Leakage from two concrete manure tanks

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Barrington, S.F., Denis, J. and Patni, N.K. 1991. **Leakage from two concrete manure tanks.** Can. Agric. Eng. 33:137-141. Two 70 m^3 in-ground concrete tanks were tested in order to determine their leakage rate to groundwater and liquid slurries. These tanks had been built with no special precautions to seal the joints between the floor and the walls. Leakage rates reached levels of 175 $L•m^{-2}•d^{-1}$ under hydraulic pressures of 0.75 m created by high groundwater tables, but leakage rates fell to 3.5 $L•m^{-2}•d^{-1}$ when the tanks were filled with water some 2.0 m above the groundwater table. When the tanks were filled with 1.65 to 2.0 m of dairy manures diluted to 1% and 3% TS, leakage rates fell to 0.65 $L•m^{-2}•d^{-1}$.

Deux réservoirs à purin, sous terre et de 70 m^3, furent observés pour déterminer leur taux de suintement soit lorqu'exposés à des nappes élevées ou lorsque remplis de lisier dilué. Ces réservoirs ont été construits, en béton armé, sans étanchéiser leurs joints de murs et de plancher. Lorsqu'exposés à des pressions de nappe de 0.75 m, les réservoirs ont laissé entrer de l'eau à un taux de 175 $L•m^{-2}•j^{-1}$. Mais, emplis d'eau, à 2.0 m audessus des nappes environnantes, ces mêmes fosses ont démontré un taux d'infiltration de 3.5 $L•m^{-2}•j^{-1}$. Ces mêmes réservoirs ont suinté à un taux de 0.65 $L•m^{-2}•j^{-1}$ lorsque remplis de lisier de bovins laitiers dilués à 1% et 3% de matière sèche.

INTRODUCTION

Concrete structures have always been considered the safest storage facilities for manures in terms of groundwater pollution. When compared to geomembranes, these reservoirs offer incomparable resistance to mechanical damage, for the same capital cost. When compared to soil structures which may reach an hydraulic conductivity of 10^{-10} m/s after thorough compaction, concrete slabs offer conductivities less than 10^{-13}m/s after 28 days of curing and at a porosity of 28% (Whitting and Walitt 1988). Despite the low hydraulic conductivity of concrete, this material is very seldom built as a single unit and the joints between the floor and walls can be a source of leakage. Concrete reservoirs are also known to develop cracks during the curing process (Jofriet 1987) as well as under ice pressures developed from the freezing of their contents.

The sealing of concrete structures at the floor and wall joints is performed by some engineers, but considered not essential by others. The Quebec Ministry of Environment, (Deschenes 1989) requires the installation of elastic sealing strips at all joints of concrete structures used for the storage of manures. These concrete structures are also required to have a groundwater control drain at the footings. According to the Quebec Ministry of Environment, these construction precautions should insure leakage rates well under 10^{-9} m/s or 0.1 $L•m^{-2}•d^{-1}$(Deschenes 1989). This leakage rate allows a maximum nitrogen discharge into the groundwater table of 600 mg $N•L•m^{-2}•d^{-1}$. Turnbull et al. (1977) did not recommend such seals for underground reservoirs exposed to high groundwater tables. Turnbull felt that floor uplifting could be prevented by the entry of water into the reservoir, which, in turn, could stabilize the hydrostatic uplifting pressures.

Groundwater quality surrounding concrete structures has been monitored by two researchers: Patni et al. (1981) and Vallieres (1982). Patni and his group investigated the impact of manure storages on the groundwater in their immediate vicinity. The three concrete structures used for this study of stored dairy manures were at the Greenbelt Farm of the Animal Research Centre of Agriculture Canada in Ottawa, Ontario. The first structure measured 37.0 m x 14.4 m x 3.0 m and stored 1350 m^3 of dairy slurry; the second structure consisted of a 100 m^3 gutter below the slotted floors of the main dairy barn, and the third structure was a 1800 m^2 concrete floor for the storage of solid dairy manures. All of these structures were built without precaution in sealing the joints or in controlling the level of the groundwaters in the vicinity. For three years, water samples were collected from monitoring wells some 3 to 10 m away from the storages. The sum of the monitored NO_3-N and NH_4-N concentrations were found to be well below the drinking water limit of 10 mg-N/L. Mean concentrations in PO_4-P and K never exceeded 15 and 9 mg/L, respectively.

