Pattle Delamore Partners Limited

TECHNICAL MEMORANDUM

INVESTIGATION	Irrigation Nutrient Balance Model Summary	**PROJECT**	Takapau Plant Wastewater Irrigation Consenting
CLIENT	**Silver Fern Farms Limited**	**PROJECT NO**	A02164500
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		DATE	30 June 2020

Introduction

This technical memorandum has been prepared by Pattle Delamore Partners Ltd (PDP) on behalf of Silver Fern Farms Limited to summarise computational modelling of the irrigation to land systems at Takapau, which has been undertaken to provide a comparison with OVERSEER and lysimeter results, and enable evaluation of potential improvements with an alternate irrigation system. This memorandum has been prepared as a follow up memorandum to a previous technical memorandum prepared by PDP "Irrigation Soil Water Balance Model Summary" dated 28 June 2019, to describe additional modelling of nutrients using the same model. This memorandum should be read with the above memorandum in addition to the assessment of environmental effects (AEE) prepared by PDP for renewal of consents at the site including the discharge to land consents governing process wastewater irrigation (DP981043Ld & DP981044Ad) and domestic wastewater irrigation (DP981040L).

To date, OVERSEER modelling has been used to assess the potential nutrient leaching from the current operation. This is the most widely applied and accepted tool for assessing nitrogen leaching from irrigated land use in New Zealand. PDP, Hawke's Bay Regional Council (HBRC) and HBRC's technical reviewers have raised some concern that the concentrations predicted using OVERSEER are lower than measured concentrations in the lysimeters on-site, which are measured approximately twice monthly. As outlined previously, the lysimeters have not been inspected by PDP to assess whether any short-circuiting may be occurring. Silver Fern Farms' staff have also reported that the installation of at least some of the lysimeters were not up to standard. Lysimeter installation was via a post-hole driver and the lysimeters were backfilled with excavated material, rather than maintaining an undisturbed column.

PDP maintains a propriety daily soil water balance model that provides a way to estimate soil water content for irrigation decision making for various projects and has previously been used to model soil moisture and drainage at Silver Fern Farms Takapau. The model also allows modelling of nutrients. This memorandum presents results from the nitrogen uptake and nitrogen leaching components of the model.

The model has been used as an alternate tool to OVERSEER to simulate nutrient leaching. The purpose of the modelling was to provide a comparison with the OVERSEER and lysimeter results, recognising that PDP's model produces conservative estimates, because the complex nitrogen transformation processes that occur in soil (e.g. nitrification, denitrification, mobilisation and mineralisation) have been simplified in the PDP model to date. It has also been used to enable a comparison to be made of the relative change in potential nutrient leaching between the current system and an alternate spray irrigation system that permits smaller but more frequent application depths.

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Model Description

The general principle of the PDP daily soil mass balance model is to track the mass of water and nutrients entering and leaving the soil over a fixed depth profile (i.e. the root-zone) so that the water content of that fixed profile can be determined to inform irrigation decision making and nutrient leaching can be assessed. A detailed summary of the soil moisture balance model can be found in the memo "Irrigation Soil Water Balance Model Summary".

The nutrient component is now incorporated within the model. The model has been set up to assess nitrogen - other chemical parameters have not been modelled.

Two scenarios were modelled to assess the potential nitrogen leaching:

- Existing travelling irrigators (scenario from previous soil moisture model)
- Proposed centre pivot layout (as per Bay Irrigation report)

Input Data

Wastewater Quality

Daily wastewater volumes for the process and domestic systems have been provided by Silver Ferns Farms. The wastewater samples used are from the 2015 – 2016 season to enable comparison with OVERSEER results. Samples have been taken monthly from February 2000 – December 2011 and from January 2012 until September 2017 the samples were taken fortnightly. The nitrogen parameter sampled was total Kjeldahl Nitrogen (TKN). It is assumed that all TKN irrigated is readily converted to forms which are available for plant uptake and leaching. It is assumed that there are no other significant sources of nitrogen in the wastewater i.e. nitrates or nitrites.

A daily input is required for the model. A linear interpolation was used to estimate the TKN concentration of the wastewater between sampling dates. A linear interpolation provides a better representation of the peaks and troughs expected during periods of high and low demand. Figure 1 shows the daily TKN input for the process wastewater. For the domestic wastewater, a constant concentration of 38.0 g/m^3 was used (as used in the OVERSEER modelling presented in the AEE).

