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SMALL SCALE WASTE MANAGEMENT PROJECT

Soil Treatment of Aerobically Treated Domestic Wastewater with Emphasis on Modified Mounds

by

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Soil Treatment of Aerobically Treated Domestic Wastewater with Emphasis on Modified Mounds[1]

James C. Converse and E. Jerry Tyler[2]

ABSTRACT

Wastewater treatment by soil beneath 35 modified mounds and 4 at-grade soil absorption units receiving aerobically treated wastewater was determined. The soil texture ranged from sand to clay loam, and estimated seasonal saturation was just below ground surface in many cases. Thirty-six dispersal units received wastewater from aerobic units and two from single pass sand filters. Effluent was distributed via pressure distribution to all systems. On approximately 50% of the soil absorption units, effluent was delivered to only half of the unit which increased effluent loading to the unit's other half. To evaluate the treatment effectiveness, soil cores were taken from beneath and adjacent to the system at 15 cm (6 in.) increments to a depth of 105 cm (42 in.). Fecal coliforms, nitrogen compounds and chlorides were evaluated.

Median (50% above, 50% below) fecal coliform in the aerated wastewater was 10^3 counts/100 mL. Wastewater fecal coliform counts ranged from <1 (non-detectable) to >10^5 counts/100 mL. Median fecal coliform counts were non-detectable at 30 cm (1 ft) beneath the infiltrative surface. At 105 cm (42 in.) below the infiltrative surface, <10% of the samples had fecal coliform >1 MPN/g dry soil. When wastewater with <10^3 counts/100 mL was added, median soil fecal coliform counts were <1 MPN/g dry soil within 15 cm (6 in.) of the infiltrative surface and, at 60 cm (2 ft) below the infiltrative surface, <10% of the samples had fecal coliform >1 MPN/g dry soil. Separation from the wastewater infiltrative surface might be based on the odds of meeting a treatment goal for the soil. For example, based on median values for all samples collected being below detection limits, it may be reasonable to set the separation distance at 30 cm (1 ft). Based on only 10% of the values exceeding detection limits, a separation limit of 60 cm (2 ft) may be selected. Similar separation distances could be assigned based on the ability of the treatment unit to reduce fecal coliforms.

Median total nitrogen concentration of the aerobically treated wastewater was 32 mg N/L. Median soil nitrate concentrations were 26 mg N/L at 105 cm (42 in.) and similar to amounts found beneath mounds and at-grade systems receiving septic tank effluent.

INTRODUCTION

The septic tank-soil absorption unit consists of a septic tank and a soil unit. Research and field experience have established long term soil loading rates and depths of soil believed necessary for adequate treatment and dispersal. The depth of treatment is referred to as the separation distance.

In the late 1960s the State of Wisconsin adopted a separation distance of 90 cm (3 ft). Long term soil loading rates range from 1-4 cm/day (0.2-0.8 gpd/ft^2) and are based on infiltration rates into

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[1] This paper is a revision from what appears in the initial printing of the Proceedings of the 8th National Symposium on Individual and Small Community Sewage Systems. Total and volatile suspended solids data were removed from this publication because of a sample preparation method (freezing) discovered after initial publication that resulted in high TSS and VSS concentrations. Table 10 was changed due to incorrectly transposing some numbers in the fecal coliform section.

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clogged soils (Wisc. Adm. Code, 1994). Other state and county jurisdictions have similar codes with depths ranging from 30-120 cm (1-4 ft) and a wide range of loading rates.

If fecal coliforms, and presumably pathogens, are removed before wastewater infiltrates into soil, less distance of travel in the soil will be needed for treatment. Converse et al. (1991) showed that some fecal coliforms may still be present in unsaturated soil beneath pressure dosed at-grade wastewater treatment systems to a depth greater than 105 cm (42 in.) receiving septic tank effluent, but no fecal coliforms were detected at similar distances beneath clogged systems or systems receiving highly pretreated effluent from aerobic units. Mounds receiving septic tank effluent showed similar treatment, as did at-grades receiving septic tank effluent (Converse et al., 1994). Additional research is needed to determine a safe separation distance for high quality effluent.

If most suspended and dissolved organic matter is removed from the wastewater before infiltrating the soil, a clogging mat is unlikely. In the absence of clogging mats, wastewater loading rates to soil can be higher. Siegrist (1987a, 1987b) indicated that loading rates could be greater for higher quality effluent than for septic tank effluent. Tyler and Converse (1994) predicted that loading rates for highly pretreated effluent might be 2-16 times greater than rates recommended for septic tank effluent. However, these higher loading rates concentrate the effluent into a smaller area, resulting in less dispersal in the environment. In the event that the pretreatment system fails, a rapid hydraulic failure of the soil system is very likely.

The contribution of nitrates to ground water, especially in subdivisions on sandy soils, is a major concern to health officials and regulators. The concern is that aerobic units and sand filters contribute more nitrates to ground water than do septic tanks. In a typical septic tank soil absorption unit, organic nitrogen and ammonia, the two main species found in domestic wastewater, are converted under aerobic conditions to nitrates beneath the soil absorption unit with the nitrate, soluble in water, carried to ground water. In aerobically treated effluent, the organic nitrogen and ammonia are converted to nitrates in the treatment unit and dispersed to the soil with the treated effluent. In both cases, nitrates are contributed to ground water with some of the nitrate converted to nitrogen gas via denitrification.

The objective of this study was to determine soil treatment performance of aerobically treated domestic wastewater with BOD and suspended solids of less than 30 mg/L and with more than 99% of the fecal indicators removed in the pretreatment process. The specific objectives were: 1) to establish a separation distance from the bottom of the soil dispersal unit to limiting conditions based on fecal coliform die-off under actual field operating conditions; and 2) to evaluate nitrogen removal as the nitrified effluent percolated through the soil profile.

