GROUNDWATER QUALITY NEAR CONCRETE MANURE TANKS AND UNDER HEAVILY-MANURED CROPLAND

N. K. Patni[1], **P. A. Phillips**[2], **F. R. Hore**[2], **and J. L. B. Culley**[3]

[1]*Animal Research Centre, Ottawa, Ontaro K1A 0C6;* [2]*Engineering and Statistical Research Institute, Ottawa, Ont. K1A 0C6; and* [3]*Land Resource Research Institute, Ottawa, Ont. K1A 0C6.*

Contribution nos. 948[1], I-223[2], and 86[3], received 16 September 1980

Patni, N. K., P. A. Phillips, F. R. Hore, and **J. L. B. Culley.** 1981. Groundwater quality near concrete manure tanks and under heavily-manured cropland. Can. Agric. Eng. 23: 37–43.

The quality of groundwater from 1.2- to 4.6-m depth was monitored between 1972 and 1979 in the vicinity of below-grade, cast-in-place reinforced concrete liquid manure storages that were built without special precautions to make the walls, floors or wall-to-floor joints watertight. Leakage of nitrate, ammonia nitrogen, orthophosphate and potassium from these storages has been small and has not led to any serious degradation of groundwater quality after 11 yr of continuous use. Results indicate that such storages have a low potential for pollution of groundwater. Groundwater from 2.4- to 6-m depth was monitored during 1973–1975 in a nearby 16-ha cropped field with deep sandy soil, on which liquid manure was applied at an average rate of 840 kg/(ha.yr) of N from 1970 to 1975. Concentrations in excess of drinking water standards for nitrate and ammonia nitrogen were observed in 1973, only 3-yr after the commencement of heavy manure applications. Results indicate that continued heavy applications of manure on well-drained soils can cause rapid impairment of groundwater quality, particularly with respect to inorganic nitrogen.

INTRODUCTION

Many liquid manure systems rely on concrete tanks for short- or long-term retention of manure. The costs of construction of such storages can be reduced if no special precautions are needed to ensure that they are watertight. However, little is known about the pollution potential of such storages due to leakage of nutrients and salts. It is generally assumed that small cracks in concrete soon become sufficiently impervious to typical liquid manures to prevent significant groundwater contamination (Turnbull et al. 1977).

Some studies have been made on groundwater around earthen storages for liquid manures. In a 3-yr study, Sewell (1978) observed that an initial rapid increase in nitrate and chloride concentrations in groundwater near an anaerobic lagoon (silt and sandy loam to 1 m and quartz sand 1–4 m) for dairy cattle manure and a holding pond for the lagoon overflow was followed by a drop in concentration close to the background levels. He attributed this to the development of effective seals in the floors of the lagoon and the holding pond. In contrast, Ciravolo et al. (1979) found increased concentrations of nitrate, ammonia nitrogen and chloride in groundwater near three anaerobic swine-waste lagoons located in soils with high water tables. Rupture of lagoon seals, leading to seepage, was attributed to drying of exposed subsoil or embankment soil during recession of lagoon liquid levels and to gas release from microbial activity in soil beneath the seal. Groundwater contamination in excess of drinking water standards for nitrate and chloride occurred around one of these three lagoons. This lagoon, in use for more than 8 yr, was located in an area with predominantly sandy surface and subsurface soil whereas the other two were located in very fine or fine sandy loam with clay subsoil.

This study is concerned with the quality of groundwater in the vicinity of non-watertight concrete storages for liquid manure and for runoff from solid manure heaps. Also of interest was groundwater quality in a 'disposal' field on which liquid manure from dairy cattle, sheep and poultry was applied at rates far in excess of crop requirements.

STUDY SITE AND PROCEDURES

The study was carried out from 1972 to 1979 at the Greenbelt Farm of the Animal Research Centre in Ottawa, Ontario, which has a large animal and poultry population. Most of the manure produced at this Farm is handled in liquid form, and is used in a land-recycling system for crop production (Turnbull et al. 1971). Banks of three to four sampling wells consisting of 18-mm diameter steel pipes terminating at depths ranging from 1.2 to 6.0 m below the ground surface were installed in 1972 and 1973 for groundwater sample collection at selected locations described below. More details on sampling wells at individual locations are included in Results and Discussion.

Liquid Manure Storages

Groundwater samples were collected in the vicinity of two types of below-grade, reinforced concrete storages, in continuous use since 1969, which were built without any special attempt to make the walls, floors, or wall-to-floor joints watertight. A site plan is shown in Fig. 1. One storage, consisting of an outdoor, covered tank of 37 × 14.4 × 3.0-m rectangular dimensions, is used for a 4- to 8-mo storage of winter-produced dairy cattle liquid manure from an adjacent 240-cow dairy barn. This tank, built with its top extending 0.3 m above the earth banks on the sides, has the adjacent land sloping downhill such that 1.8 m depth of the tank is above and 1.2 m below the surrounding ground level (Fig. 1). Filling of this tank with manure usually starts in early December and is over by mid-March, whereas emptying by tanker hauling is carried out between mid-May and August. Occasionally, during particularly wet fall periods, appearance of "liquid" to a depth 0.5 m by late November, 3 to 4 mo after the tank was emptied, seemed to indicate that this tank was not impervious to groundwater inflow. On the other hand, there was no noticeable drop in the level of manure in the tank when full, even when the water table was lower than the tank bottom. This suggested that the manure leakage out of the tank was negligible. No attempt was made to monitor or control inflow of groundwater or outflow of manure from the tank.

