VARIABILITY IN MODELLING NUTRIENT LOSSES FROM LAND TREATMENT SYSTEMS

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ABSTRACT

This study considers the potential variation in estimated nutrient loss due to data limitations, with a focus on soil properties, and variation due to adopted modelling methodology for nutrient and irrigation input.

For the inputs selected for this study, it was generally found that variation in nutrient loss was most significant due to data limitations, with the impacts of modelling methodology having minor impact on nutrient loss estimates.

Given the potential for variation, and the requirement for certainty in regulation, this study indicates that the regulation of nutrient losses from land treatment systems should not rely on Overseer® modelling of land treatment systems using default or inferred soil inputs.

Keywords: Overseer; Nutrient Loss Modelling, Variation.

INTRODUCTION

Land Treatment in New Zealand

Land treatment of wastewater via irrigation is widely practiced throughout New Zealand for both municipal and agro-industrial wastewaters. The use of land for the management of the disposal of wastewater has also been actively promoted by regional authorities throughout New Zealand over the past 20 to 30 years, not only to provide a disposal route to minimise direct discharges to surface water, but also for water reuse and as a nutrient resource for agricultural and forestry land-use activities. This has resulted in large investment in land purchase and irrigation systems for conversion to land treatment systems, which are often incorporated with complimentary farming activities.

In recent years there has been a drive from regional authorities for sustained net reductions in consequential nutrient leaching to groundwater from farming activities. One of the main mechanisms for the management of this control is the widely accepted use of the farm nutrient management model Overseer® developed by Overseer Limited.

Overseer® Use in New Zealand Land Treatment

The Overseer® nutrient budget model is a New Zealand industry standard for assessing nutrient uptake and/or leaching from agricultural activities such as sheep, beef and dairy farms, including systems where fertiliser application and irrigation occur. Due to the common use of farm land for land treatment systems, Overseer® is also now utilised to assess nutrient loss from land treatment systems. Overseer® is also being enforced by regulators as a de-facto tool to be utilised for identifying nutrient loss from land treatment systems. While

Overseer® may be a tool to assess nutrient loss management at farm level, the extension of its use is fraught with difficulties.

Overseer® has a number of limitations including an output results uncertainty range of ± 30% for models that sit within an agreed validation range. The level of output data uncertainty increases for more un-validated models such as bespoke land treatment systems modelling, and where the level of input data/accuracy is limited, or where there exists the potential for variation in modelling methodology.

Despite its limitations, Overseer® is an appropriate management tool currently available for assessing nitrogen losses below rooting depth, including when land treatment activity is incorporated into the farming operations. However, as a regulatory tool where confidence in results is required, the limitations are questionable with respect to reliability and validity of repeatable output.

Although direct field testing of leachable fraction through lysimeter monitoring can provide an indication of actual potential for leaching and for Overseer® model validation, the amount of variability in such field programmes generally preclude extensive use of comprehensive field lysimeter monitoring and its reliability for assessing leaching. To this end, the regulators generally rely on Overseer® model to assess and monitor compliance with consents.

Data Limitation and Input Methodology

In order to utilise Overseer® to estimate nutrient leaching, it is key to have sufficient input data to create a representative model of the land treatment system. However some data is not always readily available, such as site specific soil investigation information. Were available data is limited, reliance on default soil information within Overseer® and from resources such as S-map (Landcare Research NZ Ltd., 2018) is common. Reliance on this data can create variation from more representative Overseer® nutrient loss estimates were site specific soil investigation data is used.

In addition to potential limitations in available data for land treatment sites, there exists a level of latitude in the way in which some data is incorporated into Overseer®. Although Overseer® User Input guidelines provide guidance on methodology for data input into Overseer, this is primarily relating to farm system inputs. With the exception of some dairy wastewater streams (whey protein concentrate etc) there are not specific inputs or specific guidance on wastewater or treated wastewater inputs into Overseer®. This allows the user choice in methodology to input certain data into Overseer® models of land treatment systems, and can result in variation in nutrient loss estimates for similar nutrient loading rates, based on the method of input.