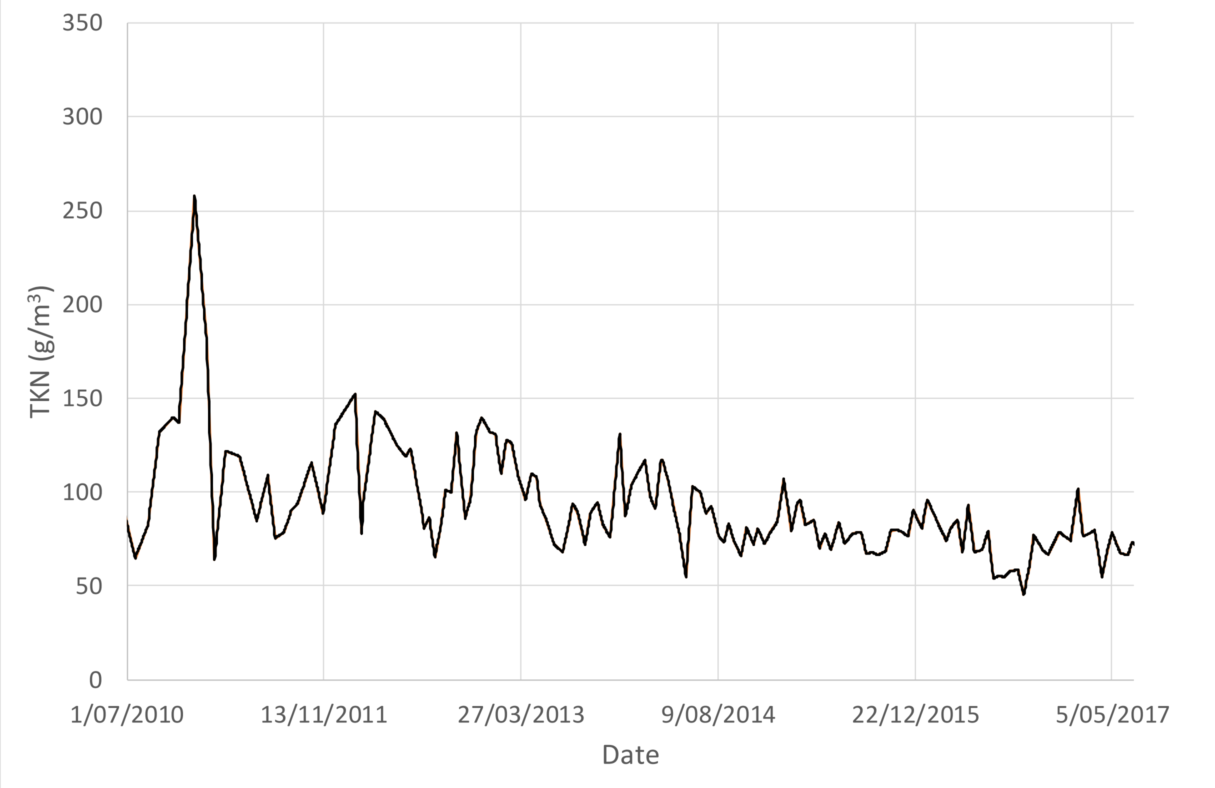


Figure 1: Daily wastewater TKN concentrations

Nutrient uptake and leaching

The nutrient uptake from plants was calculated using the harvesting data provided. The data provided included the dry matter mass per harvest and nitrogen content of the harvest. Only blocks which had continuing harvests (i.e. more than one harvest with an expected duration of no harvesting between) were included for calculating dry matter growth rates. The growth rates were calculated for each block by taking the harvest data and dividing it by the days since the last harvest. The value was then applied to the days between the current and previous harvest. This provides the average growth rate of the pasture prior to harvest. The daily growth rates from all the blocks were then averaged monthly to produce the monthly growth rates for pasture. The Lincoln University Farm Technical Manual (Fleming, 2003) provides study growth rates for pasture at Maraekakaho, located approximately 50 km from the site and these were used for comparison. The study farms are similar in climate to Takapau however, are not irrigated.

For lucerne, due to the limited data available, there is greater uncertainty with the growth rates calculated. The data used was from September 2014 to January 2017. A similar process to pasture was used to calculate the lucerne growth rates. It is noted that the blocks where lucerne has been planted, particularly Block B in the 2015/16 year, were underutilised for wastewater irrigation. This is likely to have resulted in much lower lucerne growth than would occur under improved irrigation. In general, growth/dry matter production for lucerne should be similar to or better than pasture, where the crops receive similar irrigation/rainfall.

The nitrogen content for each crop type was provided for the 2015/16 season. The percentage nitrogen from each harvest was calculated monthly in a similar process as the growth rates; this was then multiplied by the growth rates to obtain the nutrient uptake. Due to insufficient lucerne nitrogen data, an average of all the data was applied to all the months. Table 1 shows the growth rates and nitrogen uptake values calculated for the two crop types.

