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AT-GRADE ON-SITE SYSTEMS

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BACTERIAL AND NUTRIENT REMOVAL IN WISCONSIN AT-GRADE ON-SITE SYSTEMS

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The Wisconsin at-grade wastewater soil absorption system was developed for sites that do not meet the minimum separation distances for conventional in-ground systems but exceed the requirements for mound systems. Converse et al. (1989) presents the concepts and design of the at-grade unit. A manual was developed to assist professionals in siting, designing and constructing Wisconsin at-grade systems (Converse et al. 1990). Currently there are several hundred at-grade systems installed in Wisconsin.

Initially evaluation of the at-grades was based on hydraulic performance with the assumption that treatment performance would be similar to in-ground systems. The objective of this research was to evaluate the bacterial and nutrient removals from wastewaters in the soils beneath at-grade systems under actual field situations.

METHODS AND PROCEDURES

Over the past few years a number of experimental at-grade systems have been installed on residences with several being installed to accept the wastewater from trailer parks or motels. These units are considered experimental as the soil site criteria and design do not meet Wisconsin Administrative Code (1983). From over 100 experimental systems, 31 at-grade units were selected for an evaluation of treatment performance.

Since the soil beneath the system is unsaturated, except for possible ponding at the soil/aggregate interface, suction lysimeters would be required to extract water samples from the soil resulting in very questionable bacterial determinations. Thus a procedure was developed to extract soil samples from beneath and adjacent to the system for bacterial and nutrient evaluations.

Figure 1 is a cross section of an at-grade system showing the location of the soil boring for systems that used pressure distribution of the effluent through small diameter laterals and orifices. The sampling procedure consisted of locating an orifice in one of the pressure distribution laterals by excavating into the at-grade unit. The aggregate was removed adjacent to the orifice with a 15 cm (6 in.) diameter PVC pipe placed to the soil interface. If ponded conditions existed at the interface, the pipe was pushed into the soil to a depth of approximately 2.5 cm (1 in.) and the effluent removed. Using a small sterilized scoop the surface of the interface was scraped and placed in a sterile bag. A 2.5 cm (1 in.) diameter by 15 cm (6 in.) long metal tube was pushed 15 cm (6 in.) into the soil, extracted and placed in a sterile bag for bacterial analysis. A 7.5 cm (3 in.) diameter bucket auger removed the

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Table 1 Soil Descriptions for the 31 At-Grade Sites.

Site	Limiting Depth (in.)	Soil Descriptions*
1	36-37	0-14" Bl L; 14-30" Sil; 30-46" Sicl.
2	50-57	0-12" Sil; 12-31" Bn Sil; 31-49" Bn Sicl-Cl.
3	44-65	0- 8" Bn Sil; 8-24" Bn Cl-Res; 24-47" Bn Cl-SS Res w banded Sil.
4	36-38	0- 7" Dk Bn L; 7-37"; Bn Sil; 37" SS-Sh-Bn Sil-Sicl.
5	36-41	0-11" Dk Bn Si; 11-33" Bn Sil-Sicl; 33-51" Bn Sicl-Cl; 51-62" Bn Sicl-Cl.
6	38-41	0-16" Bl Sil; 16-38" Bn Sil; 38-42" Bn Cl; 42-54" Bn Cl.
7	37-41**	0-17" Bl Sil; 17-40" Bn Sil; 40" Sil-LS-Br.
8	46-48**	0-4" Bl Sil; 6-48" Bn Sil; 48" LS-Br.
9	36-46	0-11" Bl Sil; 11-26" Bn Cl; 26-62" Bn Cl.
10	40-43	0-13" Bl L; 13-45" Bn Sicl; 45-76" Bn Ls & Gr.
11	43-46	0-11" Bl Sil; 11-46" Bn Sil; 46-77" Bn Ls & Gr.
12	37-43	0- 6" Bl Sil; 6-40" Bn Sil; 40" Bn Sil.
13	42-53**	0-12" Dk Bn Sil; 12-37" Bn Sil; 37-48" R Bn Cl; 48-55" Br.
14	37-43	0-20" Bn Sil; 20-24" Bn Sil-Scl-Cl; 34-43" Bn Sil-Scl-Cl; 43-56" Bn C.
15	37-40	0-37" Bl Sil; 37-69" Bn Sicl-R Cl.
16	38-41	0-14" Bl Sil; 14-27" Bn Sil; 27-42" Sil-Sicl; 42-54" Sicl-Cl, 54" Br.
17	36-40	0- 5" Bl Sil; 5-21" Dk Bn Sil; 21-37" R Bn Cl; 37-46" R C.
18	40-42	0-29" Bl Sil; 29-50" Bn Sil.
19	36-44**	0-11" Dk Bn Sil; 11-23" Bn Sil; 23-33" Bn Cl; 33-42" R Bn C; 42" Br.
20	38-51**	0- 8" Bl Sil, 8-34" Bn Sil, 34-44" Bn Cl; 44" Br.
21	37-39	0-11" Dk Bn Sil; 11-27" Bn sil; 29" Bn Sil.
22	39-47	0- 9" Dk Bn Sil; 9-25" Bn Sil; 25-36" Lt Bn Sil; 36" Bn L-Sil.
23	38-43	0-12" Dk Bn Sil; 12-36" Bn Sil-Sicl, 36-47" Bn Sicl-Scl-Sc; 47-70" Sc; 70-84" R Bn Cl-Sc.
24	37-42	0-25" Bn Sil; 21-31" Bn Sil-Sicl; 31-46" Bl L-Sil; 46-61" Dk Gy Cl; 61-77" Gy C.
25	36-39	0-15" Bk Sil; 15-26" Bn Sil-Sil; 26-40" Bn Sil; 40-50" Bn Sil.
26	39-58	0- 9" Sil; 9-15" Sil; 15-20" Sil; 20-49" Sil: 49-75" Sil.
27	36-45	0- 9" Sil; 9-15" Sil; 15-20" Sil; 20-48" Sil, 49-75" Sil.
28	38-42	0-20" Sil; 20-30" Bn Sil; 30-60" Y Bn Sil.
29	36-41	0-15" Sil, 15-33" Sil; 33-45" Sil-Cl; 45-56" Cl.
30	28-36	0-11" Sil; 11-25" Sil; 25-37" Sil; 37" Ls-Sl-Sil Till
31	37-41	0- 5" Dk Bn Sl; 5-29" Bn Sl-Ls; 29-40" Ls.

