G (Control)	Guideline Limit
Total Arsenic (mg/kg)	3	4	< 2	20
Total Cadmium (mg/kg)	0.19	0.26	0.2	1
Total Chromium (mg/kg)	14	15	10	600
Total Copper (mg/kg)	9	12	7	100
Total Lead (mg/kg)	9.3	11.6	8.3	300
Total Nickel (mg/kg)	8	9	6	60
Total Zinc (mg/kg)	68	81	43	300

Notes:

1. *Guideline limits based on the Guidelines for safe application of Biosolids to land in New Zealand (NZWWA 2003).*

Soil Permeability

Soil core samples were collected during the 18 October 2017 site visit from the top 100 mm of soil for soil permeability testing, including both K_{sat} and K_{-40} testing. Two cores were collected from each block (except for Block B which was stony and did not allow uniform core collection), and sent to Landcare Research for permeability testing). Block B will likely have similar permeability characteristics to blocks A, C and D due to the similar soil type.

K_{sat} testing provides an indication of the rate of infiltration under saturated conditions, while the K_{-40} provides an indication of infiltration through micro-pores only. Comparison of the two measured infiltration rates provides an indication of pore size distribution in the soil and provides an indication of the ideal loading rate to promote flow though micro-pores and not through macro-pores, so as to promote land treatment. Table 5 details the results of the infiltration testing conducted on cores collected from the irrigation areas.

Table 5: Irrigation Area Infiltration Tests

Block	Soil Type	K_{-40} (mm/hr)	K_{sat} (mm/hr)
A North	Allophanic/Brown	20	689
A South		10	57
C1		6	33
C2		16	17
D1		24	556
D2		4	176
E3		10	118
E6 (average of duplicate)	Gley	0.4	301
G1 (control)		0.9	28
G2 (control)		0.6	464

Permeability testing indicated highly variable saturated infiltration rates, which will partly be due to variations in macrospores (stones, roots and worm holes) in the soil cores collected.

The K_{-40} tests for the allophanic/brown soils were only moderately variable, ranging between 4 mm/hr and 24 mm/hr. When compared with the K_{sat} results, it is apparent that the particle size in the allophanic soils is well distributed, with reduced potential for bypass flows. The irrigation rate is 31.75 mm for the modified irrigators and 43.37 mm for the unmodified irrigators. While these rates exceed the K_{-40} rate, it is generally below the K_{sat} infiltration rate. This indicates that initially, there will be some bypass flow in the top 50 mm (approx.) of soil depth, but as soil micro-pores are filled, the rate of infiltration will decrease and bypass flow will be minimised at lower topsoil depths (but still well within the root zone).

K_{-40} tests within the gley soils indicated a very low unsaturated infiltration rate, yet K_{sat} tests indicate highly variable saturated infiltration rates. This indicated that the gley soils in parts of Block E are not well distributed, with very fine clay/silt particles and that infiltration is dominated by macro-pores, encouraging bypass flow. Hand augering indicated a very tight confining clay layer below 200 mm depth (resulting in the formation of a Gley soil), and while the top soil may achieve a high saturated infiltration rate, the confining layer will restrict ongoing infiltration, ultimately resulting in saturated conditions in the top soil. Block E permeability is not comparatively different to Block G, which contains the same soil type but is not irrigated.

Based on the infiltration testing, it is apparent that the allophanic/brown soils are suitable for wastewater irrigation under most annual conditions; however, the gley soils are unsuitable for wastewater irrigation other than under deficit conditions (which generally occur in summer and early autumn). It should be noted that Silver Fern Farms already applies lower hydraulic loading to these soils, as shown by the lower irrigation to Block E (in the areas containing gley soils) in Appendix B, Table B6.

Nutrient Modelling Assessment

The whole Takapau land holdings (including process and domestic wastewater irrigation, and stockyard solids spreading activities and un-irrigated areas) has been modelled using the OVERSEER nutrient modelling program (Version 6.3.0, released May 2018). This model is used to identify nutrient utilisation and losses based on the 2015/16 processing season. This record year was chosen as the most recent full year of records without significant discrepancies. The average nutrient summary for the land holdings, as generated by OVERSEER, is provided in Table 6. The nutrient model developed for the process wastewater irrigation system is provided in more detail in Appendix B.

The nutrient model utilised incorporates a number of factors, specific to each irrigation block, to estimate nutrient losses to atmosphere and water, via leaching and runoff. These factors include:

- Location and average climatic conditions;
- Irrigation depth;
- Nutrient loads from wastewater irrigation and solids spreading;
- Soil type and nutrient monitoring results;
- Pasture yield and carry rates.

Silver Fern Farms operate the irrigation system based on blocks and sub blocks, recording irrigation rates, solid spreading rates, grazing rates and cut and carry rates based on sub-blocks. While information presented in this report has been based on the average for each block, the Overseer nutrient model has been prepared based on sub blocks. Reporting in Table 6 has been summarised in to a rate across the whole land holdings but there is significant difference between the blocks, as detailed in Appendix B.