METHODS AND MATERIALS

Full Scale Field Study

Thirty nine systems serving full time residences were studied. The pretreatment systems consisted of 37 aerobic units and 2 single pass sand filters. The soil absorption units, with pressure distribution, consisted of 35 modified mounds (Fig. 1) and 4 at-grade units (Fig. 2). The units were center fed so that half of the system could be shut off.

The modified mound is normally used where seasonal saturation is 10-15 cm (4-6 in.) beneath the ground surface and/or sites with very slowly permeable surface horizons. The sand in the modified mound provides additional separation distance and a permeable media for effluent to move down slope as it infiltrates into the slowly permeable soil surface. At a number of sites, the modified mound was used where the surface horizon was sandy loam or silt loam and the seasonal saturation was greater than 30 cm (12 in.). At-grade or shallow in-ground trenches could have been used on those sites. Several sites were evaluated twice during different years and treated as separate systems.

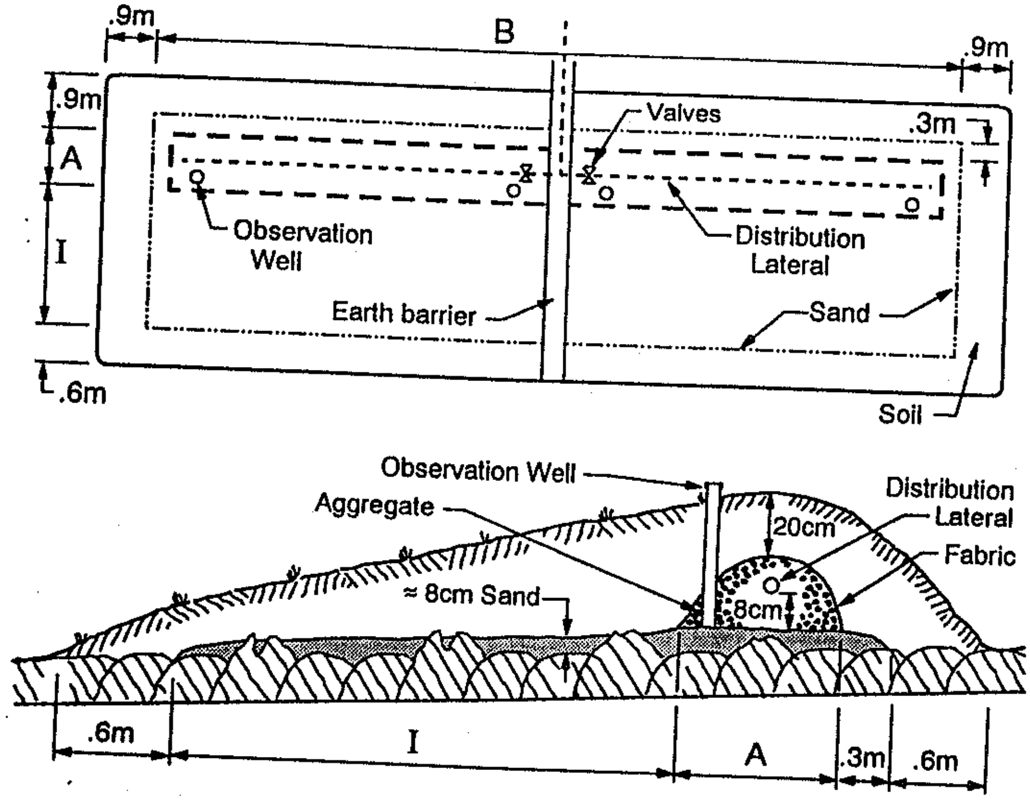

Fig. 1. Cross Section and Plan View of Modified Mound Unit

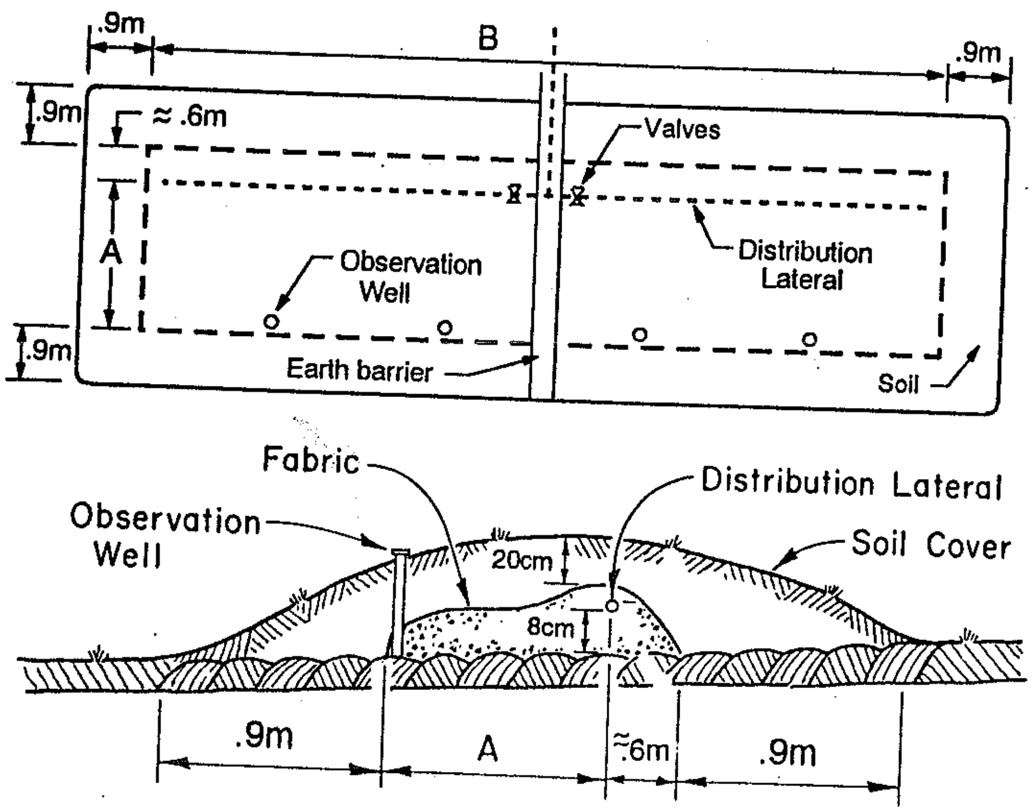

Fig. 2. Cross Section and Plan View of At-Grade Unit

Sampling procedures were similar to those used in previous at-grade and mound evaluations (Converse et al., 1991, 1994). At two locations in each system, soil cores were taken at 15 cm (6 in.) increments starting at the aggregate/soil interface to a depth of 105 cm (42 in.). On about half of the profiles, the first 2.5 cm (1 in.) of soil was sampled prior to the first core being taken and analyzed separately for fecal coliforms. For controls, soil cores were taken at two locations adjacent to the soil dispersal unit.

The procedure consisted of: 1) locating an orifice in the pressure distribution lateral, 2) inserting a 15 cm (6 in.) PVC pipe casing into the aggregate/soil interface and removing the aggregate within the casing, 3) extracting soil cores using a sterilized metal tube 2.5 cm diam. × 15 cm long (1 in. × 6 in.), and 4) taking soil cores at the same location using a 7.5 cm (3 in.) diam. bucket auger for chemical analysis. Procedures 3 and 4 were repeated every 15 cm (6 in.) increments to 105 cm (42 in.). After sampling, the holes were filled with soil and compacted. The same procedure was followed for the adjacent soils except the bacterial sample was taken only in the top 15 cm (6 in.). A pump chamber effluent sample was collected for standard wastewater parameters including fecal coliforms analysis.

In the laboratory, a soil subsample 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 plastic bags and frozen for later analysis of moisture content, total kjeldahl nitrogen (TKN), ammonia and nitrates. All analyses except 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.

Cell Study