Given the wide spread use of Overseer® to; estimate nutrient loss from land treatment systems, assess the effects of the land treatment and farm operation activity, and to regulate these activities under resource consents, an understanding of the variability in resulting nutrient loss estimates caused by modelling methodology and data limitations requires further investigation.

METHODOLOGY

Input Variation

In order to assess the variability in nutrient loss estimates for land treatment systems assessed with Overseer®, a generalized land treatment system was considered, and then various inputs modified to assess the impact of these changes.

Overseer® inputs investigated included both input methodology, i.e. different methods for inputting known data, and input limitations, i.e. variation in input based on limited or incorrect data.

The inputs considered included the following:
Data Limitation Inputs:

1. Soil Type.
2. Soil Profile Limitations (Rooting Depth, Depth to Impeded Drainage).
3. Soil Nutrient Data.

Data Input Methodology :

4. Nutrient Input (Fertilizer input/form, irrigation nutrient content input).
5. Irrigation input (Irrigation supply, irrigation applied).

Baseline Land Treatment System

For the baseline Overseer® model, a land treatment system located in the Hauraki Plains of the Waikato Region was assumed, discharging treated wastewater to a dairy farm operation. The land treatment system is summarised in Table 1 below. When developing the land treatment Overseer®, default setting were generally utilised for inputs not covered below. Specific input data and its variation is discussed further in subsequent sections.

Table 1: Land Treatment System Information

Site Information		Farm Information		Land Treatment Information	
Region	Waikato	Land Use	Dairy Farm	Hydraulic Loading	235 (mm/yr)
Area	100 ha	Stocking Rate	2.95 cows/ha		
Climate	Overseer Tool Co-Ordinate Tool	MS production	358 kg/cow	Nitrogen Loading[1]	300 (kg N/ha/yr)
		Supplement Feed	183 tonnes (Hay)		
Soil	Te Puninga (Impeded Allophanic)	Pasture growth	14,979 kg DM/ha/yr	Phosphorus Loading[2]	100 (kg P/ha/yr)
		Dairy Effluent	Exported Offsite		

Notes:

1. *Nitrogen input as Fertilizer Form "NH_4".*
2. *Phosphorus input as Fertilizer Form "Other".*

The baseline estimated nutrient loss for the land treatment system is 57 kg N/ha/yr nitrogen leaching, and 0.3 kg P/ha/yr phosphorus. Variation in estimated nutrient loss is described as a percentage change from tis baseline nutrient loss.

RESULTS AND DISCUSSION

Data Limitation Inputs

Soil Type

S-map data is usually utilised when modelling a land treatment system in Overseer® unless site specific soil mapping by qualified personnel has been carried out. This is a specialist skill, and site specific soil mapping may not always be available.

The accuracy of S-map soil locations varies from region to region, however, based on field experience and observations, the extent of soil types within the Waikato Hauraki Plains region can vary significantly at the farm scale. It is expected that topography information is a key input into the S-map derived soil locations/extent, with gleyed soils such as Waitoa expected to be located in lower lying areas. Limitations on the level or scale of topographic information may contribute to S-map variation from site investigation data. Four soils were considered from this area, Te Puninga, Ngakura, Waitoa and Ngarua soils.

Nutrient loss estimate results provided (Table 2, Fig 1, and Fig 2), show that the variation in nitrogen leaching was relatively minor between Te Puninga (baseline), Waitoa and Ngakura soils (5.3%). For the Ngarua soil the difference in nitrogen loss was higher (15%). This is likely due to variation in pore volumes within the soils. Ngarua has a lower pore volume than other soils which are relatively similar. Lower soil pore volumes promote nitrogen leaching through increased 'rinsing' of the soils for a given drainage depth.

For phosphorus loss, the variation was pronounced, with up to a 367% difference in estimated phosphorus loss from the baseline Allophanic soil to the varied gleyed soils. This is due to the higher Anionic Storage Capacity (ASC) of Allophanic soils, which binds phosphorus more strongly within the soil, and reduces runoff potential.

The potential for different soil types from that indicated in S-map to be underlying areas of land treatment will vary from region to region, however, the results of this assessment indicates that incorrect soil type inputs can have a significant impact on nutrient loss estimates, especially phosphorus.

