BENCHMARKING N & P LOSS FROM DAIRY EFFLUENT DERIVED NUTRIENT SOURCES

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Abstract

In New Zealand, farm dairy effluent (FDE) is generated in a number of locations around a dairy farm including the milking shed, off-paddock animal confinement facilities, stock laneways and silage stacks. The storage and management of this effluent, with respect to the specific attributes of the farm (e.g. soil type, proximity to water, topography and climate) has a huge bearing on the proportion of nutrients (and other potential contaminants) that are lost. However, the relative contribution of nutrients lost from FDE storage, distribution and land application are not widely documented.

This study assessed the potential and likely nutrient loss associated with a given farm management decision or a defect in the design and/or maintenance of effluent infrastructure on a typical or average Waikato farm. We have distinguished between the 'at risk' components, i.e., the total quantity of nutrient that could potentially be lost (worst case scenario), and, an 'attenuated loss', which is the quantity that is actually lost once best case soil attenuation potential is factored in. The 'at risk' and 'attenuated losses' of nutrients from a number of individual contributing factors have been reported. This approach highlights the potential non-compliance magnitude and enables farmers to prioritise management efforts toward the most influential factor contributing to overall farm losses. We suggest the greatest gains in reducing nutrient loss from effluent sources on dairy farms can be achieved by preventing pond discharges, ensuring adequate capture of effluent from off-grazing systems and employing sound irrigation practices when applying FDE to land.

Background

Farm Dairy Effluent (FDE) management has proven to be a challenge for dairy farmers and regulatory authorities throughout New Zealand. Poor management of FDE and sub-optimal effluent-related infrastructure and management practices can result in effluent being discharged directly to surface water bodies which can have deleterious effect on water quality (Houlbrooke *et al.* 2004, Houlbrooke *et al.*2008, Monaghan & Smith 2004, Muirhead *et al.* 2008).

Losses may occur at various locations around the farm where effluent is generated, stored or distributed e.g. feed pads, storage ponds or during its application to land. We have devised a method for assessing risk that quantifies the relative nutrient loss from a series of contributing factors against the total effluent resource. This includes risk components (e.g. animal shelter), management decisions (e.g. application depth or choice of irrigation infrastructure) or incidents (e.g. stalled irrigators and broken pipes). A data set of whole farm nutrient losses expected to occur during effluent storage, distribution and application to land has been complied for best and worst case scenarios. Finally, we have summarised these findings in an overview graph that fairly and equitably presents a comparison of the potential loss pathway across the whole farm, as well as their potential environmental impact.

Objectives

To provide a quantitative comparison of potential contaminant losses associated with dairy effluent sources on farm

- Whole farm vs. per hectare (spatial comparison)
- Annual losses vs. event based losses (temporal comparison)

To annualise losses and benchmark practices that will support DairyNZ's proposed Warrant of Fitness (WoF) risk assessment for sources of dairy effluent. This will enable farmers to prioritise management efforts toward the most influential factors contributing to overall farm losses.

Defining losses

From the total amount of FDE that is generated on a dairy farm there will be subsequent losses. The relative magnitude of loss will differ spatially (and to some extent temporally) across the landscape depending upon proximity (and timing) of management practices. Therefore, the actual loss will differ between and within farms depending on factors more likely to route FDE to surface waters than attenuation on land. Our approach has been to present two values which demonstrate the range of losses for a given component: an 'at risk' value versus an 'attenuation' potential. These differences in losses can be defined as:

- The 'at risk' value represents the size of the effluent resource for a given activity that could all be lost to surface water given worst case conditions. Examples include a worst case scenario given poor management or high spatial risk (i.e. broken pipe over tile drain or slope to stream).
- The 'attenuated' loss represents a best case scenario whereby environmental loss is restricted to leaching loss through the root zone (as influenced by the quantity of nutrient input and area to which it is applied) that is affected given that all nutrients are infiltrated into the soil to maximise attenuation (plant uptake and soil storage) i.e. broken pipe on flat permeable soil.

Methodology

Base farms

Two base farms were set-up using the OVERSEER® Nutrient Budgets 2012 program (version number 6.0.3). Data obtained from DairyNZ was used to model: 1) an 'average' Waikato farm (from Dairy Statistics, 2011), and 2) a DairyNZ Production System 4 farm operation (i.e., higher intensity farm). In relation to risk associated with infrastructure, soil type has limited effect on overall farm nutrient loss; therefore, we have considered a single soil (Gley, flat) type across the two base farms. However, for dairy effluent application to land, soil type has a greater influence and so we considered two soil type scenarios: a low risk Allophanic and a high risk Gley soil.

