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13 October 2020

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Dear Alison

SILVER FERN FARMS TAKAPAU - NUTRIENT MODELLING REVIEW RESPONSE

1.0 Introduction

Hawke's Bay Regional Council (HBRC) have engaged Williamson Water & Land Advisory (WWLA) to review the memorandum provided by Pattle Delamore Partners Ltd (PDP) on behalf of Silver Fern Farms summarising the irrigation nutrient balance model dated 30 June 2020. WWLA provided comments back to HBRC regarding the PDP memorandum in a memorandum dated 27 July 2020.

The purpose of this letter is to provide a response to the review comments provided by WWLA.

2.0 Review Comments and Responses

Excerpts and comments from the WWLA memo are shown in bold, with responses provided beneath each question/comment.

1.a) Figure 1 shows the interpolated TKN concentrations, but to verify the accuracy of the interpolation, actual data points need to also be plotted on the graph.

An updated figure with the data points is shown in Figure 1, below.

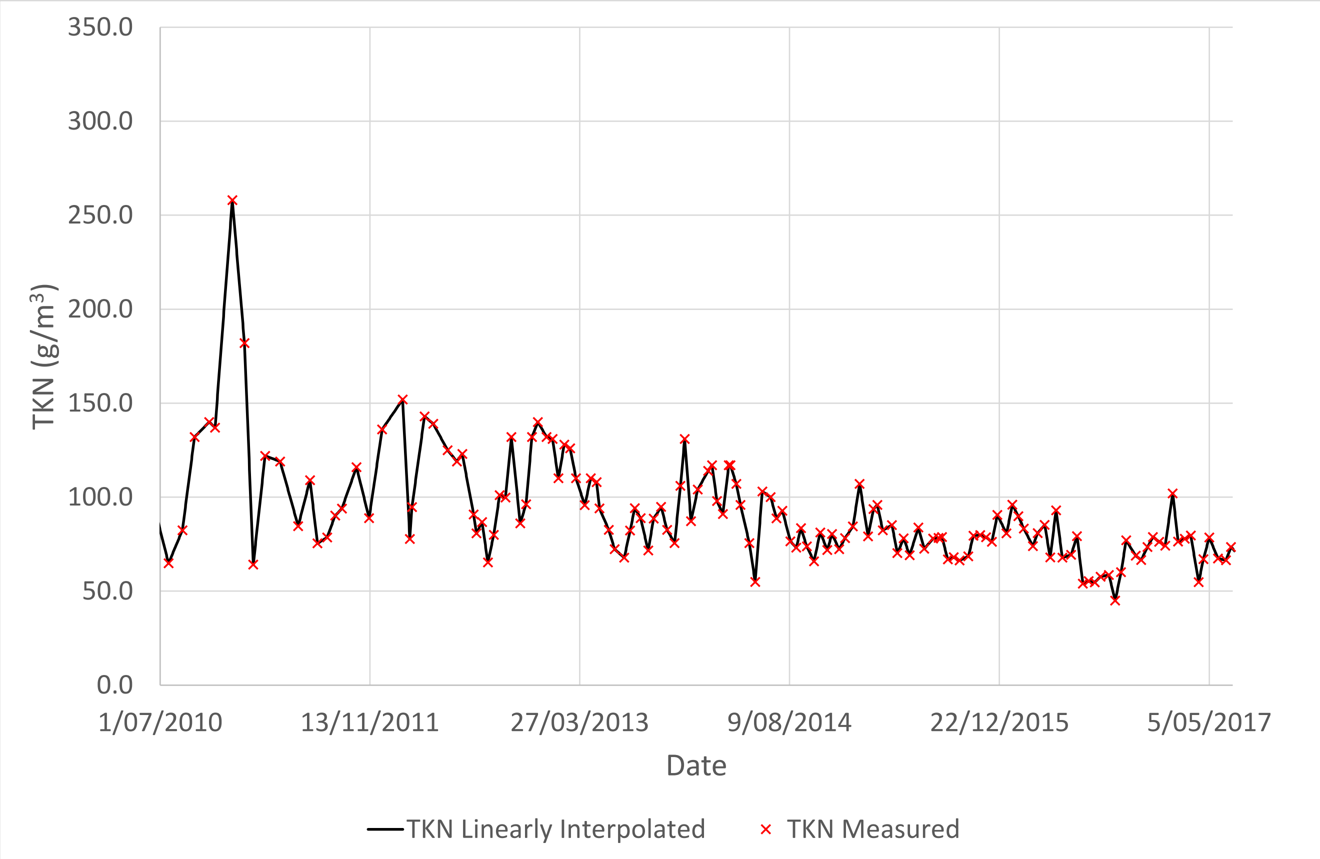

Figure 1: TKN measured and linearly interpolated

1.b) Time series plot of the soil behaviour and drainage rates with and without the prescribed irrigation loads are not provided, nor comparison of the modelled leaching rate to that measured (although there is commentary near the conclusion section that the model overestimated the lysimeter leaching rates).