Vallieres (1982) tested various methods of sealing manure storage facilities built of concrete blocks. Eight underground reservoirs were investigated; five of these structures were built in silty to sandy soils while three other sites were built in silty clay soils. Analyzing water samples obtained from groundwater wells on the eight sites investigated, Vallieres observed erratic levels of NO_3-N and NH_4-N as well as fluctuating fecal and total coliform counts. Of all structures monitored after the sealing of the walls with either a concrete coating or an exterior layer of bentonite, the five on silty to sandy soils still demonstrated significantly higher groundwater pollutant levels in the wells near the tank as compared to the control well. Nitrogen concentrations and fecal coliform counts generally exceeded drinking water threshold values even for the control wells. In some instances, it was obvious that spillage during emptying operations and leakage from the holding tank at the barn were contributing to the contamination of the groundwater. Some seepage was also suspected from cracks in the floor of the concrete structures, thus explaining the contamination of the surrounding groundwaters despite the sealing of the walls.

Barrington (1985) demonstrated that groundwater sampling through wells installed in soils is not the most accurate method of monitoring the seepage levels of manure storage structures. Seepage can be filtered extensively by the soil itself before even reaching the sampling well. Groundwater pollution detection, by a well at the sampling site, will occur either under very high seepage rates, or after an extensively long period of low seepage rate, or in soils of very low cation exchange capacity. In the first instance, the soil's filtering capacity is reduced through seepage movement along the macropores at a speed exceeding the absorption and diffusion capacity of the medium. In the second instance, the seepage has completely saturated the soil forming the layer between the reservoir and the sampling well. In the third instance, the soil has no filtering capacity to clean the seepage and the contamination effect is automatically detected by the monitoring wells. The level of saturation or of filtration of a soil depends on the capacity of the soil to absorb cations, this capacity being related to the soil's clay content and the type of clay particles. Thus, Patni et al (1981) may not have been able to detect any significant levels of N, P and K because the structures were relatively young (5 to 10 years) and they were located on soils with some filtering capacity because of their clay content. Vallieres (1982) measured high pollutant levels even in the control wells, probably as a result of contaminated sites before construction, advanced age of the structures and sites of poor cation exchange capacity due to the low soil clay content (sands and loams). Barrington therefore suggested that seepage rates should be evaluated by more direct approaches, rather than by sampling wells.

Because of the reliability attributed to concrete structures for the storage of manures, but at the same time, because of the lack of knowledge concerning the leakage of these structures, an investigative research project was carried out to acquire some initial insight. This project was designed to observe the leakage rates of two concrete tanks by actually measuring the drawdown of their manure levels, over time, with respect to the groundwater table in the vicinity.

METHODOLOGY

To directly monitor the seepage rates of concrete manure facilities, an experiment was carried out at the Greenbelt Farm of the Animal Research Centre of Agriculture Canada in Ottawa, Ontario. The research work pertained to the measurement of the apparent and overall seepage rates of two concrete storage tanks. These rates were initially observed with water and subsequently measured using dairy manures diluted to 1% and 3% total solids (TS) content. Since reservoir sealing was quite extensive at 3% TS levels, no further testing was carried out with slurries of higher solids content. All monitoring was carried out with respect to the elevation of the groundwater table measured at distances of 40 to 50 m and on three sides of the research tanks.

