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Best practice management of Farm Dairy Effluent in the Manawatu-Wanganui region.

Prepared for Horizons Regional Council

February 2008

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1. Summary

The management of farm dairy effluent (FDE) has proven a challenge for both dairy operations and Regulatory Authorities throughout New Zealand. Recent research in the regions of Manawatu and Otago has identified that poorly performing FDE systems can have large deleterious effects on water quality, particularly when direct losses of FDE with high concentrations of contaminants (phosphorus, nitrogen and faecal microbes) discharge, drain or run-off directly to surface water bodies. Furthermore, enhanced indirect losses of phosphorus have been identified in winter-spring drainage subsequent to summer-autumn land application of FDE. In particular, land application of FDE has proven difficult when it has occurred on soils with a high degree of preferential flow, soils with artificial drainage, soils with either an infiltration or drainage limitation, or when applied to soils on rolling/sloping country. The effect of these conditions can be exacerbated by climate where high rainfall can further contribute to the poor environmental performance of such land application systems. Many of the above features are characterized by the Pallic and Gley soil orders of the New Zealand soil classification, although not exclusively. In the Manawatu-Wanganui region such soils are regularly used for intensive livestock production including dairy farm operations.

In order to better utilise the nutrient resource of dairy effluent and decrease or prevent the contamination of fresh water bodies with raw or partially treated FDE, some best management practices (BMP's) have been tested to improve the management of FDE in New Zealand. The concept of 'deferred irrigation' has demonstrated that if FDE is stored in a suitably sized and lined pond when soil moisture is close to, or at field capacity, and then applied to land at a time when appropriate soil moisture deficits exist, then direct contamination of FDE can all but be eliminated. Furthermore, the high application rate of travelling irrigators has been found to be in-appropriate for soils with sloping faces, and soils with either infiltration or drainage limitations. A change to 'low application rate tools' allows for greater control of application depth as well as better matching of the soil's ability to infiltrate and absorb applied FDE, thereby improving the likelihood of storing the valuable nutrients within the plant root zone.

Existing consent conditions of the Horizons Regional Council and those proposed under rule 13-6 for the One Plan accurately describe the environmental performance required from a dairy operation applying FDE to land, but do not provide any specific information to consent holders on how to meet some of the key conditions. The proposed FARM strategy provides some options for identifying non-compliance and some steps to take towards their remedy. However, the information does not include some important BMP's that have been shown to improve environmental performance and compliance of FDE land treatment systems.

It is the recommendation of this report that Horizons Regional Council promotes the use some key BMP's for land application of FDE. A decision tree flow chart has been constructed to

guide effluent storage requirements based on soil and land form features and the volume of annual rainfall. Where critical climate, landform and soil characteristics apply it is a recommendation that Horizons Regional Council regulates the use of appropriate BMP's by making consents to land-apply FDE a 'discretionary activity' for dairy operations that do not take them up. Dairy operations with these critical conditions that do adopt the appropriate BMP's would be considered a 'Controlled activity', as would farms operating without the appropriate soil and climate constraints that are considered likely to enhance the loss of contaminants from land-applied FDE.

2. Glossary of terms

Application depth – The depth of applied farm dairy effluent from irrigation (mm).

Application rate – The rate at which a given depth of effluent is applied per unit of time (mm/hr).

Deferred irrigation – Pond storage of effluent during wet periods and its subsequent application when suitable soil moisture storage exists so as to avoid breaching field capacity.

Drainage – The movement of excess water (including effluent water) through the soil body.

Effluent irrigation – The application of farm dairy effluent to land through an irrigator.

Effluent storage pond – A suitably sealed storage pond for farm dairy effluent.

Excreta – The defecation products from cattle i.e. urine and dung.

Farm dairy effluent (FDE) – The combination of cow and wash down water collected from the milking parlor and holding yard.

Field capacity – The water content of a soil once drainage has ceased.

Infiltration-excess ponding – when the FDE application rate exceeds a soil's drainage capacity or surface infiltration rate.

Land Treatment – The use of the soil matrix as a medium for removing contaminants either dissolved or suspended, in effluent water or slurries.

Leaching – The drainage of nutrients through the soil beyond the active root zone

Low application rate sprinkler – A sprinkler suitable for irrigating FDE at low application rates (<10 mm/hr). Need to be moveable.

Mole and pipe drainage – An artificial drainage system suitable for poorly drained soils with a dense subsoil and appropriate clay content. The installation of such drainage creates a large degree of preferential flow paths for both water drainage and direct FDE loss.

Nutrient loss – The mass of nutrients lost per unit area in drainage or overland flow (kg nutrient/ ha)

Nutrient load - The mass addition of nutrients per unit area (kg nutrient/ha) as fertiliser or FDE irrigation.

Nutrient Concentration – A measure of the mass of contaminant enrichment per unit volume of water (mg/L).

Oscillating traveling irrigator – A traveling irrigator with a single boom that sweeps from side to side in a 180 degree arc.

Overland flow – The movement of water or FDE across the soil surface. Also know as surface runoff.

Rotating traveling irrigator - A traveling irrigator with twin booms that fully rotate. Currently the most common form of irrigator used applying FDE to land in New Zealand.

Root zone – The zone of soil closest to the soil surface where most of the plant roots are contained. Typically 300 mm for ryegrass-dominated pasture.

Saturation-excess ponding - When all typically air filled pores are storing water the soil has no capacity to infiltrate further water and so conditions are created and water ponds or flows down slope. This condition is pronounced when the drainage capacity is smaller than the input of water (or effluent).

Soil moisture deficit – the potential of a soil to store water up to the point of field capacity. As active drainage ceases at field capacity, it is predominantly evapotranspiration that creates soil water deficits.

3. Introduction

Dairy farming is the largest agricultural industry in New Zealand, contributing 20% of export earnings but providing a challenge for the environmentally-acceptable treatment of wastes from dairy farms. Nutrient-rich farm dairy effluent (FDE), which consists of cattle excreta diluted with wash-down water, is a by-product of dairy cattle spending time in the farm dairy, holding yards and possibly on feed-pads. To estimate the quantities of FDE being generated, the following approximations can be used. Dairy cows spend approximately 2 hours per day, over the milking season in the farm dairy or yards (i.e. effluent collecting areas) (Cameron & Trenouth 1999). If it is assumed that they deposit excreta at a constant rate over a 16 hour period (taking into account sleeping requirements), then approximately 12% of their excreta will be deposited within the farm dairy and yards. Cameron & Trenouth (1999) state that this percentage ranges from 5 to 15% and depends greatly on cattle management practices. Following milking, the yards are washed down with high-pressure hoses using approximately 50 litres of water cow^{-1} day^{-1} (Vanderholm 1984). The resulting wash-down water contains a diluted mix of cattle faeces and urine, along with any chemical that may have been used to wash down the milking plant. The physical, chemical and biological characteristics of FDE are highly variable and change within and between farms due to contrasting management of storm water, feed pads, wash-down waters, chemicals, age and breed of herd, and stock management whilst in the yards (DEC manual 2006; Longhurst *et al.* 2000). The average composition of FDE comprises 8% excreta, 4% teat washing and 86% wash down water (Longhurst *et al.* 2000). FDE has a pH of approximately 8 (DEC manual, 2006). The solid content of FDE from over 63 sites ranges from 0.04 – 5.3%, with an average of 0.9% (Longhurst *et al.* 2000). Longhurst *et al.* (2000) also reported mean nitrogen (N) and phosphorus (P) concentrations for raw FDE, derived from a number of different research trials, to be 269 mg N litre^{-1} (range 181 – 506) and 69 mg P litre^{-1}(range 21-82).

Historically, the common form of treatment for FDE in New Zealand has been the two-pond system combining both an anaerobic and facultative pond (Sukias *et al.* 2001). The combination of an anaerobic and aerobic pond efficiently removes sediment and biological oxygen demand (BOD), but high concentrations of nutrients remain (Hickey *et al.* 1989; Ledgard *et al.* 1996; Longhurst *et al.* 2000; Sukias *et al.* 2001; Craggs *et al.* 2003). Longhurst *et al.* (2000) reported that effluent discharging from a standard two-pond system to surface waters has approximate mean concentrations of 91 mg N litre^{-1} and 23 mg P litre^{-1}. Although the two-pond treated effluent represents a significant improvement compared to the nutrient concentrations of raw FDE, the concentrations of N and P in discharges from a two-pond treatment system are still more than three orders of magnitude greater than levels considered likely to promote aquatic weed growth (0.61 mg N litre^{-1} & 0.033 mg P litre^{-1}) (ANZECC, 2000). An assessment of nutrient losses from a two pond treatment system in Manawatu by Houlbrooke *et al*. (2004a) estimated that a 490 cow herd would result in the direct discharge to water of 1500 kg of N and 250 kg P. With the introduction of the Resource Management Act (RMA) in New Zealand in 1991, the two-pond treatment system, with discharge to a stream, began to be phased out by regulatory authorities and is now a consented activity for many regional councils (DEC manual 2006; Cameron & Trenouth 1999). Land application of FDE, taken from either an existing two-pond system or directly from a sump holding the daily wash-down of FDE, became the preferred treatment option for many Regional Councils in the 1990s (Environment Waikato 1994; Parminter 1995; DEC manual 2006). This allows the water and nutrients applied to land in FDE to be utilised by the soil-plant system. Since the advent of the Resource Management Act, the New Zealand dairy industry has undergone considerable expansion and intensification. The increases in cow numbers, stocking rate and total area in dairy farming has generated greater volumes of FDE requiring treatment. Since 1991 many of the dairy conversions have taken place without any effluent storage capability, with FDE pumped from a small sump at the farm dairy and land applied on a daily basis.

Managing land application of FDE has proven difficult in New Zealand, particularly on wet soils where there is a greater risk of subsequent drainage and overland flow contamination of water bodies by nutrients and micro-organisms. Poorly-operated effluent treatment systems (two-pond or land application), particularly in areas newly converted to dairying, have already begun to have visible impacts on surface and ground-water quality (Houlbrooke et al 2004a, Houlbrooke et al 2004b, Monaghan and Smith 2004, Monaghan *et al.* 2002b). Due to its high application rate, limited depth options, uneven FDE distribution and limited daily coverage area, traditional irrigator hardware in the form of a twin boom rotating travelling irrigator has proven unsatisfactory to safely apply FDE to many soils. The Manawatu-Wanganui region experiences many of the management issues surrounding FDE land application in New Zealand, particularly associated with poorly drained or artificially drained soil types and a dependably wet winter-spring period. Therefore, it is important that Horizons Regional Council stays up to date with the latest research findings and best management practices with regard to the management of FDE. The aim of this report is to review the current planning and policy framework for FDE management within the Manawatu-Wanganui region, and provide an update on recent research finding of best management practices for FDE land treatment, including their associated costs and benefits. The report will also recommend some appropriate practical solutions for improving the environmental performance of FDE land application systems in the Manawatu-Wanganui region.

4. Policy and planning

4.1 Existing consent conditions

The application of FDE to land in the Manawatu-Wanganui region is considered in most circumstances a ‘controlled’ activity; if some conditions are not met then it can also be considered as a ‘discretionary’ activity. At Horizons Regional Council, an Environmental Compliance Officer will make an assessment of all new applications to land-apply FDE, prior to a discharge permit being consented subject to certain conditions. The assessment includes details on herd size, volume of expected effluent generation, and the required FDE area as determined by a maximum N loading (either 150 or 200 kg/ha/yr). Furthermore, details are provided on the soil type within the FDE block and the potential to adversely affect surface water quality, including proximity to streams, rivers and drains. The consent conditions are typical of most regional councils within New Zealand and are carefully described so as to prevent direct discharge of FDE into water and minimise the risk of diffuse contamination as in accordance with the RMA 1991 and DL Rule 4 of the existing Land and Water Regional Plan. For the purposes of this review, a brief outline of a set of relatively standard consent conditions for a Horizons regional Council discharge of FDE to land has been summarised with comments made with regard to their appropriateness.