The purpose of the model was to compare the proposed centre pivot irrigation, with more frequent lower application depths, to the existing travelling irrigator system However, Figure 2 below shows the simulated drainage for the proposed centre pivot irrigation, the existing travelling irrigator system, and dry land for block A-North. The figure shows that when irrigation occurs, there is greater drainage, as is expected for irrigated land. The total modelled drainage depths for dry land, travelling irrigator, and centre-pivot are 88.3 mm, 374.9 mm, and 218.1 mm, respectively. This shows that the proposed centre-pivot will result in a reduction in drainage compared to the travelling irrigators for the modelled scenarios. The drainage associated with the centre-pivot scenario is closely related to rainfall events. The higher application rates for the travelling irrigator system results in a higher frequency of drainage outside of rainfall events.

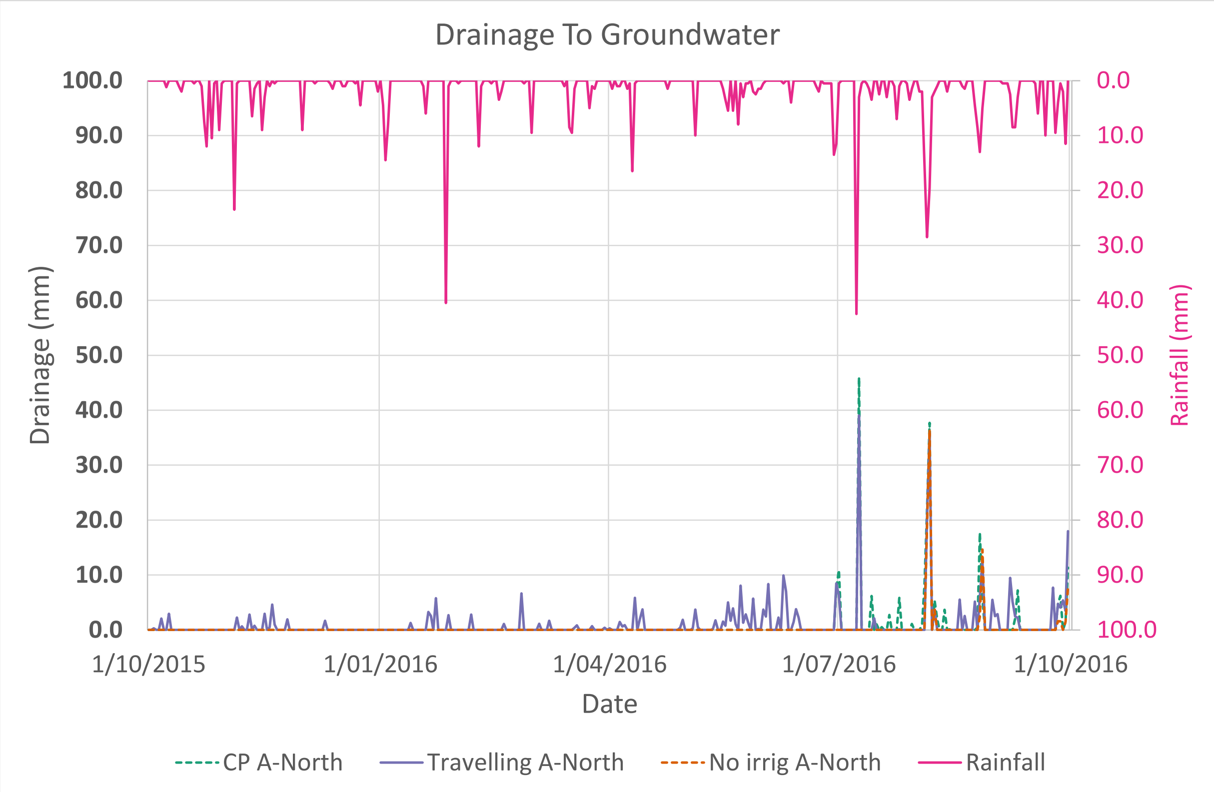

Figure 2: Modelled drainage Block A-North

The nitrogen concentrations captured by the lysimeters show that the PDP model overestimates leached nitrogen concentrations. The modelled concentrations are not considered directly comparable to the lysimeter data and provide a conservative estimate. The purpose of the model is to indicate the relative change in expected nutrient leaching between the centre-pivot system and the current travelling irrigators. The model stores nitrogen within the soil profile until there is drainage event. During a drainage event, all nitrogen stored within the soil profile is assumed to leach to groundwater. During drier periods where irrigation is applied there is a length of time between drainage events and nitrogen from the wastewater will build up within the soil profile. If there is a small drainage event (for example, less than 5 mm of drainage following a rainfall event) then the calculated nitrogen concentration is very large (unrealistically) in the model, as it is conservatively assumed all nitrogen in the soil profile is leached in the drainage.

To compare the lysimeter data to the modelled parameters, the measured concentration was converted to a monthly per hectare mass of nitrogen leached (kg/ha/month). To convert the concentrations measured by the lysimeter into mass loadings, the modelled monthly drainage corresponding to the month the lysimeter concentration was measured was used. The results for run AN-R6 are shown in Figure 3. There are three lysimeters along this run, the measured concentrations across the three different lysimeters were averaged. Modelled monthly drainage was used with these measurements, as there was too much uncertainty in the area which contributes to each lysimeter and the period over which drainage was collected (measurements appear to be taken approximately twice monthly, but not consistently) to calculate a reliable drainage volume. The lysimeter concentrations are assumed to be representative of the leached nitrogen concentration at the time of measurement.

A direct comparison is difficult due to the uncertainties around the lysimeter measurements. The modelled nitrogen leaching results presented in Figure 3 show the total leaching modelled over the entire month (this is the sum of the leaching which occurred over the month, not taken daily). The lysimeter measurements shown provide an estimate of the monthly leaching. Where there are multiple points in a month, each point provides a separate monthly estimate based on concentrations in the lysimeter at the time of measurement.

The modelled monthly leaching of the travelling irrigator scenario is consistently greater than the estimated leaching from the measured lysimeter results. This model conservatively assumes that plant uptake is the only other loss of nitrogen in the soil profile. The sub-processes such as denitrification are not included and therefore, it is expected that the modelled results are substantially higher.

Reviewing the leaching associated with the centre-pivot it can be seen all modelled drainage occurs in the winter months when the soil moisture is expected to exceed field capacity. The lower application rate results in effectively no drainage in the drier months as field capacity is not being exceeded. The first month where leaching is shown is higher than the subsequent months. This is because the first drainage event occurs after an extended period of no drainage and in our model it is conservatively assumed all nitrogen is flushed from the soil.

