WHY DO DAIRY FARM EFFLUENT TREATMENT PONDS LEAK?

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Abstract

This paper reports on Environment Waikato's investigations into seepage from dairy farm effluent treatment ponds. Seepage was measured at three different pond sites near Matamata, and intact pond floor cores were analysed for bulk density and clay content.

Mean seepage results between October 1995 and January 1996 varied from 1.3 to 4.4 mm day^{-1} for the aerobic ponds, and 0.9 to 3.5 mm day^{-1} for the anaerobic ponds between March and June 1996. This compares with a maximum seepage rate of 1 mm day^{-1} recommended by the Quebec Government (Barrington and Jutras, 1987) and the Pennsylvania Department of Environmental Resources (Reese and Louden, 1983) to avoid groundwater contamination.

The most significant cause of excessive seepage was substandard pond floor construction (insufficient clay content and/or compaction). More specific pond construction guidelines, better supervision of construction, and more advice to farmers may be required.

Earlier New Zealand research by Hills (1976) shows that seepage of less than 1 mm day^{-1} can be achieved with properly constructed anaerobic ponds. However, no similar research has been carried out for aerobic ponds. A trend of greater seepage from the aerobic ponds was observed in this study. This trend was probably due to the lower suspended solids concentration in the aerobic pond influent. Adequate pond construction is thus more critical for aerobic ponds, and a higher construction standard (e.g. greater pond floor clay content) may be required.

Keywords

1. Introduction

Seepage from dairy farm effluent treatment ponds can cause nitrate contamination of groundwater (Dalen *et al.,* 1983; Korom and Jeppson, 1994). This is a potentially serious issue in the Waikato region in view of the large number of dairy ponds and the reliance on groundwater for drinking water in the region. Consequently, Environment Waikato commissioned Lincoln Environmental in May 1994 to carry out a staged investigation into seepage from dairy farm effluent treatment ponds in the Waikato region. The first two stages comprised a scoping study followed by a prototype seepage measurement experiment, as described by Ray *et al.* (1995). The third stage, discussed in this paper, comprised measurement of pond seepage at three different pond sites near Matamata, and extraction of cores from the pond floors to assess the possible causes of seepage. The fourth stage of the study is to assess the effects of seepage on groundwater quality at two dairy pond sites. The fourth stage has been initiated but no results are available as yet.

2. Method

Three dairy farm effluent treatment pond sites were selected from the area around Matamata that is underlain by the coarse sands of the Hinuera formation, where pond seepage problems are known to be common (Figure 1). Each pond site comprised a two-stage pond system, i.e. a 3 to 4 m deep anaerobic pond followed by a 1.2 to 1.5 m deep aerobic pond, in series.
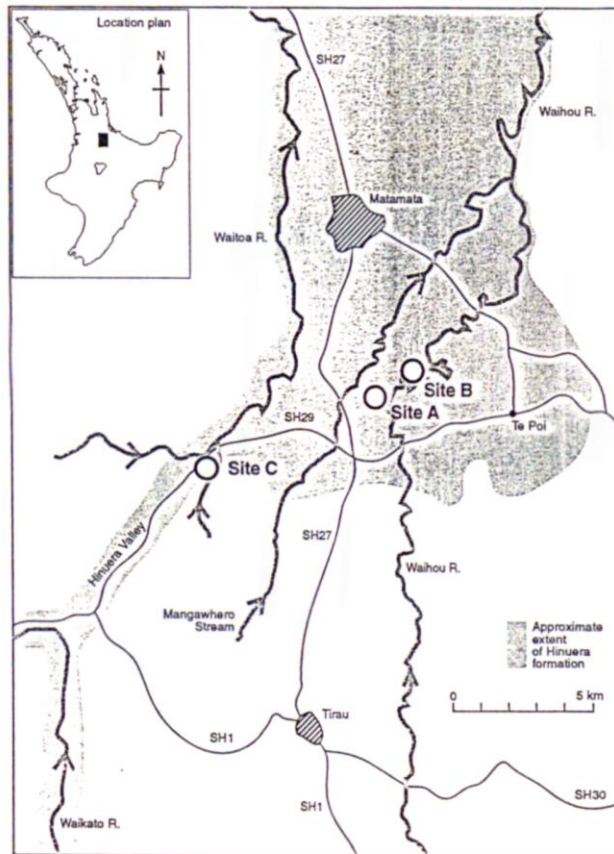
Figure 1   Site Locality Plan

