DEVELOPING BEST MANAGEMENT GUIDELINES FOR EFFLUENT APPLICATION IN HIGH RAINFALL REGIONS

S. Laurenson[1], D.J. Houlbrooke[2], R. Monaghan[1] T. Wilson[3], S. Morgan[4]

[1]*AgResearch, Invermay Agriculture Centre, Private Bag 50034, Mosgiel, New Zealand*
[2]*AgResearch, Ruakura, Private Bag 3123, Hamilton 3240*
[3]*DairyNZ, Private Bag 3221, Hamilton 3240*
[4]*Westland Milk Products, PO Box 96 Hokitika*
E-mail: Seth.Laurenson@agresearch.co.nz

Abstract

Two- (or more) pond treatment systems discharging to water have traditionally been used for managing farm dairy effluent (FDE) on the West Coast. Many existing systems continue to discharge FDE directly into high volume, short reach rivers. This practice has come under recent scrutiny due to the potential effects of soluble P on the water quality of Lake Brunner. Application of 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. However, this approach does present some challenges because high annual rainfall (i.e. approx 4.8m per annum) results in a large volume of water collected from the dairy shed catchment areas while and also limits the development of soil water deficits that are large enough to safely apply FDE to land with high risk soils.

The West Coast Regional Council (WCRC) intends to develop regulatory options for the management of FDE in the Lake Brunner Catchment that employ a decision support framework for application to land. Many West Coast soils would be defined as 'high risk' due to poor natural drainage or the hump and hollow drainage systems. In most regions of New Zealand, it is not advisable to apply FDE to high risk soils at a depth greater than the soil water deficit. On the West Coast, however, deferring FDE applications until appropriate soil conditions occur is impractical as it would require extremely large pond storage capacities and an unrealistically large effluent block size (i.e. greater than whole farm). It therefore appears that the West Coast will require a unique set of best management practices based on regionally-specific data. Here we explore alternative approaches to managing FDE in high rainfall environments that minimise the risk of P runoff and the costs associated with the provision of effluent pond storage.

Introduction

Lake Brunner is an iconic lake on the West Coast of New Zealand with high cultural and amenity value. Nutrient loss from agricultural land surrounding the lake has however become the focus of public concern over recent declines in Lake water quality (Horrox 2008; McDowell 2010). 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. The P loading from a typical dairy farm on the West Coast has been estimated using the OVERSEER® Nutrient Budget model (Wheeler *et al.* 2003) based on data collected as part of the Best Practice Dairy Catchments Study (Monaghan *et al.* 2007; Wilcock *et al.* 2007).

The key aspects of the simulated farm related to the assessment were:

- 450 cows
- 236 ha effective farm area
- 606 kg MS/ha/yr
- 2 hrs/day on standoff pad during winter months
- an average soil Olsen-P concentration of 34 mg L^{-1} (maintenance superphosphate P fertiliser)

Using this input data it was estimated that without application of FDE, a total of 1,392 kg P would be lost from the 236 ha land area per year. This represents an annual rate of loss of 5.9 kg P/ha. As a background loss from land, this is extremely high, yet is similar to those amounts measured by McDowell (2008) of 6.6-9.7 kg P/ha/yr on an aggregated basis. These high P losses were attributed to frequent runoff events, the use of soluble P fertiliser, high Olsen P soil test status and the deposition of dung on land following grazing.

As suggested by McDowell (2008) and Monaghan et al. (2007) a large amount of P will also be lost from two pond treatment systems that discharge directly to surface waters. In many regions of New Zealand land application of FDE has proven effective in lowering P losses associated with dairy farming (Houlbrooke *et al.* 2004). Evidence of effectiveness, however, is largely derived from studies carried out in regions with considerably lower rainfall than the West Coast.

Soil and landscape risk framework

The risk associated with land application of FDE varies depending upon the inherent properties of the soil to which it is applied. Application of FDE, for instance, has proven difficult on soils with infiltration or drainage impediments (including artificial drainage), or when applied to soils on rolling or hill country or soils that have coarse structure (Houlbrooke *et al.* 2004; Houlbrooke *et al.* 2008; McLeod *et al.* 1998; Monaghan *et al.* 2010). 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. Included in this framework is the determination of scheduling criteria for different soil and landscape features (Table 1).

An initial assessment of the soils around the Lake Brunner Catchment they would be assigned to either Category B (Table 1, Impeded drainage) or Category C (Sloping land) as a result of the humping and hollow drainage systems. The Hari Hari silt loam for instance, a Gley soil widely distributed throughout the Pigeon Creek catchment that is centred on Inchbonnie, has a soil hydraulic conductivity of approximately 4 mm/hour and would be defined as a high risk soil under the Soil and landscape risk framework. Best Management Practice would therefore require FDE to be applied at depths less than the soil water deficit (SWD), thereby maximising the retention of effluent constituents in the soil-plant system as oppose to allowing their loss in drainage or surface run-off (Houlbrooke and Monaghan 2010). This approach to FDE management requires effluent to be stored in a pond and irrigated strategically when there is a suitable SWD, i.e. deferred irrigation.

Table 1. Soil and landscape risk framework for FDE management

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°)
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

Annual rainfall (23 year average) at Inchbonnie is 4,782 mm and 3,895 mm at Rotomanu, the two main dairying areas surrounding Lake Brunner. The corresponding evapotranspiration rates at each of these locations are 635 and 625 mm, respectively (NIWA Ltd 2008). Soil water deficits under these climatic conditions are generally low (Figure 1) and the window of opportunity for FDE irrigation to land is thus extremely limited.

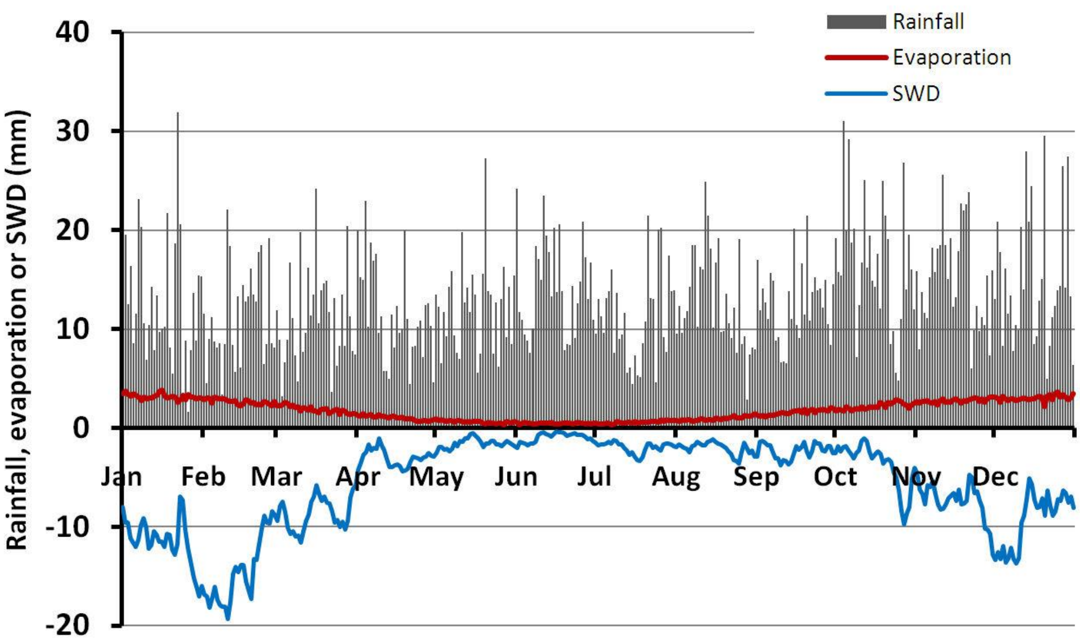


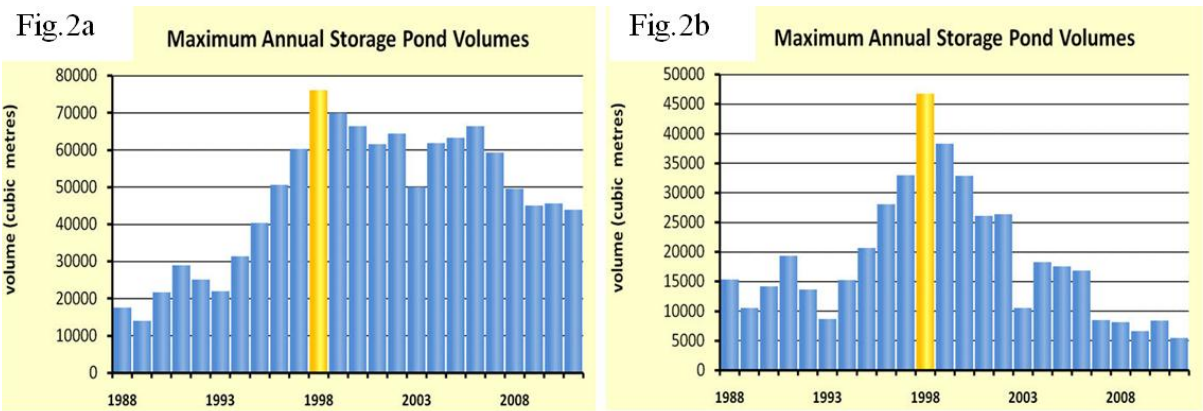
Figure 1. Average annual rainfall and evapotranspiration measured on the Otira Highway, near Inchbonnie between 1988 and 2011. Calculated soil water deficit (SWD) at this location is also shown.

Estimated pond storage requirements for Inchbonnie farms

Pond storage volumes required to operate a deferred (deficit) irrigation regime in the Inchbonnie Catchment have been calculated. Here, a model was developed that incorporated a daily soil water balance developed by Monaghan et al. (2002) where soil moisture dynamics are described by a volume-balance equation applied across a soil depth of 450 mm (Rodriguez-Iturbe 2000). A ratio between potential and actual evapotranspiration ration has been incorporated that assumes a value of 1.0 between field capacity and a limiting soil water deficit of 50% of plant available water. Thereafter evapotranspiration decreases linearly to become zero at the permanent wilting point (Monaghan et al., 2002). Pond storage requirements were calculated on a daily basis for farms located at Inchbonnie and Rotomanu for 23 years between 1988 and 2011 using climatic data from Otira Highway (Inchbonnie) and Rotomanu.

Irrigation was based on a 32-pod sprinkler system distributing effluent over an area of 2 ha, based on twice-daily shifting (when conditions were suitable). A decision to apply FDE was assumed when SWD was greater than or equal to 4 mm (i.e. irrigation trigger value) and was applicable through winter and summer. Farm specifications include a 450 cow herd that was milked twice a day from 1st August to 15th May, with no winter milking. Daily wash down was estimated to be 37.5 L per cow per milking. Yard size was set at 1242 m^2 with rainfall assumed to be diverted during the non-lactation period. Rainfall falling directly onto the pond surface was accounted for by assuming 2 ponds with a surface area of 1200 m^2 each (30m W x 40m L).

Based on the assumption that irrigation was applied to match the SWD, the required pond sizes for the Inchbonnie and Rotomanu farms were estimated (Figure 2). Pond storage capacity is reported based on an at least 9 out of 10 year design requirement, as stipulated in the Code of Practice for FDE designers and installers (DairyNZ Limited 2011). At Inchbonnie the required pond size was approximately 70,000 m^3 while at Rotomanu it was 38,000 m^3. For both locations, estimated pond sizes were impractically large.



Figures 2. Estimated maximum annual storage requirements for FDE on dairy farms located at (A) Inchbonnie and (B) Rotomanu. Effluent from feedpads, shed roofs and stand-off pads has not been included in these calculations. Irrigation is applied at depths to meet the soil water deficit (SWD) through a 32-pod system with twice-daily shifts.

Stand-off pads are a reasonably cost effective means of reducing overall farm P loss because animals can be held off paddock when soil moisture conditions are unfavourable. If however a stand-off pad (3500 m^2) was included at each property, rainfall catchment area increases and subsequent pond size requirements increase considerably. For example, pond size requirements for the Inchbonnie farm (Figure 3) progressively increase each year due to carry-over of stored effluent from wet years, indicating that deferred irrigation is not achievable.

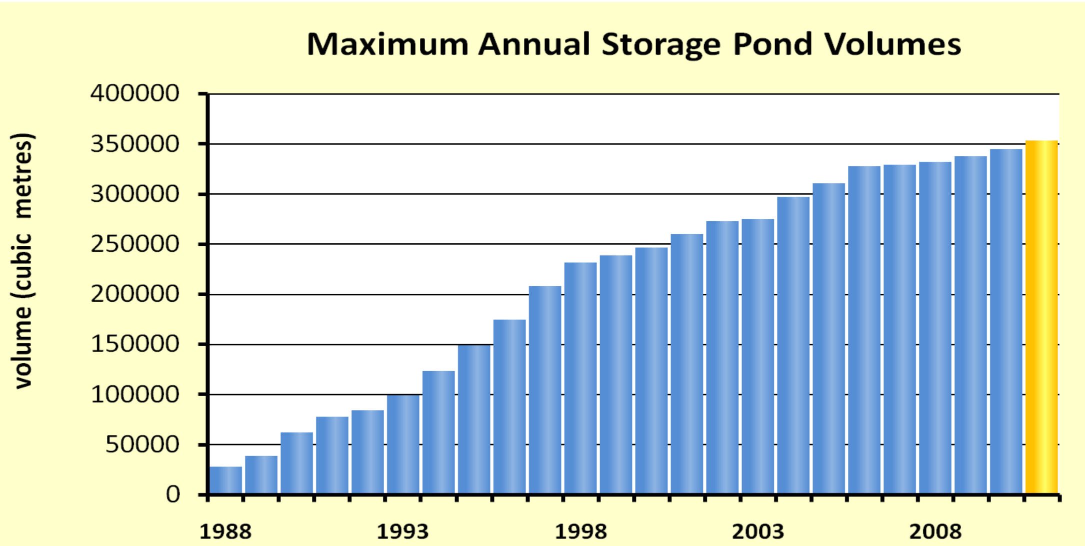


Figure 3. Estimated pond size requirements where effluent from a stand-off pad (3500m^2) is collected in the FDE 2 pond-system. Irrigation is applied at depths to meet the soil water deficit (SWD) through a 32-pod system with twice-daily shifts.

Given the above examples, a deferred irrigation approach to FDE management is unlikely to be feasible on this part of the West Coast due to the low evapotranspiration rates and high rainfall. The better management practice advice given to most other New Zealand regulatory authorities would not be easily applicable to the West Coast region. 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.

Alternative FDE management options

Controlled drainage

If a decision system was to be implemented whereby FDE was applied to soils at a depth greater than the SWD, required pond sizes would be reduced. The following scenario assumes FDE was applied on days when SWD was at or near zero, yet rainfall was less than 4 mm (i.e. large rainfall events avoided). A maximum allowable drainage of 5 mm (i.e. 5 mm in excess of soil field capacity) has also been incorporated in the model. Application rate however is assumed to be less than soil infiltration rate so as to limit surface run-off. Based on these assumptions, the estimated pond size for the Inchbonnie farm reduced substantially (Figure 4) to an attainable size 7000 m^3, based on a 9 out of 10 year design requirement.

This approach however allows considerably large volumes of water to be applied to soils in excess of SWD. Based on the current FDE system (described above) for instance, approximately 13,150 m^3 (range 6,500-17,600m^3 between 1988-2011) of soil water which is likely to include a strong FDE component, is assumed to be lost as drainage.

