An analysis of the potential use of Deferred Irrigation in the Pongakawa area using a soil water balance

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1. Introduction

Deferred irrigation has been developed to reduce the risk of direct drainage and/or runoff of farm dairy effluent (FDE) into surface and ground waters. Deferred irrigation involves storing effluent - in a two-pond treatment system, for example - and then applying it strategically when there is a suitable soil water deficit i.e. the irrigation volume does not exceed the potential soil-water storage. The risk of nutrient accumulation in the soil is reduced by the removal of at least one silage or hay crop a year from effluent treatment areas.

The manner in which rainfall and effluent application is partitioned between drainage and runoff varies with soil type. At one extreme, surface runoff will be rare or absent when effluent is applied to highly permeable soils even when they are wet. On such soils, an effluent storage facility may not be essential, as effluent can be safely applied on most days of the year. Furthermore, preferential flow in such soils is unlikely, and the travel time of the applied effluent through the root zone will usually be slow enough for most of the potential ground water pollutants to be removed during transit.

At the other extreme, in low-lying areas, and/or in less permeable soils, the water table will be close to the surface during wet periods. If effluent is applied in this situation, much of it cannot infiltrate, and so it flows across the surface to enter drains and watercourses. It appears that high water tables and the attendant risk of effluent runoff are a common occurrence in the lower lying parts of the Pongakawa/Kaituna Catchment, and is the situation considered in this report.

This analysis addresses the following three questions.

1) Given the performance limitations of the small travelling irrigators commonly used to apply FDE, on what date can land application commence in the Pongakawa area?

2) If irrigation was to be deferred until the date identified above, then how much storage is required on a typical dairy farm?
3) How much FDE would be lost as surface runoff from a typical dairy farm practising deferred irrigation?

A soil water balance was used to answer questions 1 and 3, and a separate spreadsheet was developed to calculate the storage volumes referred to in question 2.

2. When can FDE irrigation commence?

One of the most important requirements for the successful implementation of deferred irrigation is the capacity to store effluent produced in the early-winter/spring period when soil moisture deficits are small or non existent. The duration of the period between the beginning of lactation and the attainment of a suitable soil water deficit (i.e. the irrigation volume does not exceed the potential soil-water storage) is an indicator of the difficulty of implementing deferred irrigation. The length of this period will determine the minimum storage needed if runoff of effluent is to be prevented. Just because this critical deficit is first attained does not mean that irrigation of effluent will then become straightforward: in all likelihood it will rain again and the deficit will again, on occasions, decrease below the critical value. Therefore, the soil moisture deficits in the period after the critical deficit value is first reached are also important. However, it is likely that following the attainment of the critical deficit value for the first time – often in mid to late spring - the soil will be drying and so the critical value will be reached and exceeded relatively frequently. So while there may be numerous days when the soil is too wet to irrigate, there will be sufficient opportunities to irrigate and so the storage capacity will not be exceeded.

As noted above, storage capacity is a key design parameter of a deferred FDE irrigation system. To determine the size of the pond needed to provide this storage, one needs to know a number of things, including the length of the period from the start of lactation in late winter to the time when effluent can be safely irrigated onto the soil without generating runoff i.e. that target soil moisture deficit. The July-August period is critical. This is when evapotranspiration rates are lowest, averaging about 1.5 mm/d around Tauranga (Scotter and Heng, 2003). Also these are the months with the greatest number of wet days (more than 1 mm of rain in Te Puke (Anon, 1983)) - 12 and 13 days on average in July and August, respectively.

2.1 Methodology

Thirty years of daily metrological data were obtained from NIWA including daily rainfall data for Te Puke. The Priestly-Taylor reference crop evaporation was calculated using maximum and minimum air temperature and either sunshine hour or, when available, solar radiation data from Tauranga Airport. Reference crop evaporation rates were calculated using data from Tauranga Airport because the required data was not available for Te Puke. As reference crop evaporation is quite spatially uniform, extrapolating the Tauranga data to Te Puke is acceptable. A daily water balance was then computed from the rainfall and evaporation data, and the first day after 15 July, the commencement of calving, when the soil water storage was equal to the target soil moisture deficit was noted.

