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REDUCING MANURE OUTPUT TO STREAMS FROM SUBSURFACE DRAINAGE SYSTEMS

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SUMMARY:

An experiment in controlled drainage was performed in order to assess the feasibility of using this technique to attenuate the loading of nutrients and bacteria to surface water bodies after application of liquid manure on farmland. A flat field underlain by tight clay soil was divided into two equal sections. Header drains, with lateral subsurface drains feeding into them, were fitted with observation wells for monitoring flow and water quality. Prior to the application of liquid pig manure on the land, drainage under one of the sections was blocked by a stand pipe and cap located in the observation well. After 7 days, the blocked drain was released. Comparison of the total loading of nitrate, chloride, ammonium, faecal coliform, faecal streptococci, and E. coli for the two sections indicated that blocking the flow of subsurface drainage water during manure application resulted in an appreciable reduction of ammonium and bacteria.

KEYWORDS:

pollution, slurry, water quality

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Reducing Manure Output to Streams from Subsurface Drainage Systems

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BACKGROUND

The major environmental concern with subsurface drainage systems is their potential to transport pollutants to streams, rivers and lakes. Application of liquid manure on drained land is of environmental concern due to the presence and mobility of nutrients and bacteria.

Bacterial contamination and nutrient loading of surface waters caused by land application of liquid manure may be mitigated by controlled drainage. This technique requires blocking the drainage outlets during and after spreading for a fixed period of time. This may also result in an increase in the water table surface elevation. Although the mechanisms are not fully understood, this procedure may have the capability of reducing the total loading of bacteria and nutrients that normally enter surface water courses and municipal drains via subsurface drainage systems.

During blockage, a prolonged residency of contaminants in the soil interstices may result in physical and biological attenuation. For example, the rate of denitrification may be increased by controlled drainage. Blocked drains result in increased saturation of pore spaces and reduced diffusion of oxygen. Anaerobic conditions, together with the presence of bacteria and carbon, may result in accelerated denitrification, thereby partitioning nitrogen from the aqueous phase to the atmosphere. Normally, denitrification is not encouraged as it makes nitrogen unavailable for plant use. Once manure has migrated to the depth of the drains, however, nitrogen is unavailable for uptake by plant roots.

Recent research has indicated that land application of liquid manure can contribute to bacterial contamination of surface waters. Increased bacteria levels have been found in subsurface drainage effluent following liquid manure application. Evans and Owens (1972) found that the concentration of bacteria in drainage effluent increased by 30 to 900 fold within two hours of liquid swine manure spreading. Dean and Foran (1990) found that manure can travel through the soil to the drains, and that significant concentrations of bacteria are evident to a depth of 70cm in the soil. Laboratory experiments also demonstrate bacterial movement through the soil. Smith et al. (1985) found that up to 96% of the bacteria irrigated onto a soil column 280 mm deep were recovered in the effluent.

In contrast to the reported incidence of bacterial movement through soil, several studies have indicated that the soil acts as an efficient filter for bacteria (Gerba et al., 1975; Smith et al., 1972; Patni et al., 1974). Filtration through soil can greatly reduce micro-organism and bacteria populations (Smith et al., 1972).

The nutrients contained in manure can also degrade drainage water quality. Several studies have shown that nitrogen from manure can move through the soil to reach subsurface drainage systems. Evans et al. (1984) found that application of waste containing nutrients in excess of crop needs resulted in nutrient transport to subsurface drainage systems. More recent studies have shown that manure does not have to be applied in excess of crop needs for forms of nitrogen to be detected in drainage water. Fleming and Bradshaw (1992) found that shortly following liquid manure applications, ammonium exited drains in high concentrations.

Manure parameters have been observed exiting drains shortly after field application. Evans and Owens (1972) reported that 2 hours after spraying swine waste over a pasture, bacterial populations in drain water increased. Evidence of manure contamination in drainage water was reported by Dean and Foran (1990) in as little as 20 minutes following liquid manure applications.

The transport of liquid manure parameters at elevated concentrations through the soil to drains only lasts for a relatively short period of time following application. The concentrations of faecal bacteria discharged from drains following manure application returned to background levels over a period of 2 to 3 days (Evans and Owen, 1972, Dean and Foran, 1990). Patterson et al. (1974) found that after a period of 24 hours contamination of drainage water caused from the application of swine waste to a ploughed field had disappeared. A laboratory liquid manure spreading study using soil columns conducted by Fleming and Bradshaw (1991) found that as little as 17 hours after application, manure flow through the columns was nearly terminated.