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*The soil description is the average of the borings taken on the site in the area of the system. L-loam, S-sand, Ls-loamy sand, Sl-sandy loam, Sil-Silt loam, Si-silt, Scl-sandy clay loam, Sicl-silty clay loam, Cl-clay loam, C-clay, Br-bedrock, SS-sandstone, Sh-shale, Res-residium, Gr-gravel, Bl-black, Bn-brown, R-red, Gy-grey, Dk-dark, Lt-light. These soil profile descriptions are based on texture only. Current evaluation is based on texture, structure and consistence.

**Limiting condition is bedrock. All others are high water table based on mottling.

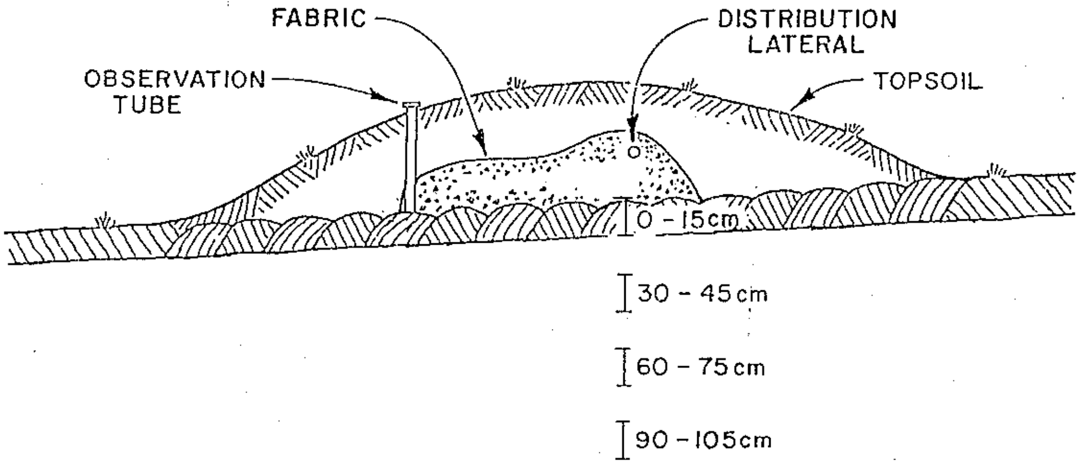

Fig. 1. Cross Section of a Wisconsin At-Grade Unit Showing the Location of the Sampling Points Beneath the System Utilizing Pressure Distribution

remaining soil in the 15 cm (6 in.) depth increment. The soil was placed in a plastic bag for chemical analysis. The bucket auger removed the next 15 cm (6 in.) of soil which was discarded. A core was extracted from the next 15 cm (6 in.) of the profile for bacterial analysis followed by soil extraction for chemical analysis using the bucket auger. This procedure was followed at 15 cm (6 in.) increments to a depth of 105 cm (42 in.). At one site all 15 cm (6 in.) increments were evaluated.

For gravity distribution systems, the procedure was identical except the sampling was done beneath the ponded surface as ponding typically occurs in small areas of gravity flow system. If a ponded surface was not located, the site was not sampled.

In the laboratory a middle section of the soil sample was removed from the metal tube for bacterial analysis, mixed and analyzed for total and fecal coliform. The soil sample was also analyzed for moisture content and chlorides. Bacterial analysis and moisture content were analyzed according to Standard Methods for the Examination of Water and Wastewater (APHA 1985) and Methods of Soil Analysis (ASA 1982) with the multiple-tube fermentation procedure used for total and fecal coliforms. Moisture content was determined on a dry basis. The chlorides were determined using an automatic coulometric /amperametric chloride titrator.

The soil samples used for chemical analyses were stored in plastic bags and frozen for later analyses. The analyses consisted of moisture content, total kjeldahl nitrogen (TKN), ammonia and nitrates. Analyses were performed according to Standard Methods for the Examination of Water and Wastewater (APHA 1985) and Methods of Soil Analysis (ASA 1982).

For 28 of the at-grade units evaluated two soil profile borings, identified as "beneath", were taken beneath each unit in areas receiving effluent. Two soil profile borings, identified as "adjacent", were taken adjacent to the at-grade unit and they represent the background data for the site.

A single suite of laboratory analyses was conducted on each soil sample and then the corresponding analyses for each were averaged for the various depths. Thus there was an average parameter profile beneath and adjacent to each system. However, several of these 28 sites were sampled at two or three different times with the data averaged together and used as a single data point. For 3 other sites, several soil profiles were taken at each site and presented individually. Thus a total of 31 at-grade units were analyzed.

On occasion it was impossible to obtain a sample at a given depth in which case a single data point or no data point was recorded. An effluent sample was collected from the pump chamber when soil cores were being taken. Various analyses were conducted on the effluent according to Standard Method for the Examination of Water and Wastewater (APHA 1985).

RESULTS AND DISCUSSION

Soil Profiles and System Characteristics

Table 1 gives the average described soil characteristics in the area of each at-grade system and the depth to limiting conditions, which was obtained by averaging the 3 to 5 soil profile descriptions written by Certified Soil Testers (CST) prior to installation of the system. At the time of these evaluations the typical soil evaluation consisted of determining the soil texture and color for each horizon and determining the depth to the limiting condition such as high water table by mottling or bedrock by percentage of rock to soil. The CST did not evaluate soil structure and consistence.