What should be the size of the soil moisture deficit that is targeted? The magnitude of this critical deficit is constrained by the application characteristics of the irrigator. In this simulation, it was assumed that FDE would be applied using travelling irrigators. The two most common types of travelling irrigators are the ‘Briggs’ type standard rotating irrigator (hereafter referred to as a ‘rotating irrigator’) and the ‘Spitfire’ oscillating boom travelling irrigator (hereafter referred to as an ‘oscillating irrigator’). The irrigators are illustrated in Plate 1. These irrigators have a maximum application depth of 13 mm when set to travel at their fastest speed (Houlbrooke et. al. 2005). Therefore, the target soil moisture deficit for this analysis was set at 13 mm drier than “field capacity”. The date that this target soil moisture deficit was reached after 15 July was noted for each year.

Plate 1. Photographs of the two types of travelling irrigators considered in the simulation. The picture at the top is of a 'Briggs' type standard rotating irrigator (referred to in the text as a 'rotating irrigator'), while the 'Spitfire' oscillating boom travelling irrigator (referred to as an 'oscillating irrigator') is pictured below.

2.2 Modelled Results

The cumulative probability distribution of the day a target deficit of 13 mm is first reached for the thirty years is shown in Fig. 1. On average, a soil water deficit of at least 13 mm is first reached 47 days after 15 July, which is on 31 August. The standard deviation was 26 days, so, assuming a normal distribution (which the shape of the curve in Fig. 1 shows is a reasonable assumption), in about 67% of years the critical date would be expected to be within four weeks of 31 August. However, in one year, a 13 mm deficit was not reached until 5 November i.e. 113 days after 15 July. Land application systems for FDE will have to be designed and managed with this possibility in mind.

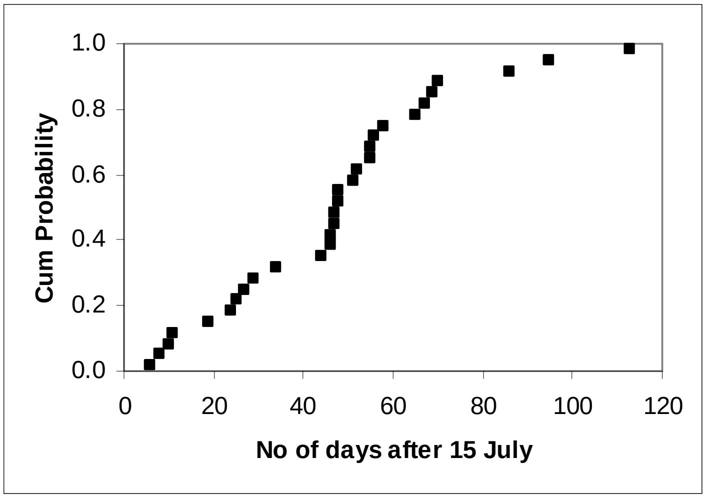

Figure 1. The cumulative probability distribution function for the number of days after 15 July when the soil water deficit first reached 13 mm for Te Puke.

A number of assumptions and approximations have been made in the above analysis. One of these assumptions is the stationarity of the climate parameters, or in other words, that the historic climate data used in this analysis is representative of the present day and future climates. If climate change occurs, average monthly rainfall and the number of rain days may change to some extent.

An obvious question arises from the above discussion, will it be more difficult to practise deferred irrigation in the Pongakawa area then in other regions'? In order to answer this question, the water balance was run using 1000 years of synthetic climate (Scotter et al. 2000) for the Gore, Dargaville, Palmerston North and Te Puke regions (Fig. 2). This synthetic data is generated using some measured climate parameters in a procedure described and evaluated for rigor by Scotter et al. (2000). They found that the generated synthetic data was very representative of real climate data but has the advantage that many more years of climate data can be generated than there are years of measured data.

In short, the answer to the above question is negative, that is, it may be more straightforward to practise deferred irrigation in the Pongakawa region than in many other areas. The simulation suggests that the period between the 15 July and attainment of a 15 mm soil moisture deficit was smaller for the Te Puke region than for either Palmerston North or Dargaville: the only region more suited to deferred irrigation, on this count, is Gore. It should be noted that while the synthetic data has proven very robust in other applications of the water balance (Scotter et al. 2000), there were some small discrepancies between the "days after 15 July" soil moisture deficit output generated using the synthetic data and real data – hence the use of real data in the rest of this exercise. However, the results in Fig 2. serve the purpose of illustrating the point that there is nothing peculiarly difficult about practising deferred irrigation in the Te Puke region.