Researchers believe that soil macropores are responsible for transporting liquid manure to drains. A macropore is a large crack, channel or passageway in the soil through which water and its constituents can travel. These large pores can be formed by plant roots, soil fauna, and swelling and shrinkage of clay soils (Beven and Germann, 1982). The previous studies observe rapid and short duration flow of manure to drains as well as the soil's inability to filter the bacterial component of manure. These observations are typical of flow through soil macropores.

Macropores are responsible for the rapid transport of water and potential contaminants through the soil to groundwater. Macropore flow can greatly reduce the retention of bacteria, viruses, colloids, suspended solids, and solutes in a soil profile and greatly increase the risk of groundwater contamination (Smith et al., 1985). Because flow through macropores essentially bypasses the soil matrix, the soil's natural retention capacity is not a factor.

Methods For Reducing Macropore Flow of Manure

The quantity of manure parameters transported to drains is controlled by the properties of the soil, field practices (tillage and application techniques), antecedent soil moisture conditions, and weather. Not all of these factors can be controlled or altered to minimize the access of manure to drains. Several methods, however, have been proposed and tested for reducing the rapid macropore flow of manure. These methods are outlined below:

a.) Pre-cultivation

Recent studies have shown that tillage prior to manure application reduces the amount of manure entering drains. Dean and Foran (1992) found that tilling land prior to manure application reduced the amount of manure contamination of the drainage effluent. They theorized that tillage prior to manure spreading broke up the soil macropores at the surface. Cultivation prior to manure spreading also reduced the amount of manure entering drains in a study carried out by Fleming and Bradshaw (1992).

b.) Precipitation and Soil Moisture Content

The amount of macropore flow of manure through the soil can be related to the amount of precipitation following manure application. When rainfall occurs shortly before or after manure spreading, higher concentrations of bacteria and nutrients will be in the drainage discharge. Dean and Foran (1991) found increased concentrations of manure components in drainage effluent when rainfall had occurred following spreading.

Soil moisture content also seems to have a direct effect on drainage water contamination. When there is no flow through drains at spreading time, manure will not enter the drains until rainfall occurs.

Controlled Drainage

Controlled drainage requires outlet control to prevent discharge from drains during certain periods (Thomas et al., 1991). By the timely use of control structures nutrient losses to surface waters through the drains can be reduced (Gilliam et al., 1986). Assuming that macropore flow of liquid manure occurs during spreading, controlled drainage technology may be useful as a means of preventing contaminated water from invading and exiting the drainage system.

Controlled drainage can be beneficial to crop production by conserving water in the soil. By using controlled drainage, the amount of water discharged from the field will be managed such that water is conserved to further improve crop production. Traffic for planting, harvesting and tillage can also be permitted. Controlled drainage provides drainage during wet periods and when traffic is required, while eliminating possible over-drainage and thus crop water deficiency.

Controlled drainage can also be used to improve water quality in drains thus reducing contamination of receiving waters. Improved subsurface drainage resulted in a 10-fold increase NO_3-N loss from some soils (Gilliam et al., 1986). By using controlled drainage, however, the NO_3-N loss was reduced (Gilliam et al., 1986). The higher water table created through use of a control structure produces ideal conditions for denitrification. If nitrate-nitrogen is subject to conditions favouring denitrification, the nitrogen loading to surface waters will be reduced.

In a moderately well drained soil, Gilliam et al. (1978) found that the nitrate-nitrogen level was reduced from 25-40 kg/ha to 1-7 kg/ha in the drains through the use of controlled drainage. Similar results were reported by Gilliam et al. (1979) and Evans et al. (1987). In all studies, the reduction in NO_3-N was attributed to a reduction in effluent volume and not an increase in denitrification.

In poorly drained soils, a 50% reduction in NO_3-N movement through drains was reported by Gilliam et al. (1978) and Gilliam et al. (1979). This decrease was not a result of an increase in denitrification. The reported cause for this reduction was an increase in deep seepage. This was also found by Evans et al. (1987). This increase in deep seepage did not result in an increase in NO_3-N at lower depths in the soil. In fact, NO_3-N was never found below a depth of 1.0 m.

