# WATER QUALITY IMPACTS OF TILE DRAINS IN SHALLOW, SLOPING, STRUCTURED SOILS AS AFFECTED BY MANURE APPLICATION

C. A. Scott, L. D. Geohring, M. F. Walter

**ABSTRACT.** *Tile drains are one of several best management practices whose purpose is to reduce the export of contaminants to receiving waters. It is conventionally assumed that contaminants are effectively retained in the soil prior to subsurface water entering the drain. Two conditions may result in significantly elevated contaminant loading in tile effluent: preferential flow through macropores, and steep slopes which increase drainage in shallow, permeable soils on a hardpan. This article presents field monitoring data on phosphorus and fecal coliforms measured in New York State watersheds under both conditions described, and examines the mechanisms for increased tile drain contaminant delivery from manure-applied fields to streams. Soluble phosphorus concentrations peaked at 1.17 mg/L, and as much as 37% of soluble phosphorus was exported from the field site via subsurface drains. Fecal coliform concentrations peaked at 71,000 organisms/100 mL. The total number of fecal coliforms discharged from the drain during the flow event would have required about 75 fold dilution to bring the fecal coliform concentration to a municipal wastewater treatment plant discharge effluent standard of 400 organisms/100 mL. Under some conditions, the contaminant discharge from subsurface drains may also have significant water quality impacts to receiving waters.*

***Keywords.*** *Hydrology, Drainage, Manure, Phosphorus, Fecal coliform.*

Watershed water quality concerns in the Northeast have focused on surface water, particularly the transport of contaminants in surface runoff. In watersheds with significant agricultural production, particularly dairy farms, nutrient and pathogen transport in runoff has been highlighted (Sharpley et al., 1994; EPA, 1990; Porter, 1975). For example, in the Catskills region which is the principal watershed supplying drinking water in reservoirs for New York City, the primary pollutants of concern are phosphorus and pathogens (particularly *Cryptosporidium*) in surface water. Given the strong adsorption characteristics of phosphorus in soils with high clay content, and aluminum and iron oxides, it is assumed that the vertical drainage of phosphorus is insignificant compared to its transport in surface runoff. Further, although the hydrologic transport characteristics of *Cryptosporidium* are not well understood, there is limited evidence to suggest that *Cryptosporidium* behaves like a colloidal substance (Brush, 1997); as a result, it is assumed that this too represents primarily a surface water contamination problem. The objectives of this research were to determine whether these contaminants can also be transported via subsurface tile drains.

## WATER QUALITY AND BEST MANAGEMENT PRACTICES

The identification of surface water as the primary contaminant transport delivery mechanism has provoked a set of management responses aimed at decreasing both the volume of surface runoff generated in contaminant loading areas and the concentration of contaminant in runoff. Since the passage of the Clean Water Act, the favored practices have been called best management practices (BMPs) which are implemented specifically to mitigate non-point source pollution (Loehr et al., 1979). One set of BMPs, which are essentially hydrologic control practices, attempt to improve water quality by altering farm hydrology so as to reduce surface runoff through contaminant loading areas. Such BMPs are distinct from pollutant source control practices which seek to manage the handling and disposal of the pollutant in the course of routine farm operations. Hydrologic control BMPs are designed to be installed in or adjacent to the manure-applied field to reduce surface runoff and off-field contaminant transport. Among the hydrologic control BMPs are subsurface 'tile' drains, which form the focus of this article.

## BMP DESIGN

The design and implementation specifications for water quality BMPs are contained in the *National Handbook of Conservation Practices* (NRCS, 1996) and various state publications (e.g., NYSDEC, 1992). It is relevant to note the particular conditions and specifications which apply to individual BMPs, in this case tiles or "subsurface drains". For example, the NRCS specifications state that subsurface drains are installed to "regulate the water table" or to "intercept . . . water movement into a wet area" (NRCS, 1996). While their effect on surface runoff is noted, water

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The authors are **Christopher A. Scott, *ASAE Student Member*, Larry D. Geohring, *ASAE Member Engineer*,** Senior Extension Associate, and **Michael F. Walter, *ASAE Member Engineer*,** Professor and Chair, Cornell University, Department of Agricultural & Biological Engineering, Ithaca N.Y. **Corresponding author:** Michael F. Walter, Cornell University, Dept. of Agricultural & Biological Engineering, Riley-Robb Hall, Ithaca NY 14853-5701; voice: (607) 255-2270; fax: (607) 255-4080; e-mail: mfw2@cornell.edu.

table regulation is the primary objective. The NRCS design criteria deal extensively with capacity, velocity and installation considerations, treating water quality essentially as a sediment control problem in the drain conduit itself (by specifying filter material, etc.). Nevertheless, the water quality considerations explicitly make reference to the "effect of changes in the delivery of dissolved salts . . . on downstream water uses and users" (*ibid*), a particular concern for shallow, sloping soils and fields installed with random drains, which may require a riser that directly admits surface water in order to dry out wet spots. The New York State specifications for subsurface drains appear to acknowledge some of the water quality processes associated with tile drains, stating that "the effectiveness of sub-surface drainage as a water quality management practice is difficult to quantify" and that subsurface drains are "not well suited to shallow soils . . ." (NYSDEC, 1992). These caveats about the water quality impacts of tile drains (further emphasized by their inclusion as construction BMPs and not agricultural BMPs; NYSDEC, 1992) suggest that field conditions determine how effective they actually are in improving water quality.

## RAPID CONTAMINANT DELIVERY

Before presenting original data on phosphorus and fecal coliforms, we will briefly outline the two conditions under which tile drains may produce significant contaminant loading to receiving waters. Under most typical, ideal conditions with deep, uniform soils on flat or very low slopes, subsurface drainage to the tile line occurs primarily as matrix flow and it is reasonable to assume that sorbed contaminants are effectively retained in the soil. However, where macropores are prevalent on shallow soils, subsurface flow can bypass the soil matrix and preferentially reach the tile line with reduced contaminant attenuation (Steenhuis et al., 1994; Kladivko et al., 1991). Macropores result from soil cracking, root penetration, animal holes, and voids in stony soil. As a result, the tile line can act as a "short circuit", routing directly to the stream contaminants that would otherwise have had increased soil contact time in shallow lateral flow. The effect of rapid contaminant delivery to a tile drain is clearly apparent in figure 1 which shows water samples collected from the tile during an irrigation event (the first clear sample on the left was taken pre-irrigation, followed by contaminated samples from left to right representing time from 35 min through 330 min after the start of irrigation).

Figure 1–A time sequenced display of tile drain samples showing rapid contaminant delivery (first on left = pre-irrigation, followed by left to right = 35 min through 330 min samples after the start of irrigation.

The second conditions occur where slopes are steep, and hence, high piezometric gradients drive tile flow. In shallow, permeable soils on a hardpan, soil contact times are decreased and drainage rates increased. In this case, the long-term volumes of tile flow may equal or exceed runoff volumes by sufficient a margin to produce comparable total contaminant loading from the tile, even though runoff concentrations during sporadic rainfall events may exceed those in tile flow. For example, GIS analysis of one sub-watershed in the New York City system showed that the mean soil depth is 52 cm and the mean slope is 20%. Soil depth here refers to depth to an impeding fragipan formed of dense glacial till less permeable than fractured bedrock. Under these conditions, shallow lateral flow behaves more like runoff than it does like groundwater in terms of velocity, soil contact time, and the pronounced pollutant concentration peaks characteristic of runoff. The steep gradients and long, wet spring and fall seasons produce lateral flow volumes that may exceed runoff volumes. As a result of raised concentrations and greater flow volumes of subsurface flow, the differences between the long-term mass loadings from runoff and from lateral flow may not be as significant as conventionally assumed.

## AGRICULTURAL NON-POINT SOURCE CONTAMINANTS

As has been mentioned, nutrients and pathogens are two critical contaminants in agricultural watersheds. Where surface water eutrophication is a problem, phosphorus is often the limiting nutrient for algae growth (Tiessen, 1995). While secondary data on phosphorus transport in runoff are common in the literature, less attention has been paid to its transport in tile drains. Data presented in Sharpley et al. (1995) indicate that average soluble and particulate phosphorus concentrations in natural subsurface flow are typically an order of magnitude lower than flow-weighted mean concentrations in runoff, with concentrations collected in subsurface drainage in between those in natural subsurface flow and runoff. As a result, the effect of the tile drain is to increase the concentration of flow which would otherwise occur as natural subsurface flow. Data indicating the processes which account for the increased tile phosphorus concentrations are presented in the Results and Discussion section.

The pathogen of primary concern for surface water treatment has been identified as *Cryptosporidium parvum*, particularly after a major Cryptosporidiosis outbreak in Milwaukee in 1993 resulted in over 90 deaths. While secondary data on pathogen transport in runoff are frequent in the literature, less attention has been paid to their transport in tile drains. For the lack of secondary data, this article presents data on fecal coliforms, which may be considered a surrogate for *Cryptosporidium*. Coliforms have a cell diameter of 3 to 10 μm which includes the 4 to 6 μm reported for *Cryptosporidium* (Brush, 1997).

## MATERIALS AND METHODS

Water samples were collected from tile drains at two field sites in New York State. The first is located on an operational dairy farm in the Catskills region. The drained field is a 2.24-ha pasture with average 10.8% ground slope where a randomly branched lateral-main tile line is installed at 90 cm belowground, into the underlying fragipan approximately 60 cm below the ground surface. The soil is a moderately well drained Willowemoc channery silt loam (coarse, loamy, mixed, frigid, *Typic Fragiochrept*) and typical of those used for agriculture in the Catskills region. Upslope water from an adjoining 6-ha contributing area is intercepted in a farm road surface ditch. The tile line outflow is instrumented with a 15-cm, 90° V-notch weir and an automated water sampler. Surface runoff from the same field is measured using a 20-cm modified Parshall flume and an automated sampler. Tile flow, surface runoff, and precipitation are recorded automatically using a datalogger. Tile flow was collected on variable intervals during storm events and over low flow periods. The data reported are for a storm event immediately following the surface broadcast application of 20 T/ha (2000 gal/ac) of liquid dairy manure as shown in figure 2.

The second site is a Cornell University experimental farm located in the Lake Champlain region where eight individual drain lines discharge into separate manholes. These drains are approximately 1 m deep and are spaced 20 m apart. Tile discharge is measured in each manhole with a 22.5° V-notch weir and a recording water level depth transducer. Water samples from this study site are grab samples collected manually at variable times and on 15- to 30-min intervals during the irrigation event. The entire plot area is surrounded with a perimeter (cutoff) drain on all sides, and has an average surface slope of 2.5%. An automated weather station is located within 250 m of the plot site. The soil is a somewhat poorly drained Rhinebeck variant fine sandy loam (mixed mesic *Aeric Ochraqualf*) which is representative of approximately 60 700 ha in New York which are primarily used for agriculture. The drainage characteristics of the Rhinebeck soil are also similar to 23 other soil series in New York which are representative of more than 400 000 ha of somewhat poorly drained soils commonly used for animal based agriculture. Liquid dairy manure was broadcast on the surface with a bulk tank spreader, similar to that shown in figure 2, at a rate of 47 T/ha (5000 gal/ac) following the removal of corn silage. The liquid manure used at this site contained 6.7% solids and had a density of 1.028 g/cm$^3$. The nutrient content of this manure was 0.22% nitrogen of which 0.09% was ammonia-N, 0.07% phosphorus, and 0.23% potassium. The fecal coliform concentration in this liquid manure was on the order of 7 × 10$^6$ organisms/100 mL. No manure had previously been applied to this site in at least 15 years.