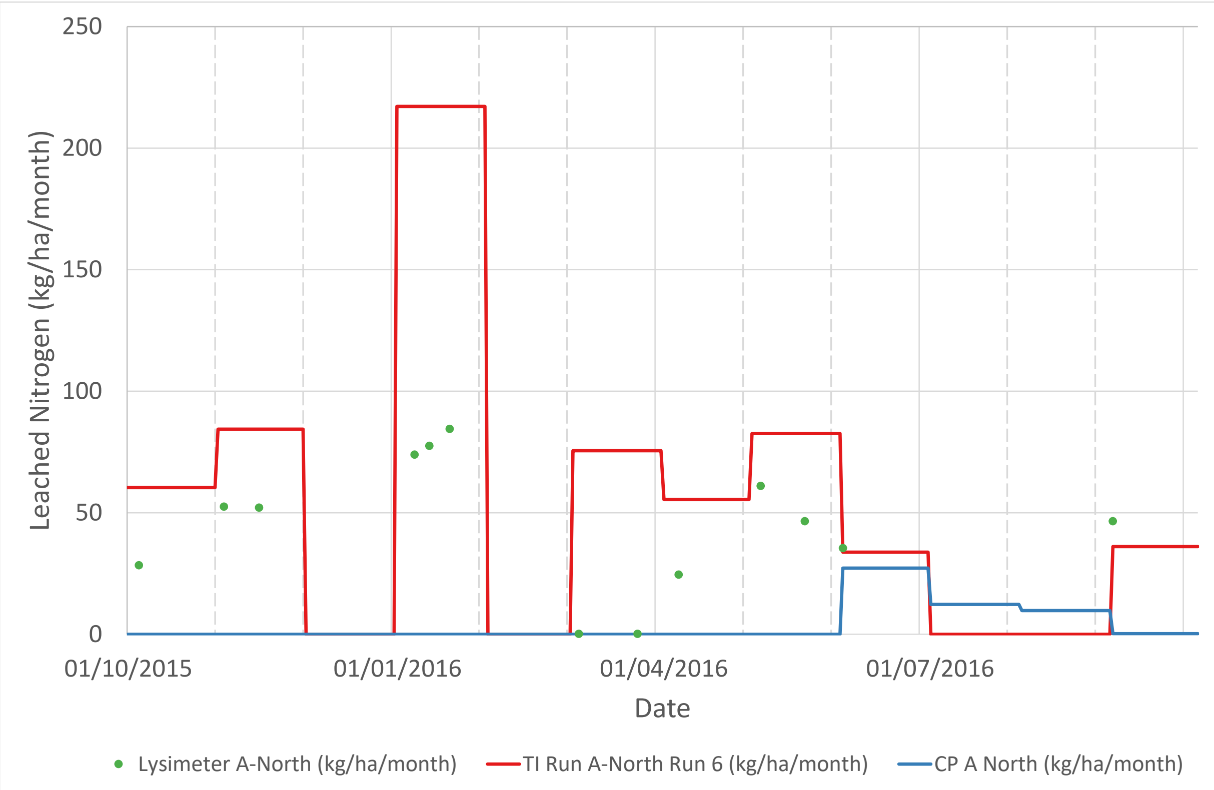

Figure 3: Comparison of modelled and lysimeter estimated nitrogen leaching for run AN-R6

7.b) the temporal (say monthly) quantification of N leached (i.e. does it all leach during winter and very little in summer)

The model stores nitrogen within the soil profile until there is drainage event. During a drainage event, all nitrogen stored within the soil profile is assumed to leach to groundwater. Given the one year of data available, nutrient results are reported annually. A higher resolution may not accurately represent leaching as a small drainage event at the end of large period of no drainage will be very high in the model, as explained above. In general, leaching of nitrogen from irrigated wastewater occurs predominantly during the winter months. The values in Figure 3 are shown in Table 1.

Table 1: Monthly nitrogen leaching for block A-North (kg/ha)

Month	Estimated Lysimeter	Modelled Travelling Irrigator[1]	Modelled Centre-Pivot
Jan	236	217	0
Feb	0	0	0
Mar	0	76	0
Apr	25	55	0
May	108	83	0
Jun	35	34	27
Jul	0	0	12
Aug	0	0	10
Sep	47	36	0
Oct	28	60	0
Nov	105	84	0
Dec	0	0	0

Notes:

1. The travelling irrigator scenario shown is for run AN-R6. This provides comparison against Lysimeters which are along this run. The monthly values in this table will not sum to the total leached shown in Figure 3 of the "Irrigation Nutrient Balance Model Summary" memo dated 30 June 2020 as Figure 3 includes all runs within the block.

2. The modelling has only assessed one year, yet the purpose of a model is to assess the long-term performance of a proposal, hence what is presented does not consider how the proposal irrigation scheduling of 3.8 mm/day would perform under winter and wetter than normal summer conditions.

The one year was chosen as it had sufficient complete data over the entire year. This enabled a comparison between what was applied and how the irrigation would have been applied with a centre-pivot.

The model was run for an entire year starting on 01 October 2015 to 30 September 2016. This captured a full summer and winter season. A wetter year would result in more drainage, this is true regardless of the irrigation system selected. A wetter year is unlikely to show significant differences when comparing the drainage between the two systems, although it is possible the centre pivot may show greater improvements than a drier year, depending on the pattern of rainfall and irrigation. A lower application rate applied more frequently reduces the chance of field capacity being exceeded.

3) My suspicion is that even at 3.8 mm, the application rate is far too high if needed to be continuously applied, and additional area is required so that some areas can be spelled especially during winter.

4) Note that there seems to be a clear disparity in daily application rates between what PDP are suggesting as an acceptable application rate of 3.8 mm/day and what has been designed by Bay

Irrigation, whose Pivot Plan of May 2019 specifies 5.5 mm/day, while their Design Specification document of August 2019 specifies 8.75 mm/day.

6.a) Not enough detail provided in this document of the volumes of water applied. Do all pivots operate simultaneously every day, or is there a rotating schedule?

7.a) Clarification of irrigation return cycles and actual loadings rates.