Nutrient modelling for the Silver Fern Farms Takapau land holdings has been carried out in the OVERSEER nutrient budget software. The results of this model show that process wastewater irrigation, domestic wastewater irrigation and solids spreading, account for 85 % of nitrogen entering the land holdings and 100 % of phosphorus. These activities contribute a modelled 120 kg/ha/yr of nitrogen and 19 kg/ha/yr of phosphorus.

The nutrient load is almost entirely utilised by the land management operations, with 119 kg/ha/yr of nitrogen and 15 kg/ha/yr of phosphorus exported as supplements.

There is some nutrient loss is via leaching through the soil column, and to the atmosphere via denitrification and volatilisation. Nitrogen leaching has been modelled at a rate of 17 kg/ha/yr, and denitrification and volatilisation is at a rate of 11 kg/ha/yr.

The nitrogen leaching rate of 17 kg/ha/yr is considered reasonable when compared to the predominantly sheep and beef farming land use in the wider area.

While the model shows that phosphorus is accumulating in the soil, due to the flat nature of the land, the model suggests that there is minimal loss of phosphorus to water.

Table 6: Whole Land Holdings Nutrient Budget Summary

	Nitrogen	Phosphorus
Nutrients Added (kg/ha/yr)		
Rainfall	2	0
Biological Fixation	17	0
Irrigation (Modelled as Fertiliser)	120	19
Total	**139**	**19**
Nutrients Removed (kg/ha/yr)		
Supplements Removed	119	15
To Atmosphere via Denitrification, and Fertilizer and Urine Volatilisation	11	0
To Water via Leaching	17	0
To Water via Runoff	0	0.1
Changes in Nutrient Pools (kg/ha/yr)		
Organic Pool	-10	18
Inorganic Mineral	0	5
Inorganic Soil Pool	0	-19

The OVERSEER model output was compared with lysimeter monitoring data collected onsite. Lysimeter data is sampled approximately twice monthly (deep and shallow) within 10 blocks. However, the failure rate of samples due to insufficient volume is high, at approximately 65 %. A summary of the modelled soil nitrogen concentration against the measured lysimeter data is provided in Table 7 below.

Table 7: Comparison of Modelled and Monitored Soil Water Nitrogen Concentrations		
Block	Modelled OVERSEER Data (g/m^3)	2015/16 Monitored Lysimeter Data (g/m^3) [1]
A North	15.7	50.5
A South	6.3	29.9
B1	11.3	23.2
C2	6.9	44.7
C3/control	2.7	18.5
D	4.1	25.5
E1/E1A	9.5	21.6
E3	5.4	23.0
E5	3.6	13.3
E6	8.6	6.7

Notes:

1. *Lysimeter data is collected in sets of 3 or more, the median sample collected for each block on each sample date was used for analysis. The result shown on this table is the average of the median results collected throughout the 2015/2016 monitoring year.*

The lysimeter data shows much higher concentrations of nitrogen in the soil water than would be expected from the land management operation, as shown with the OVERSEER results.

While OVERSEER predicts the nitrogen leaching to be low, in light of the lysimeter results and in line with good practice, it is recommended that some consideration be given to further optimising management to minimise nitrogen leaching. This could include options for increasing pasture yield, for example re-sowing some irrigation areas with high-yield ryegrass species, particularly where pasture has become patchy, and considering irrigation with clean water to prevent grass die-off, if that becomes a possibility under the replacement groundwater abstraction consent.

Summary

The Silver Fern Farms Takapau plant irrigates all wastewater to cut and carry pasture and lucerne land holdings, owned and operate by the company. An assessment was undertaken by PDP to assess the conditions of the soils within the irrigation area and nutrient management within the land holdings. Key findings of the assessment are:

- The irrigation blocks containing allophanic/brown soils (Blocks A, B, C, D and parts of E) all have soils in moderate to good condition. The gley soils in parts of Block E were in poor condition, but this is attributed to the soil type and not as a result of wastewater irrigation.
- The soils within the main irrigation blocks (Blocks, A, B, C and D) all contain elevated Olsen P, which is attributed to a higher loading rate of phosphorus in the wastewater than what is currently being removed from these blocks. While the differences in loading and removal from cropping is not substantially different for 2015/16, the Olsen P data would suggest that the difference between loading rates and removal rates via cropping may have been greater for previous years. The high Olsen P levels will also be as a result of the system being a long term land treatment system.
- Sodium levels in the soils are elevated, however, ESP levels remain low, at a level where it is unlikely to be impacting on soil permeability.

- The wastewater irrigation activity is resulting in insignificant increases in heavy metals in the soils.
- Soil permeability testing indicates that the allophanic/brown soils have good particle distribution and are suitable for the existing irrigation rate. Permeability testing of the gley soils and visual observation, confirms that wastewater irrigation of this soil type is unsuitable except for deficit irrigation during summer and early autumn.
- Nutrient modelling indicates rates of nitrogen leaching across the whole land holdings system are low for this type of wastewater management system; however this is not supported by the lysimeter data.

This memorandum has been prepared by Pattle Delamore Partners (PDP) on the specific instructions of Silver Fern Farms Management Limited for the limited purposes described in the memorandum. PDP accepts no liability if the memorandum is used for a different purpose or if it is used or relied on by any other person. Any such use or reliance will be solely at their own risk.