Pond seepage is described by the following equation:

$$\text{Seepage} = \Delta S\text{-}E + R + I\text{-} O + Q \qquad\qquad \{1\}$$

Where ΔS = change in pond storage
E = evaporation from pond surface
R = rainfall onto pond surface
I = piped inflow into pond
O = piped outflow from pond
Q = water inflow from pond surroundings (either from groundwater, surface runoff, or interflow)

The aerobic pond at each site was temporarily isolated from piped effluent inflow and outflow, rendering I and O in equation {1} equal to zero. The change in level of the pond was recorded at

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regular intervals. Rainfall input and evaporation output to and from the pond were assessed using a floating polyethylene "rainfall/evaporation tank". It was assumed that rainfall input and evaporation output to the pond was the same as that of the rainfall/evaporation tank. Surface runoff from surrounding land into the pond was prevented. Groundwater levels in the vicinity of the ponds were monitored, and were consistently below the level of the pond surface, so there was unlikely to have been any groundwater inflow to the ponds. Rainfall interflow (i.e. seepage of water from the soil above the pond surface) was assumed to be negligible. Equation {1} then becomes:

$$Seepage = \Delta S - \Delta RET \qquad \{2\}$$

Where ΔS = change in pond storage over measurement period
ΔRET = change in level of rainfall/evaporation tank over measurement period

Once measurements were completed on the aerobic pond, the procedure was repeated for the anaerobic pond. Intact cores from the pond floors were extracted and analysed for dry bulk density and particle size.

3. Seepage measurement results

Seepage measurement results are shown on Figures 2 and 3. The estimated measurement error for each seepage result was +/- 0.7 mm. The mean of the seepage rates over the measurement periods for each pond are listed in Table 1. The seepage volumes in Table 1 were calculated by multiplying the mean seepage rate by the pond surface area. There are no results for the aerobic pond at Site A (Pond A2) since it did not receive any inflow. The seepage results may be compared with those measured in other studies by reference to the literature review in Ray *et al.* (1995). For both Pond Sites B and C, the aerobic ponds had greater seepage rates than the anaerobic ponds.

Some negative seepage results are evident in Figures 2 and 3, indicating possible inflow to the ponds (other than from rainfall directly onto the pond surface). These negative results are either due to rainfall inflow (runoff from the pond walls or interflow), seepage from the anaerobic pond into the aerobic pond, or measurement inexactness. The large negative value for Pond B2 in November 1995 is considered erroneous, and has not been included in the calculation of the mean seepage for Pond B2.

Table 1: Pond seepage rates

	Anaerobic Ponds			Aerobic Ponds	
	Al (Site A)	B1 (Site B)	C1 (Site C)	B2 (Site B)	C2 (Site C)
Mean of seepage rate measurements (mm day^{-1})	3.5	1.8	0.9	4.4	1.3
Calculated mean seepage volume (m^3 day^{-1})	1.8	0.95	0.39	2.7	0.94