Table 1: Monthly Growth Rates

	Grass pasture			Lucerne	
Month	**FTM[1,2]**	**Pasture Growth Rate [2]**	**Nitrogen Uptake[3]**	**Pasture Growth Rate[2]**	**Nitrogen Uptake[3]**
Jun	10	9.9	0.33	7.5	0.24
Jul	10	6.2	0.21	7.4	0.24
Aug	20	8.7	0.28	7.4	0.24
Sep	40	82.2	1.65	8.2	0.26
Oct	40	62.3	1.32	13.9	0.44
Nov	13	32.9	0.67	13.3	0.42
Dec	14	38.6	0.74	8.2	0.26
Jan	9	30.5	0.85	9.8	0.31
Feb	13	28.1	0.87	15.5	0.49
Mar	15	33.7	0.75	11.0	0.35
Apr	18	19.4	0.63	7.8	0.25
May	18	15.3	0.50	7.8	0.25

1. Farm Technical Manual 2003
2. kg DM/ha/day
3. kg N/ha/day

All nitrogen which is not taken up by plants is assumed to be leached when the soil moisture exceeds the field capacity of the soil profile. The calculated growth rates of pasture are typically higher than theoretical values such as those found in Fleming (2003). This is attributed to the harvested plants being from irrigated areas which typically have higher growth and this is demonstrated in Fleming (2003) for irrigated areas at other study sites. A limitation of the growth rates calculated is that they are based only on the 2015/16 season. If the model were used to simulate other years, it may not adequately account for periods of lower soil moisture where plant growth is restricted. As outlined above, it is considered that the lucerne growth and uptake rates are lower than would occur under improved irrigation, which is due to periods of lower soil moisture occurring in blocks planted in lucerne that only received infrequent irrigation.

Wastewater application

The application rates used for the two scenarios previously modelled remained the same. The Bay Irrigation centre pivot scenario was assigned a constant application rate of 3.8 mm/day for all the blocks. This was because the peak application rates indicated in the Bay Irrigation report produced high nitrogen leaching in Block B, therefore, the average application rate of 3.8 mm/day was used. This is discussed further in the model results section. The model is separated into blocks to coincide with the Bay Irrigation centre pivot layout and underlying soil types. The layout is shown in the figure appended to this memo; the area E3-7 excludes E6 which is dominantly the clay Poporangi soils. The areas with “s” indicate sprinklers, which are to be used in areas not reached by the pivots. The sprinklers are applied at the same application rate as the pivot on the same block.

The domestic wastewater model application is the same as for the previous modelling.

Model Results

Process Wastewater

The model was run from 01 October 2015 to 30 September 2016 as this year had harvest data available and was the same year OVERSEER modelling was completed for. The yearly nitrogen application per hectare for the process wastewater is shown in Figure 2 with the amount leached shown in Figure 3. The centre pivot scenario is theoretical based on optimising soil moisture across the blocks, which is the reason block B and some E block applications increase. The OVERSEER results presented in Figure 3 (and Figure 5 in the domestic wastewater section) are from a updated OVERSEER model. This has resulted in minor changes to the OVERSEER leaching values reported in previous reports/memos. No changes in inputs have occurred, but the changes in outputs have occurred due to a newer version of OVERSEER being available.