The second storage consisted of a 30.6 × 2.3 × 1.4-m rectangular gutter or trench below slotted floors, inside a warm, free-stall dairy barn. This trench is used for short-term, 6- to 8-wk storage of manure from about 30 to 60 cows. Manure collects in the trench till it approaches the bottom of the slats, when it is pumped to the outdoor storage described above, using minimum necessary dilution water. The top of the trench is 0.2 m lower than the

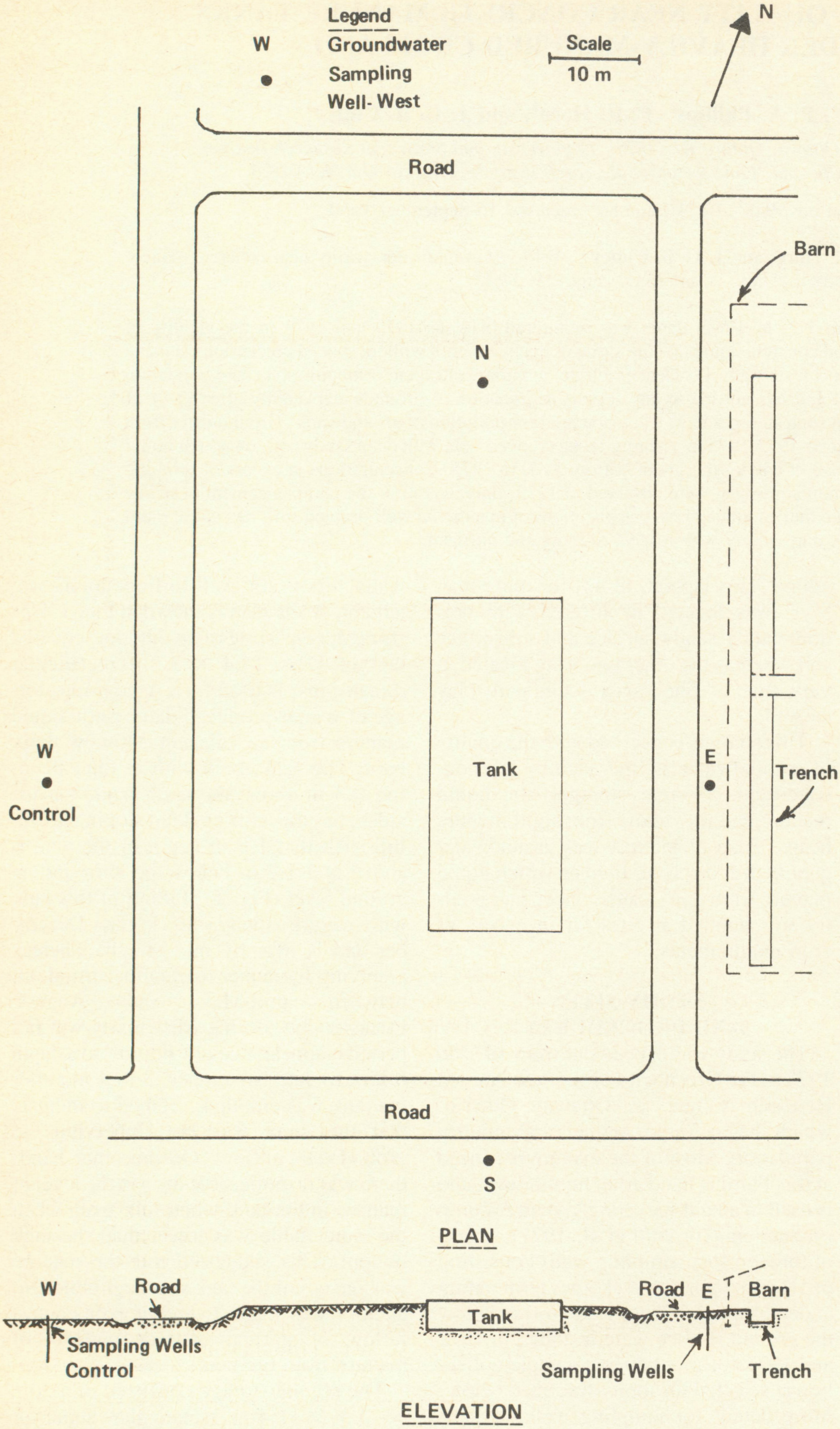

Figure. 1. Site plan for manure storages and associated sampling wells.

ground level outside the barn. For some months in 1973 and 1974, manure levels were measured daily in this and three other trenches in the same barn to determine the rate of manure accumulation. After heavy rainfall events, manure levels rose about 70% more than expected, as calculated from the manure output determined in digestibility trials with similar cows on similar rations. This suggested that the trench was not impervious to groundwater inflow. As with the manure tank, no attempt was made to monitor or control any possible inflow of groundwater or outflow of manure from this trench.

