MN Rules Chapter 7080 - 4/3/06 to 2/4//08

7080.0170 FINAL TREATMENT AND DISPOSAL.

Subp. 4. **Rapidly permeable soils.**

A. Three feet of soil with a texture of medium sand or finer must exist below the distribution medium. Soil absorption areas with a soil percolation rate of 0.1 to five minutes per inch that is not a fine sand (Table V) or soil absorption areas with a soil texture of medium sand or loamy sand (Table Va) must use at least one of the following treatment techniques:

(1) distribute the sewage tank effluent by pressure flow over the absorption area as specified in part 7080.0150, subpart 3; or
(2) divide the total soil treatment system into at least four parts with no part larger than 25 percent of the area required by subpart 2, item C, and the parts constructed for serial application.

B. Soil treatment systems placed in soils with percolation rates of less than one-tenth minute per inch or in a soil texture of coarse sand must provide at least one of the following treatment techniques:

(1) a mound system; or

(2) a trench system with at least one foot of

clean sand placed between the distribution medium and the coarse soil along the excavation bottom and sidewalls that satisfies the requirements of item A, subitem (1) or (2).

Northeast Regional Correctional Center (NERCC) Research Site

Summary of Trench Data
Gravity Distribution in Sands
Barb McCarthy
04/20/09

Research was conducted at the Northeast Regional Correction Center for the following on-site wastewater treatment technologies near Duluth during the period 1995-2003:

- Constructed wetlands (2) and single pass sand filters (2)
- In-ground peat filters (2) and modular peat filters (1 using Irish peat, 1 using Minnesota peat)
- Textile filter (followed by small sand filter using concrete sand and shallow trenches using pressure distribution)
- A suspended growth aerobic treatment unit with drip distribution
- Drip distribution using septic tank effluent, placed at 4 depths in soil, pan and suction cup lysimeters were placed 1 ft and 2 ft below drip tubing
- Trenches (4) – all drop boxes with gravity distribution of effluent, 2 trenches loaded with septic tank effluent, 1 trench with peat filter effluent, and 1 trench with constructed wetland effluent; 6 pan lysimeters were positioned below each trench at a depth of 1,2 3 feet below the infiltrative surface
- Pathogen studies were conducted using Salmonella and MS2 coliphages to determine performance of several systems, summer and winter performance
- U of M OSTP website has reports; technical papers, publications in journals

<u>Trenches Dosed with Septic Tank Effluent</u>

Trench 1 and Trench 2 were dosed with septic tank effluent during the period November 1996 through May 2001. Trench 1 was coarse sand; Trench 2 was sand. Trenches were 20 feet long and 3 feet wide. Drop boxes were used to convey effluent; drainfield rock was the distribution media. An inspection pipe was located at the end of each trench.

During the first year, both trenches were dosed with 250 to 300 gallons per day (to simulate average household use) at a hydraulic loading rate of 4 to 6 gal/ft^2/day. This was achieved by dosing each trench 6 times per day at 40 to 50 gallons per dose. Beginning the second year of operation (Oct 1997), the trenches were dosed with 50 to 60 gallons per day at a hydraulic loading rate of rate of 0.8 to1.0 gal/ft^2/day. This was achieved by dosing each trench 6 times per day with 8 to 10 gallons per dose.

Samples of ‘soil water effluent’ were collected from two sets of pan lysimeters, positioned at 1/3 and 2/3 along the trench length, at 3 depths (1, 2 and 3 ft) below trench bottoms. Two piezometers were monitored to determine depth to groundwater.

<u>Trench 1</u>

Trench 1 bottom infiltrative surface was located in loamy coarse sand, underlain with coarse sand and loamy sand. At the initial loading rates, fecal coliform bacteria were frequently detected at 1, 2 and 3 feet below trench bottom (Table 1). After the loading rate was reduced to ~1 gal/ft2/day, fecal coliform bacteria were reduced at all three depths, but fecal coliform bacteria were detected at 3 feet at low levels on two dates during the study. There was no seasonal saturation 3 ft below trench bottom (and no capillary fringe). See Appendix for fecal coliform bacteria, phosphorus and nitrogen data set.

Table 1. The percentage of 'soil water effluent' samples with 'detects' of fecal coliform bacteria from samples collected from pan lysimeters placed 1ft, 2 ft, and 3 ft below trench bottom using gravity distribution in sands (N=95).

