Effectiveness Of Standard And Alternative Design Septic Systems In Renovating Domestic Wastewater In Pinelands Soils

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EFFECTIVENESS OF STANDARD AND ALTERNATIVE DESIGN SEPTIC SYSTEMS IN RENOVATING DOMESTIC WASTEWATER IN PINELANDS SOILS

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INTRODUCTION

On-site disposal of domestic wastewater is a major source of ground-water pollution in the New Jersey Pinelands. In unsewered areas, the impact of on-site wastewater disposal on ground-water quality is closely related to housing density [Scalf and Dunlop, 1977. Perkins, 1984]. This is especially true in the Pinelands [Trela and Douglas, 1979. Brown, 1980]. In order to preserve existing ground-water quality and other resources in the Pinelands, regulations limiting housing densities have been promulgated with the adoption of the New Jersey Pinelands Comprehensive Management Plan [New Jersey Pinelands Commission, 1980].

Nitrogen has been identified as a limiting nutrient in aquatic Pinelands communities, and consequently nitrogen is of particular concern as a potential pollutant in domestic wastewater. Two on-site wastewater disposal systems which are reported to remove nitrogen from wastewater have been utilized in the Pinelands. These are pressure-dosed systems and waterless toilet/greywater systems. A third septic system, called the RUCK system, is also reported to remove nitrogen and has recently been utilized in the Pinelands.

The effectiveness of pressure-dosed designs has not been studied in the New Jersey Pinelands, and no studies on the overall effectiveness of waterless toilet/greywater systems are available. Furthermore, certain assumptions regarding the character of domestic wastewater and treatment processes in disposal systems are used to predict the impact of these systems on Pinelands ground-water quality and to determine acceptable minimum lot sizes. However, these assumptions have not been compared to information on actual systems in the Pinelands. The objectives of this study then, are to:

1. determine the relationships between nutrient concentrations of effluent and leachate in individual on-site wastewater disposal systems of various designs utilized in the Pinelands; and

2. test the validity of certain assumptions used to predict the impact of on-site wastewater disposal systems on ground-water quality in the Pinelands.

The Pinelands Commission did not approve conditional use of the RUCK septic system until after initiation of this study, consequently the design of this experimental system is not considered here. However, the Pinelands Commission has since implemented a Comprehensive Monitoring Program for RUCK septic systems.

SEPTIC SYSTEM WASTEWATER TREATMENT CONCEPTS

The standard septic system design typically involves a septic tank, distribution box, and a gravity-fed system of perforated pipe laterals in gravel trenches or gravel beds. In the Pinelands, the effluent percolates through the unsaturated zone of gravel and underlying sands. In this zone, the effluent leachate is filtered so that bacteria are expected to be removed effectively. Viruses are also expected to be removed by adsorption. Some fraction of the phosphorous is removed by adsorption. The leachate also undergoes a process of biological nitrification whereby organic and ammonia-nitrogen in the wastewater are eventually converted to nitrate-nitrogen. This process is represented by the following equations [Laak, 1980].

$$\text{ORGANIC N} \xrightarrow{\text{bacterial enzymes}} NH_4^+ + \text{other products}$$

$$NH_4^+ + 1.5\ O_2 \xrightarrow{\text{Nitrosomonas}} NO_2^- + 2\ H^+ + H_2O + \text{energy}$$

$$NO_2^- + 0.5\ O_2 \xrightarrow{\text{Nitrobacter}} NO_3^- + \text{energy}$$

If saturated conditions exist and a carbon source is available in the subsurface environment, nitrate may undergo biological denitrification whereby nitrate is converted to nitrogen gas. This process is represented by the following equation [Laak, 1980].

$$NO_3^- + \text{carbon source} \xrightarrow[\text{bacteria}]{\text{dentrifying}} N_2 + H_2O + CO_2$$

The literature generally indicates that standard septic system designs for systems located in sandy, well-drained soils are not conducive to nitrogen removal through dentrification and that all nitrogen present in standard septic tank effluent eventually reaches ground-water as nitrate. Kristiansen [1981], for example, monitored nitrogen concentrations in influent and effluent in three continuously loaded sand filter trench systems and found that insignificant amounts of nitrogen were removed in the unsaturated sand.

Pressure-dosed systems are similar to standard systems with a few important differences. The septic tank effluent is pumped under pressure through a force main and into pressure-distribution laterals, providing more even effluent loading across the disposal field area. Disposal field trenches are underlain by select fill material, which is sometimes mounded to provide a sufficient depth to the water table. The systems are designed to facilitate nitrogen removal by the nitrification/dentrification sequence. Nitrogen in the wastewater undergoes biological nitrification in the aerobic subsurface environment as it percolates through the select fill underlying the laterals. At the select fill/soil interface, saturated conditions may exist due to the periodic dosing of the effluent. In this anaerobic environment, denitrifying bacteria may convert some fraction of the nitrate to nitrogen gas as described earlier. Nitrogen gas generated by this reaction, as well as nitrous oxide generated by other denitrifying reactions, may escape through the soil to the atmosphere. Any remaining nitrate continues to percolate to ground-water.

At least two field studies on the effectiveness of pressure-dosed systems have been reported. Cogger and Carlisle [1984] studied two pressure-dosed mound systems in North Carolina soils with high water tables and found them to be generally ineffective in treating effluent due to overloading. Harkin and others [1979] conducted an in-depth field monitoring study of 33 pressure-dosed mound systems on slowly permeable soils and shallow permeable soils in Wisconsin. They found that the pressure-dosed mound systems achieved better bacterial and chemical treatment of wastewater than standard systems. In particular, it was concluded that pressure-dosed mound systems are capable of immobilizing organic and ammonium-nitrogen and that an average 44% of nitrate-nitrogen was removed by denitrification.

The type of waterless toilet/greywater system studied is designed to remove nitrogen by trapping and composting toilet wastes which contain a large proportion of the nitrogen generated by households. The toilet wastes do not enter the wastewater disposal system. Nitrogen removal is facilitated by the active venting of gaseous ammonia. After a sufficient detention time, the resulting compost is expected to be low in soluble nitrogen content. In this form it may be applied to shrubs or buried on site with no expected negative environmental impacts. However, no conclusive reports on the reliability of the waterless toilet composting process are available.

The wastewater generated by sinks, showers, and laundry, referred to as greywater, is disposed of in a septic system similar to a standard system. The greywater disposal system typically consists of a septic tank, distribution box, and disposal field or bed.

The total nitrogen in greywater represents only an estimated 17% of the total nitrogen generated by a household [EPA, 1980].

SITE DESCRIPTIONS

Three different system designs were included in the study: 1) pressure-dosed; 2) waterless toilet/greywater; and 3) standard design. Selection of sites was determined primarily by the ability to obtain an owner's consent. Six systems were available for study. These included three pressure-dosed systems, one waterless toilet/greywater system and two standard systems. Each system had been inspected and certified by the respective local health authority. Each of the six systems serviced residences through the period of study. Table 1 lists various site characteristics. Soils at each site were identified by field inspections and evaluated according to the US Department of Agriculture Classification System.