OBJECTIVES

The objectives of this study were:

1) to demonstrate a simple technique to block subsurface drainage flow in line and to measure the resultant increase in head;

2) to compare the difference in total loading of indicator parameters in the effluent of two header drains underneath two identical fields, treated with surface applied liquid manure, where one side was subjected to flow interruption for one week, and the other one was allowed to flow freely.

PROCEDURE

Farm Selection and Description

The selection of the study location was based on the following factors:

1) willingness and ability of the farmer to cooperate on a full scale trial;

2) ease of access to header drains and ease of locating lateral drains;

3) symmetry between fields with respect to subsurface drainage;

4) relatively tight soil conditions and absence of significant grade to avoid large build up of head in the first trial.

It proved difficult to satisfy all of the above criteria so a compromise was made on the third point. The farm of Arnold Kester, Lot 6 Conc. 16 (south of Shipka), Huron County, satisfied all of the above criteria except that the flow rates between the two fields differed by a factor of 2 or 3.

The 20 hectare farm had been planted in winter wheat and was under-seeded with red clover. A normal amount of residue was left standing and the red clover had established itself successfully between rows at the time of the experiment.

The soil was described as a heavy texture till (clayloam) of poor drainage, from the Brookston series. The topography was described as level (Anonymous, 1947). The farm was transected by a municipal drain, closed across the worked field and open along the north lot line.

Installation of Equipment

This experiment was timed to follow a planned upgrade of the subsurface drains (to decrease the lateral drain spacing by 1/2 of the existing spacing). The installation of new drains allowed location of the existing lateral drains as well as the header drains. Once the headers were located by trenching, a suitable section was exposed, a two foot section was cut out and removed, and an observation well for sampling was installed.

The observation wells were constructed from 2 m lengths of 1 m diameter corrugated plastic pipe. Two 15 cm holes were cut opposite each other into the wall of the observation well, through which the header drains were inserted. A geotextile fabric was installed on the bottom of the basin. The entire work area was dewatered with a sump pump during the installation. The east observation well differed from the west observation well in that the first 3 meters of the influent perforated drain tubing was replaced by smooth PVC tubing. This was required to create a leak-proof joint so the east observation well could be effectively blocked. A PVC tee was glued to the tube and a vertical standpipe installed on one side, and a threaded cap on the other. This provided a mechanism by which the water flow could be interrupted just prior to manure spreading, while allowing for removal of samples with a pump, and measurement of the head throughout the experiment.

These simple observation wells afforded access by one person, rapid pumping of the water in storage to below the inlet level, accurate measurement of the flow rate, and easy withdrawal of samples.

Layout of Subsurface Drains

The layout of subsurface lateral drains underneath the two fields was fairly systematic. Figure 1 is a schematic of the layout, showing the location of the lateral and header drains, the observation wells, and the municipal drain that transects the property.

Manure Application Protocol

Pig manure was obtained from a nearby farmer and pumped into a tank. Figure 1 shows the manure application pattern. A total of 6 passes were made; the spreader drove to the north limit of the spread pattern and sprayed manure in 9 m bands on the return. In this fashion 6 individual passes were made over 6 lateral drains (three feeding each header). No manure was spread over the recently installed drains or areas with disturbed soil.