Sites 1-29 (Table 1) has soils with loam to silt loam surface horizons, silt loam to silty clay loam shallow subsurface horizon and a silty clay loam to clay loam deep subsurface horizon. Typically these soils have a granular or subangular blocky structure in the surface horizon, subangular blocky to angular blocky structure in the shallow and deep subsurface horizons. Consistence at the surface is friable with friable to firm subsurface horizons.

Sites 1-28 (Table 1) have septic tank/at-grade units with pressure distribution and Site 29 has an aerobic/at-grade unit with pressure distribution. Two sites have a septic tank/at-grade unit using gravity flow distribution with one having a soil profile consisting of silt loam over a horizon of loamy sand, sandy loam and silt loam (Site 30, Table 1) and the other having a soil profile consisting of a sandy loam to loamy sand profile (Site 31, Table 1).

Effluent Quality

At the time the systems were being evaluated, a grab sample of the septic tank effluent was taken from the pump chamber at each of the 30 systems. Table 2 gives the average, standard deviation and 95% confidence interval for each of the parameters measured. Based on the average parameters, such as BOD and SS, this data appears to be typical septic tank effluent (EPA 1980).

Table 3 gives the effluent quality, based on 21 samples from one system, using an aerobic treatment unit instead of a septic tank. These samples were taken as grab samples from the pump chamber over a 1 1/2 year period. The effluent appears to be typical of a properly operating aerobic treatment unit with very low BOD, suspended solids and with most of the nitrogen converted to nitrate.

Based on the average fecal coliform count in the septic tank effluent (Table 2) and the aerobically treated effluent (Table 3), the fecal count in the aerobically treated effluent has been reduced from an average of 2.7E6 to 2.5E3 MPN/100 ml or a reduction of 99.9%. However, it should be noted that this fecal count of 2500 MPN/100 ml can present a health risk and must be treated accordingly.

Soil Loading Rates

All systems were sized according to the Wisconsin Administrative Code (1983) with loading rates based on the soil texture. For all of the sites the design loading rate was approximately 2.5 cm/d (0.6 gpd/ft^2). This assumes equal distribution over the total absorption area. Converse (1974) and Machmeier

Table 2 Septic Tank Effluent Characteristics for 29 Residential Sites and One Apartment/Office Complex Based on One Grab Sample Taken from the Pump Chamber at the Time of the At-Grade Evaluation.

Parameter	Units	Sample Size	Average	Stnd Dev	Range
Total Solids	mg/L	30	1271	589	457 - 2632
Vol. Solids	mg/L	30	402	118	186 - 726
Susp. Sol.	mg/L	30	99	102	44 - 572
V. Susp. Sol.	mg/L	30	60	72	19 - 402
BOD$_5$	mg/L	25	150	54	47 - 239
COD	mg/L	27	291	163	89 - 743
Org. Nit.	mg N/L	30	11	8	5 - 48
Ammonium	mg N/L	30	48	18	19 - 84
Phosphorus	mg P/L	25	5	1	3 - 7
Chloride	mg/L	29	275	333	14 - 1200
EC	umho/cm	29	2225	1251	810 - 5000
pH	-	27	8.4	0.4	7.8 - 9.1
Total Coli.	MPN/100 ml	29	1.0E8	2.1E8	3.6E6-1.0E9
Fecal Coli.	MPN/100 ml	29	2.7E6	7.7E6	2.3E3-4.1E7

Table 3 Aerobic Tank Effluent Characteristics for 1 Residential Site Based on 21 Grab Samples Taken from the Pump Chamber over 1 1/2 Years.

Parameter	Units	Sample Size	Average*	Stnd Dev	Range*
Total Solids	mg/L	21	811	96	648 - 970
Vol. Solids	mg/L	21	384	59	252 - 503
Susp. Sol.	mg/L	21	18	15	1 - 60
V. Susp. Sol.	mg/L	21	4	3	0 - 11
BOD$_5$	mg/L	17	3	2	1 - 6
COD	mg/L	20	28	13	6 - 66
Org. Nit.	mg N/L	21	1	1	0 - 2
Ammonium	mg N/L	21	0	0	0 - 2
Nitrate	mg N/L	21	53	12	25 - 77
Phosphorus	mg P/L	5	4	0	3 - 4
Chloride	mg/L	21	58	12	35 - 85
EC	umho/cm	21	1078	82	950 - 1250
pH	-	18	7.9	0.3	7.2 - 8.3
Total Coli.	MPN/100 ml	16	8.9E4	2.4E5	4.3E2-1.0E6
Fecal Coli.	MPN/100 ml	16	2.5E3	4.0E3	5.0E0-1.5E4
D.O.	mg/l	18	6.9	0.3	7.2- 8.3
Temperature	^{o}C				
Pump Tank		20	15	5	7 - 24
Aerator		17	23	4	17 - 30

*If the value was recorded as <1 mg/L by the laboratory it was listed as zero.

and Anderson (1987) showed that equal distribution does not occur in gravity flow systems and that all the wastewater is concentrated in several locations with ponding occurring due to localized overloading and clogging mat development. Pressure distribution spreads the wastewater more "uniformly" but does concentrate it in a number of locations depending upon the number of orifices in the pressure distribution network. The loading rate on these small areas is based on the number of orifices, the dose volume and the number of orifices blinded by aggregate. Falkowski and Converse (1987) showed that orifice discharge rate can be affected by rock blinding. Thus it is impossible to determine the exact loading rate at the soil interface for those areas sampled.

Wastewater Parameters in The Soil

Septic Tank/At-Grade/Pressure Distribution: Twenty-seven at-grade units serving residences and one at-grade unit serving a two apartment/small office complex were evaluated. Average household population was 3.8 adults and children. There was an average of 3.1 bedrooms per home. Over half of the homes had water softeners but it is not known if the backflush was discharged into the septic tank. The apartment/office complex housed 5 adults in three apartments and 16 personnel worked in the office. The average age of the systems, at the time of sampling, was 1.9 yrs. with a range of 0.1 to 6.5 yrs.