TABLE 1. SITE CHARACTERISTICS

SITE CODE	DESICN	NO. RESIDENTS	TWP	SYSTEM AGE ON 1ST SAMPLE DATE	SOIL SERIES	HYDROLIC SOILS GROUP	PERMEABILITY RANGE (IN/HR)
A	STANDARD	4	EVESHAM	10 YRS	EVESBORO	A	6.0 - 20
B	STANDARD	3	EVESHAM	10 YRS	DOWNER	B	0.6 - 6.0
C	PRESS.-DOSED	3,4*	MEDFORD	1 MONTH	KLEJ	B	6.0
D	PRESS.-DOSED	2	MULLICA	15 MONTHS	DOWNER	B	0.6 - 6.0
E	WATERLESS	2	EGG HARBOR	9 MONTHS	AURA	B	0.2 - 6.0
F	PRESS.-DOSED	2	WASHINGTON	1 MONTH	LAKEHURST	A	6.0 - 20

* three residents from 9/83 through 1/84, four residents from 3/84 through 8/85

MATERIALS AND METHODS

The location of the disposal field or bed of each system was determined using a steel probe. Suction lysimeters were installed according to the manufacturer's specifications so that the porous cups were positioned just below the bottom of the disposal trench or bed (shallow lysimeters) and some depth below the bottom of the disposal trench or bed (deep lysimeters - see Figure 1). The location, number and vertical separation of lysimeters at each location are listed in Table 2.

TABLE 2. LOCATION, NUMBER AND VERTICAL SEPARATION OF LYSIMETERS

LYSIMETER LOCATION	SITE CODE (See Table 1)					
	A	B	C	D	E	F
NUMBER OF SHALLOW LYSIMETERS	1	1	1	1	2	2
NUMBER OF DEEP LYSIMETERS	2	2	2	2	0	1 *
VERTICAL DISTANCE BETWEEN LYSIMETERS (FT)	2	2	2	2	-	7
NUMBER OF LYSIMETERS BELOW "COMPOST" PILE	-	-	-	-	1	-

* This lysimeter was located below the existing water table.

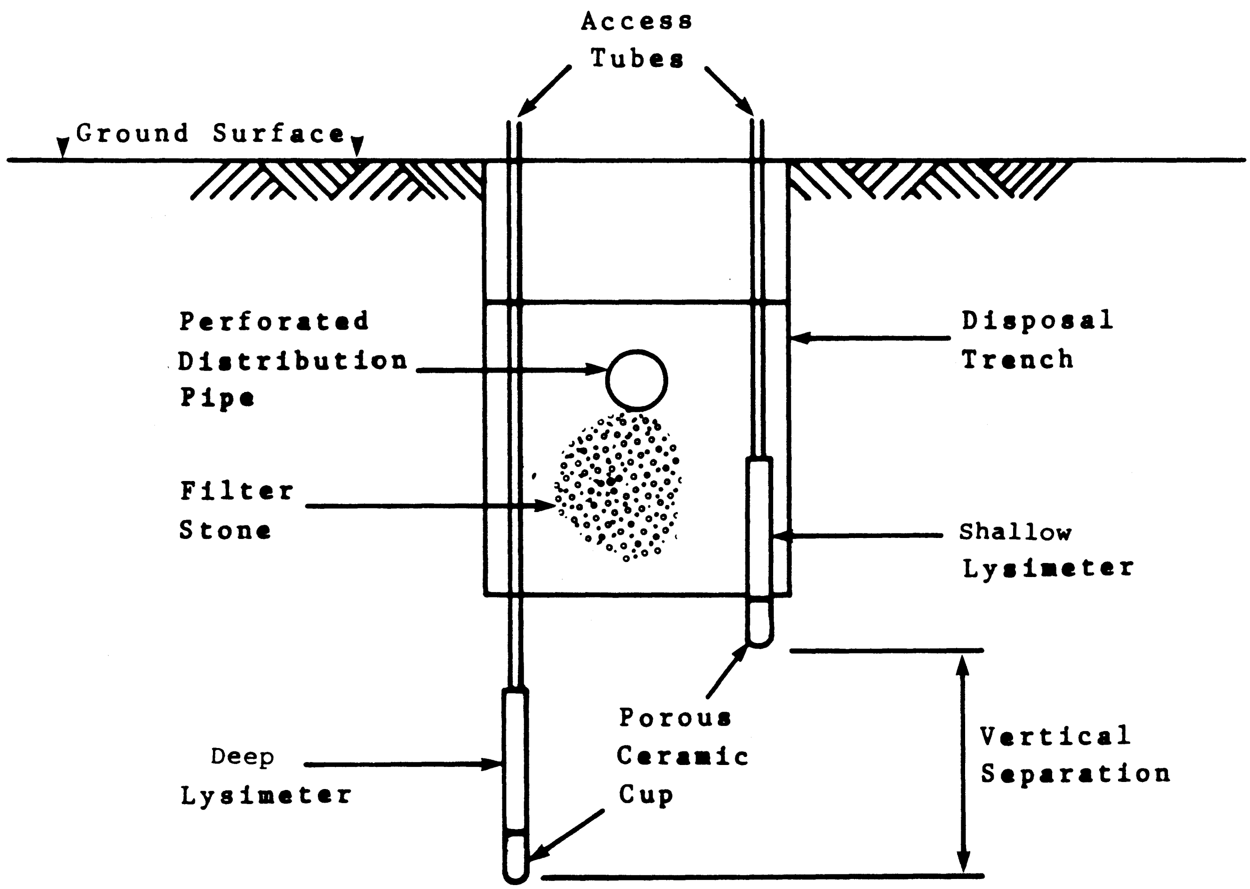

FIGURE 1. TYPICAL LYSIMETER INSTALLATION

Shallow lysimeters were installed below the greywater disposal bed. Deep lysimeters were not installed because of the method used to evaluate this system. This method is explained in more detail in the Results section for the waterless toilet/greywater system.

Water flow meters were installed in the two houses utilizing standard systems and waterless toilet/greywater system (sites A, B, and E). Pump counters, which tallied the number of dosing events, were installed at pressure-dosed sites C and D. Meters and counters were used to determine water usage by each household.

Lysimeters were prepared for soil moisture collection by applying a 65-100 cbar suction with a pressure/vacuum hand pump at least 20 hours prior to sample collection. This time was often insufficient for an adequate sample volume to collect, so the suction time was increased to a minimum of fourteen days, beginning with the ninth sample date. The data collected before and after this change in procedure were compared, and this comparison indicated that the increase in collection time did not apparently affect leachate sample quality; however, it was not possible to preserve the leachate within the lysimeters. Consequently, it is possible that biochemical reactions may have affected the chemical composition of the leachate regardless of the length of time the lysimeters were under suction. Possible reactions include nitrification, dentrification and bacterial protein synthesis. Lysimeter samples were extracted by pressurizing the lysimeter with a pressure-vacuum hand pump. Grab samples were collected from the pumping chambers of the pressure-dosed systems. The septic tanks of the standard and greywater systems were not accessible, so grab samples could not be collected from these tanks.