This memorandum has been prepared by PDP on the basis of information provided by Silver Fern Farms Management Limited. PDP has not independently verified the provided information and has relied upon it being accurate and sufficient for use by PDP in preparing the memorandum. PDP accepts no responsibility for errors or omissions in, or the currency or sufficiency of, the provided information.

APPENDIX A: VISUAL SOIL ASSESSMENT RESULTS

Table A1: Visual Soil Assessment Results - Block A

	Visual Indicator of Soil Quality		Weighting	VS Ranking	
Site	A north	A south		A north	A south
Soil Structure & Consistency	2	2	X3	6	6
Soil Porosity	2	2	X3	6	6
Soil Colour	2	2	X2	4	4
Soil Mottles	2	2	X2	4	4
Earthworm Counts	0	0	X3	0	0
Surface Relief	2	2	X1	2	2
RANKING SCORE (Sum of VS rankings)				22	22

Table A2: Visual Soil Assessment Results - Block B

	Visual Indicator of Soil Quality	Weighting	VS Ranking
Site	B3		B3
Soil Structure & Consistency	2	X3	6
Soil Porosity	2	X3	6
Soil Colour	2	X2	4
Soil Mottles	2	X2	4
Earthworm Counts	0	X3	0
Surface Relief	2	X1	2
RANKING SCORE (Sum of VS rankings)			22

Table A3: Visual Soil Assessment Results - Block C

	Visual Indicator of Soil Quality		Weighting	VS Ranking	
Site	C1	C2		C1	C2
Soil Structure & Consistency	1	2	X3	3	6
Soil Porosity	1	2	X3	3	6
Soil Colour	2	2	X2	4	4
Soil Mottles	2	2	X2	4	4
Earthworm Counts	2	1	X3	6	3
Surface Relief	2	2	X1	2	2
RANKING SCORE (Sum of VS rankings)				22	25

APPENDIX A: VISUAL SOIL ASSESSMENT RESULTS

Table A4: Visual Soil Assessment Results - Block D					
	Visual Indicator of Soil Quality		Weighting	VS Ranking	
Site	D1	D2		D1	D2
Soil Structure & Consistency	1	1	X3	3	3
Soil Porosity	1	2	X3	3	6
Soil Colour	2	2	X2	4	4
Soil Mottles	2	2	X2	4	4
Earthworm Counts	1	1	X3	3	3
Surface Relief	2	2	X1	2	2
RANKING SCORE (Sum of VS rankings)				19	22

Table A5: Visual Soil Assessment Results - Block E					
	Visual Indicator of Soil Quality		Weighting	VS Ranking	
Site	E3	E6		E3	E6
Soil Structure & Consistency	2	0	X3	6	0
Soil Porosity	2	0	X3	6	0
Soil Colour	2	0	X2	4	0
Soil Mottles	2	1	X2	4	2
Earthworm Counts	2	2	X3	6	6
Surface Relief	2	1	X1	2	1
RANKING SCORE (Sum of VS rankings)				28	9

APPENDIX B: SUMMARY OF OVESEER NUTRIENT MODELLING ASSESSMENT

COMPLETE LAND HOLDINGS SYSTEM: SUMMARY OF OVERSEER NUTRIENT MODELLING ASSESSMENT

A nutrient model has been developed by PDP for the complete land holdings system at Silver Fern Farms Takapau, utilising the OVERSEER nutrient modelling program (Version 6.3.0, released May 2018).

The results of this model aim to evaluate the likely:

- Nutrient loading to soils across the land holdings.
- Nutrient uptake in crops that are grown over the land holdings, and by animals that are grazed.
- Nutrients retained and lost in the soil profile.
- Nutrients lost to water, including via leaching at the base of the soil column.

This model is used to identify nutrient utilisation and losses based on the 2015/16 processing season. This record year was chosen as the most recent full year of records without significant discrepancies.

LAND HOLDINGS SYSTEM

1. LOCATION AND LAYOUT

The land holdings are located near Takapau in central Hawke's Bay. It is bound by State Highway 2 to the North, and Oruawharo Road to the South. It extends on both sides of Fraser Road and spans approximately 480 ha.

The Porangahau Stream runs through the land holdings from west to east. The topography is generally flat, with gentle slopes either side of the Porangahau Stream.

2. CLIMATE

The climate in the Hawke's Bay Region is temperate, and generally dry and warm. Rainfall is highly variable, the region often experiencing droughts and flooding. Daily data from the Silver Fern Farms Takapau weather station is recorded for rainfall and temperature; and potential evapotranspiration (PET) is recorded at the Central Hawke's Bay District Council weather station No. 33 (12 km from the land holdings). This data has been summarised into the following OVERSEER inputs based on the full data record (Aug 2010 to Sep 2017):

- Mean annual rainfall of 774 mm.
- Mean annual temperature of 12.6 °C.
- Annual PET of 1,304 mm with moderate variation.

3. LAND HOLDINGS OPERATION

The land holdings are operated as four different land management systems, which represent 408 ha:

- Process wastewater irrigation blocks (Blocks A – E, excluding S2/E8), which are operated as cut and carry blocks and alternated between grass and lucerne crops.
- Solids spreading blocks (Blocks F, G and S), which utilise grazing and harvesting to manage growth.
- Domestic wastewater border dyke irrigation blocks (Dam Dyke blocks).
- Other pastoral areas, which do not receive any waste products, and utilise grazing and harvesting to manage growth.

