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'LEADING INDUSTRY' LAND TREATMENT SYSTEMS FOR DAIRY FACTORY WASTEWATER – 'NEW FRONTIERS' IN NUTRIENT MANAGEMENT

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Abstract

Fonterra's new Group Environmental Policy requires that Fonterra '*minimise the impacts of discharges on the environment and ensure that farm and factory waste is treated to leading industry standards*'. This is defined as '*current industry best practice, acknowledging regional considerations and that these standards may shift over time. In the context of water discharge, this means the systems and practices which are considered leading within the dairy industry globally'.* Compliance with these self-imposed targets is required by 2026.

For sites utilising land treatment systems (LTS) for factory process wastewater, 'leading industry standards' is assessed as achieving a 'whole farm' nitrogen leaching value (via Overseer) of 20-30 kgN/ha/yr. Existing LTS on dairy farms may leach 70-90 kgN/ha/yr. Key drivers are the farming system and high nitrogen plus hydraulic load (monthly irrigation depth). Overseer modelling results show how farming system, nutrient and hydraulic loads may be optimised to meet a target of 20-30 kgN/ha/yr. A combination of a **dual discharge regime** (surface water and land irrigation) plus decoupling of nutrient versus hydraulic load (via wastewater treatment) achieved the desired outcome. Additional benefits may include lower sodium, potassium and phosphorus loadings, drier soils and resulting improvements in soil health plus pasture growth rates.

Introduction

Fonterra operate sixteen wastewater land treatment systems (LTS) in New Zealand, encompassing some 70+ farms (Brown, 2016). The LTS operate under full discretionary activity resource consents that restrict nutrient loadings and other operational factors to control environmental effects (Brown, 2017). Significant programmes for soil, surface water and groundwater quality exist to monitor any effects of the operations. The farming systems involved are tailored to complement the wastewater irrigation activities. New or recently upgraded systems have typically been destocked to < 1.5 dairy cows/ha and excess grass is exported as silage. Sites such as Edendale, Darfield, Clandeboye and Lichfield's largest farm are full Cut & Carry (C&C) systems with minor dry stock.

Fonterra's new Group Environmental Policy (version 4.0) was released in October 2015 (Fonterra, 2015). In relation to wastewater discharges it requires that Fonterra '*minimise the impacts of discharges on the environment and ensure that farm and factory waste is treated to leading industry standards*'. 'Leading Industry Standards' are defined as '*current industry best practice, acknowledging regional considerations and that these standards may shift over time. In the context of water discharge, this means the systems and practices which are considered* *leading within the dairy industry globally'.* Specifically in relation to the Fonterra owned land treatment farms, leading industry practice has been assessed as achieving nitrogen leaching within a target band of 20-30 kgN/ha/yr (Overseer assessed) by 2026. Investigations have been underway to determine options for the Fonterra owned LTS for achieving the target range for nitrogen leaching. This paper documents these findings.

Materials and methods

Overseer modelling

End-of-season Overseer modelling is conducted for all of the Fonterra owned LTS farms, either for Supply Fonterra nitrogen programme reporting of dairy farms and/or for resource consent compliance reporting. At the time of writing, Overseer version 6.2.3 was current. All end-of-season 2016/17 Overseer files were prepared in this version.

To examine possible options to achieve the target range for nitrogen leaching, a generic Manawatu dairy farm of 370 ha running 3.0 cows/ha was modelled under a typical wastewater irrigation scenario. The model farm, with 180 ha of moderate and well drained Manawatu silt loam soils and 94 ha of imperfectly drained Manawatu silt loam, was modelled initially with irrigation of untreated dairy factory wastewater irrigated at an annual hydraulic loading of 350 mm/yr and a total nitrogen loading (all sources) of 300 kgN/ha/yr (Table 1). 96 ha of pasture is not irrigated.