Samples were collected in clean glass bottles, immediately cooled, and promptly delivered to the laboratory for analysis. Samples were analyzed for TKN, NH_3-N, NO_2-N, NO_3-N, TPO_4, pH, and chloride using EPA methods [EPA, 1979]. Samples were analyzed for alkalinity using Standard Methods [American Public Health Association, 1976]. Samples were collected from September 7, 1983 to August 21, 1985 on a biweekly basis.

Home owners were provided with questionnaires which asked questions relating to water use and other factors which could influence the results of the study. Five of the six home owners completed the questionnaire. Information contained in responses did not indicate any extraordinary household conditions which would be likely to influence the results of the study.

RESULTS

Water quality data for samples collected from locations within standard and pressure-dosed systems were compared to determine changes in average concentrations occurring within each system. Of particular interest in this study are changes in the various species of nitrogen. Total nitrogen in a residential wastewater is comprised of varying amounts of ammonia-nitrogen (NH_3-N), organic-nitrogen, nitrite-nitrogen (NO_2-N), and nitrate-nitrogen (NO_3-N). Chemical analyses of these components are reported as NH_3-N, NO_2-N, NO_3-N, and TKN. TKN is the sum of [organic-N] + [NH_3-N]. Thus, total nitrogen is equal to [TKN] + [NO_3-N] + [NO_2-N]. The following statistical analyses were performed:

1. Absolute differences between average concentrations were compared for statistical significance using the student's t-test at the 0.05 level.

2. Because leachate was subject to dilution by infiltrating rainfall, a decrease in average TN concentration in leachate could be due to dilution rather than nitrogen removal. To control for dilution, CL/TN ratios were compared. Because chloride is a conservative ion species (it does not readily react in soil), an increase in the CL/TN ratio would indicate nitrogen removal. The CL/TN ratio was also used by Harkin [1979] as an indicator of nitrogen removal.

3. The percentage ratios of concentrations of three of the four nitrogen components studied were determined to provide a means of illustrating the differences in nitrogen species composition at the different sample points. Nitrite-nitrogen (NO_2-N) was not included in this statistical analysis because the average NO_2-N concentration was always less than 1% of the total nitrogen concentration.

4. An estimate of the apparent nitrogen reducing efficiency was calculated for each pressure-dosed system. This estimate took into account dilution by rainfall by considering changes in average chloride concentrations. The formula used to calculate apparent nitrogen reducing efficiency is

$$\%\ \text{N removal} = \frac{[TN1] - ([CL1] / [CL2] \times [TN2])}{[TN1]} \times 100\%$$

where:

[TN1] = avg TN concentration before potential effects of treatment and dilution (mg/l)

[TN2] = avg TN concentration after potential effects of treatment and dilution (mg/l)
[CL1] = avg Cl concentration before potential effects of dilution (mg/l)
[CL2] = avg Cl concentration after potential effects of dilution (mg/l)

5. Estimated hydraulic loading rates, based on recorded water usage and disposal field/bed design areas for sites A, B, C, D, and E are listed in Table 3.

TABLE 3. ESTIMATED HYDRAULIC LOADING RATES, SITES A,B,C,D,E.

SITE CODE	TYPE SYSTEM	AVG FLOW (GPD)	DISPOSAL FIELD AREA (FT2)	AVG LOADING (G/FT2/D)
A	STANDARD	304	284	1.07
B	STANDARD	311	300	1.04
C	PRESSURE-DOSED	186	520	0.36
D	PRESSURE-DOSED	167	400	0.42
E	WATERLESS	68	532	0.13

These rates indicate that the standard systems were subjected to higher loading rates than the pressure-dosed and greywater disposal systems studied. Differences in loading rates may have been useful in interpreting differences in nitrogen removal efficiences of systems. However, the data did not indicate any relationship between the loading rate and nitrogen removal efficiency.

Standard Systems

At the time of lysimeter installation in both standard systems, ponding of leachate was observed in bore holes, indicating the presence of a clogging mat or crust which develops with time at the gravel-soil interface in most disposal trenches. The shallow lysimeters, however, were installed just below this crust. Such crusts can be responsible for many treatment mechanisms and are generally regarded as beneficial. Crusts are discussed further in the Discussion section on pressure-dosed systems.

Water quality data for samples collected from lysimeters located at two depths, averaged over the period of study, for each standard system are listed in Table 4. Absolute differences, percent differences, and whether differences were statistically significant are also listed.