Soil Profile Limitations

Soil profile limitations considered include soil rooting depth limit and depth to impeded drainage. A limit to rooting depth could be anoxic soil conditions, or a dense or hard layer of subsoil, similarly denser and less permeable subsoil can represent an impeded drainage layer.

The default settings within Overseer® is for these soil profile limitations is 'none' or 60 cm, which is the maximum depth across which the Overseer® modelling software assesses nutrient transfer and water balancing prior to drainage to groundwater occurring.

Reduced rooting depth and depth to impeded drainage both resulted in increased nitrogen leaching estimates in the Overseer® assessment results (Table 2, Fig 3, and Fig 4) with increased nitrogen loss ranging from 12.3% to 43.9% above the baseline (default). This is expected, as reduced rooting depth and depth to impeded drainage both restrict the soil depth over which nutrient and water balancing can occur, resulting in greater loss of nitrogen to groundwater drainage.

Table 2: Land Treatment System Overseer Results - Nutrient Loss and Variation				
	Nitrogen Loss[1] (kg N/ha/yr)	**Change (% of Baseline)**	**Phosphorus Loss[2] (kg P/ha/yr)**	**Change (% of Baseline)**
Soil Type				
Te Puninga (Baseline)	57	0.0%	0.3	0.0%
Soil Ngarua	66	15.8%	1.4	366.7%
Soil Ngakura	60	5.3%	0.2	-33.3%
Soil Waitoa	60	5.3%	1.1	266.7%
Soil Profile – Rooting Depth Limit				
None (60cm, Baseline)	57	0.0%	0.3	0.0%
50 cm	69	21.1%	0.3	0.0%
40 cm	82	43.9%	0.3	0.0%
Soil Profile – Impeded Drainage Depth				
None (60cm, Baseline)	57	0.0%	0.3	0.0%
50 cm	64	12.3%	0.3	0.0%
40 cm	74	29.8%	0.3	0.0%
Soil Nutrient Olsen P Data				
32 mg/L (Default/Baseline)	57	0.0%	0.3	0.0%
60 mg/L	57	0.0%	0.4	33.3%
120 mg/L	57	0.0%	0.7	133.3%
150 mg/L	57	0.0%	0.8	166.7%
Nutrient Input				
Fertiliser form (NH_4, Other) (Baseline)	57	0.0%	0.3	0.0%
Fertiliser form (NO_3, Other)	57	0.0%	0.3	0.0%
Fertiliser soluble (Urea, superphosphate)	56	-1.8%	0.3	0.0%
Irrigation content (TN, TP)	64	12.3%	3.0[3]	900.0%
Irrigation Input				
Irrigation Supply (Baseline)	57	0.0%	0.3	0.0%
Irrigation Applied (Default)	58	1.8%	0.3	0.0%

Notes:

1. *Nitrogen loss through leaching, urines and other.*
2. *Phosphorus loss through runoff, except where noted.*
3. *Phosphorus loss: 0.2 kg P/ha/yr runoff, 2.8 kg P/ha/yr leaching.*

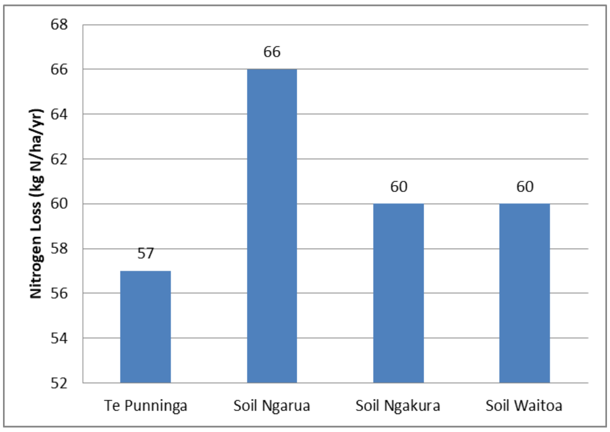

Fig. 1. Soil Type Variation - Nitrogen

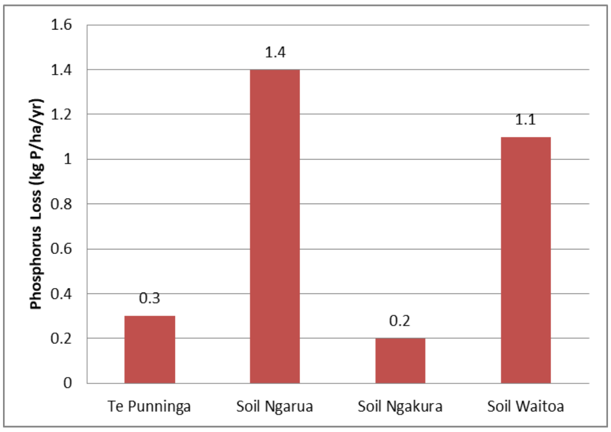

Fig. 2. Soil Type Variation - Phosphorus

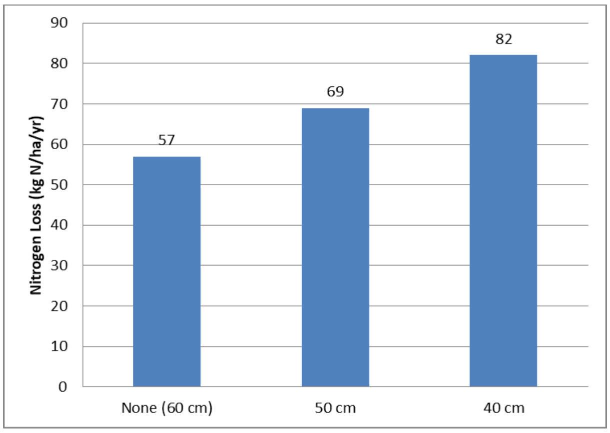

Fig. 3. Soil Rooting Depth Variation

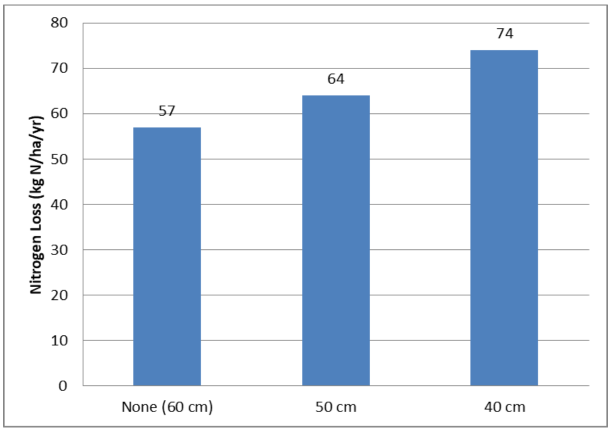

Fig. 4. Soil Impeded Depth Variation

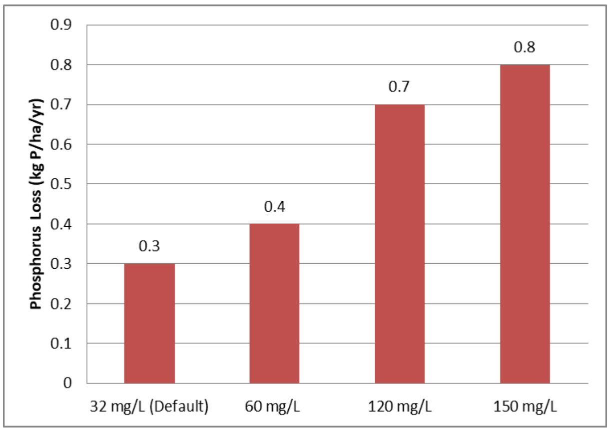

Fig. 5. Soil Nutrient Olsen P Variation

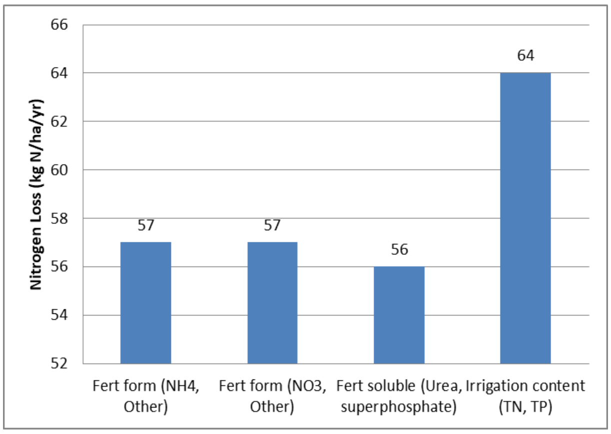

Fig. 6. Nitrogen Input Variation

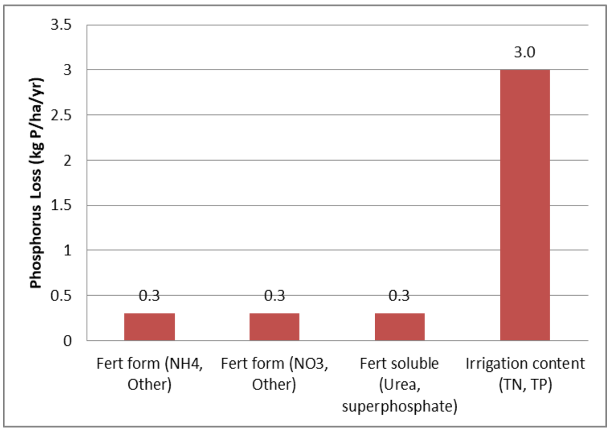

Fig. 7. Phosphorus Input Variation

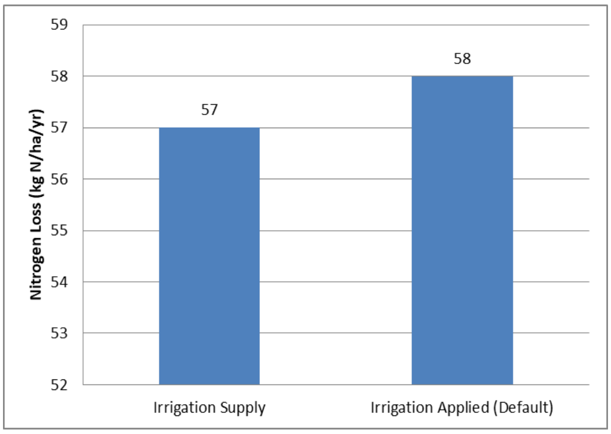

Fig. 8. Irrigation Input Variation

Unless site specific soil investigations are undertaken, it is likely that default soil profile limitations would be used in Overseer® modelling. Limited site specific soil data therefore represents the potential for rooting depth and depth to impeded drainage limitations and a significant variation in nitrogen loss estimates.

As the loss of phosphorus from soils is predominantly through runoff, the variation of soil profile limitations did not have a discernible impact nutrient leaching.

Soil Nutrient Data

For this study, the focus of soil nutrient data was soil Olsen P levels, and the effect of varied inputs on estimated phosphorus loss. Olsen P is an indirect measurement of plant available phosphorus within soil. Overseer® also utilises Olsen P inputs in estimating phosphorus loss. Increased soil Olsen P levels result in increased phosphorus runoff loss.

The default value for Te Puninga soil is 32 mg/L Olsen P, which was utilised for the baseline model. Overseer® assessment results (Table 2, Fig 5) show that increases to 60 mg/L, 120 mg/L, and 150 mg/L Olsen P resulted in increased phosphorus loss above the baseline of 33%, 133% and 167% respectively. This indicates significant sensitivity to Olsen P input data.

Although the Olsen P levels considered are elevated, it is estimated within Overseer that the modelled phosphorus loading of 100 kg P/ha/yr will maintain an Olsen P of 150 mg/L. This means that at the assessed loading rate, Olsen P would increase until an Olsen P of 150 mg/L is achieved and then that Olsen P would be sustained.

It is estimated that Olsen P would initially increase at a rate of approximately 10 mg/L Olsen P per year from the default level of 32 mg/L, based on a modelled accumulation of 65 kg P/ha/yr, and a phosphorus capital increase rate of 7 kg P per unit of Olsen P (Fert Research 2016). This increase would not be linear, with rapid increase in Olsen P initially slowing over time as soil Olsen P increased. Phosphorus loading of 100 kg P/ha/yr is not uncommon for some industrial land treatment systems.

The variability assessed, and the rate at which Olsen P can increase at elevated phosphorus loading rates, indicates limited Olsen P soil data for existing and ongoing land treatment systems is a potential for significant inaccuracies in phosphorus loss estimates, and default soil Olsen P levels should not be relied on.

Data Input Methodology

Nutrient Input

The annual distribution of nutrient loading to the land treatment system is provided in Fig 8 below.

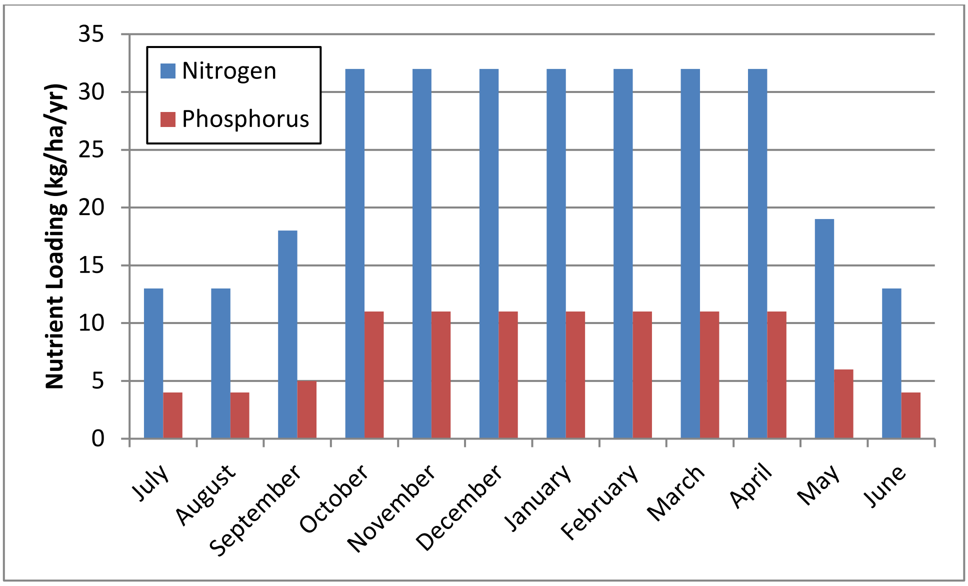

Fig. 9. Annual Nutrient Loading Distribution

There are a number of options available for the input of nutrients into Overseer®. In this study we assessed the following:

- Fertilizer form input (baseline): Allows the form of nutrient to be selected from a number of products and forms, including ammoniacal nitrogen (NH4-N), nitrate nitrate (NO_3-N), and "other" phosphorus, which were utilised for this study.
- Soluble fertilizer input: This monthly input of fertilizer assumes all nitrogen application is in the form of urea, and all phosphorus in the form of superphosphorus.
- Nutrient concentration in irrigation water: This allows the concentration of nutrients within the irrigated treated wastewater to be set. This does not allow monthly variation in nutrient content, assuming consistent nutrient content throughout the year.

Organic nitrogen was not considered as the land treatment system was for the discharge of treated wastewater, expected to have relatively minor levels of organic nitrogen.

Note that where fertilizer input options are utilised, the input of nutrient free irrigation water is still required, as exclusion of this hydraulic loading will underestimate drainage from soils and therefore provided underestimates of nitrogen loss.

The results (Table 2, Fig 6 and Fig 7) show that the variation between fertilizer input method is relatively minor for nitrogen and phosphorus, up to 1.8% and 0.0% variation from the baseline respectively.

The variation for the irrigation nutrient content input option is significant however, with an increase of 12.3 % and 900% above the baseline for nitrogen and phosphorus respectively. The loss of phosphorus is also predominantly through phosphorus leaching, which does not occur in any other models.

The cause for this increase in estimated nutrient leaching is not clear. The results from the NH4-N and NO_3-N fertilizer input models, which have equal nitrogen loss estimates, indicate that this change is not the result of the assumed form of nitrogen in irrigated treated wastewater. It is considered that the Overseer® modelling software may not be calibrated or validated for the modelling of high nutrient load irrigation water to land.

Although the nutrient input of irrigated treated wastewater as an irrigation nutrient concentration may appear logical, this may not align with the recommended use of the Overseer® modelling software. The Overseer® user guidelines (Overseer® Management Services Limited, 2015), recommend that "fertigation" nutrient applications to farm land are input as a monthly fertilizer application rather than as an irrigation nutrient concentrations.

Given that wastewater and treated wastewater is generally nutrient rich, it is considered that the input of land treatment nutrients follows the guidance laid out for "fertigation" nutrient application. For highly treated wastewater, as discharged from some advanced municipal or industrial wastewater treatment plants, there may be a potential to model treated wastewater nutrients as irrigation concentrations, however, without a better understanding of the modelling limitations for irrigation nutrient content this presents a risk of significant variation in assessed nutrient loss estimates.

Irrigation Input

The actual calculated irrigation loading depth, based off the volume of treated wastewater and the area of irrigation land cannot be entered directly into Overseer® models.

The Overseer® irrigation input is "applied irrigation depth", the water depth actually received by irrigated soils. The actual supply of water will be greater than this value, due to supply and atmospheric losses of water before it reaches the receiving soils, which is assessed in the Overseer® modelling software.

Generally farm operators will determine the irrigation requirements of the pasture, and input this data into the Overseer® model. Overseer® then provides the irrigation supply depths required to achieve this irrigation application depth, based on assumptions around 'system losses' such as delivery losses and loss to atmosphere of supplied irrigation wastewater.

However, for land treatment systems, the supply of wastewater is known. Table 3 below outlines that actual treated wastewater supply, as well as the two irrigation input options considered and the assessed modelled supply of treated wastewater resulting from these input options, including:

1. Input of actual supply as applied irrigation input.
2. Input of synthetic applied irrigation input to achieve correct actual supply as modelled supply output

Table 3: Irrigation Input Variation

Month	Jul –Aug[1]	Sep[1]	Oct -Apr[1]	May[1]	Jun[1]	Annual Total[2]
Actual supply	10	15	25	15	10	235
Supply as Applied Input	10	15	25	15	10	235
Model Supply Output	*10*	*16*	*26*	*16*	*10*	*244*
Synthetic Input	10	14	24	14	10	226
Model Supply Output	*10*	*15*	*25*	*15*	*10*	*235*

Notes:

4. *Units in mm/month.*
5. *Units in mm/year.*

The method of using actual supply as an input results in a modelled supply of 244 mm/yr, 9 mm/yr more than the actual supply of 235 mm/yr. However, this results in only minor variation from the baseline of 1.8% and 0.0% for nitrogen and phosphorus loss respectively.

CONCLUSIONS

The variation in estimated nutrient loss due to modelling methodology was found to be either minor, or where the variation was not minor as for the input of nutrients as irrigation concentrations, the methodology is not considered in be in line with the recommended Overseer® inputs and should be avoided in the modelling of land treatment systems. Excluding variation for the input of nutrients as irrigation concentrations, the variation for modelling methodology was low, ranging between -1.8/+1.8% from baseline for nitrogen loss, and 0.0% for phosphorus.

There is significant risk of variation in estimated nutrient losses where there is reliance on Overseer® default inputs or incomplete site specific information, rather than use of data based on sufficient site investigation information. Based on the findings of this study, variation for soil data input limitations ranged from 5.3% to 43.9% from baseline for nitrogen and -33% to 367% from baseline for phosphorus. This is a significant variation, especially for phosphorus.

Although this study is just a snapshot of the potential variation in nutrient loss estimates from changes in input for a particular area, it indicates that limited data has a greater impact on nutrient loss estimates than the adopted modelling methodology.

Given the potential for variation, and the requirement for certainty in regulation, this indicates that the regulation of nutrient losses from land treatment systems should not rely on Overseer® modelling of land treatment systems using default and inferred soil inputs.

The potential for variation where insufficient data for modelling inputs is available adds further uncertainty to the acknowledged uncertainty range for calibrated Overseer® modelling results of +/- 30%.

This further supports ongoing discussions around the need for alternative assessments in addition to Overseer® modelling to assess the effects of farm and land treatment systems (Parliamentary Commissioner for the Environment, 2018). Potential alternatives to assess or monitor the impacts of land treatment activities include groundwater or surface water monitoring and modelling

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