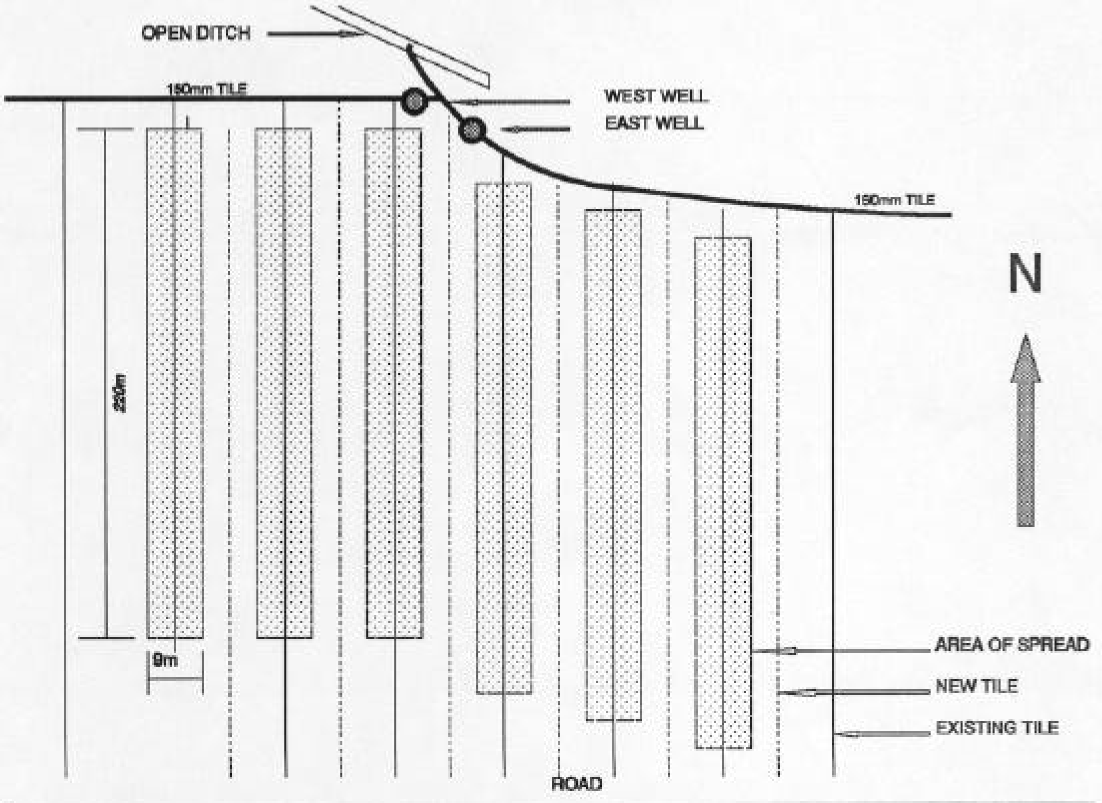

Figure 1 Schematic of Experimental Set-up

Manure was applied over 6 plots with the dimensions of 9 m wide by 220 m long at the approximate rate of 56,250 litres per hectare. One sample of manure was obtained from each of the 6 loads and they were analyzed for nitrogen, phosphorous, potassium, nitrate, ammonium, chloride, dry matter, faecal coliform, faecal streptococci, and E. coli. The first 7 parameters were analyzed at the Department of Land Resource Science at the University of Guelph, Ontario, and the latter three parameters were analyzed at the MOEE Laboratory, London, Ontario.

Sampling Protocol

The flow rate of the header tubes was measured by collecting exactly two litres of water in a graduated container from underneath the lip of the inlet tube, and timing the collection with a stop watch. The temperature was measured by a hand held probe inserted into the flowing water.

Precleaned, new sample bottles were held under the flowing water and filled in order to obtain samples for analysis. Sample bottles used to collect water for aqueous chemistry analysis were rinsed several times in the influent water and then filled to overflowing before sealing with a lid. This eliminated the presence of a head space in the sample container. Sample bottles used to collect water for bacteriological analysis were pre-preserved; no rinsing was performed and the sample bottles were filled to below the top of the neck.

A separate sample was obtained for measurement of pH and electrical conductivity in the field. Conductivity was measured in the field because it provided a useful indicator of the presence of ionic manure parameters, serving as a screening tool to assess the need for intensive sampling. There was no opportunity for cross contamination of samples sent for lab analysis.

Water samples were analyzed for faecal coliform, faecal streptococci, E. coli, nitrate, ammonium, and chloride at the MOEE Soutwestern Region Laboratory Section, London, Ontario.

Sampling Frequency and Drain Blocking

Sampling of background conditions began on November 19, 1992. Six samples were obtained over a 12 day period from each observation well. Manure was applied on the morning of December 1, 1992. The first load was applied at 10:00 am, and the sixth load was completed at 11:30 am. The west observation well was sampled 12 times on the day of the spread, approximately on the hour.

Just prior to the spread the east observation well was sampled and subsequently blocked. It remained blocked for 7 days and 2 samples were removed during this time. The water level in the stand pipe rose almost immediately to 25 cm above the invert and remained at that level for the remainder of the blockage. On December

8, 1992, the cap was removed and the water in storage, approximately 1700 L, was eliminated completely within 5 minutes. Two samples were taken during this period. Routine sampling of the flow rate and the water was recommenced almost immediately since the flow rate returned to its background level. Both observation wells were sampled several times per week until December 29, 1992.

