SOIL AND LANDSCAPE RISK FRAMEWORK FOR FARM DAIRY EFFLUENT APPLICATION TO LAND IN HIGH RAINFALL REGIONS (WEST COAST)

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ABSTRACT

On the West Coast, nutrient loss from the direct discharge of farm dairy effluent (FDE) contributes a significant nutrient loading into Lake Brunner. In this environment, anthropogenic phosphorus (P) inputs to the lake are of greatest ecological concern. Therefore curtailing P loss from farms is important for ensuring water quality. Application of FDE to land, at suitable irrigation depth and rate, can help reduce surface water pollution associated with direct discharge. However, it is apparent that nationally adopted recommendations for land application of FDE will not be practical on the West Coast where rainfall can be extremely high (e.g. up to 5 m per year). This means a large volume of water is collected from dairy shed catchment areas and also limits the potential for soil water deficits large enough to safely apply FDE to high risk soils.

This project aimed to (1) quantify the amount of nutrients lost in the direct pond discharges of FDE to streams throughout the year, and, (2) assess the suitability and practicality of a low rate FDE application system to land in the Lake Brunner Catchment. Pond discharges on three farms were monitored for 12 months and total nutrient loadings throughout this period were determined. On one property an irrigation trial was established where 10 mm of FDE was applied irrespective of the magnitude of soil water deficit. Surface run-off (concentration and volume) was monitored during three irrigation events in spring, summer and autumn.

Based on our findings, we estimate P loss from FDE can be reduced by approximately 80% when it is applied to land rather than directly discharged. Here we present a modified version of the Soil and Landscape Risk Framework for FDE management in high rainfall areas, such as the West Coast. Essentially, this adaption to the framework incorporates desirable management practices with what is practically achievable in these environments.

INTRODUCTION

Phosphorus (P) has been identified as the limiting nutrient for phytoplankton growth in Lake Brunner and a significant quantity of P is thought to be lost from surrounding agricultural land throughout the year (Horrox *et al.* 2011). A large amount of P will also be lost from two-pond treatment systems that discharge directly to surface waters (McDowell 2008; Monaghan *et al.* 2007) and have come under recent scrutiny. Application of farm dairy effluent (FDE) to land at a suitable irrigation depth (mm) and rate (mm/hr) is an alternative option with potential to curtail surface water pollution associated with direct discharge and recycle valuable nutrients for agronomic benefit (Houlbrooke *et al.* 2008). Evidence of effectiveness, however, is largely derived from studies carried out in regions with considerably lower rainfall than the West Coast.

The risk associated with land application of FDE varies depending upon the inherent properties of the soil to which it is applied. A framework has recently been developed by AgResearch that identifies minimum management practices required to adequately land-apply FDE with the intention of keeping nutrients in the root zone and avoiding direct loss of contaminants (Houlbrooke and Monaghan 2010). Included in this framework is the determination of scheduling criteria for different soil and landscape features (Table 1).

Table 1. Soil and landscape risk framework for FDE management

Category	**A**	**B**	**C**	**D**	**E**
Soil and landscape feature	Mole & pipe drainage or coarse soil structure	Impeded drainage or low infiltration rate	Sloping land (>7°) or land with hump & hollow drainage	Well drained flat land (<7°)	Other well drained but very light[X] flat land (<7°)
Application depth (mm)	< SWD*	< SWD	< SWD	< 50% of PAW[#]	≤ 10 mm & < 50% of PAW[#]
Instantaneous application rate (mm/hr)	N/A**	N/A**	< soil infiltration rate	N/A	N/A
Average application rate (mm/hr)	< soil infiltration rate	< soil infiltration rate	< soil infiltration rate	< soil infiltration rate	< soil infiltration rate
Storage requirement	Apply only when SWD exists	Apply only when SWD exists	Apply only when SWD exists	24 hours drainage post saturation	24 hours drainage post saturation
Maximum N load	150 kg N/ha/yr	150 kg N/ha/yr	150 kg N/ha/yr	150 kg N/ha/yr	150 kg N/ha/yr
Risk	High	High	High	Low	Low

* SWD = soil water deficit,

[#] PAW = Plant available water in the top 300 mm of soil,

[X] Very stony or sandy layer within 300 mm depth. Very stony= soils with > 35% stone content

