ENVIRONMENTAL ISSUES

Septic Systems as Potential Pollution Sources in the Cannonsville Reservoir Watershed, New York

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ABSTRACT

On-site septic systems require appropriate soil characteristics to provide effective wastewater treatment. The objective of this study was to evaluate siting practices and treatment efficacy of on-site septic systems within the Cannonsville Reservoir watershed (115 900 ha) in the state of New York. Using digital soil survey data, a database of on-site conditions was developed from more than 1100 existing septic system siting records. Soil map units were grouped into four classes based on their suitability to meet common septic system design criteria. A geographic information system was found to be a useful tool for assessment and visual display of septic system and landscape information. Geographic information system analysis indicated that while 80% of soils in the watershed were found to have characteristics that interfere with septic system function, 69% of septic systems installed were of designs suited for soils with no or few restrictive parameters. Since the designs of many septic systems have relied heavily on horizontal distance to streams (mean = 130 m) to provide adequate treatment, potential failures would lead to discharge of compounds of environmental concern, such as phosphorus, with public health implications. The results imply that many septic systems functioning in the watershed are in need of design improvements.

THERE IS CURRENTLY GREAT CONCERN over the amount of contaminants entering surface waters within the Cannonsville Reservoir watershed of New York State (Auer et al., 1998). The reservoir is one of the largest supplying drinking water to nearly 9 million New York City residents, some 230 km to the southeast. Recently, for regulatory purposes the reservoir watershed was declared to be "phosphorus restricted." This restriction imposes limits on the concentration of phosphorus compounds allowable in surface waters, with the ultimate goal of eliminating eutrophication in the reservoir. This means that economic growth and development of watershed communities can be restrained as requisite nutrient abatement practices are added to proposed projects.

Ongoing research intends to identify principal nonpoint sources to surface water pollution within the Cannonsville Reservoir watershed. Agriculture, primarily manure management practices from dairy farming, has already been recognized as a major contributor in the region (Kleinman, 1999; Cerosaletti et al., 2004). The USEPA (1980, 2002) has stated that septic tank effluent can typically contain contaminants of concern including pathogens, chemical and biochemical oxygen demands, and nitrogen and phosphorus compounds. The present study was undertaken to evaluate whether septic systems are a likely source of contaminants to the Cannonsville Reservoir.

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MATERIALS AND METHODS

Study Area

The Cannonsville Reservoir basin is located within the Allegheny Plateau, with most of the eastern and central portions being within the Catskill Mountain portion of this physiographic province (Fig. 1). The region is a deeply dissected plateau sloping gently to the southwest, with topography ranging from rolling uplands with steep slopes to narrow, nearly level stream valleys. Elevations range from 350 m above mean sea level at the reservoir dam to a maximum of 974 m along the northeastern boundary of the watershed. Its area is about 1160 km^2 with annual precipitation of 1070 mm, of which approximately 500 mm becomes runoff (Thompson, 1977). The underlying Devonian age bedrock consists of interlayered sandstone, siltstone, and shale (Fisher et al., 1971). Wisconsinan-age glacial till predominates in the uplands, with glaciofluvial deposits in larger valleys and on lower hillslopes (Caldwell et al., 1986). Areas with restrictive subsoils (e.g., coarse-loamy, mixed, active, mesic to frigid Typic Fragiudepts, Lithic or Typic Dystrudepts developed in glacial tills) occur in uplands, while better soils tend to occur in the relatively narrow floor (0.1–1.0 km wide) of the larger valleys (loamy-skeletal, mixed, active, mesic Typic Dystrudepts developed in alluvial or glacio-fluvial deposits).

Table 1 lists the classification of dominant soils in upland and lowland settings. Principal problems with siting septic systems result from: (i) slopes greater than 15%; (ii) Lithic Dystrudepts providing too little useable soil depth; (iii) Typic Fragiudepts commonly having either seasonally saturated zones (in moderately well drained map units) that occur above fragipans with very slow (0.01–1.4 $\mu m\ s^{-1}$) subsoil permeability, or bedrock at depths between 0.5 and 1 m; or (iv) Typic or Aeric Fragiaquepts and Aquic Fragiudepts being too wet for most leachfields to function properly. Figure 1 shows soils within the watershed that have either fragipan or bedrock occurring within 0.5 to 1 m from the surface. Most of the soils in the watershed contain considerable rock fragments. Soils with coarse loamy family textural class are most extensive (61%), while loamy skeletal soils comprise 34%.

Useable soil depth is defined as the depth of mineral soil having adequate permeability (measured as percolation rate of 0.025 m/60 to 3600 s) that is above a restrictive layer. This depth is often further limited by seasonal high water tables, perched on the restrictive layers. As a result, conventional

Abbreviations: DEP, Department of Environmental Protection; GIS, geographic information system.