The total land holdings (480 ha) includes the processing plant and unutilised areas surrounding streams.

3.1. OVERSEER GENERAL INPUT SUMMARY

The OVERSEER inputs used to model the nutrient budgets are summarised in Table 1.

APPENDIX B: SUMMARY OF OVESEER NUTRIENT MODELLING ASSESSMENT

Table B1: OVERSEER Input Summary

General Inputs	
Location	East Coast North Island
Distance From Coast	37 km
Total Land holdings Area	480 ha

General Block Inputs

Block Name [1]	**Area (ha)** [2]	**Crop Type** [3]	**Operation**	**Additional Nutrient Loads**
A North	35.2	Grass	Cut and Carry	Process Wastewater Irrigation
A South	35.7	Grass	Cut and Carry	Process Wastewater Irrigation
B1	8.4	Lucerne	Cut and Carry	Process Wastewater Irrigation
B2	4.1	Lucerne	Cut and Carry	Process Wastewater Irrigation
B3	9.8	Lucerne	Cut and Carry	Process Wastewater Irrigation
C1	4.9	Grass	Cut and Carry	Process Wastewater Irrigation
C2 a	10.3	Grass	Cut and Carry	Process Wastewater Irrigation
C2 b	10.3	Grass	Cut and Carry	Process Wastewater Irrigation
C3/control	5.0	Lucerne	Cut and Carry	Process Wastewater Irrigation
D	25.9	Grass	Cut and Carry	Process Wastewater Irrigation
E1/E1A	11.7	Grass	Cut and Carry	Process Wastewater Irrigation
E2/E2A	12.0	Grass	Cut and Carry	Process Wastewater Irrigation
E3	5.3	Grass	Cut and Carry	Process Wastewater Irrigation
E4	6.0	Grass	Cut and Carry	Process Wastewater Irrigation
E5	12.4	Grass	Cut and Carry	Process Wastewater Irrigation
E6	15.8	Grass	Cut and Carry	Process Wastewater Irrigation
E7	6.0	Grass	Cut and Carry	Process Wastewater Irrigation
F1	5.8	n/a	Pastoral	Solids Spreading
F2	16.8	n/a	Pastoral	Solids Spreading
F3	9.9	n/a	Pastoral	Solids Spreading
F4	6.9	n/a	Pastoral	Solids Spreading
G1	41.6	n/a	Pastoral	Solids Spreading
G3	17.6	n/a	Pastoral	Solids Spreading
G4	4.2	n/a	Pastoral	Solids Spreading
G5	14.0	n/a	Pastoral	Solids Spreading
S1 (North, South, Substation)	8.5	n/a	Pastoral	Solids Spreading
S2/E8	5.0	Grass	Cut and Carry	Solids Spreading
Cottage	3.2	n/a	Pastoral	
Dam Dyke 1 - 10	0.8	n/a	Pastoral	Domestic Wastewater Irrigation
Dam Dyke 11 - 20	0.8	n/a	Pastoral	Domestic Wastewater Irrigation
Domestic Dam	1.6	n/a	Pastoral	
Dressage	2.5	n/a	Pastoral	
Effluent Dam	3.5	n/a	Pastoral	
Non Potable	6.9	n/a	Pastoral	
Old Dam	5.8	n/a	Pastoral	
South River 1	13.8	n/a	Pastoral	
South River 2	7.5	n/a	Pastoral	
Sub 1	0.6	n/a	Pastoral	
Well 10	3.4	n/a	Pastoral	
Well 12	1.8	n/a	Pastoral	
Well 15	4.6	n/a	Pastoral	
Woolshed	2.7	n/a	Pastoral	

Notes:

1. *Block names and locations were taken from a Silver Fern Farms Takapau Grazing Area Map (email, 23 April 2018).*
2. *Areas were taken, where available, from the 2015/16 Annual Monitoring Report (preferred) or the harvest data. If no other data was available Areas were estimated from 03/06/2016 aerials available on Google Earth.*
3. *Crop type (relevant only for cut and carry operations) is alternated between grass and lucerne depending on soil condition. The crop type for the 2015/16 year is used in this table and in the OVERSEER model.*

APPENDIX B: SUMMARY OF OVESEER NUTRIENT MODELLING ASSESSMENT

3.2. HARVESTING SUMMARY

The OVERSEER inputs are summarised in Table B2.