** N/A = Not an essential criteria, however level of risk and management is lowered if using low application rates

Many of the soils in the Lake Brunner Catchment would be assigned to either Category B (Table 1, Impeded drainage) or Category C (Sloping land/hump and hollow drainage) thereby requiring irrigation depths < soil water deficit (SWD). However, as illustrated by Laurenson et al. (2012), deferred irrigation management of FDE is not practical on this part of the West Coast due to the low evapo-transpiration rates and high rainfall. Strict adherence to meeting, yet not exceeding the SWD, on the day of irrigation will not enable the annual effluent volume to be applied to land, particularly where a feed or stand-off pad is installed. Therefore better management practice advice given to most other New Zealand regulatory authorities would not be easily applicable to the West Coast region.

Here we explore alternative approaches to managing FDE in high rainfall environments which minimise the risk of P runoff and the costs associated with the provision of unrealistically large FDE pond storage. This project aimed to (1) quantify the amount of nutrients lost in the direct discharge of FDE to rivers, and (2) assess the suitability and practicality of a land application system. Our rationale was that, given the large volumes of FDE generated and limited opportunities to re-apply using deficit irrigation criteria, managing risk by adopting deferred irrigation would not be possible. Therefore we were looking to adopt a low application rate (intensity) and test its performance in the field with regards to avoiding surface flow losses to freshwater in a hump and hollow drained landscape prone to surface runoff movement of water.

METHODS

Pond discharges

Annual nutrient losses to surface water from discharging two pond systems on the West Coast were measured on three farms located in the Lake Brunner Catchment, near Rotomanu. These farms currently have resource consent to discharge FDE directly to streams. Weirs were installed on each farm at the point of discharge from the pond system and flow height across all weirs was measured every 15 minutes using TRUTRACK Dataloggers (WT-HR Intech Instruments) between 1 October 2011 and 30 September 2012 (365 days). A sample of the weir discharge was taken every fortnight and analysed by an accredited commercial laboratory (Eurofins/NZLABS [IANZ] in Hamilton) for a suite of nutrients including total and mineral forms of nitrogen (N) and P and potassium (K).

Low rate FDE irrigation trial

To assess potential fit-for-purpose FDE management system for high rainfall regions, a low rate FDE irrigation trial was established on one farm in the Lake Brunner Catchment on hump and hollowed land. Saturated soil infiltration at this site was 22 mm/hr. Weirs were installed across six areas of hump and hollowing (H&H) thereby comprising two catchments of 1.1 ha each under similar fertiliser management (as per current farm practice). FDE was applied to humps and hollows of one catchment while the other catchment (control) was not irrigated. During application of FDE, volume of surface runoff in the hollows was quantified by water height over the weirs. A sample was collected every hour during irrigation and analysed for nutrient concentration. Passive samplers were used to collect samples during rainfall events that proceeded FDE application. All samples were analysed as described above.

RESULTS

Pond discharges

Over the 365 day monitoring period a substantial volume of liquid was discharged from all FDE ponds into receiving fresh water bodies (Figure 1). Average volumes of daily discharge for all farms ranged between 36 and 112 m^3/day. However, this varied considerably between sites, and particularly during large rainfall events (i.e. standard deviation exceeded these values by 200-300%). High discharge volumes were most evident during November following a period of excessive rainfall (i.e. up to 180 mm/day). It is evident (Figure 1) that losses were highly responsive to rainfall events that subsequently increased the discharge rate (m^3/day) and were most apparent where the catchment area draining into the FDE pond system was greater (i.e. Farm C).