Trench	Total Gallons (gals per day)	N	Loading Rate ($gal/ft^2/day$)	Depth below trenches(ft)		
				1 ft	2 ft	3 ft
1	250 – 300	19	4 – 6	95 %	95 %	79 %
	50 – 60	30	0.8 – 1.0	14 %	10 %	7 %*
2	250 – 300	17	4 – 6	76%	71%	29%
	50 – 60	29	0.8 – 1.0	62%	34%	27%**

* 7% = 2 of 30 samples (10 and 100 MPN/100ml) and
** 27% = 8 of 29 samples (ranged from 10 to 580 MPN/100ml)

Trench 2

The bottom of Trench 2 was located in sand. At the initial high loading rates, fecal coliform bacteria were routinely detected at a depth of 1 ft and 2 ft below trench bottom; fecals were detected less frequently detected at the 3 ft depth. After the loading rate was reduced to ~1 $gal/ft^2/day$, fecal coliform bacteria were reduced at all three depths. However, fecals were detected in 27% of the samples collected at 3 ft, and ranged from 10 to 580 MPN/100ml.

Summary and Discussion Items

- The highest fecal coliform bacteria were detected at the higher loading rate. Fecals were detected at all three depths. A typical home may generate 150 to 250 gallons per day. At this average daily flow, and using gravity as the method to distribute effluent, sands are likely to be overloaded, resulting in pathogen movement to the three foot depth.

- The lowest fecals were detected at the lower loading rate, but fecal coliform bacteria were detected at all 3 depths in these sands.

- Fecal coliform bacteria are indicators of disease causing organisms; viruses are much smaller than bacteria. Phosphorus (and nitrogen in NE Minnesota) is of concern in shoreland areas.

- Soil texture, vertical separation, hydraulic (and organic) loading rate, and the method of applying effluent to sands are important factors to consider in treating and dispersing effluent.

- How do we ensure that the soil is actually used to treat sewage? We can't necessarily rely on the 'biomat' to control effluent flow into sands. We need to depend on the soil to treat and disperse sewage effluent. The degree of biological clogging varies from site to site, especially in sands, for significant periods of time.

- The best way to ensure proper treatment - use of pressure distribution (or method to have more uniform distribution of effluent across the soil infiltrative surface). This is done in mounds and sand filters.

Appendix

Trench 1. Fecal coliform bacteria, total phosphorus and total nitrogen. Values <10 cfu/100mL for fecal coliform bacteria were assigned a value of 5.

Date	Fecal Coliform (MPN/100mls)			Total Phosphorus (mg/L)			Total Nitrogen (mg/L)		
	1'	2'	3'	1'	2'	3'	1'	2'	3'
13-Nov-96	7100	1500	620	4.00	2.20	1.60	60.50	42.88	42.93
25-Nov-96	8700	6800	7200	5.10	3.40	3.15	66.42	65.16	57.90
18-Dec-96	140	20	30	6.20	4.60	4.70	112.35	106.35	101.25
7-Jan-97	50	2300	5	5.10	5.50	4.50	99.90	43.80	90.00
30-Jan-97	190	550	30	4.80	5.50	3.50	84.90	48.90	83.25
19-Feb-97	110	4100	10	3.90	6.80	3.10	63.00	64.20	74.55
3-Mar-97	4405	2300	20						
11-Mar-97	8700	640	10	5.30	6.40	3.80	81.75	73.95	83.70
19-Mar-97	8200	320	20						
1-Apr-97	4750	3000	10	5.10	6.70	3.10	82.20	73.80	76.35
22-Apr-97	5100	850	5	4.50	6.20	2.70	83.55	80.40	78.30
13-May-97	1300	620	10	5.80	7.00	3.40	64.35	64.05	51.60
3-Jun-97	500	810	5	5.00	7.00	3.30	60.75	72.30	67.05
24-Jun-97	770	1500	70	5.00	6.10	3.50	62.40	65.16	67.31
22-Jul-97	5	5	5	5.50	4.80	2.80	68.36	65.03	69.14
12-Aug-97	17000	14000	8300	3.20	2.50	2.10	86.99	88.23	51.02
2-Sep-97	1260	900	22000	3.90	1.60	1.40			
23-Sep-97	7600	510	1700	6.80	2.50	3.60	39.45	49.95	46.50
14-Oct-97	3900	2600	2100	12.70	12.20	7.30	75.45	60.30	67.95
4-Nov-97	5	5	5	1.80	0.56	0.80	118.35	364.50	318.00
16-Dec-97	5	5	5	1.00	0.24	0.53	64.80	153.30	107.40
10-Feb-98	5	5	5	1.80	0.19	0.35	68.25	69.00	70.65
24-Mar-98	5	5	5	1.90	0.19	0.58	55.80	56.70	60.90
21-Apr-98	5	5	5	1.60	0.02	0.60	52.80	61.05	57.00
19-May-98	5	5	5	1.40	0.13	0.55	71.10	94.05	99.45
23-Jun-98	5	5	5	1.30	0.13	0.47	83.85	134.70	107.25
13-Jul-98				1.40	0.12	0.28	78.75	110.55	113.25
23-Sep-98	110	90	100	4.10	0.13	0.15	61.65	77.85	71.10
13-Oct-98	5	5	5	4.80	0.07	0.10	84.69	61.36	62.79
1-Dec-98	5	5	5	3.00	0.08	0.10	69.60	97.35	79.80
19-Jan-99	640	5	5	6.70	0.15	0.18	42.15	48.00	60.45
2-Mar-99	5	5	5	6.00	0.28	0.26	117.75	66.53	74.33
13-Apr-99	5	5	5	4.70	0.12	0.19	170.85	75.38	47.55
25-May-99	5	5	5	3.50	0.06	0.26	185.88	143.18	113.90
7-Jul-99	5	5	5	3.50	0.07	0.13	132.60	134.55	106.80
10-Aug-99	5	5	5	2.60			102.75	119.25	93.60
21-Sep-99	260	5	5	2.00	0.10	0.07	76.39	67.23	60.26
26-Oct-99	5	5	5	1.40	0.07	0.07	75.60	64.05	66.60
4-Jan-00	5	5	5	1.70	0.31		54.75	72.75	58.80
15-Feb-00		5	5		0.08		NS	11.85	52.20
7-Mar-00	20	5	5	4.10	0.10	0.15	75.30	38.25	44.55