RESULTS AND DISCUSSION

Manure Application

Table 1 below shows the results of the physical, chemical and biological analysis of each of the 6 batches of manure that were spread during this experiment.

Table 1: Summary of Manure Analysis

Parameter	**Batch**					
	M1	**M2**	**M3**	**M4**	**M5**	**M6**
% N	0.35	0.29	0.30	0.30	0.29	0.29
% P	0.12	0.06	0.06	0.06	0.05	0.05
% K	0.14	0.14	0.14	0.15	0.14	0.14
$N0_3$-N mg/kg	2.77	6.69	1.27	0.76	0.43	0.76
NH_4-N mg/kg	149	150	149	148	148	150
C1 mg/kg	495	431	540	553	521	598
% Dry Matter	1.98	1.82	1.74	1.85	1.77	1.84
Faecal Coliform /100 ml	NA	$6.9(10)^6$	$7.9(10)^6$	$1.5(10)^7$	$8.1(10)^6$	$8.1(10)^6$
Faecal Strep. /100 ml	NA	$5.1(10)^6$	$4.3(10)^6$	$5.4(10)^6$	$4.7(10)^6$	$5.4(10)^6$
E. Coli /100 ml	NA	$6.8(10)^6$	$7.9(10)^6$	$5.9(10)^6$	$8.1(10)^6$	$6.1(10)^6$

Flow Rates

The flow rates differed by a factor of 2 or 3 between the two observation wells. After 12 days of background sampling, the cumulative volumetric flow for the east observation well ($5(10)^5$ L) was 2.8 times greater than the west observation well ($1.8(10)^5$ L).

Water Quality Results

Ammonium-N

Nitrogen in manure is largely in the form of ammonium. Ammonium in the soil can also come from the initial decomposition of nitrogen fixing organic matter. Before and after the manure spread, ammonium concentrations ranged from 0.1 to 0.3 mg/L. During the spread, a marked peak in ammonium concentration was observed in the west observation well. The maximum value observed was 53 mg/L. In the east observation well, the maximum value was 2.7 mg/L, observed just following the removal of the flow blockage.

The peak in concentration is demonstrated in Figures 2 and 3, where cumulative mass loading is plotted against time for the west and east observation wells, respectively. These graphs also show that flow interruption resulted in a 0.41 reduction in total mass eluted; the west well produced 181 g of ammonium, whereas the east well produced 74 g (see Table 2).

Eliminating the difference in flow rate between the two wells would produce a measurable reduction in the total mass of ammonium produced from the east well, and thereby increase the effectiveness of the drain blocking technique. This is because larger quantities of ammonium were being contributed to the east well from the natural background conditions, due to the larger catchment area that it drained.

Nitrate-N

Most nitrogen resident in agricultural soils is in the form of nitrate, derived from either chemical fertilizers, animal wastes, or the ultimate breakdown of nitrogen fixing legumes. Land application of liquid manure did not produce a peak in nitrogen-N concentration in this study. The highest concentrations observed in the east and the west wells were 2.2 and 2.3 mg/L respectively, independent of the manure application.