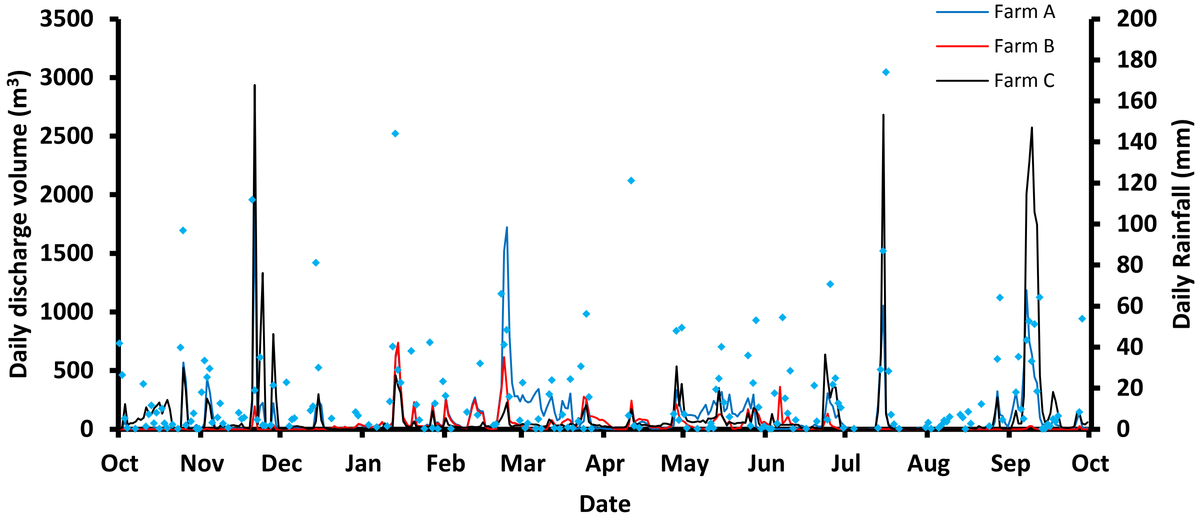

Figure 1. Measured daily pond discharge volumes (m^3) from three monitor farms, inclusive of wash down and rainfall contributions. Rainfall (mm; blue dots) relate to the secondary axis (right).

The average loss of N, P and K from the three discharging ponds are shown in Table 2. This represents a significant loss of potential nutrient resource. Using current fertiliser prices for urea, superphosphate and potash we have determined that 1 kg of N, P and K is worth \$1.73, \$3.83 and \$1.69, respectively. We have determined that the mean value of nutrients discharged to freshwater across the three farms between October 2011 and September 2012 monitoring period was equivalent to approximately \$32 per cow (Table 2).

Table 2. Nutrient in FDE discharged from the three farms, expressed as kg/yr and \$/cow/yr. Standard deviation (SD=1) between farms is also shown

Nutrient	Total loss (kg/yr)		Value (\$/cow/yr)	
Nitrogen	2,400	±565	\$7.70	±1.80
Phosphorus	545	±75	\$8.00	±1.10
Potassium	2,750	±640	\$16.40	±3.75

Low rate FDE irrigation trial

Over the experimental period, nutrient loading on the FDE-receiving area was equivalent to 42 kg N/ha, 10 kg P/ha and 20 kg K/ha (sum of three events). Total N loading was considerably lower than the 275 kg N/ha loading permissible under regional council legislation (N.B. there is no permissible limit for P). Estimates of total losses of nutrients were significant relative to amounts applied in FDE. Importantly however, there was a limited difference between FDE and control plots (Table 3). This indicates that nutrient loss attributable to FDE is minor relative to that which is lost from these systems under current farm grazing practice.

Table 3. Summary of total surface runoff (m^3/ha) and total nutrient losses (kg/ha) during FDE irrigations, and from rainfall received following application.

	Control	FDE
Total runoff volume (m^3/ha)		
Irrigation events	< 1	< 1
Rainfall events	4018	4346
Total nutrient loss (kg/ha)		
Nitrogen	10.75	8.47
Phosphorus	2.22	2.78
Potassium	16.15	16.85

We strongly advocate that the instantaneous rate of application is important and should be less than the infiltration rate of the soil. Where the rate of FDE application exceeds soil infiltration rate, the risk of surface run-off increases and will lead to greater nutrient loss into hollows. These areas are highly connected to surface waters and therefore act as rapid transmission pathways for nutrients. It will be important therefore to ensure that rates of FDE application are always less than the soil infiltration rate in order to prevent surface water run-off.

RECOMMENDATIONS

There are a range of soil types on the West Coast, including humped and hollowed, poorly drained and rapidly drained soils. The landscape risk identified by the effluent framework will need to encompass a range of management approaches. As noted, a deferred (deficit) irrigation regime in the Lake Brunner Catchment is not practical due to large pond storage requirements. Therefore in high rainfall environments such as the West Coast, application depths in excess of SWD are inevitable and some degree of loss will be expected. While it is possible to operate a land application system on Category E soils (Table 1), a separate set of criteria will need to be developed for High Risk soils (Category A, B and C soils).