11-Apr-00	5	5	5	3.00	0.06	0.10	142.95	55.65	52.50
23-May-00	5	5	5	2.60	0.06	0.10	rrx20	78.30	67.35
11-Jul-00	5	5	10	2.20	0.11	0.12	229.38	71.63	67.67
5-Sep-00	5	5	5	2.60	0.09	0.21	59.79	35.30	48.87
36816	5	30	5	1.80	0.07	0.08	64.76	51.87	68.35
36844	5	5	5	1.40	0.06	0.06	66.43	60.85	60.98
23-Jan-01	5	10	5	2.40	0.11	0.12	22.17	31.71	43.85
6-Mar-01	5	5	5	1.40	0.06	0.16	93.79	65.38	35.59
17-Apr-01	5	5	5	1.30	0.08	0.26	82.61	56.73	39.64

Trench 1. Hydraulic loading rates and fecal coliform bacteria 3 ft below infiltrative surface.

Date	Actual Loading ($gal/ft^2/day$)	Fecal Coliform Bacteria (3 ft below trench bottom) (MPN/100ml)
20-Nov-96	4.9	620
25-Nov-96	6.2	7200
6-Jan-97	4.9	30
22-Jan-97	3.4	5
11-Feb-97	4.4	30
21-Feb-97	4.4	10
28-Feb-97	4.4	20
4-Mar-97	3.9	10
18-Mar-97	4.2	20
1-Apr-97	4.2	10
7-May-97	3.5	5
28-May-97	3.7	10
17-Jun-97	4.0	5
9-Jul-97	4.7	70
5-Aug-97	5.1	5
27-Aug-97	5.3	8300
17-Sep-97	5.1	8300
8-Oct-97	13.1	1700
14-Oct-97	6.3	2100
6-Nov-97	1.5	5
24-Dec-97	0.9	5
24-Feb-98	0.9	5
18-Mar-98	0.8	5
14-Apr-98	1.0	5
20-May-98	1.0	5
1-Jul-98	0.8	5
6-Oct-98	0.8	100
28-Oct-98	0.7	5
16-Dec-98	0.7	5
3-Feb-99	0.8	5
17-Mar-99	0.7	5
28-Apr-99	0.7	5
6-Jun-99	0.6	5
21-Jul-99	0.6	5
31-Aug-99	0.5	5
5-Oct-99	1.0	5
16-Nov-99	0.4	5
19-Jan-00	0.9	5
1-Mar-00	0.9	5
22-Mar-00	0.8	5
26-Apr-00	0.8	5
7-Jun-00	0.8	5
7-Aug-00	1.0	10
20-Sep-00	0.5	5
1-Nov-00	1.0	5
29-Nov-00	0.9	5
7-Feb-01	0.9	5
28-Feb-01	0.9	5
2-May-01	0.8	5

Trench 2. Fecal coliform bacteria, total phosphorus and total nitrogen. Values <10 cfu/100mL for fecal coliform bacteria were assigned a value of 5.