Table 1. Modelled wastewater monthly irrigation depths and nitrogen loadings

	Hydraulic loading (mm)			Nitrogen loading (kgN/ha)*		
Annual Total	**350**	**220**	**200**	**300**	**250**	**225**
August	16	-	-	10	3	-
September	34	-	-	20	10	-
October	35	35	15	30	30	35
November	34	37	32	30	30	35
December	40	75	37	35	26	26
January	52	36	42	35	35	28
February	47	37	25	35	30	30
March	52	-	29	35	30	30
April	12	-	15	20	13	13
May	10	-	5	18	13	-
June	13	-	-	2	1	-
July	5	-	-	2	1	-
September urea				28	28	28

* Urea + treated wastewater + treatment bio-solids. Bio-solids may be applied alone via truck spreader.

The second range of scenarios involved full biological treatment of the wastewater (final treated wastewater concentration of 5 gN/m^3) and a change of the farming system to 'partial C&C' where the cow numbers drop to 1.2 cows/ha and excess silage at 4 T DM/ha is cut and exported from the farm. Base, minimal spring and deficit irrigation scenarios were modelled. For the minimal spring and deficit irrigation scenarios, the biologically treated wastewater not irrigated was assumed to be discharged to a surface water.

The third range of scenarios involved a further change in farming system to full C&C with minor dry stock (0.5 heifers/ha). The target range of grass silage removal was 8 T DM/ha. Base, minimal spring and deficit irrigation scenarios were modelled (Table 1). Finally, the impact of using reverse osmosis (RO) as a further tertiary nutrient removal step for wastewater discharged to surface waters was examined. RO is able to reduce total nitrogen concentrations to < 1 gN/m^3.

Results and discussion

2016/17 End-of-season Overseer results

A summary of the end-of-season 2016/17 results for the Fonterra owned wastewater land treatment farms is shown in Figure 1, where the mid-point of the 20-30 kgN/ha/yr range is shown for convenience. The large farms associated with the South Island Edendale, Clandeboye and Darfield factories are run as C&C operations with limited dry stock and are already in the target band. The five farms associated with the Longburn and Pahiatua factories in the lower North Island, a mix of full dairy or partial C&C, are close to being within the range. The partial or full C&C farms of the Central Plateau are even closer. The two Taranaki farms are roughly twice the target due to large amounts of factory wastewater irrigation and full dairying systems. The three central Waikato farms, located just outside Cambridge near the Hautapu factory were 2-3 times higher than the target for similar reasons as in Taranaki. However, these Hautapu farms have recently transitioned to full C&C, thus should decrease substantially for the 2017/18 season.

