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Nitrogen and Fecal Coliform Removal in Wisconsin Mound System

by

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NITROGEN AND FECAL COLIFORM REMOVAL IN WISCONSIN MOUND SYSTEM

J.C. Converse, E.J. Tyler, S.G. Litman*

ABSTRACT

Thirteen Wisconsin mound systems were evaluated for treatment effectiveness. Soil samples were collected from beneath the system at two locations at 15 cm (6 in.) increments to a depth of 105 cm (42 in.) beneath the aggregate. Adjacent soil samples were taken for background. The soil samples were analyzed for fecal coliforms, moisture content, TKN, ammonium, nitrate and chlorides. Fecal coliform concentrations at 103 MPN/g of dry soil, nitrate nitrogen concentrations of 34 mg N/L and chloride concentrations at 454 mg/L were found exiting the mound treatment area which was identified as 90 cm (3 ft) beneath the aggregate.

KEYWORDS: Wastewater treatment, Mounds, Fecal coliform, Nitrogen, Soils.

INTRODUCTION

The Wisconsin mound system was developed in the early 1970s to overcome problems of subsurface wastewater infiltration systems in selected soils. The Wisconsin mound has been incorporated into many local and state codes. A siting, design and construction manual was developed to aid professionals in using Wisconsin mound systems (Converse and Tyler, 1990).

Harkin et al. (1979) evaluated treatment effectiveness of Wisconsin mound systems. Converse and Tyler (1992) found very low levels of fecal coliforms in the effluent in mound toes during periods of seasonal saturation. Converse et al. (1992) reported on the treatment effectiveness of Wisconsin at-grade wastewater infiltration systems where fecal coliform counts were low at 90 cm (3 ft) beneath the aggregate/soil interface but not as low as found beneath systems that had mature clogging mats. Based on the at-grade results, a study was initiated on the treatment effectiveness of the Wisconsin mound system in removing nitrogen and fecal coliforms from the wastewater before it entered the groundwater.

MATERIALS AND METHODS

Thirteen mound systems were selected for evaluation. Sampling procedures, similar to those used in the at-grade evaluation (Converse et al., 1992), were followed since unsaturated conditions normally exist beneath the Wisconsin mound. At two locations in each mound, sand/soil cores were taken in 15 cm (6 in.) increments starting at the sand/aggregate interface to a depth of 105 cm (42 in.). Similarly, soil cores, taken in 15 cm (6 in.) increments were taken at two locations in the native soil adjacent to the mound.

The procedure consisted of 1) locating an orifice in the pressure distribution pipe, 2) inserting a 15 cm (6 in.) PVC casing into the sand/aggregate interface while removing the aggregate within the casing, (if ponding was present, the casing was pressed several centimeters into the sand and the effluent pumped from within the casing), 3) extracting soil cores using a sterilized metal tube [2.5 cm (1 in.) diameter by 15 cm (6 in.) long], and 4) taking soil cores at the same

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location using a 7.5 cm (3 in.) bucket auger for chemical analysis. Procedures 3 and 4 were repeated every 15 cm (6 in.) increment to a depth of 105 cm (42 in.) below the sand fill/aggregate interface. After sampling, the hole was filled with similar soil, sand fill or aggregate and the system restored to its original condition. The same procedure was followed for the two adjacent profiles except a bacterial sample was taken only from the top 15 cm (6 in.). A pump chamber effluent sample was collected for analysis of fecal coliforms and other standard wastewater parameters.

In the laboratory, a representative soil sample was taken from the metal tube, mixed and analyzed for fecal coliforms, moisture content and chlorides. Soil samples, collected for chemical analysis, were stored in a plastic bag and frozen for later analysis of moisture content, total kjeldahl nitrogen (TKN), ammonia and nitrates. If a core intersected the sand/soil interface, the sample was subdivided into sand and soil components with analysis conducted on each component. Depths of each component were recorded and each were treated as separate entities. All analyses, except for chlorides, were conducted according to procedures in Standard Methods for the Examination of Water and Wastewater (APHA, 1985) and Methods of Soil Analysis (ASA, 1982). Chloride analysis was conducted using an automatic coulometric/ amperametric chloride titrator.

RESULTS AND DISCUSSION

Effluent Characteristics

Table 1 gives the average influent characteristics of the septic tank effluent based on one grab sample taken from the 13 pump chambers at the time the mounds were sampled. These data are similar to typical septic tank effluent with average values for TKN and fecal coliforms of 53 mg N/L and 3.12×10^6 counts/100 ml, which are very similar to values reported by Converse et al. (1991).

Sand/Soil Characteristics and Distances

Mound fill sands were either medium or coarse sand. The soil was typically a silt loam to clay loam soil over a silt loam to clay loam subsoil with seasonal high water table within a few inches of the ground surface at some time during the year.

Table 1. Septic Tank Effluent Characteristics for 13 Residential Sites Based on One Grab Sample Taken from the Pump Chamber at the Time of the Mound Evaluation.