The following response is intended to answer Q3, 4, 6.a), and 7.a)

The model irrigates all the wastewater from the wastewater treatment plant each day. A model assumption is that there is no storage capacity in the system, so the inflow volume is equal to the outflow volumes. The constant application rate of 3.8 mm/day refers to the maximum instantaneous rate which can be applied by centre-pivot in the model. Infrequently, at periods of very high inflow, this rule may not be met in the model. This is based on the weekly rate at which the irrigator will be set as outlined in the Bay Irrigation Design Specification, August 2019. The design brief is for a preferred application rate of 27 mm per week with a 5 day return. The 3.8 mm used in the model accounts for an application rate of 27 mm per week with no rest days over the full seven days. There is very little impact of using this average daily rate in terms of drainage and in practice, future irrigation scheduling should be based on soil moisture at the time of irrigation to avoid drainage occurring.

The centre pivot and wastewater application rate selected is based on multiple input parameters and daily soil conditions in the model (as it will be in practice). During normal operation, up to six blocks can be irrigated simultaneously. In the model, the selected paddocks to be irrigated are dependent on the following factors (in order).

1. The irrigation demand (the maximum irrigation which can be applied on any given day, which accounts for start/stop triggers)
2. Number of days since previous irrigation
3. Soil moisture deficit (application depth required to reach field capacity)
4. Irrigation area ID (Block priority order: A, B, C, D, E)

If there is a large volume of wastewater supply, then the number of blocks irrigated and/or the application depth rules may not be met in the model. This occurs on two days over the modelling period. The maximum daily irrigation rate which exceeds 3.8 mm is 6.0 mm on 11 August 2020 and 5.5 mm on 29 June 2020. These occur over three different blocks (including the sprinkler areas) on each occurrence.

The wastewater supply is not every day. There are frequently days where there is no wastewater supplied to be irrigated. The wastewater supply is shown in Figure 4. Figure 5 and Figure 6 show the irrigation applied by the centre pivot over blocks A-North and B-North respectively.

The actual irrigation applied is at or below the peak application rate of 3.8 mm/day in the model (noting the infrequent exceptions above). There is then a rest period until the next application. Taking the 7-day rolling average shows that over a week, the irrigation will not result in a continuous 3.8 mm/day application over the block.