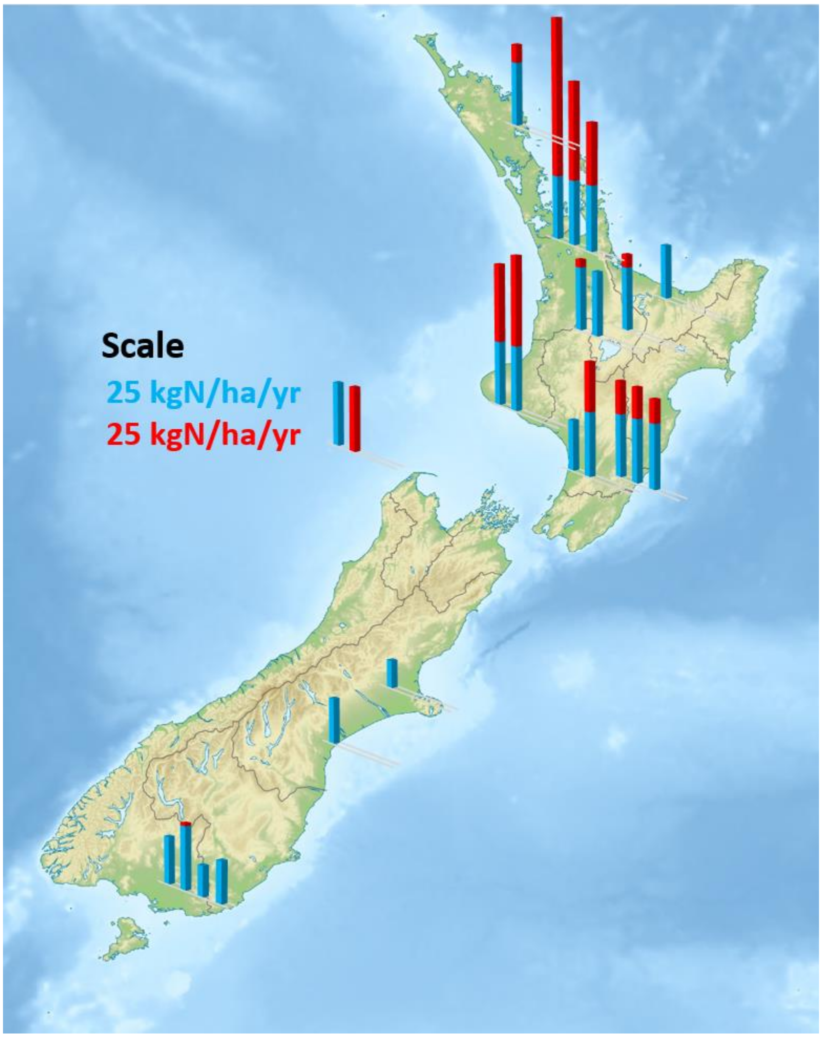

Fig. 1. 2016/17 end-of-season Overseer results for Fonterra owned dairy factory wastewater land treatment farms. Full blue scale bar indicates whole farm leaching of 25 kgN/ha/yr and anything above 25 kgN/ha/yr then becomes red e.g. for the northern most farm at the Kauri site leached 32 kgN/ha/yr in 2016/17.

The beginning of the 2017/18 season saw a wet winter compounded by a very wet spring which caused considerable operational pressures on many of the wastewater land treatment systems. Wastewater volumes of 3,000-6,000 m^3/day can originate from early August when the dairy factory processing season begins. Without wastewater treatment the effluent cannot be stored otherwise significant odours will arise. At the recently upgraded Pahiatua and Lichfield sites, which have both full biological treatment plus 100,000 m^3 of treated wastewater storage, irrigation restrictions due to the extreme wet weather saw the storage ponds getting close to maximum capacity. Significant methods to reduce wastewater production including trucking to other sites and/or limiting factory production were being considered to reduce this issue. Pasture pugging occurred at several sites through excessively wet soils. Alternatives to wastewater irrigation during wet weather events therefore form a key part of this study.

Scenario modelling of mitigation options

The generic wastewater land treatment farm for evaluation of mitigation options was modelled as being close to Palmerston North, within the Manawatu region, however the relative magnitude of the results would be equally applicable elsewhere in New Zealand. Under a full dairying scenario (A), when untreated wastewater was irrigated on the farm at an annual hydraulic loading of 350 mm/yr and a nitrogen loading rate of 300 kgN/ha/yr, the predicted rate of ‘whole farm’ nitrogen leaching was 55 kgN/ha/yr on a per hectare basis or 20,350 kgN/yr annually (Table 2).

For Scenario B1, the farm system changes to partial C&C with dairying. Biological treatment is implemented (Fig. 2) and the nitrogen load drops to 250 kgN/ha/yr which is a common limit on many Fonterra land treatment farms. A substantial portion of the overall nitrogen load is from treatment bio-solids being added back into the irrigation water to maintain sufficient nitrogen to maintain pasture production requirements. The irrigation regime still follows the factory production season which typically begins in early August and finishes in mid-June. Nitrogen leaching is predicted to decrease to 31 kgN/ha/yr or 11,470 kgN/yr. While this is an improvement of 44% it is still outside the target range.