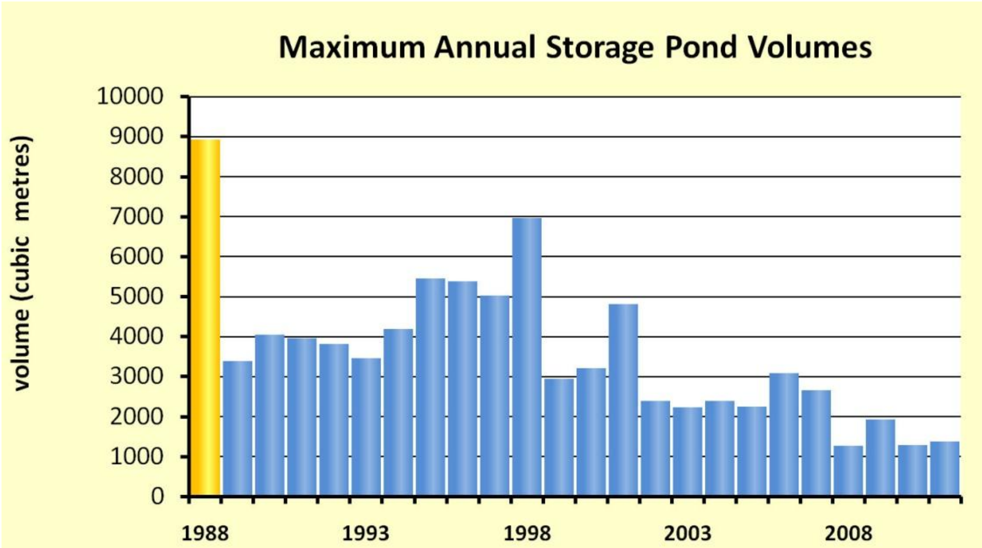


Figure 4. Estimated pond size required when FDE is assumed to be irrigated to the Inchbonnie farm using a controlled drainage approach where depth of irrigation exceeds soil water deficit (SWD) by up to 5 mm. Excess FDE applied is assumed to be lost in deep drainage. Application is via a 32-pod system with twice-daily shifts.

Covered yards and stand-off pads

Covering yards and stand-off pads, as an alternative to controlled drainage, will significantly reduce the water contribution from rainfall. Although this is an expensive mitigation option the resulting pond requirements are significantly reduced (Figure 5). Furthermore effluent that is irrigated to land is applied to meet the SWD, therefore losses via drainage and surface run-off are assumed to be zero.

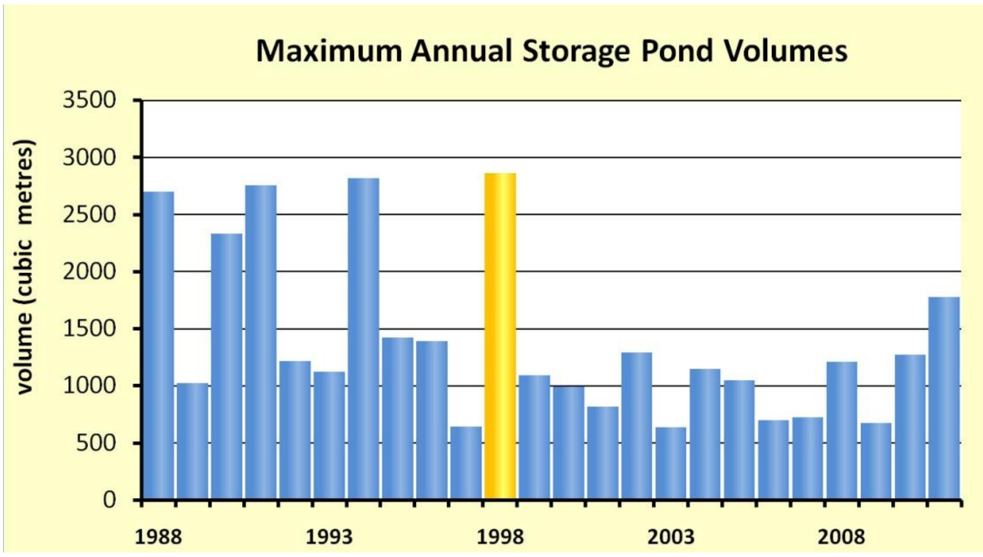


Figure 5. Estimated pond size required where the milking yard and stand-off pad (3500 m^2) have been covered in order to exclude the water contribution from rainfall at Inchbonnie. Irrigation is applied at depths to meet the soil water deficit (SWD) through a 32 pod-system with twice-daily shifts.