Nutrient loss associated with off-paddock facilities was determined based on modelling of the System 4 farm because it was more likely to have feed pads, stand-off pads and/or animal shelters. Assumed characteristics of both base farms are defined in Table 1. Background farm losses were determined by exporting (i.e. taking off-farm) all FDE generated on the base farm.

Table 1: Farm characteristics of 'average' Waikato and typical DairyNZ System 4 farm.

Farm characteristics	Units	Average[1]	System 4[2]
Effective farm area	ha	112	132
Total cow numbers (July 1)	cows	328	449
Stocking rate (cows wintered)	cows/ha	2.93	3.40
Cow live-weight	kg	445	412
Yearlings grazed on or off farm		off farm	off farm
Days in milk	days	268	270
Milk solids production/ha	kg MS/ha	929	1312
Annual pasture production (consumed)	t DM/ha	9.32	11.57
Brought in supplements	t DM/ha	1.34	3.43
Conserved pasture silage	t DM	30	110
Fertiliser nitrogen used (5 applications) [3]	kg N/ha	150	150
Stock wintered off farm	%	0	0

[1] Data produced from a combination of LIC statistics and an average value obtained from DairyBase®
[2] Data supplied courtesy of Alfredo Alder, Agricultural Consultant, Waikato.
[3] Fertiliser N application rates were set at 150 kg N/ha matching Waikato Regional Council effluent loading limit.

A number of scenarios including risk components, management decisions or incidents, were individually incorporated into the two modelled base farms. An actual contribution to farm nutrient loss is then attributable to each individual factor. Here we have assumed that there is no compounding effect from a series of contributing factors that might occur on farm.

Nutrient losses are reported as absolute values (kg/yr) rather than as proportional losses. This enables farmers to add various components together, such as a broken pipe, unlined off paddock facilities or FDE applications via a travelling irrigator to high risk soil. The sum of these components will be the estimated nutrient loss across the whole farm. Two assessments (leaking pipes and stalled irrigators) are not year-round contributors and so were assessed on an event basis. We have then benchmarked this with other components on the assumption of having only one such event per year. This also means that the factor is potentially multiplied by the expected occurrence if required to determine greater frequency of these events.

<u>Components within effluent management that contribute to nutrient loss</u>

A list of the various components included in this risk assessment study is provided (Table 2). Various methods were used to predict the risk posed from each of the components. This task was achieved by compiling knowledge from literature values, whole farm modelling (using the OVERSEER® model; Wheeler et al, 2006) and where no information was available, using scientific first principles. Note that OVERSEER® assumes best management practice.

Table 2: Components within the effluent generation, distribution and application process that contribute to whole farm nutrient losses.

Effluent risk assessment area	
Infrastructure	**Land Application**
Pond discharge to water	Pond storage capacity
Stone trap cleanings	High risk soils
Leaking ponds	High risk soils – mole and tile drained
Laneways/ Underpasses	Low risk soils
Leaking/broken pipes	Travelling irrigator
Silage stack leachate	Low rate applicator
Feed pad (effluent not contained)	Application depths
Stand-off pad (uncovered & drainage not captured)	
Animal shelter (unsealed carbon base)	

Assumptions made in assessing component contribution
For an assessment of the risk from different components within the effluent generation some assumptions have had to be made. A snapshot of these assumptions is provided below.

Infrastructure components:

Pond discharges to water
The two-pond (anaerobic/aerobic) system was the main form of FDE treatment and management prior to 1990. Where farmers still hold existing resource consent, these two-pond systems may still be discharging to waterways. OVERSEER® has been used to calculate direct loss of N and P to water ways from a discharging FDE treatment pond.

Stone trap cleanings
Sand/stone traps are designed to intercept, slow and modify effluent flow so that inert heavier materials (sand, stones and debris) drop out, thereby preventing blockages or excessive wear and tear on pumping systems. The Waikato Regional Council (WRC) undertook a sand trap study on six dairy farms (Harford, 2010). It was assumed that 4 tons of material was collected in sand traps per year and had a nutrient concentration similar to that detailed by Harford (2010). Storage was assumed to be on an unlined area of 10 m^2.