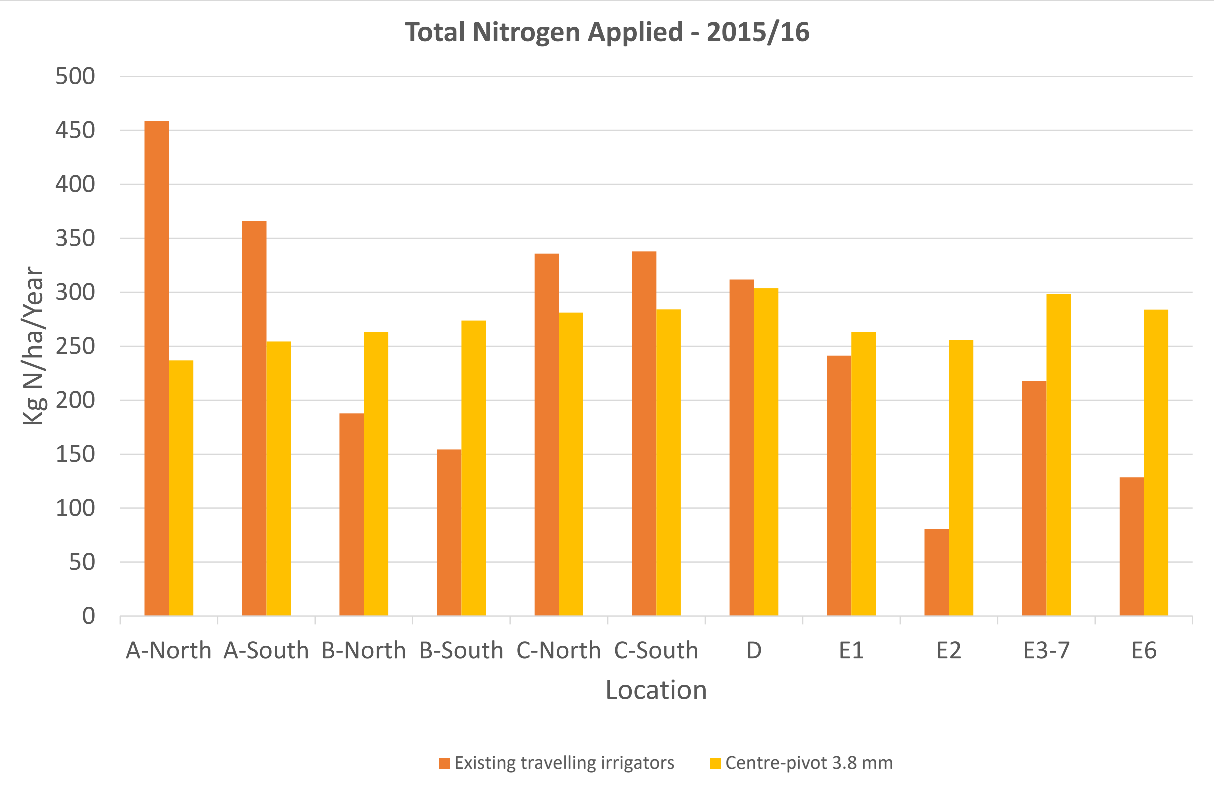


Figure 2: Nitrogen application to irrigation blocks

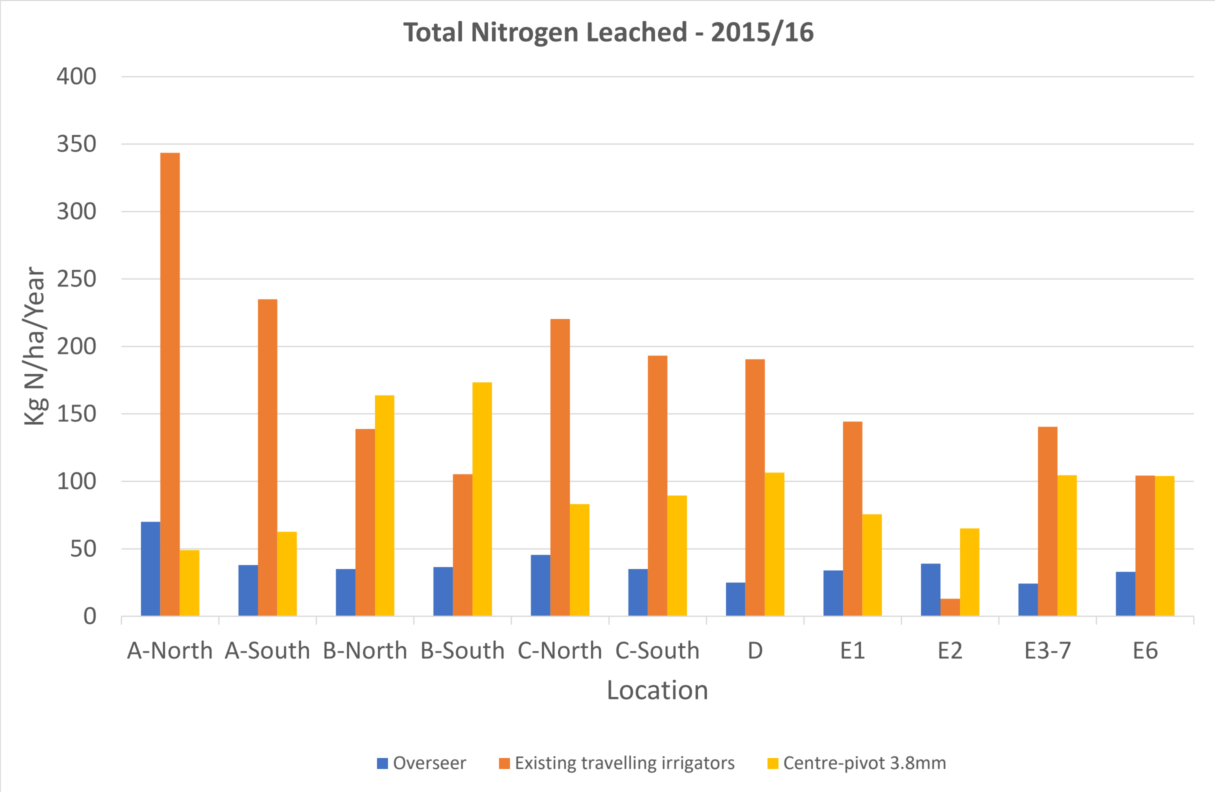


Figure 3: Nitrate leaching results

The proposed peak application rates from the centre pivot scenario result in a reduction in leached nitrogen in all the blocks except for the B blocks, E6 and E2, a summary is provided in Table 2**.** E2 has a portion of Poporangi soils and had lower irrigation volumes applied compared to the theoretical centre pivot scenario as shown by a lower nitrogen application rate in Figure 2. The irrigation of Block B in 2015/16 may not be representative of normal operations. The block was resown with lucerne during this period. Lucerne has a higher rooting depth providing greater water holding capacity of the soil which allows for a greater volume of irrigation. The travelling irrigator runs in block B are short lengths which resulted in the block being underutilised. The centre-pivot scenario uses the soil moisture condition to prioritise irrigation. This approach better utilises block B increasing the irrigation applied to block B (shown by an increase in nutrient application). In addition, as outlined above, the growth and nitrogen uptake rates presented in Table 1 for lucerne are considered to be much lower than would occur under more frequent irrigation, for example under a centre pivot system that is not restricted by run lengths. Due to these parameters the indicated leaching in block B is estimated as higher than the current travelling irrigators and is considered to be overestimated due to the low lucerne uptake rates. For any future irrigation system, the actual leaching can be controlled by considering crop type and making good decisions on irrigation based on soil moisture levels.

Table 2: Leaching Summary

	Values (kg N/ha/year)			Difference (kg N/ha/year)		
Block	**Overseer**	**Existing travelling irrigators**	**Centre-Pivot 3.8mm**	**Travelling[1] /Overseer**	**Centre-Pivot[1]/Overseer**	**Centre-pivot[1] /Travelling**
A-North	70	343	49	273 (390%)	-21 (-30%)	-294 (-86%)
A-South	38	235	63	197 (518%)	25 (66%)	-172 (-73%)
B-North	35	139	164	104 (297%)	129 (369%)	25 (18%)
B-South	37	105	173	68 (184%)	136 (368%)	68 (65%)
C-North	46	220	83	174 (378%)	37 (80%)	-137 (-62%)
C-South	35	193	90	158 (451%)	55 (157%)	-103 (-53%)