Based on the approved plans the pressure distribution network has an average of 37.8 orifices with a range of 16 to 60 orifices; an average orifice spacing of 96 cm (38 in.) with a range of 43 to 152 cm (17 to 60 in.); an average dose volume of 643 L/dose (170 gal./dose) with a range of 227 to 1593 L/dose (60 to 421 gal./dose); and an average loading of 19 L/orifice/dose (5.1 gal./orifice /dose) with a range of 4.5 to 42.0 L/orifice/dose (1.2 to 11.1 gal./orifice /dose). Most orifice diameters were 0.63 cm (1/4 in.) with several slightly larger or smaller.

Table 4 gives the average and 95% confidence interval of each wastewater parameter determined at each depth based on dry weight of the soil beneath the 28 systems using a septic tank/at-grade unit with pressure distribution (Sites 1 - 28, Table 1). Samples were taken at the surface and at every other 15 cm (6 in.) interval. The results are an average over the 15 cm depth interval. Average fecal coliform counts beneath the systems decreased from 1389 MPN/g of dry soil at the aggregate soil interface to 193 MPN/g of dry soil in the 90-105 cm (36-42 in.) depth or a reduction of 86%. This reduction, although significant, still leaves a high fecal coliform count at the 90 cm depth. The Wisconsin Administrative Code (1983) assumes that all the fecal coliforms are removed from the effluent within 90 cm (3 ft) beneath the system. There is considerable variation in the results from site to site with a 95% confidence interval of 72-314 MPN/g dry soil at the 90-105 cm (36-42 in.) depth.

The background fecal coliform counts were determined at each site for the 0-15 cm depths and at several sites to the same depth as those taken beneath the system. In most cases the fecal coliform count below the 15 cm depth were below the detectable level (<1 MPN/g of dry soil). For the 0-15 cm depth the average fecal coliform count was 3 MPN/g of dry soil with a range of <1 to 29 MPN/g of dry soil. In 18 of these 28 systems, the background fecal counts were <1 mpn/g of dry soil in the 0-15 cm depth. Two sites were excluded from the background average as the systems were located in a calf pasture which probably contributed to the high fecal counts of 175 and 365 MPN/g dry soil in the 0-15 cm (0-6 in.) depth. Ziebell et al. (1975) showed fecal coliform background levels adjacent to a ponded in-ground trench to be <2 MPN per gram of soil. These numbers are relatively insignificant when compared to the fecal counts beneath the system.

When fecal coliforms are measured in unsaturated soils, as in this study, the data are reported as MPN/g of dry soil. The treatment effectiveness, for the case in point, is either to compare the results to the adjacent background values or to literature values reporting fecal coliforms in MPN/g of dry soil, of which there is very limited data. For health and safety purposes, fecal coliforms limits are based on water volume with units of MPN/100 ml. There is no standard of comparison for fecal coliform limits in soil based on MPN/g dry soil as there is for water. It would be convenient if a comparison could be made between the two sets of data which can be done only if one assumes that all of the fecal coliforms are associated with the soil water and not attached to the soil particles. Since fecal coliforms are particulate matter, this assumption may not be valid.

If this assumption is used, then the MPN/g of dry soil can be converted to MPN/100 ml of soil water using the moisture content on a dry basis. Using the

Table 4 Average Soil Profile Parameters And Lower and Upper 95% Confidence Interval Based on Soil Weight for Beneath, Adjacent and Beneath Minus Adjacent for 28 Septic Tank/At-Grade Units Using Pressure Distribution on Similar Soil Profiles For Sites 1-28 of Table 1.

Depth (cm)	Beneath*			Adjacent			Beneath - Adjacent		
	Lower	Avg	Upper	Lower	Avg	Upper	Lower	Avg	Upper
Fecal Coliform (MPN/g dry soil)									
0 -2.5	518	1389	2261						
0 - 15	290	715	1140	1	3	6			
30 - 45	149	422	695						
60 - 75	-22	483	987						
90 -105	72	193	314						
Moisture Content (% dry basis)**									
0 -2.5	33	37	41						
0 - 15	30	34	37	19	21	24			
30 - 45	24	26	28						
60 - 75	23	25	27						
90 -105	23	25	28						
Total Kjeldahl Nitrogen (mg N/kg dry soil)									
0 - 15	1731	2136	2560	1598	2048	2499	-47	94	235
30 - 45	721	973	1224	668	930	1192	-162	-6	151
60 - 75	473	569	666	422	525	627	-60	19	97
90 -105	320	400	479	280	348	415	-11	38	86
Ammonium Nitrogen (mg N/kg dry soil)									
0 - 15	14	29	43	5	11	18	3	17	30
30 - 45	8	17	27	3	5	8	3	12	21
60 - 75	7	17	26	2	3	5	4	11	17
90 -105	5	15	26	1	3	5	2	8	14
Nitrate Nitrogen (mg N/kg dry soil)									
0 - 15	15	21	27	13	28	43	-22	-7	8
30 - 45	9	12	15	9	16	23	-10	-4	3
60 - 75	8	11	14	7	13	18	-7	-2	4
90 -105	6	9	12	5	10	15	-6	-1	5
Chloride (mg/kg dry soil)									
0 - 15	46	102	159	6	30	54	30	73	117
30 - 45	41	79	118	6	30	53	22	51	79
60 - 75	42	81	121	8	29	50	16	44	73
90 -105	37	78	119	9	29	49	16	48	80
Moisture Content (% dry basis)***									
0 - 15	29	33	36	19	22	24	8	11	14
30 - 45	25	27	29	19	21	23	4	6	8
60 - 75	24	26	29	19	21	24	3	4	6
90 -105	23	26	28	20	23	26	2	3	5

*Beneath is below the system receiving effluent and adjacent is next to the system and not receiving effluent; **Moisture content associated with fecal coliforms; ***Moisture content associated with the other parameters.

average fecal coliform count of 193 MPN/g of dry soil at the 90-105 cm (36 to 42 in.) depth (Table 4) and an average soil moisture content of 25% at the same depth (Table 4), the fecal coliform concentration is 77,200 MPN/100 ml of soil water which contrasts to the control of <400 MPN/100 ml (assuming <1 MPN/g of dry soil and a moisture content of 25% db). This <1 MPN/g of dry soil is the lowest detectable level with actual fecal coliform count ranging between 0 and 400 MPN/100 ml.