Date	Fecal Coliform (MPN/100mls)			Total Phosphorus (mg/L)			Total Nitrogen (mg/L)		
	1'	2'	3'	1'	2'	3'	1'	2'	3'
13-Nov-96	1,200	620	5	1.80	0.23	0.23	55.95	2.04	2.73
25-Nov-96	11,700	2,800	1,690	4.75	2.16	0.72	58.26	8.58	6.87
18-Dec-96	15,600	160	50	7.70	4.10	1.20	66.66	41.46	20.76
7-Jan-97	29,000	3,200	5	6.30	3.40	1.90	63.30	67.98	45.77
30-Jan-97	1,090	100	5	2.90	2.60	1.80	85.50	92.10	63.75
19-Feb-97	2,400	5	5	4.40	3.20	1.60	87.75	103.05	79.05
11-Mar-97	3,500	80	5	4.50	2.80	1.30	82.80	98.10	99.00
1-Apr-97	350	5	5	2.90	2.60	1.10	85.95	96.15	91.35
22-Apr-97	460	280	70	1.90	2.80	1.10	79.50	82.20	90.60
13-May-97	30	5	5	2.20	2.80	1.10	85.20	105.30	82.95
3-Jun-97	5	5	5	1.70	2.00	1.10	103.80	99.00	104.10
24-Jun-97	5	40	5	2.30	2.10	0.93	68.86	79.20	100.95
22-Jul-97	5	5	5	2.50	2.50	1.00	68.87	111.45	91.95
12-Aug-97	7	50	50	2.30	1.90	0.80	87.12	92.10	114.15
2-Sep-97	70	20	5	2.40	1.20	0.56			
23-Sep-97	640	590	10	4.30	1.50	0.49	62.85	55.35	72.90
14-Oct-97	4,200	280	5	5.60	6.10	0.17	71.55	68.70	64.65
4-Nov-97	240	10	5	2.90	2.10	0.38	89.85	92.55	83.25
16-Dec-97	170	5	5	2.60	1.40	0.29	67.35	82.65	89.55
10-Feb-98	10	710	5	3.80	2.70	0.28	72.15	43.80	51.60
24-Mar-98	5	5	5	4.90	3.20	0.72	68.85	68.55	62.25
21-Apr-98	5	5	5	4.60	2.20	1.20	78.30	78.90	71.25
19-May-98	5	5	5	5.00	3.30	1.60	88.80	100.50	115.80
23-Jun-98	5	50	5	3.40	3.30	1.20	92.10	72.15	93.75
13-Jul-98				2.00	2.10	1.00	87.90	98.70	109.65
23-Sep-98	200	480	580	2.00	1.30	0.62	69.30	83.85	85.95
13-Oct-98	10	5	5	2.30	0.90	0.42	48.29	60.34	75.83
1-Dec-98	730	240	10	2.70	1.10	0.40	54.15	50.70	51.45
19-Jan-99	370	5	5	3.50	1.30	0.25	118.80	97.50	84.60
2-Mar-99	5	5	5	4.50	1.60	0.28	103.20	88.20	82.95
13-Apr-99	30	60	20	7.20	2.20	1.20	76.95	30.60	42.23
25-May-99	5	5	5	7.90	2.10	0.31	133.38	128.30	48.18
7-Jul-99	20	5	5	8.00	2.50	0.46	120.15	98.85	126.45
10-Aug-99	5	5	5	4.10	1.70	0.40	59.70	109.35	155.25
21-Sep-99	5	5	10	2.80	1.20	0.37	46.39	98.05	117.49
26-Oct-99	5	5	5	3.00	2.50	0.37	85.80	69.15	57.75
15-Feb-00	40	5	5	4.00	2.50	0.55	110.25	27.60	48.60
7-Mar-00	60	20	120	5.50	3.30	0.88	61.20	11.10	24.00
11-Apr-00	5	5	5	4.10	1.60	0.46	130.80	123.60	39.90
23-May-00	5	5	5	8.20	1.60	0.41	80.85	90.15	72.15
11-Jul-00	30	10	10	2.90	3.00	1.00	84.99	46.29	73.47
5-Sep-00	10	5	5	2.30	1.60	0.62	43.82	51.63	55.08
17-Oct-00	230	5	5	2.10	1.40	0.43	35.71	40.67	46.82
14-Nov-00	TNTC	5	10	3.60	1.20	0.53	30.14	30.79	31.10
23-Jan-01	100	5	5				89.45	65.07	26.27
6-Mar-01	1500	10	5	6.40	0.97	0.32	65.57	30.01	66.60
17-Apr-01	20	60	100	5.80	3.30	2.60	35.06	30.48	31.61

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Development of a Standard for Gravelless Trench Products - Results of a Pilot Protocol Series

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Abstract. The Idaho Department of Environmental Quality provided funding to the National Sanitation Foundation (NSF) International to develop a standard for onsite gravelless trench products with the intention that the standard becomes an American National Standard. A task group of regulators, industry and consulting engineers developed a draft standard including testing procedures and pass/fail criteria. A pilot test of a gravelless (test) technology against gravel trench system (control) was completed following the draft standard. Five replicates each of the test and gravel control systems were installed in constructed soil trenches, which were constructed to provide for distribution of dosed wastewater within the trenches, and for collection, quantification and analysis of the water applied to the trenches. Soil analyses were completed on the constructed trenches to determine the consistency of construction. Results obtained from the soil testing and pilot test, including ponding data within the test and control trenches, chemical analysis of wastewater, and fecal coliform data for water samples collected from the trenches, will be used to make revisions to the draft standard. The methods and results of observations and laboratory analyses obtained during the pilot test are described in this paper.