Parameter	Units	Sample Size	Average	Std Dev	Range
Total Solids	mg/L	12	1268	628	607 - 2959
Vol. Solids	mg/L	12	273	948	169 - 517
Susp. Sol.	mg/L	12	41	26	13 - 108
V. Susp. Sol.	mg/L	12	29	15	12 - 66
BOD ₅	mg/L	8	111	58	43 - 203
COD	mg/L	12	228	853	118 - 346
TOC	mg/L	8	61	34	16 - 135
Org. Nit.	mg N/L	12	10	5	6 - 24
Ammonium	mg N/L	12	43	15	21 - 77
Chloride	mg/L	13	417	467	41 - 1350
EC	umho/cm	13	2288	1277	980 - 5600
pH	-	5	7.6	0.4	7.1 - 9.1
Total Coli.	#/100 ml	13	3.4E7	6.4E7	4.5E5 - 2.1E8
Fecal Coli.	MPN/100 ml	13	3.1E6	4.9E6	9.5E4 - 1.7E7

in Fig. 1. The surface soil materials are relatively uniform from site to site and none are estimated to be saturated. The surface materials are silt loam or silty clay loam texture. Deeper in the soil the variability of characteristics from site to site increases and the probability of soil saturation increases. From 15 cm to 60 cm (6-24 in.) soil textures ranged from silt loam to clay.

Below 60 cm (2 ft.) variability of soil texture among sites increased. Soil structure or consistence was seldom reported. However, it is believed that surface horizons have moderate grade of structure. Shallowest soil saturation was estimated at about 13 cm (5 in.) from original grade. However, in some cases estimated soil saturation was deeper than the observation pit. The most common estimated shallowest depth to soil saturation was between 20 and 50 cm (8-20 in.).

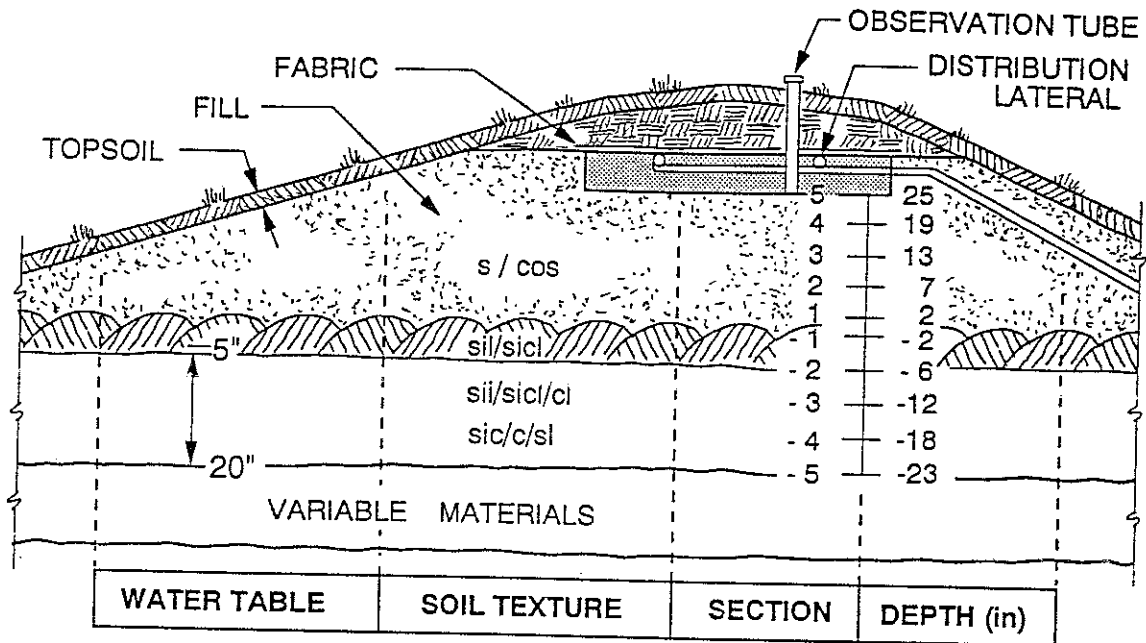


Figure 1. Cross Section of Wisconsin Mound Showing Relation of Sampling Increments with Reporting Sections, Selected Soil Characteristics and Range of Estimated Shallowest Soil Saturation.

The distance from the sand fill/aggregate interface to the sand fill/soil interface varied from mound to mound and within each mound with an average sand fill depth at 48 cm (19 in.) and the average sampled soil depth of 56 cm (22 in.) for an average profile depth of 104 cm (41 in.) (Table 2). The sand fill depth beneath the sand fill/aggregate interface varied from 13 cm (5 in.) to 119 cm (47 in.) while the sampled soil profile varied from 18 cm (7 in.) to 79 cm (31 in.).

Because of the varying sand depths, the zero depth point was set at the sand fill/soil interface. Increments are defined as 15 cm (6 in.) segments taken during sampling. The parameter concentration and the distance from the zero point to the center of the increment was assigned to the center point of the increment with each increment assigned a number relative to its location to the zero point (sand fill/soil interface), (i.e. 1, 2 etc. above and below the zero depth point). Soil core increments containing both sand and soil were subdivided with each sub-increment evaluated for the various constituents and each sub-increment assigned a number and each treated as an increment of varying depth.