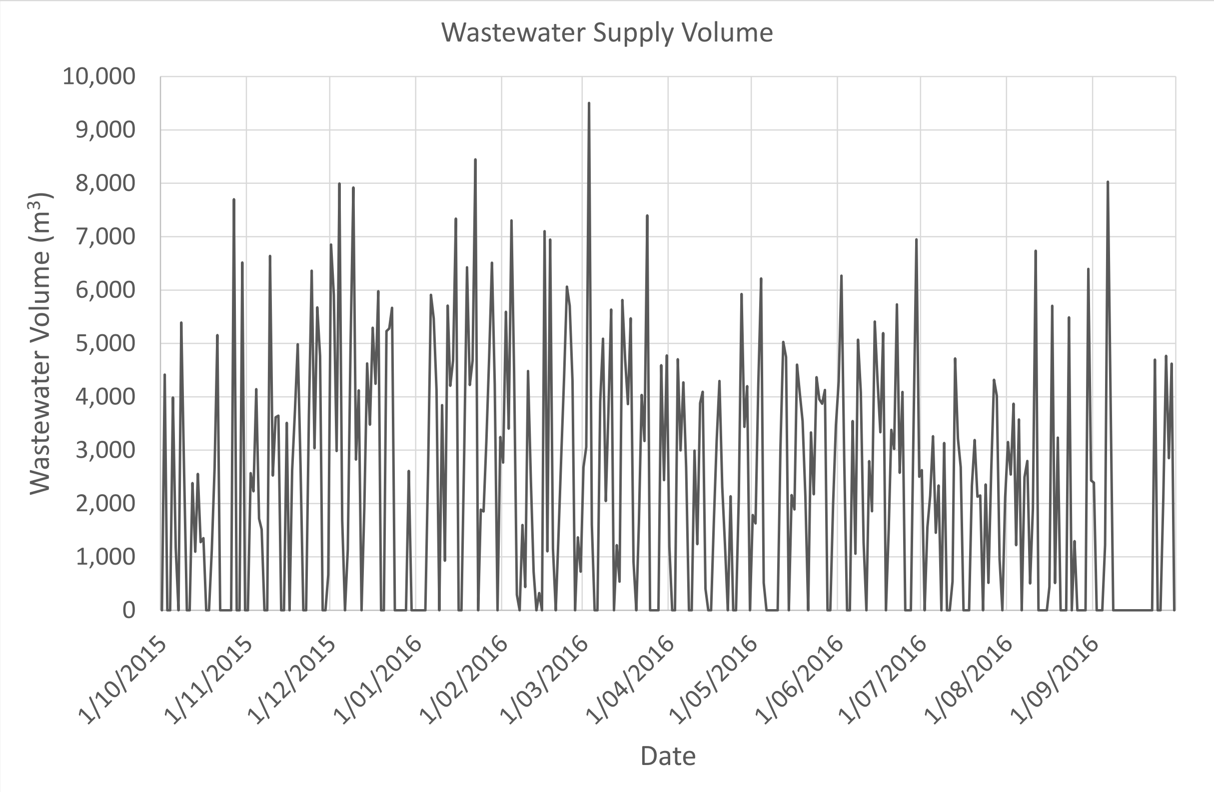

Figure 4: Wastewater Supply Volume

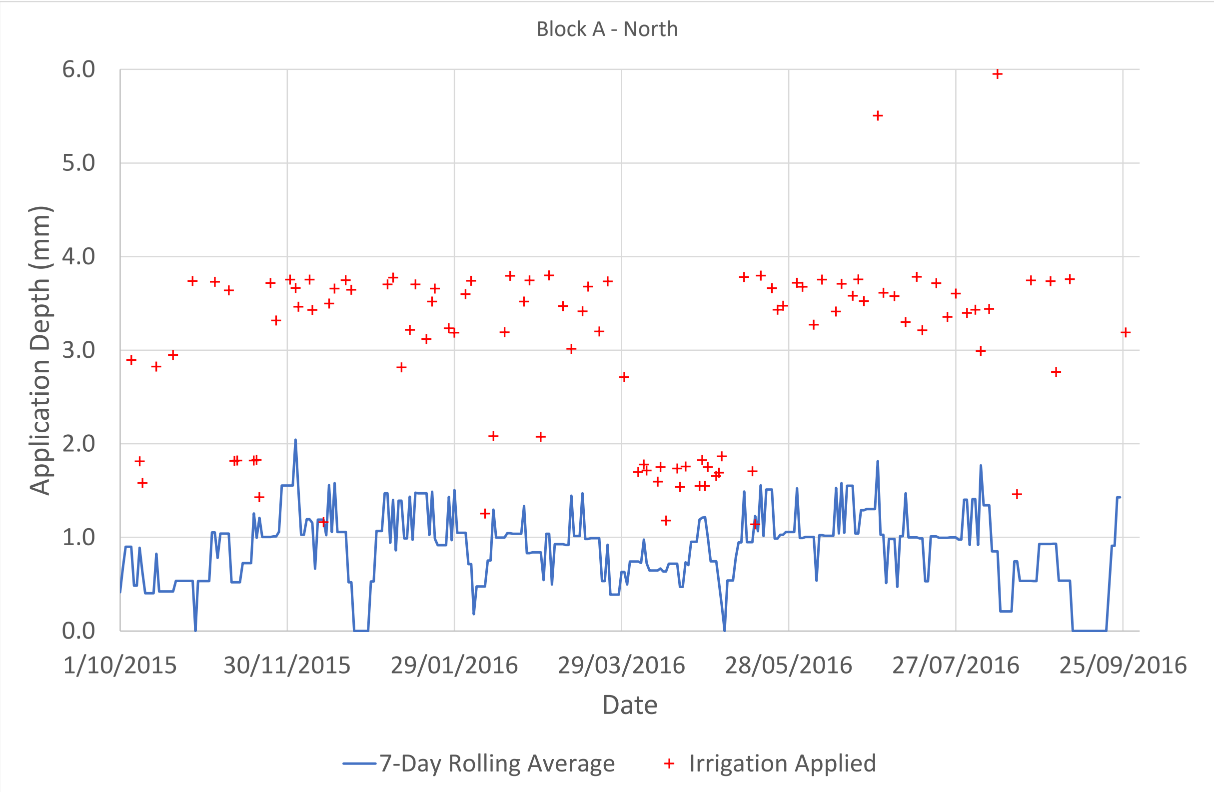

Figure 5: Irrigation applied to block A - North

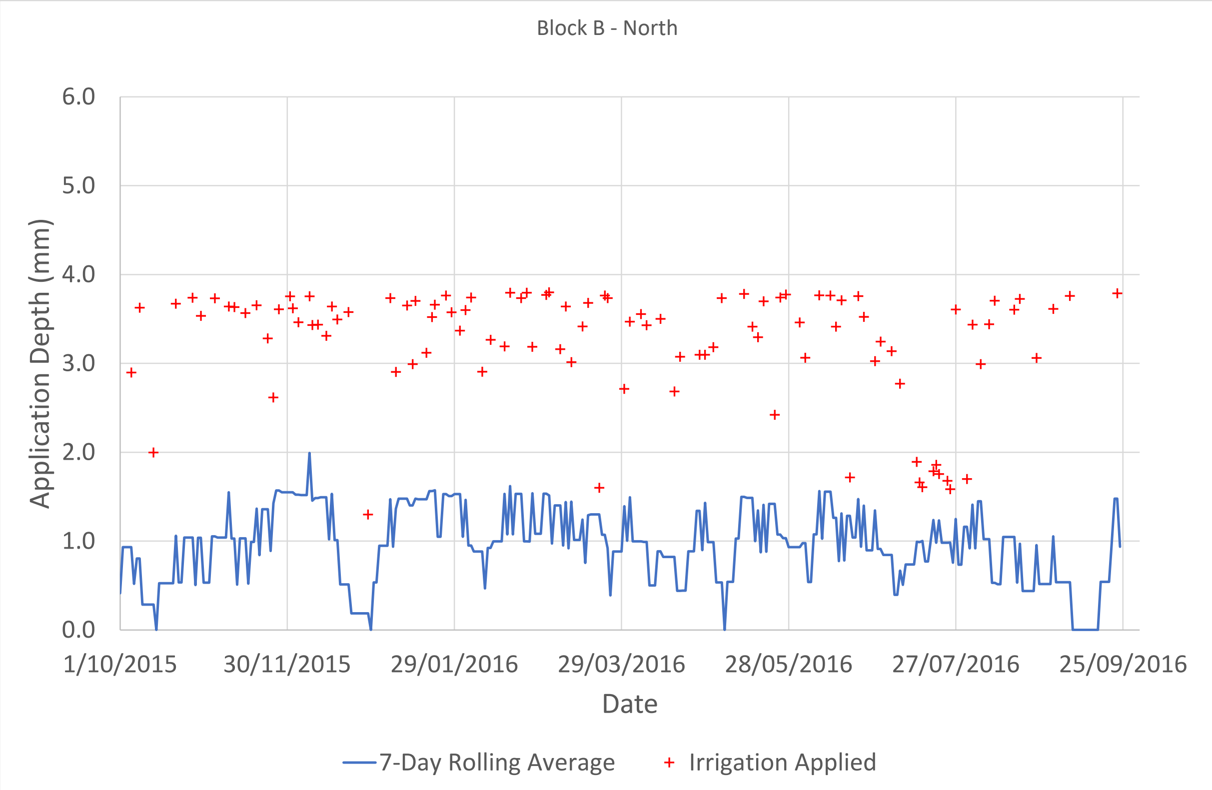

Figure 6: Irrigation applied to Block B -North

6.b) How does management of irrigation scheduling account for half circle pivots i.e. the ends of the pivot get double applications in quick succession (unless the pivot is walked back dry).

The model assumes that on an irrigation day, the water is applied at an application rate over the full irrigation area. The application depth is calculated daily by dividing the volume to the block by the area (the depth is limited by the peak application depth of 3.8 mm under normal circumstances).

In practice the application may occur at a set higher rate over a smaller area (effectively a lower application rate over the entire land area). The weekly irrigation rates in the model are