Both the tank and the trench storage for manure are located on poorly-drained, dark-gray clay loam underlain by silty clay and clay of marine origin (Dalhousie association). Some limited rearrangement of the soil profile immediately adjacent to the manure tank and the trench occurred at the time of their construction.

Runoff Storage

Runoff from a 60 × 30-m concrete pad, used to store bedded or "solid" manure from a dairy bull herd, was collected via an underground drain, in a below-grade 5.5 × 5.5 × 2.4-m concrete tank. The top of the tank extends 0.2 m above the surrounding ground level. This runoff storage tank, in continuous use since 1970, was also built without special precautions for watertightness, similar to the manure storage tank described above. The design of the manure pad and the runoff collection tank is such that when the tank is full, the overflow will be stored on the pad itself. On some occasions after heavy rainfall events and during initial snowmelt, runoff exceeded the storage capacity of the tank and backed up on the concrete pad as well as around the tank. This tank is normally emptied whenever full, usually about four to five times a year. It is located on imperfectly drained sandy loam to loamy sand of about 1-m depth, overlying fine-textured marine clay (Manotic association). Groundwater samples were obtained from two banks of sampling wells, installed in 1973, 3.3 m away, as shown in Fig. 2. These sampling wells were located between the runoff storage tank and a subsurface tile main nearby, such that groundwater movement was from the runoff tank towards the sampling wells.

Manure Disposal Field

A 16-ha rectangular field was used for land disposal of excess liquid manure from dairy cattle, sheep and occasionally poultry, by the rapid plow-cover technique (Feldman and Hore 1971). Applications depended on ground conditions and disposal requirements for excess manure, and were not controlled to meet crop requirements. The soil in this field is rapid-draining, coarse-textured loamy sand to sandy loam to a depth of 6 m (Uplands association). The well-drained soil made this field ideal for land disposal of manure because it permitted manure spreading very early in the spring and very late in the fall when other fields were too wet for heavy machinery.