Here we propose more flexibility around land management criteria by enabling water to be applied when soils are at, or near, field capacity. However, the instantaneous application rate should be less than the saturated hydraulic conductivity of the soil in order to prevent surface runoff. Although this will result in soil drainage, a degree of P attenuation within the profile is likely and is considerably more favourable than direct discharge to surface waters. When FDE is applied at a depth less than the SWD, P attenuation is assumed to be 100%. However, based on previous work by Monaghan and Smith (2004) we assumed this would decrease to 70% when applied up to 10 mm in excess of the SWD. Soils sampled on the West Coast have similar P retention capacity to the Pallic soils studied by Monaghan and Smith (2004) when correction is made for the high stone content and therefore we believe that P retention will be similar when FDE is applied at low depths (i.e. ≤ 10mm). In a study reported by Houlbrooke et al. (2004), it was evident that P attenuation decreased to 50% when the depth of FDE application exceeded the SWD by more than 10 mm.

Essentially therefore, the degree of P attenuation is dependent on the flow characteristics of FDE through soils. When FDE is applied to a dry soil for instance, flow will be predominantly through small pores less than 30 µm, allowing for maximum attenuation of P. However, as the soil exceeds field capacity, larger macropores (>30 µm in size) will participate in flow and P attenuation will decrease. Here we have estimated 70% attenuation in small micropores under such conditions. If more water is applied to these soils, flow will principally be through very large macropores (those greater than 300 µm) that have limited P attenuation capacity. Given the necessity to apply FDE to wet soils, a compromise is met whereby application to saturated soils (with >300 µm pore space conducting water) should be avoided, yet application with a soil water deficit will not always be attainable. Therefore we recommend daily application depths be restricted to 10 mm in order to maximise soil P attenuation. In low risk Category E soils, we expect P attenuation to be greater than 70% and will be a conservative estimate in these soils.

The proposed modified FDE framework for high rainfall environments is shown in Table 4 below. Considering the importance of different soil water transport mechanisms, we recommend that FDE management practices are matched with soil and landscape features in order to minimise direct losses of effluent contaminants. A decision tool has been constructed to guide appropriate effluent management practice considering the effects-based assessment of different soil and landscape features (Table 4). It should be noted that these criteria are considered the minimum conditions that should be adhered to, to minimise direct losses of land-applied FDE constituents in high rainfall environments.

Table 4. Minimum performance criteria for a land-applied effluent management system in high rainfall regions such as the West Coast.

Category	**A**	**B**	**C**	**D**	**E**
Soil and landscape feature	Artificial drainage or coarse soil structure	Impeded drainage or low infiltration rate	Sloping land (>7°) or land with hump & hollow drainage	Well drained flat land (<7°)	Other well drained but very light[X] flat land (<7°)
Risk	High	High	High	Low	Low
Instantaneous application rate (mm/hr)‡	< soil infiltration rate when no SWD^	< soil infiltration rate when no SWD^	< soil infiltration rate	N/A	N/A
Average application rate (mm/hr)	< soil infiltration rate	< soil infiltration rate	< soil infiltration rate	< soil infiltration rate	< soil infiltration rate
Storage requirement‡	Avoid application while soil draining	Avoid application while soil draining	Avoid application while soil draining	Avoid application while soil draining	Avoid application while soil draining
Maximum N load	150 kg N/ha/yr	150 kg N/ha/yr	150 kg N/ha/yr	150 kg N/ha/yr	150 kg N/ha/yr
Max application depth ‡	10 mm & < 50% of PAW*	10 mm & < 50% of PAW	10 mm & < 50% of PAW	25 mm# & < 50% of PAW	10 mm & < 50% of PAW

^ When application depth exceeds soil water deficit (SWD) * PAW = Plant available water in the top 300 mm of soil, [X] Very stony sandy layer within 300 mm depth. # 25 mm is the suggested maximum application depth when a suitable SWD exists (≥ 15 mm). Field capacity should not be exceeded by more than 10 mm using a high rate irrigator.
‡Key parameter that differs from criteria stipulated in Table 1

Implications for P loss risk

We have compared P losses from two FDE management systems: (1) direct discharge of FDE to surface waters, and, (2) application to land under the set criteria in Table 4. A comparison in P loss between systems and pond storage requirements has been made. Here the farm specifications are assumed to be:

- Farm area of 236 ha (effective area)
- 450 cow herd
- Twice a day milking (from 1st August to 15th May)
- No winter milking
- Daily wash down volume of 70 L per cow per day (37.5 L per milking)
- Yard size of 1242 m^2 (rainfall diverted during non-lactation period)
- Total pond surface area 1200 m^2 (2 ponds, each 30 m W x 40 m L).
- Application via a 32-pod system with twice-daily shifts (covering a total land area of 2 ha per day).