Scenario B2 builds further on the earlier B1 by examining the effect of ceasing all irrigation in August and September, then again during June plus July. The annual irrigation depth decreases to 200 mm/yr, however the nitrogen loading of 250 kgN/ha/yr is maintained by slight increases in bio-solids addition. During the months of no irrigation the bio-solids would be exported for composting and the treated effluent (5 gN/m^3) discharged to a surface waterway. The decrease in irrigation depth of 150 mm/yr would equate to 411,000 m^3 of treated effluent to be discharged, adding 2,060 kgN/yr to the surface waterway during higher flow periods. The reduction in spring irrigation decreases calculated soil drainage rates and predictably farm leaching drops to 27 kgN/ha/yr which is within the target band. However, the combined total nitrogen to the environment from the farm plus surface water discharge of 12,040 kgN/yr is higher than that for B1. While any adverse effects of wetter spring pastures in terms of pugging damage may be reduced, the environment would see a slight net increase as compared to B1.

Table 2. Overseer modelling results of mitigation options.

Scenario	Farm Type	Wastewater Treatment	N load (kgN/ha/yr)	Irrigation regime	Irrigation depth (mm/yr)	Farm N leached (kgN/ha/yr)	Farm N loss (kgN/yr)	N to water (kgN/yr)	Total N to environment (kgN/yr)
A	Full dairy	No	300	August - June	350	55	20,350	0	20,350
B1	C&C + dairy	Biological	250	August - June	350	31	11,470	0	11,470
B2	C&C + dairy	Biological	250	Minimal spring	200	27	9,980	2,060	12,040
B3	C&C + dairy	Biological	250	Deficit Oct – Feb	220	29	10,570	1,780	12,350
C1	C&C + dry stock	Biological	250	August - June	350	28	10,460	0	10,460
C2	C&C + dry stock	Biological	250	Minimal spring	200	24	8,880	2,060	10,940
C3	C&C + dry stock	Biological	225	Minimal spring	200	17	6,340	2,060	8,400
D	C&C + dry stock	Bio. + RO	225	Minimal spring	200	17	6,340	410	6,750

Fig. 2. Examples of aerated biological treatment and treatment bio-solids export at Fonterra Pahiatua site: (a) aerated treatment pond, (b) 100,000 m^3 storage pond and (c) treatment bio-solids export to composting plant.

Typically, the volumes of factory wastewater are not sufficient in summer months for the irrigation to maintain soil moisture levels at just below field capacity. With Scenario B3, when full deficit irrigation during October to February is trialled, Overseer predicts an increase in total irrigation depth to 220 mm/yr applied during these months. These slightly higher irrigation rates increase predicted leaching slightly to 29 kgN/ha/yr, while the spring surface water discharge decreases slightly due to the increased irrigation. The total nitrogen to the environment however increases further above B2 to 12,350 kgN/yr. Therefore, in contrast to common expectations, the perceived superior option of deficit irrigation does not appear to result in any significant improvement for these systems as compared to a simpler minimal spring irrigation scenario. Thus, despite resulting in a dramatic decrease from the base dairying scenario, the B scenarios involving partial C&C either did not reach the target range (B1) or the inclusion of the surface water discharge raised total losses to above the no surface water discharge case (B2 or B3).

Further farm system change to full C&C (with minimal dry stock) was examined. Scenario C1, with nitrogen loading of 250 kgN/ha/yr and full season irrigation regime resulted in 1,000 kgN/yr less nitrogen loss than the equivalent partial C&C + dairy scenario (B1), due to more grass silage being exported and the lower stocking rate decreasing the 'urine patch' contribution to leaching. The magnitude of the difference was less than expected, thus a minimal spring irrigation scenario was trialled (C2). Less irrigation in wetter spring months will help improve soils by allowing them more time to drain. This should promote better pasture growth rates and reduced the risk of soil structure damage through animal pugging or movement of heavy silage equipment. Diverting the treated wastewater from irrigation to the surface water also decreases the amount of soil drainage, a direct driver of nitrogen losses, thus modelled leaching drops to 24 kgN/ha/yr. While the farm loss is in the middle of the target range, the additional stream discharge results in a total nitrogen loss of 10,940 kgN/yr which is slightly higher than the C1 starting position.