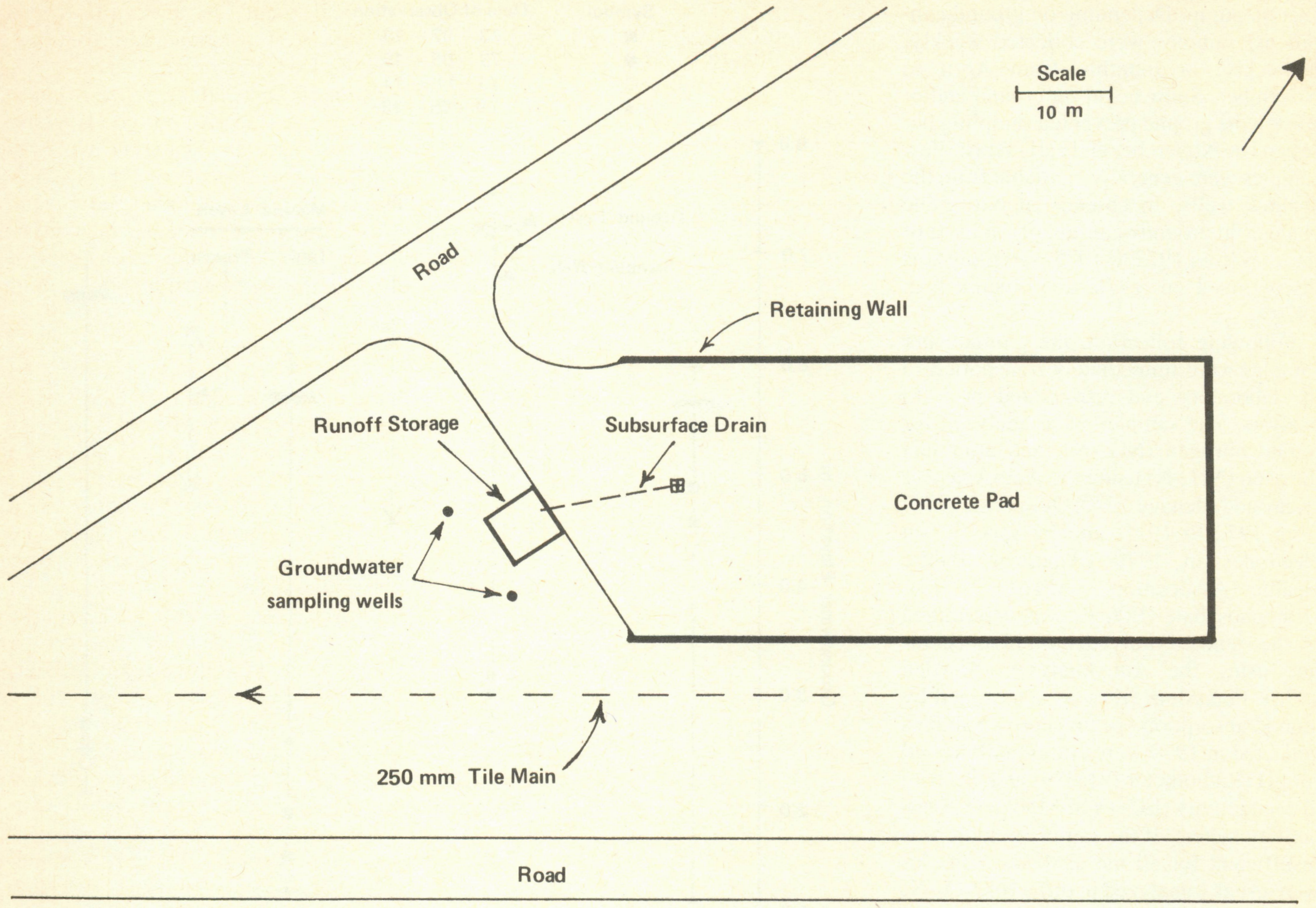

Figure. 2. Site plan for solid manure storage and runoff collection tank.

Starting in 1970, manure applications in excess of crop requirements were normally made in spring prior to planting and in fall after harvest. A record of the crops grown and manure or fertilizer nutrients applied from 1967 to 1975 is shown in Table I. From 1970 to 1975, manure nitrogen was applied at an average annual rate of 840 kg/ha, approximately half in spring and half in fall. The nitrogen requirement for corn in the area is considered to be about 110 kg/ha, and it is generally assumed that only about 50% of the spring-applied manure nitrogen is available to the crop in the year of application as compared to the nitrogen in manufactured fertilizer (Lantz and Henderson 1980). Also, no significant corn yield response was noted in a 5-yr period when dairy cattle liquid manure from the same source was applied at or above the rate of 560 kg(ha.yr) of manure N compared with 224 kg(ha.yr) (Phillips et al. 1981). Based on these considerations, nitrogen applications in excess of crop requirements are estimated to be in the neighborhood of 600 kg/ha each year, not counting the residual nitrogen of previous years that became available in the following years.

Groundwater samples from this field were obtained from four banks of sampling wells located at four corners of a central rectangular grid, 170 m × 280 m. Initially, in 1972, wells terminating at depths of 1.2 and 2.4 m only were installed, but due to the deep sand soil, no groundwater samples were available even though 1972 was a relatively wet year. Consequently, in 1973, additional wells were installed down to 6.0 m depth, when the first groundwater samples were obtained from this field. No samples were available in 1979 due to dry weather conditions.

Groundwater Sample Collection and Analyses

Groundwater samples were obtained from a total of 38 sampling wells at the different locations described above, using a portable, battery-operated peristaltic

TABLE I. NUTRIENT TYPE AND APPLICATION RATES FOR THE 16 ha EXPERIMENTAL DISPOSAL AREA FOR MANURE

		Nutrient† application rate (kg/ha)		
Year	Crop	N	P	K
1967	None	0	0	0
1968	Oats	27 F	23 F	45 F
1969	Hay	0	29 F	28 F
1970	Hay	500 M	180 M	390 M
1971	Oats	690 M	250 M	540 M
1972	Oats	1460 M	430 M	980 M
1973	Corn	1090 M	300 M	560 M
1974	Corn	730 M + 88 F	160 M + 56 F	560 M
1975	Corn	590 M + 50 F	160 M + 56 F	620 M

†F, fertilizer nutrient applied as a starter at planting time; M, manure nutrient applied in spring and/or fall.

suction pump. Depending on ground conditions, samples were collected weekly, bi-weekly, or monthly from April to November. Snow cover on ground and/or frost in the ground prevented sampling between late November and early April. Few samples were generally available from the shallow wells. In absence of noticeable changes in groundwater quality at most of the sites from 1972 to 1975, sampling was discontinued in 1976 and resumed in 1979.

Following collection, the groundwater samples were immediately transported to the laboratory and refrigerated prior to analysis. The samples were analyzed for nitrate nitrogen (NO_3-N), and ammonia nitrogen (NH_4-N) using the AutoAnalyser (Keay and Menage 1970; Quin et al. 1974) from 1972 to 1975, and by specific-ion electrodes in 1979 (American Public Health Association (APHA) 1975). Orthophosphate (PO_4-P) was determined by the standard molybdenum blue technique using the AutoAnalyser (Sowden 1972). Potassium (K) was determined by atomic absorption spectroscopy. Samples collected in 1979 were additionally tested for pH (Radiometer PHM29) and electrical conductivity (EC) (YSI Model 33 conductivity meter). If the sample volume was insufficient for all the analyses, samples were usually analyzed in order for NO_3-N, NH_4-N, PO_4-P, and K. Samples were not analyzed for PO_4-P in 1979.