Keywords. Gravelless technology, Standards development

Introduction

In 2004, the Idaho Department of Environmental Quality provided funding to National Sanitation Foundation (NSF) International to develop a standard for evaluation and certification of gravelless/aggregate-free soil absorption system products. The need for the standard arose because of an increase in the number of products claiming to provide the same level of performance afforded by traditional soil absorption systems utilizing distribution pipes bedded in washed aggregate. NSF formed a panel of experts from various universities, regulatory agencies, consultant organizations and industry affiliations to develop a test protocol to incorporate into the standard.

Deliberation and discussion during 2004 and 2005 resulted in a draft standard that described procedures for testing gravelless products. Idaho DEQ and NSF agreed that a pilot test following the proposed procedures should be initiated to observe and validate the elements of the proposed test procedures. Major elements of the proposed test included: (1) the gravelless product should be tested in replicate at the same time, using the same influent quality and dosing schedule as replicate gravel systems; (2) both series of trenches should be installed in a reproducible soil matrix; (3) each trench should be constructed with an impervious liner to contain all water passing through the system to allow for sampling and monitoring of the treated volume; (4) control trenches should have a minimum length of 6 m to limit end effects; (5) each trench should have a minimum of 0.3 m of cover comprised of the same soil matrix in which the infiltrative surfaces are constructed; (6) a fabric cloth should be placed at the surface to preclude the growth of vegetation; (7) the hydraulic loading to the gravelless system should be in accordance with the manufacturer's specifications for reduction in required trench length; and (8) ponding depth should be used to determine equality of performance of the gravelless product with regard to the gravel system.

Several aspects of the proposed test procedures were not fully resolved, including: (1) the point at which test "failure" would be reached; (2) in the absence of a failure, how long the test should proceed; (3) other measurements to be made to verify the comparability of trench construction; (4) the parameters, other than ponding depth, to be considered to demonstrate equivalency of the gravelless product and the gravel system; and (5) whether all trenches should be constructed to the same length (with appropriate hydraulic loading in conformance with the manufacturer's specifications).

Materials and Methods

Test Facility General. The pilot test trenches were constructed in January 2006 at the Massachusetts Alternative Septic System Test Facility in Falmouth, Massachusetts which intercepts domestic wastewater generated at military housing for use as influent to test onsite wastewater products.

Dosing Mechanism. Wastewater dosed to the trenches was drawn from a pump chamber receiving the effluent from a 5678 L (1500 gal) septic tank dosed with approximately 3596 L (950 gal) of raw wastewater per day, following the schedule described in NSF/ANSI Standard 40.

The volume of wastewater dosed to the gravel trenches was based on the dosing rate for the soil configuration created at the site (sandy soil) and was 0.060 $m^3/m^2/d$ (1.48 $gal/ft^2/day$) based on the basal area of the control trench. The dosing volume to the gravelless trenches was equivalent to the gravel trenches, approximately 333 L/day (88 gal/day).

Trench Construction. Five gravel systems were constructed to a length of 7.3 m (24 ft) to serve as "control" trenches for comparison with the "test" trenches of the gravelless product. The gravel trenches had an exposed basal width of 0.76 m (30 in.) to be comparable with the gravelless product, and were constructed such that 0.15 m (6 in.) of the 1.8-6.4 cm (3/4 in to 2-1/2 in) gravel aggregate was below the 10.2 cm (4 in.) distribution pipe (Fig 1). The total aggregate depth was 0.3 m (1 ft). The distribution pipe was placed on a level grade with end plates installed approximately 0.15 m (6 in.) from each end of the trench to reduce end effects for the trench. A woven filter fabric was placed on top of the aggregate to prevent intrusion of fine materials into the aggregate (Fig 2). The aggregate contained 0.2% fines as determined by ASTM C117.

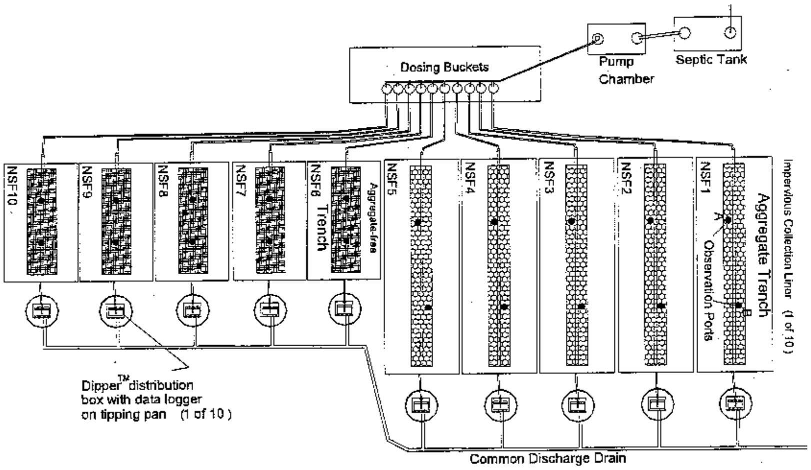

Figure 1. Layout of pilot protocol site for testing gravel-laden and gravelless trenches at the Massachusetts Alternative Septic System Test Center.