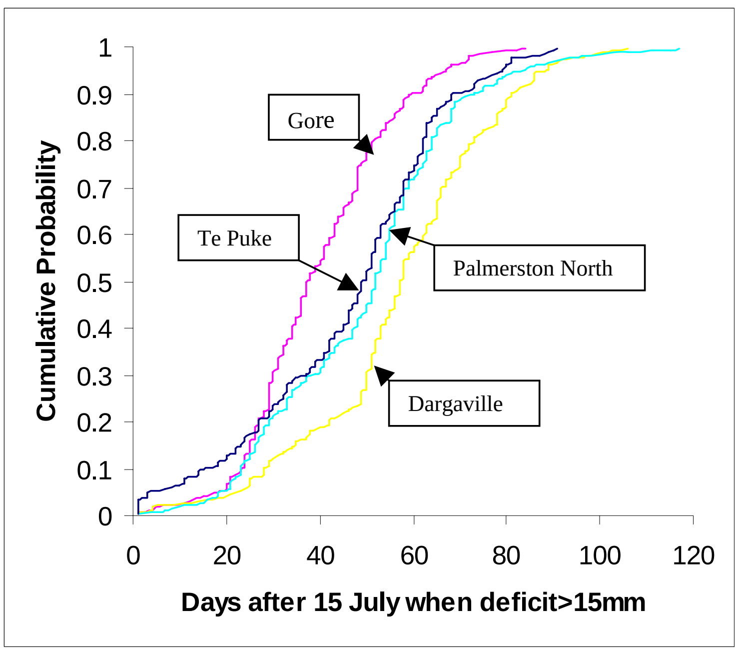

Figure 2. The cumulative probability distribution function for the number of days after 15 July when the soil water deficit first reached 15 mm for Gore, Dargaville, Palmerston North and Te Puke. Synthetic climate data was used in the water balance.

3. The Size of the Storage Needed

Having estimated the period for which dairy effluent needs to be stored, the next step is to estimate the required size of the storage pond.

3.1 Methodology

An Excel spreadsheet was also constructed to estimate the storage required. Where appropriate, inputs were taken from a case study farm in the Pongakawa area. For the case study farm, it is assumed that:

- 550 cows are being milked,
- calving starts on 15 July and occurs over 42 days,
- 53 litres of effluent per cow per day is produced in the dairy shed,
- the runoff from the concrete yard (780 m^2 in area) exits into the pond,
- the pond has a surface area of 300 m^2,
- there is no other runoff into the pond,
- the pond is empty (or very nearly empty) on 15 July,
- there is no seepage from the pond, and
- daily rainfall and evaporation equal the long-term average values during each month for Te Puke and Tauranga, respectively.

It is acknowledged that zero-leakage from ponds constructed in the sandy soils of the Pongakawa area is unlikely unless the bottom of the ponds have been sealed. In this situation, the use of liners seems to be the best means of limiting effluent loss to groundwater.

3.2 Case Study Results

The cumulative individual contributions to the pond; from the milking shed, from runoff from the concrete yard area, and from the net rainfall/evaporation addition/loss to the pond itself, for the 100 day period starting on July 15, are shown in Fig. 3. It can be seen that, given the assumptions for the model farm, except for the first few weeks when not many cows are being milked, the bulk of the effluent reaching the pond is the water used to clean the yards after milking. From this analysis it might be inferred that rain water runoff to ponds from existing sheds with average sized yards may not be a major problem.

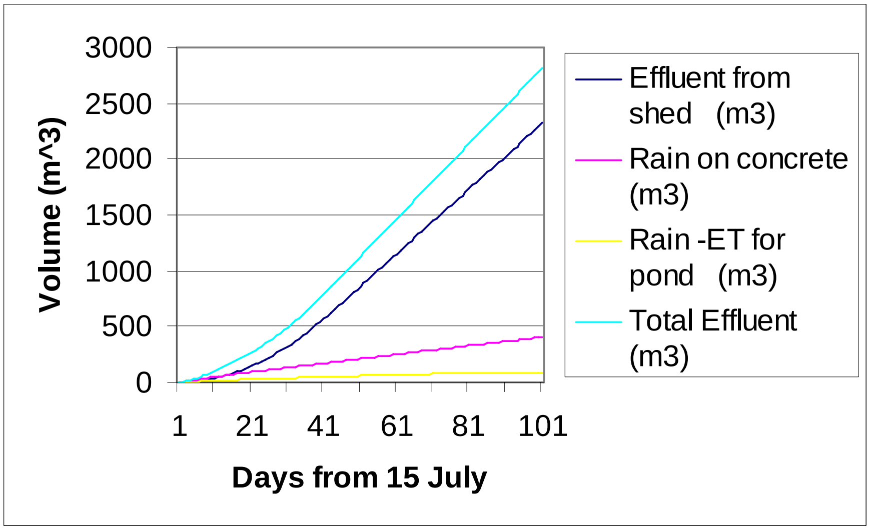

Figure 3. The cumulative water inputs to a storage pond as a function of the number of days after milking commences. See the text for details.