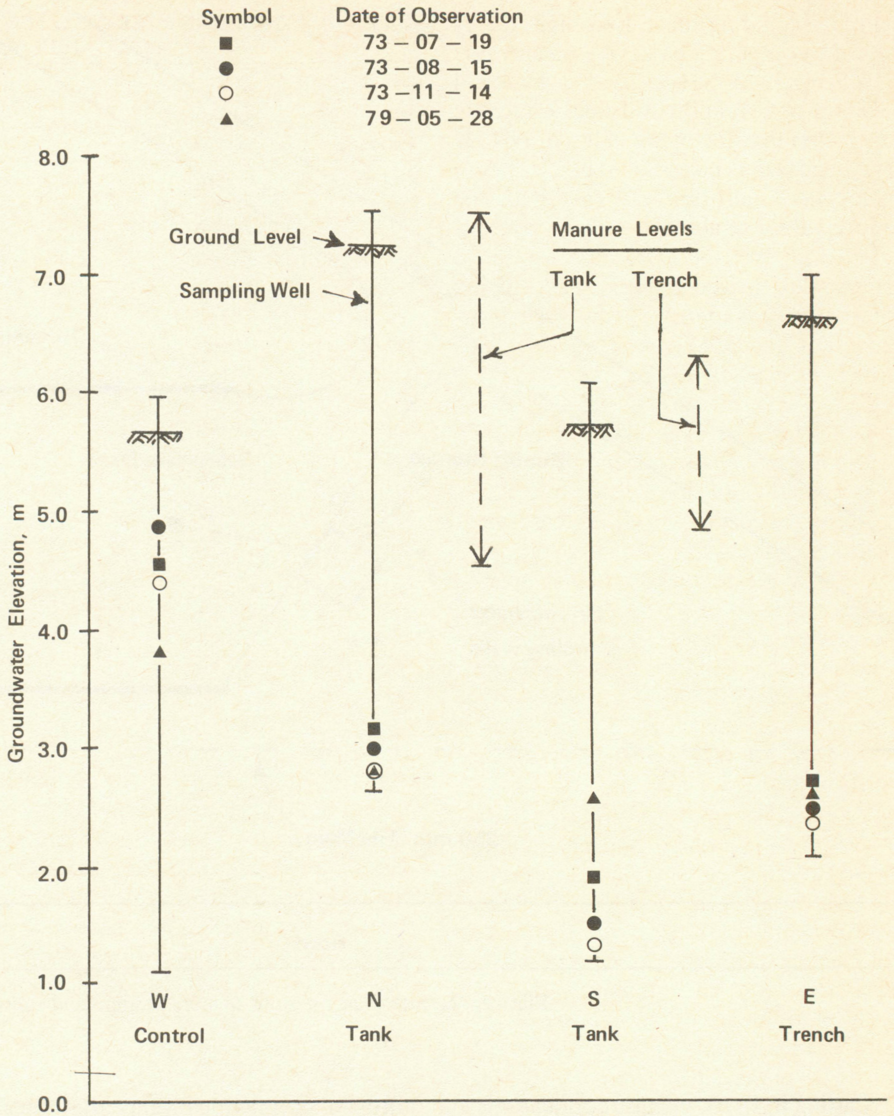

Figure. 3. Groundwater elevations in 4.6-m deep sampling wells, and manure levels in the tank and trench above an aribtrary datum.

RESULTS AND DISCUSSION

Groundwater Observations

Groundwater elevations in 1973 and 1979, in the four banks of sampling wells (Fig. 1), indicated that groundwater moved from the north-west to the south-east, that is, approximately in the longitudinal direction of the tank. Figure 3 shows a typical set of observations. Any leakage of manure and associated pollutants from the manure tank, caused by the head of manure in the tank, is expected to take place in all directions. For the purpose of discussion, the quality of groundwater represented by the two banks of sampling wells on the north and south sides (Fig. 1) was considered to be mainly affected by the manure tank, whereas that from the bank of wells on the east side was considered to be mainly affected by the manure trench because of the close proximity of the trench to the sampling wells. Groundwater samples from the sampling wells on the west side were termed 'control' samples because of the relatively remote location of this bank, 42.7 m from the tank and 74.4 m from the trench, and the south-easterly direction of groundwater movement.

Manure Storages

The dry matter content of the manure ranged from 5 to 10% in the tank and from 7 to 15% in the trench. Typical concentrations of nutrients in the manure ranged from 2200 to 3000 mg/L for total N, from 1100 to 1500 mg/L for NH_4-N, from 450 to 800 mg/L for total P, and from 1800 to 3700 mg/L for K.

Results of groundwater quality in the vicinity of storages for liquid manure are shown in Table II. Mean concentrations of NO_3-N were mostly below 1.1 mg/L in all sampling wells, at all depths throughout the study period, and the drinking water limit of 10 mg/L was not reached in any of the samples. Mean concentrations at the tank and at the trench were not significantly different from the control concentrations.