With this assumption it appears based on both the MPN/g of dry soil and the MPN/100 ml of soil water that these silt loam soils are not adequately treating the septic tank effluent under the existing loading regimes at the levels expected. This should not reflect upon the ability of the at-grade system and the underlying soil of treating the wastewater to acceptable levels, but should reflect upon the inability of the pressure distribution networks to deliver low dose rates uniformly over the infiltrative surface with sufficient detention time for effective treatment. Thus it appears to be appropriate to examine the relationship between orifice spacing and size, number of orifices, dose volume and the resulting localized loading rates for various soil textures and structures in order to improve the treatment capability of the soil. Gravity systems during start-up will probably give equally or poorer fecal attenuation until a clogging mat develops. However, data is lacking to prove this point.

Another parameter significant to ground water quality is nitrogen. Table 4 gives the nitrogen (total kjeldahl (TKN), ammonium and nitrate) profiles beneath the system, adjacent to the system and the difference (beneath -adjacent) on a dry soil basis.

Of the nitrogen species, the organic nitrogen concentration (TKN - ammonium) is by far the dominant species accounting for 94 to 98% of the total nitrogen (Table 4) at all depths of the profile for beneath and adjacent to the system. The ammonium profile at all depths is higher beneath the system than adjacent to the system showing the impact of the wastewater addition to the soil. The ammonium level decreases with depth for both profiles with the concentrations 2.1 to 3.0 times greater beneath the system than adjacent to it (Table 4).

The nitrate level beneath the system is slightly less than adjacent to the system on a dry soil basis (Table 4). However, if both ammonium and nitrate concentrations were added together, the concentration beneath the system would be greater than adjacent to the system for all depths measured. It appears that something is limiting the nitrification beneath the system as one would expect the nitrate concentrations to be higher beneath than adjacent to the system. The nitrification process is very sensitive to sufficient oxygen levels and the higher soil moisture beneath the system may be inhibiting oxygen transfer.

The background nitrate levels at all depths appear to be much higher than expected. Bundy and Malone (1988) reported much lower nitrates beneath agricultural fields receiving zero or moderate amounts of fertilizer for corn production. There is no explanation for these high values other than that most of these systems are located in lawns that may be highly fertilized. However, one would not expect such high nitrate concentrations in the soil profile beneath the lawns if they were fertilized properly (Kussow 1991). Several systems are located in calf pastures and adjacent to animal facilities.

If one assumes that all of the nitrate is associated with the soil water and not with the soil particles, which is a fair assumption since nitrates are soluble and move with the soil water, the average nitrate concentrations beneath the system range from 66 mg N/L at the 0-15 cm depth to 35 mg N/L at the 90 -105 cm (36 to 42 in.) depth with corresponding values of 122 mg N/L and 42 mg N/L adjacent to the system (Table 5). Dilution, denitrification or lack of mineralization activity may be the reasons for the lower concentrations beneath the system than adjacent to the system.

Table 5 Average Soil Profile Parameters And Lower and Upper 95% Confidence Interval For Nitrates and Chlorides From Table 4 Based on Soil Water Volume.

Depth (cm)	Beneath*			Adjacent			Beneath - Adjacent		
	Lower	Avg	Upper	Lower	Avg	Upper	Lower	Avg	Upper
Nitrate Nitrogen (mg N/L)**									
0 - 15	49	66	84	66	122	177	-110	-54	2
30 - 45	36	46	56	47	78	109	-60	-32	-3
60 - 75	31	42	54	35	64	92	-47	-20	8
90 -105	23	35	48	22	42	62	-27	-7	13
Chloride (mg/L)									
0 - 15	142	287	432	30	124	219	43	164	285
30 - 45	148	283	418	37	121	204	58	164	270
60 - 75	153	287	421	39	125	211	41	148	255
90 -105	145	287	429	44	117	189	41	156	270

*Beneath is below the system receiving effluent and adjacent is next to the system and not receiving effluent. **Assuming that the parameter is associated only with the soil water, the conversion from mg/kg of dry soil to mg/L of water is: mg/L = (Concentration in mg/kg)/(Moisture Content in dry basis).

Obviously the soil water beneath and adjacent to the system does not meet the 10 mg N/L nitrate standard. Further reduction in nitrate concentration is unlikely before it reaches the groundwater because the conditions are not conductive to denitrification at these lower depths. Since there is considerably more water percolating beneath the system than adjacent to the system, the impact of the system discharging nitrate to the ground water is probably greater than for the adjacent area.

Based upon the information presented in Tables 4 and 5, it is impossible to calculate the average soil nitrate beneath the system as the profiles evaluated are directly beneath the areas receiving the highest concentration of effluent and do not represent other areas beneath the system. These profiles probably represent the worst case scenario as they receive the highest concentration of wastewater.

Using the chloride/nitrate ratio to estimate denitrification losses is somewhat questionable as relatively high concentrations of chlorides are being added to the system and the soil beneath and adjacent to the system have very high nitrogen concentrations.

Chloride profiles beneath the system were higher than adjacent to the system for both the dry soil basis (Table 4) and the water volume basis (Tables 5). On the water volume basis there was essentially no concentration decrease beneath and adjacent to the system with concentrations of approximately 287 and 124 mg/L, respectively, (Table 5), measured throughout the profile depth. Chloride levels from site to site are quite variable due to the use or non-use of water softeners.