Taking the 47 day value for the storage period required, a pond storage volume of 1029 m^3 is required in an average year i.e. this is the storage required for the period following the commencement of lactation.

Storage volumes for a wide range of other input values can be found using the spreadsheet developed here.

4. How much effluent runs off: a risk analysis

The question remains as to how effective deferred irrigation, incorporating the storage facility identified above, would be in minimising runoff.

4.1 Methodology

To simulate the quantity of runoff, 150 m^3 irrigation was scheduled on any day that any of three following criteria are met:

1. cows are being milked, there is more than 150 m^3 in the pond, and the soil water deficit is less than 13 mm,
2. cows are being milked, and the pond is full, and
3. no cows are being milked, and there is at least 150 m^3 in the pond.

This final criteria was used to ensure that the pond was empty at the start of the lactation period: it would often involve, particularly in late winter, the irrigation of clean i.e. rain water.

The daily water balance model using 30 years of Te Puke rainfall data described above was then extended to include irrigation using these criteria.

4.2 Modelled Results

Taking the same values given above, and using the estimated pond size needed in an average year of 1029 m^3, then on average 9070 m^3 of effluent would be irrigated during the milking season. The daily water volume in the pond for one year of this analysis, covering the period from 1 June 1977 to 31 May 1978 is shown in Fig. 4. The pond has filled on several occasions, so some irrigation onto wet soil would have occurred.

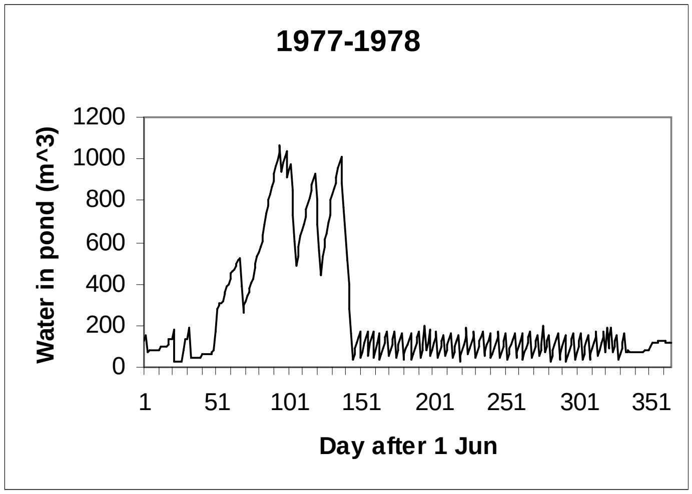

Figure 4. The computed volume of water stored in the pond from 1 June 1977 to 31 May 1978 for the example discussed in the text.

In order to estimate the amount of effluent that runs off the soil surface, some further assumptions need to be made. The main assumption relates to the equivalent depth of water applied at each irrigation. The application uniformity under travelling irrigators tends to be poor, particularly under rotating irrigators. Houlbrooke et al. (2004) describe the major effect that this variability in application depth has on drainage and runoff patterns under travelling irrigators. The model developed here accounts for such variation in application depth. Based on values measured for a rotating arm irrigator (Houlbrooke et. al. 2004) set to travel at its fastest speed, it is assumed that 70% of the 150 m^3 is applied at 8 mm per application, and the other 30% at 13 mm. This means that 1.9 ha is irrigated. If 4 ha of land is allocated for FDE irrigation per 100 cows, then the case study farm will have a land treatment area of 22 ha. There would be 11 irrigations before any land would be irrigated a second time in any one milking season.

The percentage of effluent that is applied to soil with zero water deficit (i.e. saturated soil) over the 30 years was then calculated. Effluent that is applied to saturated soil will runoff. The average quantity of annual effluent runoff was found to be 4.5%. In other words, if deferred irrigation is practised as described in the assumptions above, then on average 4.5% of the irrigated effluent will runoff to surface drains. The quantity of effluent runoff varied from zero to 26% in individual years, as shown in Fig. 5.