In order to determine the effect of soil loading on the movement of fecal coliforms and nutrients beneath the system, a small field cell study was initiated. The system consisted of three 60 cm diam. × 45 cm high (2 ft × 18 in.) corrugated steel culvert units. The sod was removed, and the culverts were driven into the soil about 5 cm (2 in.). The soil surface was roughened to simulate tilling. Fifteen cm (6 in.) of No. 1 (1.9-3.8 cm or 3/4-1 ½ in.) stone was placed on the soil surface. A distribution network, consisting of 2.5 cm (1 in.) diam. PVC pipe in a 30 cm (12 in.) square with a 3.2 mm (1/8 in.) orifice drilled in the top center of each leg of the square, was place on the aggregate. A 10 cm (4 in.) PVC cap served as the orifice shield. Additional stone was placed over the network and shields. The culvert was covered with plywood. A feeder line through the sidewall was connected from each network to a single manifold. The manifold was connected to a small pump located in a tank receiving aerobically treated effluent. A solenoid valve was inserted into each feeder line and was controlled by a timer. Soil was mounded around the cells to simulate an at-grade unit and to minimize temperature fluctuations.

Influent was applied to each cell 6 times daily with frequent dosing in the morning and evening hours to simulate effluent generation from the home. A series of timers activated and deactivated the solenoids. A water meter was also installed to monitor flow to all three cells. Each network was calibrated prior to installation. The effluent was applied starting July 1, 1996. On August 5, 12 and 19, a soil core was taken from each cell. This was done by disassembling the network and placing a 15 cm (6 in.) PVC casing through the aggregate and centered directly below an orifice. Soil cores were taken at 0-2 cm (0-1 in.), 2-15 cm (1-6 in.) and 15 cm (6 in.) increments to depth of 105 cm (42 in.) using the same procedures as described for the full scale field study earlier. The hole was refilled with soil, compacted, casing removed, and system placed back in operation until the following week when the same procedure was followed. Influent samples were taken weekly.

The soil consisted of a well drained silt loam soil (0-15 cm) with moderate granular structure over silty clay loam (15-30 cm) with moderate blocky structure over sandy clay loam (30-45 cm) with moderate blocky structure, and over sand with some stones and clay deposits (45-105 cm). The underlying material is a gravely till.

RESULTS AND DISCUSSION

Full Scale Field Study

Characteristics of the aerobically treated effluent entering the soil dispersal units are given in Table 1. Median values are used throughout this discussion as they are more representative since one or two numbers can skew averages. The median biochemical oxygen demand (BOD) and suspended solids (SS) were 10 and 18 mg/L, respectively. Median BOD and SS values, based on 89 and 103 samples taken from 21 septic tanks with screened vaults, were 210 and 67 mg/L, respectively (Converse and Converse, 1998). Compared to these concentrations, the aerobic units/ sand filters reduced the BOD by 95%. Likewise, fecal coliforms were reduced from median septic tank effluent values of 5.1×10^5-1000 cols./100 mL for aerobic effluent or a 99.8% reduction. Total nitrogen was reduced approximately 39% in the aeration units. Thus, the soil receiving aerobically treated effluent is required to treat only a fraction of the pollutant constituents that the soil receiving septic tank effluent is expected to treat to meet the same effluent quality as it leaves the soil treatment unit.