Table B2: OVERSEER Harvesting Summary

Block Harvested	Supplement Made	Dry Weight (Tonnes)	Destination
A North	Grass Silage	286	Off site
A South	Grass Silage	457	Off site
B1	Lucerne Silage	7	Off site
	Lucerne Baleage	9	Off site
B2	Lucerne Silage	3	Off site
	Lucerne Baleage	5	Off site
B3	Lucerne Silage	6	Off site
	Lucerne Baleage	19	Off site
C1	Grass Silage	46	Off site
C2 a/b	Grass Silage	228	Off site
C3/control	Lucerne Silage	18	Off site
D	Grass Hay	280	Off site
	Grass Silage	208	Off site
E1/1A	Grass Baleage	9	Off site
	Grass Silage	54	Off site
E2/2A	Grass Baleage	6	Off site
	Grass Silage	56	Off site
E3	Grass Baleage	5	Off site
	Grass Silage	35	Off site
E4	Grass Baleage	5	Off site
	Grass Silage	33	Off site
E5	Grass Baleage	30	Off site
	Grass Silage	87	Off site
E6	Grass Baleage	43	Off site
	Grass Silage	66	Off site
E7	Grass Silage	37	Off site
F1	Grass Hay	102	Off site
F2	Grass Hay	28	Off site
F3	Grass Hay	102	Off site
	Grass Silage	19	Off site
F4	Grass Silage	19	Off site
G1	Grass Silage	62	Off site
S1 (North, South, Substation)	Grass Silage	9	Off site
S2/E8	Grass Silage	22	Off site
South River 1	Grass Silage	55	Off site
South River 2	Grass Silage	14	Off site
Well 10	Grass Silage	10	Off site
Well 12	Grass Silage	8	Off site

Notes:

1. *Harvesting quantities and products were taken from harvesting records provided by Silver Fern Farms Takapau for the 2015/16 monitoring year (October 2015 to September 2016).*

APPENDIX B: SUMMARY OF OVESEER NUTRIENT MODELLING ASSESSMENT

SOILS

SOIL TYPES

Several different soil types are identified by Landcare's S-map online soil database on the land holdings; however, many of these soil types are relatively similar. The land holdings were observed to have three groups of soils that demonstrate differing characteristics when irrigated. These are:

- Allophanic and Orthic Brown soils.
- Perch-gley Pallic soils.
- Fluvial Raw soils.

The Allophanic Brown and Orthic Brown soils underlie the majority of the process water irrigation blocks. Orthic Brown soils are moderately well drained, with medium phosphorus retention. The Allophanic Brown soils are Brown soils that contain an Allophanic soil horizon. This horizon typically increases the phosphorus retention and drainage class to high phosphorus retention and well drained respectively.

The Perch-gley Pallic soil extends across approximately half of Block E. This soil contains a confining clay layer that forms a rooting and hydraulic barrier. This soil is typically associated with poor drainage and low phosphorus retention. This was supported by PDP observations of highly saturated soil in this area (*site walkover*, 18 October 2017), and by a reduced irrigation loading rate to this area (Section: Irrigation).

The Fluvial Raw soils are found underlying streams, which run through the land holdings. This soil is very young due to sedimentation processes occurring from stream flow. Consequently; it lacks a significant topsoil layer. This soil is typically well drained, with low to moderate profile available water and very low phosphorus retention.

The interface between the soil types is irregular, and has been approximated by the block operational area delineation for simplicity. All soil types are summarised in Table B3.

Table B3: Soil Irrigation Characteristics

Dominant Sibling Name	Soil Order	Phosphorus Retention	Drainage Class	Profile Available Water	Area (ha) [1]	Blocks
Ruat_7a.1	Perch-gley Pallic Soil	Low (22 %)	Poorly Drained	Moderate to High	35	E2, E6, E7, G1, S2/E8
Tarar_6a.1	Allophanic Brown Soil	High (66 %)	Well Drained	Moderate to High	33	B1, C2 b, C3/control, D, E1, E3, E4, E5, Effluent Dam, Old Dam
Bushg_14a.1	Allophanic Brown Soil	High (66 %)	Well Drained	Moderate to High	36	A North, F1, F4, Sub 1
Mand_22a.1	Orthic Brown Soil	Medium (36 %)	Moderately Well Drained	Moderate to High	59	A South, B2, B3, C1, C2 a, S1
Orono_83a.1	Orthic Brown Soil	Medium (36 %)	Moderately Well Drained	Moderate to High	84	F3, G4, Dressage, Woolshed, Non Potable
Ashb_38a.1	Fluvial Raw Soil	Very Low (3 %)	Well Drained	Low to Moderate	161	F2, G3, G5, Domestic Dam, Dam Dyke, South River 1, South River 2, Well 10, Well 12, Well 15

Notes:

1. *The dominant soil type for each block was chosen for OVERSEER modelling purposes, other soil types were often present. Soil type delineation was from PDP A02164201 Figure 3 Rev C and where further information was required; Landcare Research S-map online database was used. The area above is calculated as the total area that was modelled as that soil type (based on the dominant soil of the block).*

APPENDIX B: SUMMARY OF OVESEER NUTRIENT MODELLING ASSESSMENT

CURRENT SOIL NUTRIENT CONDITIONS

Annual soil testing is carried out within every block by Silver Fern Farms. The results of the soil testing is summarised in Table B4.

Soil testing across the land holdings shows high phosphorus levels (Olsen P), which are above the optimum range for pasture growth in sedimentary soils. Potassium and magnesium also have elevated quick test results, which are above optimum levels for pasture growth (Dairy NZ, 2012).

Elevated phosphorus, potassium and magnesium levels are occurring across the land holdings with the exception of some of Block E. This indicates that wastewater irrigation is likely to be contributing to these levels as Block E receives lower irrigation rates (refer to the section below on irrigation).