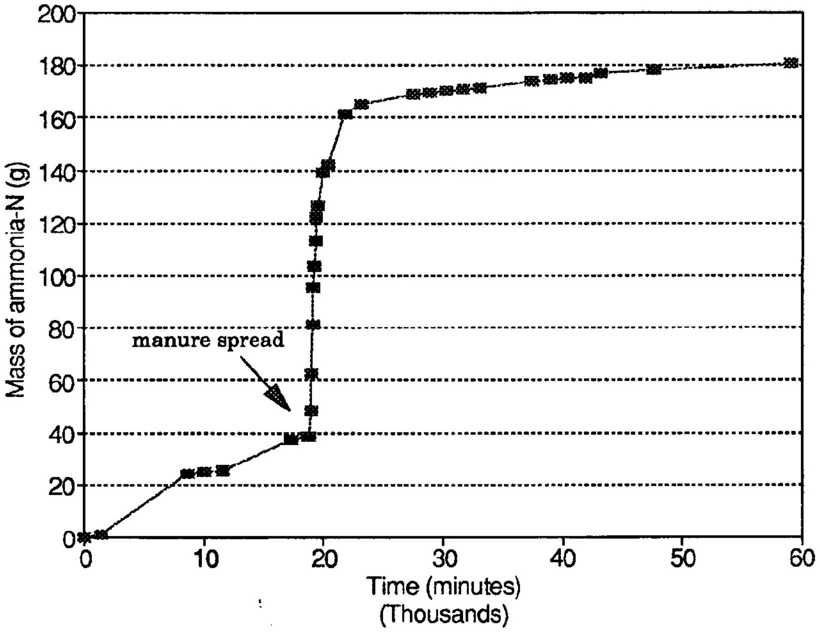

Figure 2 Cumulative Ammonium-N Loading: West Well

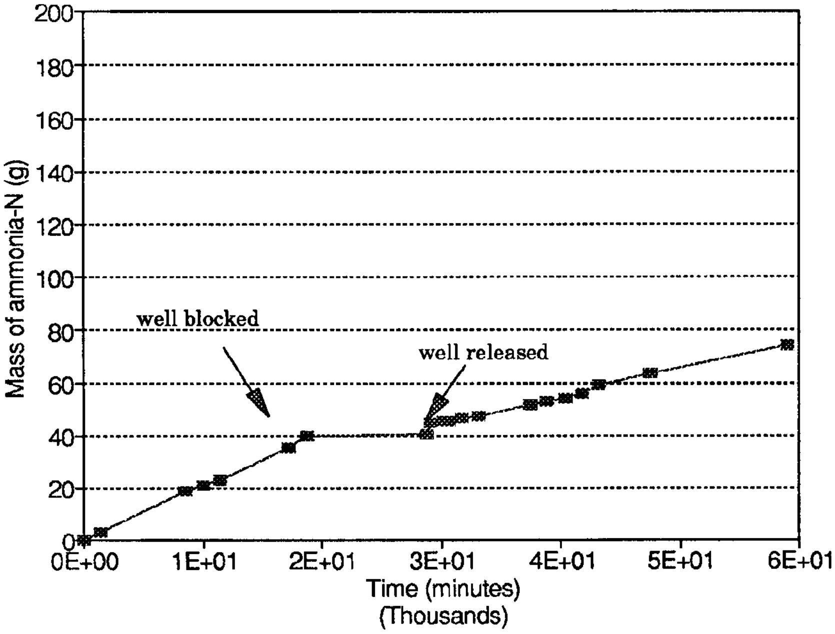

Figure 3 Cumulative Ammonium-N Loading: East Well

The total mass eluted from the east field was 1084 g, and 566 g from the west field (see Table 2). This is consistent with the larger flow rate for the east well, and the lack of impact on nitrate from the manure application. Figures 4 and 5 illustrate the cumulative mass loading versus time for each well. It was expected that the slope of the line intersecting the observation points would be constant. This was generally true except in the case of the blocked flow condition, where the interruption is illustrated by a flat portion in the line.

Table 2: Summary of Cumulative Loadings

Water Quality Parameter	East Well	West Well	Ratio E:W
Ammonium-N (g)	74	181	0.41
Nitrate-N (g)	1084	566	1.92
Chloride (g)	17092	7620	2.24
Faecal Coliform *	$4.09(10)^8$	$2.00(10)^{10}$	0.02
Faecal Strep. *	$6.95(10)^8$	$8.63(10)^9$	0.08
E. Coli *	$3.76(10)^8$	$1.65(10)^{10}$	0.02
Cumulative Flow (L) (Nov. 19 to Dec. 1)	$5.0(10)^5$	$1.8(10)^5$	2.8