Septic Tank/At-Grade/Gravity Distribution: Two systems using gravity distribution were evaluated. Table 6 gives the results for an at-grade unit on a silt loam soil (Site 30, Table 1). The house is a 3 bedroom unit with two adults and two children with an average measured water use of 818 Lpd (214 gpd). The system was sectioned into 4 equal parts with the flow directed to 1/4 of the system, resulting in an average loading rate of 4.46 cm/d (1.1 gpd/ft^2). Sampling was conducted 2 and 3 years after system installation.

Table 6 Average Soil Profile Parameters Based on Soil Weight for 1 Septic Tank /At-Grade Unit Using Gravity Flow Distribution for Site 30 in Table 1.

Depth	Beneath*					Adjacent		
(cm)	5/86**	5/86	5/87	8/87	Ave	5/87	8/87	Ave
Total Coliforms (MPN/g dry soil)								
0 -2.5	19000	769	2300	428	5624	9	33	21
0 - 15	3800	604	10	33	1112	11	11	11
30 - 45	19	192	1500	<1	428	<1	<1	<1
60 - 75	<1	714	36	<1	188	36	<1	19
90 -105	1	4	2	<1	2	-***	<1	<1
Fecal Coliforms (MPN/g dry soil)								
0 -2.5	253	18	95	190	139	-	-	-
0 - 15	126	6	1	2	34	<1	<1	<1
30 - 45	1	9	34	<1	11	<1	<1	<1
60 - 75	<1	126	36	<1	41	<1	<1	<1
90 -105	<1	<1	2	<1	<2	-	<1	<1
Total Kjeldahl Nitrogen (mg N/kg dry soil)								
0 -2.5	1830	1698	1864	1833	1806	-	-	-
0 - 15	1874	2019	1872	1770	1884	1546	2120	1833
30 - 45	691	713	671	524	650	339	870	604
60 - 75	315	350	231	434	333	138	372	255
90 -105	245	209	339	352	286	-	484	484
Ammonium Nitrogen (mg N/kg dry soil)								
0 -2.5	116	25	170	162	118	-	-	-
0 - 15	148	58	162	210	145	13	24	19
30 - 45	12	72	17	14	29	7	12	10
60 - 75	6	17	9	11	11	5	11	8
90 -105	8	5	12	8	8	-	7	7
Nitrate Nitrogen (mg N/kg dry soil)								
0 -2.5	6	25	6	2	10	-	-	-
0 - 15	5	8	4	4	5	7	5	6
30 - 45	10	3	17	11	10	4	1	3
60 - 75	7	9	9	12	9	1	2	2
90 -105	4	8	9	9	8	-	2	2
Chlorides (mg N/kg dry soil)								
0 -2.5	168	173	174	294	202	-	-	-
0 - 15	395	207	146	242	248	35	35	35
30 - 45	75	157	133	144	127	31	23	27
60 - 75	104	106	116	144	118	22	21	22
90 -105	30	101	112	121	91	-	33	33
Moisture Content (% db)								
0 -2.5	28	23	28	39	29.5	-	-	-
0 - 15	30	38	29	28	31.3	17	19	18.0
30 - 45	22	23	22	22	22.3	10	19	14.5
60 - 75	16	18	16	20	17.5	6	22	14.0
90 -105	16	14	19	15	16.0	-	14	14.0

*Beneath the system and receiving effluent, adjacent to the system and not receiving effluent. **Month and year sampled. ***Not sampled.

Table 7 Average Soil Profile Parameters Based on Soil Weight for 1 Septic Tank /At-Grade Unit Using Gravity Flow Distribution for Site 31 in Table 1.

Depth	Beneath*					Adjacent		
(cm)	8/86**	8/86	7/87	9/87	Ave	7/87	9/87	Ave
			Total Coliforms (MPN/g dry soil)					
0 -2.5	-	-	28000	67485	47742	-***	-	-
0 - 15	269	93	930	3237	2083	8	3	6
30 - 45	<2	<2	<1	<1	<2	<1	<1	<1
60 - 75	<2	<2	<1	<1	<2	<1	<1	<1
90 -105	<2	<2	29	<1	9	<1	<1	<1
			Fecal Coliforms (MPN/g dry soil)					
0 -2.5	-	-	500	9536	5018	-	-	-
0 - 15	181	13	5	218	104	<1	<1	<1
30 - 45	<2	<2	<1	<1	<2	<1	<1	<1
60 - 75	<2	<2	<1	<1	<2	<1	<1	<1
90 -105	<2	<2	<1	<1	<2	<1	<1	<1
			Total Kjeldahl Nitrogen (mg/kg dry soil)					
0 -2.5	-	-	555	396	475	-	-	-
0 - 15	408	393	454	488	435	428	349	388
30 - 45	169	166	203	115	164	100	174	177
60 - 75	66	67	112	109	88	149	119	134
90 -105	109	70	144	67	98	137	77	107
			Ammonium Nitrogen (mg N/kg dry soil)					
0 -2.5	-	-	30	37	34	-	-	-
0 - 15	8	13	12	72	26	12	12	12
30 - 45	7	4	6	6	12	3	5	4
60 - 75	1	1	4	7	3	7	9	8
90 -105	4	1	7	6	5	5	8	7
			Nitrate Nitrogen (mg N/kg dry soil)					
0 -2.5	-	-	1	4	3	-	-	-
0 - 15	8	6	7	9	8	2	5	4
30 - 45	4	1	5	4	4	0	4	2
60 - 75	3	0	3	4	3	1	5	3
90 -105	5	2	5	5	4	0	3	2
			Chlorides (mg N/kg dry soil)					
0 -2.5	-	-	47	26	37	-	-	-
0 - 15	30	43	24	19	29	7	12	10
30 - 45	29	25	19	13	22	6	10	8
60 - 75	27	28	13	12	20	15	2	9
90 -105	16	25	12	17	18	7	5	6
			Moisture Content (% db)					
0 -2.5	-	-	39	29	34.0	-	-	-
0 - 15	16	20	18	17	17.8	9	8	8.5
30 - 45	11	10	14	10	11.3	7	7	7.0
60 - 75	8	11	8	9	9.0	7	10	8.5
90 -105	13	9	13	13	12.0	8	10	9.0

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*Beneath the system and receiving effluent, adjacent to the system and not receiving effluent. **Month and year sampled. ***Not sampled.