Table 2. Sand and Soil Depths for 13 Mounds Each Evaluated at Two Locations.

Parameter	Sand cm (in.)	Soil cm (in.)
Average Depth	48 (19)	56 (22)
Maximum Depth	119 (47)	79 (31)
Minimum Depth	13 (5)	18 (7)
Standard Dev.	(8)	(7)
Number	26	26

The center point depths for each like numbered increment were averaged together to give an average distance above or below the zero point (sand fill/soil interface). Each calculated number was defined as a section with the average value at the center point of the section resulting in 10 sections, 5 above and 5 below the zero point. The 95% confidence intervals are also given for each average value (Table 3). Table 3 also gives the number of increments averaged with the number ranging from 4 for the top section (first increment sampled just below sand fill/aggregate interface) to 26 for the sections around the zero point. Thus sections 2, 3 and 4 contained top section increments thus skewing the parameter profiles as presented in Table 4 and the remaining figures. Also, because of this averaging approach, the total depth presented in Table 4 and the following figures is greater than the average depths given in Table 2. However, except in one case the maximum sampling depth beneath the sand fill/aggregate interface was 105 cm (42 in.).

The same procedure was used for the controls with the average center points of the sections at a slightly different elevation than those beneath the mounds. Likewise, the same procedures were followed for determining the various parameter profiles.

Table 3. Section Characteristics of Depth Beneath and Adjacent to Mounds.

Section	Count	-----Beneath-----			Count	-----Adjacent-----		
		Ave	Lower ^a	Upper		Ave	Lower	Upper
		----- (in.) -----				----- (in.) -----		
S	5	4	25	23	27			
a	4	11	19	19	20			
n	3	21	13	13	14			
d	2	25	7	8	8			
	1	26	2	2	2			
-----Zero Point (Sand Fill/Soil Interface)-----								
S	-1	26	-2	-2	-1	21	-3	-3
o	-2	26	-6	-7	-5	21	-9	-9
i	-3	22	-12	-13	-11	21	-15	-15
l	-4	20	-18	-19	-17	17	-21	-21
	-5	13	-23	-24	-22	12	-27	-27

^aLower and Upper refer to the 95% confidence interval.

Wastewater Parameters in Sand and Soil

Fecal Coliform: Figure 2 and Table 4 presents the average concentration and 95% confidence intervals for the fecal coliforms with depth. The sharp increase in Section 3 is the result of averaging a number of top increments (just below the sand fill/aggregate interface) with lower increments. The coliform concentration for Sections -3 thru -5 were very similar, [16-20 cm (40 to 51 in.) beneath the sand fill/aggregate interface] ranging from 80 to 103 MPN/g dry soil with an upper 95% confidence interval limit of 210 MPN/g dry soil (Table 4). This compares to an average value of 393 MPN/g dry soil for a similar depth beneath the aggregate/soil interface for the at-grade systems (Converse, et al., 1991). This indicates that the combination of sand fill and soil may be more effective in removing fecal coliforms than fine textured structured soils alone under pressure dosing regimes with minimal clogging mat. Treatment capacity will probably improve as the clogging mat develops as it has been shown that the fecal coliform