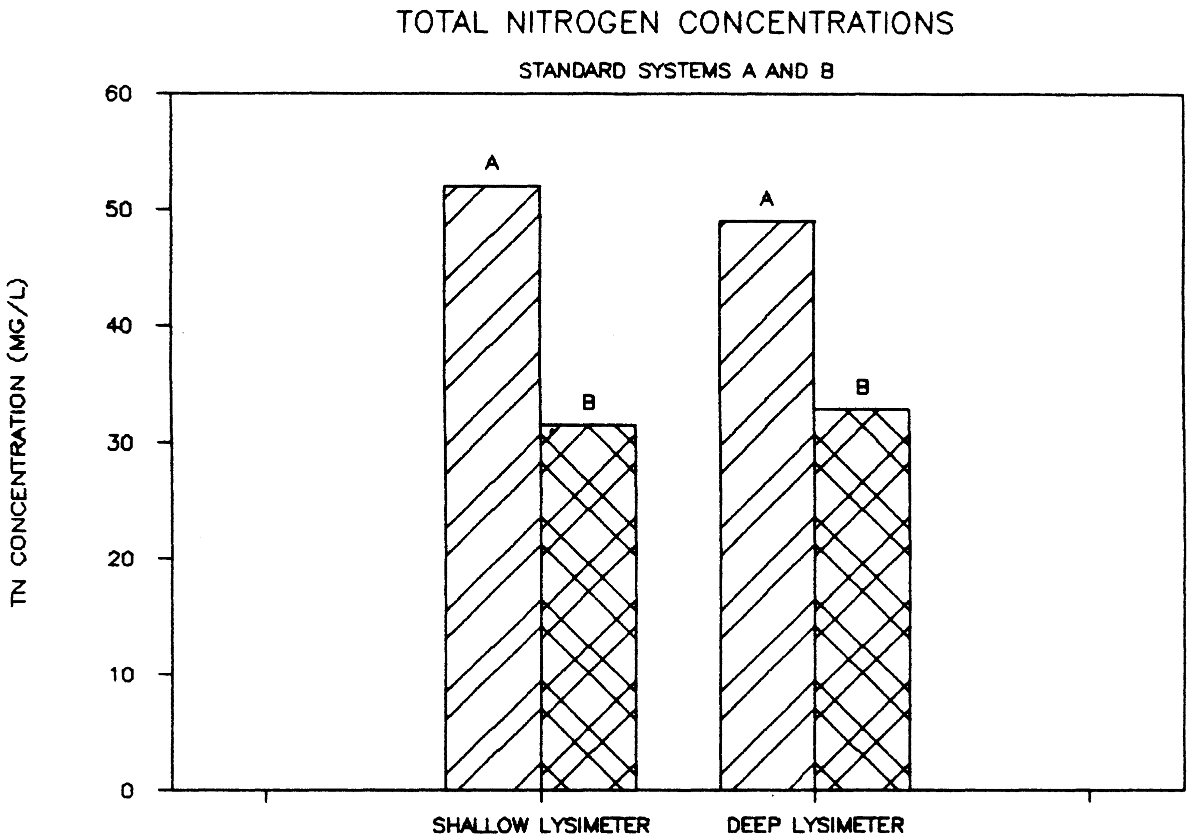

FIGURE 2. AVERAGE TOTAL NITROGEN CONCENTRATIONS IN STANDARD SYSTEMS A AND B

Standard system A:

Leachate quality of samples from the shallow lysimeter was different from typical domestic wastewater quality in that the nitrogen was mostly NO_3-N with little NH_3-N. This indicates that the effluent had already largely undergone nitrification by the time it reached the deep lysimeter. While the nitrogen species ratio did not change substantially with depth, significant absolute decreases with depth were observed in TKN, NO_2-N, NH_3-N, and pH. Decreases with depth were not observed in TN, NO_3-N, or TPO_4. Alkalinity comparisons were not possible for this system because the pH of leachate below the trench was always lower than the titration endpoint pH in alkalinity analysis. Chloride comparisons and CL/TN comparisons were not possible because deep lysimeter sample volumes were always insufficient for laboratory chloride analysis. On the basis of TN concentrations and NO_3-N concentrations, no evidence of nitrogen removal was observed below the disposal field of this system.

Standard system B:

Leachate quality of samples from the shallow lysimeter more closely resembled typical domestic wastewater quality in that total nitrogen was mostly NH_3-N with little NO_3-N. Deep lysimeter leachate had been largely nitrified, indicated by an absolute increase in NO_3-N and an absolute decrease in NH_3-N. Because hydrogen ions are generated in the nitrification process, the observed decrease in pH (reflecting a hydrogen ion increase) also indicates nitrification. Nitrification is further indicated by the change in the nitrogen species ratio; the NO_3-N percentage of TN increased from 9% to 95% while the NH_3-N percentage of TN decreased from 80% to 2%. Significant absolute decreases with depth were also observed in TKN, TPO_4, and alkalinity. Significant decreases with depth were not observed in TN, NO_2-N, or CL.

The CL/TN ratio increased with depth. However, because no significant changes with depth in CL or TN were observed, the change in CL/TN ratio is not considered significant. The ratio change with depth is almost entirely due to anomalous CL concentrations observed in the deep lysimeter on a few occasions late in the study.

On the basis of TN concentrations alone then, no evidence of nitrogen removal was observed below the disposal field of this system.

Pressure-dosed Systems

Water quality data for samples collected from pumping chambers, shallow lysimeters, and deep lysimeters, averaged over the study period, are listed in Tables 6-8. For each site, pumping chamber effluent is compared with shallow lysimeter leachate at the top of the table, and shallow lysimeter leachate is compared with deep lysimeter leachate at the bottom of the table.

A comparison of total nitrogen concentrations, at the three sample locations for the three pressure-dosed sites is shown graphically in Figure 3. Nitrogen species ratios are listed in Table 9. Estimates of apparent nitrogen removal efficiency are listed in Table 10. Estimated hydraulic loading rates, based on recorded pump counter data, dosing event design volume, and disposal field design areas for sites C and D are listed in Table 5. Pump counter data were not available for site F, so the hydraulic loading rate of this system could not be estimated.

TABLE 6. AVERAGE CONCENTRATIONS AND pH VALUES FOR PRESSURE-DOSED SITE C.

CONCENTRATION UNITS = MG/L

	TN	TKN	NO_3-N	NO_2-N	NH_3-N	TPO_4	CL	CL/TN	ALK	pH (units)
PUMPING CHAMBER	46.2	46.2	0.1	0.03	38.3	12.2	23.2	0.4	238.7	7.2
SHALLOW LYSIMETER	5.8	1.0	4.7	0.01	0.2	0.1	6.3	1.1	220.1	6.7
DIFFERENCE (mg/l)	-40.4	-45.2	4.7	-0.02	-38.1	-12.1	-16.9	*****	-18.6	-0.5
DIFFERENCE (%)	-87.4	-97.8	9320.0	-66.7	-99.4	-99.2	-72.8	*****	-7.8	*****
SIGNIF @ 0.05 LEVEL	*	*	*	*	*	*	*	*****	*	
SHALLOW LYSIMETER	5.8	1.0	4.7	0.01	0.2	0.10	6.3	1.1	220.1	6.7
DEEP LYSIMETER	10.1	0.9	8.8	0.01	0.2	0.06	7.3	1.0	107.5	7.0
DIFFERENCE (mg/l)	4.3	-0.1	4.1	0.00	-0.1	-0.04	1.0	*****	-112.6	0.3
DIFFERENCE (%%)	73.5	-7.9	86.4	0.0	-22.7	-40.0	15.2	*****	-51.1	*****
SIGNIF @@ 0.05 LEVEL	*		*					*****	*	

***** INDICATES THAT EITHER DATA WERE NOT AVAILABLE OR THE STATISTIC DOES NOT APPLY
*   INDICATES THAT THE DIFFERENCE IN AVG CONCENTRATIONS IS STATISTICALLY SIGNIFICANT

TABLE 7. AVERAGE CONCENTRATIONS AND pH VALUES FOR PRESSURE-DOSED SITE D

CONCENTRATION UNITS = MG/L

	TN	TKN	NO_3-N	NO_2-N	NH_3-N	TPO_4	CL	CL/TN	ALK	pH (units)
PUMPING CHAMBER	54.3	54.2	0.01	0.03	47.9	12.7	31.9	0.7	254.8	7.3
SHALLOW LYSIMETER	19.3	1.6	17.9	0.01	0.2	0.8	24.3	1.8	27.5	6.4
DIFFERENCE (mg/l)	-34.9	-52.7	17.9	-0.02	-47.7	-12.0	-7.6	*****	-227.2	-1.0
DIFFERENCE (%)	-64.4	-97.1	2E+05	-66.7	-99.5	-93.8	-23.9	*****	-89.2	*****
SIGNIF @ 0.05 LEVEL	*	*	*	*	*	*		*****	*	*
SHALLOW LYSIMETER	19.3	1.6	17.9	0.01	0.2	0.8	24.3	1.8	27.5	6.4
DEEP LYSIMETER	29.7	0.6	30.2	0.01	0.2	0.03	34.0	1.1	1.5	5.1
DIFFERENCE (mg/l)	10.4	-0.9	12.3	0.0	0.0	-0.8	9.8	*****	-26.0	-1.2
DIFFERENCE (%)	53.8	-59.9	68.7	0.0	0.0	-96.2	40.4	*****	-94.6	*****
SIGNIF @ 0.05 LEVEL	*		*			*	*	*****	*	*