Table 1. Effluent characteristics for 38 residential sites based on one grab sample from the pump chamber at the time of soil dispersal unit evaluation. Pretreatment units consisted of 36 aerobic units and 2 single pass sand filters. (One aerobic unit was not sampled.)

Parameter	Units	Sample Size	Median	Average	Std. Dev.	Range
Total Solids	mg/L	38	749	934	506	377 - 2500
Vol. Solids	mg/L	38	211	258	134	114 - 845
BOD_5	mg/L	31	10	19	21	1 - 88
COD	mg/L	36	49	76	76	2 - 330
TOC	mg/L	33	18	29	27	6 - 143
TKN	mg N/L	37	6	15	26	0 - 128
Ammonia	mg N/L	36	3	10	15	0 - 56
Nitrate	mg N/L	36	26	28	22	0 - 87
Tot. Nit.†	mg N/L	-	32	43	-	-
Chloride	mg/L	35	68	267	475	24 - 2053
EC	Umho/cm	36	1050	1390	940	520 - 4500
pH	-	34	7.27	7.15	0.65	4.56 - 8.22
Total Cols.	co./100 mL	35	4.3E04	9.1E06	4.6E07	520 - 2.8E05
Fecal Cols.	co./100 mL	35	1.0E03	2.8E04	7.9E04	<1 - 4.5E05
D.O.	mg/L	31	2.6	2.7	1.9	0.5 - 6.6
Temperature	°C	26	22.6	22.6	3.7	16.5 - 30.2
Ambient Temp.	°C	32	20.5	20.7	5.9	6.1 - 33.0

† Sum of the TKN and nitrate and TKN is the sum of ammonia and organic nitrogen.

Fecal coliform profiles beneath the soil dispersal units are shown in Table 2. The effluent fecal coliform count varied from <1-4.5×10^5 cols./100 mL (Table 1). Since there was a great variation between sites and treatment units and combining all the data together could mask the effects, the data are presented based on all sites combined and their groupings of various fecal coliform concentrations in the wastewater. If all data (39 sites, 78 profiles) were combined, the median fecal coliform count is below detectable levels (<1) within 15 cm (6 in.) after the effluent enters the soil.

Table 2. Fecal coliforms beneath the soil dispersal units based on the fecal coliform concentration of the influent (aerobically treated effluent) entering the dispersal unit at the time of sampling.

Depth (cm)	Inf. Fecal Coliforms - cols./100 mL, Log*					Inf. Fecal Coliforms - cols./100 mL, Log*				
	0 -<6	0 - 3	3 - 4	4 - 5	5 -<6	0 -<6	0 - 3	3 - 4	4 - 5	5 -<6
	Median (MPN/g dry soil)					Average (MPN/g dry soil)				
0 - 2	8	1	14	40	329	58	8	16	48	364
2 - 15	3	1	5	9	112	44	15	8	34	270
15 - 30	<1†	<1	<1	1	39	18	2	11	22	90
30 - 45	<1	<1	<1	<1	15	15	1	3	5	116
45 - 60	<1	<1	<1	1	38	18	1	1	10	137
60 - 75	<1	<1	<1	<1	9	14	1	1	3	123
75 - 90	<1	<1	<1	<1	5	8	1	1	6	52
90 -105	<1	<1	<1	<1	1	2	1	1	3	2
Control‡	<1	<1	<1	<1	<1	10	16	5	2	8
No. Sites§	39	19	7	9	4					

Depth (cm)	Inf. Fecal Coliforms - cols./100 mL, Log					Inf. Fecal Coliforms - cols./100 mL, Log				
	0 -<6	0 - 3	3 - 4	4 - 5	5 -<6	0 -<6	0 - 3	3 - 4	4 - 5	5 -<6
	90% Less Than (MPN/g dry soil)					Stand. Dev. (MPN/g dry soil)				
0 - 2	54	2	17	83	700	160	24	8	42	366
2 - 15	81	5	18	98	773	149	78	7	45	350
15 - 30	37	2	9	46	254	54	9	29	52	116
30 - 45	8	1	5	4	354	74	1	5	16	197
45 - 60	4	1	2	3	383	76	4	5	36	183
60 - 75	2	<1	2	3	300	89	0	6	8	247
75 - 90	2	<1	<1	3	111	43	1	8	21	112
90 -105	1	<1	2	2	2	5	1	11	8	1
Control	16	12	14	5	23	46	66	8	5	13

Depth (cm)	Inf. Fecal Coliforms - cols./100 mL, Log				
	0 -<6	0 - 3	3 - 4	4 - 5	5 -<6
	Numbers				
0 - 2	39	17	6	12	4
2 - 15	77	37	14	18	8
15 - 30	77	37	14	18	8
30 - 45	74	34	14	18	8
45 - 60	72	33	13	18	8
60 - 75	65	29	12	17	7
75 - 90	60	25	11	17	7
90 -105	52	25	8	15	4
Control	74	35	14	17	8

† <1 is considered non-detectable.
* Log 0 = 1, Log 3 = 1000, and Log 4 = 10,000 cols./100 mL.
‡ Controls were taken from 0-15 cm.
§ Number of cores is normally double the number of sites. But in some instances there may have been only one profile taken or profile not taken to 105 cm due to an obstruction. The number section represents the number of samples analyzed for a given location.

It is similar at sites receiving effluent with fecal coliform concentrations in the range of log 0-3 (1-1000), log 3-4(1000-10,000) and log 4-5 (10,000-100,000) cols./100 mL. For aerobically treated effluent with concentrations of log 5-6 (100,000-1,000,000) cols./100 mL, non-detectable levels are not obtained until the effluent reaches at least 90 cm (36 in.) below the infiltrative surface which is similar to profiles beneath non-clogged dispersal units receiving septic tank effluent with similar fecal coliform concentrations (Converse et al., 1991, 1994). Table 2 also gives average values, 90% of the values less than, standard deviations, and number of samples analyzed for each location. Based on the 90% less than values, fecal coliform concentrations were reduced to non-detectable levels (<1 MPN/g of dry soil) at 60 cm (2 ft) for those sites receiving influent fecal coliform counts of log 0-3 (<1-1000 cols./100 mL). For the sites receiving greater concentrations of fecal coliforms, the fecal count in the soil was not reduced to undetectable levels within 105 cm (42 in.). For those sites receiving effluent with log 4 and log 5, the fecal count was reduced to less than 5 MPN/g dry soil after passing through 45 cm (18 in.) of soil (Table 2).

It appears that pretreatment units utilizing aerobic principles vary in their ability to remove fecal coliforms. Converse and Converse (1998) showed that single pass sand filters had fecal coliform concentrations <1000 cols./100 mL 94% of the time while two different types of aerobic units only accomplished that feat 50.9 and 15.1% of the time. Thus, it would appear that the separation distance for sand filter effluent could be 30 cm (12 in.) if the median values (50%) are used or 60 cm (24 in.) if a lower risk factor (90%) is desired. Greater separation distances could be chosen for those units producing higher fecal coliform counts. Unfortunately, there is very little known about the health risk with fecal coliform values based on MPN/g dry soil. Society has established criteria for fecal coliform counts in waters such as <200 cols./100 mL for body contact and 0 cols./100 mL for drinking water. No such criteria is established for soil systems and as yet there is no equating one with the other.

Fecal coliform profile, based on dispersal system type, is given in Table 3. Although 90% of the systems are modified mounds, there appears to be essentially no difference, based on median values, in performance between modified mounds with sand (average depth of 15 cm (6 in.)) and the at-grades as both systems reduced the fecal coliforms to below detectable levels within 15 cm (6 in.) of entering the soil or sand. Based on average values, the at-grade unit appeared to perform better.

Table 3. Fecal coliforms beneath the modified mounds and at-grade units and treated influent concentration entering units.

Depth (cm)	Modified Mound					At-grade Unit				
	Median	Average	STD	Max	No.	Median	Average	STD	Max	No.
	(MPN/g dry soil)				-	(MPN/g dry soil)				-
0 - 2	8	59	162	789	38	-	-	-	-	-
2 - 15	3	49	156	1033	69	1	2	1	4	7
15 - 30	<1	19	57	341	69	<1	2	3	9	7
30 - 45	<1	16	78	593	66	<1	1	1	2	7
45 - 60	<1	20	81	536	64	<1	4	8	23	7
60 - 75	<1	16	94	719	58	<1	1	0	<1	6
75 - 90	<1	9	45	325	55	<1	1	0	<1	4
90 - 105	<1	2	5	34	48	<1	1	0	<1	3
Influent Fecal Coliform Concentration† - Cols./100 mL										
-	1000	33835	81840	450000	35	1910	4795	6019	5000	4

† Influent concentration is the aerobically treated effluent that enters the soil dispersal unit.

but there were fewer sites and the influent concentration, based on the average and maximum values, were much less, although the median value was higher for the at-grade unit. The at-grade unit did not receive any effluent with fecal coliform counts in the range of 10^5 cols./100 mL as did the modified mounds (Table 3). This clearly shows the effects of a few high numbers and their effect on the averages. Thus, with some caution due to unequal sample sizes, similar results should be obtained from other types of systems such as shallow in-ground trenches placed in the native soil. However, further testing may be warranted.

Fecal coliform profiles based on soil texture are shown in Table 4. The soil textures were divided into coarse textured soils (sands/sandy loams) and fine-textured soils (silt loams to clay loams). Based on the median values, fecal coliforms were below detectable levels (<1) within the first 30 cm (12 in.) for fine textured soils and 45 cm (18 in.) for the coarse textured soils. Based on average values, the coarse textured soils appear to perform slightly better than the fine textured soils even though the influent median and average values entering the soil were greater for the coarse textured soils than the fine textured soils. But the maximum value was much greater for the fine textured soils than the coarse textured soils. The coarse textured soils comprised about 40% of the soil profiles studied.

Table 4. Fecal coliform profiles based on soil texture and effluent concentration entering soils.

Depth (cm)	Fine Textured Soils					Coarse Textured Soils				
	Median	Average	STD	Max	No.	Median	Average	STD	Max	No.
	(MPN/g dry soil)				-	(MPN/g dry soil)				-
0 - 2	10	31	41	140	19	2	83	217	798	20
2 - 15	3	47	172	1033	49	5	40	96	482	28
15 - 30	<1	15	57	341	49	2	22	48	216	28
30 - 45	<1	20	93	593	46	<1	6	14	70	28
45 - 60	<1	18	82	536	45	1	19	66	318	27
60 - 75	<1	19	112	719	40	<1	7	24	120	25
75 - 90	<1	13	54	325	37	<1	1	2	9	23
90 - 105	<1	2	6	34	30	<1	1	1	5	22
Influent Fecal Coliform Concentration - Cols./100 mL										
-	550	29221	89468	450000	25	1850	33778	51612	50000	14

TKN, ammonium, nitrate and chloride concentrations, based on grams of dry soil, are presented in Table 5. As noted earlier, 35 of the 39 sites were modified mounds with an average of 15 cm (6 in.) of sand. The sand effect is noted in Table 5 under TKN and ammonia where the values for the 0-15 cm (0-6 in.) depth are considerably lower than the adjacent values which represent top soil and considerably lower than the beneath values at 15-30 cm (6-12 in.). Since, on average, about 15 cm (6 in.) of sand was placed on the soil surface, the profile depths do not quite correspond, and no attempt was made to adjust the depths between the two to compensate for the added sand as was done in the mound analysis (Converse, et al. 1994).

For both median and average values, the TKN concentration was lower beneath the system than adjacent to the system, even if one were to shift the adjacent down one increment of depth. This same trend was noted for the at-grades (Converse, et al., 1990) and mounds (Converse, et al., 1994).

The ammonia concentrations were only slightly higher beneath than adjacent except for the sand increment (B, 0-15 cm), while for the mounds and at-grades the difference was much greater between, beneath and adjacent. This was expected as the effluent nitrogen concentration in the previous studies was primarily ammonia with no nitrate while in this study it was primarily nitrates with much less ammonium and organic nitrogen. The nitrate and chloride concentrations in the lower profiles were higher beneath than adjacent to the system indicating a system impact on the environment.

Table 5. TKN, ammonia, nitrate, and chloride concentrations with depth beneath (B) and adjacent (A) to dispersal units receiving aerobically treated effluent for 74 profiles.

Depth (cm)	Median B	Median A	Average B	Average A	Std. Dev. B	Std. Dev. A	Min. B	Min. A	Max. B	Max. A
	TKN - mg N/kg dry soil									
0 - 15	149	1616	408	1712	554	864	20	475	1983	5391
15 - 30	1238	1485	1195	1511	899	607	13	600	3700	2889
30 - 45	847	589	974	721	644	499	24	44	2900	2518
45 - 60	619	480	656	543	426	202	100	333	2960	1213
60 - 75	414	268	442	301	284	218	40	22	2100	1061
75 - 90	257	359	289	401	202	201	20	102	1100	797
90 -105	162	192	186	227	106	201	10	1	432	9
	Ammonia - mg N/kg dry soil									
0 - 15	2	9	4	11	6	6	0	2	35	34
15 - 30	7	7	13	10	17	8	0	3	96	37
30 - 45	6	4	11	6	15	6	1	0	112	29
45 - 60	5	3	7	4	8	2	1	1	38	8
60 - 75	4	2	7	2	10	2	0	0	44	7
75 - 90	3	2	7	2	15	1	0	1	95	2
90 -105	2	1	4	2	6	2	0	0	33	14
	Nitrate - mg N/kg dry soil									
0 - 15	4	6	7	10	7	9	0	1	33	56
15 - 30	7	8	9	12	6	13	1	3	29	57
30 - 45	7	3	8	5	5	7	1	1	23	42
45 - 60	7	3	8	4	5	4	0	1	22	13
60 - 75	6	2	7	2	5	2	0	0	25	7
75 - 90	4	2	5	2	4	1	0	1	21	3
90 -105	4	1	4	2	3	2	0	0	15	9
	Chloride - mg N/kg dry soil									
0 - 15	11	8	25	20	32	64	0	0	132	544
15 - 30	18	8	51	20	79	33	1	0	358	155
30 - 45	21	4	50	11	67	16	0	0	253	88
45 - 60	17	9	46	16	58	20	1	0	211	72
60 - 75	19	9	45	14	56	16	1	0	190	81
75 - 90	17	11	41	14	46	12	4	2	153	43
90 -105	20	8	40	16	41	29	2	0	146	165

Nitrate and chloride concentration, based on the water content, are given in Table 6. The median nitrate concentration beneath the system was 26 mg N/L and only 7 mg N/L adjacent to the system at 90-105 cm (36-42 in.) which indicates that the system does have an impact on the environment at that distance beneath the system. In a previous study by Converse et al. (1994), average values were reported. Recalculation of the data revealed a median value of 27 mg N/L at the same distance beneath the infiltration surface. Thus, pretreatment with aerobic units had very little effect on reducing nitrogen to ground water. Some denitrification is occurring in the soil beneath the dispersal unit as the nitrate concentrations decrease with depth but not for chlorides thus ruling out dilution effects.

Table 6. Soil moisture content and soil solution nitrate and chloride concentration with depth beneath (B) and adjacent (A) to dispersal units receiving aerobically treated effluent for 74 profiles.

Depth (cm)	Median B	Median A	Average B	Average A	Std. Dev. B	Std. Dev. A	Min. B	Min. A	Max. B	Max. A
	Moisture Content (% db)									
0 - 15	9	22	12	21	8	8	4	6	45	46
15 - 30	24	20	22	22	9	5	4	13	40	30
30 - 45	23	19	22	18	7	7	4	3	48	30
45 - 60	21	20	21	19	6	6	7	10	33	27
60 - 75	20	18	19	17	6	7	8	3	31	32
75 - 90	17	19	16	20	6	5	1	12	29	29
09 -105	16	17	16	16	5	6	6	3	28	27
	Nitrates - mg N/L of soil solution									
0 - 15	44	35	56	51	43	43	5	10	236	222
15 - 30	36	39	42	61	31	70	0	12	178	319
30 - 45	35	18	41	36	25	47	7	3	95	258
45 - 60	32	13	39	29	28	36	0	4	115	119
60 - 75	31	11	36	17	27	17	0	0	115	75
75 - 90	29	8	33	10	23	7	3	3	100	25
90 -105	26	7	30	15	28	17	0	1	167	66
	Chlorides - mg/L of soil solution									
0 - 15	101	36	297	60	488	71	4	0	2372	370
15 - 30	78	38	239	64	363	85	0	2	1536	376
30 - 45	96	28	230	59	307	74	0	1	1340	383
45 - 60	83	40	234	92	325	108	2	2	1381	367
60 - 75	99	65	247	87	339	92	0	2	1458	511
75 - 90	114	67	294	73	372	49	21	11	1467	148
09 -105	125	45	300	125	350	240	17	2	1400	1375