At the 2.4-m depth, the mean NH_4-N concentrations in groundwater at the tank and the trench, 0.8 and 0.7 mg/L, respectively, were not significantly different from each other ($P < 0.05$), but only the trench value of 0.7 mg/L was significantly higher than the control concentration of 0.2 mg/L. At the 3.4-m depth, neither at the tank nor at the trench, NH_4-N concentrations were significantly higher than the control concentration. In contrast, at the 4.6-m depth, both at the tank and at the trench, concentrations of NH_4-N, 0.7 and 0.3 mg/L, respectively, were significantly higher than the control concentration of 0.2 mg/L. The large standard deviation of 1.5 mg/L for NH_4-N in groundwater at the 4.6-m depth near the manure tank, compared to a mean value of 0.7 mg/L, was due to two high values in a total of 52 values. Excluding these two high values from the computations gave a mean value of 0.5 mg/L of NH_4-N with a standard deviation of 0.4 mg/L, and did not alter the conclusion that the mean value of NH_4-N in groundwater near the tank at 4.6-m depth was significantly higher than the control value. In absolute values, concentrations of NH_4-N were not excessive compared to the recommended acceptable criterion of 0.5 mg/L for raw water supplies in Canada (Working Group, Environment Canada 1972).

Mean concentrations of PO_4-P in groundwater near the tank and the trench were comparable to concentration at the control location (Table II). Mean concentrations at all depths at all of these three locations, ranging from 2 to 15 μg/L, were well below the recommended acceptable concentration of 67 μg/L for inorganic phosphates, expressed as PO_4-P, in raw water supplies (Working Group, Environment Canada 1972). Concentrations of K in samples collected at the 3.4- and 4.6-m depths near the tank and the trench were significantly higher than the control concentrations. However, the mean concentrations did not exceed 5.4 mg/L. There are no guidelines for acceptable concentration of K in raw water supplies. EC values are representative of the concentrations of dissolved ionic compounds or soluble salts. The only EC value significantly higher than the control was at the lowest depth near the tank. This value of 531 μmhos/cm at the 4.6-m depth was comparable to the mean EC value of 569 μmhos/cm observed between 1975 and 1977 in the effluent from 1.2-m deep tiles in a chemically fertilized field with the same soil type at the same Farm (Patni and Hore 1978). The pH of the groundwater at all locations and depths was near neutral in 1979.

The values of NH_4-N, K and EC at the 3.4- and 4.6-m depths near both the tank and the trench suggest a small outward movement of nutrients and dissolved ionic compounds. However, the absolute concentrations have been low, and no serious degradation of groundwater has been noted after 11 yr of continuous use. It appears that manure was adequately contained within these concrete storages built without special precautions for watertightness.

Runoff Storage

Concentrations of Kjeldahl-N, NH_4-N, total P and K in the runoff from the manure pad were typically about 110, 35, 25 and 110 mg/L, respectively. The runoff was essentially precipitation-induced and probably varied substantially in nutrient content depending on the amount of precipitation, quantity and age of the solid manure on the concrete pad, and ambient temperatures. Substantial variations probably also occurred in the runoff during storage, as has been observed elsewhere (Dickey and Vanderholm 1977; Linderman and Ellis 1978). No attempt was made to monitor or control such variations or the amount of runoff.

Table III summarizes groundwater quality observed in the vicinity of the runoff storage tank. Mean concentrations of NO_3-N at all depths ranged from 0.6 to 0.8 mg/L, well below the drinking water limit. A small increase in concentration of NO_3-N with time was noted. Mean concentrations at the 1.2, 2.4- and 4.6-m depths were, respectively, 0.3, 0.05 and 0.2 mg/L in the 1973-1975 period, and 1.4, 1.5 and 0.9 mg/L in 1979. Such an increase with time was not observed for NH_4-N, average concentrations of which had the low absolute value of 0.2 mg/L at all depths. These values are comparable to the groundwater NH_4-N concentration at the control site and slightly lower than the concentrations near the manure tank and trench, Table II. Concentrations of NO_3-N and NH_4-N in the groundwater near the manure and the runoff storages would be affected by nitrogen concentrations in the runoff and the manure itself, distance of the sampling wells from the storages, and nitrogen transformations that may be occurring in the soil.

Mean concentrations of PO_4-P in groundwater near the runoff storage were low at all depths, ranging from 4 to 6 μg/L (Table III). These values were comparable to the concentrations in groundwater near the manure tank and the trench. Similarly, mean concentrations of K in groundwater