Based on the data provided above, potential P loss risks associated with different FDE management options have been estimated for a farm located at Inchbonnie (Table 5). Here it is assumed all irrigation applied in excess of the SWD is lost to the local hydrological system as deep drainage. The concentration of P in stored FDE was assumed to be 20 mg L^{-1} (the average concentration across all farms monitored).

In the following scenario, FDE was applied at a depth of 10 mm when SWD was at or below zero. On days when soil moisture was above field capacity (i.e. saturated), no FDE was applied in order to prevent preferential flow through very large macropores (> 300 µm). The instantaneous application rate was assumed to be less than soil hydraulic conductivity so as to limit surface run-off and minimise preferential flow. Based on these assumptions, the estimated pond size for the Inchbonnie farm reduced substantially. Under the deferred irrigation regime, for instance, the required pond capacity was 300,000 m^3, while under a wet day avoidance regime this was reduced to an attainable size of 3,500 m^3, based on a 9 out of 10 year design requirement.

This approach to FDE management enables a considerable volume of FDE to be applied to land. However, it does imply that a large volume will be lost in deep drainage. Based on the current FDE system (described above), for instance, approximately 16,410 m^3 (range 10,850-21,530 m^3, between 1988-2011) of soil water, which is likely to include a strong FDE component, is assumed to be lost as drainage. Based on a soil P attenuation of 70%, the comparative risk of P loss relative to direct discharge has however decreased by 80%. When considered within a whole farm context, estimated P loss under this management approach is relatively low.

Table 5. Estimated risks of P loss under various FDE management approaches for a hypothetical farm located at Inchbonnie.

FDE management approach[β]	Ave. vol. FDE loss/yr (m^3)	Ave. P loss/yr (kg)[#]	Req. pond size (m^3)[§]	Comparative FDE risk[‡] (%)
Direct discharge	27,270	546	N/A	100
w. stand-off pad	40,483	810	N/A	150
Land Application	16,410	115^	3,500	20
w. stand-off pad	22,860	160^	7,500	30

[β] In all cases a stand-off pad size of 3500 m^2
[#]Assumes a total phosphorus concentration of 20 mg/L, except where otherwise indicated
[§]Based on a 9 from 10 year maximum, as per Code of Practice
[‡] Calculation based on 'current practice' which is direct discharge, 'no stand-off pad', where 100% comparative risk indicates maximum risk for FDE management.
^Assumes 7 mg/L drainage P concentration based on 70% P retention in saturated soils (Monaghan and Smith 2004).

Rainfall contributions to FDE volumes are substantially greater than the effluent derived from wash-down and from direct deposition at the milking parlour and holding yard. Therefore, exclusion of this otherwise fresh water source has significant benefits for FDE management. Housing cows under shelter pre-milking enables required pond sizes to be substantially reduced. This greatly reduces the potential risk of P loss from FDE applications to land.

CONCLUSIONS

Compared to discharging pond treatment systems, land application of FDE is expected to decrease P losses from dairy farms in high rainfall areas such as those surrounding Lake Brunner. Current best management guidelines adopted by many Regional Councils require FDE to be applied to high risk soils at depths equivalent to the SWD. This would be prohibitively costly for farms in the high rainfall environments of the West Coast due to the volume of storage required, particularly if effluent from stand-off and feed pads contribute to the total volume of FDE captured.

There will be a requirement therefore that guidelines, developed for FDE irrigation on the West Coast, are flexible on scheduling and allow for traditional low risk soil criteria irrespective of the soil risk status. However, it is also important that the instantaneous rate of application to high risk soils should, as stipulated in the AgResearch soil risk framework for FDE management on the West Coast, be less than the soil hydraulic conductivity so as to limit direct loss of P in surface run-off and preferential flow though large macropores. In addition, strict control of application depth will be required so as to help minimise any drainage excess created from FDE application. Ideally, covered yards and stand-off and feed pads should be considered in these high rainfall areas to minimise the rainfall contribution to total effluent volumes.

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