Sand used in the trench construction met the specification of ASTM C33 (Standard Specification for Concrete Aggregates). Sand was placed in 0.15 m (6 in) lifts and uniformly compacted to depth of 0.6 m (2 ft) prior to the placement of either the gravel trench or the gravelless product. Approximately 0.9 m (3 ft) of sand was placed between the lateral edge of the leaching structure and the containment liner. Tests for construction consistency are described in the section on soil testing. A slotted 10.2 cm (4 in.) pipe, bedded in pea stone, was used as a collection drain. The collection drain was conveyed to a Dipper™ distribution box (Polylok, Inc.), from which total flow-through volume could be estimated. Observation ports were installed at a distance of one-third of the trench length from each end and consisted of a 10.2 cm (4 in.) PVC pipe with slots cut in the sides and placed at the basal soil interface.

Selection of the gravelless product for the tests was based on local availability of both the product and a manufacturer-certified installer. Trench length was based on the manufacturer's specification regarding equivalency with a conventional gravel trench. Care was taken to match the length of both the control trenches and the test trenches to avoid having to cut a whole section of the tested product.

Five control trenches were constructed adjacent to each other, as were the test trenches. Construction of the trenches was sequential, with the aggregate trenches being constructed first. Sand was placed in the test cells to the elevation of the basal soil interface to allow for collection of soil samples to evaluate the consistency and characteristics of the sand. The gravel aggregate or gravelless product was then placed in the test cells along with the soil cover. Prior to the placement of the stone aggregate or gravelless product, core samples were taken using an Uhland Sampler. The cores were 7.6 cm (3 in.) tall and 7.6 cm in diameter, and were collected at relatively equidistant locations longitudinally along the long axis of the cells. Upon extraction of the core samples, both ends of the Uhland sampler core were covered with plastic discs and placed in pint-sized containers for transport to the laboratory. All efforts were made to keep the cores undisturbed during transport.

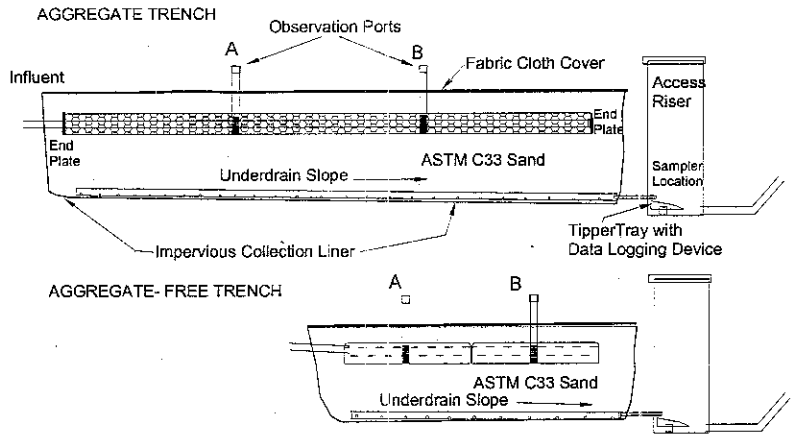

Figure 2. Side-view representation of pilot protocol test cells.

Soil Testing. Physical properties of soils determine the suitability of their use for wastewater infiltration in on-site wastewater systems. These properties which include dry bulk density, hydraulic conductivity, particle size distribution, soil-moisture retention at various tensions, effective grain size and uniformity coefficient were analyzed using standard procedures (Pradhan and Hoover, 2007).

The sediment grain size and percentage of various sediment fractions present in the soil play a very important role in determining porosity as well as hydraulic conductivity of soils. Grain size distributions of soils were determined using sieve analyses (Das, 1986). A set of standard ASTM (American Society of Testing Material) sieves used for this study contained sieve numbers 4 (4.750 mm opening), 10 (2.00 mm opening), 20 (0.850 mm opening), 40 (0.425 mm opening), 60 (0.250 mm opening) and 200 (0.075 mm opening). The grain size distribution curves (percentage of grains by weight passing through each sieve) were plotted on semi logarithmic paper. Uniformity coefficients ($CU = D_{60}/D_{10}$) and effective grain size (D_{10}) were determined using these grain size distribution curves.