Calcium and sodium have no upper limit for optimum pasture growth. However, elevated sodium levels can cause degradation of the drainage characteristics of the soil. It is recommended that ESP levels are maintained below 6%. As per Table 3, ESP as monitored on 30 August 2017 was below 3% for all blocks.

Table B4: Soil Test Results

Sample Location	Olsen P	Potassium (MAF)	Calcium (MAF)	Magnesium (MAF)	Sodium (MAF)
A North	78	32	11	22	13
A South	80	35	12	25	22
B1	83	23	9	23	13
B2	63	18	8	21	12
B3	102	27	9	23	13
C1	104	30	12	21	7
C2	89	32	14	28	23
C3/control	29	15	13	13	2
D	82	24	10	20	17
E1/1A	42	14	15	27	16
E2/2A	17	6	15	30	19
E3	46	19	14	23	18
E4	44	7	16	28	19
E5	31	7	11	19	14
E6	18	3	12	22	21
E7	60	20	15	30	17
F1	45	11	15	27	9
F2	32	10	13	25	6
F3	53	9	14	34	7
F4	39	9	11	20	4
G1	18	3	11	22	6
G3	42	8	8	17	8
S2/E8	48	4	14	37	5
Optimum Pasture	**20 - 30**	**5 - 8**	**> 1**	**8 - 10**	**> 1**

Notes:

1. *MAF conversion method was as described by Hill Laboratories (2017).*
2. *Soil sampling results from 29 June 2015 were used to best represent the soil condition prior to the nutrient loading during the 2015/16 monitoring year. These results were not available from Blocks F1, F2, F3, F4 and G3 so the 29 July 2016 results were used.*

APPENDIX B: SUMMARY OF OVESEER NUTRIENT MODELLING ASSESSMENT

PROCESS WASTEWATER IRRIGATION

Treated wastewater, produced from Silver Fern Farms' processing plant, is irrigated across the Blocks A, B, C, D and E, with a combined irrigation area of 218 ha. The treated wastewater contains residual nutrients, which contribute a nutrient load to the irrigated land.

Wastewater generated from the processing plant each day varies. The volume of the wastewater discharge is limited to 35,000 m^3/7 day period and 1,365,000 m^3/year (between 1 October and 30 September) by the existing Resource Consents DP981043Ld and DP981044Ad. The average measured nutrient concentrations in the treated wastewater are summarised in Table B5.

Table B5: Average Nutrient Data

Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Sodium
73.6 g/m^3	11.8 g/m^3	75.5 g/m^3	36.2 g/m^3	7.9 g/m^3	82.5 g/m^3

Notes:

1. *Average nutrient data is based on sampling results from the 2015/16 monitoring year (October 2015 to September 2016).*

Irrigation is via a travelling irrigator system, irrigating a row at a time. Daily irrigation records are recorded by run. Irrigation occurs year round and the application area shifts daily to spread the treated wastewater evenly across the irrigable areas. Poor drainage across Block E limits the application rate at this location, and lower irrigation loads are applied across this block. Table B6 shows there is no or minimal irrigation on Block E at certain times of year, which is consistent with the reported operation.

Average monthly irrigation rates have been assessed for each block, based on the 2015/16 monitoring year (October 2015 to September 2016), and are shown in Table B6.

Table B6: Average Monthly Irrigation Rates for Each Block

	A	B	C	D	E
July (mm)	17	12	48	59	18
August (mm)	19	20	36	54	12
September (mm)	6	3	2	4	1
October (mm)	38	0	33	36	0
November (mm)	38	0	47	50	10
December (mm)	39	25	47	60	21
January (mm)	49	23	21	28	38
February (mm)	36	39	12	8	27
March (mm)	55	4	64	24	37
April (mm)	41	34	54	17	20
May (mm)	74	10	5	40	27
June (mm)	43	20	52	42	31
Annual Total (mm)	**455**	**190**	**421**	**422**	**242**

Wastewater irrigation was modelled as fertiliser application and irrigation of clean water. Monthly nutrient loads were determined for each block based on Tables B5 and B6. This modelling method was chosen to better model the expected nitrogen uptake, as the primary form of nitrogen in this wastewater is organic nitrogen.

DOMESTIC WASTEWATER IRRIGATION

Treated domestic wastewater, produced from the Silver Fern Farms plant, is irrigated across the BDIS with a combined irrigation area of 1.6 ha. The treated wastewater contains residual nutrients from the wastewater that contribute a nutrient load to the irrigated land. The average nutrient concentrations in the domestic

APPENDIX B: SUMMARY OF OVESEER NUTRIENT MODELLING ASSESSMENT

wastewater are summarised in Table B7. Please note that this data varies from the domestic irrigation nutrient model (PDP 2018) in that it utilises data for 2015/16 only and has been developed utilising Overseer version 6.3.0.

Table B7: Average Nutrient Data

Nitrogen [1]	Phosphorus [2]
38.0 g/m^3	7.6 g/m^3

Notes:

1. *Average nitrogen data is based on sampling results from the 2015/16 monitoring year (October 2015 to September 2016).*
2. *Average phosphorus is based on typical domestic nitrogen to phosphorus ratio of 5:1.*

Irrigation is via a border dyke irrigation system, which periodically floods Block 1 – 10 or Block 11 - 20.