Leaking ponds
Oxidation ponds were the main means of effluent treatment on NZ's 14,000 dairy farms until the late 1980s (Hickey et al, 1989). The normal configuration was a two-pond treatment system with both ponds typically having a clay-based liner material. Seepage rates, based on the IPENZ (2013) equation, from an effluent pond area of 750 m^2 with different degrees of clay liner compaction were calculated. Heights (i.e. head pressure) of FDE were assessed. An 'at risk' nutrient loss value was determined assuming zero attenuation within the clay liner or subsoil below. The 'potential attenuated' loss was determined based on OVERSEER® modelling through a subsoil with low organic C content and low production potential (plant uptake) which closely mimics the likely poor attenuation potential under a long term pond site.

Laneways/Underpasses

Runoff from laneways is a potential nutrient loss pathway. In a Waikato farmlet study, Ledgard *et al.* (1999) reported that approximately 5% of cow excreta was deposited on laneways. However, total loss will be highly dependent on the degree of trafficking (including herd size and frequency of use), the connectivity & proximity of the laneway to waterways and the amount of rainfall. Nutrient loss in laneway runoff has been calculated using data reported by Monaghan and Smith (2012). Estimates of runoff concentrations for two distances, near (within 100 m) and far (beyond 100 m) from the dairy shed have been included.

Underpasses allow cows to pass from one area of the farm to another without the need to cross over roads, thus removing the potential for cows to excrete on roadways. They are normally sited at a low point of the landscape into which rainfall and effluent tend to converge. It is assumed that the combined volume of rainfall and effluent was pumped from the underpass onto an adjacent paddock. Paddock losses have been modelled using OVERSEER® assuming soils are at or near field capacity at the time underpass effluent is applied. Subsequent effluent remaining in the underpass after pumping was subject to leaching across an area of 30 m^2 (i.e. underpass floor area).

Leaking/broken pipes

There are several potential areas of a farm where broken pipes can lead to an unmanaged flow of effluent. Here we assume a pipe 150 m in length and 90 mm in diameter empties FDE to a small area before being discovered. Our approach is similar to that used for sand-trap cleanings. The amount of FDE contained in the 150 m length of 90 mm pipe was assumed, based on judgement, to flood over a small area (10 m^2). Potential runoff and leaching losses from the leaking pipe were modelled using OVERSEER®. Losses were scaled up to a per hectare basis to obtain N and P losses, and then scaled back to 10 m^2 to determine the pipe's contribution to losses at the whole-farm scale.

Stewart & Rout (2007) reported that small leaks in water lines that are under pressure can lead to big losses over time. These losses could be hard to detect in effluent pipes if they are buried. We have assumed an effluent pumping time of 2 hours per day.

Silage stack leachate

The contamination potential from silage leachate is significant due to a high concentration of nutrients, particularly N and its biological oxygen demand (BOD) (Vanderholm, 1984). Leachate problems are more prevalent when silage is poorly wilted (prior to being placed in the bunker) because the volume produced is greater (ECAN, 2009). The transport of nutrients in silage leachate will be considerably greater during prolonged high rainfall events. Silage was commonly made when between 20-40% DM. Howse *et al.* (1996) reported that the average quantity of pit or stack silage was 115 t fresh weight (FW) at 31% dry matter (DM) and averaged 2.4% N. The volume of leachate produced from an average silage stack of 115 t FW is 15 litres per tonne grass or 1,725 L per stack (assuming bulk density of silage leachate is 1:1) per year. We assumed the 115 t FW silage stack covers a 40 m x 5 m area (200 m^2). Estimated nutrient losses based on soil attenuation were modelled through OVERSEER®.

Feed pads

A recent survey of Waikato dairy farmers found that 24% had feed pads. Of those, 87% were constructed with concrete, 6% gravel and a further 6% were described as "other" (WRC, 2012). The WRC (2012) survey also found that 7% of feed pads had no adequate effluent containment; this is an improved situation from an earlier AgResearch survey where 17% of feed pads had no runoff collection (Kira *et al.* 2008). Fenton (2011) investigated the potential scale of ponding effects and seepage from feed pads (and stand-off pads) on nutrient loss and found that significant total farm losses could occur if runoff from the pad surface was not well managed. Fenton reported N losses could be 25% greater when no proper effluent management (i.e., solid and liquid components) was in place.

The assumptions made in this scenario were for feed pad usage of 2 hours per day for six months of the lactation season. It was also assumed that although the feed pad has its manure scraped, the liquid component is not properly contained. OVERSEER® was used to model the difference between a feed pad being scraped with effluent exported and a feed pad from which all effluent is exported.

<u>Stand-off pads (uncovered)</u>
Stand-off pads are typically constructed with a carbon-based material, such as fence post peelings or wood chips to provide a comfortable surface for resting cows. The minimum recommended stand-off pad area is $5m^2$/cow (Dexcel, 2005). A WRC (2012) study found that 22% of Waikato dairy farms had a pad and that these structures were more likely to be found in regions with typically wet soils. These structures are normally uncovered and therefore present a large catchment area for rain. Drainage is produced from pads when liquids (urine and rainwater) percolate throughout the media profile. Most farms capture this drainage in an effluent storage pond. However, if the stand-off pad has an unlined base, then drainage has potential to contribute to groundwater contamination.

The WRC (2012) survey also found that of the farms with stand-off pads, 45% were unlined pads, with a further 3% not knowing if a lining was in place. The WRC (2012) report also found that 67% of farms stood cows off-paddock for 9-16 hours/day on at least some occasions.

When estimating losses from the stand-off pad it was assumed that the herd uses the pad for long-term use over the wintering period, i.e., cows spend 12 hours per day on the pad over a six week period. Losses were modelled using OVERSEER® by setting up two scenarios with a lined and unlined stand-off pad. Nutrient loss in drainage was then determined and compared between the two scenarios.

<u>Animal shelters</u>
Animal shelters are defined as temporary or partial housing structures. They are essentially covered stand-off pads, usually with an internal or external feeding lane. Many shelters are constructed with a drainage system but have an unlined base. Normally at least 30 cm of bedding material, i.e., woodchips or carbon-based product, is spread across the shelter floor. Bedding materials are periodically turned using cultivation equipment in order to soak up effluent and reduce effluent run-off. Animal shelters with under floor concrete bunkers are not included in this scenario as their liquid fraction is adequately contained. Nutrient losses were modelled through OVERSEER® using the same approach as for the stand-off pads.

Land application components:

<u>Pond storage capacity</u>
Pond storage is considered an essential requirement in order to defer FDE application when soils are wet (Houlbrooke *et al.* 2004, Houlbrooke *et al.* 2008, Monaghan & Smith 2004). OVERSEER® has been used to demonstrate the effect of no effluent storage facilities by comparing an average farm spraying directly from the sump versus spraying from a storage pond (i.e. deferred irrigation) on both low and high-risk soils (soil risk detailed below) .

Application depths

Travelling irrigators are the most popular method of FDE application to pastures. The application depth is governed by the irrigator's speed, i.e., the faster the speed the less time taken to apply FDE and therefore a lower application depth. Three FDE application scenarios were modelled using OVERSEER® for the average base farm, for three applied depths: <12mm, 12-24mm, or >24mm. Applying depths greater than 24mm will increase the nutrient loading to pastures from a single event and increase the risk of ponding, runoff and/or preferential flow losses (Houlbrooke *et al.* 2004).

High risk soils

Land application of FDE has proven difficult when it has occurred on soils with a high degree of preferential flow, soils with artificial drainage or coarse structure, soils with infiltration or drainage impediments, or when applied to soils on rolling/sloping country (Monaghan *et al.* 2010). The effect of these conditions can be exacerbated by high rainfall and result in poor environmental performance of the land application system.

Low risk soils

In comparison, well drained soils with fine to medium soil structure tend to exhibit matrix rather than preferential drainage flow, even under soil moisture conditions close to, or at field capacity (McLeod *et al.* 2008). These soils, therefore, pose a lower risk of direct loss of effluent contaminants. Houlbrooke and Monaghan (2010) designed a soil risk framework which categorises all soil and landscape features into one of 5 different classes that can be labelled as either 'high' or 'low' risk. The key management difference is the scheduling criteria whereby high risk soils must have an application depth less than any soil water deficit. In contrast, low risk soils can only receive modest depths (< 10 mm) of applied FDE before they reach field capacity.

Travelling irrigators

Travelling irrigator malfunction can result in nutrient contamination of waterways. Such incidents could include: winch wire breaking, nozzles blowing off, or the anchor point being pulled out of the ground. A mechanical breakdown of the travelling irrigator has been scenario tested assuming this occurred two hours into an eight hour run and remained stationary for six hours. Potential leaching losses from a 'donut' effluent pattern have been calculated accounting for soil attenuation using OVERSEER®. Losses have been scaled up to a per hectare basis to obtain N and P losses, then scaled back to 10 m^2 to determine the donut's contribution at the whole-farm scale. In choosing this method it is recognised the position of a stalled irrigator will most likely differ spatially between years. However, OVERSEER® assumes it remains constant and therefore losses may be overestimated. Furthermore, it is also recognised that the nutrient loading rates applied in these areas (albeit a small area) is likely to be outside the validation dataset for the model.

Low rate applicators

Low rate application systems for FDE irrigation have increased in popularity since being introduced about a decade ago. The instantaneous and average application rate achieved is typically 4 to 5 mm/hr which provides greater control of depth and uniformity of application. Considerable decreases in both the volumes of mole and pipe drainage (and overland flow), and the relative concentration of effluent contaminants in the flows was measured when low rate applicators were used to apply FDE in Otago (Monaghan *et al.* 2010). FDE low rate application scenarios were modelled in OVERSEER® to compare against the travelling irrigators on both low and high risk soils, as described in the previous section.

Modelled and scenario tested results

Benchmarking components

The total amount of FDE generated on the average 112 ha Waikato dairy farm (328 cows) was 2,240 kg N and 224 kg P per year. The magnitude of both worst case scenario losses (at risk portion given poor management and/or a high level of spatial risk) and best case scenario losses based on maximising the soil's potential attenuation of nutrients (i.e. good management practice and/or lowest spatial risk) for these components has been summarised (Table 3). This table presents the components collectively so the relative magnitude of potential risk and attenuation can be compared against each other. The data is also presented pictorially to better illustrate the impact of the multiple components. The cumulative total represents the size of the effluent resource requiring management on the farm.

Results from Figures 1-4 and Table 3 show that 'at risk' losses from land application, uncontained feed pads, unsealed animal shelters, silage stacks and leaking ponds can be large (> ~300 kg N). However, when attenuation is accounted for, the actual loss is considerably less. Pond discharges of 784 kg N and 78 kg P are lost directly to water, representing approximately one third of the total FDE resource. These losses are the largest of any of the FDE management or infrastructure components tested and clearly represent an area to target for reducing environmental losses from farms. Pond leakage represents a large at-risk potential loss of N and P but soil attenuated losses in the subsoil below the pond are greatly reduced. However, there is still a clear knowledge gap regarding attenuation potential of subsoil below a leaking pond.

By far the largest 'at risk' proportion of effluent on a farm is the quantity of N and P in FDE stored in pond(s) before being applied to land. In this case we have allowed for one pipe breakage, one pipe leak and one travelling irrigator fault (that causes it to stall while still operating) to occur over the year. The volume of these extraordinary losses has been subtracted from the annual total FDE volume.

Table 3: Summary of the 'at risk' and 'attenuated' losses of N and P (kg/yr) for each of the contributing factors.

Contributing factor		**At Risk**		**Attenuated loss**	
		N	P	N	P
Pond discharge		2,240	224	784	78
Land application		2,240	224	156	6
Stone trap clearings		6.4	1.2	0.5	0
Pond leakage		296	47	9	0.2
Laneway		21	15	0.4	0.4
Underpasses		30	4	6	2
Leaks/drips		0.5	0.1	0.4	0
Silage	(Average farm)	32	1.4	7	0
	(System 4 farm)	299	13	50	0.1
Feed pad		1,227	110	60	0.1
Stand-off pad		883	201	165	1
Animal shelter		883	201	10	0

Table 4 demonstrates that the typical attenuation of nutrients in soil increases with decreasing application depth of FDE, resulting in decreased losses from the relevant management block on a per-hectare basis. As a proportional loss reduction, the greatest potential reduction from improving FDE management (decreasing application depth) is observed for P, rather than N. For example, a 25% decrease in whole block P loss is achieved on high risk soils by managing the depth of FDE application alone, compared to c. 10% for N.

Table 4: Predicted effluent block N and P losses (kg/year) from different management scenarios on high and low-risk soils.

Storage	Depth (mm)	Other feature	High risk soil*		Low risk soil*	
			N (kg)	P (kg)	N (kg)	P (kg)
Sump	>24		219	15	397	5.0
Sump	12-24		209	13	393	4.3
Sump	<12		198	11	389	3.8
Sump	12-24	M&P	350	28	n/a	n/a
Pond	< 12	DI	152	8	394	1.0
Pond	< 12	DI, LR	156	6	393	1.0
Pond	<12	M&P, DI, LR	188	9	n/a	n/a

M&P = mole and pipe drainage, DI = deferred irrigation, LR = low rate application (mm/hr)

* NB: Whole farm N losses on the average farm are 1,300 kg N/yr and 109 kg P/yr for high-risk soils; and 3,103 kg N/yr and 50 kg P/yr for free-draining low-risk soils.

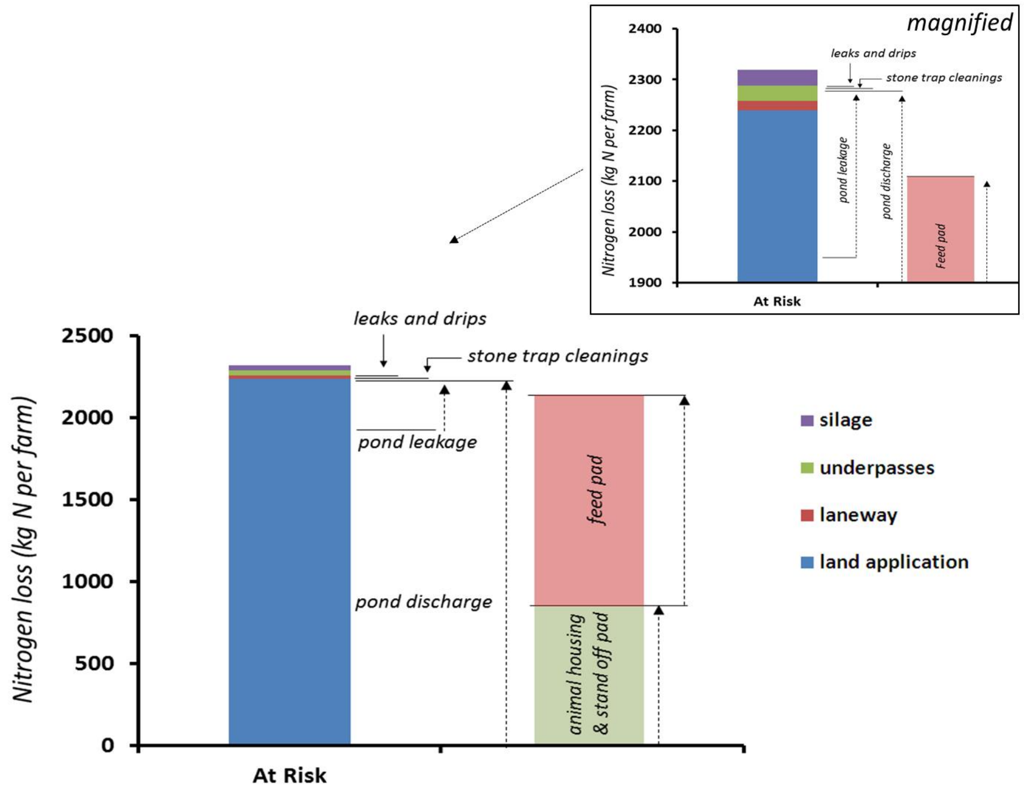

Figure 1: Estimates of 'at risk' loss of N (kg/yr) from the multiple components.

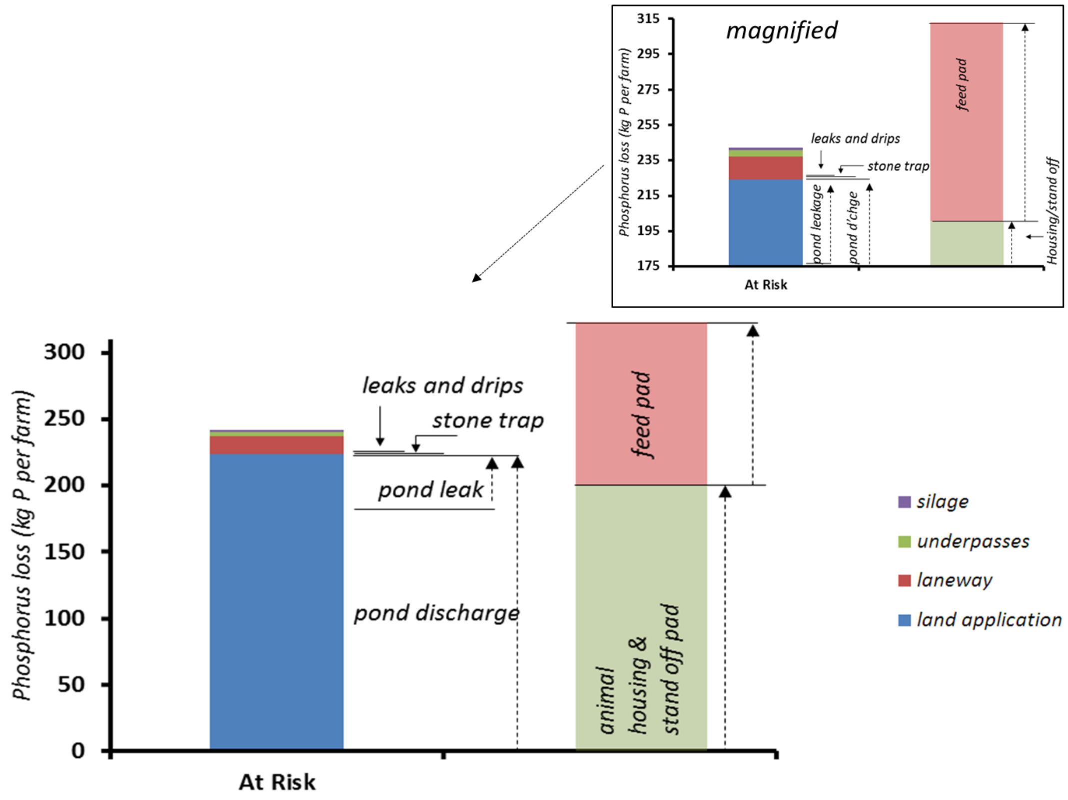

Figure 2: Estimate of 'at risk' loss of P (kg/yr) from the multiple components.

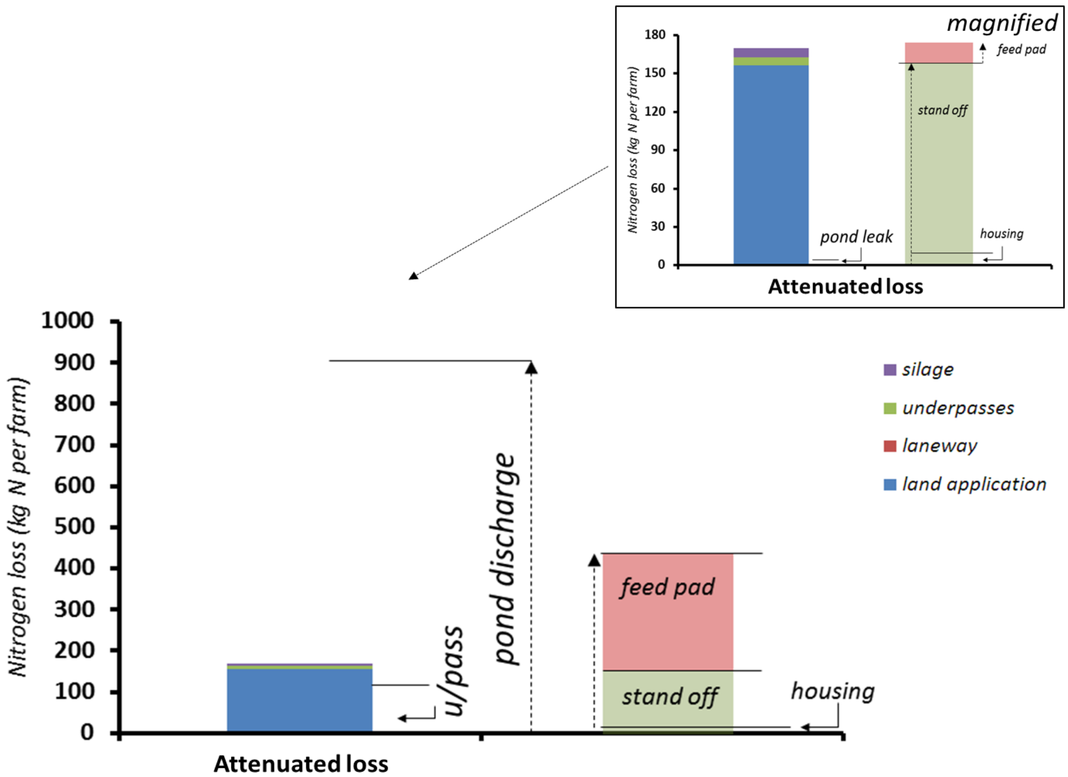

Figure 3: Attenuated loss of N (kg/yr) derived from the multiple components.

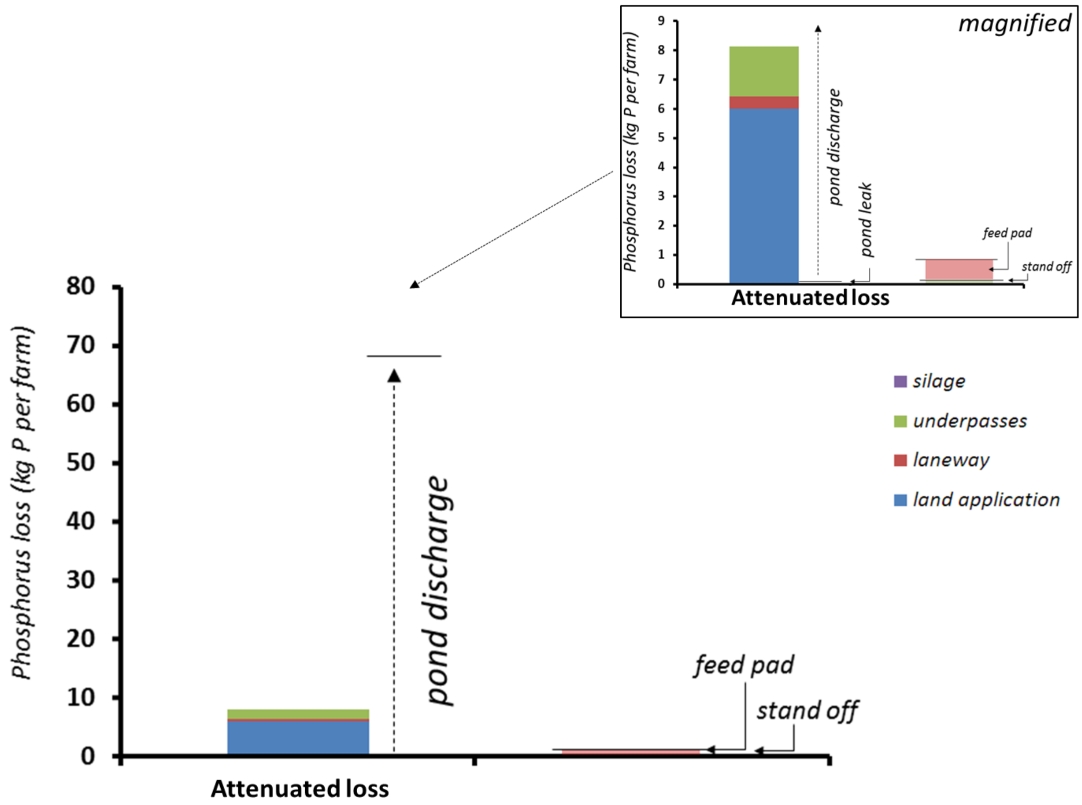

Figure 4: Attenuated loss of P (kg/yr) derived from the multiple components.

Conclusions

- Hotspots for potential nutrient loss (i.e., high 'at risk' value) appear to be where large amounts of effluent are generated or stored, such as feed pads and ponds. Similarly, attenuation benefits for these same locations are large and present themselves as priorities for whole farm effluent management.
- Discharges from treatment ponds pose the greatest risk to surface waters. Poor management (lack of collection) of feed pad effluent will result in large nutrient losses (i.e. high 'at risk' value). The attenuation benefit gained from managing this effluent source is large.
- Laneway runoff presents a high potential for P loss. Attenuation in this case is achieved by locating laneways away from waterways. This essentially lowers the risk to almost zero. By preventing underpass effluent from draining to water, losses are further reduced.
- On System 4 farms, nutrient losses, in particularly N, from silage stacks is considerably greater than on the System 2 farm (due to the difference in quantity of silage that is stored). However, in both cases losses can be reduced considerably with adequate soil attenuation, or removed altogether with leachate collection and re-use. In the case of the average farm the estimated attenuated loss is insignificant.
- All areas included in this study contribute to nutrient loss and promoting good practice should be paramount. However, we have presented the relative effect of each factor in order to isolate those which are most influential on overall farm nutrient loss.

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