D	25	191	107	166 (664%)	82 (328%)	-84 (-44%)
E1	34	144	76	110 (324%)	42 (124%)	-68 (-47%)
E2	39	13	65	-26 (-67%)	26 (67%)	52 (400%)
E3-7	24	141	105	117 (488%)	81 (338%)	-36 (-26%)
E6	33	104	104	71 (215%)	71 (215%)	0 (0%)
Average:	38	166	98	128 (339%)	60 (159%)	-68 (-41%)

Notes

1. Difference values reported below show decreases (negative values) or increases (positive values) in leaching for the first listed scenario compared to the second. Percentages have been calculated using the difference divided by the second scenario.

A key limitation in the model is that it assumes that when leaching occurs, all available nitrogen within the soil profile is immediately leached. Whilst this provides conservative leaching estimates, the values reported are higher than would occur as the soil will retain some nutrients. This in addition to other transformation processes not accounted for, is the reason the leaching estimated by OVERSEER is lower than in the PDP model. The model does demonstrate how a well-controlled centre-pivot/sprinkler system with lower application depths than currently occur with the travelling irrigators, could result in a significant net reduction in leaching over the site. The loading can be applied at a lower rate and spread more consistently across the site (with respect to soil conditions). Overall, use of centre-pivot/sprinklers or an alternate irrigation system with a lower more frequent application depth (including for example a well-managed travelling irrigator system) is expected to result in a reduction in nitrogen leaching provided appropriate application, use and crop selection. The one year of data available results in the theoretical centre-pivot scenario being sensitive to the assumptions of each block.

Domestic Wastewater

The nitrogen application of the domestic wastewater is shown in Figure 4 with the leaching shown in Figure 5. There is a 422 m^3 difference in wastewater applied due to the end of the year occurring before the next border dyke application. This means that the missed days are not irrigated, resulting in the volume not summing up to the border dyke volume. There is therefore, approximately 10.1 Kg N/ha less applied over the entire area in the spray scenario. This small difference is not considered to significantly alter the results.