The project was carried out using two dairy cow paddock concrete tanks numbered 55 and 56 (Fig. 1). These reservoirs each offered a storage volume of 70 m^3 and measured, inside, 5.9 m x 4.5 m by 2.8 m in depth. The walls, floors and roof of these two tanks were reinforced with two rows of reinforcement bars. The reinforcement consisted of M 15 bars (400 MPa) spaced at 250 mm vertically and at 300 mm horizontally. The floor was 300 mm thick while the walls and the roof were 250 mm thick. The two concrete tanks could be filled and observed for several days without having to receive any supplemental manure. Nevertheless, rainfall events would cause some paddock runoff which, in turn, would accumulate in the tanks. Because the experiment was carried out during the summer, and rainfalls were well spaced out, this did not result in any serious problems.

The level of liquid in each concrete tank was monitored using water level recorders with a vertical movement reduction scale of the order of 1/12. Because the recorder tape could be read at an accuracy level of +1 mm, the error associated with the reading of the reservoir liquid level was of the order of +12 mm.

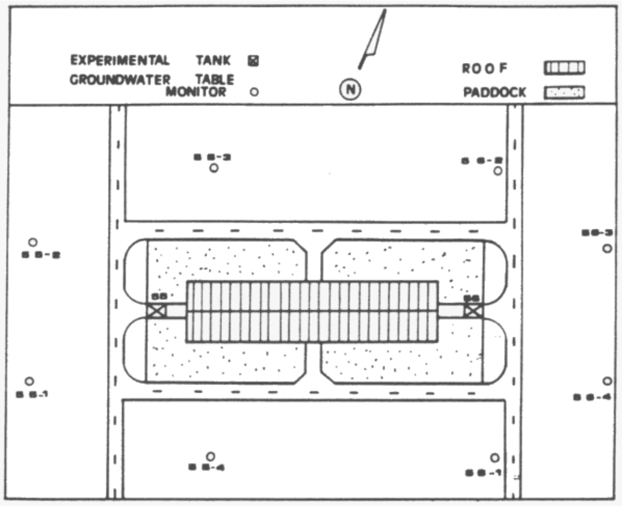

Fig. 1. Plan of the experimental set-up at a scale of 1:100.

The elevations of the groundwater tables were monitored at eight positions around the two experimental tanks (Fig. 2). Water level recorders, similar to those used in the tanks, were used for this purpose. The reading points for all water level recorders were linked to a common reference elevation with an engineer's level. The fluctuation of the groundwater tables could thus be related to that of the liquid levels in the experimental tank. Preliminary testing before the experimental trials indicated that water levels in the tanks came to an equilibrium within 0.05 m of the average measured groundwater levels. Also, during the experimentation, the groundwater levels demonstrated a consistent gradient of 0.2% towards the West. The groundwater level recorders did therefore represent the elevation of the groundwater table near the tank despite their distance of 40 to 50 m from the tank.

The leakage of water from both tanks was measured after thoroughly washing them. Initially, the tanks were emptied and the rate of groundwater entry into the tanks was measured twice. This process was carried out first since it helped dislodge any manure particles within fissures of the concrete structures. Then the tanks were filled with water and the drawdown rate was measured one more time.

Once the tanks were characterized by their respective leakage to groundwater, they were filled twice with dairy manures diluted to 1% TS and once with dairy manure at 3% TS Tank 56 demonstrated so little manure level change during the first trial with 1% dairy manures, that it was not tested a second time with 3% dairy manures.

All readings were corrected for evaporation. To measure this process, a pail containing water was suspended inside one of the experimental tanks and its liquid level was measured regularly.