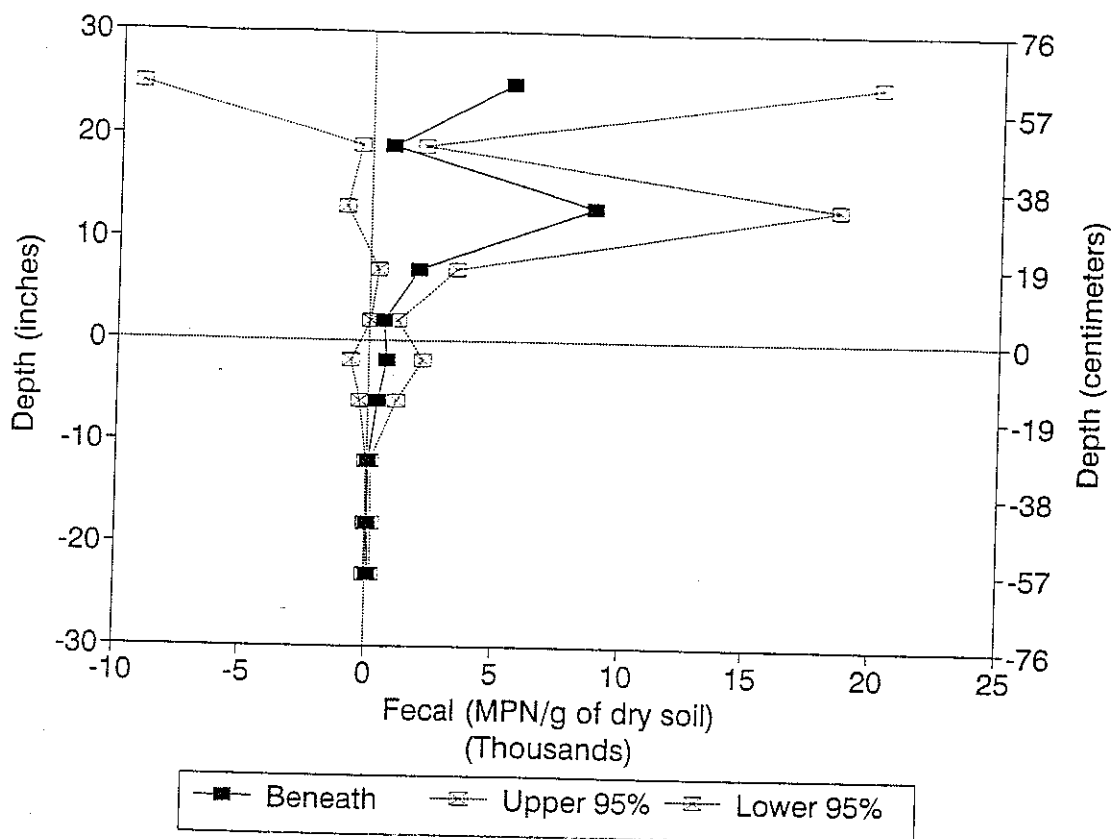


Figure 2. Average Fecal Coliform Profile Beneath Wisconsin Mounds.

counts beneath ponded systems are below the detectable level at similar distances beneath the aggregate/soil interface (Converse, et al., 1991; Ziebell et al. 1975).

Nitrogen: The native soil TKN (adjacent) as depicted in Fig. 3 and Table 4, is nearly equal to TKN found in soil beneath the mounds. Average soil TKN beneath mounds and for the adjacent area is much greater than in the sand fill. The added TKN from the septic tank effluent may have some impact as the average concentration is higher beneath the mound than adjacent to the mound (2448 vs 1811 mg N/kg dry soil) but no statistical evaluation was performed.

There is a slight decrease in ammonium concentration with sand depth and a significant increase in ammonium concentration in the soil surface horizon followed by a decrease (Fig. 4). The impact of the septic tank effluent is quite noticeable with the average concentrations considerably higher beneath the mound (Sections -3 thru -5) than adjacent to the mound (10 vs 2 mg N/kg) (Table 4). The slight decrease in the sand is probably due to nitrification.

The nitrate concentration (mg N/L) decreases with depth in both the sand and soil profiles (Fig. 5). The septic tank effluent nitrogen is impacting the groundwater beneath the system as the nitrate concentrations beneath the system are higher than adjacent to the system (34 vs 8 mg/L) (Table 4). It is interesting to note that the nitrate concentration adjacent to the system was higher than beneath the at-grade units (Converse et al. 1992). The data indicates that the nitrogen leaving the system boundaries [(90 cm (3 ft) beneath the aggregate)] does not meet the groundwater standards of less than 10 mg N/L. Additional denitrification and dilution may reduce the concentration further. Harkin et al. (1979) found that 19.5 mg N/L of nitrate exited the system boundaries at about 55 cm (22 in.) beneath the sand fill/soil interface, which is about half the concentration found in this study.