as specified in the Bay Irrigation report. Accounting for the rest period required per block, the 3.8 mm application modelled is the maximum average daily rate which can be applied over a week. As outlined above, future irrigation scheduling (and rates) should be based on soil moisture at the time of irrigation to avoid drainage occurring.

6.c) The operational constraints of the pivots need to be explained, and then this needs to be compared to the way water was applied in the model.

Refer to response to 6.b) above

5) In the conclusion of the PDP report, it tends to suggest that the OVERSEER results should be relied upon, presumably because the leaching rates are less than what is shown in their model. I think this is a very poor conclusion to draw, given that the purpose of the daily modelling was to be calibrated to actual field data, and to assess the leaching under different weather patterns and climate cycles. OVERSEER being an annual load model, cannot achieve this.

The purpose of the modelling was not to calibrate to field data. The modelling provided a comparison of irrigation methods modelled using a daily timestep. No calibration was undertaken as the inputs used was measured data. These inputs were not altered from what was measured in the field, and it would not be considered appropriate to adjust these inputs, which include the recorded irrigation rates, measured concentrations, crop harvest and other information. Where data was not available it was interpolated, as shown in Figure 1. We have also assumed that the soil information is accurate and do not think it reasonable to adjust field capacity information etc to match lysimeter data (for a number of reasons, including our concerns with the reliability/installation method of the lysimeters). Overall, there are no parameters in this model that would be considered reasonable to adjust.