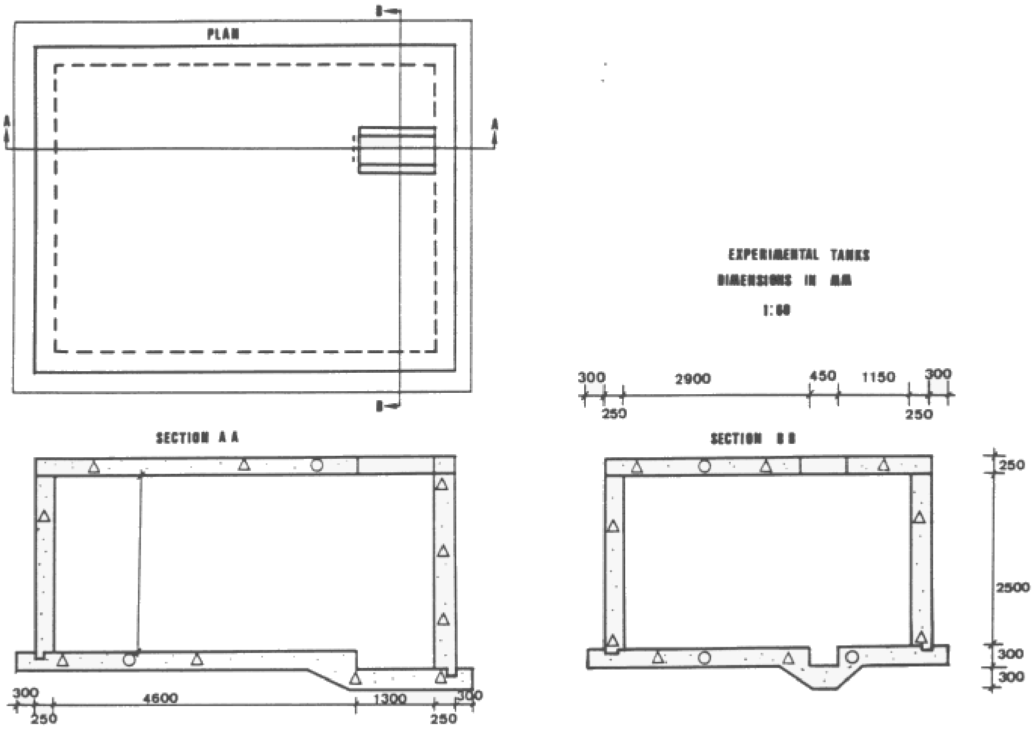

Fig. 2. The experimental tanks.

The TS levels of all dairy slurries were determined by drying five 500 ml samples at 103ºC until a constant weight was obtained (Parkamsam et al. 1974). The settling of the diluted dairy manures used in the experimental tanks was measured by sampling the liquids at various levels (300, 600, 1500 and 1800 mm above the floor of the tanks) and by determining their TS content.

The leakage of the two experimental tanks was computed from:

$$I = 1000\, y \bullet A / [T \bullet (H \bullet P + A)] \qquad (1)$$

where:

I = infiltration rate ($L \bullet m^{-2} \bullet d^{-1}$),
y = change in tank liquid level over time, T (m),
A = floor area of experimental tanks (m^2),
T = time of infiltration (d),
H = average liquid depth inside or outside of tanks over time, T (m), and
P = inside perimeter of tank walls (m).

This equation simply distributes the leakage rate over the tank surface exposed to liquid entry or exit. Tank liquid levels exceeding those of the surrounding groundwater table will be designated as positive while negative pressures pertain to tank liquid levels under that of the groundwater table. Presentation of the data in this form serves as a means of comparing the performance of the experimental tanks to the regulation of 0.1 $L \bullet m^{-2} \bullet d^{-1}$ required by the Quebec Ministry of Environment (Deschenes 1989).

Groundwater sampling was attempted immediately beside each experimental tank. Unfortunately, this was not possible because of crushed stone layers, concrete works and asphalt roads encountered in the vicinity of the tanks. It was therefore impossible to relate reservoir leakage to groundwater quality.

RESULTS AND DISCUSSION

The experimental tanks were initially characterized by measuring their leakage rate to water and then by measuring their leakage rate to diluted dairy manures.