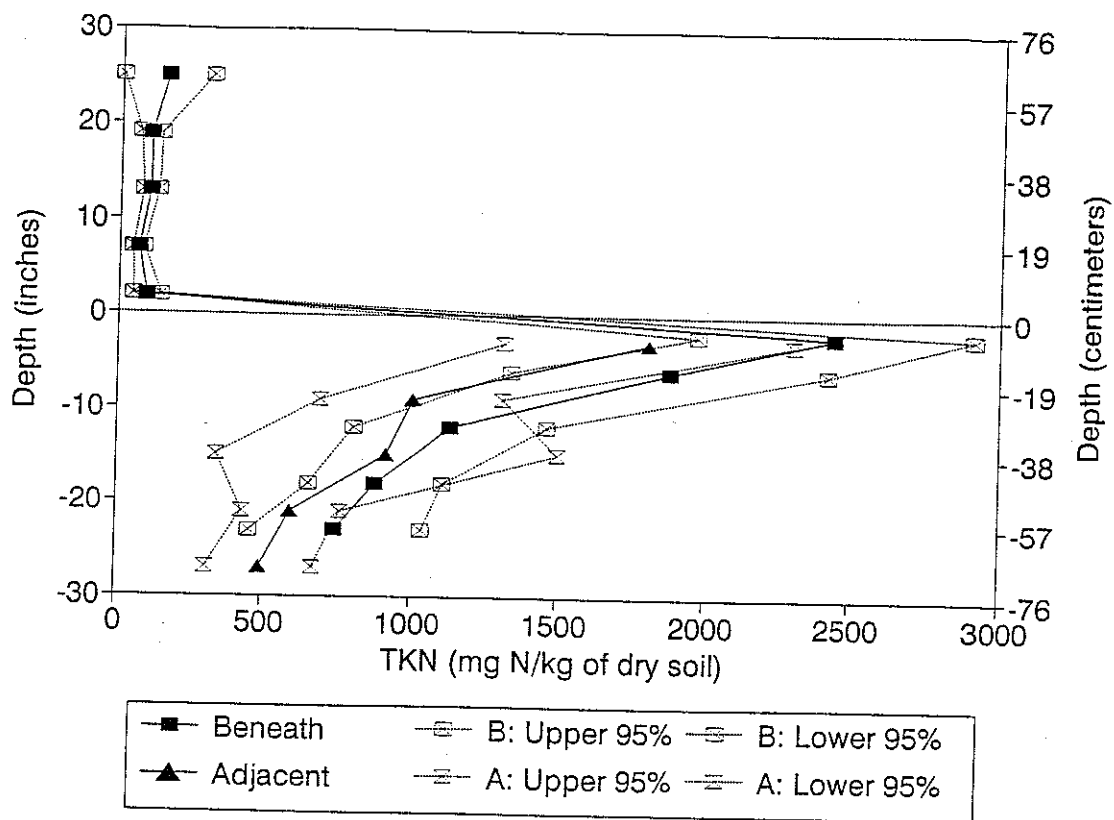


Figure 3. Average TKN Profile Beneath and Adjacent to Wisconsin Mounds.

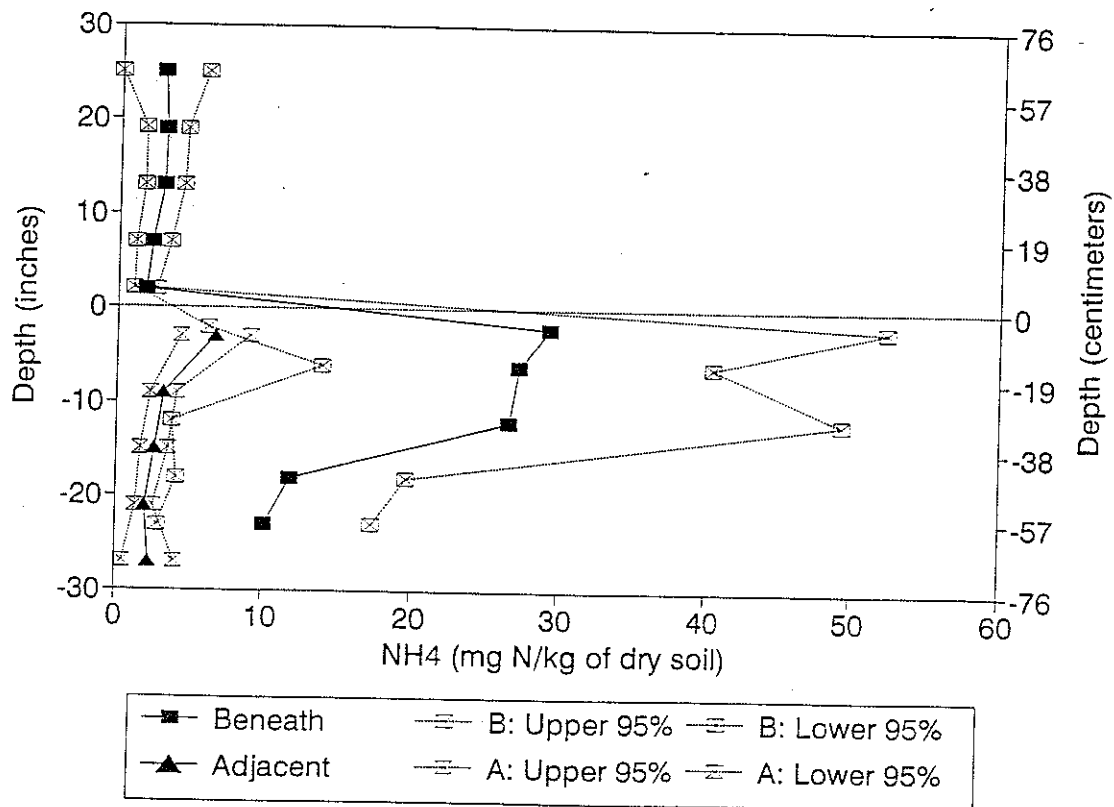


Figure 4. Average Ammonium Nitrogen Profile Beneath and Adjacent to Wisconsin Mounds.