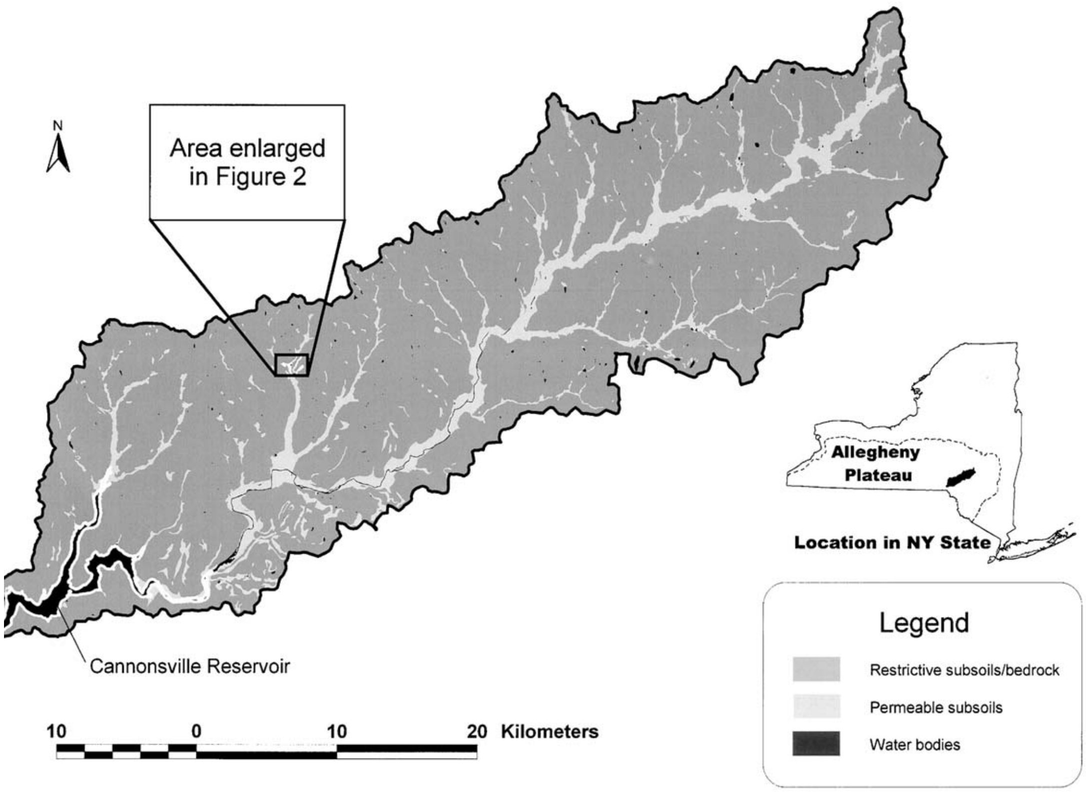

Fig. 1. Location of the study area and extent of permeable and restrictive subsoils within the Cannonsville Reservoir watershed, New York.

septic systems, which require a minimum of 1.2 m of useable soil depth, are currently seldom installed in the Cannonsville watershed. There are four general septic system designs approved for use on the watershed, as described in Table 2. Additional details may be found in Canter and Knox (1985).

The area is rural, with about 200 dairy farms using the more favorable land, especially along stream corridors. Vegetative cover is about 70% forest, 24% grass, and 3% alfalfa and corn (Effler and Bader, 1998). The principal stream draining the watershed is the West Branch of the Delaware River.

Records

Records on file at the New York City Department of Environmental Protection (DEP) branch office in Downsville, NY, for septic systems within the Cannonsville basin were reviewed. The records contained site-specific information for each proposed septic system. Relevant septic-system siting and installation information was extracted from 1182 records for years 1987 to 1996. The above time span was chosen because site locations were documented on planimetric quadrangle maps, and because it included a period of transition in understanding

Table 1. Classification of the most extensive soil series in the Cannonsville watershed in upland and lowland settings.

Dominant series in map unit	Taxonomic classification	Drainage class	Extent in watershed	Structure in the Bw horizon†
			%	
		Uplands		
Halcott‡	loamy-skeletal, mixed, active, frigid Lithic Dystrudepts	somewhat excessive	20.6	weak sbk
Willowemoc	coarse-loamy, mixed, semiactive, frigid Typic Fragiudepts	moderately well	13.7	moderate sbk
Lewbeach	coarse-loamy, mixed, semiactive, frigid Typic Fragiudepts	well	13.0	weak sbk parting to moderately granular
Lackawanna§	coarse-loamy, mixed, active, mesic Typic Fragiudepts	well	9.7	weak sbk
		Lowlands		
Tunkhannock	loamy-skeletal, mixed, superactive, mesic Typic Dystrudepts	well, somewhat excessive	3.2	weak sbk
Barbour	coarse-loamy over sandy or sandy-skeletal, mixed, active, mesic Fluventic Dystrudepts	well	1.5	very weak sbk
Basher	coarse-loamy, mixed, active, mesic Fluvaquentic Dystrudepts	moderately well	0.8	very weak sbk

† From USDA official soil series descriptions, where sbk is subangular blocky.
‡ Mapped in an undifferentiated group with two well drained members of Typic Dystrudepts, 0.5 to 1 m to bedrock.
§ Mapped as a consociation, as an undifferentiated group with another well drained Typic Fragiudept, and as a complex with an Aeric Fragiaquept.

Table 2. Design parameters for selecting effluent absorption systems.

Device type	Description	Required depth to limiting soil layer
		m
Seepage pit	After a pit is excavated to the appropriate depth, a cylindrical (1–3 m in depth, radius = 0.5–2 m) concrete vessel is installed that has large drainage holes penetrating its exterior wall. It is then backfilled with coarse gravel below the level of the inlet pipe, and with native soil to the surface.	±1.5 to >3.0
Conventional trench leachfield	Parallel trenches (≥2) are excavated (0.6 m wide, 0.6 m deep, <18 m long) following land contours, with >1.2 m of undisturbed soil remaining between adjacent trenches. A 0.3-m-thick layer of coarse gravel is spread on trench bottom, within which perforated distribution pipe (radius = 0.05 m) is placed. Gravel + pipe are backfilled with native soil.	≥1.2
Shallow trench leachfield	Similar layout to conventional trench leachfield, but installed at reduced soil depth. Often requires redistribution of on-site soil to create adequate backfill depth.	0.6 to 1.2
Raised trench leachfield	Similar layout to conventional trench leachfield, but select sandy fill material must be imported and carefully distributed on the leachfield site. Trenches are installed at elevations above existing grade and completely within the fill material.	0.3 to 0.6

and implementation of regulations. A database was created based on records from sites on which a septic system was either installed, repaired, or replaced. The database also compiled available geographic files in UTM coordinates for digital Soil Survey (SSURGO) maps, USGS topographic contour maps, highway, road and house locations, planimetric maps, hydrography data, tax parcel locations, as well as orthographic photography.