The monthly irrigation rate for each block was calculated from the 2015/16 monitoring year (October 2015 to September 2016), and is summarised in Table B8.

Table B8: Average Monthly Irrigation Rates for Each Block

	Block 1 - 10	Block 11 - 20
January (mm)	66	0
February (mm)	93	93
March (mm)	0	93
April (mm)	92	77
May (mm)	92	0
June (mm)	93	92
July (mm)	0	87
August (mm)	93	0
September (mm)	92	62
October (mm)	81	65
November (mm)	0	64
December (mm)	89	80

Wastewater irrigation was modelled as fertiliser application and irrigation of clean water. Monthly nutrient loads were determined for each block based on Tables 4 and 5. This modelling method was chosen to better model the expected nitrogen uptake, as the primary form of nitrogen in this wastewater is organic nitrogen.

SOLIDS SPREADING

Sheep yard solids are spread across Blocks F, G and S and spread in runs which are 2.5 m wide and 550 – 570 m in length. The solids are washed down from the sheep yard and collected on a screen. This application was treated as nutrient loads of nitrogen and phosphorus as monthly applications of fertiliser. The sheep yard solids were not specifically analysed for phosphorus, and this has been estimated assuming a 5:1 ratio of nitrogen to phosphorus.

The monthly solids application for each block is summarised in Table B9.

APPENDIX B: SUMMARY OF OVESEER NUTRIENT MODELLING ASSESSMENT

Table B9: Monthly Nutrient Loads from Solids Spreading

Nitrogen Loads

	E8/S2	F1	F2	F4	G3	G4
January (kg/ha)					19	
February (kg/ha)					18	
March (kg/ha)	2	3			8	2
April (kg/ha)	20	2				
May (kg/ha)		15				
June (kg/ha)		22				
July (kg/ha)		5	1			
August (kg/ha)			3			
September (kg/ha)			1			
October (kg/ha)				2	5	
November (kg/ha)				27		
December (kg/ha)				19	7	

Phosphorus Loads

	E8/S2	F1	F2	F4	G3	G4
January (kg/ha)					4	
February (kg/ha)					4	
March (kg/ha)	0	1			2	
April (kg/ha)	4	0				
May (kg/ha)		3				
June (kg/ha)		4				
July (kg/ha)		1	0			
August (kg/ha)			1			
September (kg/ha)			0			
October (kg/ha)				0	1	
November (kg/ha)				5		
December (kg/ha)				4	1	

Notes:

1. *Nitrogen loads are based on records provided by Silver Fern Farms Takapau for the 2015-2016 monitoring year (October 2015 to September 2016).*

GRAZING

A grazing map provided by Silver Fern Farms Takapau indicates that grazing occurs across the majority of the land holdings area excluding process wastewater irrigation blocks. Grazing is irregular; however, good grazing records are kept for Blocks F, G and S1 and are summarised for the 2015/16 monitoring year (October 2015 to September 2016) in Table B10. Grazing records were modified to a suitable OVERSEER input into an equivalent flock grazing the block full time for a month for the land holdings.

For the blocks without grazing records, it was confirmed with Silver Fern Farms Takapau that nominal grazing does occur, so a nominal 5 sheep/ha were applied across these areas.

APPENDIX B: SUMMARY OF OVESEER NUTRIENT MODELLING ASSESSMENT

Table B10: Monthly Nutrient Loads from Solids Spreading

	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Number of Sheep	813	49	117	81	1,857	2,778	696	1541	932	870	1,494	2335

OVERSEER does not allow for different stocking rates to be applied for each month and block; rather, land holdings stock numbers per month, and relative productivity of the blocks. The grazing records were used to determine the average stocking rates, which were used for relative productivity for each block and are summarised in Table B11.

Table B10: Monthly Nutrient Loads from Solids Spreading

Block	Average Stocking Rate
F1	6.8 sheep/ha
F2	6.8 sheep/ha
F3	6.8 sheep/ha
F4	6.8 sheep/ha
G1	6.8 sheep/ha
G3	6.8 sheep/ha
G4	6.8 sheep/ha
G5	6.8 sheep/ha
S1 (North, South, Substation)	16.7 sheep/ha
Cottage	5.0 sheep/ha
Dam Dyke 1 - 10	5.0 sheep/ha
Dam Dyke 11 - 20	5.0 sheep/ha
Domestic Dam	5.0 sheep/ha
Dressage	5.0 sheep/ha
Effluent Dam	5.0 sheep/ha
Non Potable	5.0 sheep/ha
Old Dam	5.0 sheep/ha
South River 1	5.0 sheep/ha
South River 2	5.0 sheep/ha
Sub 1	5.0 sheep/ha
Well 10	5.0 sheep/ha
Well 12	5.0 sheep/ha
Well 15	5.0 sheep/ha
Woolshed	5.0 sheep/ha

APPENDIX B: SUMMARY OF OVESEER NUTRIENT MODELLING ASSESSMENT

NUTRIENT BUDGET

The irrigation activity and underlying land management systems have been modelled using the OVERSEER nutrient modelling program (Version 6.3.0, released May 2018). This model is used to identify nutrient utilisation and losses. The previously described characteristics have been used to generate the nutrient budget. The average nutrient summary for the land holdings, as generated by OVERSEER, is provided in Table B11.