The dry bulk density of soil is the mass of oven-dried soil per unit volume (g/cm^3) and was determined using Blake and Hartge's method (1986). Saturated hydraulic conductivity (K_{sat}) defines the rate at which water moves through a soil under saturated conditions at a unit hydraulic gradient. Saturated hydraulic conductivity was determined using the Marriott Bottle technique (Klute and Dirksen, 1986). Soil moisture contents were determined at various tensions by slowly wetting the soil samples to their natural saturation points, draining them to the desired tensions (applied pressure heads), and determining the water content at each applied pressure head. The series of tensions (cm of water) applied to the soil cores were 10 cm (0.009

bars), 20 cm (0.019 bars), 30 cm (0.029 bars), 50 cm (0.049 bars), 100 cm (0.098 bars) and 200 cm (0.196 bars). Soil texture (or relative size distribution of the primary particles in the soil) was determined using the USDA classification scheme. This classification is divided into three major size classifications: sand (2.0-0.05 mm), silt (0.05-0.002 mm), and clay (< 0.002 mm). Since all 50 soil cores contained less than 10% fines (clay and silt) fraction, particle size analysis was performed using a pipette method (Gee and Bauder, 1986). Particles larger than 2.0 mm diameter are not part of fine-earth fraction of soils and are termed coarse fragments.

Analysis of Variance (ANOVA) to compare soil characteristics was conducted using the student's t-test at an $\alpha = 0.05$ level to test for statistically significant differences in soil physical properties between the 10 cells. Statistical analysis was also conducted to test for significant differences between the sandy fill material used to construct long cells vs. short cells and its placement into the test cells. The Statistical Analysis System (SAS, 2003) was used for data analysis.

Percolate Monitoring. Composite samples were collected monthly from April 2006 to February 2007 and were analyzed for chemical oxygen demand (COD), carbonaceous biochemical oxygen demand (CBOD), nitrate, nitrite, total Kjeldahl nitrogen (TKN), ammonium, alkalinity and fecal coliform using standard methods. Additional grab samples were occasionally taken for the nitrogen species and fecal coliform.

Ponding Observations. The depth of system ponding (wastewater elevation above the basal soil interface) was measured for each trench, at each observation port, between 1045 h and 1100 h daily Monday through Friday, which was selected because it the morning doses (0600 h-0900 h, 35% of daily dose), and occurs just prior to the start of the mid-day dose. Measurements were taken in mm from a consistent point on the top rim of the port to the free water surface.

Weather and Temperature. Rainfall was measured to the nearest 0.3 cm (0.1 in.) using two plastic rain gauges until September 2006, at which time an automated data logger was installed and used to measure rainfall.

Results and Discussion

Soil Testing. Table 1 documents the overall properties of the sand used, as well as the consistency after placement in the test cells. The uniformity coefficient (C_U) defines how well graded or sorted the grains in the soil are. The lower the uniformity coefficient, the more uniform the soil. If the uniformity coefficient is less than 5 to 6 (Kresic, 1997 and Bowles, 1984), the soil is considered well sorted and visa versa for natural soils. The average uniformity coefficient for the constructed soils was 3.14, with a range from 3.60 to 2.81, standard deviation of 0.18 and a coefficient of variation of 5.8%. The uniformity coefficient average, ranges and coefficients of variation indicate that the material used to fill the cells was well graded or well sorted as well as being relatively uniform. The sandy fill material meets the specifications of ASTM C33 sand. The relatively low standard deviation and low coefficient of variation for K_{sat} are unusual for soil materials.

Table 1. Summary of physical properties of soils used in test cells.

Property	Average	Range	Standard Deviation	Coefficient of Variation (%)
Effective grain size :				
D_{10} (mm)	0.27	0.22 – 0.70	0.02	8.3
D_{60} (mm)	0.84	0.79 – 1.0	0.06	7.6
Passing 200 Sieve (%)	1	0.3 – 2.9	0.56	54.5
Uniformity coefficient(C_U)	3.14	2.81 – 3.60	0.18	5.8
Dry bulk density (gm/cm^3)	1.68	1.56 – 1.78	0.04	2.4
Saturated hydraulic conductivity (K_{sat} -cm/min)	2.12	1.29 – 2.60	0.40	19

Once a biomat has formed, most septic systems operate at about 30-40 cm tensions (Bouma 1975). For the 50 undisturbed core samples, an average of 56% to 80% of the total water content was drained when 30 cm and 50 cm of water tension were applied, respectively. An average of 92% of the total water content was drained by 200 cm of tension head. Average porosity in the soil cores was 29% and ranged from 32% to

24% with a standard deviation of 1.50 and coefficient of variation of 5.2%. Soil-moisture drained at various tensions is presented in table 2.

Soil textural composition (percent sand, silt, and clay) affects soil-water retention characteristics, leaching and erosion potential, plant nutrient storage, organic-matter dynamics, and carbon-sequestration capability. Soil texture is also typically related to porosity and permeability. The average sand, silt and clay contents in these artificially constructed soils were 99.15%, 0.60% and 0.24%, respectively. While the sand

Table 2. Soil moisture drained at various tensions from soil cores taken at locations longitudinally along the long axis of test cells.