To digitize the geographic coordinates of each septic system, the New York City DEP staff's handwritten notes on USGS contour maps were consulted, each of which provided a file code in their tracking system. Each septic system location was then visually identified on color infrared orthographic images. Digital coverages of topographic contours and tax parcels were used to locate areas that were downslope of the dwelling, largely cleared of forest vegetation, and within the tax parcel. The approximate centroid of each area thus presumed to contain a septic system was then digitized in a geographic information system (GIS) and linked to the data table. A total of 714 septic systems were digitized, 11 of which could not be analyzed since only septic tanks had been replaced, and no leachfield-related data were available. Excel software (Microsoft, 1999) was used in database management, and ArcView (ESRI, 2000) with extensions was used for GIS analysis and map generation.

The SSURGO data required editing along matchlines (to allow quadrangle joining) to create the uniform, basin-wide soils coverage needed for GIS analyses. The NRCS recognized 132 soil mapping units occurring in the Cannonsville reservoir watershed (excluding areas mapped as water). The map units represent 96 consociations, 25 undifferentiated groups, six complexes, and five taxa mapped at the suborder or great group level. Each map unit was reclassified into one of four classes based on its ability to support septic systems. Soils with depth to restricting horizons of ≥1.2 m and that permit installation of conventional trench leachfields were considered most "suitable"; reduced depths of useable soil were considered less suitable. Soils that present few or no problems for septic system installation and effluent treatment are in Class 1 (also called "well-suited soils"), soils with the most severe restrictions are in Class 4 (also called "unsuitable soils"), and Class 2 ("moderately suited soils") and Class 3 ("marginal soils") represent intermediate suitabilities. Detailed descriptions of each class are given in Table 3.

Best-case scenarios were assumed to avoid exaggerating the extent of Class 3 and 4 soils. For example, soils that would otherwise be suitable except for being located on rarely inundated floodplains, or those with gravelly and rapidly permeable subsoils, were generally included in higher soil classes (e.g., Class 2, Table 3) despite the potential for compromised treatment of effluent. This allowed a wider selection of soils considered capable of providing adequate wastewater treatment. The principal factors used to separate classes were (i) useable soil depth to bedrock, fragipan, or water table and

Table 3. Description and composition of soil suitability classes.

Class	Description of soils in class	Leachfield designs typically used for soil class	Soils within class and occurrence in watershed
1, Well-suited soils	Few or no characteristics (e.g., fragipan, bedrock or seasonal water table) that interfere with installation of conventional leachfields or treatment of septic system effluent. These included well drained soils on slopes of ≤15% having no restrictive subsoils at or within 1.2 m of the soil surface.	conventional leachfields or seepage pits	9 soil map units comprising 4% of the watershed
2, Moderately suited soils	Soils with characteristics that interfere with treatment of septic system effluent, but occurring at a depth (≥0.6, <1.2 m) or of a type (e.g., fast percolating gravels) that often support a modified version of conventional leachfields. Also included were selected soils with bedrock at 0.5- to 1.0-m depths, rarely flooded (0–5% chance) alluvial soils, and deep soils on 15 to 20% slopes that have no restrictive subsoils.	shallow trench leachfields	33 soil map units comprising 16% of the watershed
3, Marginal soils	Soils with restrictive subsoil characteristics at depths between 0.3 and 0.6 m, or with common flooding concerns (5–50% chance). Selected soils on 15 to 20% slopes were included if no restrictive subsoils exist, thus allowing slope modification to ≤15%.	raised trench leachfields (requiring site modification by importation of select fill)	17 soil map units comprising 29% of the watershed
4, Unsuitable soils	Soils with restrictive subsoil characteristics at depths of <0.3 m and either slopes of >15% or common to frequent flooding problems (5 to >50% chance).	generally not allowed for new construction	73 soil map units comprising 51% of the watershed