***** INDICATES THAT EITHER DATA WERE NOT AVAILABLE OR THE STATISTIC DOES NOT APPLY
*   INDICATES THAT THE DIFFERENCE IN AVG CONCENTRATIONS IS STATISTICALLY SIGNIFICANT

TABLE 8. AVERAGE CONCENTRATIONS AND pH VALUES FOR PRESSURE-DOSED SITE F

CONCENTRATION UNITS = MG/L

	TN	TKN	NO_3-N	NO_2-N	NH_3-N	TPO_4	CL	CL/TN	ALK	pH (units)
PUMPING CHAMBER	46.3	46.2	0.01	0.02	41.8	6.1	31.8	0.6	216.5	7.1
SHALLOW LYSIMETER	17.0	3.3	13.1	0.01	0.3	0.03	23.1	1.3	0.0	4.1
DIFFERENCE (mg/l)	-29.3	-43.0	13.1	-0.01	-41.5	-6.1	-8.7	*****	-216.5	-2.9
DIFFERENCE (%)	-63.2	-92.9	1E+05	-50.0	-99.2	-99.5	-27.3	*****	-100.0	*****
SIGNIF @ 0.05 LEVEL	*	*	*	*	*	*		*****	*****	*
SHALLOW LYSIMETER	17.0	3.3	13.1	0.01	0.3	0.03	23.1	1.3	0.0	4.1
DEEP LYSIMETER	9.5	0.5	10.0	0.01	0.1	0.01	12.9	1.3	0.4	4.4
DIFFERENCE (mg/l)	-7.5	-2.8	-3.1	0.0	-0.3	-0.02	-10.3	*****	0.4	0.3
DIFFERENCE (%)	-44.0	-84.8	-23.5	0.0	-79.4	-66.7	-44.4	*****	*****	*****
SIGNIF @ 0.05 LEVEL	*					*		*****	*****	*

***** INDICATES THAT EITHER DATA WERE NOT AVAILABLE OR THE STATISTIC DOES NOT APPLY

* INDICATES THAT THE DIFFERENCE IN AVG'CONCENTRATION IS STATISTICALLY SIGNIFICANT

TABLE 9. TN : NH_3-N : ORG-N : NO_3-N PERCENTAGE RATIOS, PRESSURE-DOSED SYSTEMS

	SITE C	SITE D	SITE F
PUMPING CHAMBER	100 : 83 : 17 : 0	100 : 88 : 12 : 0	100 : 90 : 10 : 0
SHALLOW LYSIMETER	100 : 4 : 14 : 81	100 : 1 : 7 : 93	100 : 2 : 17 : 77
DEEP LYSIMETER	100 : 2 : 8 : 87	100 : 1 : 1 : 102	100 : 1 : 5 : 105

TABLE 10. ESTIMATES OF APPARENT NITROGEN REMOVAL EFFICIENCIES OF PRESSURE-DOSED SYSTEMS

AVG APPARENT REMOVAL BETWEEN PUMPING CHAMBER AND SHALLOW LYSIMETER

	TN1	TN2	CL1	CL2	% REMOVAL
SITE C	46.2	5.8	23.2	6.3	54
SITE D	54.3	19.3	31.9	24.3	53
SITE F	46.3	17.0	31.8	23.1	49

AVG APPARENT REMOVAL BETWEEN SHALLOW AND DEEP LYSIMETERS

	TN1	TN2	CL1	CL2	% REMOVAL
SITE C	5.8	10.1	6.3	7.3	-50
SITE D	19.3	29.7	24.3	34.0	-10
SITE F	17.0	9.5	23.1	12.9	0

AVG APPARENT OVERALL REMOVAL BETWEEN PUMPING CHAMBER AND DEEP LYSIMETERS

	TN1	TN2	CL1	CL2	% REMOVAL
SITE C	46.2	10.1	23.2	7.3	31
SITE D	54.3	29.7	31.9	34.0	49
SITE F	46.3	9.5	31.8	12.9	49

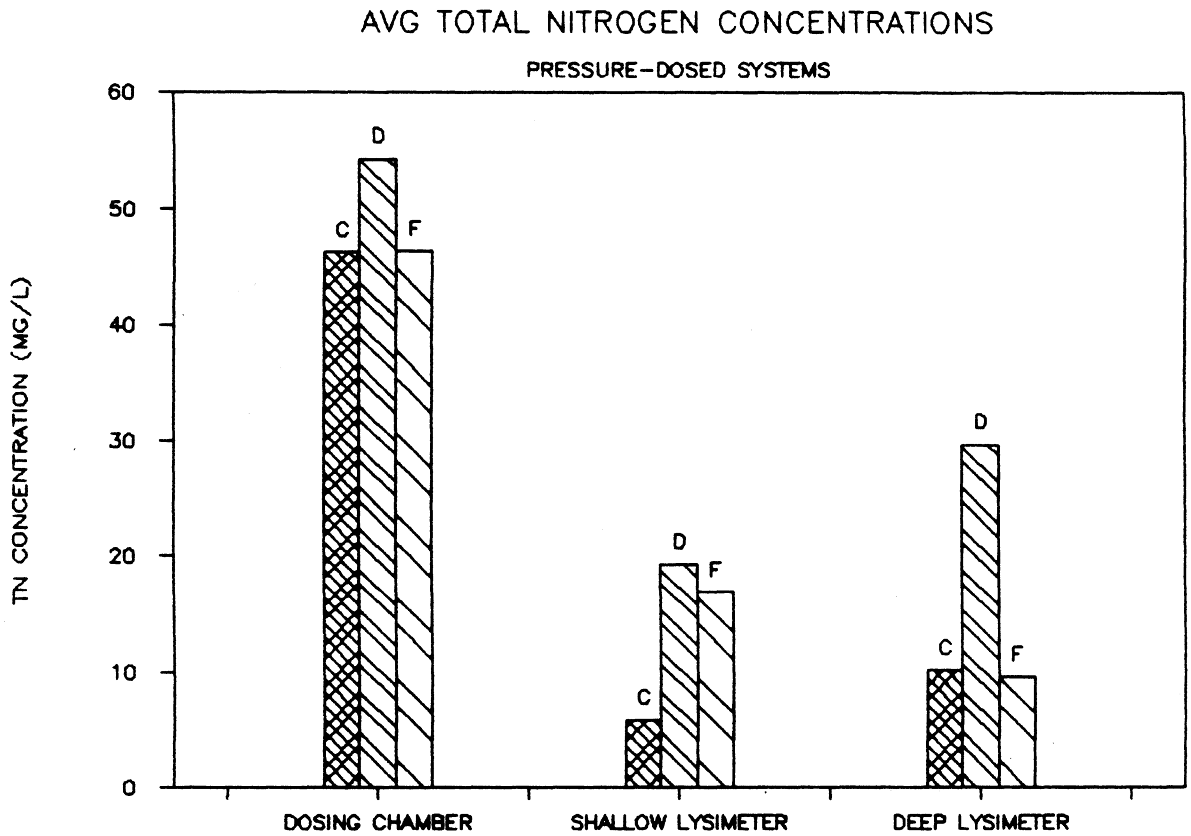

FIGURE 3. AVERAGE TOTAL NITROGEN CONCENTRATIONS IN PRESSURE-DOSED SYSTEMS C, D AND F

Pressure-dosed site C:

Observed pumping chamber effluent quality was similar to typical domestic wastewater quality in that nitrogen was mostly NH_3-N with little NO_3-N. Between the pumping chamber and the shallow lysimeter, significant decreases were observed in TN, TKN, NO_2-N, NH_3-N, TPO_4, alkalinity and CL. A significant increase in NO_3-N was observed. No significant change in pH was observed. The CL/TN ratio increased, indicating nitrogen removal between the pumping chamber and the shallow lysimeter.

Betweeen the shallow and deep lysimeters, the only significant decrease with depth observed was in alkalinity. Significant increases with depth were observed in TN and NO_3-N, while no significant changes with depth were observed in TKN, NO_2-N, NH_3-N, TPO_4, CL, or pH. The CL/TN ratio decreased with depth, indicating a nitrogen increase with depth.

The nitrogen species ratios indicate a shifting with depth from organic-N and NH_3-N to NO_3-N.

Analysis of TN and CL concentrations in pumping chamber effluent and deep lysimeter leachate indicates an overall apparent nitrogen removal efficiency of 31%, all of which occurred between the pumping chamber and the shallow lysimeter.

Pressure-dosed site D:

Observed pumping chamber effluent quality was similar to typical domestic wastewater quality in that nitrogen was mostly NH_3-N with little NO_3-N. Between the pumping chamber and the shallow lysimeter, significant decreases were observed in TN, TKN, NH_3-N, TPO_4, alkalinity and pH.

A significant increase in NO_3-N was observed. No significant change in CL was observed. The CL/TN ratio increased, indicating nitrogen removal between the pumping chamber and the shallow lysimeter.

Between the shallow and deep lysimeters, significant decreases with depth were observed in alkalinity, pH and TPO_4. Significant increases with depth were observed in TN, NO_3-N and CL. No significant changes with depth were observed in NO_2-N, NH_3-N, or TKN. The CL/TN ratio decreased with depth, indicating a nitrogen increase with depth.

The nitrogen species ratios indicate a shifting with depth from organic-N and NH_3-N to NO_3-N.

An analysis of TN and CL in pumping chamber effluent and deep lysimeter leachate indicates an overall apparent nitrogen removal efficiency of 49%, all of which occurred between the pumping chamber and the shallow lysimeter.

Pressure-dosed site F:

Observed pumping chamber effluent quality was similar to typical domestic wastewater quality in that nitrogen was mostly NH_3-N with little NO_3-N. Between the pumping chamber and the shallow lysimeter, significant decreases were observed in TN, TKN, NO_2-N, NH_3-N, TPO_4 and pH. A significant increase in NO_3-N was observed. No significant change was observed in CL. The CL/TN ratio increased, indicating nitrogen removal between the pumping chamber and the shallow lysimeter.

Between the shallow and deep lysimeters, significant decreases with depth were observed in TN and TPO_4. A significant increase with depth in pH was observed. No significant changes with depth were observed in TKN, NO_3-N, NO_2-N, NH_3-N or CL. The CL/TN ratio did not change substantially with depth, indicating no nitrogen increase or decrease.

The nitrogen species ratios indicate a shifting with depth from NH_3-N to NO_3-N.

An analysis of TN and CL in pumping chamber effluent and deep lysimeter leachate indicates an overall apparent nitrogen removal efficiency of 49%, all of which occurred between the pumping chamber and the shallow lysimeter.

Nitrogen Loading

One of the assumptions tested is the per capita nitrogen loading on septic systems in the Pinelands. The value currently accepted is 11.2 g/capita/day [EPA, 1980]. Using the number of regular inhabitants, the dosing frequency, the dosing event design volume and pumping chamber effluent quality data, the per person nitrogen loading rates for two of the systems were estimated. One of the homes was occupied by two different families (C1 and C2) at different times, so separate nitrogen loading estimates are given for each of these households.

Household	TN Loading (g/person/day)
C1	9.9
C2	8.4
D	17.2

The average of these three values is 11.8 g/person/day. The 11.2 g/person/day value currently assumed falls within a 95% confidence interval for this estimate. This means that the observed average nitrogen loading rate was not significantly different from the accepted value. The data also indicate that the per capita nitrogen loading rate in the Pinelands may vary widely from household to household.

Waterless Toilet/Greywater System

Site E:

In order to evaluate the effectiveness of the waterless toilet/greywater system in reducing the amount of nitrogen entering the subsurface environment, it was necessary to determine the amount of nitrogen present in the greywater. This was done by collecting soil moisture samples from lysimeters installed just below the bottom of the disposal bed. The lysimeters were not installed at different depths in this system because nitrogen removal beneath the disposal bed was not expected to be significant. The solid toilet waste end-product was assumed not to contain significant amounts of soluble nitrogen. Samples from a lysimeter installed beneath the end-product pile were collected as a check on this assumption.

Water quality data for samples collected from the greywater disposal bed lysimeters and the end-product pile lysimeter, averaged over the period of study, are listed in Table 11. Of particular interest are the exceptionally high nitrogen species concentrations in end-product leachate samples. The greywater leachate total nitrogen concentrations averaged 4.3 mg/l. Dilution of the leachate by infiltrating rainfall may have affected this result.

In order to approximately quantify the amount of dilution which took place, a water budget for the disposal field was calculated using water usage data, the disposal field area, and climatalogical data. The average hydraulic loading rate from greywater over the period of study was 0.13 gallons/ft^2/day, or 0.21 inches/day. The average infiltration rate (precipitation minus actual evapotranspiration) over the period of study was about 0.06 inches/day (Hughes et al, 1985). Thus, infiltrating precipitation diluted the leachate by an approximate factor of 1.3. Assuming negligible nitrogen in precipitation, it can then be estimated that the average total nitrogen concentration of greywater, prior to release to the subsurface, was more likely between 5 and 6 mg/l. Using the value of 5.5 mg/l and the water usage data, the per capita greywater nitrogen loading can be roughly estimated:

AVG GREYWATER TN LOADING = AVG TN CONC x AVG WATER USE

= 5.5 mg/l x 117.3 l/person/day x 1 gm/1000 mg

= 0.6 gm N/person/day.