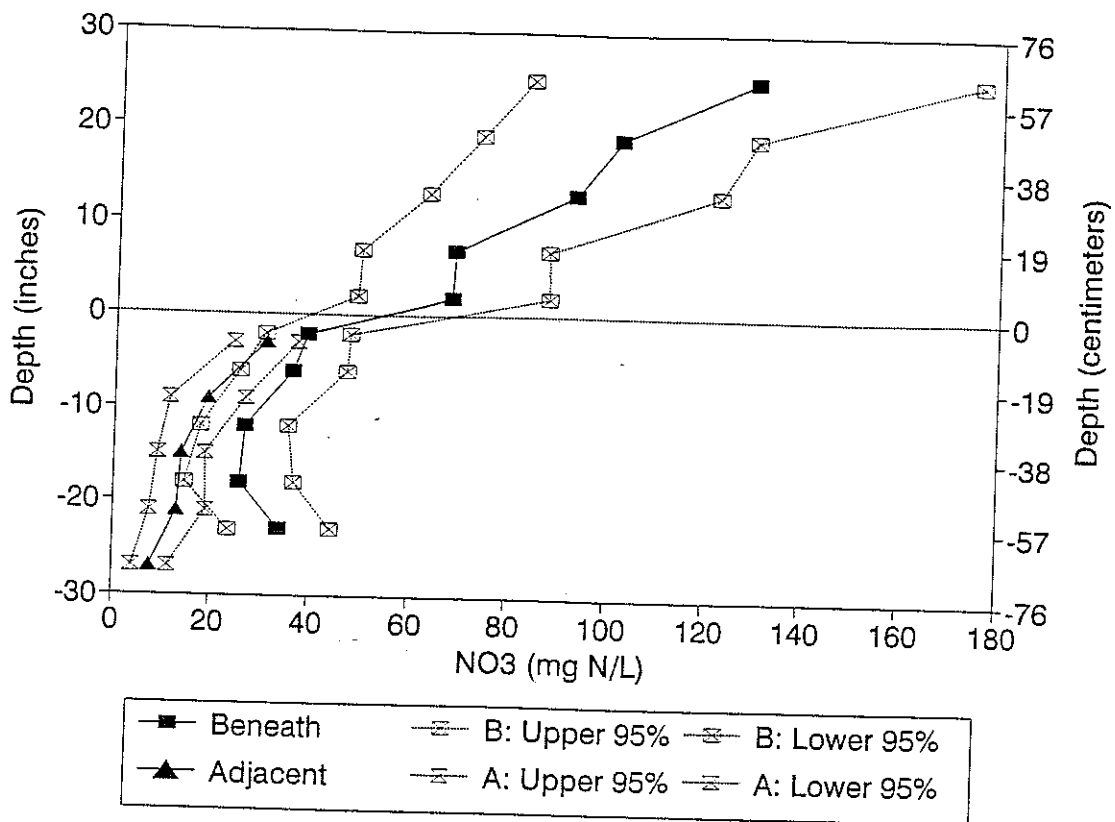


Figure 5. Average Nitrate Nitrogen Profile Beneath and Adjacent to Wisconsin Mounds.

The nitrate concentration in the top layer (Section 5, just below the aggregate) appears to be quite high averaging about 130 mg N/L (Table 4) which is considerably higher than the 53 mg N/L of total nitrogen content (organic nitrogen and ammonium) in the effluent (Table 1). The upper sand fill layer may be storing nitrogen in ammonia and organic nitrogen forms as part of a biological mat and slowly nitrifying and releasing it. There is a very low correlation ($R^2 = 0.26$) between the ammonium plus nitrate concentration in the septic tank effluent with the nitrogen concentration in the top sand layer where all top layers (26) were included regardless of sand depth.

Table 4. Average Soil Profile Parameters and Lower and Upper 95% Confidence Intervals Based on Soil Weight for Beneath and Adjacent for 13 Septic Tank/Mound Units Using Pressure Distribution on Similar Soil Profiles.

	-----Beneath ^a -----			Section	-----Adjacent-----		
	Lower	Upper	Ave		Ave	Lower	Upper
				Fecal Coliform (MPN/g dry soil)			
S	-9176	20284	5554	5			
a	- 414	2100	843	4			
n	- 914	18646	8866	3			
d	354	3457	1905	2			
	82	1112	597	1			
-----Zero Point-----							
S	- 683	2112	715	-1	<1	<1	<2
o	-333	1104	386	-2			
i	- 22	181	80	-3			
l	- 25	212	94	-4			
	- 3	210	103	-5			

Table 4. Cont.

	-----Beneath ^a -----			-----Adjacent-----			
	Lower	Upper	Ave	Section	Ave	Lower	Upper
	Moisture Content (% dry basis) ^b						
S	4	10	7	5			
a	6	8	7	4			
n	6	8	7	3			
d	6	7	7	2			
	8	9	8	1			
-----Zero Point-----							
S	31	41	36	-1	24	20	27
o	26	33	30	-2	22	19	26
i	25	32	29	-3	23	19	28
l	24	29	26	-4	21	18	24
	20	26	23	-5	21	18	24
Total Kjeldahl Nitrogen (mg N/kg dry soil)							
S	7	317	162	5			
a	66	142	104	4			
n	79	131	105	3			
d	48	85	66	2			
	51	144	98	1			
-----Zero Point-----							
S	1978	2918	2248	-1	1811	1315	2307
o	1339	2427	1883	-2	1004	697	1311
i	812	1464	1138	-3	922	346	1498
l	660	1111	885	-4	599	434	765
	458	1039	749	-5	494	313	675
Ammonium Nitrogen (mg N/kg dry soil)							
S	0	6	3	5			
a	2	5	3	4			
n	2	4	3	3			
d	3	6	5	2			
	1	3	2	1			
-----Zero Point-----							
S	6	52	29	-1	7	4	9
o	14	41	27	-2	3	2	4
i	4	49	27	-3	3	2	4
l	4	20	12	-4	2	1	3
	3	17	10	-5	2	1	4
Nitrate Nitrogen (mg N/kg dry soil)							
S	7	10	9	5			
a	5	8	7	4			
n	4	9	6	3			
d	3	6	5	2			
	4	6	5	1			
-----Zero Point-----							
S	11	15	13	-1	8	5	10
o	7	131	10	-2	4	3	5
i	5	9	7	-3	3	1	6
l	4	9	6	-4	2	2	3
	5	10	7	-5	2	1	2

Table 4. Cont.

-----Beneath ^a -----				-----Adjacent-----			
	Lower	Upper	Ave	Section	Ave	Lower	Upper
Nitrate Nitrogen (mg N/L) ^c							
S	84	176	130	5			
a	74	130	102	4			
n	63	123	93	3			
d	50	88	69	2			
	49	88	69	1			
-----Zero Point-----							
S	31	48	39	-1	31	24	37
o	26	47	36	-2	19	11	27
i	18	36	27	-3	14	9	19
l	15	37	26	-4	13	7	19
	24	44	34	-5	8	4	11
Chlorides (mg/kg dry soil)							
S	-18	89	36	5			
a	7	47	27	4			
n	16	56	36	3			
d	22	62	42	2			
	24	67	46	1			
-----Zero Point-----							
S	70	154	112	-1	36	-11	82
o	69	170	119	-2	31	4	57
i	60	154	107	-3	23	-2	48
l	53	147	100	-4	21	2	40
	32	146	89	-5	48	-2	99
Chlorides (mg/L) ^c							
S	-216	1244	514	5			
a	99	689	394	4			
n	233	791	512	3			
d	327	886	607	2			
	280	774	527	1			
-----Zero Point-----							
S	234	593	414	-1	135	2	267
o	260	664	462	-2	117	34	200
i	234	616	425	-3	100	0	199
l	215	609	412	-4	102	19	184
	156	752	454	-5	193	7	379

^aBeneath is below the system receiving effluent and adjacent is next to the system and not receiving effluent;

^bMoisture content associated with all parameters except fecal coliforms.

^cAssuming that the parameter is associated only with the soil water. The conversion from mg/kg of dry soil to mg/L of water is: $\text{mg/L} = (\text{Concentration in mg/kg}) / (\text{Moisture content on dry basis})$.

Chlorides: The chloride concentration in mg/L is relatively constant with depth indicating that there is no dilution effect taking place in the mound (Fig. 6). This is important as it shows that the chloride concentration is quite stable and can be used to help assess denitrification beneath the system. There appears to be a good correlation ($R^2 = 0.80$) between the septic tank effluent and the chloride concentration in the top sand layer where all top layers (26) were included

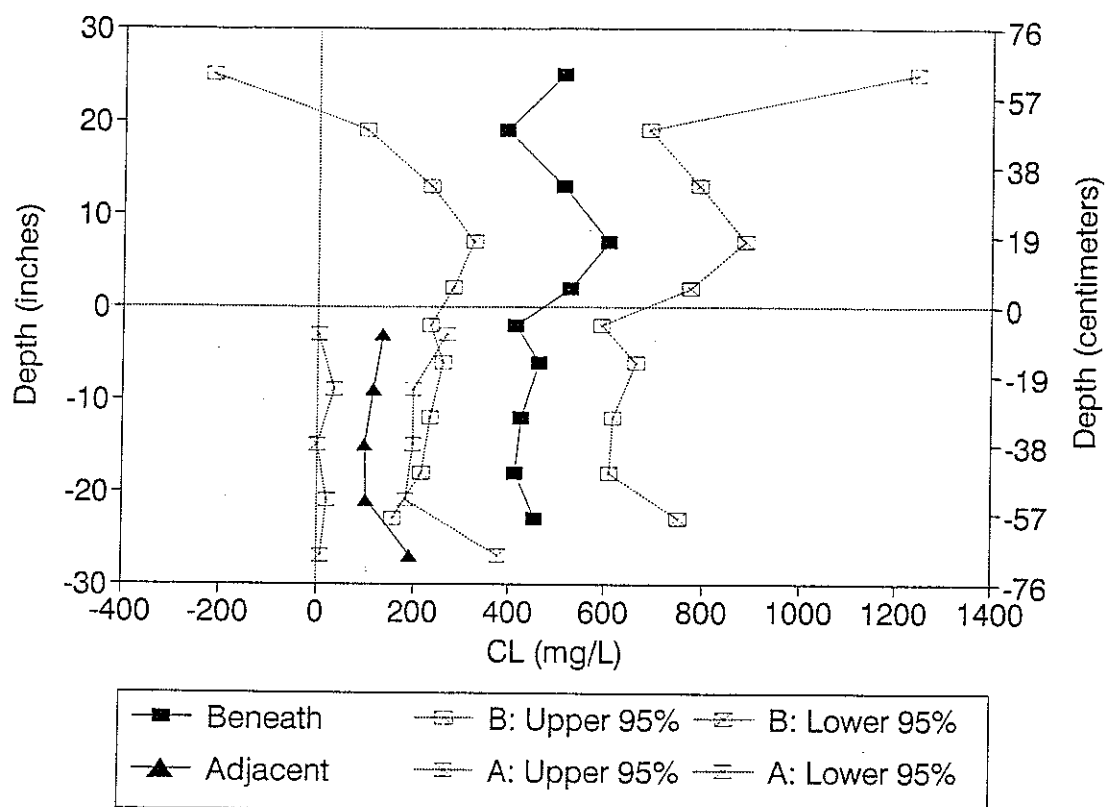


Figure 6. Average Chloride Profile Beneath and Adjacent to Wisconsin Mounds.