* Number of organisms

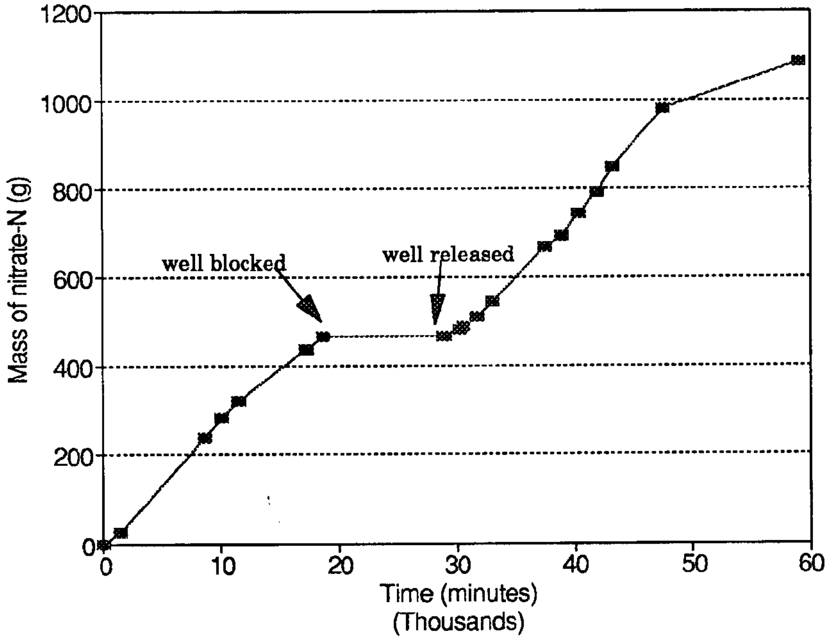

Figure 4 Cumulative Nitrate-N Loading: East Well

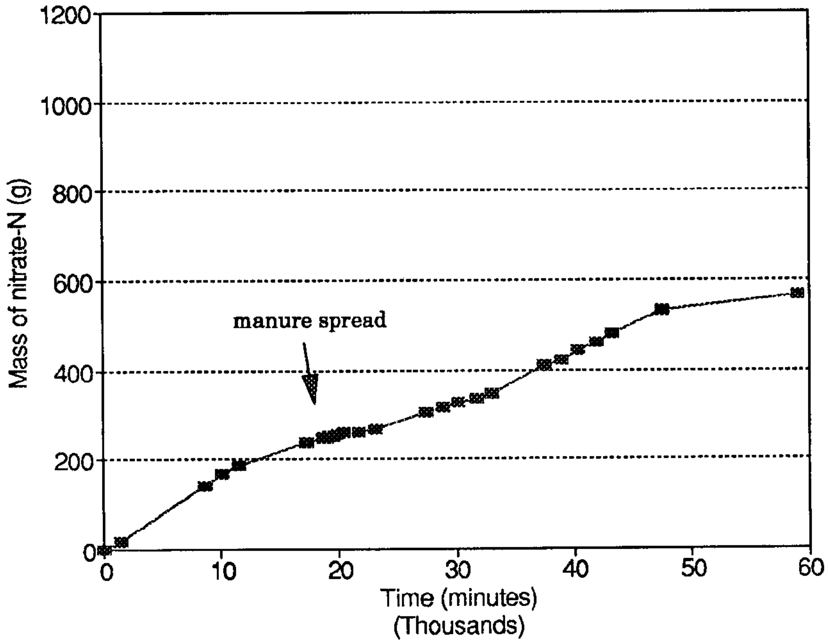

Figure 5 Cumulative Nitrate-N Loading: West Well

Chloride

Chloride resides in the soil matter as a result of the application of chemical fertilizers or animal waste products. The highest concentrations observed in the east and west well were 23 and 106 mg/L, respectively, which occured shortly after manure spreading in the west well. This marks a significant reduction in the peak concentration as a result of flow interruption.

Notwithstanding, the difference in flow rate explains more than a 2-fold increase in mass eluted from the blocked drains (east well: 17092 g) over the unblocked drains (west well: 7620 g). The chloride and nitrate results are analogous (see Table 2). Chloride was present in high enough background concentrations to dampen out the effect of manure spreading, even though it did result in a shock load to the west well, and produced mass loadings consistent with the larger catchment area on the east side.

Bacteria

Water samples were analyzed for the following bacteria: faecal coliform, faecal streptococci, and E. coli. From Table 2 it is evident that the results of cumulative mass loading were very similar for all three; blocking drainage flow resulted in a reduction by a factor of 0.02, 0.08, and 0.02, respectively. The following discussion will therefore centre on E. coli as a representative indicator bacteria.

The peak concentration of E. coli was observed to be 53,000 organisms per 100 mL in the west well, and 14,000 organisms per 100 mL in the east well. This represents a significant reduction in the peak concentration. On the basis of mass eluted, the total was reduced from 1.65 $(10)^{10}$ organisms (west well - figure 6) to 3.76 $(10)^{8}$ organisms (east well - figure 7). Before commencing manure application the total number of organisms eluted were actually greater for the east catch basin by one order of magnitude: 1.14 $(10)^{7}$ (east) vs. 4.10 $(10)^{6}$ (west). In the case of faecal coliform the pre-spreading difference was about 2 orders of magnitudes. This means that manure application contributes significantly to the loading of bacteria to subsurface drainage water. In this study, if the cumulative mass loadings were normalized for surface area drained, the reduction in mass transport of bacteria via interim blocked flow would be even greater than the 50-fold reduction that was observed.