Table 11. AVERAGE CONCENTRATIONS AND pH VALUES FOR WATERLESS/GREYWATER SYSTEM E

CONCENTRATION UNITS = MG/L

	TN	TKN	NO3-N	NO2-N	NH3-N	TPO4	CL	ALK	pH (units)
SHALLOW LYSIMETER #1	4.8	2.4	2.2	0.02	1.0	3.8	63.7	185.5	6.9
SHALLOW LYSIMETER #2	3.8	2.7	2.1	0.02	1.7	4.4	71.5	200.9	6.8
COMPOST LYSIMETER	294.6	156.8	141.6	4.6	104.9	26.2	*****	135.6	6.4

***** INDICATES THAT DATA WERE NOT AVAILABLE

EPA [1980] estimates that 17% of the estimated 11.2 grams of nitrogen generated per person per day is disposed with greywater. This equals 1.9 grams/person/day. The 0.6 grams/person/day estimated for this system is lower than that estimated by EPA.

The household utilized two waterless toilets until 5/21/85 when they were replaced by two standard flush toilets after a fire had destroyed one of the bathrooms. Based on the size of the lot, the dwelling still met the 2 ppm nitrate-nitrogen requirement contained in the Pinelands Comprehensive Management Plan. After this date, toilet wastewater was discharged into what was formerly the greywater disposal bed, so the system was then no longer considered a waterless toilet/greywater system. Data collected after this date were excluded from the previously noted statistical analyses. Following 5/21/85, the observed average total nitrogen concentration in the disposal bed leachate increased from 4.3 mg/l to 21.7 mg/l.

A comparison of TN concentrations in the shallow lysimeters of all six systems of various designs is depicted in Figure 4.

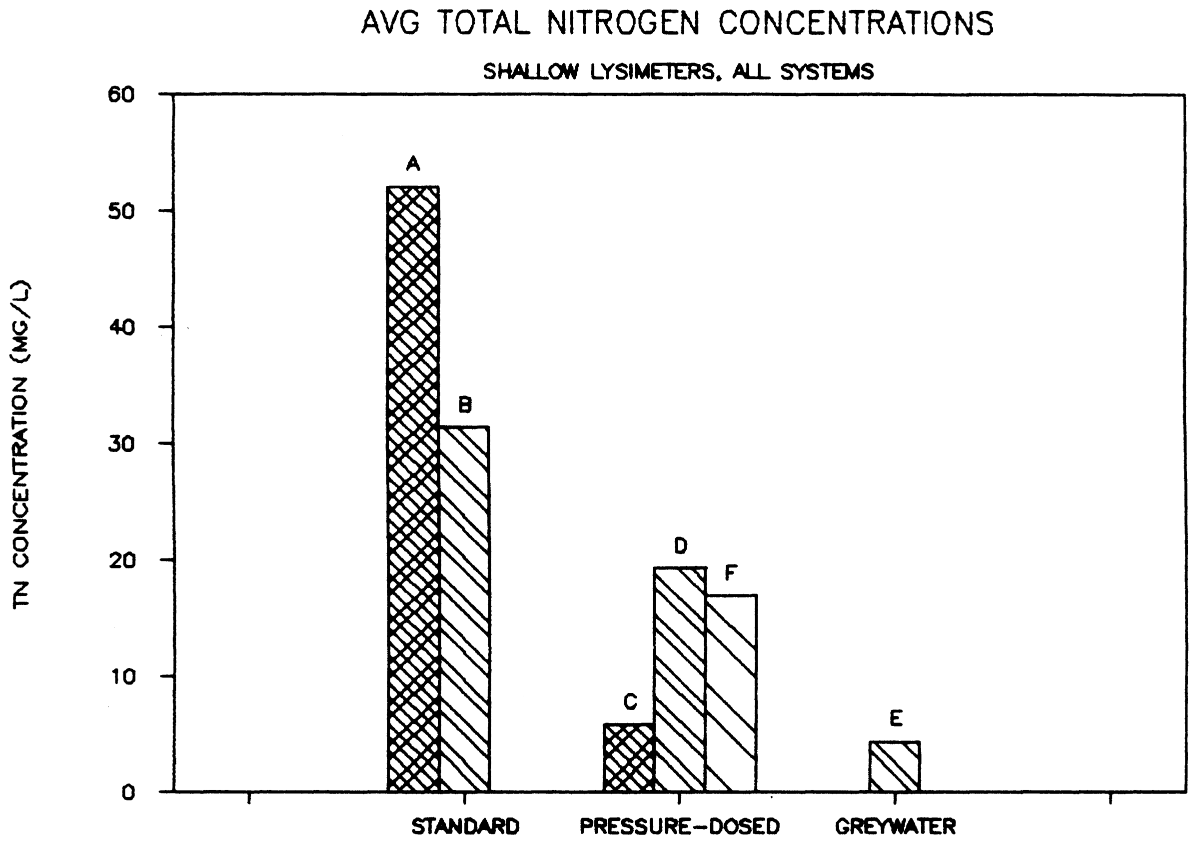

FIGURE 4. AVERAGE TOTAL NITROGEN CONCENTRATIONS IN SHALLOW LYSIMETERS, ALL SYSTEMS

DISCUSSION

Standard Systems

While the leachate quality in the shallow lysimeters in the two standard systems differed considerably in TKN, NO_3-N, pH and alkalinity, the leachate quality in the deep lysimeters of both systems was similarly low in TKN, NO_2-N, NH_3-N, pH and alkalinity, and high in NO_3-N. In neither system was evidence of nitrogen removal with depth observed. It is unfortunate that septic tank samples could not be obtained at these sites, because such samples would have indicated whether or not nitrogen was removed between the tank and the trench bottom, as was observed in the pressure-dosed systems studied. The data do tend to corroborate the conclusion of other investigators that nitrogen removal by denitrification in standard septic systems in sandy soils is unlikely [Walker, 1973, Kristiansen, 1981].

Significant phosphate removal was observed in system B but not in system A. This could be due to the difference in soils; System B was located in a Downer loamy sand, which is expected to have a greater phosphorus adsorption capacity than the Evesboro fine sand of system A. Again, however, the phosphate content of the septic tank effluent was not known for either system, so any phosphate removal between the tank and the shallow lysimeters could not be determined. Another contributing factor could be the difference in pH in the shallow lysimeters. The pH at this point in System A was low (4.2). At a pH of about 4, the phosphate is probably soluble rather than adsorbed, and would not be retained.