TABLE II. GROUNDWATER QUALITY NEAR CONCRETE STORAGE TANK AND TRENCH FOR LIQUID MANURE DURING 1972-1979

Parameter	Sampling location	Means and standard deviations (in parentheses) for samples collected at depths of 1.2 m	2.4 m	3.4 m	4.6 m
NO_3-N (mg/L)	Control	0.2 (0.1)	0.3 (0.3)	0.4 (0.9)	0.3 (0.3)
	Tank	0.4 (0.4)	1.1 (2.5)	0.4 (0.7)	0.5 (0.9)
	Trench		0.1 (0.3)	0.2 (0.3)	0.2 (0.4)
NH_4-N (mg/L)	Control	1.4 (1.6)	0.2 (0.1)	0.2 (0.2)	0.2 (0.2)
	Tank	1.2 (2.3)	0.8 (1.3)	1.1 (2.0)	0.7 (1.5)
	Trench		0.7 (0.7)	0.3 (0.3)	0.3 (0.2)
PO_4-P† (μg/L)	Control		6 (6)	2 (2)	3 (3)
	Tank		6 (5)	3 (2)	4 (4)
	Trench		15 (27)	2 (1)	4 (4)
K (mg/L)	Control			1.6 (0.9)	1.9 (1.0)
	Tank		8.4 (9.2)	5.4 (2.8)	3.1 (0.4)
	Trench		1.9 (0.4)	3.7 (0.2)	4.3 (0.7)
EC‡ (μmhos/cm at 25°C)	Control		329 (188)	280 (130)	283 (49)
	Tank		208 (47)	352 (219)	531 (178)
	Trench			220 (5)	282 (99)
pH‡	Control		7.4 (0.3)	7.6 (0.3)	7.5 (0.3)
	Tank		7.5 (0.4)	7.8 (0.7)	7.6 (0.4)
	Trench			7.6 (0.1)	7.9 (0.4)

†1972-1975
‡1979

TABLE III. GROUNDWATER QUALITY NEAR A CONCRETE BARNYARD MANURE RUNOFF COLLECTION TANK DURING 1973-1979

Parameter	Mean and standard deviation (in parentheses) for samples collected at depths of 1.2 m	2.4 m	4.6 m
NO_3-N (mg/L)	0.6 (0.9)	0.8 (0.8)	0.6 (0.8)
NH_4-N (mg/L)	0.2 (0.1)	0.2 (0.2)	0.2 (0.3)
PO_4-P† (μg/L)	5 (5)	6 (4)	4 (5)
K‡ (mg/L)	3.6 (0.9)	6.0 (1.8)	4.7 (2.5)
EC§ (μmhos/cm at 25°C)	1589 (475)	1308 (193)	383 (122)
pH§	7.2 (0.3)	7.2 (0.2)	7.4 (0.2)

†1973-1975.
‡1974-1979.
§1979.

near the runoff storage were low, ranging from 3.6 to 6.0 mg/L. However, mean EC values of 1589 and 1308 μmhos/cm in groundwater at the 1.2 and 2.4 m depths, respectively, in 1979 were comparable to highly mineralized potable waters (APHA 1975). EC value at each depth was significantly different from the EC value at any other depth. Results indicated a decreasing concentration of soluble salts in groundwater with depth. Soluble salts could have reached the groundwater during occasional overflowing of the storage tank, but some leakage from the tank itself cannot be discounted. All samples of groundwater near the runoff tank had near neutral pH in 1979.

Except for a somewhat high concentration of soluble salts in shallow groundwater, no serious degradation of groundwater near this runoff storage tank was noted after 10 yr of continuous use.

Manure Disposal Field

As no samples were available from this field in 1972 and 1979, data for the 1973-1975 period only are shown in Table IV. In 1973, mean NO_3-N concentrations in groundwater at the 2.4- and 3.4-m depths were less than 15 mg/L, significantly lower than the mean concentrations of over 30 mg/L observed in 1974 and 1975. In contrast, at the 4.6-m depth, NO_3-N concentration of 48.9 mg/L in 1973 was significantly higher than the 1974-1975 value of 34.1 mg/L. At the 6.0-m depth there was no significant difference between the two time periods. Concentrations at all depths were in excess of 10 mg/L, the permissible level in drinking water. About half of the total nitrogen in the applied manure was in the ammonia form and a negligible amount or none in the nitrate form. Nitrification of at least some of the N in the plow layer and leaching of NO_3-N to lower depths of the soil is indicated by these results.

Concentrations of NH_4-N in groundwater at all depths in this heavily manured field in all years were about 1 to 2 orders of magnitude higher than concentrations in groundwater in the vicinity of manure and runoff storages (Tables II and III). This is not surprising because of the deep sandy nature of the soil which would offer a lower resistance of downward movement of groundwater and also far fewer adsorption sites for the NH_4^+ ion compared to the clay soil at the sites where the manure and runoff storages were located. Whereas in 1973 the NH_4-N concentrations were in a narrow range of 11.1-13.1 mg/L, in 1974 and 1975 this range widened from 8.9 to 29.3 mg/L. However, NH_4-N concentrations were significantly higher in 1974-1975 compared to 1973, only at the lower depths of 4.6 and 6.0 m. Ammonia-N was obviously leaching to a depth of 6 m in this field within 4 yr following yearly heavy applications of manure. The observed high concentrations of both NO_3-N and NH_4-N in the groundwater in this field can be directly attributed to the heavy applications of manure N (Table I). Mean concentrations of PO_4-P in the groundwater in this field at all depths, ranging from 2 to 14 μg/L, were not excessive. Potassium concentration approaching 20 mg/L in groundwater at 2.4-m depth dropped to less than 8 mg/L at lower depths. The values at lower depths were comparable to those in groundwater around the manure and runoff storages.