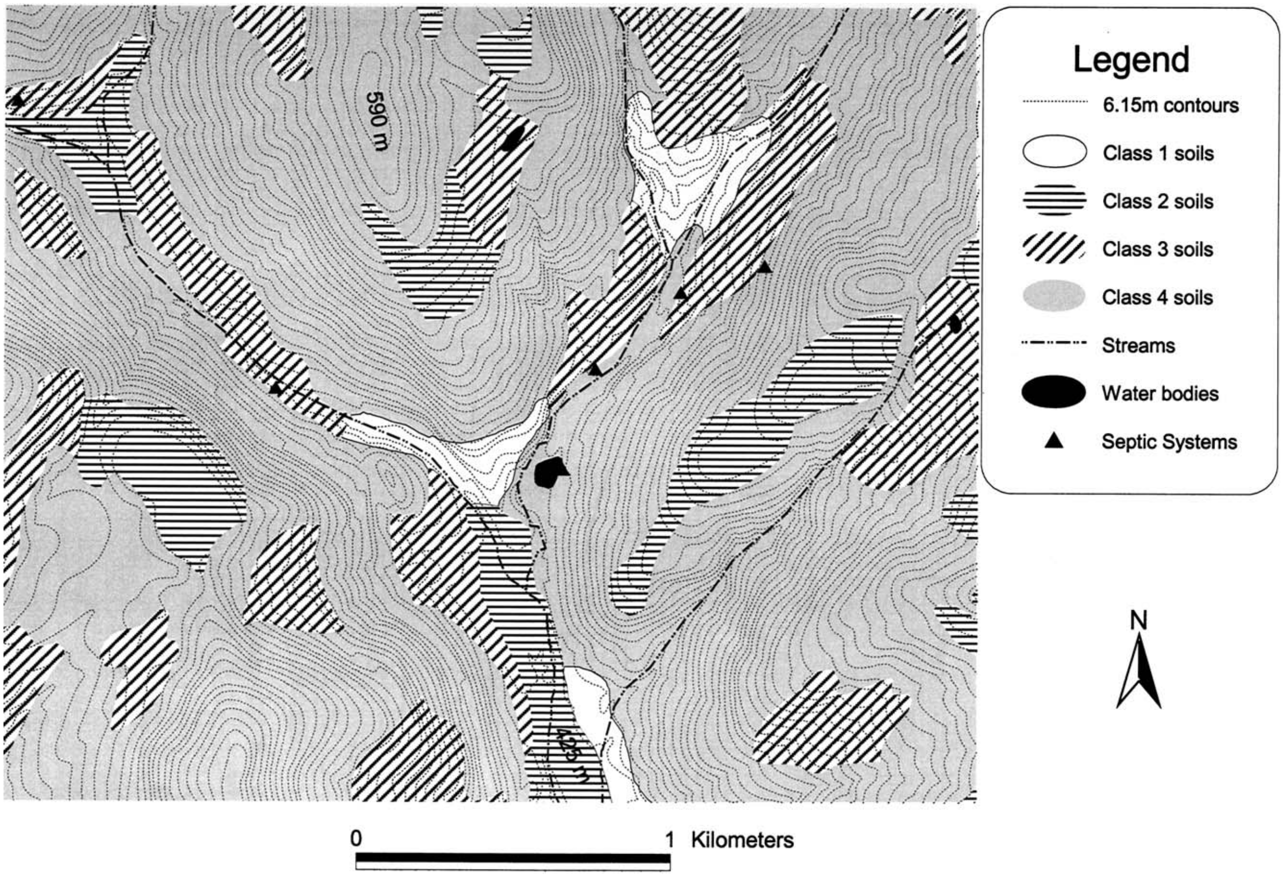

Fig. 2. Juxtaposition of four soil classes, septic system locations, and areas of surface water within a typical area of the Cannonsville watershed.

(ii) soil surface slopes either less than or greater than 15%. If the soil had no restrictive subsoils, then 20% was used to separate classes, thus allowing regrading of surface topography to 15% if no other restrictions existed.

Health regulations require that conventional trench leachfields be installed in soils having a minimum of 1.22 m of useable soil depth to a restrictive layer. Thus, a soil with a fragipan at a 0.91-m depth would ordinarily have "severe limitations" for septic system installations. Note, however, that such a soil would be favorable for leachfield designs other than the conventional trench.

RESULTS AND DISCUSSION

Most of the soils in the Cannonsville watershed have characteristics that present problems to conventional leachfield installation (i.e., steep slopes or <1.2 m of useable soil depth). Soil map units representing slopes greater than 15% occur over 48% of the watershed. To further evaluate surface slopes, the mean of the slope range for each soil map unit was recorded wherever septic systems occurred. From these data the median slope was calculated to be 11.5% (standard deviation = 10.9). As shown in Table 3, combining Classes 3 and 4 suggests that 80% of the soils are marginal or unsuitable for septic systems. Septic systems could be installed in these areas, but special leachfield designs would be needed. Figure 2 shows a selected area containing 46 soil map units that have been grouped into soil Classes 1 through 4, and where they typically occur on the landscape. Soil survey map unit descriptions (Soil Survey Staff, 2004) state that when an area in the field was mapped as a given soil series (i.e., a consociation) it may contain up to 20% inclusions of other soils. Because small areas of included soils occur in virtually every soil survey map unit, a small proportion of each soil is likely to have interpretations different (either more or less well suited) from the dominant soil(s) for which the map unit is named.

Siting and Evaluation

The 1182 systems studied were assumed to be representative of other existing septic systems in the watershed, except that systems installed since the latest regulations became effective (1990) were relatively contemporary in terms of system age, design standards, flow capacity, and materials of the septic tank and absorption field.

Most septic systems constructed during the study period were concentrated in valleys. Few septic systems were installed in the general vicinity of the Cannonsville Reservoir, probably due to both the large proportion of Class 4 soils and to a large proportion of New York City DEP land ownership, where no residential development is allowed.