Implications for P loss risk

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 2). Here it is assumed all irrigation applied in excess of the SWD is lost to the local hydrological system. Given the high connectivity of water throughout the lake and river systems, there is a high potential for this effluent P to be delivered to Lake Brunner. The concentration of P in stored FDE has been estimated to be 20 mg L^{-1} (obtained from current AgResearch work underway on the West Coast).

Table 2. Estimated risks of P loss under various FDE management approaches for a hypothetical farm located at Inchbonnie.

FDE management approach$^{\beta}$	Ave. vol. FDE loss/yr (m^3)	Ave. P loss/yr (kg)$^{\#}$	Req. pond size (m^3)§	Comparative FDE risk‡ (%)
Direct discharge	28,300	566	N/A	100
with stand-off pad	42,330	847	N/A	150
Controlled drainage$^{\alpha}$	13,152	79^	5,900	14
with stand-off pad	15,950	96^	23,157	17
Covered yard	0	0	2,820	0
with stand-off pad	0	0	2,820	0

$^{\beta}$ In all cases stand-off pad size is 3500 m^2

$^{\#}$Assumes total phosphorus concentration of 20 mg L^{-1} 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 a P concentration of 10 mg L^{-1}, based on a 70% retention of P in saturated soils (Houlbrooke at al. 2004).

Based on the clear assumption that the solution to FDE management will not be met through implementing storage alone (i.e. deficit irrigation), implementing a controlled drainage schedule or installing a covered yard appear to be effective in reducing P loss risk relative to the current practice of directly discharging to surface waters. When FDE is applied in excess of the SWD, drainage occurs. The amount of drainage (inclusive of FDE and rainfall) has been capped at 5 mm per irrigation event. Cumulative excess drainage per annum is considerable (Table 2), although a degree of P retention within the profile is likely despite this. Rate of FDE application is important and should be maintained below the soil infiltration rate to prevent direct losses in surface run-off, particularly on sloping hump and hollow landscapes. This will maximise matrix flow and therefore interaction between FDE and the soil (Houlbrooke and Monaghan 2010). Retention of P is assumed to be 100% when the application depth is less than SWD. When applied beyond the SWD, retention of P in the induced effluent drainage or surface run-off is however assumed to drop to 70% (Monaghan et al. 2010). Essentially therefore some degree of P treatment is attainable when FDE is applied to wet soils at a suitable rate and depth. If uncovered stand-off or feed pads are installed, the rainfall captured increases significantly, thereby raising pond storage requirements. This is likely to invoke a need for either greater leniency on drainage losses (that in turn will increase nutrient loss), or installing a purpose designed cover over the pad.

As illustrated by the values shown in Table 2, the rainfall contribution to FDE volumes is substantially greater than the effluent derived from wash-down and direct deposition at the milking parlour and holding yard. Therefore exclusion of this otherwise fresh water source has significant benefit for FDE management. Housing cows under shelter pre-milking enables required pond sizes to be substantially reduced (Figure 5). This greatly reduces the potential risk of P loss from FDE applications to land. If it is assumed that 70% of the effluent P in the controlled drainage management strategy is attenuated by the soil, the potential risk of P loss from this approach to FDE management is also reduced considerably and to a level that accounts for about 5% of the calculated whole [i.e. whole farm P loss risk = 236 ha x 6 kg P/ha (as described in the introduction), plus the annual direct FDE discharge load, which is estimated to be 566 kg P (Table 2). This equates to a total loss of 1982 kg P/farm. Under controlled drainage FDE management, the P loss contribution from effluent decreases from 30% of total P to only 5%.]. When considered in context of the whole farm, estimated P loss under controlled drainage is notably low.

Figure 6. Covered yard, near Lake Brunner, West Coast with complete rainfall diversion. Cows are housed prior to entering the parlour

Conclusions

Compared to two-pond 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 contributes 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 depth of application i.e. maintain drainage to < 5mm. However, it is also important that the rate of application should, as stipulated within the AgResearch soil risk framework for effluent management, to be less than the soil infiltration rate so as to limit direct loss of P in surface run-off. Ideally, covered yards and pads should be considered in these high rainfall areas to minimise the rainfall contribution to the total effluent volume. AgResearch in conjunction with DairyNZ are currently undertaking research around Lake Brunner to assess these management options and compare them with a discharging two pond system.

References

DairyNZ Limited (2011) Farm Dairy Effluent (FDE) Design Code of Practice. DairyNZ Limited.

Horrox J (2008) State of the environment report: West Coast surface water quality. West Coast Regional Council, Greymouth, New Zealand.

Houlbrooke DJ, Horne DJ, Hedley MJ, Hanly JA, Scotter DR, Snow VO (2004) Minimising surface water pollution resulting from farm dairy effluent application to mole-pipe drained soils. I. An evaluation of the deferred irrigation system for sustainable land treatment in the Manawatu. *New Zealand Journal of Agricultural Research* **47**, 405-415.

Houlbrooke DJ, Horne DJ, Hedley MJ, Snow VO, Hanly JA (2008) Land application of farm dairy effluent to a mole and pipe drained soil: implications for nutrient enrichment of winter-spring drainage. *Australian Journal of Soil Research* **46**, 45-52.

Houlbrooke DJ, Monaghan RM (2010) Land application for farm dairy effluent: development of a decision framework for matching management practice to soil and landscape risk. In 'Farming's future: minimising footprints and maximising margins. In 'Fertilizer and Lime Research Centre Conference'. Massey University. (Ed. LD Currie) pp. 35-45.

McDowell RW (2008) Phosphorus in humped and hollowed soils of the Inchbonnie catchment, West Coast. II: Accounting for losses by different pathways. *New Zealand Journal of Agricultural Research* **51**, 307-316.

McDowell RW (2010) Evaluation of two management options to improve the water quality of Lake Brunner. *New Zealand New Zealand Journal of Agricultural Research* **53**, 59 - 69.

McLeod M, Schipper LA, Taylor MD (1998) Preferential flow in a well drained and a poorly drained soil under different overhead irrigation regimes. *Soil Use and Management* **14**, 96-100.

Monaghan R, Rutherford A, McDowell R, Smith C (2007) Linkages between land management practices and potential impacts on soil and water quality within the Inchbonnie catchment: summary report prepared for the Inchbonnie catchment group. Invermay Agricultural Centre, Mosgiel.

Monaghan RM, Houlbrooke DJ, Smith LC (2010) The use of low-rate sprinkler application systems for applying Farm dairy effluent to land. *New Zealand Journal of Agricultural Research* **53**, 389-402.

Monaghan RM, Paton RJ, Drewry JJ (2002) Nitrogen and phosphorus losses in mole and tile drainage from a cattle-grazed pasture in eastern Southland. *New Zealand Journal of Agricultural Research* **45**, 197-205.

NIWA Ltd (2008) Virtual Climate Station rainfall data. (NewZealand National Institute of Water and Atmospheric Research Limited: Wellington).

Rodriguez-Iturbe I (2000) Ecohydrology: A hydrologic perspective of climate-soil-vegetation dynamics. *Water Resources Research* **36**, 3-9.

Wheeler DM, Ledgard SF, de Klein CAM, Monaghan RM, Carey PL, McDowell RW, Johns KL (2003) OVERSEER® nutrient budgets– moving towards on-farm resource accounting. *New Zealand Grasslands Association Proceedings* **65**, 191-194.

Wilcock RJ, Monaghan RM, Thorrold BS, Meredith AS, Betteridge K, Duncan MJ (2007) Land-water interactions in five contrasting dairying watersheds: Issues and solutions. *Land Use and Water Resources Research* **7**, 2-10.