Table 7 gives the results for the other at-grade unit on a sandy loam soil (Site 31, Table 1). The house is a 3 bedroom unit with 3 people. Average loading rate was 1.0 cm/d (0.25 gpd/ft^2). Sampling was performed 1 1/2 and 2 1/2 years after start-up.

Since both of these systems have gravity flow distribution, the effluent is probably concentrated into a small area of unknown size resulting in localized ponding. For both sites sampling was taken beneath the ponded area at three different times and adjacent to the system at two different times. The results for both are presented individually and averaged (Table 6 and 7).

For the silt loam soil (Table 6) the total and fecal coliforms were <1 MPN/g dry soil at the 90-105 cm (36-42 in.) depth beneath the system in 3 of the 4 profiles and 2 MPN/g of dry soil in the other profile. Based on an average of <2 MPN/g of dry soil, the fecal coliform count is <1250 MPN/100 ml of soil water if all the fecal coliforms are assumed to be in the water phase. Fecal coliforms measured throughout the profile adjacent to the system were below detection limits (< 1 MPN/g of dry soil) and only a few total coliforms in the upper portion of the soil profile were detected.

For the sandy loam soil, fecal coliform counts were <2 MPN/g dry soil (<1820 MPN/100 ml) at the 30-45 cm (12-18 in.) depth and below for the first sampling period and <1 MPN/g dry soil (<770 MPN/100 ml) for sampling periods 2 and 3 for the same depths (Table 7). Fecal coliform counts adjacent to the system were <1 MPN/g dry soil (<1100 MPN/ 100 ml) throughout the soil profile. The results for both sites are similar to the results reported by Ziebell et al. (1975) beneath a ponded in-ground trench system.

Organic nitrogen levels (TKN - ammonium) in the silt loam soil profile (Table 6) are similar to those reported for Sites 1-28 (Table 4) as the soils are similar. The nitrate concentration of 8 mg N/kg of dry soil at the 90-105 cm (36-42 in.) depth beneath the ponded area is about 4 times higher than the 2 mg N/kg of dry soil found at the same elevation adjacent to the system but comparable to the 9 mg N/kg of dry soil found beneath the 28 at-grade units with pressure distribution. If it is assumed that all of the nitrate is in the soil water, then the concentration beneath the gravity system at 90-105 cm (36-42 in.) profile is 65 mg N/L which compares to 35 mg N/L (Table 5) found beneath the pressure distribution systems. The notable difference between the two sites is the moisture content of the soil.

The organic nitrogen levels in the sandy loam soil are about 1/3 to 1/5 times those for the silt loam soils throughout the soil profile. The average nitrate nitrogen concentration at the 90-105 cm (36-42 in.) depth is 4 and 2 mg N/kg of dry soil beneath and adjacent to the system, respectively (Table 7). If it is assumed that the nitrate beneath the system is associated only with the soil water, then the concentration is about 35 mg N/L which is close to one half the concentration of the other gravity system and similar to the average of the 28 pressure distribution systems. Very little denitrification is expected to occur beneath this depth.

Chloride concentrations (mg/kg of dry soil) beneath this system with silt loam soil decrease with soil depth while the adjacent profile concentration remains relatively uniform. At the 90-105 cm (36-42 in.) level the chloride concentration beneath the system is 3 times the concentration adjacent to the system at the same depth (Table 6). Table 7 shows that the chloride concentrations are considerably less than those in Table 6 for both profiles (beneath and adjacent) as the effluent concentration is 31 mg/L as compared to 381 mg/L for the site in Table 6.

<u>Aerobic Unit/At-Grade/Pressure Distribution</u>: Table 8 gives the profile data beneath and adjacent to this system. The site was sampled one time at two locations. Table 3 gives the effluent characteristics for this site. Profile sampling was done about 9 months after the system was put into operation. For

Table 8 Average Soil Profile Parameters Based on Soil Weight for an Aerobic/ At-Grade Unit Using Pressure Distribution for Site 29 in Table 1.

Depth (cm)	Beneath*			Adjacent		
	7/90**	7/90	Ave	7/90	7/90	Ave
Fecal Coliforms (MPN/g dry soil)						
0 - 15	3	1	2	-	-	-
15 - 30	<1	9	5	-	-	-
30 - 45	<1	2	1	-	-	-
45 - 60	<1	1	1	-	-	-
60 - 75	<1	<1	<1	-	-	-
75 - 90	<1	<1	<1	-	-	-
90 -105	<1	<1	<1	-	-	-
Moisture Content (% dry basis)***						
0 - 15	21	16	18.5	-	-	-
15 - 30	22	19	20.5	-	-	-
30 - 45	24	25	24.5	-	-	-
45 - 60	24	24	24.0	-	-	-
60 - 75	18	25	21.5	-	-	-
75 - 90	21	25	23.0	-	-	-
90 -105	20	16	18.0	-	-	-
Total Kjeldahl (mg N/kg dry soil)						
0 - 15	1598	1447	1522	2656	1723	2190
15 - 30	1147	1424	1286	1514	1330	1422
30 - 45	986	1060	1022	1114	720	1114
45 - 60	696	702	709	757	548	653
60 - 75	511	541	526	477	486	481
75 - 90	393	367	380	351	226	289
90 -105	305	282	293	380	212	296
Ammonium Nitrogen (mg N/kg dry soil)						
0 - 15	3	6	4	5	3	4
15 - 30	3	4	4	4	3	4
30 - 45	3	13	8	3	2	3
45 - 60	1	2	2	2	1	2
60 - 75	1	1	1	1	2	2
75 - 90	1	1	1	1	1	1
90 -105	1	1	1	1	1	1
Nitrate Nitrogen (mg N/kg dry soil)						
0 - 15	19	27	23	21	15	18
15 - 30	16	16	16	9	6	8
30 - 45	10	17	14	4	3	4
45 - 60	8	14	11	3	3	3
60 - 75	8	11	10	3	6	5
75 - 90	6	8	7	1	3	2
90 -105	3	6	5	1	2	2

Table 8 con't

Table 8 Continued

Depth	Beneath*			Adjacent		
(cm)	7/90**	7/90	Ave	7/90	7/90	Ave
			Chlorides (mg/kg dry soil)			
0 - 15	11	15	13	<1	2	2
15 - 30	18	13	12	<1	3	2
30 - 45	14	18	16	1	2	2
45 - 60	18	16	17	2	8	5
60 - 75	19	18	19	1	19	10
75 - 90	14	14	14	2	13	8
90 -105	14	18	16	4	17	11
			Moisture Content (% dry basis)****			
0 - 15	23	18	20.5	23	14	18.5
15 - 30	24	23	23.5	24	17	20.5
30 - 45	23	25	24.0	23	17	20.0
45 - 60	25	26	25.5	24	20	22.0
60 - 75	25	26	25.5	22	18	20.0
75 - 90	17	21	19.0	18	12	15.0
90 -105	16	17	16.5	17	11	14.0

*Beneath the system and receiving effluent, adjacent to the system and not receiving effluent. **Month and year sampled with all samples taken on the same day. ***Moisture content is associated with fecal coliforms. ****Moisture content is associated with other parameters.

this 3 bedroom home with 2 people the average flow rate was 310 Lpd (81 gpd) with a loading rate of 1.7 cm/d (0.42 gpd/ft^2).

The system was dosed with 460 L/dose (120 gallons/dose) every 1.5 days on the average. The effluent was dosed into 1/4 of the system through a lateral with 7 orifices resulting in a dose volume of 66 L/orifice/dose (17 gal./orifice /dose). Assuming a 0.38 m^2 (4 ft^2) wetted area per orifice the localized loading would be 17.4 cm/dose (4.3 gallons/ft^2/dose) or an average daily loading rate of 11.6 cm/d (2.9 gpd/ft^2). No ponding has been observed in the system.

The fecal coliform count was no greater than 9 MPN/g of dry soil with the average decreasing to 1 MPN/g of dry soil in the 30-45 cm (12-18 in.) depth interval. This is a marked contrast to the other sites as this soil is receiving a much cleaner effluent with 99.9% of the fecal coliforms destroyed in the pretreatment unit. Thus it appears that the top 45 cm (1.5 ft) is removing the fecal coliforms to <1 MPN/g of dry soil (<465 MPN/100 ml).

The organic nitrogen concentration in the profiles is similar to the other silt loam soil systems. Since the effluent contains very little ammonium the impact upon the soil profile is negligible. The nitrate concentration at the 90-105 cm (36-42 in.) depth is 5 mg N/kg of dry soil beneath the system compared to 2 mg N/kg of dry soil for the control. If the nitrate is associated only with the soil water, the nitrate concentration at this depth is 30 mg N/L beneath the system compared to 14 mg N/L adjacent to the system. Neither meets the groundwater standards at 90 cm (3 ft) beneath the system. The system probably has a greater impact on the ground water than the adjacent area as more water is percolating through the soil beneath the system than adjacent to it and the concentration is about twice as high.

The chloride concentration beneath the system is greater than adjacent to the system by about 50%. There appears to be a slight chloride concentration increase with depth for both.

SUMMARY AND CONCLUSIONS

The Wisconsin at-grade system was developed as an alternative soil absorption system. The system base is placed at the ground surface with 1) the aggregate placed on the tilled surface, 2) the distribution system placed in the aggregate, 3) the fabric placed on the aggregate and 4) the soil placed over the fabric. Several hundred such systems have been in place with the oldest installed in 1982. Thirty-one of these systems were evaluated for treatment. Twenty-eight units incorporated a septic tank and pressure distribution and were placed on sites with soil profiles primarily of silt loam to silty clay loam; two units incorporated a septic tank and gravity distribution with one unit placed on a silt loam soil and the other one placed on a sandy loam soil; and one unit incorporated an aerobic unit and pressure distribution on a silt loam soil. Each site was sampled by taking soil cores at 0-15 cm (0-6 in.) intervals beneath the system and background samples adjacent to the system to a depth of 105 cm (42 in.). The cores were evaluated for fecal coliforms, TKN, ammonium, nitrates, chlorides and moisture content. The results for the 28 systems were averaged together with a 95% confidence interval. The results of the remaining three sites are presented individually.

The fecal coliform count for the 28 systems using a septic tank with pressure distribution on silt loam soil was significantly higher than adjacent to the system. At the 90-105 cm (36-42 in.) depth the average fecal coliform count was 193 MPN/g of dry soil beneath the system and <1 MPN/g of dry soil adjacent to the system.

The fecal coliform count beneath the ponded surface for the two systems using a septic tank with gravity flow distribution was very close to background levels at the 90-105 cm (36-42 in.) averaging <2 MPN/g of dry soil. The fecal coliform attenuation with depth was much greater for the sandy loam soil than for the silt loam soil.

For the one system on silt loam soil receiving aerobically treated effluent, the fecal coliform count was reduced to 1 MPN/g dry soil at 45-60 cm (18-24 in.) and to <1 MPN g of dry soil at 90-105 cm (36-42 in.).

There is no reference health standard for fecal coliforms for soil as there is for water. It is difficult to determine if the soil system is treating the effluent to sufficient levels. It is recommended that a health standard for fecal coliforms in soil be established.

In all systems tested the nitrate levels exceeded the 10 mg N/L at the 90-105 cm (36-42 in.) depth beneath and adjacent to the system if all the nitrate in the soil is assumed to be associated with the water phase.

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