Figure 3 shows the recorded depths to limiting soil layers over the study period. The figure suggests that soil depths used as a design criterion decreased markedly from 1987 through 1996, with the medians leveling

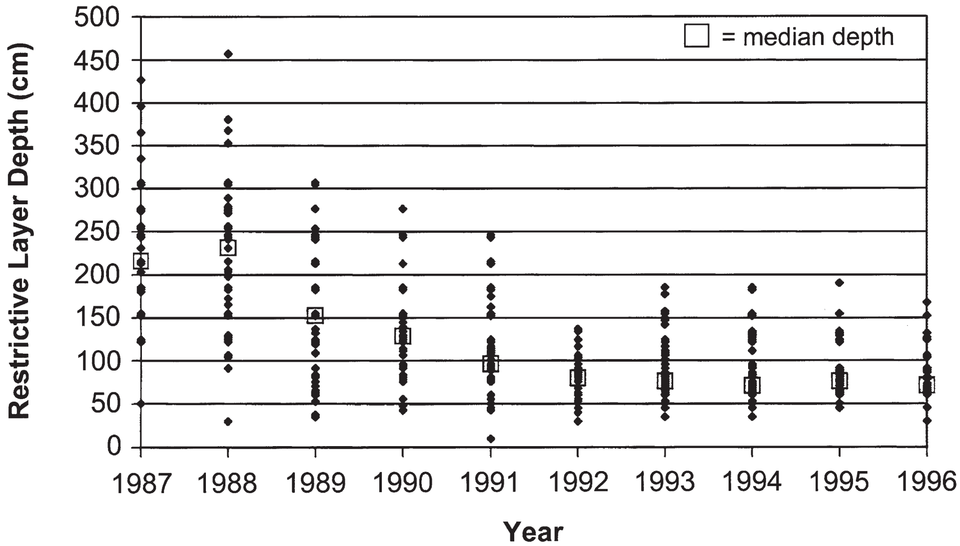

Fig. 3. Distribution of reported depth of useable soil by year.

off to 0.8 m after 1991. The trend indicates a shift in the field application of health regulations. Before 1991, soils were largely considered acceptable for seepage pit or conventional trench leachfield designs. After 1991, soils were generally found to be acceptable for mainly shallow trench leachfields. Currently, field site evaluations focus on locating sites for a septic system on any building lot, with at least the minimum of 0.6 m of useable soil required for installation of a shallow trench leachfield.

The trend evident in Fig. 3 is in response to a number of related factors that converged around 1991. These included issuance of the current version of Department of Health Public Health Law and draft watershed regulations released by the New York City DEP (fall, 1990), which were considerably more stringent than previous regulations. Additional factors included on-site evaluation of soil profiles being witnessed by New York City DEP staff, ongoing soil survey efforts that focused on locations experiencing rapid development, and training of New York City DEP staff and town planning boards that targeted restrictive subsoils, perched water tables, and their influence on septic system design and function.

Between 1987 and 1996, of the 703 leachfield systems installed, 6% were seepage pits, 53% were conventional trench leachfields, 34% were shallow trench leachfields, and 7% were raised trench leachfields. Over time, numbers of conventional trench systems that require greater depths of useable soil decreased, with a corresponding increase in shallow trench and raised trench leachfields that require less deep soils. Conventional trench and seepage pits comprised 97% of all absorption systems installed during 1987. By 1992 these types of systems were installed at only 10% of locations.

Table 4 shows the distribution of septic system locations between the four soil classes. The majority (73%) occurred on either unsuitable or marginal soils, while only 26% were installed in well-suited or moderately suited soils. However, 94% of leachfields installed on these Class 3 and 4 soils were either seepage pits or conventional or shallow trench leachfields, which need Class 1 or 2 soils to function properly. Results suggest that septic system effluent may not be treated effectively by the soils.

Common practice before the 1987–1996 time period was to install seepage pits or conventional trench leachfields for effluent disposal. Compared with shallow trench or raised trench leachfield designs, and because of limitations of the available soils, such systems are unlikely to provide adequate treatment of effluent.

Setback Distance

To determine typical setback distances of septic systems from streams, a total of 4693 house locations were analyzed. Nested buffer zones of selected increments were set up in GIS around each stream in the digital hydrography coverage. The analysis gave both the number of septic system locations and proportion of soil Classes 1 through 4 found within each buffer. The results

Table 4. Number of effluent dispersion devices in soil classes within the Cannonsville watershed.†

	Soil class			
Device type	1	2	3	4
43 Seepage pits	1 (2%)	14 (33%)	6 (14%)	22 (51%)
377 Conventional trench leachfields	15 (4%)	88 (23%)	97 (26%)	177 (47%)
237 Shallow trench leachfields	11 (5%)	44 (18%)	81 (34%)	101 (43%)
46 Raised trench leachfields	2 (4%)	11 (24%)	15 (33%)	18 (39%)
703 Total	29 (4%)	157 (22%)	199 (28%)	318 (45%)

† Numbers in parentheses indicate relative proportions within each device type category.

Table 5. Occurrence of digitized house locations† within soil classes.

Soil class	Septic systems	
	number	% (n = 4693)
1, Well-suited	350	8
2, Moderately suited	1380	29
3, Marginal	1392	30
4, Unsuitable	1571	33

† From New York State Department of Transportation map, 1983 edition.

Table 6. Distance of digitized house locations† from watercourses in the Cannonsville watershed.

Distance from watercourse	Number of all septic systems occurring within distance	Cumulative percentage (total = 4693)
m		%
15	340	7.2
31	756	16.1
61	1613	34.4
152	3378	72.0
152–305	4427	94.3
>305	4693	100

† From New York State Department of Transportation map, 1983 edition.

in Table 5 show that 63% of septic system locations occurred within soil Groups 3 and 4, while Table 6 shows that the average distance between septic systems and a watercourse was between 61 and 152 m.