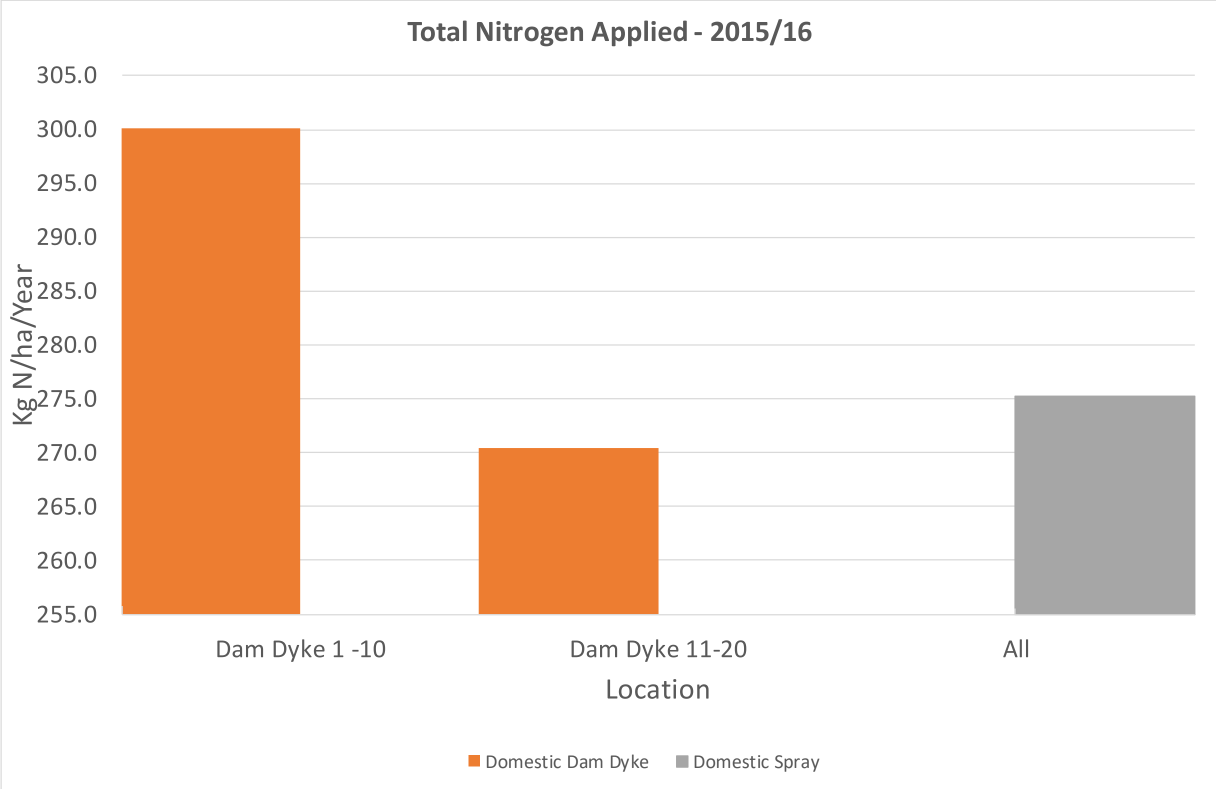


Figure 4: Domestic wastewater application

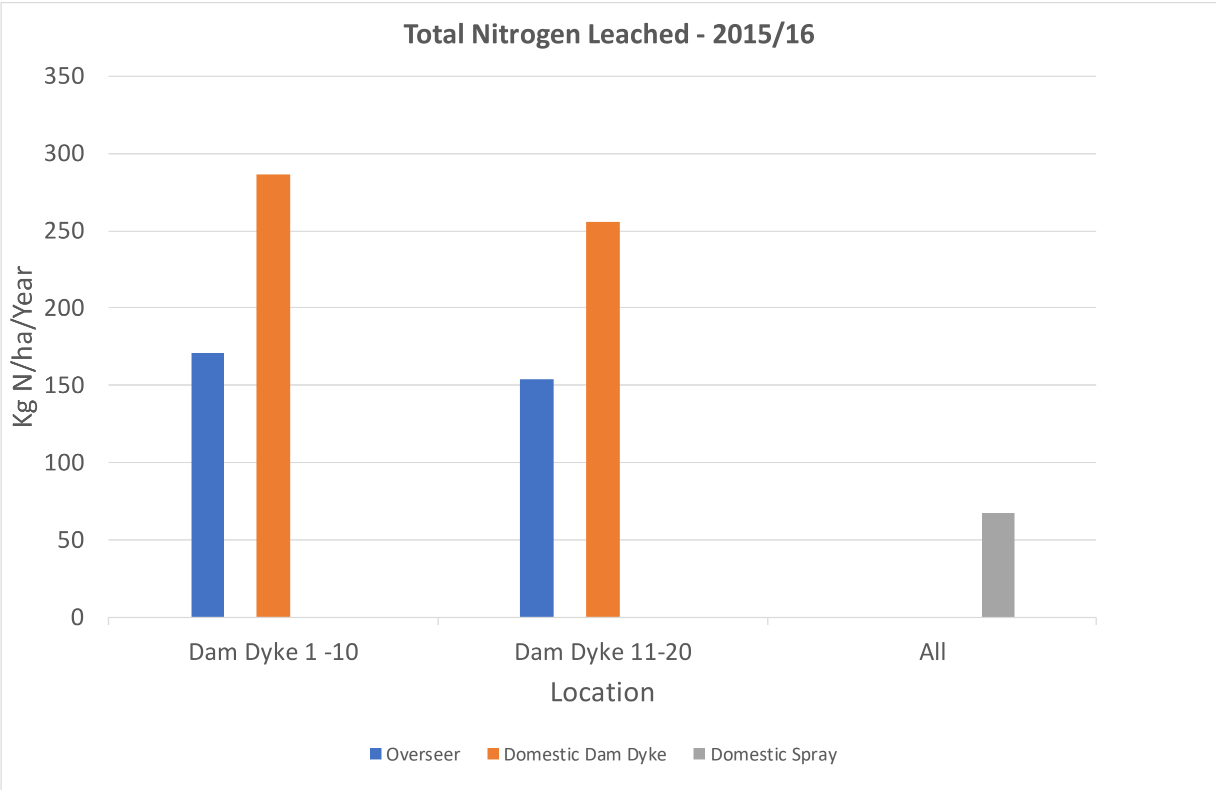


Figure 5: Domestic wastewater leaching

The results show that a spray irrigation system for the domestic wastewater would be expected to result in a significant reduction in the nitrogen leached compared to the current border dyke system.

Lysimeter Data

A comparison with nitrogen concentrations captured by the lysimeters showed that the model over estimated leached nitrogen concentrations by a large amount. This is due to the reason described in the process wastewater results where all nitrogen is leached from the soil profile when drainage occurs. If only small amounts of drainage occur, the concentration of nitrogen estimated by the model can be greater than the application concentration applied, even though the corresponding mass flux of nitrogen leached may be small. In the model, all nitrogen is stored in the soil until it is either leached or taken up by plants. When the soil moisture decreases due to evapotranspiration being greater than the nitrogen uptake from plants, the concentration of nitrogen within the water in the soil profile ultimately increases until discharge. The modelled concentrations were therefore not considered directly comparable to the lysimeter data. However, the greater modelled concentrations show how the model is providing a conservative estimate of leaching, and actual leaching is expected to be less than predicted by the model, especially when considering the lysimeters may be overestimating leaching due to poor installation techniques. However, as discussed above, while the model may be conservative in terms of total leached nitrogen predictions, the model provides a good indication of the relative changes in leaching for the different irrigation systems.

Conclusion

Further modelling has been undertaken on behalf of Silver Fern Farms Limited to further assess the potential nitrogen leaching from the irrigated wastewater. The model results show that switching from the current travelling irrigators to a centre-pivot/sprinkler system with a lower more frequent application depth is expected to provide a reduction in nitrogen leached for all blocks, although there were exceptions in the model scenarios primarily due to current low application rates, limited site-specific lucerne growth and uptake rates resulting in conservative growth rates for the centre pivot scenario and the model theoretically applies the wastewater based on soil moisture deficits. The domestic wastewater is also indicated to have a significant reduction in nitrogen leaching with spray irrigation at a lower more frequent application depth than the current border dyke system. Overall, while overestimating the quantities of leaching, the model shows that switching to a lower more frequent application rate results in a comparative reduction in leached nitrogen.

Overall, while it provides conservative results, it is considered that the soil moisture model provides a useful illustration of the potential improvements with an alternate irrigation system, given its ability to model daily soil moisture change that can capture improvements with lower more frequent application depths.