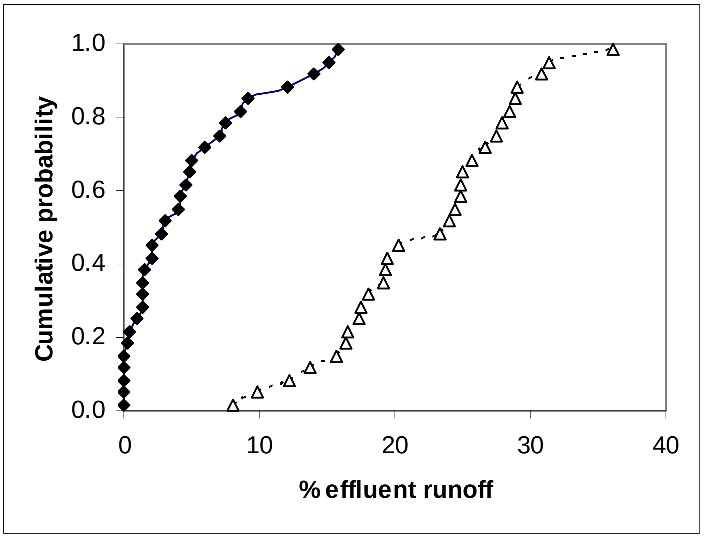

Figure 5. Calculated cumulative probability of annual percentage of effluent runoff caused by irrigation onto saturated soil, with a 1029 m^3 storage pond (♦), and with a 200 m^3 storage pond (∆). See text for other assumptions.

In contrast to the above, if instead of 1029 m^3 of pond storage, only minimal storage of say 200 m^3 was available, then on average, 22% of the effluent has to be applied to soil with zero water deficit. The amounts in particular years varied from 8% to 36% (Fig. 4). So increasing the pond storage from 200 m^3 to 1029 m^3 gives a five-fold reduction in likely effluent runoff.

It is also of interest to simulate what would happen if a oscillating irrigator, applying a uniform 13 mm depth per irrigation, were used. Each 150 m^3 irrigation would be irrigated onto 1.3 ha of land, and with 22 ha of land available there would be 19 irrigations per rotation. On average, 5.1% of the effluent applied using an oscillating irrigator would runoff. That there is runoff is due to the higher average application rate (13 mm), that there is so little runoff can be attributed to the uniformity of effluent application by this type of irrigator. In terms of the quantity of effluent runoff there would seem to be little difference between the performance of the rotating and oscillating irrigators.

The above analysis assumes that effluent is always applied to land that has not received effluent in that irrigation season. This was done to avoid unnecessary complication in the model. However, due to the relatively large number of irrigations in each rotation, and the fact that most irrigation onto saturated soil occurs early in the milking season when evaporation rates are low, this simplifying assumption had little effect on the analysis. For the example of the oscillating irrigator just given, 94% of the predicted runoff occurred during the first 19 irrigations of the first rotation. For the rotating irrigator 87% of the runoff came from the 11 irrigations of the first rotation. Therefore, this simplifying assumption would only lead to a small underestimation of the potential effluent runoff.

Another option for the irrigation of effluent is emerging – this involves the use of small stationary irrigators like the k-line system (Plate 2). The advantage of these types of irrigators is that they are much more flexible in the amount of effluent that can be applied. As effluent is applied from a series of pods, very small amounts can be applied over short time intervals. Currently, there are some difficulties associated with nozzle blockage by effluent that need to be resolved but these types of irrigators have the potential to make deferred effluent irrigation even easier to manage in areas like the Pongakawa.

Plate 2. K-line irrigators which may be adapted for use as irrigators of effluent.

5. Conclusions

Given the nature of the landscape and soils in the Pongakawa region, it is surface runoff of FDE that is likely to pose the greatest environmental threat.

However, deferred irrigation may potentially be used to minimise the FDE lost in surface runoff. Deferred irrigation would be no more difficult to practice in the Pongakawa area than it is in the Manawatu (near Palmerston North) where the merits of deferred irrigation are being widely promoted by researchers, farm advisors (e.g. Dexcel) and the Regional Council.

Deferred irrigation requires a storage facility. A spreadsheet was developed that uses a number of parameters including those related to: climate, the target soil moisture deficit, herd size, calving spread, wash water use and yard dimensions to calculate the storage requirements for a farm. On average, the case study farm (i.e. 500 cows) would require a storage capacity of 1029 m^3.

If deferred irrigation was practised on the case study farm (550 cows) as outlined above (i.e. using a storage facility of 1029 m^3, irrigating FDE only when the soil moisture deficit was 13 mm or greater, and standard travelling irrigators set to travel at their fastest speed) then on average only (approximately) 5% of the irrigated FDE would runoff.

The soil water balance suggests that where the appropriate infrastructure is in place, and this is married with careful management, deferred irrigation of FDE to land could have limited impact on water quality in the Pongakawa area.

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