Pressure-Dosed Systems

Observed changes in effluent and leachate quality were similar among the three pressure-dosed systems. In general, nitrogen in pumping chamber effluent was mostly ammonia-N and organic-N, with little NO_2-N or NO_3-N. The pH was about 7. Alkalinity was above 200 mg/l. Significant decreases in TN, TKN, NO_2-N, NH_3-N, TPO_4 and alkalinity, and a significant increase in NO_3-N were observed between pumping chambers and shallow lysimeters of all three systems. A decrease in pH was observed in two of the three systems. The increase in NO_3-N indicates that the effluent had undergone considerable nitrification. CL/TN ratios increased in all three systems, indicating nitrogen removal between the pumping chambers and the shallow lysimeters. This result was unanticipated because nitrogen removal was expected to occur below the depth of the shallow lysimeters, as was observed by Harkin [1979], rather than between the pumping chambers and the shallow lysimeters. Between the shallow and deep lysimeters, TN and NO_3-N increased in two of the systems while continuing to decrease in the other. Alkalinity continued to decrease with depth in these. Other than these changes, the leachate quality remained relatively stable with depth.

A variety of physical, chemical, and biological processes may have contributed to the unanticipated nitrogen removal between the pumping chamber and shallow lysimeter in each of these systems. Nitrogen must be in either nitrate or nitrite form in order to undergo denitrification. As nitrate was found in shallow lysimeter leachate, it is conceivable that denitrification had taken place within the trench itself. It is more probable, however, that nitrogen was accumulating in the trench, perhaps in a crust which is common in standard septic systems. Crusts in standard septic systems typically consist of adsorbed ammonium-nitrogen, organic solids, and bacterial cell matter, living and dead [Laak, 1980]. Nitrogen accumulation is thus a possible "temporary" removal mechanism in both standard and pressure-dosed systems. It is possible that denitrification occurred within the lysimeters themselves, because of the detention time prior to sampling, and the fact that samples could not be preserved within the lysimeters.

Walker [1973] found that a large amount of nitrogen in septic tank effluent is retained in the crust in standard septic systems, and that the amount retained increases with the age of the system. Laak [1980] observes that eventually the build-up and breakdown of the crust reaches a state of equilibrium. The time required for a crust to reach equilibrium is probably highly dependent on site-specific conditions. The extent of completed research in this area is unknown.

Harkin [1979] described the excavation of several pressure-dosed mound systems in his study. After two years of operation, none of the systems had developed a "mature" crust, which he attributes to effluent dosing, as opposed to effluent trickling in standard systems. However, while mature crusts were not found in Harkin's study, the pressure-dosed mound systems in that study exhibited a high capacity for immobilizing organic-nitrogen and ammonia-nitrogen. It was not reported whether the nitrogen accumulation within the systems had reached a maximum or whether it was still increasing after two years.

No attempt was made in this study to directly examine organic and ammonium-nitrogen accumulations within the systems, nor was it possible to excavate the systems to determine whether crusts had developed. Consequently, it cannot be determined whether the apparent nitrogen removal was due to denitrification, accumulation, or both. It also cannot be determined whether nitrogen removal can be expected to continue in these systems after accumulation and mineralization of nitrogen in the trench and select fill reach a steady-state. A long-term study extending for several years would be required to make these determinations.

Waterless Toilet/Greywater System

Observed greywater leachate quality was similar to the quality of greywater in an Ontario household as reported by Brandes [1978], with the exception of lower TKN and TN concentrations. According to EPA [1980] the total nitrogen concentration of greywater is expected to be about 17 mg/l. This value is higher than the 11.5 mg/l from Brandes [1978], the 6.5 mg/l reported by Olsson [1968] or the 4.3 mg/l in greywater leachate found in this study. Dilution of the greywater by infiltrating rainfall may have affected this result. The undiluted TN concentration of the greywater was probably closer to 5 or 6 mg/l. Direct sampling of the greywater septic tank was not possible.

The observed total nitrogen concentration of toilet waste end-product leachate from this system was much higher than expected. The average TN concentration of 295 mg/l indicates that the removal of nitrogen from toilet wastes by composting and evaporation was certainly not complete. Further evidence that the composting process was incomplete prior to removal from the house is that the compost deposited on the pile beginning in September, 1984 more closely resembled raw human waste than compost in appearance. It was the end-product leachate collected after these deposits which exhibited the high nutrient concentrations. The end-product pile was situated in a wooded area which would not have been affected by lawn fertilization.

It is not clear why this system did not apparently remove nitrogen from toilet wastes efficiently. The manufacturer's specifications for this particular toilet indicate that one toilet can handle the load from four adults year-round. In the household studied, two identical toilets serviced two adults year round. The owners stated that toilet use was divided approximately equally between the two toilets. Thus, it can be assumed that in this case, the toilets were used at about one quarter the manufacturer - specified rate. The manufacturer also specifies that a toilet will need to be emptied only once or twice a year with normal use. However, the owners needed to empty both toilets more frequently despite the lower per unit use due to the build-up of waste material. It appears to be a strong possibility that the manufacturer's specified capacity for this toilet is over-estimated. However, it should be noted that this study did not include other waterless toilet designs which may perform satisfactorily. No attempt was made to actually quantify the nitrogen removal efficiency of the composting process.

CONCLUSIONS

Two standard septic systems, three pressure-dosed septic systems, and one waterless toilet/greywater system were sampled biweekly for a period of two years to determine the relationships between nutrient concentrations of effluent and leachate and to test certain assumptions used to predict the impact of such systems on ground water quality in the New Jersey Pinelands.

As leachate moved downward through standard disposal fields, pH decreased. As expected, no evidence of nitrogen removal was observed below the disposal fields of the standard systems. The average nitrate-nitrogen concentrations of deep lysimeter leachate samples from two standard disposal fields were 46.3 and 31.2 mg/l.

As leachate moved downward through pressure-dosed disposal fields, nitrate-nitrogen increased and pH decreased. Contrary to what was expected, no evidence of nitrogen removal was observed below the disposal fields of the pressure-dosed systems. The average nitrate-nitrogen concentrations of deep lysimeter leachate samples from three pressure-dosed fields were 8.8, 30.0 and 10.0 mg/l. These conclusions corroborate that of Brown [1980], that "dilution is an essential mechanism for reducing the impacts of nitrogen originating from on-site wastewater disposal systems in the Pinelands." Evidence of nitrogen removal was, however, observed between the pumping chamber and shallow lysimeters in each of the three pressure-dosed systems. This removal may have been due to denitrification or accumulation of nitrogen within the disposal field. Of these two possibilities, the latter is more likely. If the nitrogen removal in these systems was in fact due to accumulation, and the capacity of the disposal field to accumulate nitrogen is reached with time, then the nitrogen reducing efficiency of the system would be expected to decrease with time. The overall (perhaps temporary) nitrogen reducing efficiencies of the three pressure-dosed systems for the period of study were 31%, 49% and 49%. The average of observed per person nitrogen loading rates for three of the households studied was not significantly different from the value of 11.2 g/person/day currently accepted for predictive purposes. The data indicate, however, that this rate may vary widely from household to household.

The total nitrogen concentration of greywater leachate was lower than expected. Nutrient concentrations of waterless toilet solid end-product leachate were much higher than expected, indicating that waterless toilet solid end-product could have a significant impact on ground-water quality. Following the replacement of waterless toilets with standard flush toilets, the average total nitrogen concentration in shallow lysimeter leachate increased substantially.

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