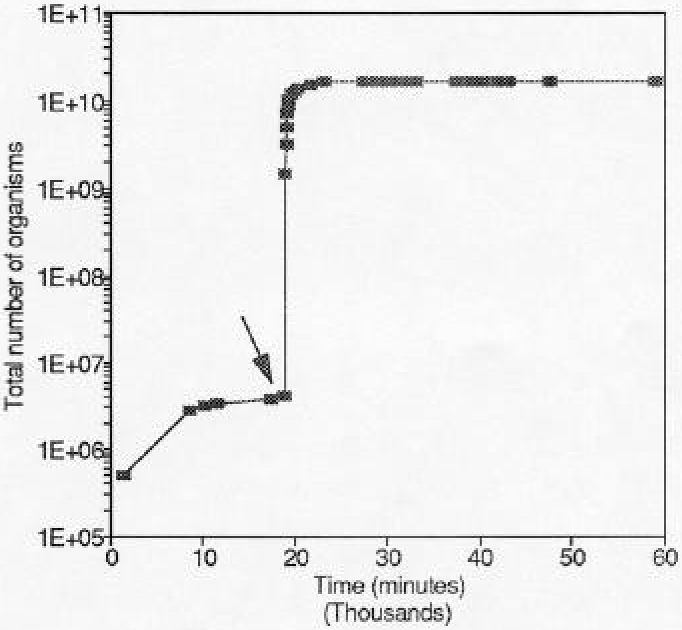

Figure 6 Cumulative E. Coli Loading: West Well

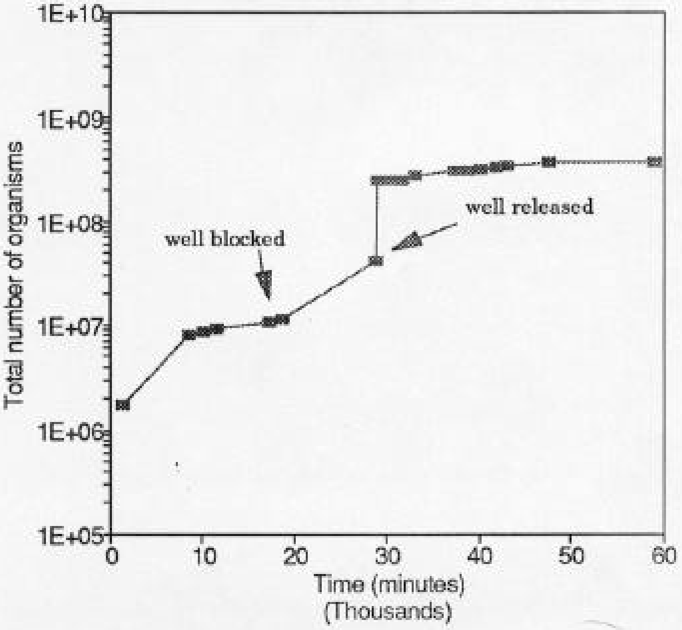

Figure 7 Cumulative E. Coli Loading: East Well

SUMMARY

Blocking subsurface drainage flow produced marked effects on both the peak concentration and total mass eluted of measured parameters. The peak concentration of ammonium, chloride, and all three species of bacteria (faecal coliform, faecal strep., and E. coli) were significantly reduced. Spreading manure did not have an effect on nitrate concentration.

The total loadings of ammonium and bacteria were reduced by factors ranging from 1/2 to 1/500. These factors would be even smaller if data were normalized according to the catchment area.

Total mass loading of chloride and nitrate was not reduced by flow interruption. This was attributed to the larger catchment area that was drained by the (blocked) observation well and the mass balance of these parameters present in the soil prior to spreading.

The reduction in leaching of ammonium and bacteria observed in this study suggests that for specific field conditions, subsurface flow interruption is a viable means of attenuating several of the deleterious components of liquid manure, and ultimately, improving the quality of receiving surface water bodies.

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