SEEPAGE FROM DAIRY FARM EFFLUENT TREATMENT PONDS

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ABSTRACT

An investigation into the extent and effects of seepage from dairy farm waste treatment ponds has been commissioned by Environment Waikato. The principal concern is the potential for groundwater contamination. The literature shows that it is difficult to predict whether a pond will seal adequately without the use of a liner, and that significant contamination of groundwater can occur. A review of a selection of Waikato dairy farm pond monitoring records suggests that many ponds leak to varying degrees, particularly in coarse soil types. A prototype seepage measurement experiment has been trialled. Preliminary results indicate that seepage measurement to an accuracy of +/- 1 mm d^{-1} should be achievable. It was estimated that about 15% of the inflow was leaking from the anaerobic pond being monitored, even though the pond appeared from casual observation to be well sealed. This experiment will now be repeated on three different pond sites.

KEYWORDS

Dairy farm effluent, treatment, ponds, seepage, groundwater, contamination.

1. INTRODUCTION

About 50% of the population of the Waikato region rely on groundwater for their water supply. Dependency on groundwater is steadily increasing due to increasing farming activity and population growth. Between 1991 and 1994, about 400 new groundwater bores were drilled (Selvarajah et al., 1994).

Elevated nitrate levels in groundwater in the Waikato region have been highlighted by Selvarajah et al. (1994). Nitrates in drinking water have been linked with a number, of adverse health effects in humans, including the potentially fatal 'blue baby' (methaemoglobinaemia) effect (Burden, 1982). There are no confirmed records of adverse effects on human health caused by nitrate pollution in New Zealand, although a case of an infant with 'blue baby' symptoms in South Auckland was recently reported in the New Zealand Herald (1994).

One of the suggested sources of nitrate contamination of Waikato groundwater is seepage from dairy farm effluent treatment ponds (Selvarajah et al., 1994). In worst cases, contaminants such as bacteria and dissolved organic carbon are also suspected to enter groundwater aquifers. There are approximately 6,600 dairy farms in the Waikato Region, and about 4,000 of these have two-stage anaerobic/aerobic waste treatment ponds. The actual extent of seepage from these ponds and the environmental effects that seepage may be causing is not known in New Zealand. In response to this, Environment Waikato commissioned Lincoln Environmental in mid 1994 to carry out a long term investigation into pond seepage. This paper reviews the progress of the investigation.

2. REVIEW OF THE LITERATURE

This review is an attempt to collate studies which have examined seepage from dairy farm effluent treatment ponds.

Seepage from farm effluent treatment ponds has been observed to reduce by several orders of magnitude within a few months of the commissioning of the ponds (Hills, 1976). This is caused by a progressive sealing of the bottom and side walls of the ponds. The sealing mechanisms may be physical, chemical or biological (Hills, 1976). Physical clogging results from the blockage of soil pores by suspended solids that are filtered out of the effluent as it passes through the soil. Chemical sealing causes dispersion of the soil's colloids with resulting reduction in permeability. The biological seal is created by the excretions of micro-organisms clogging the soil pores (Hills, 1976). Barrington and Jutras (1983) and Barrington et al. (1987a and b) found that physical sealing was the most dominant of the three sealing mechanisms. The authors concluded that effective sealing should result if the clay content of the substrate is greater than 5%.

A number of studies have investigated the extent of seepage from unlined ponds and the effects of this seepage on groundwater quality. Several of these studies have suggested 'tnat seepage from unlined ponds is minimal and that effects on groundwater are not significant. For example, Davis et al. (1973) conducted a seepage study on two ponds sites on a sandy loam receiving dairy and beef feedlot effluent. The seepage rate for clean water was 1,200 mm d^{-1}. After two weeks of manure being added, seepage dropped to about 50 mm d^{-1}, and after 4 months, to about 2 mm d^{-1}. The pond was considered to be "effectively sealed" after four months. Similar seepage results were measured by Robinson (1973) for beef cattle excreta discharged into an unlined lagoon excavated into a clav loam. The initial seepage rate of 112 mm d^{1} reduced to 5.6 mm d^{-1} after 3 months and 3.0 mm d^{-1} after 6 months.

In a comprehensive laboratory study carried out for New

Zealand soils and wastes, Hills (1976) built 12 model lagoons using 600 mm diameter drums and typical New Zealand loams, silt loams, sand loams and a clay loam. These soils were compacted at optimum moisture content to achieve Proctor maximum compacted density. Dairy farm effluent was applied at depths between 2 m and 4 m. Seepage rates for all soils fell to about 1 mm d^{-1} within 20 weeks, except for the clay loam which fell to about 0.2 mm d^{-1}.

Several studies have not measured seepage directly, but have instead focused on the effects of seepage on groundwater quality. For example, Sewell (1978) monitored groundwater quality from 7 boreholes near a dairy farm anaerobic pond and effluent holding pond located on a silt loam underlain by sands and clay layers in the USA. Nitrate levels increased about 4 fold in the 3 months following the commissioning of the ponds, but then decreased to levels near those of the period prior to loading. This suggests that any seepage from the ponds was not sufficient to cause significant effects after the first 3 months of operation.

Both seepage and groundwater quality were monitored by Miller et al. (1985) for a newly constructed 2 ha unlined pond located in coarse sands into which effluent from a 4500 head beef feedlot was discharged. Although high seepage was noted when the pond was first commissioned, this decreased to an estimated seepage rate of less than 1 mm d^{-1} after 12 weeks, at which point the pond bottom was considered "effectively sealed". Groundwater quality monitoring below the pond showed only background levels of nitrate.

The above studies suggest that seepage from dairy farm effluent treatment ponds should reduce to low levels within 3 to 4 months, and that long term impacts on groundwater should be minimal. However, other studies have resulted in less encouraging conclusions. For example, Hart and Turner (1965) observed substantial seepage through sandy loam soils when they used pilot-sized lagoons to study the anaerobic decomposition of dairy farm effluent. The infiltration rate ranged from 66 mm d^{-1} at an early stage of operation to 41 mm d^{-1} 2 years later.

Similarly, Loehrand Ruf (1986) conducted a wide range of monitoring on a 2 year old two-stage dairy farm effluent pond located on sandy silts. Seventy seven percent of the total inflow leaked from the pond during the 12 month monitoring period. The seepage rate averaged 26 mm d^{-1}.

Nordstedt et al. (1971) showed that ponds located in coarse soils with a high water table could cause significant groundwater contamination. They observed nitrate-N (NO_3-N) levels exceeding 10 mg l^{-1} up to 15 m from a three-stage pond. Seepage rates were not measured.

Severe groundwater contamination from an 8 year old dairy farm effluent pond located in coarse soils was observed by Korom and Jeppson (1993). They found NO_3-N levels exceeded 10 mg l^{-1} and sometimes 100 mg l^{-1} in the unsaturated zone in a very gravely loam. Seepage from the pond was estimated at between 13 and 91 mm d^{-1}. A second site located on cobbly clay loam also had highly elevated NO_3-N levels in the unsaturated zone (up to 100 mg l^{-1}). It was postulated that the high concentration of NO_3-N was probably due to nitrification in the aerobic zone beneath the treatment ponds.

The U.S. Soil Conservation Service is developing guidelines for the need for and design of pond liners (Moffit et al., 1993). These guidelines are still being developed, but preliminary recommendations for design parameters have been made by the U.S. Soil Conservation Service (USDA, 1993). Lining of ponds is advised where the substrate has a clay content less than 15% (note that this is at variance with the suggestion by Barrington et al. (1987a and b) that effective sealing can be achieved with a clay content of only 5%). A maximum allowable seepage rate of 9 mm d^{-1} is suggested. This maximum figure compares with the Pennsylvania Department of Environmental Resources' definition of an "impermeable" pond having seepage less than 0.9 mm d^{-1} (Reese and Louden, 1983). Demmy et al., (1993) argued that significant groundwater nitrate contamination could occur with seepage as low as 0.1 mm d^{-1}. However, this argument was based on a series of "worst case" assumptions, such as no attenuation of ammoniacal-N in the seepage process, complete nitrification of all ammoniacal-N in the zone beneath the ponds, no denitrincation of nitrate in the soil, and no progressive dilution of the leachate by lateral groundwater flow. These assumptions seem overly conservative when compared with suggestions by Dalen et al. (1983) and Selvarajah et al. (1994) that nitrate contamination appears to be attenuated by soil mineralogy effects, denitrification, and dilution by groundwater flow.

In summary, seepage from unlined dairy farm treatment ponds has been shown to reduce by several orders of magnitude within a few months of the commissioning of the ponds. In many situations, this "self-sealing" will prevent significant contamination of groundwater. However, seepage after the sealing period may, in some circumstances, still be sufficient to cause significant nitrate contamination of groundwater. Despite the number of pond seepage studies that have been undertaken, it is still not possible to confidently predict whether a particular pond will or will not leak. Those ponds which appear to seal best are those located in medium to fine textured soils, with a clay content of more than 5-15%.

3.PRELIMINARY INVESTIGATIONS

The first stage of Lincoln Environmental’s field investigations comprised a scoping study. This was completed in July 1994. A selection of Environment Waikato's pond inspection records were reviewed to assess the extent of known leaking ponds. Pond inspections are carried out by MAF on behalf of Environment Waikato. This review of the records showed that leaking ponds were generally concentrated in the highly porous pumice soils in the Taupo volcanic zone, and the Hinuera sands in the vicinity of Matamata (Barkle, 1994). Eight pond sites in the Matamata area were inspected. Three categories of pond leakage were noted. The most severe was where the first pond had never filled, and thus all in/low was escaping into the ground, apart ›m the relatively small fraction lost by evaporation. The next ›st serious category was when the first pond was full, but the cond pond was not. This implied that the second pond was finitely leaking, and that the first pond might also be leaking. ıe third category was where both ponds were full and there ıs a discharge from the second pond, but it appeared that t/low was less than inflow, indicating some seepage losses.

A dairy farm effluent treatment pond performance survey in the Waikato region also indicates that most ponds do not discharge during dry periods (Selvarajah, 1995). Even with an average of 5 mm of evaporation per day from the pond surfaces during these dry periods, the absence of discharge from the second pond implies average seepage losses of about 4 mm d^{-1} if inflow to the ponds is 50 l cow^{-1} d^{-1} as suggested by Vanderholm (1984). This implies that about 40% of the inflow leaks from the ponds.

The Lincoln Environmental scoping study recommended that a prototype seepage measurement experiment be conducted for the second stage of the investigations. A suitable site was identified within the Hinuera formation, near Matamata. It was decided to conduct the test on a pond which appeared to be 'sealed' (i.e. both ponds were full and there was a discharge from the second pond), to determine how much a 'sealed' pond actually leaked.

4. SEEPAGE MEASUREMENT METHOD

The chosen methodology was a water balance measurement. Pond inflow, outflow, evaporation, rainfall, and change in storage were measured over a defined period, and thus seepage losses were deduced. A field prototype was established at the chosen two-stage pond. The ponds received waste from a dairy shed milking 140 cows, approximately 4 km south of Matamata. The ponds arc located on Waihou silt loams (McLeod and Kennedy, 1990; Mcleod, 1992). Pond inflow was measured with a 5000 litre polyethylene tank fitted with a float level recorder connected to a datalogger. Pond outflow was measured with a standard tipping bucket. Evaporation and rainfall was measured with a floating 1300 mm diameter 800 mm deep translucent polyethylene tank located near the middle of the first pond. Pond level was measured with a stilling well fitted to a stake located near the middle of the pond.

Numerous problems were experienced with the inflow measuring tank, principally with sludge building up and fouling the float level or discharge pipe. Due to these ongoing problems, the methodology was reviewed and a new approach adopted. One of the two ponds was isolated from inflow and outflow, and thus only evaporation, rainfall and change in pond level required recording. This essentially changed the methodology from one of a constant head seepage test to that of a falling head test. Seepage was measured simply by deducting the combined evaporation and rainfall from the change in pond level. Advantages of the revised methodology are the reduced number of measurements and hence reduced source of errors, less costly equipment and reduced labour input. A disadvantage is that the inflow to the ponds is not measured.

5. PRELIMINARY RESULTS AND DISCUSSION

The level of the first pond fell 88 mm in 17 days. Measurements were taken at two to four day intervals. Net seepage measurements (i.e. after evaporation and rainfall effects were deducted) varied from 2.8 mm d^{-1} to 4.1 mm d^{-1} (Figure 1). Average seepage was 3.3 mm d^{-1}. Combined rainfall and evaporation varied from a net loss of 0.1 mm d^{-1} to a net loss of 4.2 mm d^{-1}. This suggests that the methodology yielded reliable results, since the large fluctuation in rainfall and evaporation did not result in large fluctuations in seepage measurements.

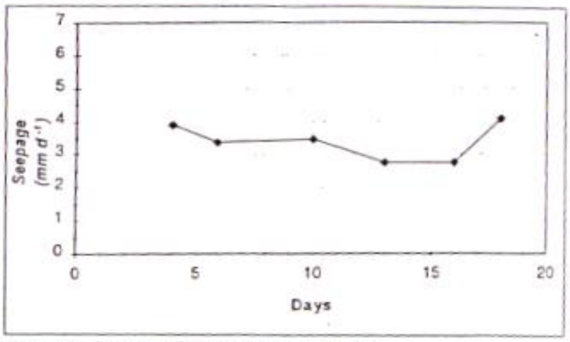

Figure 1: Results of Seepage Measurement

The soils beneath the pond are sandy loams. Samples taken from the bottom of the first pond indicated considerable sealing of the soil with manure solids.

Vanderholm (19S4) suggests an average effluent production of 50 1 cow^{1} d^{-1}. For the 140 cow dairy farm, this would result in an average inflow to the first pond of 7 m^3 d^{-1}. The average seepage loss of 3.3 mm d^{-1} implies a seepage discharge of approximately 1 m^3 d^{-1} from the first pond. Thus even for a pond which appears from casual observation to be well sealed, about 15% of the inflow could be leaking from the pond.

The average seepage rate of 3.3 mm d^{-1} falls within the U.S. Soil Conservation Service's "recommended design limit" of 9 mm d^{-1} (USDA, 1993). However, it exceeds the Pennsylvania Department of Environmental Resources definition of an "impermeable'" pond having seepage less than 0.9 mm d ^{1} (Reese and Louden, 1983).

The methodology appears to be capable of giving relatively reliable seepage measurements. It is considered that the accuracy of measurement is at least +/-1 mm d and could be improved to about +/- 0.5 mm d^{1} by increasing the length of time between measurements.

The next phase of the investigation is now underway. Three separate pond sites which represent severe leakage, moderate leakage and minor leakage have been identified. Seepage at these sites will be measured simultaneously, first for the second pond and then for the first pond. Depending on the results of these measurements, groundwater sampling wells will be installed to assess the effects of seepage on ground water quality.

6. CONCLUSIONS

A review of the literature shows that it is difficult to predict whether a dairy farm effluent pond will seal adequately without the use of a clay or synthetic liner. Coarse soils are more prone to significant leakage, particularly if the clay content is less than 5 per cent. The effects of seepage are variable, and depend on the mineralogy of the soil, the potential for nitrification and denitrification, and the nature of groundwater flow. There are differing opinions as to the maximum seepage rate to avoid the potential for groundwater contamination, but most research suggests that a rate of less than 1 mm d^{-1} should not cause significant contamination. For a two-stage pond system conforming to MAF design guidelines, seepage of 1 mm d^{-1} would result in about 10% of the influent leaking from the two ponds.

The prototype seepage measurement methodology used in the study appears to be capable of measuring pond seepage to about +/- 1 mm d^{-1}. Seepage measured from an anaerobic pond, which appeared from casual observation to be well sealed, was estimated as about 15% of the inflow. Further seepage measurements and the effects of seepage will be assessed by monitoring seepage loss contaminant levels in adjacent groundwater. It is hoped that these studies will give a clearer indication of the soil types for which pond lining is required.

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