The possibility to add or remove the treatment bio-solids allows the hydraulic load and nitrogen load to be decoupled to a large degree. A slight drop in nitrogen loading to 225 kgN/ha/yr in Scenario C3, and more importantly adjusting the timing of nutrient applications to better suit grass growth requirements (Table 1), suggests farm nitrogen leaching could drop as low as 17 kgN/ha/yr. The annual losses for C3 including the surface water discharge are 8,400 kgN/yr which is 2.4 times lower than the no treatment and full dairying Scenario A.

Finally, any discharges of treated wastewater to surface waters may require further 'tertiary polishing', depending on the receiving water, especially for phosphorus. Reverse osmosis is a cost effective technology that can achieve very low nitrogen and phosphorus concentrations. If this was applied at times of discharge to surface waters, nitrogen loads could drop below 410 kgN/yr and combined losses of 6,750 kgN/yr are one-third of the original Scenario A.

Other nutrients

Sodium is present in large quantities in dairy factory wastewaters as a result of caustic cleaners or via salts used in cheese making. Sodium salts are extremely soluble and carry through the treatment process in the liquid phase. Careful management of irrigated soils must be undertaken in terms of application rates and adding calcium via gypsum or lime to avoid damage to soil structure.

Dairy factory wastewaters are rich in phosphorus via calcium phosphate present in the milk, which transfers to the liquid waste streams. Decades of irrigation of untreated wastewaters has led to soil Olsen P levels well above agronomic norms at some sites. Biological treatment accumulates significant phosphorus in the bio-solids. Export of some of the bio-solids will decrease phosphorus loads being irrigated. Further reductions in phosphorus loads down to ‘maintenance levels’ could be achieved by greater degrees of bio-solids export, however nitrogen levels would also drop significantly thereby decreasing pasture yields.

High levels of potassium in normal dairy milking shed effluent can lead to nutrient imbalances, particularly in lactating dairy cows at certain times of year. The same applies to dairy factory wastewater. Factories may have high or low levels of potassium in their wastewater depending on which dairy products are being manufactured and if potassium hydroxide based cleaners are used. As with sodium, even if wastewater treatment is installed, the potassium remains largely in the liquid phase and is irrigated. Levels of potassium exported in the grass silage from the South Island full C&C farms are so significant that regular potash fertiliser applications are required. For partial C&C or full dairying systems, management of dietary potassium is required.

Conclusions

Fonterra aims to have all its wastewater land treatment systems operating at ‘leading industry standards’ by 2026. Achieving the targeted nitrogen leaching rate of 20-30 kgN/ha/yr will require new frontiers to be explored in terms of the full integration of farming systems, wastewater treatment, treated wastewater storage and irrigation, plus several options for surface water discharges. Biological wastewater treatment coupled with partial or complete removal of treatment bio-solids allows the irrigation hydraulic and nutrient loadings to be tailored independently to pasture growth requirements, thereby maximising nutrient uptake and minimising nutrient leaching. A dual discharge regime, where treated wastewater is land treated via pasture irrigation during dry periods or discharged to surface water when soils are too wet to irrigate, would help mitigate against the risks of pasture pugging and subsequent damage to soil structure. While a minimal spring irrigation scenario should decrease nitrogen leaching from LTS, the associated discharge of treated wastewater to the surface waterway results in fractionally more nitrogen being lost to the environment. However if tertiary nutrient removal was conducted, by techniques such as reverse osmosis, prior to the surface water discharge then overall losses to the environment could be reduced to around one third of those from a LTS operated as a dairy farm and irrigated all season with untreated wastewater.

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