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Role of livestock effluent suspended particulate in sealing effluent ponds

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ABSTRACT

Intensive livestock feed-lots have become more prevalent in recent years to help in meeting the predicted food production targets based on expected population growth. Effluent from these is stored in ponds, representing a potential concern for seepage and contamination of groundwater. Whilst previous literature suggests that effluent particulate can limit seepage adequately in combination with a clay liner, this research addresses potential concerns for sealing of ponds with low concentration fine and then evaluates this against proposed filter-cake based methodologies to describe and predict hydraulic reduction. Short soil cores were compacted to 98% of the maximum dry density and subject to ponded head percolation with unfiltered-sediment-reduced effluent, effluent filtered to <3 μm, and chemically synthesized effluent. Reduction in hydraulic conductivity was observed to be primarily due to the colloidal fraction of the effluent, with larger particulate fractions providing minimal further reduction. Pond sealing was shown to follow mathematical models of filter-cake formation, but without the formation of a physical seal on top of the soil surface. Management considerations based on the results are presented.

1. Introduction

The occurrence of intensive livestock feedlots has increased worldwide in order to alleviate food production pressure from a growing population (Fraiture et al. 2007). Large scale beef feedlots have become prevalent over the past two decades, with cattle numbers increasing from two hundred thousand to over a million in Australia, while individually these feedlots contain anywhere from 5000 to 50,000 head of cattle (AFLA/MLA, 2014). However, in addressing the demand for food through intensive feedlots, the accumulation of effluent is also intensified. Hence, management needs to consider the potential environmental impacts of the localised and cumulative concentration of nutrients and salts. Effluent liquid and organic particulate runoff, caused during rainfall and washing practices, are usually captured in effluent ponds to avoid overland flow. Effluent ponds are typically saline-sodic, as well as high in nitrogen and phosphorus. This raises concerns for the contamination of groundwater and proximal soil resources used for agriculture, due to seepage from effluent ponds. On this basis, regulating environmental authorities have begun to implement beneath pond seepage limits. Within Australia, guidelines for establishment and operation of beef cattle feedlots have proposed a coefficient of permeability (saturated hydraulic conductivity) no greater than 1.0×10^{-9} m/s (Skerman, 2000). This guideline is based on seepage limits imposed on contaminated landfill.

Various methods for the reduction of beneath pond seepage currently exist. However, the treatment of *in situ* soil is preferable to rubber liners and imported clay liners, due to associated differences in cost. Mohamed and Antia (1998) have suggested that infiltration rates in the order of 1.0×10^{-9} m/s can be achieved by compacted clay lined effluent ponds. Assouline et al., (1997) showed that soil compaction decreases volumetric water content at high matric potentials, while slightly increasing at low potentials. This results from a decrease in the proportion of macropores and an increase in meso/micro-pores. The active macropores are known to significantly contribute to water flow where 10% of macropores (>0.5 mm) and mesopores (0.06–0.5 mm) contribute to approximately 90% of the total water flux (Lin et al. 1996). Finer pores are characterised by increased inter-particle points of contact with greater internal aggregate strength and a lower wettability (Goebel et al., 2004; Ferrero et al., 2007). Consequently, an increase in bulk density of only 8% was observed to cause a 70% decrease in

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macropores and reduce saturated hydraulic conductivity (K_{sat}) by 69% (Zhao et al., 2010). Hence, clay liners and *in situ* soils are often compacted to 98% of the maximum dry density. However, due to a larger internal angle of friction and particle size, soils containing high sand contents would not be expected to obtain a coefficient of permeability less than 1.0×10^{-9} m/s, even at 98% of the maximum dry density.

Previous research concerning limitation of seepage beneath effluent storages has shown that the particulate contained in the effluent entering the ponds contributes to pore blockage, with the majority of literature referring to the occurrence of a physical seal above the soil interface coupled with a gradual decrease in hydraulic conductivity over time (Meyer et al. 1972; Ham, 2002; Tyner and Lee, 2004; Cihan et al. 2006). These seal layers have been reported as occurring due to straining where the particles are bigger than the soil pores and are usually measured in centimetres. Ham (2002) showed that organic sludge reduced seepage to a narrow range, observing an average apparent hydraulic conductivity of 1.8×10^{-9} m/s for 20 anaerobic lagoons. The suggestion was thus made that seepage testing should be done four month after addition of effluent to the pond due to the profound effect of sludge on hydraulic conductivity. It was further observed by Meyer et al. (1972) that a sludge layer had formed at the soil interface limiting seepage to the point that after 15 months the soil solution beneath the ponds was lower in nutrient concentration than adjacent wells, with no observable effects in proximal groundwater. Literature has shown that sludge layer development is similar to the formation of a filter cake layer and that this mathematical approach may offer a solution to calculation of pond permeability (Abboud and Corapcioglu, 1993; Tyner and Lee, 2004). This suggests that beneath pond seepage is a function of soil characteristics prior to sludge layer build up and then primarily a function of effluent total solids and concomitant conductivity of the sludge layer (Cihan et al. 2006). However, advances in pond construction and management in Australia and New Zealand have seen the use of sediment traps or filters prior to effluent entering storage ponds (Lott and Skerman, 1995; Meat and Livestock Australia, 2012). Thus, the total solids are significantly less than where a sediment trap/filter is not used, and the question is subsequently raised concerning the amount and nature of sediment required for the sludge layer effect to occur.