## RESULTS AND DISCUSSION

At the Catskills site, an early summer rainstorm was monitored just after liquid dairy cow manure had been applied (fig. 2). The data presented in figure 3 are from samples collected on a 60 min interval for a total of 24 h beginning at the time of manure application. Samples were analyzed for total phosphorus (TP) using an ammonium persulfate extraction, and for soluble reactive phosphorus (SP) using the ascorbic acid colorimetric method.

At the Lake Champlain site, manure was applied to corn land after silage harvest, then sprinkler-irrigated at an average application rate of 11.5 mm/h. Tile outflow samples were collected on a variable interval ranging from 15 to 30 min; irrigation was stopped after 180 min, and a

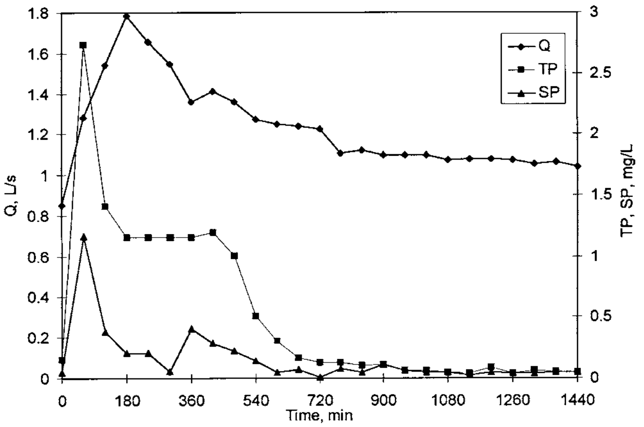

**Figure 3–Phosphorus delivery in the tile drain during a June 1996 rainstorm event at the Catskills site.**

**Figure 2–Liquid manure application on a sloping field during a rainstorm at the Catskills site.**

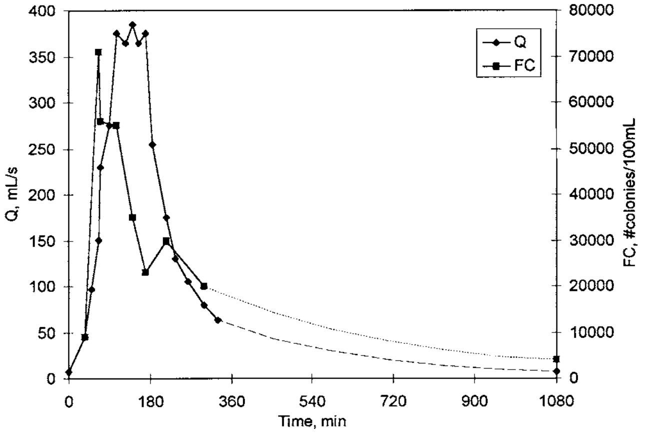

**Figure 4–Fecal Coliform (FC) delivery in the tile drain during a September 1996 irrigation event at the Lake Champlain site.**

final sample was collected 18 h after irrigation started. Samples were immediately refrigerated and analyzed within 24 h for fecal coliforms using standard water/wastewater analysis procedures. The rapid delivery of manure based contaminants to the tile line was strikingly apparent in the dark color (and odor) of the water samples as shown in figure 1. Figure 4 shows the data on tile discharge and fecal coliform delivery with time after the start of irrigation.

In both cases, contaminant concentration peaks occurred before the tile outflow peaks, indicating that contaminants were delivered to the tile drains on the order of 60 min after application/irrigation. Assuming a value of saturated conductivity within the representative range of 5 to 15 cm/h for these soils (50 to 100 cm deep), the rates of contaminant delivery to the tile cannot be explained assuming uniform matrix flow. This indicates that preferential flow to the tile lines is capable of delivering contaminants significantly more rapidly. Although the peak concentration of fecal coliforms in the tile discharge was reduced two orders of magnitude from the liquid manure slurry, the concentration was still high enough throughout the irrigation event to deliver a 0.34% recovery of fecal coliforms within 18 h. This rapid and high degree of contamination requires substantial amounts of ‘clean’ water to bring this effluent to more acceptable levels.

In the first case where phosphorus was measured, uniform flow assumptions would suggest that phosphorus would adsorb to the soil and therefore that SP concentrations would reflect biogeochemical concentrations (on the order of 0.01 to 0.04 mg/L), yet the data show that SP peaked at 1.17 mg/L, or two orders of magnitude greater. This peak occurred prior to the peak in the tile discharge indicating the flushing or bypass of phosphorus through macropores before it had adequate time to fully adsorb to the soil and prior to all of the pore matrix contributing to the tile discharge. Further, the observed differences between TP and SP of up to 1.81 mg/L must be attributable to organic and sediment-bound particulate P which is not conventionally thought to be transported in tile flow. At the end of the monitoring period this difference approached zero along with the absolute values of TP and SP concentrations, suggesting that macropore drainage had been surpassed by matrix drainage.

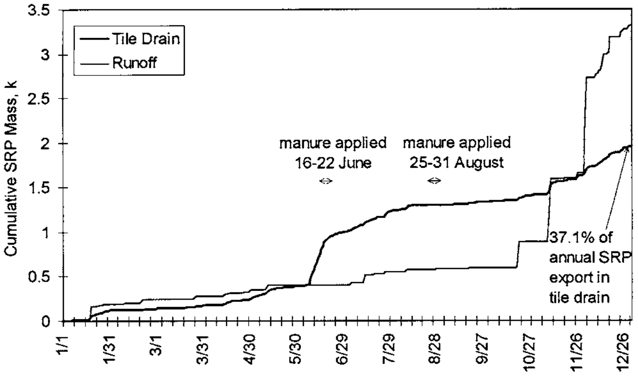

**Figure 5–Cumulative annual soluble reactive phosphorus delivery from the tile drain and surface runoff during 1996 at the Catskills site.**

In the case of fecal coliforms, a similar trend was observed, i.e., that fecal coliform concentration peaked on the rising limb of the outflow hydrograph in figure 4. Some attenuation of fecal coliform occurred initially in the macropores. By the time of the outflow peak, dilution had taken place and fecal coliform concentrations began to decline further. The dashed lines show the interpolated exponential decay of both outflow and coliform concentrations between the final sample at 330 min and the post-event sample at 18 h.

As a result of increased contaminant concentrations during and after rainfall events, long-term tile line contaminant loading to receiving waters may be of similar magnitude to runoff loading, if tile outflow volumes exceed runoff volumes by a ratio greater than the inverse of their concentrations. This is illustrated in figure 5 which shows the 1996 annual mass export of soluble phosphorus from the Catskills site. Based on over 100 flow samples collected during storm events and low flow periods, 37% of the soluble phosphorus exported from the field was estimated to have been delivered in subsurface drainage.

## CONCLUSION

The assumption that surface runoff is the primary delivery mechanism for agricultural contaminants to streams is problematic for shallow, sloping, and structured soils. Although the installation of tile drains provides many hydrologic and other indirect benefits, the installation of tile drains as a water quality best management practice may not be as advisable as conventionally believed, in particular where macropores result in rapid contaminant delivery to the tile drain, and where steep soils on shallow restricting layers produce long-term tile outflow volumes which exceed surface runoff volumes. The data presented here indicate that tile drains installed under these conditions are capable of delivering significant concentrations and total loadings of manure-based phosphorus and coliforms to streams. On a note of caution, practitioners need to be aware of the potential water quality impacts of tile drains.

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