Water meters were installed to record water usage in 36 of the 39 homes. The median and average water usage was 709 and 775 L/d (183 and 200 gpd), respectively, during and around the period that the soil absorption units were evaluated (Table 7). The soil absorption systems were fed at the center, with a single pressure distribution lateral extending in each direction along the contour. A valve was installed at the inlet to the laterals so half the system could be shut off (Figs. 1 and 2). Of the 39 systems evaluated, 20 systems had 50% of the absorption area loaded, 17 systems had 100% of the absorption area loaded, and two systems had 25% of the absorption area loaded but, for evaluation purposes, were grouped with the 50% group.

Orifice size and spacing varied within the same system and between systems. Some systems had one lateral with 0.6 cm (1/4 in.) orifices spaced 1.2 m (4 ft) apart, and the other lateral had 0.3 cm (1/8 in.) holes spaced 30 cm (12 in.) apart. Other systems had 0.3 cm (1/8 in.) orifices spaced 30 cm (12 in.) apart for both laterals. For the systems with half the area loaded, 8 had 0.6 cm (1/4 in.) orifices and 14 had 0.3 cm (1/8 in.) orifice. For the full systems, 12 systems had a combination 0.6 cm (1/4 in.) and 0.3 cm (1/8 in.) orifices, 2 systems had 0.6 cm (1/4 in.) orifices, and 3 systems had 0.3 cm (1/8 in.) orifices. For those systems with the combination orifices, 3 were sampled beneath the 0.6 cm (1/4 in.) orifice, and 8 were sampled beneath the 0.3 cm (1/8 in.) orifice. It was assumed that the flow rate out of the 0.3 cm (1/8 in.) orifice was one quarter the flow rate out of the 0.6 cm (1/4 in.) orifices.

Table 7. System configuration and loading rates.

Parameter	Units	Median		Average	
		Half	Full	Half	Full
Aggregate Loading	cm/d (gpd/ft^2)	4.3 (1.1)	1.9 (0.5)	4.9 (1.2)	2.1 (0.5)
Basal Loading	cm/d (gpd/ft^2)	1.3 (0.3)	0.5 (0.1)	1.7 (0.4)	0.7 (0.2)
Orifice Flow -					
0.3 cm (1/8 in.)	L/d (gpd)	16 (4.1)	10 (2.5)	20 (5.1)	13 (3.4)
0.6 cm (1/4 in.)		50 (12.9)	29 (7.5)	54 (13.9)	1 (8.0)

The median flow rate ranged from 10-29 L/d (2.5-7.5 gpd) for the full systems. The median flow rate ranged from 16-50 L/d (4.1-12.9 gpd) for the half systems (Table 7), assuming equal flow out each orifice, which is highly unlikely. The median aggregate loading rates were 2.1 cm/d (0.5 gpd/ft^2) for the full systems and 4.3 L/d (1.1 gpd/ft^2) for the half systems. For the modified mound units, the effluent spread was probably less than in the at-grades as the sand was more porous than the native soil. The median basal loading rates, sand/soil interface, were 1.3 cm/d (0.3 gpd/ft^2) and 0.5 cm/d (0.1 gpd/ft^2) for the half and full systems, respectively. (The basal loading rate and aggregate loading rate is the same for at-grades.) The flow spread at the soil/aggregate interface is unknown and certainly not uniform. The loading rate data are presented only as a point of reference and must be used cautiously.

Fecal coliform profile data were also grouped based into half and full system usage. Table 8 shows the median, average, standard deviation, and maximum values for both groups. In both cases, based on median values, fecal coliform counts were below detectable levels (<1) after passing through 30 cm (1 ft) of soil. However, based on average values, detects were found to a greater extent in the half system than in the full system, but the median, average and maximum fecal coliform count in the influent was 4-5 times greater for the half system than the full systems, and they were loaded heavier, both of which affected the fecal coliform detects based on averages. Therefore, it was impossible to tell if higher loading rates influenced the treatment, but the combination of higher concentrations and loading rates did appear to impact the fecal coliform profile based on average values but not on median values. Thus, some caution should be exercised in downsizing, especially for aeration systems that don't remove as many of the fecal coliforms.

Table 8. Fecal coliform counts beneath the half used and fully used systems and influent concentration entering units.

Depth (cm)	Half Used System					Fully Used Systems				
	Median	Average	STD	Max	No.	Median	Average	STD	Max	No.
	(MPN/g dry soil)				-	(MPN/g dry soil)				-
0 - 2	7	66	183	798	29	8	35	48	140	10
2 - 15	3	56	181	1033	44	3	29	87	482	33
15 - 30	<1	22	62	341	44	<1	11	40	220	33
30 - 45	<1	22	95	593	44	<1	3	12	70	30
45 - 60	<1	26	94	536	44	<1	6	30	160	28
60 - 75	<1	21	111	719	42	<1	2	7	34	23
75 - 90	<1	12	51	325	41	<1	1	1	5	19
90 - 105	<1	2	6	34	36	<1	1	1	3	16
Influent Fecal Coliform Concentration - Cols./100 mL										
-	2150	47518	99561	450000	22	550	9296	18007	64000	17

These systems were pressure dosed, thus spreading the effluent along the total length of the system. Systems loaded by gravity will concentrate the effluent into a small area, thus possibly limiting the soil's ability to provide final treatment of the effluent before the effluent reaches ground water. Converse and Converse (1998) found differences in fecal coliform concentration in the pump chamber effluent serving several aeration systems.