TABLE IV. GROUNDWATER QUALITY IN A SANDY, HEAVILY MANURED FIELD DURING 1973-1975

		Mean and standard deviation (in parentheses) for samples collected at depths of			
Parameter	Year(s)	2.4 m	3.4 m	4.6 m	6.0 m
NO_3-N (mg/L)	1973	15.1 (14.9)	12.4 (17.1)	48.9 (19.9)	26.9 (18.2)
	1974, 1975	36.4 (11.8)	30.4 (21.5)	34.1 (31.1)	41.5 (50.2)
NH_4-N (mg/L)	1973	12.3 (10.7)	12.0 (4.3)	11.1 (6.1)	13.1 (6.0)
	1974, 1975	8.9 (4.2)	19.0 (13.3)	21.8 (14.3)	29.3 (10.2)
PO_4-P (μg/L)	1973			7 (7)	13 (14)
	1974, 1975	2 (1)	14 (21)	9 (16)	5 (3)
K (mg/L)†	1974, 1975	19.8 (17.5)	4.4 (5.3)	7.9 (7.4)	6.4 (4.2)

†K not determined in 1973.

Repeated heavy applications of manure to deep sandy soil appeared to increase concentrations of NO_3-N and NH_4-N down to 6-m and K concentrations to 2.4-m depth in a 4-yr period. Continued repeated applications could lead to further deterioration of water quality.

CONCLUSIONS

1. On the basis of this study, potential for groundwater pollution from below-grade, concrete liquid manure storages, built without special precautions to make the walls, floors, or wall-to-floor joints watertight, appears to be low.

2. The practice of manure disposal, that is, continued heavy applications of liquid manure, on well-drained sandy soils can lead to a rapid build-up of NO_3-N and NH_4-N concentrations in groundwater well above the drinking water standards. This should be a cause for concern if domestic well water supplies are located nearby.

ACKNOWLEDGMENTS

The technical assistance of M. Leuty, C. O'Meara, J. Gall and D. Lowe is gratefully acknowledged.

REFERENCES

AMERICAN PUBLIC HEALTH ASSOCIATION. 1975. Standard methods for chemical analysis of water and wastes. 14th ed. APHA, Washington, D.C.

CIRAVOLO, T. G., D. C. MARTENS, D. L. HALLOCK, E. R. COLLINS, Jr., E. T. KORNEGAY, and H. R. THOMAS. 1979. Pollutant movement to shallow groundwater tables from anaerobic swine waste lagoons. J. Environ. Qual. 8: 126-130.

DICKEY, E. C. and D. H. VANDERHOLM. 1977. Feedlot runoff holding ponds—Nutrient levels and related management aspects. J. Environ. Qual. 6: 307-312.

FELDMAN, M. and F. R. HORE. 1971. A plow-down method for rapid cover of liquid manure. Can. Agric. Eng. 13: 65-68.

KEAY, J. and P. M. A. MENAGE. 1970. Automated determination of ammonium and nitrate in soil extracts by distillation. Analyst 95: 379-382.

LANTZ, K. and L. C. HENDERSON. 1980. Field crop recommendations. Publ. 296, Ontario Ministry of Agriculture and Food. Toronto, Ont. pp. 5, 41.

LINDERMAN, C. L. and J. R. ELLIS. 1978.Quality variation of stored feedlot runoff. Trans. ASAE (Amer. Soc. Agric. Eng.) 19: 337-341.

PATNI, N. K. and F. R. HORE. 1978. Pollutant transport to subsurface and surface waters in an integrated farm operation. PLUARG Report, International Joint Commission, Windsor, Ont. 79 pp.

PHILLIPS, P.A., J.L.B. CULLEY, F. R. HORE, and N. K. PATNI. 1981. Pollution potential and corn yields from selected rates and timing of liquid manure applications. Trans. ASAE (Amer. Soc. Agric. Eng.) 24: 139-144.

QUIN, J. R., J. G. BOISVERT, and I. WOOD. 1974. Semi-automated ninhydrin assay of Kjeldahl nitrogen. Anal. Biochem. 58: 609-614.

SEWELL, J. I. 1978. Dairy lagoon effects on groundwater quality. Trans. ASAE (Amer. Soc. Agric. Eng.) 21: 948-952.

SOWDEN, F. R. 1972. Effects of silicon on automated methods for the determination of phosphate in water. Can. J. Soil Sci. 52: 237-243.

TURNBULL, J. E., F. R. HORE, and M. FELDMAN. 1971. A land recycling liquid manure system for a large-scale confinement operation in a cold climate. *In* Livestock waste management and pollution abatement. Amer. Soc. Agric. Eng. PROC.-271. pp. 39-43.

TURNBULL, J. E., P. A. PHILLIPS, and F. R. HORE. 1977. Design concepts and construction costs of eight different manure storages. Can. Agric. Eng. 19: 65-70.

WORKING GROUP, ENVIRONMENT CANADA. 1972. Guidelines for water quality objectives and standards. Tech. Bull. 67, Inland Waters Directorate, Environment Canada, Ottawa, Ont. p. 31.