Table B11: Nutrient Budget Summary

	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Sodium
Nutrients Added (kg/ha/yr)						
Rainfall	2	0	2	2	4	16
Biological Fixation	17	0	0	0	0	0
Irrigation (Modelled as Fertiliser)	120	19	118	56	12	129
Nutrients Removed (kg/ha/yr)						
Supplements Removed	119	15	102	26	5	7
To Atmosphere via Denitrification, and Fertilizer and Urine Volatilisation	11	0	0	0	0	0
To Water via Leaching or runoff	17	0.2	29	62	7	23
Changes in Nutrient Pools (kg/ha/yr)						
Organic Pool	-10	18	0	0	0	0
Inorganic Mineral	0	5	-8	-3	-4	-5
Inorganic Soil Pool	0	-19	-4	-28	9	120

Nutrients enter the land holdings primarily through process wastewater irrigation, domestic wastewater irrigation and solids spreading: accounting for 85 % of nitrogen entering the land holdings and 100 % of phosphorus. These activities contribute 120 kg/ha/yr of nitrogen and 19 kg/ha/yr of phosphorus.

The nutrient load is almost entirely utilised by the land management operations, with 119 kg/ha/yr of nitrogen and 15 kg/ha/yr of phosphorus exported as supplements.

The remaining nutrient loss is via leaching through the soil column, and to the atmosphere via denitrification and volatilisation. Nitrogen leaching has been modelled at a rate of 17 kg/ha/yr, and denitrification and volatilisation is at a rate of 11 kg/ha/yr.

1. NITROGEN BLOCK SUMMARY

A summary of the key aspects of the nitrogen budget for each modelled block is in Table B12.

The highest nitrogen losses per hectare were seen in the domestic wastewater irrigation blocks, with elevated nitrogen loss also in some of the process wastewater irrigation blocks which received higher hydraulic loading. The lowest nitrogen loss was seen on Block C3/control.

APPENDIX B: SUMMARY OF OVESEER NUTRIENT MODELLING ASSESSMENT

Table B12: Nitrogen Block Summary				
Block	**Total N lost**	**N lost to water**	**N in drainage**	**N surplus**
	kg N/yr	kg N/ha/yr	ppm	kg N/ha/yr
A North	2,163	61	15.7	128
A South	876	25	6.3	37
B1	250	30	11.3	73
B2	146	36	12.7	74
B3	264	27	9.7	51
C1	188	38	9.8	74
C2 a	289	28	7.2	46
C2 b	252	24	6.5	46
C3/control	25	5	2.7	-13
D	410	16	4.1	-34
E1/E1A	315	27	9.5	58
E2/E2A	382	32	10.8	60
E3	80	15	5.4	22
E4	127	21	7.5	40
E5	126	10	3.6	2
E6	401	25	8.6	42
E7	141	23	8	39
F1	50	9	4.5	-179
F2	175	10	4.8	4
F3	75	8	4.1	-157
F4	56	8	4.2	7
G1	311	7	4	-4
G3	190	11	5	55
G4	31	7	4	14
G5	145	10	4.8	14
S1 (North, South, Substation)	106	12	6.5	10
S2/E8	25	5	2.7	-35
Cottage	29	9	4.1	12
Dam Dyke 1 - 10	119	149	23.5	300
Dam Dyke 11 - 20	97	122	23	269
Domestic Dam	14	9	4.1	12
Dressage	17	7	3.8	11
Effluent Dam	23	7	3.8	11
Non Potable	47	7	3.8	11
Old Dam	39	7	3.8	11
South River 1	124	9	4.1	-45
South River 2	67	9	4.1	-8
Sub 1	4	7	3.8	11
Well 10	31	9	4.1	-23
Well 12	16	9	4.1	-55
Well 15	41	9	4.1	12
Woolshed	19	7	3.8	11

APPENDIX B: SUMMARY OF OVESEER NUTRIENT MODELLING ASSESSMENT

CONCLUSIONS AND RECOMMENDATIONS

Nutrient modelling for Silver Fern Farms land holdings has been carried out in the OVERSEER nutrient budget software. The results of this model show that process wastewater irrigation, domestic wastewater irrigation and solids spreading: accounting for 85 % of nitrogen entering the land holdings and 100 % of phosphorus. These activities contribute 120 kg/ha/yr of nitrogen and 19 kg/ha/yr of phosphorus.

The nutrient load is almost entirely utilised by the land management operations, with 119 kg/ha/yr of nitrogen and 15 kg/ha/yr of phosphorus exported as supplements.

There is some nutrient loss is via leaching through the soil column, and to the atmosphere via denitrification and volatilisation. Nitrogen leaching has been modelled at a rate of 17 kg/ha/yr, and denitrification and volatilisation is at a rate of 11 kg/ha/yr.

REFERENCES

Dairy NZ. (2012). *Critical Nutrient Levels for Pasture* (Farmfact No. 7-5). Dairy NZ.

Hill Laboratories. (2017). *Soil Tests and Interpretation: Technical Note* [Version 5]. Hamilton: Hill Laboratories.