Our conclusion that OVERSEER is more appropriate for the estimation of leached nitrogen is in part due to the higher leaching rates; but this is because we know our model overestimates leaching as it does not account for all the processes that control nitrogen leaching that are accounted for in OVERSEER. Our in-house model is a simple and conservative tool that is useful for comparing leaching between irrigation methods.

OVERSEER is currently widely used as a tool to assess nitrogen leaching for wastewater application to land around NZ, in addition to its standard agricultural use (a recent example of a consented wastewater discharge with an OVERSEER condition is AUTH124824.01.02 for the Tatua Co-operative Dairy Company Limited). We are aware that one of the disadvantages for wastewater applications is it does not model leaching of nutrients at a daily time step (the time step in OVERSEER for leaching is monthly), so in our view it may underestimate leaching when regular exceedances of field capacity occur within a month. However, we still consider it to be more accurate than our in-house model, because it accounts for more processes and does not conservatively assume that all nitrogen will be flushed from the system every day there is an exceedance of field capacity.

Overall, it is considered that OVERSEER is the most reasonable choice of model for the wastewater discharge in this setting and it is widely used and accepted in resource consent processes for wastewater discharges across NZ. In addition, it is the standard method required for assessments of nutrient leaching across the Ruataniwha Plans by HBRC.

However, in this instance, we consider our model provides a useful comparison between relative potential leaching for different irrigation methods, which is what it was set-up to achieve. This comparison would be difficult to achieve with OVERSEER, given the monthly time steps.

7.c) what is the resulting impact of this on groundwater concentrations and downgradient plumes?

The groundwater flow direction is generally to the south-east. Silver Fern Farms have been monitoring the groundwater quality via upgradient and downgradient bores. A detailed description of the groundwater quality is presented in the AEE, Table 2 summarises the existing groundwater nitrogen quality trends as presented in the AEE.

Table 2: Groundwater Quality

	Shallow groundwater water quality
Nitrate-N	Most upstream bores have generally remained stable, expect for bore 15960 which has shown a steady reduction since 2012. 15960 is technically a down-gradient/downstream bore relative to Block D. The downstream bores generally reflect the same patterns as upstream, with bore 4455 showing significant improvements since 2000. The only significantly elevated bore is 15958, although this shows a gradual reduction from elevated levels since 2012. Levels in bore 15638 have increased over time.

Table 2: Groundwater Quality	
Shallow groundwater water quality	
Ammoniacal-N	Ammoniacal-N has been generally low but variable. Upstream bore 15872 is slightly elevated. Downstream bores generally reflect upstream bore patterns with low levels since 2013.
Total Kjeldahl Nitrogen	TKN level have a similar pattern to ammoniacal-N, which is expected given TKN is a measure of ammoniacal and organic nitrogen. Both upstream and downstream bores show similar patterns as upstream. The TKN levels compared to Nitrate-N indicate that most nitrogen leached has been converted to nitrate.
Deep groundwater water quality	
Nitrate-N	Both upstream bores have only returned detections sporadically. In contrast, downstream bore 15871 has remained elevated for most of its monitoring period, while bore 2898 showed an increasing trend and is now more stable.
Ammoniacal-N	Levels in both upstream bores have been low and steady. Most downstream bores reflect the same pattern, with the odd spike in levels.
Total Kjeldahl Nitrogen	A similar pattern to ammoniacal-N occurs in upstream and downstream bores.

The assessment of the groundwater quality in the AEE was based on the current and ongoing operation of the travelling irrigator system. The modelling work comparing the travelling irrigator and the centre-pivot systems shows that there is an expected reduction in the leaching of nitrogen with the centre-pivot system. The centre-pivot system is therefore expected to result in relative improvements in nutrient concentrations in both aquifers, in line with the improvements indicated in Figure 3 of our memo dated 30 June 2020.

3.0 Limitations

This report has been prepared by Pattle Delamore Partners Limited (PDP) on the basis of information provided by Silver Fern Farms Ltd and others (not directly contracted by PDP for the work), including Waterforce Ltd. PDP has not independently verified the provided information and has relied upon it being accurate and sufficient for use by PDP in preparing the report. PDP accepts no responsibility for errors or omissions in, or the currency or sufficiency of, the provided information.

This report has been prepared by PDP on the specific instructions of Silver Fern Farms Ltd for the limited purposes described in the report. PDP accepts no liability if the report 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.

Yours sincerely

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