1). *The permit holder shall ensure that the storage of effluent in the storage facility (pond) and the rate, frequency and method of discharge of dairy shed effluent, stone trap sludge and wash water into and onto land does not result in any contamination of groundwater, excessive ponding of* *effluent on the soil surface, or in any runoff of effluent to water courses (including drains) flowing continuously or intermittently or to subsurface drains.*

There is a lot of information wrapped up in this statement. However, I consider that it effectively covers the important details of a compliant dairy effluent system that will not result in nutrient enrichment of associated water bodies. The term ‘excessive ponding’ is very subjective and a potential debatable point. This will be raised further in the ‘compliance’ section below.

2) *Nitrogen loading limit of either 150 kg/ha or 200 kg/ha within FDE block.*

Whilst such a loading limit is important, this should not be a concern if farms were accurately nutrient budgeting and applying FDE in accordance with potassium (K) loadings which would likely result in N loadings considerably less than the above stated limits. This will be discussed further in section 6.3.

3) *Prevent the discharge of odour and spray drift within property boundaries.*

Considered a sensible condition, although can be subjective.

4) *Withholding distances for FDE application from water bodies, public buildings, threatened habitats and other protected sites.*

The setback distances all seem appropriate for the circumstances described in the conditions. Most of these setback distances are related to the risk of aerosols creating unpleasant smells. The potential impact of such contamination is very subjective and beyond the scope of this report. The dairy industry (DEC manual) does not promote recommended numbers for with holding distances, rather it refers farmers to comply with consent conditions and use some common sense regarding climatic conditions and the buffer required or necessity to irrigate FDE near property boundaries. Of greater interest is the described setback distance of 20 m from water ways. It could be argued that if best practice land application of FDE is adopted, then applied nutrients would remain in the root zone. Therefore, a decreased setback distance less than the existing 20 m would be possible. However, when near waterways, the risk of getting the management wrong is very high. Even under a deferred irrigation regime, operators could still generate overland flow due to ‘infiltration excess’ conditions if they use a high application rate travelling irrigator. This risk is even further pronounced by the tendency for land to slope towards water ways over the 20 m buffer in question. Additionally, a decrease in this 20 m buffer would enhance the risk of aerosol deposits directly into the water if effluent is applied under anything other than still conditions. Furthermore, even if no direct losses of FDE occur, there have been observations of enhanced loss of soluble P in rainfall induced winter-spring drainage water from land receiving summer-autumn applications of FDE (Houlbrooke et al. 2008, McDowell et al. 2005 and Houlbrooke et al. 2003) as described in section 5.1.2.

Therefore, it is considered that a 20 m setback distance from all waterways is maintained as described by existing consent conditions.

5) *No discharge or overflow from storage facilities.*

This requires appropriate storage volumes or application of FDE to land when soil moisture conditions are less than optimum. This is in preference to overflow of raw or partially treated FDE directly to waterways. This will be discussed further in sections 5.2.1, 6.2 and 6.4.

6) *Maximum application depth.*

This condition varies depending upon soil type and is derived from the DEC manual (2006). The figures presented in this manual seem appropriate for each soil texture class.

7) *Provision of a warning system that alerts staff to a pump failure.*

This condition is sensible and could be expanded to cover the stalling of a travelling irrigator, where these tools are used for land application of FDE.

7) *Provision of an alternative pumping system within eight hours of mechanical failure.*

This condition could be relaxed if there was provision for suitable storage. i.e. > 3 days

8) *Rainfall water roof diversion.*

An important way for decreasing the volumes of FDE generated.

9) *Nutrient budget.*

This is considered important and will be discussed further in section 6.3

9) *Apply FDE to the whole effluent block as evenly and uniformly as possible.*

The 'as possible' section of this statement could be considered subjective as this will be limited by the irrigator hardware that each farming operation uses and will be discussed further in section 5.2.2. However, I agree with the inclusion of this condition.

10) *Provision of review of conditions*

This condition is important when consents are granted for extended periods, and will effectively allow for the inclusion of best management practices as new research and technology comes forward.

4.2 Proposed consent conditions (One Plan & FARM strategy)

The discharge of farm animal effluent onto production land, including effluent from dairy sheds and feed pads, is covered by rule 13-6 of the Proposed One Plan (POP). The conditions within the rule appear to be a cut-down version of the existing conditions discussed above and appear to capture the important terms for land application of FDE. It is presumed that, where necessary, conditions such as those discussed above in points 2, 6, 7, 9 and 10 can be added to each consent, as required. In addition to the POP rule 13.6, some properties in the Manawatu-Wanganui region with land uses and activities specified by the POP rule 16-1 will need to apply FDE in accordance with the FARM Strategy, module 2 (Effluent disposal). The module has 10 checklists that need to be filled out to determine compliance with the FARM strategy and the implementation of actions where steps are not met. I agree with 7 out of 10 of the checklists/steps. However, 3 of the steps require further discussion. Furthermore, consideration should also be given to changing the name of this module to 'Effluent management' rather than 'Effluent disposal' which suggests that FDE is a waste product without highlighting it potential as a nutrient resource.

Step 3. Is all effluent collected in a sump or pond that has the capacity to hold at least two days volume of effluent before the effluent is discharged?

Two days FDE storage may be sufficient for pump breakdown scenarios. However, such small storage capacities are not sufficient to avoid the application of effluent to soils with little or no capacity to store applied liquid. Such limited storage facilities are only suitable where irrigation will take place on flat, free drained (i.e. alluvial) soil types where surface water contamination is unlikely and ground water contamination is primarily a function of animal numbers and associated urine and dung patches. This will be discussed further in section 5.2.1 and 6.1.

Step 4 and 7. Withholding distances

There appears to be two considerable discrepancies between set back distances promoted in both the 'old plan' and the 'one plan' vs. the FARM strategy module. Step 4 suggests a 200 m setback from all residences, marae, public buildings and schools compared to only 20 m for both the plans. Additionally step 7 suggests a setback of 100 m from all bores, surface water bodies and coastal areas compared to only 20 m for both the 'old plan' and 'one plan'. These large setbacks do not seem justifiable and possibly not even practical and so it is recommended that the FARM strategy steps are changed back in line with the 'one plan' conditions.

Step 9. Will there be any ponding of effluent on the soil surface more than five hours following application?

The causes of ponding have been correctly identified whereby ‘infiltration excess’ ponding takes place when application rate exceeds the soil’s infiltration capacity; ‘Saturation excess’ ponding may also occur where the soil matrix is already full of water and any subsequent application ponds on the soil surface if drainage capacity is limited or non existent. Ponding is an indicator of contamination risk and ‘saturation excess’ conditions have a considerably greater risk than ‘infiltration excess’ conditions. As such, the conservative five hour ponding period post application is more suited to ‘infiltration excess’ conditions than ‘saturation excess’ conditions. If the operator agrees that ponding will occur then they are referred to response reference A9 of module 2 in the FARM strategy. The table then referred to is essentially an adapted version of Table 2.4-1 from the DEC manual (2006). In this table there are two columns described as ‘maximum application rate’. The first of these columns should read ‘maximum application depth’ as only the second column refers to a time component. Whilst I agree with the ‘maximum application depths’ designated against each soil type, the maximum ‘application rates’ described would be considered conservative, particularly the maximum application rates listed for soils with a sand component. The infiltration capacity for these soils would be considerably greater than the 17 to 32 mm/hr recommended for maximum application rate. Such low figures effectively rules out the use of travelling irrigators whose application rate has been measured in excess of 100 mm/hr (Houlbrooke et al 2004c, Monaghan and Smith 2004) and will be further described in section 5.2.2.

4.3 Compliance

Upon talking to the Compliance Officers at Horizons Regional Council, it would appear that non compliance of consent conditions is variable but that excessive ponding is a common form of non-compliance related to soil type, region and time of year that inspections took place. In particular, non compliance associated with excessive ponding during the wetter spring period would suggest that saturation excess conditions were the predominant cause of ponding and/or surface runoff. As such, the risk associated with ponding can be listed from greatest to least for the following scenarios.

- ***‘Saturation excess’ ponding on soils uniformly wet prior to irrigation.***

When FDE is applied to soils that are close to, or at field capacity (thus without a suitable soil water deficit), then nutrient rich FDE cannot be stored in the root zone and excess effluent will simply drain through the soil profile or run-off as overland flow. Such ponding therefore comes with a high degree of hydrological connectivity with surface water bodies, particularly on sloping land or land with artificial drainage.

• ‘***Saturation excess’ ponding on soils with a pre-irrigation soil water deficit.***

If FDE is applied to soil with a soil water deficit and ‘saturation excess’ ponding occurs in localised areas under the irrigation footprint, then this will cause the application depth to exceed the available soil water deficit. Such ponding poses a lower risk than when soils are also uniformly wet surrounding the FDE irrigation area. However, it is still a considerable risk where this takes place on sloping land or land with artificial drainage.

• ***’ Infiltration excess’ ponding on sloping land***

Ponding caused by ‘infiltration excess’ conditions (application rate exceeds soil infiltration rate) poses less risk than ‘saturation excess’ ponding. However, ‘infiltration excess’ conditions on sloping land are a considerable risk to surface water bodies as a result of surface runoff generation.

• ‘***Infiltration excess’ ponding on flat land***

‘Infiltration excess’ ponding on flat land is low risk if it simply results in a time lag between application and infiltration into the soil, so long as a soil moisture deficit exists and the nutrients applied remain in the root zone. Relatively uniform ponding remaining in the paddock five hours after application would suggest that the application depth is greater than the recommended maximum depth as specified by the DEC manual (2006).

4.4 Existing education

Together with Dexcel and Dairy Insight (now merged together to make Dairy NZ), Horizons Regional Council has produced a booklet called ‘A guide to managing farm dairy effluent’ for the Manawatu/Wanganui region. This booklet is written as a farmer resource for education of best management practices for farm dairy effluent. Much of the information in this booklet is available from the DEC manual (2006), and is a summary of the important information written specifically for farmers. The booklet should be considered an important education tool into the future. However there are a number of areas that could be updated:

- *Page 21*. The table displaying maximum application rates per soil type is as discussed above somewhat conservative for free-draining sandy soils (32 mm/hr), and beyond the reach of any travelling irrigator available in New Zealand. Most have application rates in excess of 100 mm/hr (Houlbrooke et al. 2004c, Monaghan and Smith, 2004). This table is derived from the DEC manual (2006).

- *Page 23*. This page of the booklet is designed to teach farmers how to calculate both application depth and rate for their own travelling irrigator. The calculation of average depth from four catch containers is correct, although it should be noted that this may lead to a slight under-estimate of the average, unless at least one of the four trays is moved to the outside of the irrigator throw where the application peak is at its highest. Conversely, if two of the four containers are placed under the application peak at the edge of the irrigator's throw, then this will result in an over-estimation of application depth. Of greater concern is the incorrect information regarding the calculation of application rate from a travelling irrigator, which states that you take the application depth and divide by the time taken for the irrigator to pass, and then scale to a one hour time period. For example, an average application depth of 18 mm over a 30 min period was then multiplied by two, to suggest an application rate of only 36 mm/hr. This rate is approximately one third of the rate measured by Houlbrooke et al. (2004c). The reason for this discrepancy is that FDE from a travelling irrigator is not applied continuously to the same piece of land (in this case a catch container) during the nominated 30 min period that the irrigator took to pass over the tray. Instead the area under direct spray at any one time from the irrigator's throw would be approximately 10% of the coverage area. Therefore the time that FDE actually lands into the tray is limited to two bursts of 1.5-2 m of swath when the travelling irrigator is covering ground at an approximate speed of 0.75 m/min. The true application rate a from travelling irrigator should be measured in units of mm/min rather than mm/hr (i.e. approximately 2 mm/min as opposed to >120 mm/hr as measured by Houlbrooke et al. (2004c)) otherwise confusion can occur when only small depths (< 10 mm) are actually applied.

- *Page 27*. The table/check sheet printed on page 27 was adapted from a check sheet originally written by M Hedley, D Houlbrooke and D Horne. Most of the information on this list is still valid, although some small changes would improve its accuracy. The 'optimum/good practice' column for the 'effluent storage' row should be changed to "Irrigate from a sealed storage pond with 10-12 weeks storage capacity". 'Okay' practice should be changed to "Irrigate from a sealed storage pond with approximately 6 weeks storage capacity"; and 'not okay' should be left as it is. Furthermore the row title 'Application rate' should be changed to 'Application depth'. 'Optimum/good practice' should state that "Effluent is applied only using a low rate sprinkler system with depths of 10 mm or less". The existing 'Okay' and 'Not okay' practices should make reference to the use of travelling irrigators. Table 1 below shows an adapted version of the above-mentioned table. Where the existing wording is considered satisfactory, the box is filled with a green tick.