Water leakage from the two experimental tanks was measured three times, twice under negative water pressure and once under positive water pressure (Fig. 3). Under negative pressures, water entry into the reservoir was quite obvious during the cleaning operation as air bubbles were seen flowing into the tank with the groundwaters at the floor and wall joints. Water leakage rates reached levels as high as 125 and 175 $L \bullet m^{-2} \bullet d^{-1}$ for tanks 55 and 56, respectively, under negative hydraulic pressures of 0.75 m. This leakage rate decreased with time and with a falling groundwater pressure head. Under positive pressure, leakage rates were much lower as the maximum entry rate of the groundwater reached levels of 45 and 20 L/m^2-d under hydraulic heads of 1.5 and 2.0 m, for tanks 55 and 56 respectively.

During the tests carried out with negative groundwater pressures, the leakage rates of the tanks were highly correlated with both time of leakage and groundwater hydraulic head (Table I). This high correlation probably results from the fact that the groundwaters could enter freely into the tank. Under positive groundwater pressures, water leakage rate from the tanks showed poor correlation with hydraulic pressure. This lack of relationship is obvious from Fig. 3 where large variations in leakage rates occur with little or no pressure head changes. Thus a sealing phenomenon must have been introduced during this process, most probably the blockage of concrete fissures and joints by some organic matter still left in the tanks despite the cleaning.

Tests carried out with manures diluted to 1% and 3% TS produced leakage rates of 20 $L{\cdot}m^{-2}{\cdot}d^{-1}$ decreasing rapidly to rates of 0.65 $L{\bullet}m^{-2}{\bullet}d^{-1}$, under positive pressures of 1.6 to 2.0 m (Fig. 4). These rates are still higher than those allowed by the Quebec Ministry of Environment. Since the rates presented also corresponded to the smallest rate which the experimental setup could possibly measure, further testing will require laboratory experimentation. Nevertheless, the 3% TS manures produced leakage rates one-tenth those of the 1% TS manures, indicating that higher levels of solids in the slurry leads to more extensive sealing.

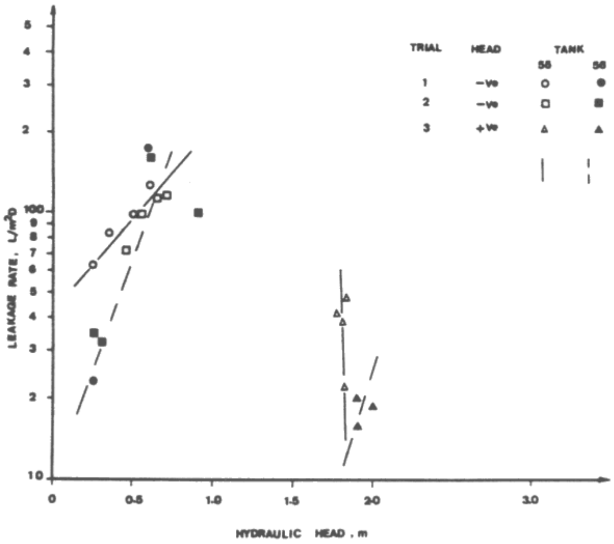

Fig. 3. Leakage rates with water.

Table I. Correlation coefficients for water leakage rates as related to hydraulic head and seepage time

Tank	Trial	Hydraulic head	Correlation time	Coefficient head
55	1.2	-ve	-0.94	0.88
	3	+ve	-0.09	-0.19
56	1.2	-ve	-0.82	0.87
	3	+ve	-0.92	0.61

Note: The logarithmic value of the leakage rate was used to calculate the correlation coefficients