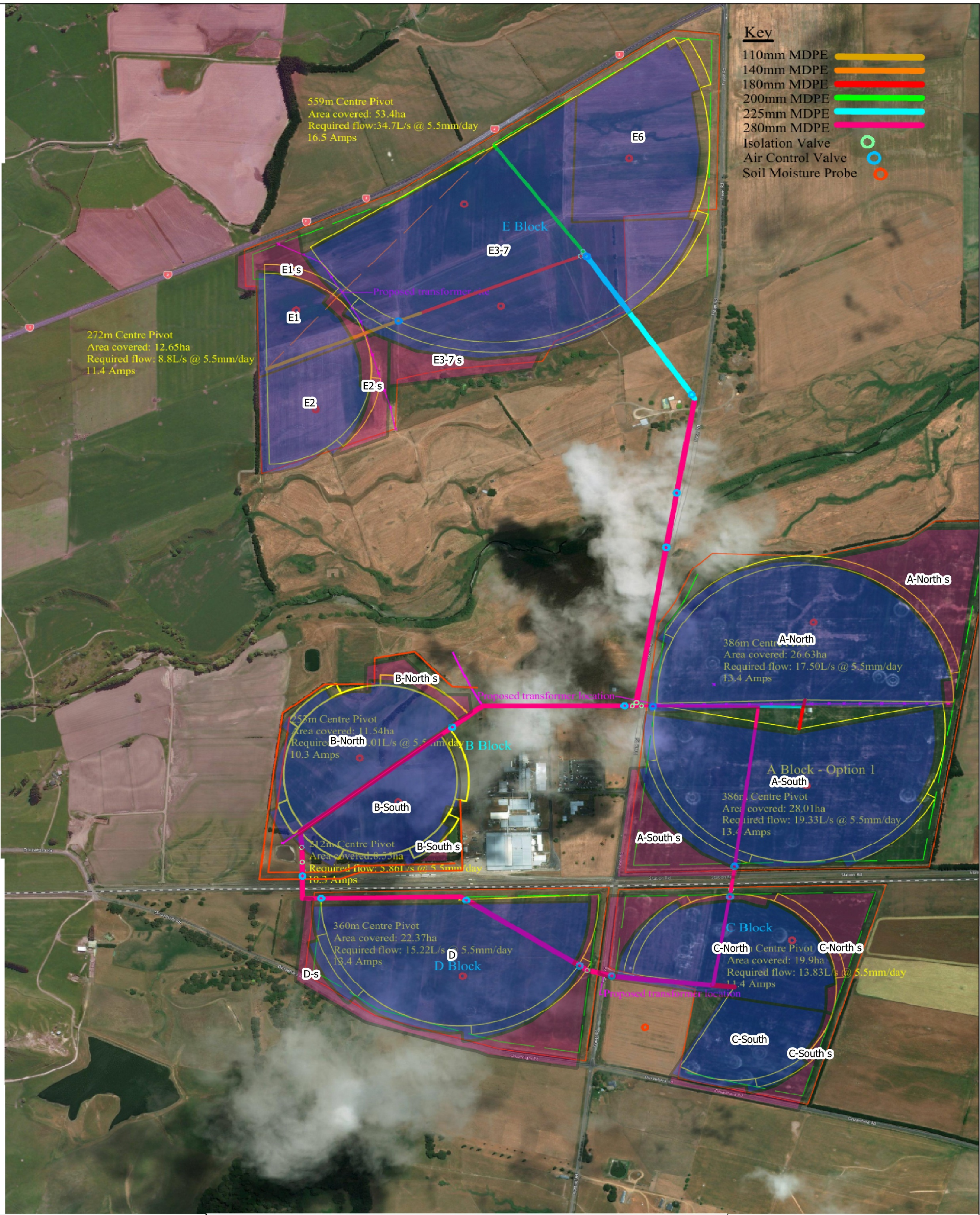
It is recommended that OVERSEER should continue to be used to assess overall leaching from the farming system as a whole, given its ability to allow for more complex soil processes than our in-house model does at present. However, based on the soil moisture and nutrient leaching modelling undertaken with our in-house model and the lysimeter results, it is possible that OVERSEER may be potentially underestimating the leaching from the existing travelling irrigator system, although given the conservative nature of the our modelling together with the concerns raised around sub-standard lysimeter installation, this is difficult to determine. It is considered that OVERSEER would be more accurate for an irrigation system with lower application depths and more frequent application, such as the centre-pivot system proposed, provided the system is optimised for soil moisture and crop-type.

Ongoing monitoring of soil moisture, groundwater and lysimeters should occur under any centre-pivot system installed. It is also recommended that any irrigation system should be carefully controlled based on daily climatic and soil moisture information and consideration of other variables such as crop type.

Silver Fern Farms are looking to implement some additional treatment involving screening to allow for irrigation through the centre pivots. The effectiveness of this treatment in terms of wastewater quality can be reviewed once the system is in place and consideration could be given to whether further pre-treatment of the wastewater may be warranted in periods of high soil moisture to reduce potential nutrient leaching, when the capacity for land treatment of the wastewater is reduced.

References

Farm Management Group (edited by Peter Fleming). (2003). *Farm Technical Manual.* Christchurch: Lincoln University.



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Scale: