MINIMISING NUTRIENT LOSS - WHERE BEST TO TWEAK

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ABSTRACT

This paper explores challenges that are being faced by land treatment system managers, investigating which components of land treatment/farm management practices can be altered to provide nutrient loss mitigation, while maintaining viable farming systems.

Overseer® modelling was carried out to assess the effects of various management options on reducing nitrogen leaching for a conceptual Waikato combined dairy farm and land treatment system. Various soil properties have also been modelled to assess potential mitigation of nutrient losses when selecting new land treatment sites.

Modelling assessment results indicate mitigation through further wastewater treatment can be limited and that expanding irrigation area to reduce hydraulic and nitrogen loading may provide very little benefit depending on the surrounding land use. Modelling indicates that standoff pads and stocking rate reduction are more significant factors for lower nitrogen leaching.

The results of the modelling indicated that nitrogen losses can be higher for well drained soils. This shows that conventional thinking, where well drained soils are generally preferred for hydraulic management in land treatment systems, does not necessarily provide optimum land treatment for nitrogen removal. In addition, variables such as shallow free draining layers and limited rooting depths have a significant bearing on nitrogen leaching potential.

KEYWORDS

Land Treatment, Overseer®, Nitrogen Leaching

1 INTRODUCTION

Land treatment of wastewater through the irrigation of wastewater to land is widely practiced throughout New Zealand for both municipal and industrial wastewaters. Land treatment of wastewater has been promoted by regional authorities throughout New Zealand, not only to provide a disposal method to minimise discharges to surface water but also as an irrigation water supply and nutrient resource for agricultural and forestry land-use activities.

Over the past 20 to 30 years there has been a progressive push from regulatory authorities for treated municipal and industrial wastewater to be irrigated to land rather than discharged directly to surface water. This has resulted in large investment in land purchase and irrigation systems for conversion to land treatment systems, which are often incorporated with independent farming activities.

Land treatment systems in New Zealand are often a combination of seasonal irrigation to land and discharge to surface water during wetter seasons when irrigation is not feasible. A dual discharge system allows the discharge of wastewater to land during drier periods when the demand by land-use activities for water is high. This is also generally when surface water bodies such as rivers are at low flows and most vulnerable to the effects of wastewater discharge. During wetter periods, when soil moisture conditions are generally less likely to be conducive to irrigation, surface water flows are higher and the effects of dilution help to mitigate surface water discharge.

In recent years there has been a drive from regional authorities for net reductions in nutrient leaching rates to groundwater catchments, with the farm nutrient model Overseer® being the recommended tool for managing farm nutrient use to minimise nutrient losses to the receiving environment. The Overseer® nutrient budgets model is a New Zealand industry standard for assessing nutrient uptake / leaching for agricultural activities such as sheep, beef and dairy farms, including systems where fertilizer application and irrigation occur.

Due to the common use of farm land for land treatment systems, Overseer® is also being promoted by regulators as a tool to be utilised for identifying nutrient loss from land treatment systems. While Overseer® may be an effective tool to identify nutrient loss management measures at farm level, these measures do not necessarily accommodate land treatment systems, due to the need to irrigate outside of normal agronomic requirement.

One of the major challenges currently faced by land treatment system managers, is how to maintain a land treatment system and achieve a reduction in nutrient leaching rates, yet also not substantially alter farm practices. This is especially challenging when the land treatment system is operated on land owned by farming operators independent of the wastewater source, as their priority will be to operate the farm efficiently rather than to optimise a wastewater disposal system.

This paper explores the challenges that are being faced by land treatment system managers and, with the aid of Overseer®, investigates which land treatment and farm management practices can be altered to minimise nutrient loss, while still maintaining viable economic farming systems.

This paper also explores what parameters are optimal for minimising nutrient leaching to assist with identifying the best areas for new land treatment systems. Historically, the mitigation of the effects from land treatment systems has focused on the hydraulic capacity of receiving soils to accept wastewater irrigation without causing runoff to surface water, damage to soil or excessive groundwater mounding. Conventional thinking for land treatment systems has been that well drained soils, with high infiltration rates, are better suited to receiving wastewater irrigation than soils with lower infiltration rates and impeded drainage. More recently, Overseer® modelling suggests that higher infiltration rates result in elevated nutrient losses to groundwater, challenging conventional thinking.

As most New Zealand soils generally have appreciable phosphorus retention capacity, this paper has focused only on mitigating loss of nitrogen to groundwater through leaching. Loss of phosphorus from land treatment systems is dependent on soil type, retention capacity and topography, and therefore very site specific.

2 METHODOLOGY

2.1 CONCEPT

A conceptual base scenario for a land treatment and farming operation was developed within Overseer® in order to allow land treatment/farm management variables to be manipulated to identify potential impacts on nitrogen losses. The conceptual model was based on a combined dairy farming and land treatment operation in the Waikato region, receiving treated industrial wastewater as well as fertiliser. For this scenario it was assumed that there is a dual discharge system, and that wastewater not applied to the land treatment system during wetter months is discharged to surface water. Dual discharge systems are common through New Zealand and within the Waikato region where soils conditions are not ideal for irrigation during wetter months of the year.

Modelling of high intensity land-use systems such as dairy operations, which generally have higher nitrogen losses through leaching than sheep or beef farming operations, will indicate the effects of variable manipulation with greater clarity than modelling low intensity systems. Notwithstanding this, it is considered that the assessment of mitigation options for the modelled dairy farm land treatment operation will be applicable to sheep or beef farm land uses. Cut and carry and other cropping operations are already well understood to be an effective way to reduce nitrogen losses to groundwater and therefore are not included in this assessment.

For a land treatment system, it is often unclear as to whether excessive nitrogen leaching is primarily an effect of the land-use, hydraulic flushing from over irrigation, or the nitrogen loading from wastewater irrigation and/or fertiliser loading. Therefore, four scenarios including the base scenario were modelled (refer to Section 2.1.2). Once the base scenario was in place, the effectiveness of changing variables within the confines of an existing land treatment and farm operation, to mitigate nutrient losses to groundwater, was undertaken. The base scenario was also used to model nutrient losses for different soil properties in order to identify potential nitrogen losses when selecting sites for future land treatment areas. Mitigation options are outlined in Section **Error! Reference source not found.** below.

2.1.1 OVERSEER® ASSUMPTIONS

The Overseer® model is based on three assumptions:

1. Long term annual average conditions.
2. Near equilibrium conditions exist.
3. Actual and reasonable inputs used.

To assess potential mitigation options we were unable to fully conform with the third assumption as the variables being manipulated are hypothetical not actual. However, all modelling inputs are considered reasonable.

2.1.2 SENARIOS MODELLED

In order to provide context, demonstrating the effect of fresh water irrigation and wastewater irrigation on nitrogen losses when compared with non-irrigated farming operations, four initial scenarios were developed:

- Farm receiving fertiliser and no irrigation.
- Farm receiving fertiliser and fresh water irrigation.
- Farm receiving wastewater irrigation and no fertiliser.
- Farm receiving wastewater irrigation and fertiliser (base scenario).

The following farm and land treatment operation variables were then investigated for their effect on nitrogen loss mitigation for the base scenario. The variables investigated are those which are considered reasonably feasible for implementation within a land treatment system on an independently owned dairy farm operation:

- **Wastewater Treatment:** The level of pre-treatment of wastewater before it is irrigated to the land treatment system, reducing the nutrient load in the wastewater applied to land.
- **Irrigation Depth:** The effect of reducing the volume of wastewater applied to each hectare of the land treatment area, reducing the volume of water and nutrient load (associated with the wastewater) applied to land.
- **Stocking Rate:** The number of stock (dairy cows) per hectare of land on the land treatment area, i.e. lowering the land use intensity to reduce nutrient return from stock to land.
- **Timing of Land Treatment Application:** The months in which wastewater is applied to the land treatment area rather than discharged to surface water, reducing the volume of water and nutrient load applied to land in wetter winter shoulder months when leaching is most likely to occur.
- **Standoff Pads:** Placement of stock onto standoff pads to reduce nutrient return from stock to land.

The base scenario was also used to model nutrient losses for different soil properties in order to identify potential mitigation of nutrient losses when selecting new wastewater irrigation sites, including:

- **Soil Drainage Properties:** Different soils with a range of drainage properties were modelled to assess the effect of soil drainage properties on nitrogen losses to groundwater.

- **Rooting Depth:** The effect of rooting depth on nitrogen losses to groundwater was investigated to assess the significance of this factor for nitrogen loss mitigation.

- **Stony Soil Layers:** The effect of a stony soil layer, which may be present in a well-drained soil, on nitrogen losses to groundwater was investigated to assess the significance of this factor for nitrogen loss mitigation.

2.2 OVERSEER® MODEL INPUTS

The following sections outline the various inputs utilized for the different Overseer® models in order to obtain the nitrogen leaching rate estimates outlined in Section 3.

In order to provide a concise summary of inputs, inputs for the base scenario where the Overseer® default values used have been omitted from this summary. For all other scenarios, only inputs that differ from the base scenario inputs have been recorded to avoid repetition.

2.2.1 BASE SCENARIO

The basis of inputs into the base scenario Overseer® model are outlined in Table 1 below.

Table 1: Overseer® Inputs for Base Scenario

Parameters	**Overseer® input**	**Justification**
Farm Scenario		
Location	Waikato Region	Selected scenario location.
Blocks	100 ha Pastoral	This was assigned to obtain an average per ha results.
Enterprises (stock)	Dairy	
Structures	None	No standoff or wintering pads
Dairy effluent system	All exported	In order to simplify the scenario s and presentation of data, dairy effluent has been assumed to be exported offsite except for the standoff pad scenarios. However, scenarios which included separate blocks for dairy effluent were run and the effects mitigation measures on the separate dairy effluent block were minor, with the exception of standoff pads.
Supplementary feed	0.52 t DM/cow/year 170 t DM/year Hay (average quality)	The supplement feed requirements were estimated based on stocking rate, the relationship between stocking rate and pasture consumption described in literature (MacDonald et al, 2001) and average monthly pasture growth for the Waikato region (Dairy NZ, 2010).
Enterprise		
Numbers	330 dairy cows (milking herd – Friesian and Jersey cross)	The average stocking rate for the Waikato region is 2.95 (Dairy NZ stats, 2014) however, a higher stocking rate was selected so that the effects of reducing stocking rates could be more

	3.3 cows/ha	clearly demonstrated.
Average mob weight	469 kg/cow	Based on stocking rate and the relationship between stocking rate and mob weight described in literature (MacDonald et al, 2001)
Production	353kg milk solids/cow/yr 116,490 kg milk solids/year (Never once a day milking, i.e. twice a day milking)	Based on stocking rate and the relationship between stocking rate and milk solids production described in literature (MacDonald et al, 2001)
Block		
General	Flat, 40 km from coast.	As we are concerned with nitrogen losses to groundwater, not runoff, a flat site was selected.
Mean annual rainfall	1,250 mm/yr	Based on rainfall data for a site in the Waikato region.
PET seasonal variation	Low	Typical within Waikato region
Supplements made	none	
Soil Description	Waihou S-map ling: Ngak_9a.1	Common within the Hauraki Plains of the Waikato region.
Rooting Depth	Limited to 40 cm	Rooting depth can generally reach up to 60 cm for pastures, however, the majority of root mass occurs above 30 cm. A restricted rooting depth of 40 cm will result in a higher nitrogen leaching rate and provide comparison with unrestricted and variable rooting depths.
Pugging	Rare	As a well-drained soil it is unlikely to be affected by pugging.
Pasture type	Ryegrass/white clover (medium clover content)	Default setting
Irrigation wastewater concentrations	Total nitrogen (TN):30 mg/L Total phosphorus: 4 mg/L Potassium: 45 mg/L. Sulphur: 26 mg/L.	Typical treated industrial wastewater concentrations.
Irrigation management	25 mm/month October – May Inclusive	25 mm/month is based on industrial wastewater land treatment systems in the Waikato region. The timing of irrigation extends further into Autumn than is typical for land treatment systems. Although there are

		systems that operate in this manner, this irrigation period was selected so that the effect of altered irrigation periods could be observed in mitigation scenarios.
Irrigation nitrogen load	~60 kg-N/ha/year	
Fertiliser application	DAP:157 kg/ha/application (1 application, Sep) Urea: 26 kg TN//ha/application (4 applications Aug, Sep, Nov, Jan) Lime: 35 kg/ha/month (4 applications Aug, Sep, Nov, Jan)	Based on phosphorus, potassium and sulphur requirements to maintain soil fertility estimated from maintenance rates for various stocking rates as outlined in literature (New Zealand Pastoral Agricultural Research Institute Ltd and Dairying Research Corporation Ltd, 2009). The nutrients already supplied by wastewater are considered before determining fertilizer requirement.
Fertiliser nitrogen load	~140 kg-N/ha/yr	
Total nitrogen load	200 kg-N/ha/yr	Additional nitrogen fertiliser was applied to achieve a total nitrogen loading of 200 kg-N/ha/year. This is considered in line with nitrogen loading practices for high intensity farming operations, but is at the upper end of suggested nitrogen loading for pasture identified in literature (Fert Research, 2009).

2.2.2 NO IRRIGATION (FERTILIZER ONLY) SCENARIOS

In order to model nitrogen losses from a non-irrigated dairy farm, the irrigation inputs for the base scenario were removed. A range on fertilizer inputs were utilised in order to model the nitrogen losses from the dairy farm pasture for varying nitrogen loading rates. The inputs are outlined in Table 2 below.

Table 2: Overseer® Inputs for Non-Irrigation Scenario

Fertilizer Nitrogen Loading	**kg-N/ha/yr**	**0**	**50**	**75**	**100**	**125**	**150**	**175**	**200**
Urea (Aug, Sep, Nov, Jan)	kg-N/ha/application	0	2	8	15	21	27	33	40
DAP (Sep)	kg/ha/application	0	232	232	232	232	232	232	232
Lime (Aug, Sep, Nov, Jan)	kg/ha/application	0	30	32	35	37	40	42	45

2.2.3 IRRIGATION SENARIOS

To model the effect of freshwater irrigation on a pasture system receiving fertiliser, the irrigation water nitrogen concentration input of the Overseer® model was reduced to 0 mg/L (nitrogen only). A range of fertiliser loading rates were utilised in order to model the nitrogen losses from the dairy farm pasture for varying nitrogen loading rates when receiving freshwater irrigation water. The inputs are outlined in Table 3 below.

Table 3: Overseer® Inputs for Fertilizer + Freshwater Irrigation Scenario

Irrigation Nitrogen Loading	**kg-N/ha/yr**	**0**	**51**	**99**	**139**	**159**	**171**	**179**	**191**	**199**
Irrigation Nitrogen Conc.	mg/L	0	0	0	0	0	0	0	0	0
Urea (Aug, Sep, Nov, Jan)	kg-N/ha/application	0	4	16	26	31	34	36	39	41
DAP (Sep)	kg/ha/application	0	197	197	197	197	197	197	197	197
Lime (Aug, Sep, Nov, Jan)	kg/ha/application	0	26	31	35	37	38	39	40	41

In order to model nitrogen losses from a dairy farm receiving wastewater irrigation only, the fertiliser applications were removed from the scenario. A range of nitrogen concentrations for irrigated wastewater were utilised in order to model the nitrogen losses from the dairy farm pasture for varying nitrogen loading rates. The inputs are outlined in Table 4 below.

Table 4: Overseer® Inputs for Wastewater Irrigation Scenario, No Fertilizer Application

Irrigation Nitrogen Loading	**kg-N/ha/yr**	**0**	**11**	**21**	**32**	**42**	**63**	**105**	**158**	**210**
Irrigation Nitrogen Conc.	mg/L	0	5	10	15	20	30	50	75	100
Urea (Aug, Sep, Nov, Jan)	kg-N/ha/application	0	0	0	0	0	0	0	0	0
DAP (Sep)	kg/application	0	0	0	0	0	0	0	0	0
Lime (Aug, Sep, Nov, Jan)	kg/ha/application	0	0	0	0	0	0	0	0	0

2.2.4 WASTEWATER TREATMENT SCENARIO

In order to assess the effects of reducing nitrogen in irrigated wastewater through pretreatment, irrigation nitrogen concentration inputs were varied for the wastewater treatment scenarios.

The inputs for the wastewater treatment mitigation scenarios are outlined in Table 5 below.

Table 5: Overseer® Inputs for Wastewater Treatment Scenario s

Irrigation Nitrogen Loading	**kg-N/ha/yr**	**0**	**11**	**21**	**32**	**42**	**63**	**105**	**158**	**210**
Irrigation										
Irrigation Nitrogen Conc.	mg/L	0	5	10	15	20	30	50	75	100
Fertilizer										
Urea (Aug, Sep, Nov, Jan)	kg-N/ha/application	41	39	36	34	31	26	16	4	0
DAP (Sep)	kg/ha/application	197	197	197	197	197	197	197	197	0
Lime (Aug, Sep, Nov, Jan)	kg/ha/application	41	40	39	38	37	35	31	26	0
Fertilizer Nitrogen Loading	*kg-N/ha/yr*	*199*	*191*	*179*	*171*	*159*	*139*	*99*	*51*	*0*
Total Nitrogen Loading										
Total Nitrogen Loading	*kg-N/ha/yr*	*199*	*202*	*200*	*203*	*201*	*202*	*204*	*209*	*210*

To avoid effects on farming operations, nitrogen loading of pasture will need to be maintained even when nitrogen concentrations in the irrigated wastewater are reduced. To model this, fertilizer applications were varied in proportion to nitrogen concentrations, so that total combined nitrogen loading of the pasture from irrigated wastewater and fertilizer was approximately 200 kg-N/ha/year for all scenarios.

2.2.5 IRRIGATION DEPTH SCENARIOS

In order to achieve a reduced irrigation depth whilst still applying the same volume of wastewater to land, the area of the land treatment system must be expanded. In order to model this, a number of different inputs needed to be altered including area, imported supplement, stocking numbers and milk solids production. As the volume and nitrogen load of wastewater applied per hectare decreased, fertiliser application was also increased to maintain nitrogen loading of approximately 200 kg-N/ha/yr. The varied inputs for the irrigation depth scenarios are outlined in Table 6 below.

Table 6: Overseer® Inputs for Irrigation Depth Scenarios

Irrigation Depth	**mm/month**	**25**	**20**	**15**	**10**
Area	ha	100	125	166.7	250
Supplement imported	t DM/yr	170	213	284	426
Stock numbers	animals/farm	330	413	550	825
Production	kg/yr	116,490	145,613	194,150	291,225
Urea (Aug, Sep, Nov, Jan)	kg-N/ha/application	20.9	23.1	25.2	27.4
DAP (Sep)	kg/ha/application	157	163	169	174
Lime (Aug, Sep, Nov, Jan)	kg-N/ha/application	28	30	31	33

2.2.6 STOCKING RATE SCENARIOS

In order to model the effect of stocking rate on nitrogen losses to groundwater from the base dairy farm scenario, the stock numbers were varied whilst maintaining the same grazed area. As a result of changing stocking rate, inputs derived from stocking rate such as milk solids production, stock weight, imported supplement consumption and fertiliser requirements were also changed. The inputs for the stocking rate scenarios are outlined in Table 7 below.

Table 7: Overseer® Inputs for Stocking Rate Scenarios

Stocking Rate	**cow/ha**	**2.8**	**2.9**	**3**	**3.1**	**3.2**	**3.3**
Supplement imported	t DM/yr	112	122	134	147	158	170
Stock numbers	animals/farm	280	290	300	310	320	330
Stock weight	kg	382	381	379	378	376	375
Production	kg/yr	109,664	111,338	112,858	114,224	115,434	116,490
Urea (Aug, Sep, Nov, Jan)	kg-N/ha/application	23	22	22	22	21	21
DAP (Sep)	kg/ha/application	122	129	136	143	150	157
Lime (Aug, Sep, Nov, Jan)	kg-N/ha/application	24	25	26	27	27	28

2.2.7 TIMING OF LAND TREATMENT APPLICATION SCENARIOS

In order to assess the impact of land treatment during shoulder months, a number of scenarios were developed with different irrigation periods. Irrigation depth was not increased where the period of irrigation was decreased, as the assumption is that the ability to discharge treated wastewater to surface water when not discharged to land exists. As the volume and nitrogen load of wastewater applied to the land treatment system is decreased with decreased irrigation periods, fertiliser application was increased to maintain nitrogen loading of approximately 200 kg-N/ha/yr. The varied inputs for the scenarios are outlined in Table 8 below.

Table 8: Overseer® Inputs for Stocking Rate Scenarios

Irrigation Period		Oct-May	Nov-May	Nov-April	Dec-April	Dec-March	Dec-Feb
Urea (Aug, Sep, Nov, Jan)	kg-N/ha/application	26	28	30	31	33	35
DAP (Sep)	kg/ha/application	197	201	205	210	214	219
Lime (Aug, Sep, Nov, Jan)	kg-N/ha/application	35	36	37	39	40	41

2.2.8 STANDOFF PAD SCENARIOS

The placement of stock onto standoff pads allows the capture of cow excreted nitrogen that would otherwise be deposited on the pasture and soil. This means a portion of nitrogen is removed, reducing the overall nitrogen loading of the system. Urine in particular creates concentrated point source loading of pastures. It is not uncommon in Overseer® model scenarios of grazed pasture systems for approximately 90% of nitrogen leaching to be from urine patches.

In order to identify the potential benefit in reducing nitrogen losses to groundwater by utilising standoff pads the following periods of standoff pad utilization were modelled; July, June-July, June-August, May-August, and May-September.

The capture of cow excreted nitrogen on standoff pads will create additional effluent to be exported offsite, if utilising the base scenario settings. In order to capture this increased effluent disposal within the standoff pad scenarios, each scenario was run with the export of effluent offsite, and again with the effluent spread across the dairy farm pasture. The inputs for the standoff pad scenarios are outlined in Table 9 below.

Table 9: Overseer® Inputs for Standoff Pad Scenarios

Parameters	Overseer® input
Structures	Winter stand-off and loafing pad
Pad Surface	Carbon rich (sawdust, bark, woodchips)
	Lined, concrete floor or subsurface drained and effluent captured
	Surface scrapped regularly
Winter standoff usage	16 hours a day for 100% of herd within selected months
Effluent Application to Pasture Setting	
Management of scraped surface solids	Spread on selected blocks
	Covered (from rain)
	2 months in storage
Liquid effluent application	12-24 mm application depth
	Application are actively managed
Solids effluent applications	Solids from loafing pad
	Applied in September

2.2.9 SOIL DRAINAGE SCENARIOS

A number of soils from the Waikato region, with drainage properties ranging from well drained to poorly drained, were selected to investigate the effect of soil drainage on nitrogen losses to groundwater. Soils with very poor drainage properties were not included in the investigation as it is likely that the infiltration rates for these soils will exclude them from land treatment systems. The soil types and s-map link reference for the soil drainage scenario are outlined in Table 10 below.

Table 10: Overseer® Inputs for Soil Drainage Scenarios

Soil Drainage	**Well (Waihou)**	**Moderately Well (Morrinsville)**	**Imperfectly (Te Puninga)**	**Poor (Waitoa)**
S map Link	Ngak_9a.1	Morr_3a.1	Punn_1a.1	Eure_9a.1

2.2.10 ROOTING DEPTH SCENARIOS

The greater the rooting depth of pasture, the greater the depth from which water and nutrients can be taken up by the plant, meaning greater root depth results in greater plant uptake of nitrogen. The rooting depth of the base scenario was varied from 10 cm to 60 cm in 10 cm increments to indicate what level of impact this would have on nitrogen leaching. Increasing rooting depths above 60 cm has no effect on nitrogen uptake. This is because 60 cm is considered the upper limit for pasture root depth. It is likely that Overseer® limits the rooting depth to 60 cm even if a value is specified above this, which is why there is no effect when rooting depths of over 60 cm are selected.

2.2.11 STONY SOIL LAYER SCENARIOS

The presence of non-standard layers within soils can affect the infiltration rates, drainage properties and soil moisture holding capacity of soils. In order to assess the significance of non-standard layers with regard to nitrogen losses to groundwater a stony layer was included in the soil profile at depths varied from 10 cm to 60 cm in 10 cm increments.

3 RESULTS AND DISCUSSION

The Overseer® simulated base scenario, representing a conceptual existing dairy farm receiving irrigated wastewater and fertiliser as described in Section 2.2.1, estimated a nitrogen leaching rate to groundwater of 77 kg-N/ha/yr.

The results of the various Overseer® modelling scenarios are presented and discussed in the following sections.

3.1 EFFECTS OF IRRIGATION AND WASTEWATER IRRIGATION ON NITROGEN LOSSES

Before discussing the results of potential nitrogen leaching mitigation, the nitrogen leaching from irrigated and non-irrigated dairy farm systems give context to the selected base scenario.

Figure 1 below shows the nitrogen leaching rates for the base scenario and for variations of the base scenario, where no irrigation, freshwater irrigation and wastewater irrigation are utilised. For all scenarios the total nitrogen loading rate is approximately 200 kg-N/ha/yr.

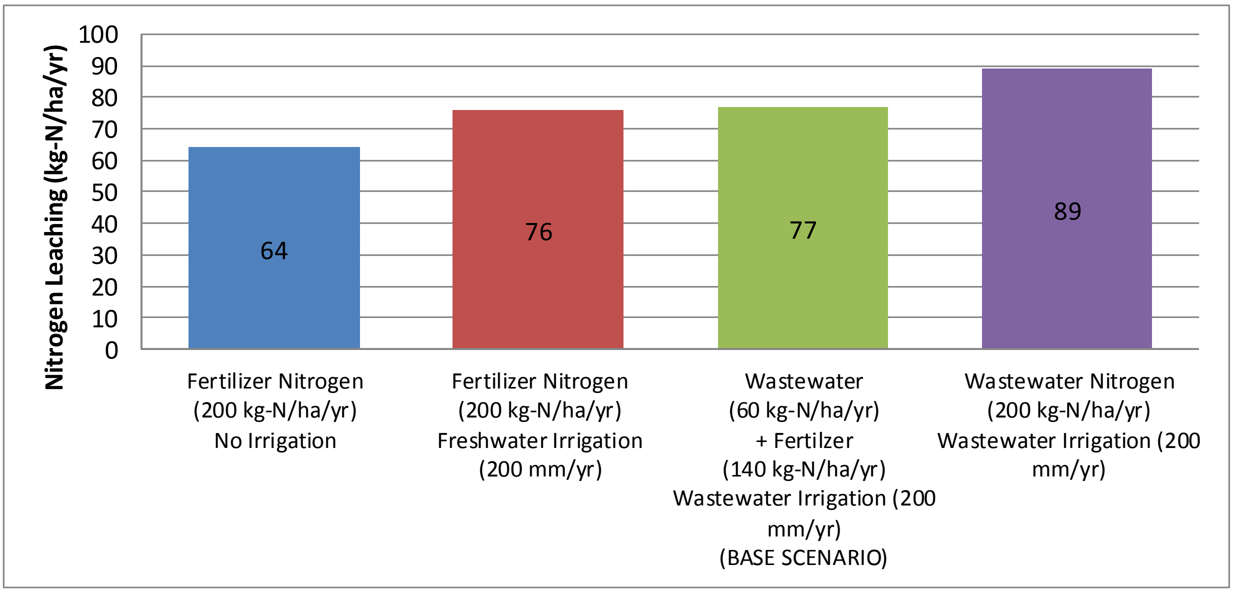

Figure 1: Effect of Freshwater Irrigation and Wastewater Irrigation on Nitrogen Leaching Rates from Dairy Pasture at a Nitrogen Loading of 200 kg-N/ha/yr

Figure 2 below shows the nitrogen leaching rates for different nitrogen loading rates for a system where no irrigation is used (Series 1), where freshwater irrigation is used (Series 2) and where wastewater irrigation is utilised (Series 3). The nitrogen leaching rates for the base scenario with different levels of irrigation nitrogen concentrations i.e. the wastewater treatment scenario is also shown for comparison (Series 4). For the wastewater treatment scenario results, which are discussed further in Section 3.2 below, the wastewater nitrogen loading has been plotted along the x axis, however, the actual total nitrogen loading of wastewater irrigation and fertiliser application will remain constant at approximately 200 kg-N/ha/yr.

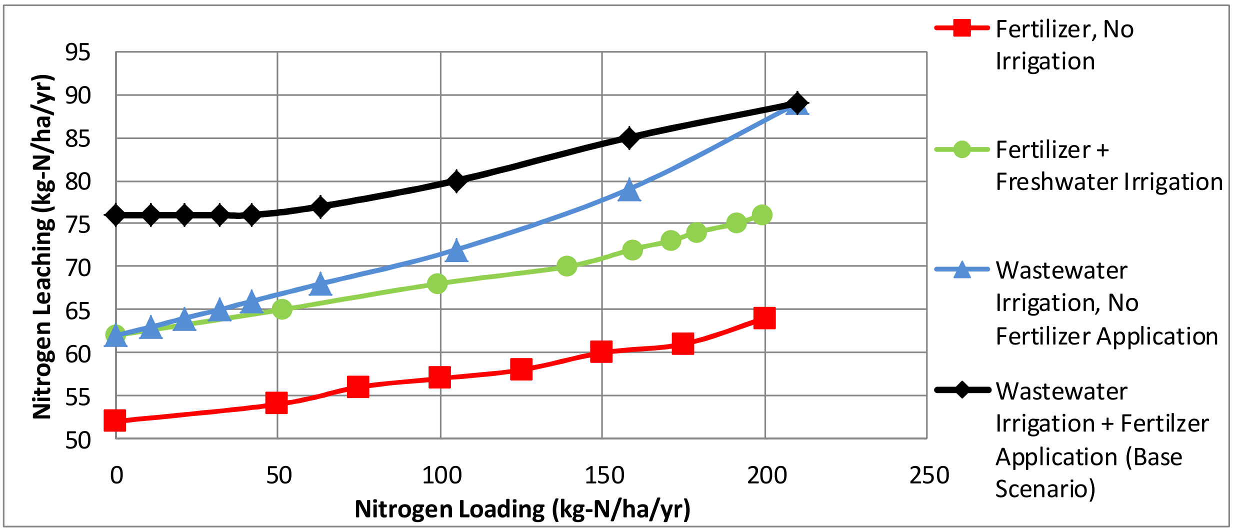

Figure 2: Effects of Irrigation and Wastewater Irrigation on Nitrogen Leaching Rates from Dairy Farm Pasture at Various Nitrogen Loading Rates

3.1.1 NITROGEN FLUSHING EFFECT

As shown in Figures 1 and 2, the leaching loss from the scenarios receiving fertilizer application at the same loading rate was greater for the scenario also receiving freshwater irrigation. This is demonstrating the flushing effect of irrigation water on receiving soils. Irrigated water allows mobile nutrients to travel through the soil profile. The more water that is flushed through the soil, the greater the leaching rates of nitrogen to groundwater. Unlike rainfall, which generally falls more within the wetter winter months of the year, irrigation is usually applied to pasture at similar times to fertiliser application, during late spring and summer months when water and nutrient demands of the pasture are highest. This means irrigation broadens the annual period when flushing of nitrogen from soil can occur.

3.1.2 FORM OF NITROGEN BEING LEACHED

As shown in Figures 1 and 2, for the same nitrogen loading rate, the scenario receiving wastewater irrigation results in a greater nitrogen leaching rate than for the scenario receiving fertilizer and freshwater irrigation. Both these scenarios have received the same depth or volume, with 25 mm/month being applied October to May, at a depth of 200 mm annually.

The cause of higher nitrogen leaching rates for the irrigated wastewater scenario is likely associated with the form of nitrogen that is present in the wastewater. The irrigation function of the Overseer® models was primarily designed for the irrigation of groundwater from farm groundwater bores to the farm systems. Although the nitrogen input into the Overseer® model is recorded as total nitrogen (TN) the form of nitrogen modelled in irrigation water is as nitrate nitrogen (NO_3-N). Nitrate nitrogen is much more mobile in soils than other nitrogen forms.

The majority of municipal and industrial land treatment systems apply pre treated wastewater to land. Aeration of wastewater during treatment processes results in the majority of nitrogen in effluent wastewater being in the form of nitrate nitrogen, therefore, the Overseer® assumptions around the form of nitrogen in most wastewater irrigation systems are applicable.

The majority of nitrogen rich fertilizers utilised for pasture systems contain ammoniacal nitrogen (NH_4^+) or organic nitrogen, which is mineralized within soils to form ammoniacal nitrogen. Ammoniacal nitrogen binds more readily to soil particles and needs to be oxidized to nitrate nitrogen before it can be leached to groundwater.

As a result of the difference in nitrogen form, the nitrogen present in wastewater irrigation is more readily leached to groundwater than nitrogen associated with fertilizer application.

3.2 WASTEWATER TREATMENT

For the wastewater treatment scenario results, shown in Figure 2 above (wastewater irrigation + fertilizer application), the wastewater nitrogen loading has been plotted along the x axis, however, the actual total nitrogen loading of wastewater irrigation and fertilizer application will remain constant at approximately 200 kg-N/ha/yr, as discussed in the base scenario inputs (Section 2.2.1).

Figure 2 indicates that reductions in wastewater nitrogen loading through wastewater treatment will reduce nitrogen leaching rates for systems with high wastewater nitrogen loadings, however, for systems with low nitrogen loading, the benefits of reducing nitrogen loading further are minor.

For wastewater nitrogen loading of 200 kg-N/ha/yr (100 mg/L TN) nitrogen leaching is approximately 89 kg N/ha/yr. Through improved wastewater treatment to achieve a wastewater nitrogen loading of 40 kg N/ha/yr (20 mg/L TN), this leaching rate can be decreased to 76 kg-N/ha/yr. However, further treatment to reduce wastewater nitrogen loading will not result in decreased nitrogen leaching rates, or changes are so minor that they are not observable in Overseer® outputs due to rounding. This is because as nitrogen levels within wastewater are reduced, the land treatment approaches the leaching rate of 76 kg-N/ha/yr for the modeled system receiving fertilizer and freshwater irrigation water, as presented in Figure 1 above. This indicates that leaching rates cannot be reduced below this level through wastewater treatment alone. As indicated in Figure 2, leaching rates for a system receiving fertilizer and freshwater irrigation can be reduced, but only through reducing fertiliser loading rates which may have a detrimental impact on farming operations.

This is an important finding, as it indicates that wastewater treatment is not always a viable option. If fertiliser application cannot be easily reduced without affecting farming operations, other mitigation methods may need to be investigated. The modelling shown in Figure 2 is a good example of modelling that should be done to determine whether further treatment of wastewater is a viable mitigation method for reducing nitrogen losses to groundwater.

For the base scenario, with a wastewater nitrogen loading of 60 kg-N/ha/yr (30 mg/L TN), the nitrogen leaching rate is 77 kg-N/ha/yr. This can be reduced to 76 kg-N/ha/yr but no further without reducing nitrogen fertilizer supply for pasture. To achieve this 1 kg-N/ha/yr reduction in nitrogen leaching, the nitrogen levels in treated wastewater will need to be decreased by 33% which relates to a reduced wastewater nitrogen loading of 20 kg N/ha/yr. For the base scenario, wastewater treatment is therefore unlikely to be the most efficient mitigation method.

For each farming and land treatment operation, the limit to what nitrogen leaching mitigation can be achieved with wastewater treatment will vary, depending on the pasture and fertiliser requirements and a number of other factors. For example, if a low intensity farm was being operated for the base scenario, and fertiliser applications could also be reduced, the minimum leaching that could possibly achieved without alternative mitigation measures is 62 kg-N/ha/yr. Only by identifying the limit to wastewater treatment mitigation can operators assess the value of wastewater treatment as a mitigation measure.

3.3 IRRIGATION DEPTH

Figure 3 below shows the nitrogen leaching rates from scenarios where different irrigation depths were used. As expected the leaching losses were lower for scenarios with lower irrigation depths, as this will result in lower hydraulic wastewater loading and wastewater nitrogen loading and less flushing of nutrients from soils.

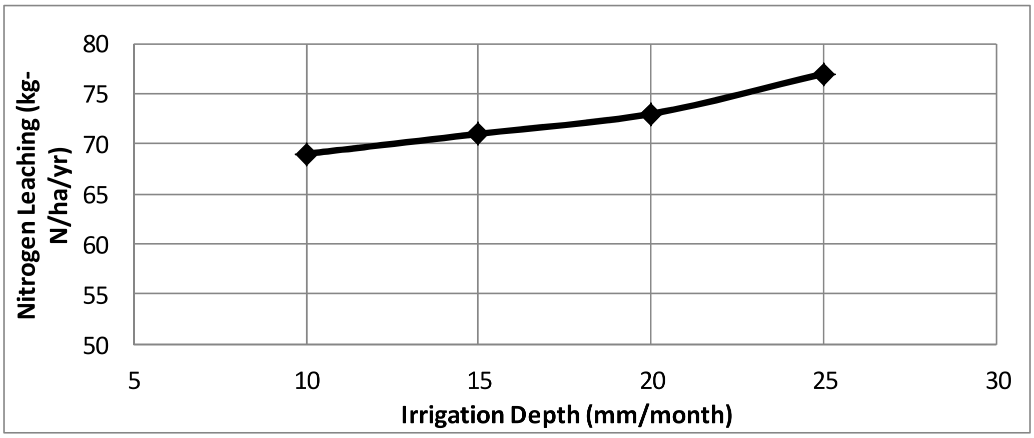

Figure 3: Effects of Irrigation Depth on Nitrogen Leaching Rates

This reduction in leaching losses does not necessarily indicate that this mitigation method will provide a net reduction in nitrogen losses to groundwater. In order to achieve a lower irrigation depth, a larger irrigation area will be required for the land treatment system. This means a larger portion of available farm land must be utilised. Therefore in order to assess the net effect on nitrogen losses to groundwater, the nitrogen losses from all land treatment and potential land treatment areas must be considered.

The area of available farm land is assumed to be 250 ha. The base scenario assumes a land treatment area of 100 ha, meaning that 150 ha of land operates as a dairy farm. In order to decrease irrigation rates from 25 mm/month to 10 mm/month the full available 250 ha area will need to operate as a land treatment system. In order to assess the net loss of nitrogen to groundwater for this scenario, the increase in nitrogen leaching for the additional 150 ha was considered as well as the decrease in leaching within the 100 ha of the original land treatment area. This has been assessed for all modelled irrigation depths and required land treatment areas as shown in Table 11. The area not utilised for land treatment was modelled as a dairy farm operation receiving 200 kg-N/ha/yr fertilizer (nitrogen leaching 64 kg-N/ha/yr) and as a as a dairy farm operation receiving 200 kg-N/ha/yr fertilizer and freshwater irrigation at 25 mm/month (refer to Figure 2).

Table 11: Net Nitrogen Loss Assessment

Land Treatment Area			Available Dairy Farm Area			Net Loss to Groundwater
Area	**Leaching Rate**	**Net Nitrogen Loss**	**Area**	**Leaching Rate**	**Net Nitrogen Loss**	
ha	kg-N/ha/yr	kg-N/yr	ha	kg-N/ha/yr	kg-N/yr	kg-N/yr
Available Dairy Farm Area Non Irrigated, 200 kg-N/ha/yr Fertilizer						
100	77	7,700	150	64	9600	17300
125	73	9,125	125	64	8000	17125
166.7	71	11,833	83	64	5333	17167
250	69	17,250	0	64	0	17250
Available Dairy Farm Area Freshwater Irrigated, 200 kg-N/ha/yr Fertilizer						
100	77	7700	150	76	11400	19100
125	73	9125	125	76	9500	18625
166.7	71	11833	83	76	6333	18167
250	69	17250	0	76	0	17250

As shown in Table 11, and in Figures 4 and 5 below, the effectiveness of mitigating net nitrogen losses through the expansion of the land treatment system and the reduction of irrigation rates is dependent on the existing operations within the areas where expansion is proposed.

Where the additional land was being used for non-irrigated dairy farming with fertiliser application only, the expansion of the land treatment system resulted in very minor reductions net nitrogen loss to groundwater, likely due to the flushing effects of irrigation within previously non-irrigated areas. Given that this expansion would require the installation of an irrigation system, it would provide minor benefit for the required investment and disruption to existing farming operations.

Where additional land was in use as an irrigated dairy pasture, the expansion of the land treatment system resulted in reduced net nitrogen losses. In addition the existing land irrigation system could potentially be utilised for the land treatment system, limiting the disruption to existing activities and reducing capital investment requirements.

This modelling indicates that the expansion of the land treatment system is not always the most effective mitigation measure, which potentially goes against conventional thinking.

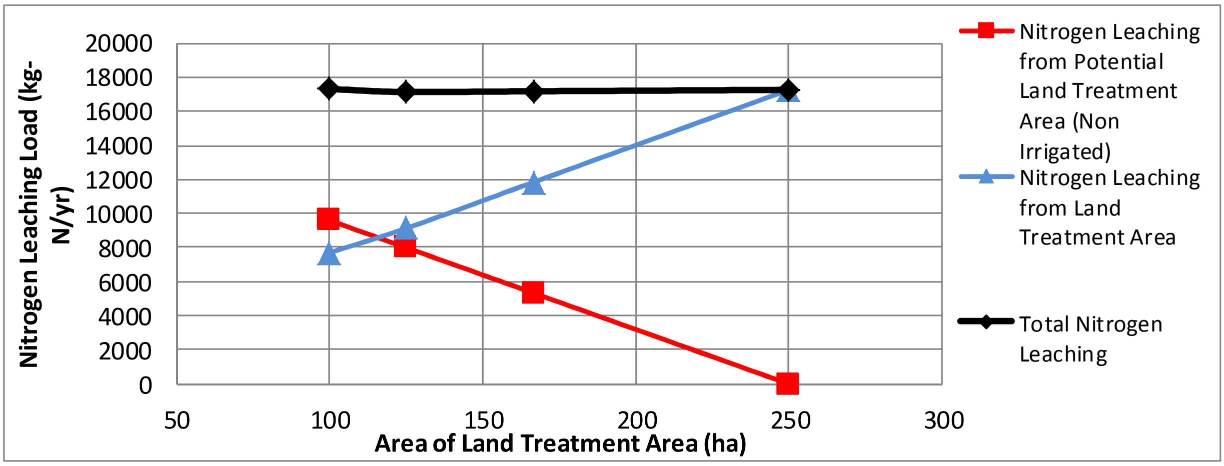

Figure 4: Effects of Expanding Land Treatment System into Non-irrigated Dairy Farm Land on Net Nitrogen Losses to Groundwater

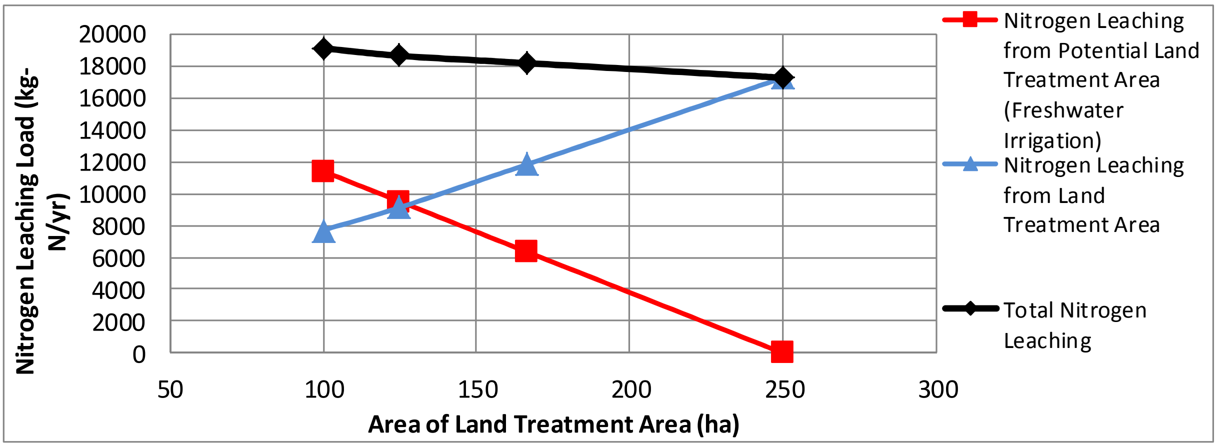

Figure 5: Effects of Expanding Land Treatment System into Irrigated Dairy Farm Land on Net Nitrogen Losses to Groundwater

3.4 STOCKING RATE

As expected, reducing stocking rates within the farm and land treatment system resulted in reduced leaching rates to ground, as shown in Figures 6 and 7. Point sources (urine patches) account for a significant portion of nitrogen losses to groundwater in a dairy farm system. By reducing stocking rates, this point source leaching is reduced. However, milk solids production decreases with lower stocking rates, as shown in Figure 6. This is not ideal for a dairy farm operation, and creates conflict between the management of the farming operation to maximize production and the land treatment operation to reduce nitrogen losses to groundwater.

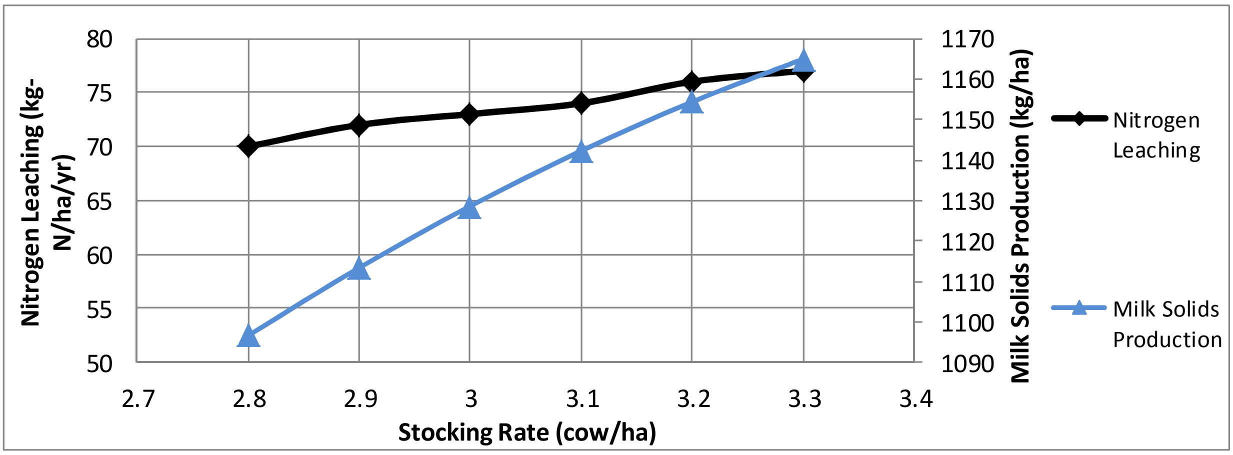

Figure 6: Effects of Stocking Rate Nitrogen Leaching Rates and Milk Solids Production

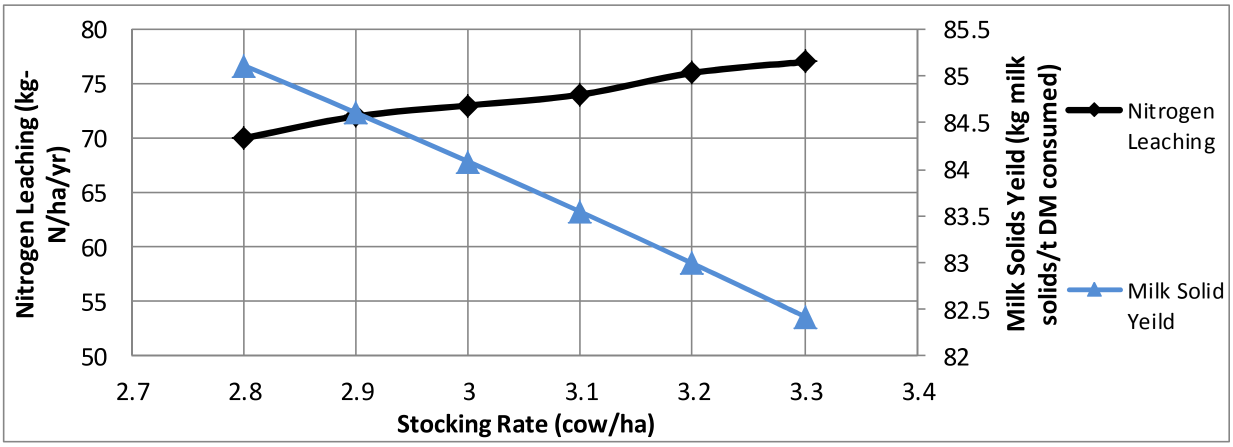

Figure 7: Effects of Stocking Rate Nitrogen Leaching Rates and Milk Solids Yield

Notwithstanding this, maximizing production does not necessarily mean maximizing economic performance. Although milk solids production increases with stocking rate, the milk solids yield decreases per tonne of dry matter consumed with stocking rate (Figure 7).

To determine what stocking rate and associated milk solids production and yield is the most economically viable for a farming operation would require a detailed assessment of fertiliser and supplement feed costs, stock maintenance costs and other factors by an experienced farming consultant. However, the results of this modelling indicate that a reduction in stocking rates is worthy of consideration given that there is potential for a reduction in nitrogen losses from a farm system and an improved economic performance of the farm.

3.5 TIMING OF LAND TREATMENT APPLICATION

As shown in Figure 8, the leaching of nitrogen to ground water is reduced when wastewater is discharged to river more often and applied to land less frequently. However, in order to assess the overall net nitrogen losses, the fate of groundwater nitrogen and the nitrogen loads discharged directly into the river must be considered.

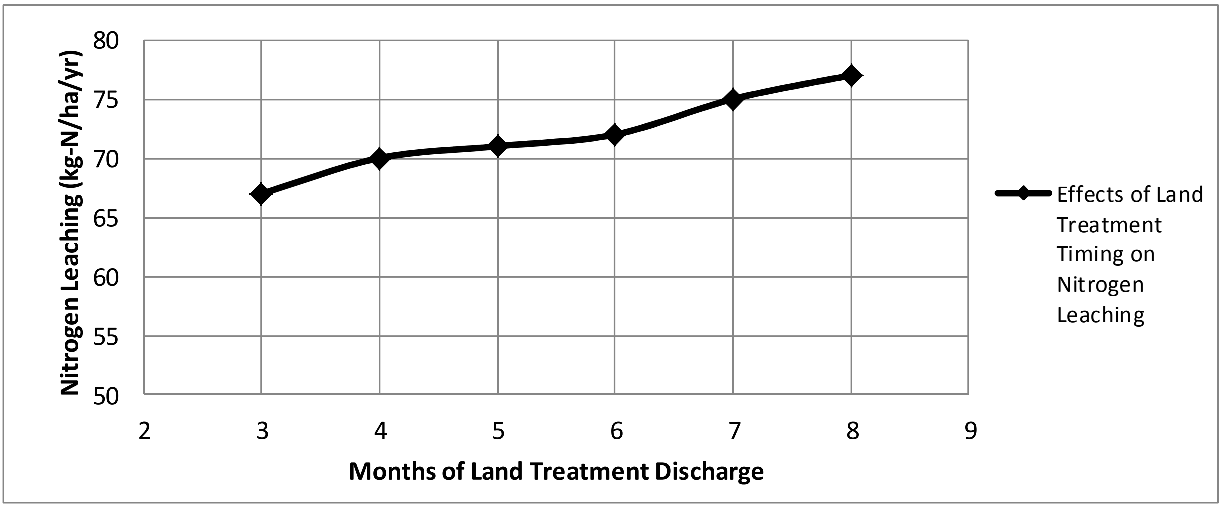

Figure 8: Effects of Land Treatment Timing on Nitrogen Leaching Rate

In a land treatment system, nitrogen leached to groundwater will drain to shallow groundwater. If the system is operating as a dual discharge system, and the river receiving treated wastewater is located in the vicinity of the land treatment system, it is not unreasonable to assume that the shallow groundwater will flow to the same receiving surface water body. For a simplified model, we assume that denitrifying conditions do not exist in the groundwater system, and all nitrogen lost to groundwater will flow to the receiving river or stream.

Assuming that the wastewater volume discharged per month to land at 25 mm/d over 100 ha is consistent with wastewater flows to river during the remaining months then the required flow to river when irrigation is not occurring is 25,000 m^3/month. Assuming that nitrogen concentrations are consistent (30 mg/L TN) this relates to a discharge load of 750 kg-N/month.

The nitrogen load to river from the land treatment system can be assessed based on the number of months of discharge, the area of 100 ha and the leaching rates modelled, as shown in Figure 8. The direct discharge to river is simply the number of months of discharge at 750 kg-N/month.

The result of this assessment are provided in Figure 9, and indicate that increased utilisation of the land treatment system will provide a reduction in the overall net nitrogen losses to the receiving environment, despite increased nitrogen leaching rates from the land to groundwater.

Based on this modelling, the mitigation potential of increasing discharge to river are limited, however, this simplified model does not consider the actual effects on the receiving environment, which may be mitigated during winter discharges to river when river flows are high. In situations where groundwater conditions are not as assumed above, the effects of land treatment may be more complex and discharge to river may have useful applications.

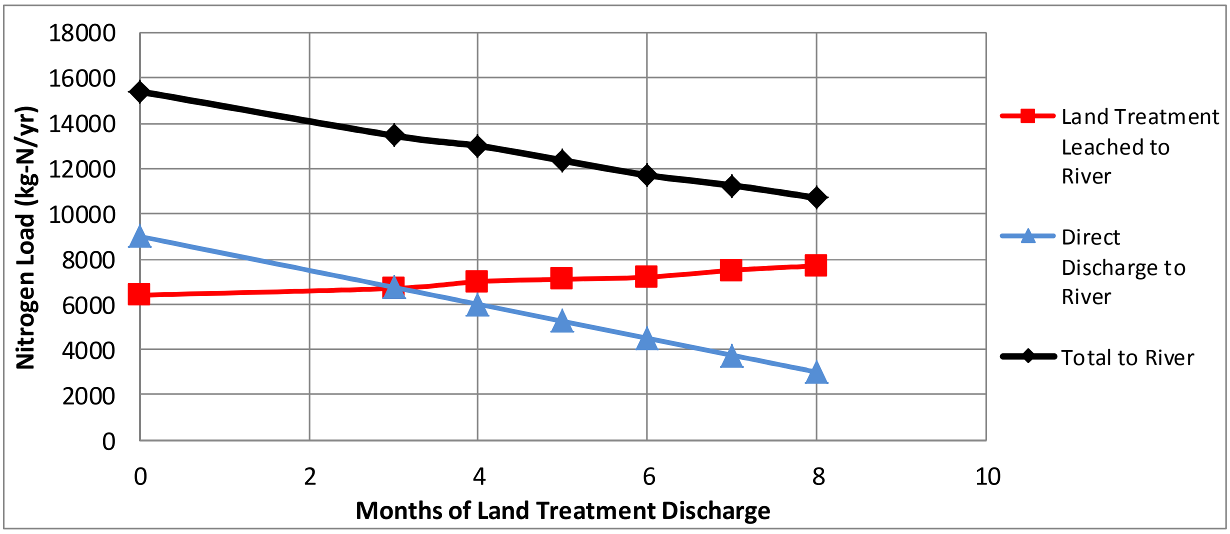

Figure 9: Effects of Land Treatment Timing on Net Nitrogen Loads to River

3.6 STANDOFF PADS

The results of standoff pad scenarios are shown in Figure 10. These results show that increased utilisation of standoff pads will reduce nitrogen leaching rates, however, the reduction achieved for each additional month of standoff pad use decreased as more months were utilised.

The effects of discharging effluent collected within standoff pads back to the land treatment areas resulted in higher leaching rates than when the standoff pads were utilised for the same months but effluent was exported offsite. However, the utilisation of standoff pads still resulted in a net decrease in leaching rates to groundwater as shown in Figure 10. This is due to the redistribution of otherwise point source (urine patch) loading from stock evenly over the land treatment area.

This modelling indicates that standoff pads will reduce nitrogen leaching from land treatment systems. Standoff pads will also help prevent pugging for farms by reducing the time spent on pasture by stock during wet winter months. Standoff pads require a large capital investment by farming operators, however, based on the results of modelling, they should be considered seriously for the mitigation of nitrogen losses to groundwater. It is acknowledged that modelling standoff pads in Overseer® automatically adjusts pasture yield down and therefore, modelled leaching rates may be conservatively high as more standoff pad use months are utilised.

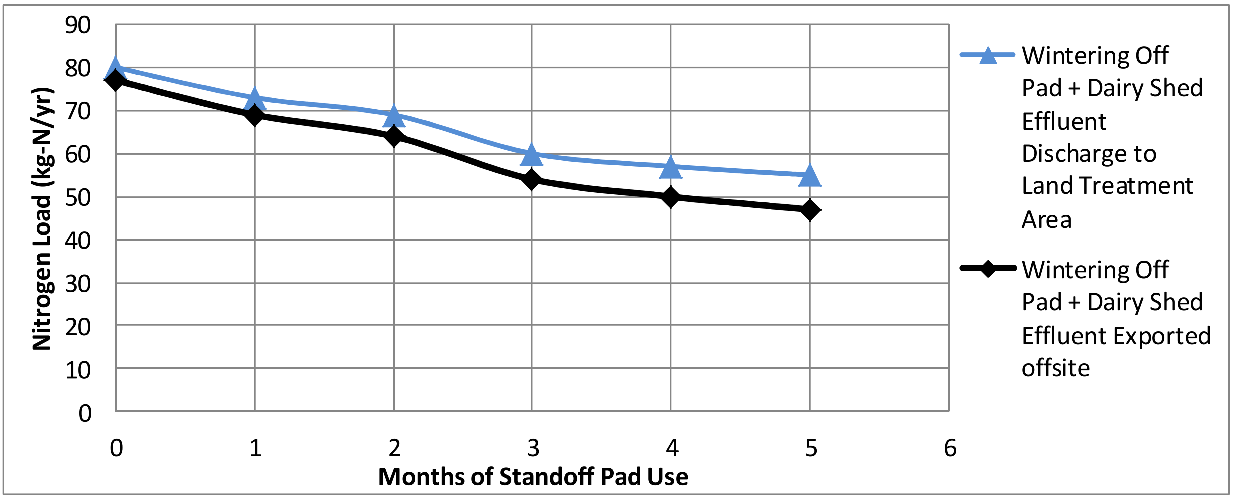

Figure 10: Effects of Standoff Pads on Nitrogen Leaching Rate

3.7 SOIL DRAINAGE

While soil drainage characteristics are not something that can be easily manipulated for an existing system, it is an important characteristic when assessing new or expanded irrigation areas.

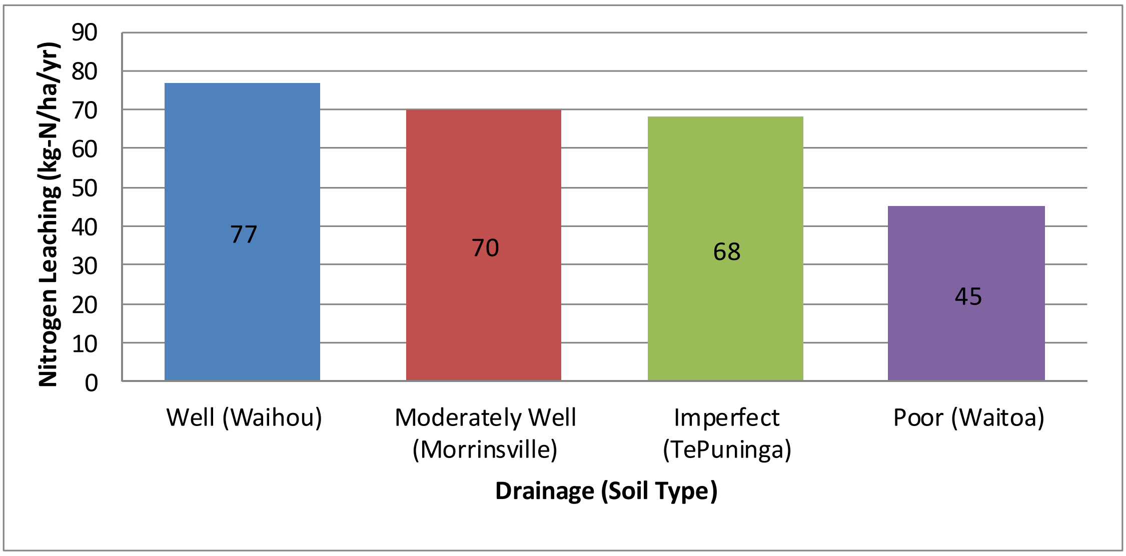

Figure 11: Effects of Soil Drainage Properties on Nitrogen Leaching

Figure 11 shows the leaching rates for soil types with different soil drainage properties. These results indicate that decreased soil drainage performance will result in reduced nitrogen leaching rates, suggesting that conventional thinking that well drained soils are the most appropriate for land treatment systems may not be correct when considering the mitigation of nitrogen losses to groundwater.