This "buffering" approach was further used for the 703 septic system leachfield locations digitized from New York City DEP records. Ten buffers with 31-m increments were created around each stream in the coverage (e.g., 31, 61, 91 . . . 305 m), and the number of occurrences of each leachfield type was determined. Figure 4 shows that few septic systems occurred within a distance of 31 m; most were installed at greater distances, with 22% installed at distances greater than 3045 m. By considering the occurrences of both the total 714 digitized septic system points and the 4693 house locations within each buffer, the mean distance to watercourses in the basin was 130 m. This separation distance substantially exceeds minimum requirements for protecting public health, assuming all guidelines are followed for site and soil evaluations and for proper septic system design, installation, and maintenance. However,

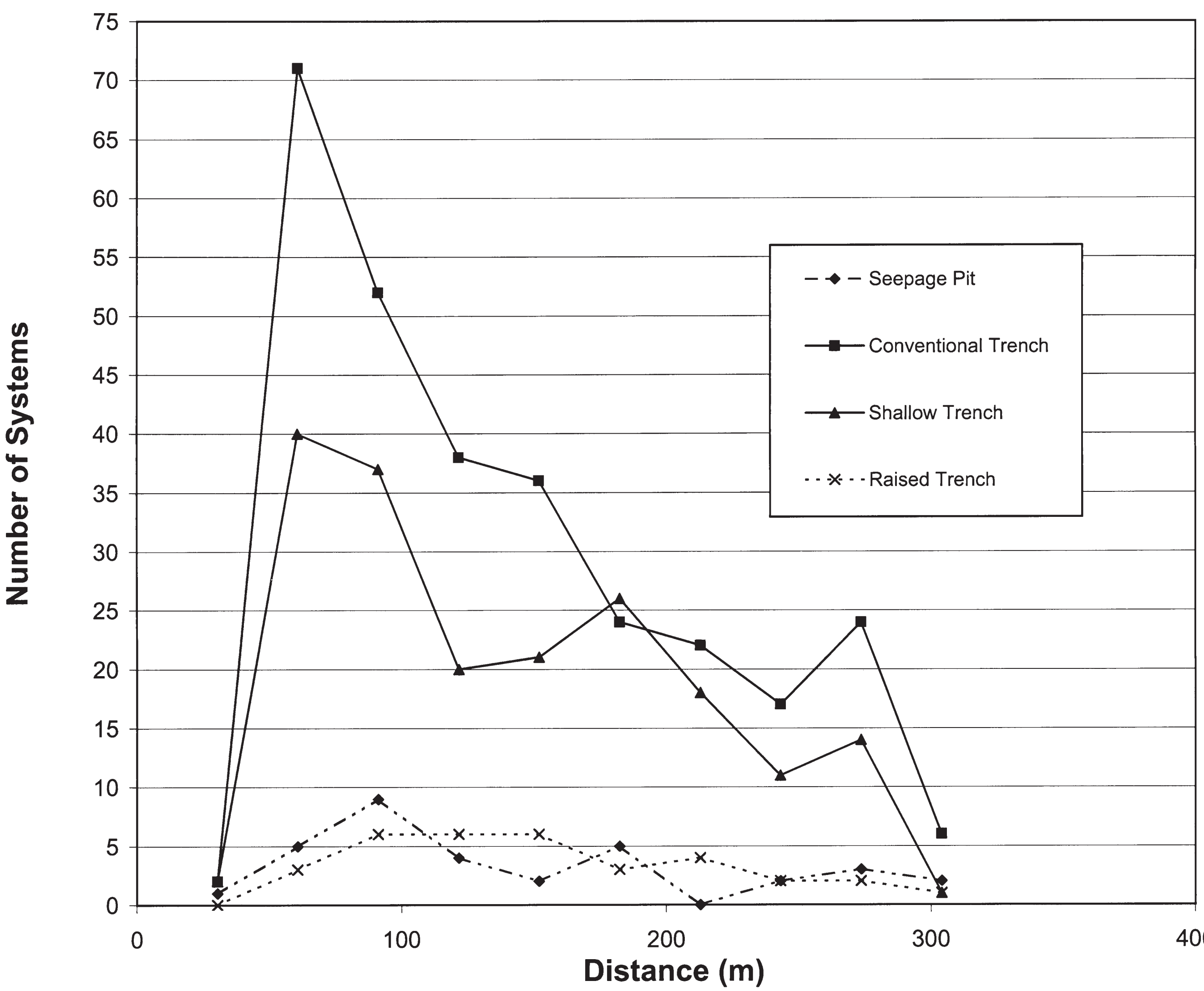

Fig. 4. Mean separation distances between septic systems and surface waters.

since the data in Tables 3 and 4 imply that a large percentage of septic systems were not designed and installed to overcome existing soil limitations, these septic systems have been relying primarily on horizontal separation distance from streams for adequate treatment of wastewaters. Also, because the available hydrography coverage was based largely on the location of perennial streams from USGS topographic maps, many intermittent watercourses were not represented by the GIS analysis.

Septic System Failures

Total failure rates and septic system impacts over time may be greater than septic system failure surveys indicate. Such studies do not include those systems that might be contaminating surface or ground water in ways that are detectable only through on-site monitoring (USEPA, 2002). The distinction between septic systems experiencing hydraulic failures and those systems experiencing subsurface "treatment failures" is important, since septic systems that otherwise appear to have acceptable hydraulic function can create health and environmental risks when they exceed the capacity of soil to handle pollutant loads (Siegrist and Van Cuyk, 2001). However, because of extensive presence of restrictive layers on Cannonsville watershed, contamination of ground water is less likely.

In the late 1990s, the New York City DEP began issuing legal notices of system failure to homeowners with hydraulically failing septic systems. Failure was confirmed by flushing dye down a toilet in the dwelling, and observing suspected failure locations (e.g., wet spots on the lawn) for visible evidence of the dye on the ground surface. Where failure was confirmed the owner was often eligible for substantial financial assistance to repair or fully replace failed septic system components. Thus, the following septic system failure data only represent funded recipients available from 1998 through 2000.