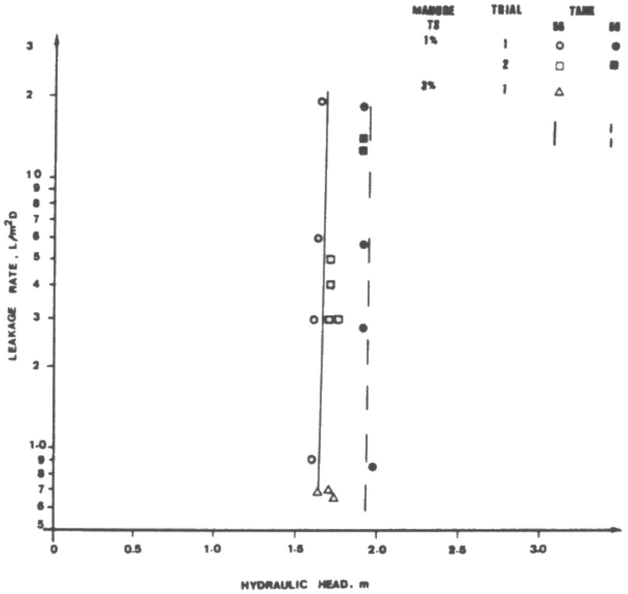

Fig. 4. Leakage rates with diluted dairy manures.

Correlation coefficients were computed between leakage rates and hydraulic head as well as time (Table II). Although there is a good correlation between leakage rate and leakage time, the relationship between leakage rate and hydraulic head is either non-existent or negative. These negative correlation coefficients between leakage rate and pressure head result from the lack of groundwater table drawdown *as* the manure level in the tanks is falling. Thus the total pressure head equal to the groundwater elevation minus that of the falling manure level, increases with time while the leakage rate decreases slightly. The decrease in manure leakage rate was much more a function of time than of hydraulic head (Table II), a phenomenon also observed with soils as they become sealed by the organic matter of infiltrating liquid wastes.

Tests were also carried out to determine the extent of settling of the diluted manures placed in the experimental tanks (Table III). These analyses indicate that the 1% TS slurries settled very little whereas the 3% TS slurries settled to 11.4% TS at the bottom of the tank. Therefore, settling of manure slurries may play an important role in controlling the level of leakage if crack and joint sealing is a phenomenon which comes into play.

CONCLUSION

The design of concrete storage facilities exposed to high groundwater tables should include the sealing of joints; otherwise, extensive leakage can occur. Following the entry of large quantities of water into a reservoir already containing some manure, the seepage rate out of the tank may be very slow.

Table II. Correlation coefficients for manure leakage rates as related to hydraulic head and seepage time

Tank	Trial	Manure	Correlation	Coefficient
		T.S.	time	head
55	1, 2	1%	-0.82	0.12
	3	3%	0.93	-0.82
56	1, 2	1%	-0.89	-0.82

Note: The logarithmic value of the leakage rate was used to calculate the correlation coefficients.

Table III. Total solids level of the diluted dairy manures used for the leakage measurements

Parameter			Total solids level %	
Nominal			1.0	3.0
Actual	- Average		0.69	2.61
	- s.d.		0.010	0.106
With depth in the tank after one week of settling:		300 mm	0.37	11.05
		600 mm	032	5.34
		1500 mm	034	1.40
		1800 mm	034	1.40

Note: The depth in the tank was measured from the floor.

Thus the sealing of the wall-floor joints, for example, may not be an environmental criteria but rather a method of saving storage space for manures. If the structure's joints are sealed, drainage mechanisms have to be used around the reservoir to control hydrostatic pressures exerted by high groundwater levels.

This preliminary investigation is an initial step towards the examination of leakage from concrete reservoirs used for the storage of manures. It does demonstrate that concrete tanks can leak unless necessary construction procedures are respected. Because of the limitation of the experiment, further testing is recommended under laboratory conditions. These tests should be geared at determining the leakage rate obtained when specific fissure widths are developed. These tests could produce valuable information with respect to the design requirements of concrete reservoirs in order to reach leakage rates of 0.1 $L \bullet m^{-2} \bullet d^{-1}$.

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