These results should not be interpreted to suggest that all well drained soils will provide lower nitrogen removal capacity than poorly drained soils, as a number of other soil properties contribute to nitrogen removal which potentially outweigh the effect of soil drainage. What these results do indicate is that soils with lower drainage properties should not be excluded from consideration for land treatment areas based on lower hydraulic capacity, as they can provide increased nitrogen mitigation.

The soil type of any proposed land treatment system should be considered carefully. Drainage properties are important to ensure that available land areas have the capacity to receive wastewater applications, however, as these results show, consideration should also be given to the nitrogen removal capacity of different soil types.

3.8 ROOTING DEPTH

Rooting depth of pastures can be influenced by impervious layers or anoxic zones, for example, and cannot easily be changed for an existing land treatment system. However, for a new or expanded site, available rooting depth is an important consideration. The result of rooting depth scenarios as shown in Figure 12 show that rooting depth has a severe impact on the nitrogen leaching rates from a land treatment system, with leaching rates increasing as rooting depth is decreased.

A decrease in rooting depth from 60 cm to 50 cm in the Overseer® model resulted in an increase in leaching rate of 11 kg-N/ha/yr. This increase in leaching rate is greater than the difference in leaching rates between a well-drained soil and an imperfectly drained soil. Referring to Figure 1, this increase in leaching rate is similar to the increase resulting from applying 200 mm/yr of irrigation water to a system that previously received only fertiliser application, and is only slightly less than the increased nitrogen leaching resulting from increasing the nitrogen loading on an irrigated site from 0 to 200 kg-N/ha/yr. As rooting depth is decreased the effects of further reductions in rooting depth become more pronounced.

Rooting depth is a pasture property of significant importance to nitrogen losses to groundwater and should be considered carefully for any future potential land treatment system area.

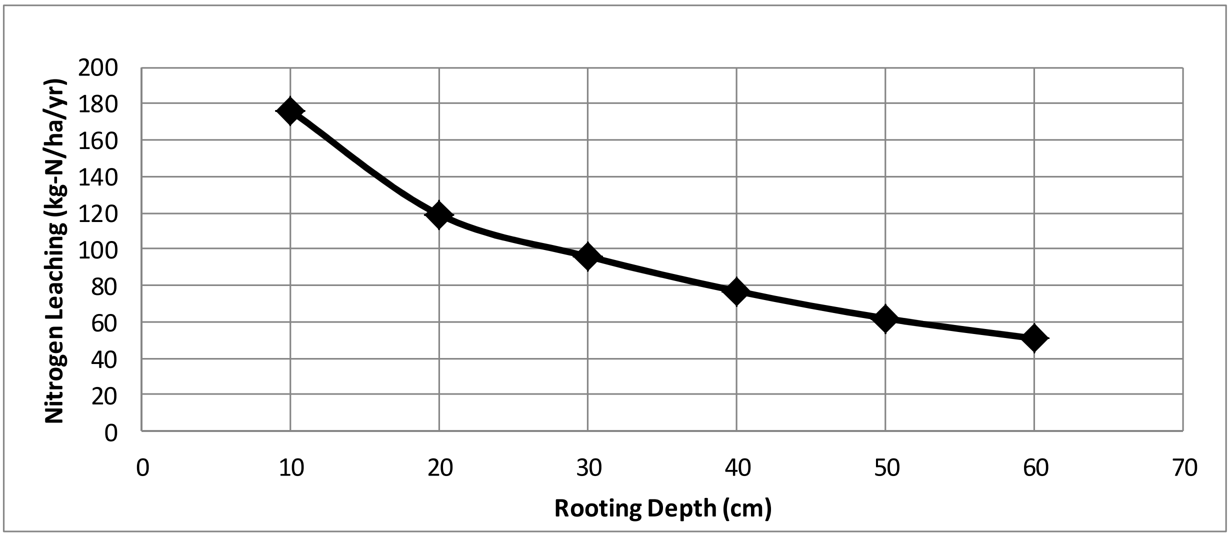

Figure 12: Effects of Rooting Depth on Nitrogen Leaching Rate

3.9 STONY SOIL LAYER

The results of stony soil layer scenarios as shown in Figure 13 show that leaching of nitrogen to groundwater is increased as the depth to the stony soil layer decreases, however, the effect is less pronounced than for changes in rooting depth.

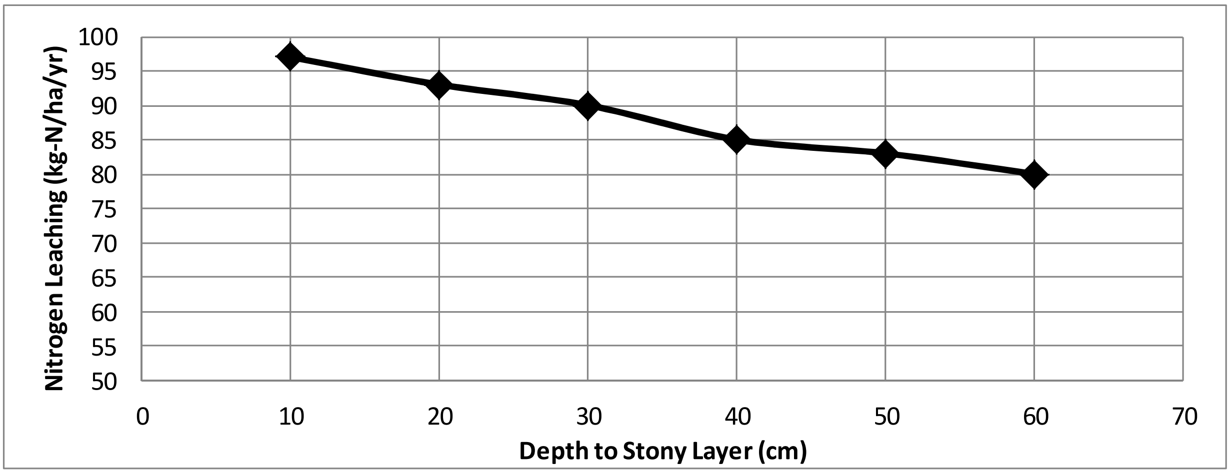

Figure 13: Effects of Stoney Soil Layer on Nitrogen Leaching Rate

4 CONCLUSIONS

The Overseer® modelling discussed in this report has indicated the effect of various management options in reducing nitrogen losses to groundwater. While these results indicate the potential of mitigation options and areas where mitigation should be considered, variation between sites means that these results may not be relevant to all land treatment systems.

Improving wastewater treatment and reducing hydraulic loading rates could be considered conventional mitigation options. However, for the base scenario selected for this investigation we have found that potential mitigation through further wastewater treatment is limited, and that expanding irrigation to reduce hydraulic and nitrogen loading may provide very little benefit in reducing nitrogen leaching losses depending on the surrounding land use.

For an existing land treatment system on a dairy farm operation, Overseer® modelling indicates that standoff pads and, to a lesser extent, stocking rate reduction are tools which may provide for lower nitrogen leaching.

While there may be more opportunity to reduce nitrogen leaching rates further, through reductions in fertiliser nitrogen loading rates, the scope for significant changes to the farm operation may be limited if it is independently owned and operated.

For potential future land treatment systems, Overseer® modelling has highlighted the importance of rooting depth in mitigating nitrogen leaching rates, and has shown that conventional thinking on preferred well drained soils for land treatment systems do not always address the mitigation of nitrogen losses to groundwater. The results of the investigation indicate that a poorer drained soil with no limitation on rooting depth will provide for better land treatment, provided that the hydraulic loading rate is managed within the capacity of the soil type and its drainage characteristics.

4.1.1 LIMITATIONS

As the authors of this paper are not farming consultants, there has been no optimization of farm management for economic return within the scenarios. The purpose of this paper is to highlight potential areas for change within an existing farming operation in order to mitigate nitrogen losses to groundwater.

Farming operations and soil and groundwater conditions are complex and vary significantly across New Zealand and within the Waikato region. This paper is intended as a discussion document for where potential nitrogen loss mitigation can occur, however, only a limited number of variables could be considered within the scenarios discussed. The best solution to mitigate nitrogen leaching for any individual land treatment system will be need to consider specific farming operations and soil and groundwater conditions at the site.

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