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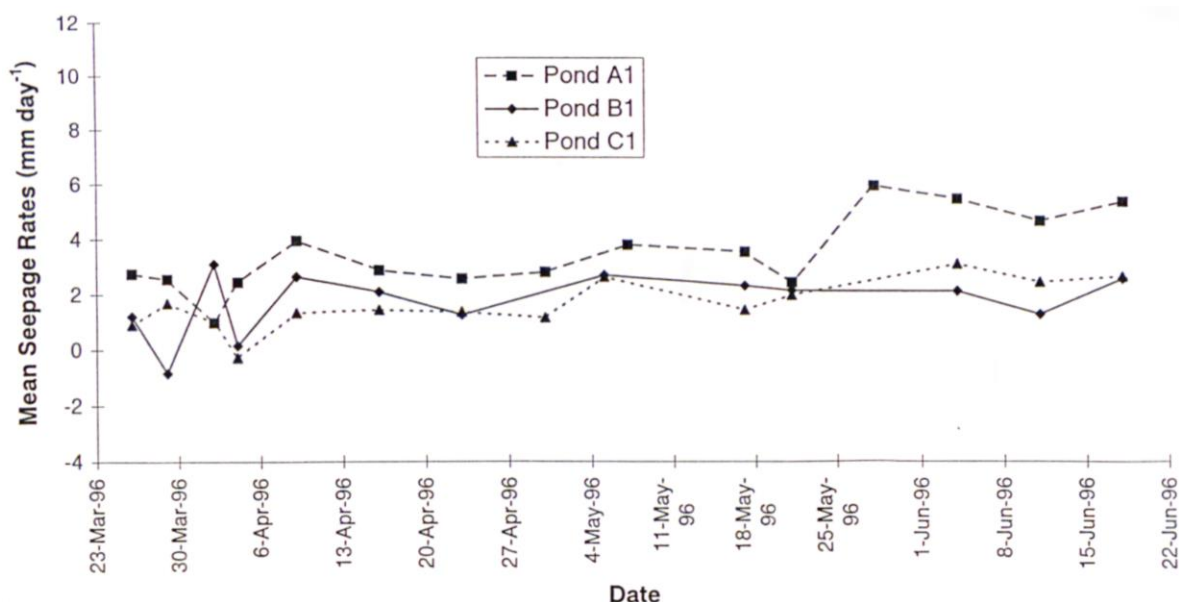
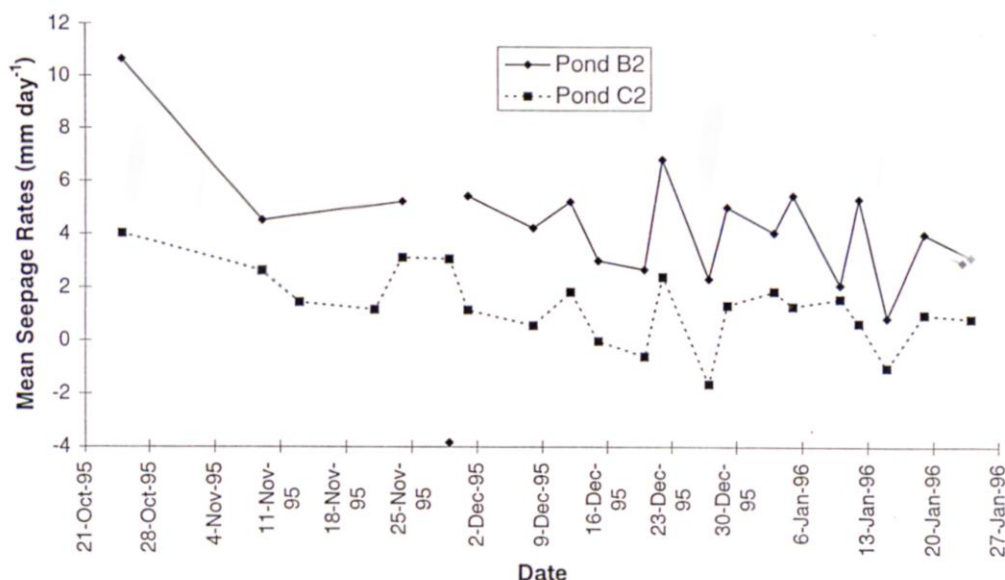Figure 2:   Seepage Measurement Results for Anaerobic Ponds