	Optimum/ Good Practice	Okay	Not Okay
Effluent Storage	Irrigate from a sealed storage pond with 10-12 weeks storage capacity	Irrigate from a sealed storage pond with approximately 6 weeks storage capacity	√
Nutrient loading	√	√	√
Application depth, not rate	Effluent is applied only using a low rate sprinkler system with depths of 10 mm or less	The travelling irrigator is set up to travel at its fastest speed (applying 10 mm)	The travelling irrigator is set up to travel at its slowest speed (applying > 20 mm)
Scheduling of irrigation	√	√	√
Nutrient management	√	√	√
Staff	√	√	√
Maintenance	√	√	√

Table One. Adapted table from page 27 of the booklet. ‘A guide to managing farm dairy effluent’

5. Research Summary

5.1 The impacts of farm dairy effluent on New Zealand water quality

For a land treatment system to be sustainable it must be efficient in both the retention of effluent in the soil and the subsequent plant uptake of nutrients applied in the effluent. The longer the effluent resides in the soil’s active root zone, the greater the opportunity for the soil to physically filter the effluent whilst absorbing nutrients and making them available to plants. A literature review of New Zealand data by Houlbrooke et al. (2004b) on land-applying FDE, and its affects on water quality, has shown that between 2 and 20% of both the nitrogen (N) and phosphorus (P) applied in FDE is either lost as runoff or leached from the soil profile. In all studies, the measured concentrations of N and P in drainage water were higher than the ecological limits considered likely to stimulate un-wanted aquatic weed growth. Losses of FDE can be measured in the direct drainage of untreated or partially-treated effluent immediately following irrigation events and/or in the indirect drainage that occurs in the following winter/spring period.

5.1.1 Direct losses

Direct losses of FDE occur when effluent is applied to soils that (i) have a limited capacity to store the applied moisture (thus resulting in drainage or ‘saturation excess’ overland flow) or (ii) Occur on sloping land where the risk of ‘infiltration excess’ overland flow is high . Direct losses of FDE are particularly undesirable as nutrient concentrations remain high with little opportunity for effective land treatment. Under wet soil conditions, all soils carry a high risk of direct losses if FDE is applied. However, soils with direct connectivity to surface water bodies’ pose the greatest risk e.g. soils with artificial drainage, such as mole and pipe drains, or poorly drained soils (either on flat land in the presence of a shallow water table or sloping land where the generation of overland flow is likely). Under these circumstances there is a high degree of potential loss for N, P and faecal micro-organisms. In comparison, soils with freely-drained profiles are unlikely to contaminate surface water bodies as excess water will be drained through the soil profile into unconfined groundwater systems. While this drainage water is likely to be nutrient-rich, the potential loading to groundwater from this contamination is only one component of the likely nutrient loading on any one day at a farm scale. FDE typically makes up only 10% of a dairy herd's nutrient output with the remaining 90% of nutrients will be added as dung and urine patches; animal excreta is thus an important contributor to groundwater contamination if nutrients move below the pasture root zone. The depth to the groundwater will dictate the likely extent of treatment en route. The key point here is that FDE application to freely drained soils is likely to be a minor contributor to water contamination.

Research on the Massey University No 4 Dairy farm demonstrated the considerable impacts of direct losses of nutrients when land applying FDE to soils with limited soil water deficit (Houlbrooke et al. 2004b). The soil was a naturally poorly drained Tokomaru silt loam with mole and pipe drainage installed. When 25 mm of FDE was applied to a soil near field capacity (6 mm deficit), approximately 40% of the applied effluent left the soil profile as mole and pipe drainage and 30% as surface run-off. The concentrations of N and P in the mole and pipe drainage were approximately 50% of the concentrations applied in the FDE. The impact of this one-off event on P contamination can be seen in Figure 1. N contamination is not visible as FDE is derived of organic and ammonium N sources rather than nitrate. The relative concentrations of N and P in surface run-off was approximately 80% of that in the raw FDE. The greater concentration of nutrients in surface runoff reflects minimal interaction between soil and FDE. The total losses from artificial drainage and surface runoff equated to 12 kg N ha^{-1} and 2 kg P ha^{-1}. These nutrient losses from a single, badly-managed irrigation are significant, particularly when compared to annual drainage losses of around 27 kg N ha^{-1} and less than 0.4 kg P ha^{-1} reported by Monaghan *et al*. (2005) and Houlbrooke *et al*. (2003) from pastures grazed by dairy cattle without effluent irrigation. In other words, N losses from a single FDE irrigation event to wet soil equated to about 45% of the expected annual N drainage loss from grazed dairy pasture, while P losses were equivalent to more than twice the expected annual drainage loss from grazed a dairy pasture.

5.1.2 Indirect losses

Indirect losses of nutrients associated with land application of FDE are the result of nutrient enrichment of the soil during the summer-autumn period followed by leaching during the subsequent winter-spring drainage period. Research conducted at the same Massey University site described above has reported the loss of nutrients in artificial drainage from plots that received nutrients from FDE and plots that received typical farm fertiliser applications. Both treatments were grazed according to standard farm rotations (Houlbrooke at al. 2003 and Houlbrooke at al. 2008). Over the two winters monitored (2002 and 2003) there were no significant differences in nitrate-N losses between treatments, suggesting that applying nitrogen in the form of FDE does not enhance the subsequent loss of N in winter drainage compared to N-fertilised plots. In contrast, winter drainage from plots enriched with FDE did show a significant increase ($P<0.001$) in total P loss, equating to an additional 1.03 kg P/ha. This represented a loss of 3.3% of applied P. Figure 1 demonstrates the enhanced concentration of Dissolved Reactive Phosphorus (DRP) in mole and pipe drainage water from plots receiving FDE during the previous summer-autumn period. Enrichment of P in winter mole-pipe drainage from land receiving FDE has also been reported by McDowell et al. (2005).

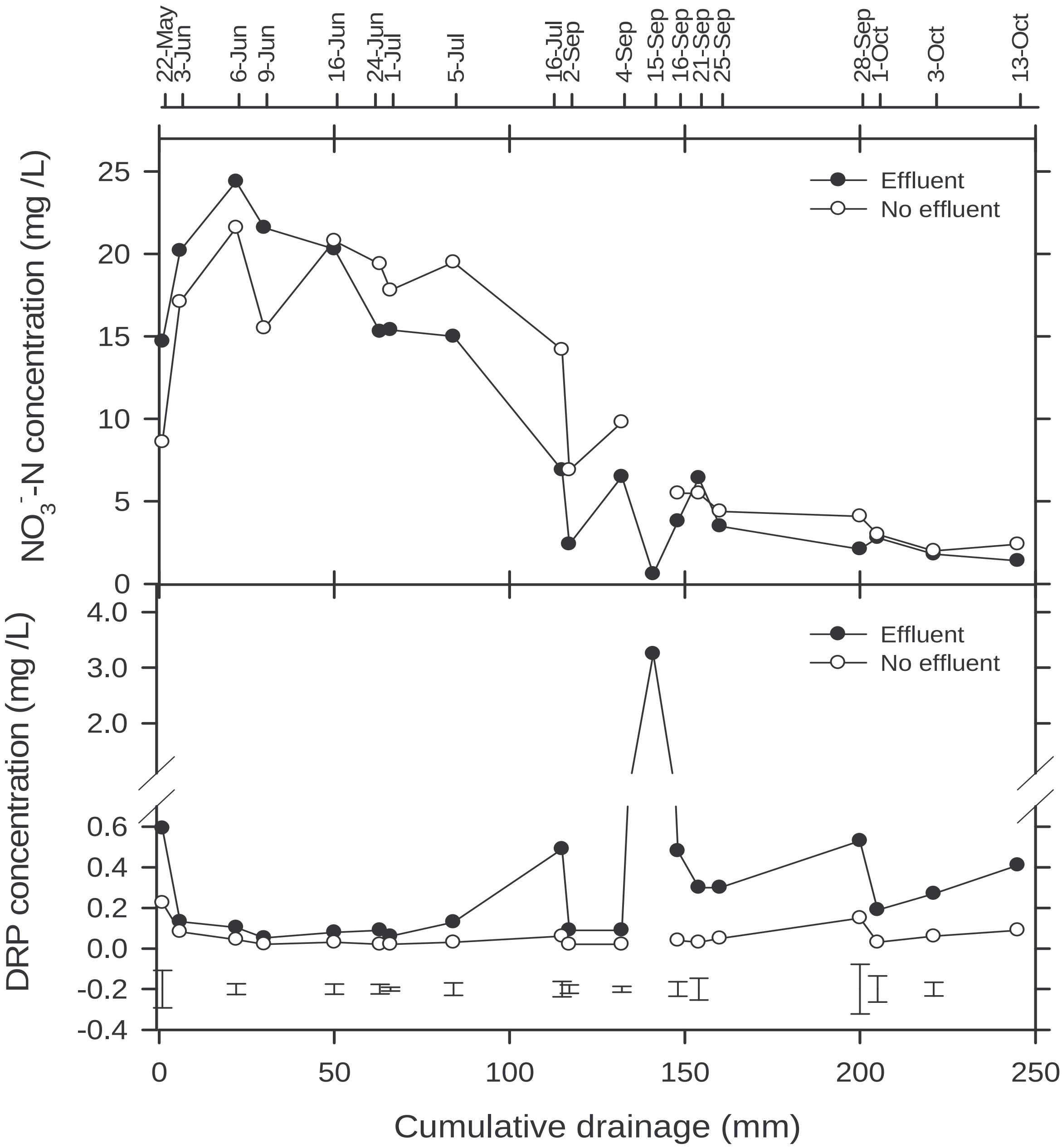

Figure 1. NO_3^--N and DRP concentrations in 2003 pipe drainage water collected from No. 4 Dairy. The poorly timed mid-September application of FDE occurred at c. 140 mm mean cumulative drainage. Error bars represent a 5% l.s.d (Houlbrooke et al. 2008).

5.2 Best management practice for farm dairy effluent

5.2.1 Deferred irrigation

To help overcome the problems associated with the spray irrigation of FDE to artificially drained soils and soils with drainage limitations, an improved treatment system called 'deferred irrigation' has been developed. The concept of deferred irrigation was designed and evaluated at the Massy University No.4 Dairy farm near Palmerston North. Deferred irrigation involves storing effluent in a pond (photo one), then irrigating it strategically when there is a suitable soil water deficit, thus avoiding the risk of generating surface runoff or direct drainage of effluent. When applied effluent adds to the pool of plant available water (rather than the pool of drainage water), then the soil-plant system's ability to remove soluble nutrients via plant uptake and immobilisation processes is maximised. Thus, the application criteria for spray irrigation of FDE if drainage is to be avoided are presented in the following equations:

$$E_i + \theta_i Z_R \leq \theta_{FC} Z_R \qquad \text{eq. 1}$$

$$E_i \leq Z_R (\theta_{FC} - \theta_i) \qquad \text{eq. 2}$$

Where E_i is the depth of FDE (mm) applied on day i, Z_R, is the effective rooting depth (mm), θ_{FC} is the soil water content at field capacity ($m^3\ m^{-3}$), and θ_i is the soil water content on day i ($m^3\ m^{-3}$) (Houlbrooke et al. 2004a). Both of these equations effectively state that the existing soil moisture deficit in the root zone plus the depth of applied FDE is required to be less than maximum soil water storage (field capacity).

Houlbrooke et al. (2004a) reported the results of a 3-year research trial at Massey University that assessed direct losses of nutrients in mole and pipe drainage when FDE was applied to land according to the deferred irrigation criteria. When averaged over all three lactation seasons (2000/01 to 2002/03), FDE application to the soil generated drainage equivalent to 1.1% of the total effluent applied. Over the three seasons a range of different application depths were assessed. The 2001/02 season was wetter than usual with smaller summer deficits available; 63 mm of effluent was therefore, irrigated over seven events at an average of 9 mm depth. The strategy of irrigating smaller quantities of FDE, more frequently, resulted in zero drainage of applied effluent through the mole and pipe drainage system, and consequently, no direct loss of nutrients. Average annual nutrient losses from direct drainage of FDE following irrigations using the deferred irrigation criteria over three lactation seasons were c. 1.1 kg N ha^{-1} and 0.2 kg P ha^{-1}. Similar environmental performance has also been reported in the Otago region by Monaghan and Smith (2004) when FDE was stored applied at appropriate suitable soil water deficits. This shows that an improved FDE land application system, such as a deferred irrigation strategy, can minimise the environmental risk associated with a daily application system. However, if insufficient storage is available to fully implement deferred irrigation practice, then FDE irrigations should be applied at the lowest depths possible during the critical times of the season to reduce the risk of FDE drainage and run-off.

Photo 1. A large storage pond suitable for use under a deferred irrigation strategy.

In Manawatu, regular soil water deficits greater than 10 mm mainly occur between the months of October and May. However, the generation of FDE starts at the beginning of lactation in late winter (late July/August). Consequently, having sufficient storage for FDE is essential to ensure that spray irrigation only occurs during times when an adequate soil water deficit exists. Whilst storage is the most important infrastructural requirement, the accurate scheduling of FDE to coincide with soil moisture deficits is also critical. Soil water deficits can either be modelled using a water balance approach or measured on a volumetric basis in the field. Most dairy farms are not likely to create a soil water balance; however a there is the potential to create water balance software with a farmer friendly interface as a decision support tool for helping schedule FDE irrigation. Additionally a number of different tools exist to provide actual soil moisture data. An on-farm 'aquaflex' tape is an excellent means of recording soil moisture and plotting trends over time. The compromise is that the soil moisture reading directly relates only to the paddock that it sits in and therefore the paddocks place in the FDE block rotation needs to be accounted for as do any differences in application depth between paddocks. The alternative is the use of a hand held soil moisture meter such as a TDR probe. The advantage of such a system is that it can be readily carried around the property, providing soil moisture data on paddock by paddock case. The disadvantage is that this data is often not electronically recorded and so good soil moisture records are difficult to establish. With some common sense approaches and self calibration, judicious operators should, however, be able to determine when adequate water deficits occur based on visual assessment of the soil and time since the last rainfall event.

An alternative system for providing soil moisture information to enable farmers to make better decisions around the scheduling of FDE is for Horizons Regional Council to provide a network of soil moisture monitoring sites. These sites could be spread around different soil types and rainfall zones to provide farmers with an option that will be most applicable to their farming situation. Such data would act as a guide for FDE irrigation scheduling; some on-farm comparisons would also be a worthwhile comparison. Soil moisture networks have been established within the regions of Environment Southland and the Otago Regional Council (websites:http://map.es.govt.nz/Departments/LandSustainability/fde/guidelines/index.aspx and http://land.orc.govt.nz/landinfo/). The establishment of such regional data is most useful at the start of the lactation season or following a large rainfall event when soil moisture has returned to field capacity. This coincides with the period that is considered 'highest risk' for land-application of FDE. Farmers can thus observe soil moisture depletion until a suitable deficit for irrigation exists. Regional soil moisture data becomes less useful as the season progresses and between farm management will result in potentially large discrepancies between a regional measure and paddock actual data. The use of either volumetric soil moisture data with appropriate risk zones, or the presentation of actual soil moisture deficits for a stated soil depth, would prove the most beneficial way for farmers to make judgements regarding the potential to safely irrigate effluent to land. Reporting potential evaporation would also help the scheduling process; however, on its own, it would be difficult for most operators to accurately relate this to a soil water deficit without calculating their own soil water budget.

Many irrigated farmers employ the services of an irrigation consultant to measure soil moisture throughout the irrigation season (Sept – May), and provide advice regarding the scheduling of water. The cost of providing such a service is approximately $800 per annum (Dan Bloomer pers. comm.). Farmers could utilise a similar service for scheduling the application of FDE. However it is considered that such detail (and cost) is not really required for the safe application of FDE to land. The decisions of when to apply irrigation water and how much water to apply, have important productive and financial implications. In contrast, the depths of FDE to be applied will likely stay fairly consistent across the lactation season (approx 10-15 mm) so long as a suitable soil moisture deficit exists. Therefore, it is recommended that a one-off purchase of a soil moisture probe and/or the use of regionally available soil data would be more than sufficient to help farmers make informed decisions regarding the scheduling of FDE irrigation.

5.2.2 Irrigator hardware

A range of different irrigators are available in New Zealand for applying FDE to land The most common option is the rotating twin boom travelling irrigator (Photo 2a). More recent options on the market include an oscillating travelling irrigator “Spitfire” (Photo 2b) and low rate applicators such as K-Line (Photo 2c) and Iarall (Photo 2d). The depth of effluent applied to the soil at any one application has important implications for determining the likelihood of ponding, surface runoff and drainage of applied FDE. Application depth = application rate (mm/hr) multiplied by the time an application lasts for. It is important that the application depth applied to a soil is less than the soil water deficit available at the time. Unfortunately, irrigators do not apply FDE evenly. In accordance with the deferred irrigation criteria, to safely apply effluent the maximum application depth must not exceed the soil water deficit. Traditional twin boom rotating irrigators have the poorest application uniformity with application peaks approximately twice as high as the mean application depth (Houlbrooke et al. 2004c, Monaghan and Smith 2004). The Spitfire and low application rate options (Iarall and K-Line) provide more uniform application patterns (so long as K-Line pods are spaced appropriately to avoid overlap). The Iarall system has the highest application peak within a 1 m radius of the pod; however, this peak makes up only 0.3% of the wetted footprint compared to the 20% high application area under a twin boom travelling irrigator (Figure 2). When only very small soil water deficits are available (i.e. < 8 mm depth) then both of the twin boom and oscillating irrigators struggle to apply depths less than this deficit, especially the twin boom irrigator with its high application peaks. Under these circumstances it is important to run travelling irrigators at their fastest travel speed to provide their lowest application depth. In comparison, low rate applicators such as K-Line and Iarall are temporarily fixed in one place and deliver at rates of approximately 4 mm an hour. Therefore a one hour application would provide only 4 mm of FDE to the soil which in this scenario is only half of the water deficit available. A standard setup of K-Line includes 24 pods with a coverage area of c. 7000 m^2. In comparison, a standard Iarall setup includes 16-24 sprinklers that cover 1000 m^2 per sprinkler which can apply FDE over two-three times the daily coverage area of either travelling irrigators or K-Line systems. The increased infrastructure requirements for this system come with a greater establishment cost (See Section 5.3). In principle, any tool capable of delivering FDE at a rate less than 10 mm/hr can be considered ‘low rate’.

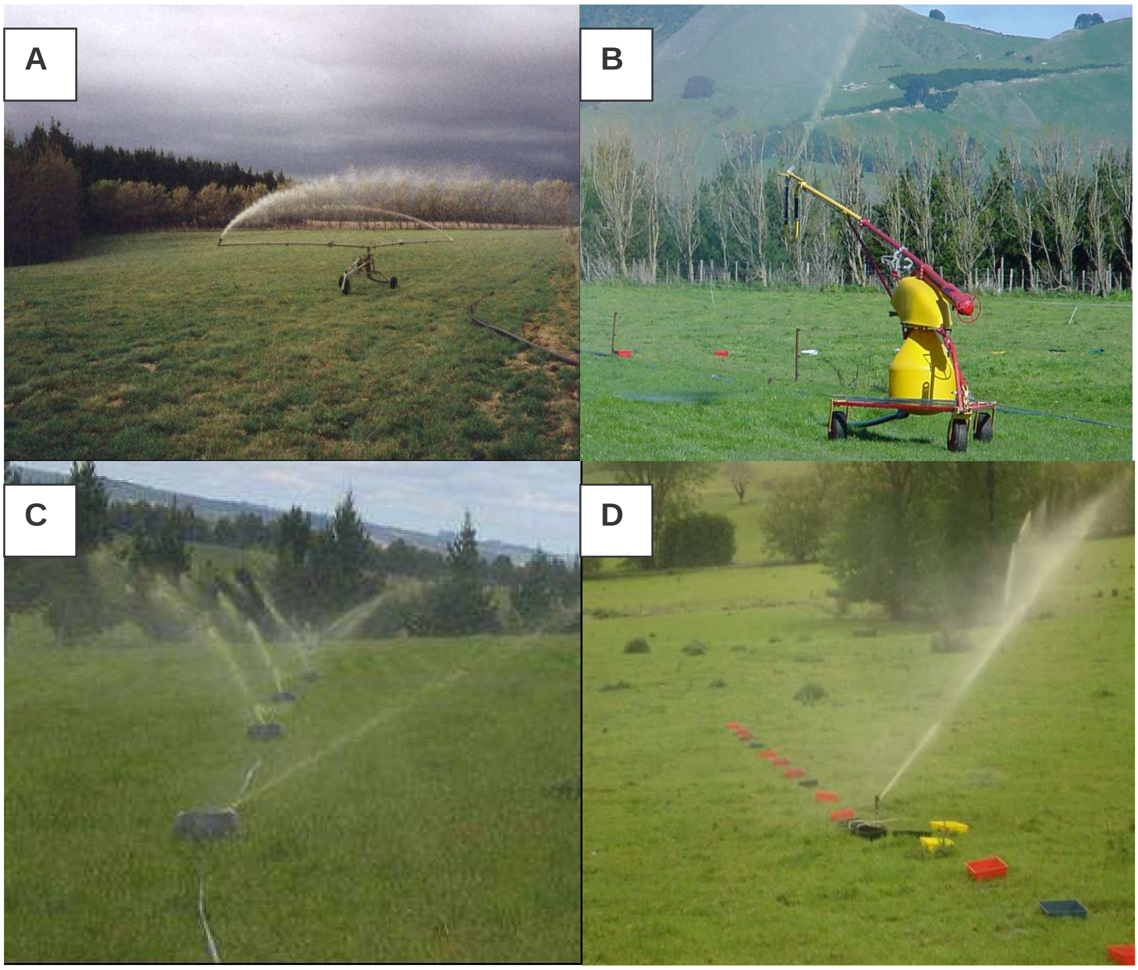

Photo 2. A: Rotating twin boom irrigator. B: Oscillating “Spitfire” irrigator. C: Low application rate “K-Line” irrigation pods D: Low application rate “Larall one” irrigation pod.

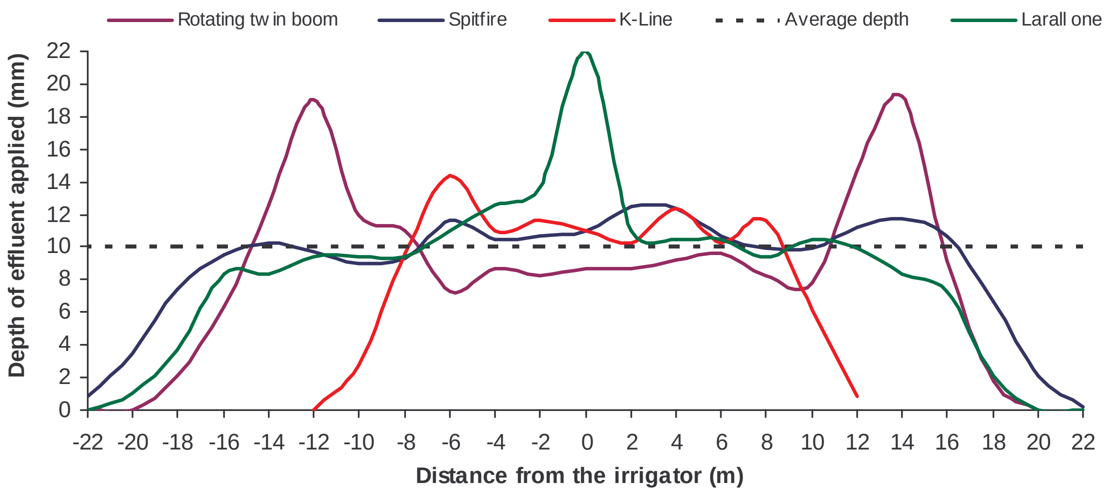

Figure Two. Application depth and uniformity of a range of different tools available for irrigation of FDE in New Zealand.

Houlbrooke et al. (2004c) compared the environmental performance of the two most common types of travelling irrigator available on the New Zealand market (Rotating twin boom vs. oscillating Spitfire). The measured application profiles and a soil water balance were used to simulate drainage and nutrient losses under each irrigator type. In early spring and late autumn, when soil water deficits were low, the more uniform application profile of the oscillating irrigator, set at its lowest application depth of 10 mm, created less risk of partially-treated FDE reaching pipe drains. The simulation model estimated that, when operating at a set average application depth of 25 mm, the rotating irrigator and oscillating irrigator required soil water deficits of 44 mm and 32 mm, respectively, to avoid generating drainage. When FDE was applied at 25 mm depth with a deficit of only 18 mm, substantial quantities (30%) of partially-treated effluent were estimated to have drained from the soil no matter which irrigator was used. When application depth equalled the moisture deficit, the more uniform oscillating irrigator had a lower drainage loss (7%) compared to the rotating irrigator (14%). With only a small buffer of 7 mm between soil moisture deficit and application depth, it was estimated that the oscillating irrigator achieved zero drainage. When set at their fastest travel speeds, the peak application depths of the rotating and the oscillating irrigators were similar (13 mm) and therefore these irrigators have the same number of operational irrigation days at times when soil water deficits are low. In contrast the low rate sprinklers of K-Line and larall have a considerably greater number of operational days than travelling irrigators as their relative uniformity and high degree of control of application depth (15 mins run time = 1 mm depth). Therefore, there is much increased scope to apply FDE depths using low rate systems (i.e. < 8 mm) during short windows of low soil water deficit.

In addition to the importance of irrigator uniformity, the application rate of an irrigator has a strong influence upon environmental performance, particularly on soils with drainage limitation or sloping land. Different soils have different infiltration rates and abilities to absorb and drain water. For example, sandy soils have a greater infiltration rate than silt soils which in turn are considerably greater than clay soils. Irrigation application rates should be matched to a soil type’s ability to absorb or infiltrate effluent. Travelling irrigators have very high instantaneous application rates typically greater than 100 mm/hr. However, due to the donut application pattern (Houlbrooke et al. 2003) not all ground under a travelling irrigator continuously receives effluent as an irrigator pass is being made. Low rate applicators such as larall and K-Line apply FDE at rates of only 4 mm/hr or less and therefore reduce the risk of exceeding a soils infiltration capacity, thus preventing ponding and surface runoff of freshly applied FDE. Furthermore, the slower application rates increase the likelihood of retaining the applied nutrients in the root zone.

Low rate effluent irrigation technology in the form of ’K-Line’ has been evaluated as a tool for applying FDE to land and its environmental performance compared with that of a traditional rotating travelling irrigator (Houlbrooke et al. 2006). Two research sites were used in West and South Otago, both on the poorly drained and structured Pallic soil (the Waikoikoi silt loam), which is similar in nature to Manawatu Pallic soil types such as the Tokomaru silt loam. The West Otago site was mole and pipe drained. Drainage monitoring showed that concentrations of contaminants in artificial drainage where much reduced when comparing a K-Line applicator was used instead of a rotating travelling irrigator. Specifically much of the P, ammonium-N and *E. coli* bacteria contained in the FDE was filtered by the soil when FDE was using low rate technology. Concentrations of total P, ammonium N and *E. coli* measured in drainage induced by the application of the FDE without intermittent pumping were, on average, only 5, 2 and 25% of that found in the applied FDE, respectively. These figures could be further decreased by adopting an intermittent pumping regime of 12 minutes on followed by 48 minutes off. This was in contrast to that observed when FDE was applied using a travelling irrigator (mean application depth of 9 mm), where concentrations of total P, ammonium N and *E. coli* measured in drainage induced by the application of the FDE were 33, 30 and 85% of that found in the applied effluent (Monaghan & Smith, 2004).

The South Otago site was located on sloping land with poor surface infiltration. Applications of FDE made at this site under similar moisture conditions resulted in 78% of the volume of FDE applied using a rotating travelling irrigator being generated as overland flow, compared to 44% when using K-Line irrigation. As for the mole and pipe drainage research site, there was also an attenuation effect where by the relative concentrations of ammonium N, Total N and P in overland flow generated following the application of FDE using a travelling irrigator were all greater than 90% of the concentration applied as raw FDE. In contrast, the relative concentrations of these contaminants in overland flow generated following the application of FDE using a K-line system were considerably lower (between 20 to 45%). The success of low rate irrigation tools on sloping land, and land with artificial drainage, is attributed to the greater filtration of nutrients in the FDE, compared to that achieved under the high instantaneous rate of application observed under a rotating travelling irrigator. The low application rate and associated decrease in surface ponding of FDE allows a greater volume of applied FDE to move through smaller soil pores via matrix flow, thus allowing for greater attenuation of effluent contaminants.

5.2.3 Alternative systems

With most Regional Councils phasing out two-pond treatments systems, the alternatives to land treatment of FDE in New Zealand are limited. Craggs et al. (2003) reported on an advanced pond system (APS) developed by NIWA which contains an anaerobic pond, a high rate pond, algae settling ponds and a maturation pond (Photo 3). The APS system results in considerably improved discharge water quality compared to a two-pond treatment system.

However, concentrations of DRP in discharge water are still considerably greater than appropriate for receiving water bodies.

Photo 3. High rate pond component of an APS

Photo 4. Covered concrete grating of a Herd Home dairyard.

A further technology for managing FDE is currently being developed by Herd Homes New Zealand (http://www.herdhomes.co.nz/portal/). The technology, called a “Dairyard”, involves replacing the traditional concrete holding yard with a roofed yard of concrete slats similar to those found in a Herd Home (Photo 4). Animal dung and urine is collected in a manure bunker below the gratings and periodically emptied and land-applied as dry waste through muck spreaders. To date, only limited farm research has been undertaken on the use of Dairyard technology and limited information is available regarding their environmental performance (http://www.dairyinsight.co.nz/projects/project.php/20208).

5.3 Cost of implementing best practice systems

The adoption of best practices such as deferred irrigation and low rate irrigator technology for land application of FDE comes at a cost. Data derived from the AgResearch 'BMP Toolbox' calculates the cost of building a plastic lined pond with 2000 cubic meters of storage at $25,000 dollars. This equates to enough storage for 80 days (11 weeks) for a herd of 500 cows (assuming all rainfall is diverted from the wash-down yard and shed roof) , at a setup cost of c. $50/cow. This would also be enough storage for 16 weeks for a herd of 350 cows at a cost of $71/cow. The cost of converting to low rate irrigation depends upon the existing infrastructure in place. Assuming that most dairy units would already be land-applying FDE, the cost associated with upgrading from a traditional travelling irrigator to a set of 24 K-line pods with a sludge bed to capture solids would be $17/cow for a 350 cow herd, or $12.60/cow for a 500 cow herd. If the sludge bed was replaced with a solids separator then the cost, including the 24 K-Line pods and piping, would be $85/cow or $60/cow for 350 and 500 cow herds, respectively. The cost of upgrading to a larall system is less easy to price as the system requires a lot of piping and hydrant infrastructure. Therefore, the applicability of existing infrastructure has a considerable impact on the end cost. The designers of the larall system say that most setups that include pipe infrastructure and a lined pond cost between $1500 and $2500 per ha. This equates to a total setup cost of between $96/cow to $146/cow for a 500 cow herd.

The labour costs associated with the different irrigation hardware options are difficult to quantify as they vary considerably between properties depending upon variables such as herd size, volume of FDE generated, the potential for pond storage and pump size. It has been observed and reported by farmers that the time associated with moving either a Spitfire irrigator or a set of 24 K-Line pods is similar to that for moving a rotating travelling irrigator. However the ease of movement is improved. The manufacturers of larall suggest that up to 2 minutes is required to move each irrigation sprinkler. If 24 larall sprinklers are shifted, then this would require longer than a between-paddock shift of K-Line pods or a travelling irrigator. However, the time would be quicker than a between paddock shift of K-Line pods or a travelling irrigator. Furthermore without the need to un-lock and re-attach couplings, the job is a lot cleaner. The greatest gain in labour savings using the Larall system arises from the 4 fold increase in coverage area per day compared to the above mentioned systems, therefore requiring only 25% of the time spent moving irrigators. Another potential cost saving associated with deferred irrigation is the optimisation of staff resources. The period when FDE is likely to require storage (due to wet soil moisture conditions) coincides with the busy spring period on a farm when calving takes place. The low input of labour into FDE management during this period increases the resources available for calving and milking. These resources can then be directed towards FDE management once calving is complete and suitable soil water deficits are developing.

5.4 Applicability to the Manawatu-Wanganui region

The applicability of the existing best management practices of ‘deferred irrigation’ and ‘low application rate tools’ varies with climate and soil type. The Manawatu-Wanganui Region has many soil types with infiltration and/or drainage limitations in combination with relatively high natural rainfall (> 1000 mm/yr). Some different soil type and farming system scenarios are discussed below with regard to their applicability for best practice FDE management.

5.4.1 Mole-pipe drained land

In many circumstances in the Manawatu-Wanganui region, dairy farming occurs on poorly or imperfectly drained soils. In order to farm these fine-textured soils in an intensive manner, artificial drainage systems are required to alleviate regular winter and spring water-logging. These poorly and imperfectly drained soils are commonly of the Pallic and Gley soil orders as described in the New Zealand Soil Classification (Hewitt 1998). Such soil types are particularly common on the loess-covered terraces of Manawatu. Pallic soil types in dairying regions of New Zealand are often accompanied by mole and pipe drainage systems which remove excess drainage water (Figure 3, Photo 5). The application of FDE to mole and pipe drained land has proven difficult to manage because of the preferential drainage pathways for the rapid movement of irrigated FDE. The risk of direct loss of contaminants following FDE irrigation is particularly high in the early spring period when soil is often close to, or at, field capacity (Houlbrooke et al 2004a, Monaghan and Smith 2004). The provision of suitable effluent storage for periods when soil moisture is close to, or at field capacity, and a method for accurately determining soil moisture contents, would allow for FDE to be scheduled in a deferred irrigation manner, thus minimising or preventing the likelihood of direct contaminant losses of raw or partially-treated FDE entering waterways via the pipe drain network.

The cause of direct drainage of irrigated FDE is related to application depth and the high instantaneous rate of application. Standard rotating travelling irrigators can result in a high degree of preferential flow through the large macropore network above the mole channels. Such preferential flow can occur whether there is a suitable deficit or not, particularly if travelling irrigators are not applying low depths (<10 mm average). In contrast, low application rate tools provide a high degree of flexibility in control of application depth whilst the lower rate encourages increased transmission of water through micropores. The combination of low rate tools with deferred irrigation offers much potential for preventing direct drainage losses of contaminants following irrigation of FDE to mole and pipe drained land. Examples of dairy farmed mole and pipe drained soils include Pallic soils such as the Tokomaru, Marton and

Milson silt loams, situated on the up-lifted marine terraces associated with the Rangitikei, Oroua and Manawatu rivers.

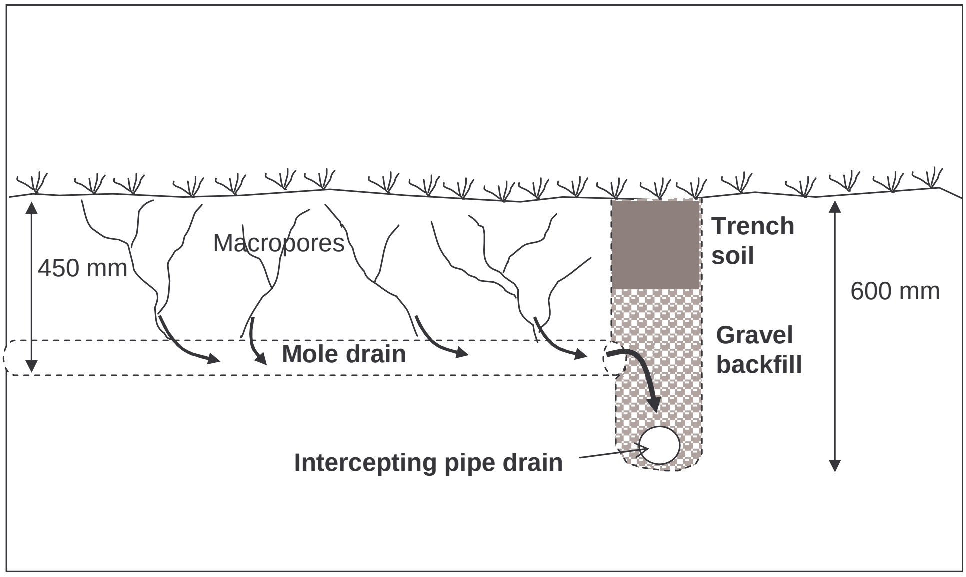

Figure 3. Diagrammatic representation of a mole-pipe drained soil.

Photo 5. Excavated mole channel

5.4.2 Soils with low infiltration rates and sloping land

In some circumstances intensive dairy farm operations in the Manawatu-Wanganui Region are located on rolling country with weakly structured soils. For the purposes of FDE management sloping land should be considered > 5°. These soils also typically belong to the Pallic Soil Order which are characterised by high density, slowly permeable subsurface horizons often over a fragipan which has a highly restricted permeability when wet (Hewitt 1998). These Pallic soil types, such as Tokomaru, Marton and Milson silt loams often have a rolling phase or sloping terrace faces, which may or may not include mole and pipe drainage. The low infiltration rates (< 100 mm/hr) of many of these soils in combination with sloping land poses a high risk of surface ponding and subsequent overland flow when FDE is applied using high application rate travelling irrigators. Low rate irrigation tools have application rates more suitable for these soil types and thus allow for soil infiltration and hence storage and subsequent filtration of contaminants in the applied FDE. For a number of practical and environmental reasons, it is recommended that such systems are run in accordance with deferred irrigation.

5.4.3 Soils with shallow water tables and artificial drainage

Some dairy farming in the Manawatu-Wanganui region takes place on relatively flat land with relatively severe drainage limitation. The limitation is usually a result of a regular shallow water table during the winter-spring period. To allow intensive dairy farming on these soils they are often drained and therefore pose an increased risk of contamination of surface drainage waters as a result of poorly timed applications of FDE. Examples of such soil types are Kairanga series (alluvial parent material, Gley soil order) on the Manawatu river plains and the Opiki peat soils (Organic soil order) in the lower Manawatu plains. The provision of adequate FDE storage and a deferred irrigation approach for the scheduling of FDE application to these soils would minimise the chance of contaminating the installed drainage system with raw or partially-treated FDE. With respect to the Kairanga soil series, the texture can range from fine sandy loam to a heavy silt loam. Where the soil texture is a silt loam or finer there is also a likelihood of slow infiltration and passage of water. Under these circumstances there would also be a further benefit from applying FDE with low application rate tools.

5.4.4 Farms with an existing two-pond treatment system.

Prior to the introduction of the Resource Management Act (RMA) in 1991 and the large expansion of dairy farming over the past 15 years, the use of a two-pond anaerobic/aerobic system with discharge to a stream was the common method of FDE treatment (Houlbrooke et al. 2004b). Whilst most of the existing two-pond anaerobic/aerobic treatment systems in the Manawatu region have been phased out, some of the systems are still in operation and discharging to fresh water systems. Dairy properties with existing two-pond systems are ideally suited for conversion to land application using deferred irrigation, with low rate irrigation as a final polish for pond FDE pumped from the second pond (Photo 6). Providing the existing pond is appropriately sited and sealed, it would act as a suitable storage pond during periods of low soil moisture deficit. Furthermore, a property converting to land application of FDE is ideally suited to putting in place suitable infrastructure to run low rate irrigation tools. The existing two pond systems remove the necessity for and cost of installing some form of solids separation that is required to remove larger particles that can potentially block the spray irrigation nozzles of a K-line system. Blockages of Larall sprinklers are reportedly rare as a result of their larger nozzle size.

Photo 6. The existing two-pond treatment system of the Massey University No. 4 dairy farm. The anaerobic pond is on the right and the aerobic pond with floating pump is on the left

5.4.5 Dairy farm conversions.

As for properties with existing treatment ponds, dairy conversions (from dry-stock farming) are ideally placed to future-proof their farming operation and establish their FDE system in keeping with best management practice. A suitably lined storage pond would allow the implementation of deferred irrigation. Furthermore, if the conversion was on land with artificial drainage, sloping land, or land with drainage limitations, then appropriate infrastructure for low rate irrigation should also be considered. However, even without these soil/landform characteristics there would still be many cost-effective advantages in opting for a best practice combination of deferred irrigation and low rate tools.

5.4.6 Existing properties without infiltration or drainage limitation.

Dairy operations that exist on free draining soils with little or no connection to surface water will benefit least from adopting best practice effluent management. Free draining soils are often characterised by high surface infiltration rates and would therefore have the least to gain from applying FDE with low application rate tools. Under these circumstances travelling irrigators should prove adequate for land applying FDE. There would however be some advantages in using travelling irrigators with a more uniform application pattern, such as the Spitfire, so as to avoid over irrigating soils with low water holding capacities. If standard rotating travelling irrigators are used to land apply FDE, then they should be run at their fastest travel speed to therefore apply their lowest depth. This would help avoid breaching field capacity and draining applied nutrients beyond the root zone. Examples of such soils are the free draining, alluvial

Manawatu silt loam or fine sandy loam and the stonier Ashhurst stony silt loam on the Manawatu plains. The free draining soils developed on the rolling sand country in the Western Manawatu, such as the Foxton sandy loam are another relevant category. Despite their free draining nature, these soils will still experience some periods of low soil water deficit, particularly in early spring. Some FDE storage capacity and a deferred irrigation strategy for land applying FDE would help prevent the movement of added contaminants beyond the root zone and in to shallow ground water. However, the extent and impact from contaminants added as FDE to free draining soils that leach to ground water should be kept in context. As FDE makes up approximately 10% of the daily nutrient load from cattle excreta, nutrient loading from animal excreta deposited in the field is usually the main contributor. Furthermore, the nutrient loads into groundwater will differ from that which left the root zone and will reflect the length of time for further filtration (depth to water table) and any denitrification that may take place throughout the vadose zone. In summary, when drainage and runoff pathways to surface water bodies are limited then the current practice of daily application using a high application rate travelling irrigator is probably suitable with regards to minimising potential environmental effects.

6. Recommendations to Horizons Regional Council

6.1 Implementation of best practice effluent management

Section 5.2 has outlined the environmental, nutrient management and system flexibility benefits of adopting, where appropriate, some best management practices such as FDE storage, deferred irrigation and low application rate irrigator technology. Furthermore, section 5.4 has outlined the potential applicability of these technologies to the Manawatu-Wanganui region. It is therefore proposed Horizons Regional Council promotes the following best practices:

- Appropriate FDE storage
- Soil moisture monitoring
- Deferred irrigation
- Low application rate irrigation tools
- Risk mapping to identify safe and unsafe areas for the application of FDE.

As discussed in Section 5.4, the greatest benefits from adopting a deferred irrigation strategy and, where appropriate, low application rate irrigator technology, will occur on soil types and climatic zones that have reliably wet spring periods and soil types with either restricted drainage, artificial drainage, soils with a high degree of preferential flow or soils on sloping land. It is therefore a recommendation of this report that, where these relevant soil and climate conditions occur, Horizons goes beyond a promotion of ‘best practice’ or ‘preferred option’ land application strategy and moves to a regulatory approach. However, enforcing the ‘best practices’ as standard consent conditions may prove to ridged. It is therefore, recommended that where appropriate BMP’s are not implemented that land application of FDE becomes a ‘Discretionary Activity’. This would provide a regulatory incentive for adopting ‘best practice’ whilst providing Horizons Regional Council with the ability to closely monitor and evaluate the performance of dairy farms operating with a higher risk approach to land application of effluent. For dairy operations operating on free draining alluvial or sand plain soils, there would be little advantage of using low application rate technology. While there would still be some advantages in adopting a deferred irrigation policy, this should not be considered essential, considering the low environmental risk posed by this soil type and land management risk. Under these circumstances then it could be ‘business as usual’, with operations able to apply FDE as a ‘Controlled activity’ without the need to implement ‘best practice’. It is however, a further recommendation of this report that as part of their consent activity all properties should have to prepare a farm plan and risk map identifying all areas of waterways, drainage and buildings. This plan should be used to outline paddock dimensions and an effluent irrigation rotation plan. Page 18 of the existing Dexcel/Dairy Insight/Horizons booklet on farm dairy effluent accurately outlines the type of effluent block map that is required.

6.2 Dairy effluent storage requirements

Dairy effluent storage requirements to meet deferred irrigation criteria vary with climate and the risk associated with land applying FDE to the soil type present. Houlbrooke (2005) modeled the effluent storage requirements of the Massey University No. 4 dairy farm (1000 mm annual rainfall). The simulation was based on actual farm parameters (soil type, effluent block and herd size) and was conducted using 30 year historical meteorological data, and a required water deficit of 15 mm before application using a rotating twin boom traveling irrigator could begin. The findings of this modeling showed that, ‘on average’, approximately 4 weeks of storage was required to safely implement a deferred irrigation strategy through the traditionally wet spring period. However, to design storage requirements around an average season’s water deficit would mean insufficient storage capability for half of the time. Over the 30 year period modeled, the largest storage requirement throughout the spring period was 11 weeks. Therefore where soil and landform features are appropriate, it would seem that the storage requirement for a dairy using a traveling irrigator with annual rainfall < 1100 mm would be 11 weeks. This rainfall scenario covers approximately 64% of dairy farms in the Manawatu-Wanganui region. Farms with rainfall between 1100 and 1500 mm should consider a storage capacity of 13 weeks (c. 12% of dairy farms), while dairy farms in high rainfall areas (> 1500 mm) make up the remaining 24% of Manawatu-Wanganui region dairy farms and should consider 15 weeks of storage. See appendix one for a map of rainfall bands in the Manawatu-

Wanganui region. In comparison to the above requirements, if properties were to adopt deferred irrigation in tandem with low rate application tools then the greater degree in flexibility of application depths and increased attenuation would allow the safe application of depths less than 8 mm. Storage requirements may therefore be as low as half of those for a traveling irrigator which requires at least 15 mm of soil water deficit to begin FDE application. Properties operating low rate irrigation tools should only require 6, 7 & 8 week's storage respectively for the <1100, 1000-1500 & >1500 mm rainfall zones. However the provision of at least two months storage would still provide greater labour flexibility throughout the busy spring period. The smaller provision of 4 to 6 weeks of FDE storage is likely to be satisfactory for properties on free draining alluvial and sand country soils, should properties decide to implement a deferred irrigation strategy. See Appendix two for a summary flow of chart effluent management practices and associated pond storage requirements. It is important to note that the above listed storage requirements for differing climatic and landform conditions should be considered a 'rule of thumb' assessment. Exact storage requirements should be calculated on a site specific basis at the time of consent application should the 'rule of thumb' requirement be contested by the applicant.

6.3 Nutrient budgeting and FDE block size

Currently N loading limits of either 150 or 200 kg/ha/yr are used for determining the minimum area required to apply FDE to land. Whilst the industry minimum was considered to be 4 ha/100 cows (prior to recent intensification), the dairy industry now promotes a figure of 8 ha/100 cows for determining the size of an FDE block (DEC manual, 2006). The rules of thumb of between 3 and 4 ha/100 cows were based around achieving N loading limits of 200 or 150 kg N/ha/yr. The figure of 8 ha/100 cows is now promoted as it accommodates the high potassium loading rates that typically occur on FDE blocks. As a general rule, a FDE block will require twice the area determined on K than for N loading. Unlike N and P, K is not considered an environmental contaminant. It is, however, an animal health risk if dairy cattle are grazing pasture on soils with high K levels (Houlbrooke et al. 2004b). The Overseer® nutrient budget model (http://www.agresearch.co.nz/overseerweb/) is capable of determining the appropriate size of an effluent block to avoid the excessive build up of K and hence prevent the likelihood of animal metabolic disorders. The use of a nutrient budget to determine appropriate FDE block sizes should be used in conjunction with existing N loading limits and would thus provide the farm operation and Regional Council staff with information regarding the likely inputs, outputs and flows of nutrients within the FDE block. Nutrient budgeting would also allow for the wise use of fertiliser, taking into account the nutrients being applied in the FDE and should be an essential practice of any dairy farm applying FDE to land. In accordance with the Clean Streams Accord, all dairy farmers should already be able to produce an up-to-date nutrient budget. As stated, 8 ha/100 cows is only a rule of thumb to allow for the considerable loading of K in FDE. On many intensive dairy farms this rule should be sufficient to prevent excess K build-up. However, where additional K is bought into the dairy platform via external feed (i.e. feed-pad use) then this rule may still be insufficient, further highlighting the importance of the use of nutrient budgeting for accurate determination of FDE block size. Future land-use intensification (such as increased herd numbers) should be considered at the time of block establishment for dairy conversions. Under no circumstances should FDE block size be determined on hydraulic properties such as those described in the DEC manual (2006) or the FARM strategy taking into account maximum daily application depths and minimum return times. These parameters are designed to help avoid excess drainage and surface run-off on a daily basis and do not account for nutrient loading issues.

6.4 Pond infrastructure requirements

6.4.1 Pond sealing

If deferred irrigation is going to become a best practice or even condition for land application of FDE in the Manawatu/Wanganui region, then the existence of suitable pond storage will be an essential element. Many properties do not have any existing storage capacity, whilst many properties with existing ponds originated from old two-pond treatment systems that are now used for their storage capacity prior to land application. Ponds pose a potential risk to shallow groundwater contamination if they are not adequately sealed. In particular, some existing ponds are sited next to waterways for ease of discharge during two pond treatment, and now pose a potentially greater hydrological risk. The POP rule 13.6 currently states that all FDE ponds must be sealed to a permeability of less than 1x 10^{-9} m/s. This value would seem appropriate for preventing the contamination of FDE from pond leakage as it relates to a leakage of less than 0.1 mm/day. Such a leakage restriction would require an appropriate clay base, a thick plastic liner, a spay-on water proof film or concrete. The cost for heavy duty polyethylene plastic liner (1 mm thick) is c. $12/m^2.

It would seem appropriate that any new ponds that are being put in place (particularly dairy farm conversions) should be required to meet the POP rule. The lining of a pond with clay may require an appropriate engineer’s certificate to guarantee compliance. In the medium to longer term it may become necessary to test the compliance of existing pond systems for permeability. Such an exercise will prove difficult as it will either require an appropriate in situ clay base sample for analysis or a mass balance assessment of the volume of FDE inputs and outputs to determine the potential leakage component. All ponds should be built in accordance with the standards presented in section 3.6 of the DEC Manual (2006). In the short term it would seem more appropriate to have effluent storage capacity in an old two pond treatment system that may leak some nutrients than to have no storage at all and be forced to lose nutrients to water when FDE is applied to wet soil. In other regions of New Zealand there have been reported cases where farmers have removed their existing pond storage and reverted to daily pumping from a sump rather than be forced to prove that their system complies with the required permeability limits. To avoid this occurring in the Manawatu-Wanganui region it will be important that all operators are made fully aware of the considerable advantages of pond storage so that the potential future requirement for existing ponds to be tested and potentially sealed is understood.

6.4.2 Effluent generation

The cost associated with building ponds is related to the storage capacity required. If all FDE is to be sent to a storage pond then appropriate measures should be taken to decrease the volume of FDE generated in the milking shed and holding yard. The industry standard for calculating daily wash down requirements is 50 L/cow/day (DEC Manual, 2006; Flemmer and Flemmer, 2007). This figure was presented by Vanderholm et al. (1984) when the average herd size for the 1983-84 season was 139 cows (Dairy Statistics, 2002). Anecdotal reports suggest that there can be wide variation around this figure based upon herd and yard size and individual farming circumstances. A recent study at Massey University No. 4 dairy farm suggests that water usage is more like 100L/cow/day (James Hanly pers. Comm.). However this research farm does have a considerable wash down area (from two sheds and holding yards). It should be noted that as cow herd numbers increase then water use efficiency should also increase and this conservative figure should therefore remain the industry standard unless more compelling monitored evidence suggests otherwise. However there is not enough current information available to accurately differentiate water use requirements from large vs. small herds or the difference between herring bone systems and large rotaries with potentially higher water use. This is an obvious information gap and there would seem some necessity for more research and monitoring to be carried out to update available data.

To decrease the volume of FDE generated, farming operations should follow section 1.6 of the DEC manual (2006) and attempt to minimise animal defecations in the farm dairy and yards, and also the water requirements for yard washing. Successful measures include storm water diversion from roofs, storm water diversion from clean concrete yards, and the use of rubber yard scrapers attached to backing gates (e.g. “Dung-busters”) to move animal excreta. Storm water diversion from roofs should be essential and will decrease the volume of water entering effluent storage ponds. Storm water diversion from holding yards is potentially risky and requires a judicious approach at each milking to prevent potential contamination with fresh FDE. Complete storm water diversion should however be considered best practice for decreasing the volume of FDE generated. Where this is not possible the increased volume of FDE generated needs to be accounted for when calculating storage requirements. This requirement is currently calculated using 50 L water/cow/ day and assumes that rainfall and evaporation on the pond surface will be similar. Additional volume is therefore a function of the annual rainfall and the holding yard size including any uncovered feed pads. The DEC manual (2006) suggests that herd management strategies such as gentle treatment in the holding yard, split herd management, and reductions in noise near the farm dairy (particularly dogs) will help keep cows less stressed and likely to produce less excreta. Water conservation methods include pre-wetting the yard prior to the herd arrival to prevent excreta stickiness to the concrete surface and wash down hoses with high pressure and low volume.

At the time of writing this report, the recycling of FDE wash-down water is not permitted for further wash-down use. However, Fonterra and Spitfire irrigators are currently proposing to the NZ Food Standards Authority that this rule should be relaxed to allow one of the two daily wash downs (yard only not parlour) to be with FDE liquor with some degree of solids removal or settling. It is estimated that such a practice would potentially decrease FDE generation volumes by 30-40%.

6.4.3 Management of solids

If FDE is to be stored in ponds, then effluent solids become part of the effluent management programme. Without stirring, sediment will sink to the bottom of a pond and form a nutrient rich sludge that will need to be periodically cleaned out (Longhurst et al. 2000). The frequency of such an operation is dependent upon both the pond and herd size and typically occurs every 2-5 years. The emptied sludge should be land applied to an area not already receiving FDE via irrigation. If a single pond system is with a plastic liner is employed without prior solids separation then contractors should take care when emptying the pond. Under this circumstance a layer of material (probably clay) should be placed on top of the plastic liner to help prevent the potential for liner damage. Some farms keep their FDE ponds well stirred (via mechanical means) so as to prevent the build up of sediment sludge and therefore regularly irrigate it combined in solution with the liquid FDE (Photo 7). Such an operation can be achieved with most travelling irrigators and the Iarall system when fitted with a self-cleaning screen at the pump. However, K-Line, with its small (4 mm) nozzle size, requires some degree of solid separation to avoid nozzle blockages. Screw press solid separators are commercially available in New Zealand (photo 8) but come at a high cost (section 4.3). A cheaper alternative known as a ‘sludge bed’ system has recently been developed in Southland. The sludge bed separates sediment from the liquid effluent in order to provide FDE suitable for application using K-Line irrigation systems. Sludge beds contain a solids reservoir in front of a slatted wooden wall that gravity feeds liquid effluent to a storage pond (Photos 9 & 10). The liquid effluent is suitable for application through K-Line systems or any other irrigation system should the operator wish to separate out the sediment and liquid components of FDE.

Photo 7. Large effluent storage pond with solids stirrer

Photo 8. Screw press solids separator.

Photo 9. Sludge bed feeding liquid FDE into a large storage pond

Photo 10. Liquid FDE flowing through the wooden slatted 'weeping' wall.

6.5 Education and labour

There are a range of activities that could be either implemented on-farm or carried out by Horizons Regional Council, in conjunction with farmers, which would enhance the environmental performance of FDE land application systems. The Dexcel/Dairy InSight/Horizons booklet is a useful resource for farmers wishing to responsibly manage FDE on their properties. However, this manual can sometimes be a little generic between other Regional Councils, and a smaller more easily readable handout/leaflet could be compiled by Horizons that summarizes the best management practices for FDE under appropriate soil type and climatic conditions found within the Manawatu-Wanganui region. This sort of handout/booklet could contain information on appropriate storage requirements and applicability of low rate systems. It could also promote a contact within the Horizons Regional Council for specialised advice on the most appropriate management of FDE for specific farming conditions. I have heard some farmers state that they feel uncomfortable approaching Compliance Officers regarding on-farm information for best practice effluent advice for fear that discussions indicate existing non-compliance.

On many existing dairy operations the job of applying FDE to land is sometimes shared around the staff, creating a situation where no one person is responsible for its management. At worst, this job is passed on to the newest (and often least experienced) member of staff. This member has usually received little or no training for managing FDE, its potential environmental consequences or the consent conditions with which they must comply. I would recommend that on larger dairy operations a dedicated effluent manager should be identified. This person could therefore be responsible for monitoring soil moisture conditions, pond levels, scheduling of irrigation events and the tracking and recording of subsequent irrigation events. Of particular importance would be the recording of information on dates, application depths applied, and antecedent soil moisture before irrigation. Furthermore, this dedicated manager would ensure that FDE is applied relatively evenly around the whole effluent block (taking into account N loading restrictions) and that traveling irrigators do not spend time sitting at the end of a run creating a heavy application 'donut'. Warning devices can now be fitted to traveling irrigators to warn staff that the machine has come to a halt whilst still pumping. For small owner/operator properties, it would make sense for the owner to take responsibility for dairy effluent management. A final recommendation would be that all staff that handle dairy effluent are put through appropriate training. This could involve an official 'effluent training course' that set out to educate operators with regards to soil types and associated application rates and depths, the tools available for land application, the animal health considerations and the nutrient value of FDE.

7. Conclusions

●The management of FDE has proven a challenge for both dairy operations and Regulatory Authorities throughout New Zealand. Poor performing FDE land application systems are capable of causing adverse effects on water quality.

●The impact of poorly performing FDE land application systems is most pronounced on soils with artificial drainage, sloping land, or soils with either infiltration or drainage limitations.

● Existing and proposed consent conditions describe the environmental performance required from a dairy operation land applying FDE to prevent water contamination, but do not provide practical options to achieve the required consent compliance.

● 'Deferred irrigation' and 'low application rate' strategies have demonstrated improved environmental performance for land application of FDE.

●Where high risk soil/landscape and climate conditions occur; greater regulatory control should be placed on dairy operations to encourage the uptake of best management practices.

8. Acknowledgments

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10. Appendix one

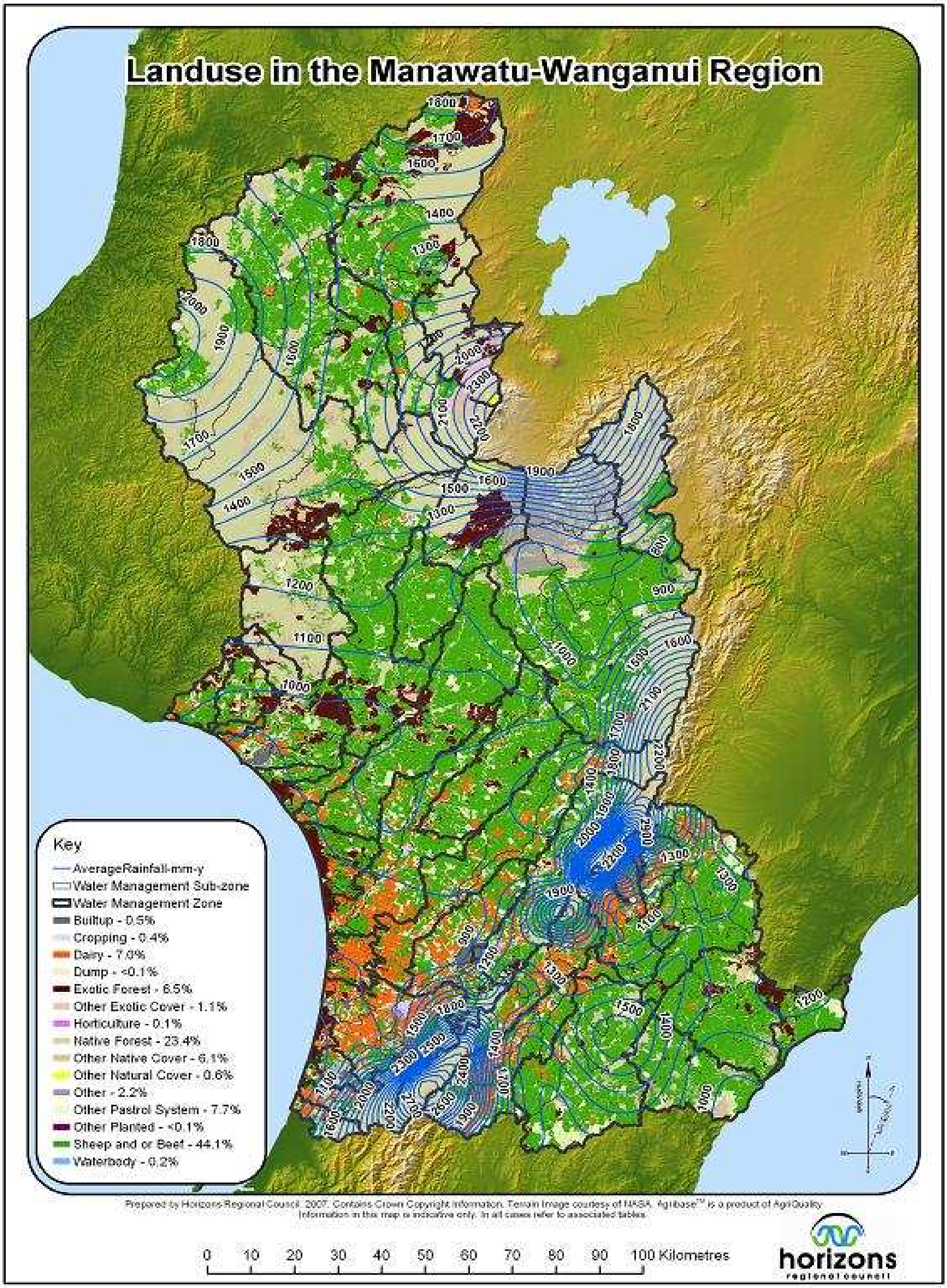
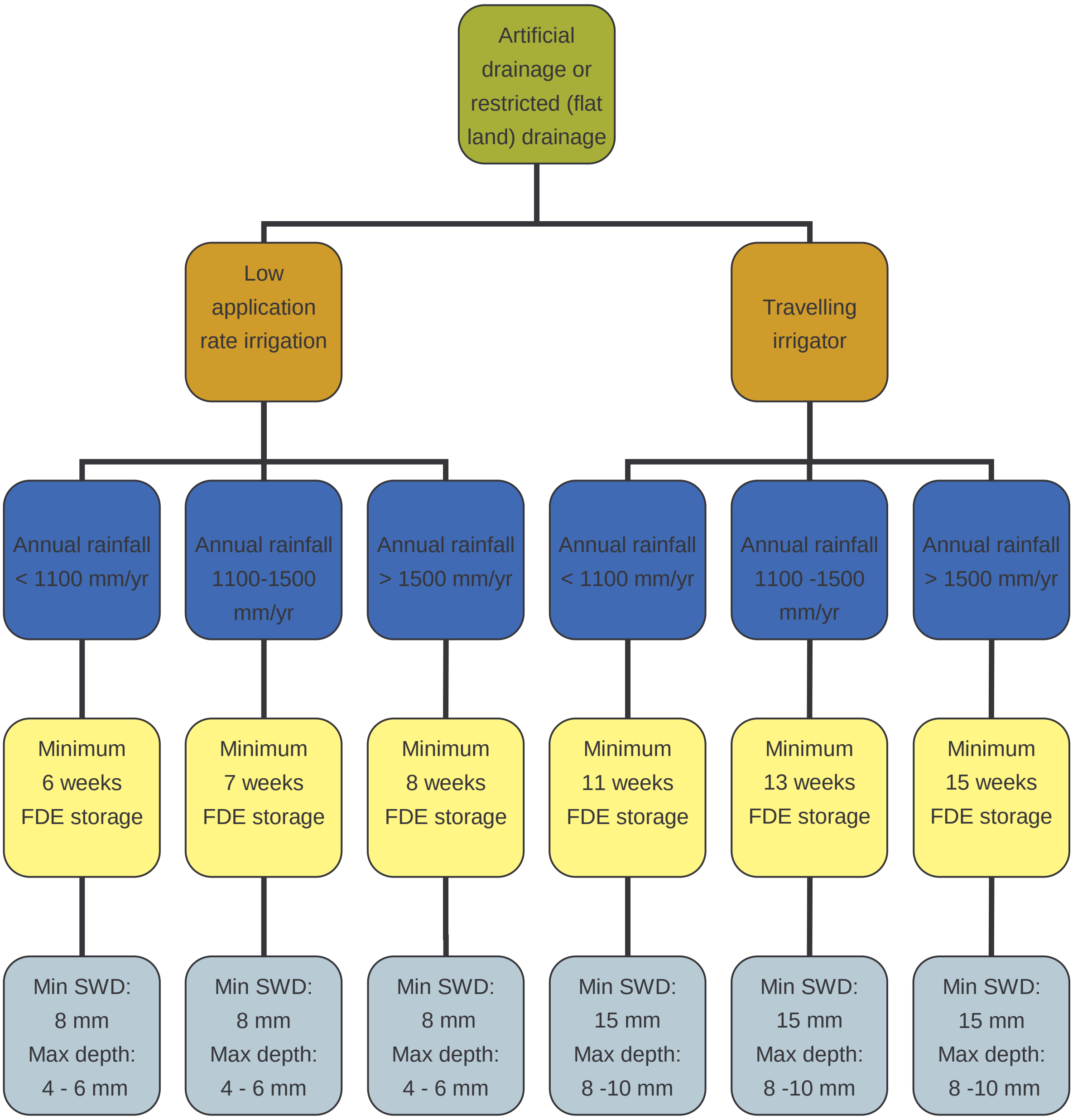


Figure 4. Annual rainfall bands (mm) over land-use for the Manawatu-Wanganui region. < 1100 mm/yr = 64% of dairy farms, 1100-1500 mm/yr = 12% of dairy farms, > 1500 mm/yr = 24% of dairy farms.

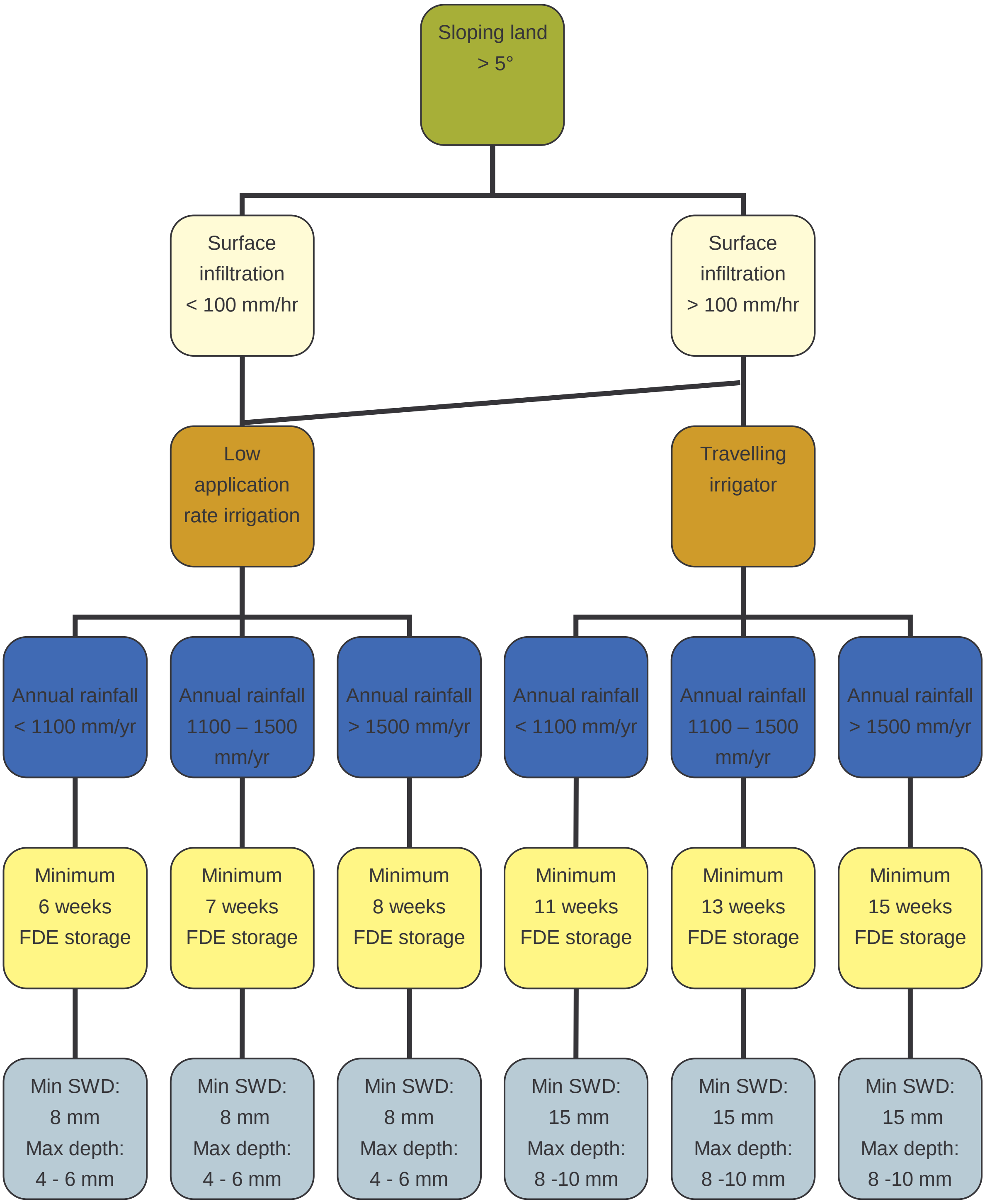
11. Appendix two

A suggested framework to guide decision making around matching farm dairy effluent (FDE) application depths, rates and storage requirements to a sites inherent risk. Min SWD is the minimum soil water deficit required before FDE can be safely applied at an appropriate maximum depth using the corresponding applicator. Four decision trees have been constructed based on the following soil/landscape features:

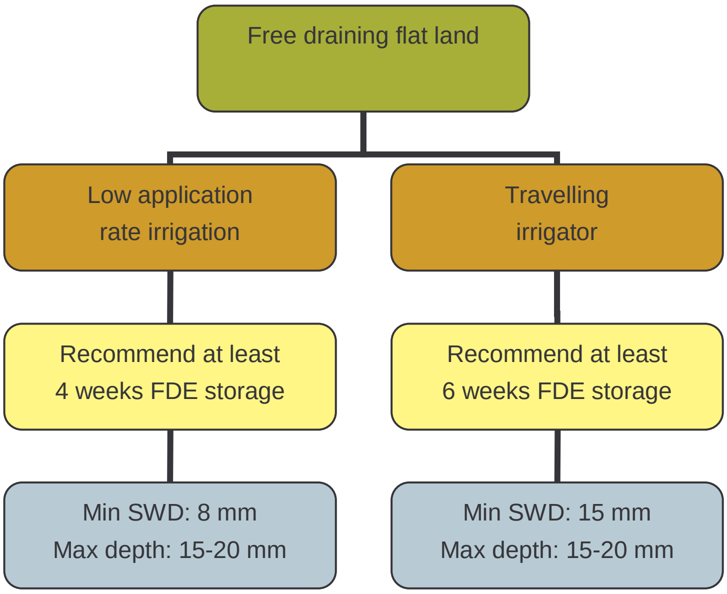
- **Tree A**. Land with artificial drainage or flat land with restricted drainage and/or low infiltration
- **Tree B**. Sloping land greater than 5°
- **Tree C**. Free draining flat land



Decision tree A. Land with artificial drainage or flat land with restricted drainage and/or low infiltration**.**



Decision tree B. Sloping land greater than 5°



Decision tree C. Free draining flat land