Therefore, this study investigates the role of reduced sediment load effluent solution particulate in reducing beneath pond conductivity, and then evaluates this against proposed filter-cake based methodologies to describe and predict this hydraulic reduction. Results are further discussed in the context of Australian regulatory guidelines for pond seepage.

2. Methods

2.1. Soil sampling, preparation and characterisation

A clay and clay loam soil were sampled from two Australian intensive livestock industry subsoils proximal to previously constructed feedlot effluent ponds; these subsoils had not been influenced by effluent. The soil samples were air-dried before being crushed to pass a <2.36 mm threshold. Chemical analysis for characterisation of soil pH, electrical conductivity (EC), organic matter content (OM), exchangeable cations (calcium, magnesium, sodium and potassium), calcium to magnesium ratio (Ca:Mg), exchangeable sodium percentage (ESP), and effective cation exchange capacity (ECEC) were undertaken consistent with Rayment and Lyons (2010). Soil clay content was determined through particle size analysis (PSA) consistent with Bowman and Hukta (2002), with the exception of using ultrasound as the aggregate dispersion source (Gregorich et al. 1988). These characteristics are displayed in Table 1.

2.2. Soil column preparation

To investigate the effects of effluent chemistry and contained particulate on soil permeability, short soil columns were prepared to represent the soil layer beneath an effluent pond.

The maximum dry density (MDD) for each soil was determined using Australian Standard 1289.5.1.1. Soils were compacted into a soil core of diameter 87.5 mm and height 50 mm with the desired bulk density at 98% of the MDD. The resulting bulk densities were 1.46 and 1.66 g/cm^3 for Soil D and Soil E, respectively. Compaction occurred in 50 mm PVC columns encased within a metal sleeve to ensure no expansion of the PVC column during compaction. Soil was compacted into the column in two flights of 25 mm.

The compacted columns were placed on top of a Whatman No. 4 filter paper inside a 90 mm PVC/mesh filter socket (Fig. 1). A 90 mm PVC end-cap socket was placed on top of the column and the screw-on end-cap was sealed with a 3 mm thick neoprene gasket. The end-cap was modified to receive a 19 mm adaptor, which was sealed to the end-cap using an o-ring and brass nut. Silicon paste was used to seal the join formed by the end-cap socket and PVC/mesh filter socket. This completed the compacted leaching column.

Five replicates for each treatment to be applied to each soil were constructed, giving a total of 40 soil columns.

2.3. Experimental treatment solutions

To investigate the effect of solution chemistry and suspended particulates four treatments were used: 1) $CaCl_2$; 2) chemically synthesised effluent; 3) filtered effluent; and 4) raw, or unfiltered, effluent. The $CaCl_2$ experimental solution and chemically synthesised effluent were matched to livestock effluent EC (Table 2) and the Sodium Adsorption Ratio (SAR) for these solutions was 0 and 4.47, respectively. The SAR and alkalinity of the latter was prepared using $CaCl_2$ and NaCl, along with $NaHCO_3$. The $CaCl_2$ experimental solution formed the control for the experiment and represented the soils in their most permeable state. Reductions in hydraulic conductivity were calculated from this treatment. The chemically synthesised effluent represented the effluent chemically, but had no solids or suspended particulates, which allowed the effect of suspended particulates to be elucidated. The filtered effluent contained suspended particulates <3 μm in diameter and was filtered from the raw effluent. Filtration was conducted to achieve a final suspension with properties similar to suspended clay (<2 μm in diameter).

2.3.1. Feedlot effluent and chemical analysis

Representative feedlot effluent was sourced from an effluent pond in the Darling Downs region, Qld. This effluent source was chosen as it represented the weighted mean of 79 feedlot effluent sources throughout Australia, in terms of EC and SAR. The water supplied had an EC of 4.96 dS/m and SAR of 4.47 (Table 2). Sampling of the effluent was from the evaporation pond, which was situated after a sediment trap. To ensure suspended solids were in suspension during sampling, the effluent solution was agitated prior to sampling.

The EC and SAR of the effluent could be expected to maintain soil structural integrity, albeit dependent on soil properties. However, the bicarbonate alkalinity is extremely high (38.36 mmol/L) in comparison to the observed concentration of Ca^{2+} and Mg^{2+}, resulting in a high residual alkalinity of 29.0 meq/L (see Landon, 1985) and an effective SAR of 6.67 (see Rayment and Higginson, 1992).

Total solids (TS) of the effluent were measured by evaporation of liquid from an effluent subsample of 50 mL placed in an oven set to