A GIS analysis was performed to determine the distribution of failed septic systems among soil classes. Of the 357 total repaired septic systems, 35 (10%) were in Class 1 soils, 93 (26%) were in Class 2, 116 (32%) were in Class 3, and 113 (32%) were in Class 4. The large proportion of failures that occurred on unsuitable and marginal soils appears to corroborate the observation that many septic systems in the watershed were installed in inappropriate soils. The most common causes for failure were reported (M. McGiver, Catskill Watershed Corporation, personal communication, 2003) to be poor soils and septic systems that were either old or used beyond their design capacity. It should be pointed out, however, that installation practices and homeowner maintenance of septic systems play critical roles in system longevity.

The 2000 U.S. census report was used to estimate the median age for structures in the Cannonsville watershed by township and by village (United States Census Bureau, 2000). Considering the age-by-township data, the eight principal townships had a median structure age of 51 yr. The average lifespan of most new septic systems is commonly accepted to be somewhere in the range of 10 to >30 yr, depending on the level of maintenance employed, quality and quantity of wastewater, proper design, installation, etc. (Hoxie and Frick, 1985; Keys et al., 1998; Sherman et al., 1998).

Phosphorus Transport Potential

Because P is a nutrient of concern in the watershed, the likelihood of P reaching surface waters from septic systems was considered. Phosphorus tends to be sorbed and effectively retained by most soils, moving slowly downward through the soil matrix (Eghball et al., 1990; Sims et al., 1998), or laterally through interflow (Akhtar et al., 2003). Under certain circumstances such as high rainfall rates, small but significant amounts of P can move through preferential flow paths, bypassing the soil matrix (Mansell et al., 1985; Scott et al., 1998; Simard et al., 2000). Shallow subsurface flow is gaining recognition as an important P transport mechanism in agricultural settings (Geohring et al., 2001).

Studies using a hydrology model developed by Cornell University (Frankenberger et al., 1999) indicate that perched water tables that occur in sloping landscapes strongly influence the flux of subsoil moisture in uplands. In moderately well-drained upland areas of Typic Fragiudepts that occur in the Cannonsville watershed, seasonal water tables that are perched above the fragipan would be expected. Zaslavsky and Rogowski (1969) demonstrated that a lateral flow component may form in subsoils occupying lower portions of hillslopes where only a slight increase in subsoil density occurs (i.e., even without the occurrence of relatively dense fragipans).

The recent work by Akhtar et al. (2003) suggests that well-developed soil structure could be a dominant predictor of preferential P transport in upland soils. Among the soils they tested, the Lackawanna soil was moderately subject to preferential P transport under saturated conditions, despite having a relatively high affinity for P. Sloping upland till soils with structure and textures similar to the Lackawanna series (Soil Survey Division, 2004) are extensive in the Cannonsville watershed (Table 1). Tofflemire and Chen (1977) demonstrated that the P retention of soils varies widely across New York, but depends greatly on geologic parent material and soil horizon. Among the 35 representative soils they studied, acid tills tended to be the most effective in P sorption, with maximum sorption capacity occurring in the B horizon. However, they noted that on-site septic systems in New York often discharge wastewater into the subsoil, below the B horizon.

With seasonal perched water tables, slopes often greater than 10%, coarse textures, and moderately developed structure common in soils of the Cannonsville watershed, it appears that conditions may favor lateral movement of P in subsoils under some circumstances. Septic systems installed in inappropriate soils could favor P migration, but the substantial horizontal distance separating most septic systems from surface waters would limit the risk of P breakthrough. Ongoing research will further investigate this possibility under various land use scenarios.

CONCLUSIONS

The criteria used to group the soils into four suitability classes were based on typical characteristics that affect septic system leachfield designs without specific focus on pollutant retention or transport. Even when best-case scenarios are assumed, many septic systems in the study area appear to have been sited on soils to which they are not suited. These results suggest that adequate on-site wastewater treatment is not being effected across the Cannonsville Reservoir watershed.

Although hydraulic failures are only beginning to be documented, the poor fit between septic systems and soils implies that treatment failures may be commonplace. Currently the lateral distance separating septic systems from surface waters is being relied on for treatment.

Soil characteristics that affect septic system performance began to be recognized in the watershed between 1987 and 1996. This implies that although the situation may be improving with newer construction, many old and poorly sited septic systems still remain in use. Considering their advanced age, many of these systems should probably be upgraded or replaced in the near future.

Conventional leachfield designs installed at soil depths just above the fragipan may inject wastewater effluent directly into perched water tables, potentially allowing transport of pollutants down-gradient. Soils in the Cannonsville watershed have some characteristics that would favor lateral migration of contaminants. However, due to soil parent material type and adequate setback distances from surface waters, in most circumstances the risk of substantial P transport appears to be small.

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REFERENCES

Akhtar, M.S., B.K. Richards, P.A. Medrano, M. deGroot, and T.S. Steenhuis. 2003. Dissolved phosphorus from undisturbed soil cores: Related to adsorption strength, flow rate, or soil structure? Soil Sci. Soc. Am. J. 67:458–470.

Auer, M.T., K.A. Tomasoski, M.J. Babiera, M.L. Needham, S.W. Effler, E.M. Owens, and J.M. Hansen. 1998. Phosphorus bioavailability and P-cycling in Cannonsville Reservoir. J. Lake Reservoir Manage. 14(2–3):278–289.

Caldwell, D.H., G. Connally, R. Dineen, P.J. Fleisher, and J. Rich. 1986. Surficial geologic map of New York, Hudson-Mohawk sheet. New York State Museum, Geol. Survey Map and Chart Ser. 40. State Education Dep., Albany, NY.

Canter, L.W., and R.C. Knox. 1985. Septic tank system effects on ground water quality. Lewis Publ., Chelsea, MI.

Cerosaletti, P.E., D.G. Fox, and L.E. Chase. 2004. Phosphorus reduction through precision feeding of dairy cattle. J. Dairy Sci. 87:2314–2323.

Effler, S.W., and A.P. Bader. 1998. A limnological analysis of Cannonsville Reservoir, NY. J. Lake Reservoir Manage. 14(2–3):125–139.

Eghball, B., D.H. Sander, and J. Skopp. 1990. Diffusion, adsorption, and predicted longevity of banded phosphorus-fertilizer in three soils. Soil Sci. Soc. Am. J. 54:1161–1165.

ESRI. 2000. ArcView Version 3.2a. Environ. Syst. Res. Inst., Redlands, CA.

Fisher, D., Y. Isachsen, and L. Rickard. 1971. Geologic map of New York, Hudson-Mohawk sheet. New York State Museum and Sci. Serv. Map and Chart Ser. 15. State Education Dep., Albany, NY.

Frankenberger, J.R., E. Brooks, M. Walter, M. Walker, and T. Steenhuis. 1999. A GIS-based variable source area hydrology model. Hydrol. Processes 13:805–822.

Geohring, L.D., O.V. McHugh, M.T. Walter, T.S. Steenhuis, M.S. Akhtar, and M.F. Walter. 2001. Phosphorus transport into subsurface drains by macropores after manure applications: Implications for best manure management practices. Soil Sci. 12:896–909.

Hoxie, D.C., and A. Frick. 1985. Subsurface wastewater disposal systems designed in Maine by the site evaluation method: Life expectancy, system design and land use trends. p. 362–371. *In* On-site wastewater treatment. Proc. 4th Natl. Symp. on Individual and Small Community Sewage Systems, New Orleans. 10–11 Dec. 1984. Am. Soc. Agric. Eng., St. Joseph, MI.

Keys, J.R., E.J. Tyler, and J.C. Converse. 1998. Predicting life for wastewater absorption systems. p. 167–176. *In* On-site wastewater treatment. Proc. 8th Natl. Symp. on Individual and Small Community Sewage Systems, Orlando, FL. 8–10 Mar. 1998. Am. Soc. Agric. Eng., St. Joseph, MI.

Kleinman, P.J. 1999. Examination of phosphorus in agricultural soils of New York's Delaware River watershed. Ph.D. diss. Cornell Univ., Ithaca, NY.

Mansell, R.S., P.J. McKenna, and M.E. Hall. 1985. Simulated solute movement in wastewater- ponded soil. Soil Sci. Soc. Am. J. 49:541–546.

Microsoft. 1999. Excel 2000. Microsoft, Redmond, WA.

Scott, C.A., L.D. Geohring, and M.F. Walter. 1998. Water quality impacts of tile drains in shallow, sloping, structured soils as affected by manure application. Appl. Eng. Agric. 14:599–603.

Sherman, K.M., R. Varnadore, and R.W. Forbes. 1998. Examining failures of onsite sewage treatment systems in Florida. p. 43–51. *In* On-site wastewater treatment. Proc. 8th Natl. Symp. on Individual and Small Community Sewage Systems, Orlando, FL. 8–10 Mar. 1998. Am. Soc. Agric. Eng., St. Joseph, MI.

Siegrist, R.L., and S. Van Cuyk. 2001. Wastewater soil absorption systems: The performance effects of process and environmental conditions. p. 41–51. *In* K. Mancl (ed.) On-site wastewater treatment. Proc. 9th Natl. Symp. on Individual and Small Community Sewage Systems, Ft. Worth, TX. 11–14 Mar. 2001. Am. Soc. Agric. Eng., St. Joseph, MI.

Simard, R.R., S. Beauchemin, and P.M. Haygarth. 2000. Potential for preferential pathways of phosphorus transport. J. Environ. Qual. 29:97–105.

Sims, J.T., R.R. Simard, and B.C. Joern. 1998. Phosphorus loss in agricultural drainage: Historical perspective and current research. J. Environ. Qual. 27:277–293.

Soil Survey Division. 2004. Official soil series descriptions [Online]. Available at http://soils.usda.gov/technical/classification/osd/index.html (verified 19 July 2004). USDA, Washington, DC.

Soil Survey Staff. 2004. Soil survey of Delaware County, New York. U.S. Gov. Print. Office, Washington, DC (in press).

Thompson, J.H. 1977. Geography of New York State. Syracuse Univ. Press., Syracuse, NY.

Tofflemire, T.J., and M. Chen. 1977. Phosphate removal by sands and soils. Ground Water 15:377–387.

United States Census Bureau. 2000. U.S. census report. U.S. Dep. of Commerce, Washington, DC.

USEPA. 1980. Design manual. Onsite wastewater treatment and disposal systems. EPA 625/1-80-012. U.S. Gov. Print. Office, Washington, DC.

USEPA. 2002. Onsite wastewater treatment systems manual. EPA 625/R-00/0008. U.S. Gov. Print. Office, Washington, DC.

Zaslavsky, D., and A.S. Rogowski. 1969. Hydrologic and morphologic implications of anisotropy and infiltration in soil profile development. Soil Sci. Soc. Am. Proc. 33:594–599.