Figure 3:   Seepage Measurement Results for Aerobic Ponds

4. Pond floor core analysis results

4.1 Particle size distribution

Five pond floor cores were recovered from each of Ponds B2 and C2, and three from each of Ponds A1 and CI. The soil types in the cores are listed in Table 2, with particle size analyses results shown in Figures 4 and 5.
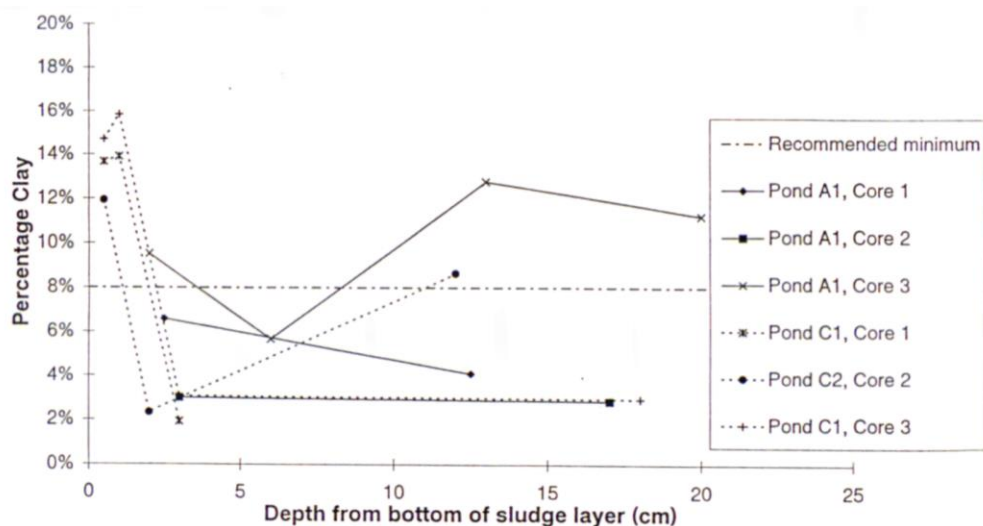
Ray, D.E., Balks, M.R., Barkle, G.F. and Selvarajah, N. 1997. *Why do dairy farm effluent ponds leak?* **In** *Proceedings of the New Zealand Water and Wastes Association Conference, Rotorua, New Zealand, 26 - 29 August 1997. pp 273-278.*

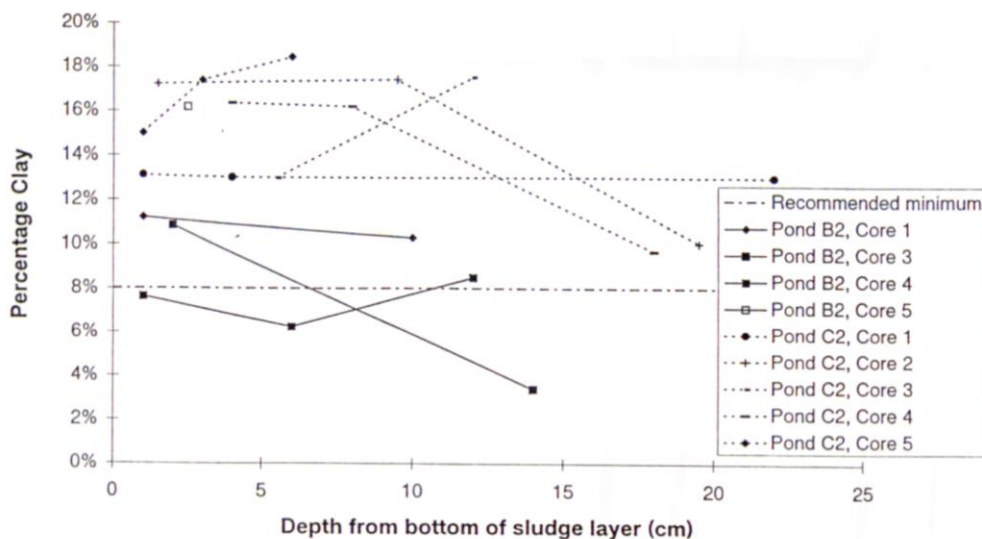**Figure 4:** Percentage clay in anaerobic pond floor cores

Figure 5: Percentage clay in aerobic pond floor cores

To minimise dairy pond seepage losses, New Zealand authorities specified a minimum clay content of 8% for pond floors (MAF, 1985). For Pond A1 (which had the highest seepage rate of the three anaerobic ponds), the floor core subsamples had clay contents of less than 8% in two of the three cores (Figure 4). For Pond C1 (which had the lowest seepage rate of the three anaerobic ponds), the cores had a low clay content except in a 1 cm layer of soil immediately below the sludge layer. In this 1 cm layer the clay content ranged from 12% to 16%. Clay content in the cores of aerobic ponds B2 and C2 was noticeably higher than in the anaerobic pond cores, and generally equalled or exceeded 8%.

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Table 2: Pond floor core soil types

	Anaerobic Ponds		Aerobic Ponds	
	A1	CI	B2	C2
Range of soil types (classified using | texture triangle)[1]	sand loamy sand sandy loam	sand loamy sand silt loam	loamy sand sandy loam silt loam	sandy loam silt loam

[1](McLaren and Cameron, 1990)

4.2 Dry bulk density

The mean dry bulk density of all the core subsamples was 1.1 t m^{-3} (standard deviation = 0.2 t m^{-3}). This compares with dry bulk densities of between 1.7 and 1.9 t m^{-3} achieved by Hills (1976) for loam, silt loam, sandy loam and clay loam soils compacted to the Proctor test standard for a pilot scale pond seepage trial, and 1.4 to 1.55 t m^{-3} for intact Hinuera formation subsoils reported by Joe (1986). Thus it appears that none of the Matamata ponds were well compacted during construction.

5. Discussion

5.1 What degree of pond seepage is acceptable?

A fundamental question in the consideration of pond seepage is what is the maximum seepage to avoid the risk of significant groundwater contamination? A maximum allowable seepage rate of 9 mm day^{-1} as suggested by the USDA (1993) seems excessively high, since calculations show that this would allow all the wastewater inflow to leak from a typical dairy pond system. On the other hand, the suggestion by Demmy and Nordstedt (1994) of possible nitrate contamination resulting from a seepage rate of only 0.1 mm day^{-1} was based on a number of very conservative assumptions. The maximum seepage rate of 1 mm day^{-1} suggested by the Pennsylvania Department of Environmental Resources (Reese and Louden, 1983) and the Quebec Government (Barrington and Jutras, 1987) appears to be more realistic. A seepage rate of 1 mm day^{-1} is roughly equivalent to the seepage of clean water that would occur from a 3 m deep pond constructed with a 300 mm thick clay liner with a coefficient of permeability of 1 x 10^{-9} m s^{-1}.

The means of the seepage rate measurements for all of the ponds except Pond CI exceeded 1 mm day^{-1}. However, the estimated error of each measurement was +/- 0.7 mm day^{-1}, and Figures 2 and 3 show considerable variation in the seepage measurements over time.

5.2 Possible causes of seepage

Seepage from the aerobic ponds was greater than that of the anaerobic ponds at the same pond sites. The possible influence of differences in groundwater levels was considered. However, groundwater level monitoring showed no correlation between hydraulic head and seepage rates over the range of measurements made. This result is consistent with the findings of Hills (1976). The trend of greater aerobic pond seepage is consistent with the preliminary pond inspections carried out as part of this study. Fourteen of the 25 aerobic ponds inspected were not full, while only three of the 25 anaerobic ponds were not full, suggesting greater seepage losses from the aerobic than the anaerobic ponds. Greater seepage from aerobic ponds was also reported by Vanderholm (1984).

The bulk density of the pond floor cores were all similar. However, the clay content in the aerobic pond floor cores was higher than that in the anaerobic pond cores, which should have resulted in lower seepage rates for the aerobic ponds. The most likely explanation for the greater seepage rates of the aerobic ponds was the lower suspended solids (SS) concentration of aerobic pond influent. Little sludge was evident on the aerobic pond floor, while a sludge layer of between 2 and 9.5 cm thick was observed in the anaerobic Pond C1 cores. Milking parlour wash-down effluent discharging into anaerobic ponds typically has a SS concentration about 10 times higher than that of aerobic pond influent (Vanderholm, 1984; Selvarajah, 1996). DeTar (1979) found that the effluent total solids (TS) content has a greater effect on the seepage rate than the initial permeability of the pond floor. He also noted that the seepage rate for low concentration effluent (such as that of aerobic pond influent) was more sensitive to the initial permeability of the pond floor soil. This suggests that adequate clay content and compaction of the pond floor is more critical for aerobic ponds than for anaerobic ponds.

Given that the clay contents in most of the core subsamples of both aerobic ponds were near to or greater than the minimum recommended for unlined pond construction (8%), it is noteworthy that the seepage rates of both ponds were greater than 1 mm day^{-1}. In view of the low bulk densities measured in all the aerobic pond cores, it is likely that neither of the pond floors were well compacted, and this may be the cause of the seepage rates of both aerobic ponds being higher than 1 mm day^{-1}.

The excessive seepage measured at anaerobic Pond A1 is likely to have resulted from insufficient clay content of the pond floor.

5.3 Adequacy of existing pond construction guidelines

MAF (1985) pond construction guidelines specify compaction of the pond floor with heavy, wheeled machinery, but do not give detailed specifications of how the pond floor should be compacted, or what pond floor bulk density is to be achieved. This leaves the judgement of adequate compaction to the farmer or pond construction contractor, which could result in inadequate compaction.

The MAF guidelines also specify a minimum clay content of 8%, but no clay content assessment methods are provided. It is not practical to use laboratory techniques to assess clay contents at every pond site. A quick, reliable method of assessing clay content would help to prevent unlined ponds being constructed in soils with low clay content. Professional assistance for farmers to assess pond construction requirements may be appropriate.

The investigations of Hills (1976) showed that anaerobic ponds with clay contents of about 8% and compacted to the Proctor standard can achieve seepage rates of about 1 mm day^{-1} or less within four months of pond commissioning. Thus if more specific compaction and clay content standards are included in the MAF guidelines, seepage in excess of 1 mm day^{-1} from anaerobic ponds should be avoided if they are constructed in accordance with the MAF guidelines.

No trials have as yet been carried out to confirm whether the MAF guidelines are adequate to prevent excessive seepage from aerobic ponds. In view of the apparently higher incidence of seepage from aerobic ponds compared with anaerobic ponds, the MAF guidelines may not be adequate to prevent excessive seepage from aerobic ponds, even if the compaction and clay content standards are made more specific. For example, a clay content considerably in excess of 8% may be required for aerobic ponds.

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5.4 Supervision of pond construction practices

Inadequacies in the construction standard of some of the pond floors have been noted earlier. In particular, the clay content of anaerobic ponds A1 and CI was appreciably lower than the MAF guideline of 8%. The compaction of the pond floors also appeared inadequate. This suggests that better supervision of the pond construction guidelines and advice to farmers may be required, particularly in areas where pond seepage problems are known to be common.

6. Conclusions

1. The most significant cause of seepage from the dairy ponds in this study was substandard construction of the pond floors. Better supervision of pond construction and advice to farmers may be required, particularly in areas where pond seepage problems are common.

2. The existing MAF pond construction guidelines require more explicit specifications for pond floor compaction standards and clay content assessment methods.

3. Earlier research in New Zealand by Hills (1976) shows that excessive seepage should not result from anaerobic ponds constructed in accordance with MAF pond construction guidelines, once the guidelines are made more specific.

4. Adequate clay content and compaction of the pond floor is more critical for aerobic ponds than anaerobic ponds. This is due to the lower suspended solids concentration in aerobic pond influent. It is not clear whether the MAF guidelines will be adequate to prevent excessive seepage from aerobic ponds, even if they are made more specific. For example, a greater clay content than that presently specified may be required.

Acknowledgements

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