Cell Study

The loading rates in the cell study were 4.2 cm/d (1.04 gpd/ft^2), 11.9 cm/d (2.93 gpd/ft^2), and 24.5 cm/d (6.02 gpd/ft^2) for cells 1, 2 and 3, respectively. The median and average fecal coliform concentrations were 4,900 and 6,066 cols./100 mL, respectively. Both the median and average nitrates concentrations were 28 mg N/L (Table 9).

Table 9. Influent characteristics for the field cell study.

Parameter	Units	Sample Size	Median	Average	Std. Dev.	Range
BOD	mg/L	7	3	3	1	1 - 4
COD	mg/L	7	25	25	2	21 - 28
Fecal Coliform	cols./100 mL	7	4900	6066	4575	560 - 15000
TKN	mg N/L	7	1	1	0	1 - 2
NH_4	mg N/L	7	0	0	0	0 - 1
NO_3	Mg N/L	7	28	28	4	22 - 23

Table 10 gives the average fecal concentration with depth along with the minimum and maximum values. Median values are not reported since there were only 3 replicates. A statistical analysis using SAS was done between the 3 cells. There was no significant difference between cells at the 5% level, due primarily to the low number of replicates and large variability in the data. There is a significant differences at the 10% level between cells at several depths. The data indicates a strong trend with the heavier loaded cell having higher fecal coliforms in the soil profile than the lower loaded cell. The data shows a decrease with depth of fecal coliforms with the lower loaded cell and higher fecal coliforms with depth for the higher loaded cell. The data suggests that the soil may not be able to adequately reduce the fecal coliforms to acceptable levels at the higher loading rates. Further evaluation is needed with different fecal coliform concentrations, loading rates and soil types to confirm but it does raise the question on loading rates.

Fecal coliforms were found at higher concentrations and at greater depths in the cell study than in the 39 sites tested. This was expected as the fecal coliform concentrations (median) were about one-fourth the values in the field study than in the cell study, and the loading rates were probably much less in the field systems, though impossible to determine. This relationship was also indicated when comparing half to full systems (Table 8).

There was no significant difference, using SAS, in nitrate concentrations between loading rates for all depths. It is interesting to note that the average nitrate influent concentration was about 28 mg N/L which is considerably less than the nitrate concentration in the soil profile. No background data were collected at this site.

SUMMARY AND CONCLUSIONS

Thirty nine soil absorption units receiving aerobic units or sand filter effluent were evaluated for a reduction in separation distance and downsizing. Two soil cores at 15 cm (6 in.) increments were taken to a depth of 105 cm (42 in.). Effluent samples were taken during the time of soil sampling. Surface horizon soil texture ranged from sands to very slowly permeable clay loams.

Table 10. Fecal coliform and nitrate concentrations in soil profile beneath the 3 cells receiving aerobically treated effluent.

Depth (cm)	Average			Minimum			Maximum		
	Loading Rates (cm/d)								
	4.2	11.9	24.5	4.2	11.9	24.5	4.2	11.9	24.5
	Fecal Coliforms - MPN/g dry soil								
0 - 2	17	6	55	2	2	23	37	10	82
2 - 15	10	2	7	2	1	2	16	2	12
15 - 30	1	2	6	1	<1	<1	2	6	16
30 - 45	3	1	16	2	<1	2	4	2	35
45 - 60	5	3	25	2	2	2	6	5	53
60 - 75	1	30	121	<1	3	9	2	84	322
75 - 90	5	18	17†	5	3	14	7	32	19
90 -105	<1	19	19†	<1	1	18	<1	51	19
	Nitrates - mg N/L								
2 - 15	47	44	38	27	26	20	65	69	64
15 - 30	60	58	48	48	51	26	77	62	68
30 - 45	43	33	34	36	25	23	55	40	50
45 - 60	33	35	28	30	33	20	36	38	36
60 - 75	35	36	37	25	29	29	41	46	48
75 - 90	44	30	30†	41	23	27	46	37	33
90 -105	35	26	28†	28	19	18	41	37	39

† Average of 2 numbers, all others are average of 3 numbers.

Based on median values, fecal coliform counts were not detected at distances greater than 30 cm (12 in.) in soils receiving effluent with median fecal coliform counts <10^4 MPN/100 mL for: 1) different types of systems, primarily modified mound and at-grade units; 2) both fully or half utilized soil systems; and 3) both coarse textured and fine textured soils. Effluent was pressure distributed to all systems studied.

Soil dispersal units were downsized by 50% with no adverse effect on fecal coliform removal. However, based on average values, there was some indication that increased loading rates and elevated fecal coliform counts in the effluent will be detected further in the soil profile thus affecting the amount of downsizing possible. Design configuration of soil dispersal units must account for effluent getting away from the unit in slowly permeable soils and during periods of elevated seasonally saturation.

Soil water nitrate concentrations were 26 mg N/L (median values) which is similar to those found beneath mounds and at-grades, indicating that the nitrogen species applied to soil has very little impact as it moves through the soil profile. Nitrate concentrations were higher beneath systems than adjacent to systems, indicating a nitrate impact at 105 cm (42 in.) beneath the soil dispersal unit.

A more controlled field cell study, with loading rates ranging from 4.2-24.5 cm/d (1-gpd/ft^2) showed no significant difference at the 5% level between cells but did at the 10% for several depths. There was a strong trend to higher fecal coliform with depth in the high loaded cell than the lower loaded cell. There was no significant difference in nitrates between cells. This may suggest that there is a limit to the mass loading rate (combination concentration and loading rate) to the soil for final polishing of the effluent.

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