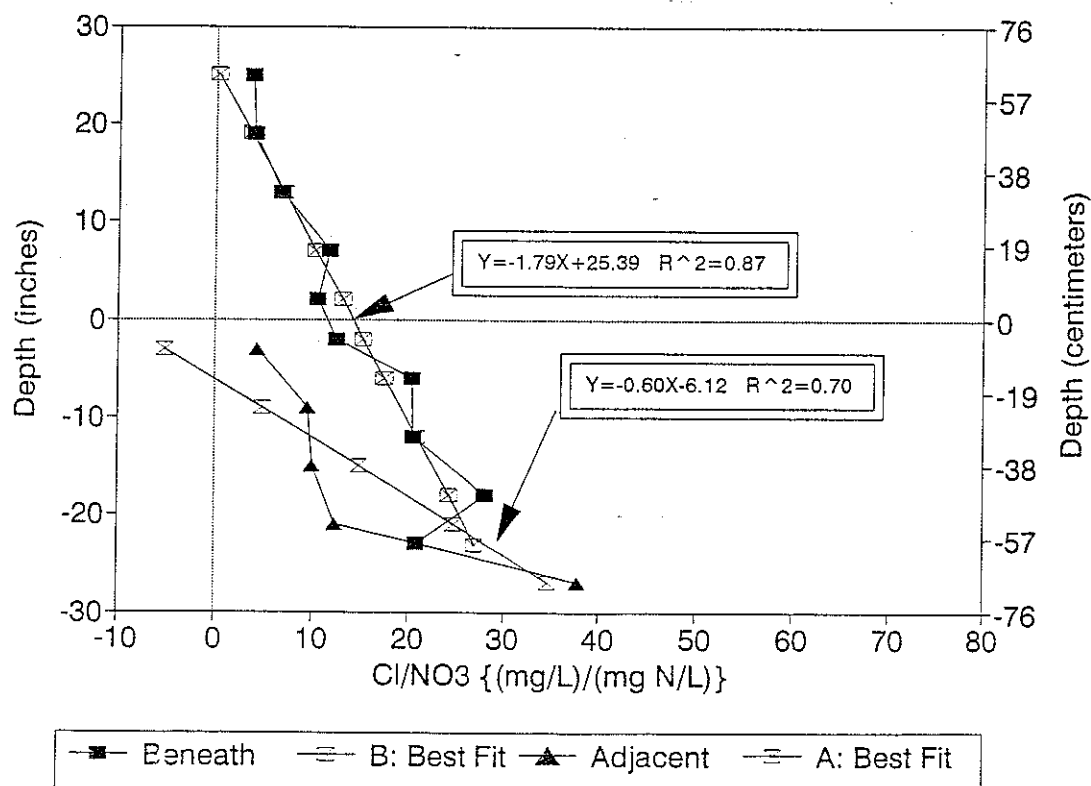


Figure 7. Average Chloride/Nitrate Nitrogen Ratio Profile Beneath and Adjacent to Wisconsin Mounds.

regardless of sand depth.

Chloride/Nitrate Nitrogen Ratio: The chloride/nitrate nitrogen ratio versus depth suggests that some denitrification is taking place in and beneath the mound (Fig. 7). A plot of the data yields a prediction equation with an $R^2 = 0.87$. The data also suggests that denitrification is also taking place adjacent to the mound yielding a prediction equation with $R^2 = 0.70$. However, there is not sufficient denitrification taking place beneath the system for the effluent to meet drinking water standards at the exit boundary.

SUMMARY AND CONCLUSIONS

Thirteen septic tank-mound systems were sampled to determine treatment performance by coring beneath the system and analyzing for fecal coliform, nitrogen and chloride profiles.

The average depth of sand fill was 48 cm (19 in.) with the average depth of soil sampled to 56 cm (22 in.). The sand fill was a medium to coarse sand and the soil was a silt loam to clay loam texture with seasonal high water table.

The average fecal count was 103 MPN/g dry soil at the 56 cm (22 in.) depth of native soil [(104 cm (41 in.) including sand fill plus soil] which is higher than expected and higher than typically found beneath ponded gravity systems with a clogging mat but lower than found beneath at-grade systems. Thus, it appears that the sand fill plus the native structured soil provides a better treatment than native structured soil under pressure distribution conditions with minimal clogging mat development.

The chloride concentration (mg/L) was similar throughout the profile indicating no dilution effect as the effluent moves downward. The average chloride concentration was 454 mg/L exiting the system.

Nitrate nitrogen decreased beneath the system through denitrification as the Cl/NO_3^- ratio increased with depth. The nitrate nitrogen concentration (mg N/L) exiting mound influence [90 cm (3 ft) beneath the aggregate] was 34 mg N/L which exceeds the drinking water standard by 3.5 times. This value is the same as found beneath at-grade systems.

In conclusion, mounds appear to be adequately treating fecal coliforms but even though they are denitrifying nitrogen, the nitrogen level exiting the system boundary does not meet the drinking water standard of less than 10 mg N/L.

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