Cell No.	Core ID	% water in core	Percent of water drained at (cm of water tension) 0	3.8	10	20	30	50	100	200	Cell Avg. Porosity
1	285	26.29	0.00	5.38	6.23	10.79	63.18	92.28	97.75	99.47	
1	286	28.43	0.00	1.13	2.08	18.65	51.12	87.22	89.27	91.27	
1	290	28.31	0.00	1.34	1.34	2.34	59.35	89.90	92.49	93.72	
1	300	28.51	0.00	2.82	4.21	16.99	46.52	86.01	89.32	91.99	
1	381	30.85	0.00	1.93	3.42	36.21	63.40	85.88	88.50	90.87	28.48
2	299	25.95	0.00	2.94	4.07	21.02	53.86	87.58	97.64	99.83	
2	387	29.65	0.00	3.59	6.40	33.31	63.14	85.79	88.36	90.65	
2	393	28.04	0.00	4.10	6.23	30.11	61.55	84.45	84.41	98.88	
2	364	30.35	0.00	1.52	2.30	19.33	50.64	86.77	89.54	91.68	
2	365	29.86	0.00	2.70	3.18	35.80	63.36	86.74	89.88	92.53	28.77
3	253	28.77	0.00	3.52	4.53	18.61	52.14	84.80	88.32	91.48	
3	257	30.16	0.00	3.26	4.45	23.53	57.73	86.92	89.36	91.64	
3	281	24.32	0.00	2.98	3.33	21.46	68.03	87.87	88.19	87.45	
3	291	28.60	0.00	3.10	3.14	20.48	55.08	85.40	88.66	91.37	
3	280	30.91	0.00	2.79	10.02	36.85	58.77	85.80	89.08	90.86	28.55
4	259	29.97	0.00	4.08	5.43	26.35	61.13	87.35	89.70	91.79	
4	294	28.18	0.00	0.45	1.53	25.64	55.73	85.62	88.70	91.53	
4	362	28.85	0.00	2.23	3.21	21.92	55.45	86.38	89.06	91.67	
4	390	29.50	0.00	2.85	3.47	38.84	64.35	85.06	88.07	90.52	
4	394	32.08	0.00	2.60	5.36	25.95	59.12	79.79	82.71	93.69	29.71
5	272	29.12	0.00	3.88	5.24	36.50	75.55	86.51	88.37	89.92	
5	382	28.45	0.00	2.94	3.91	37.42	66.02	86.20	88.78	91.39	
5	395	25.65	0.00	3.96	7.11	35.69	76.13	95.37	97.82	97.79	
5	399	30.24	0.00	2.02	4.65	32.33	63.15	86.82	89.12	91.35	
5	261	28.98	0.00	5.58	14.09	47.70	63.14	85.97	88.92	90.94	28.49
6	288	29.43	0.00	3.39	3.88	14.36	29.80	71.86	87.01	90.20	
6	373	28.28	0.00	0.62	3.60	28.71	62.30	86.38	88.62	91.07	
6	392	28.18	0.00	0.00	1.79	7.01	15.69	40.74	86.81	92.05	
6	361	28.56	0.00	1.59	4.55	29.47	64.22	83.76	88.55	91.16	
6	348	31.75	0.00	3.37	3.85	25.03	54.13	72.38	87.31	90.77	29.24
7	263	28.56	0.00	2.29	2.27	24.53	56.68	85.81	89.27	91.93	
7	282	29.00	0.00	4.87	5.64	9.78	57.27	83.65	88.60	90.16	
7	292	27.92	0.00	0.00	1.81	3.83	9.29	20.75	49.32	88.90	
7	279	29.23	0.00	4.84	5.60	40.48	57.57	84.00	88.91	90.52	
7	284	28.25	0.00	1.14	1.79	26.39	55.48	73.21	80.60	89.03	28.59
8	273	28.89	0.00	2.82	3.54	23.72	56.21	83.71	87.11	89.66	
8	293	28.87	0.00	3.63	4.12	12.04	24.14	68.22	86.60	89.51	
8	287	29.94	0.00	3.78	12.50	36.19	64.52	86.48	88.42	90.52	
8	267	29.17	0.00	1.76	2.17	9.73	24.11	68.34	86.81	90.10	
8	400	29.17	0.00	2.99	4.08	22.85	57.07	68.51	86.76	89.61	29.21
9	243	28.40	0.00	3.70	4.71	38.87	73.05	86.15	88.85	90.48	
9	262	29.57	0.00	4.38	4.38	19.14	28.17	68.59	84.49	87.17	
9	266	25.75	0.00	2.47	2.54	41.97	79.59	93.85	96.83	98.75	
9	265	32.12	0.00	1.54	11.39	35.25	52.82	84.40	88.43	91.07	
9	268	28.69	0.00	2.15	2.79	38.73	62.66	86.18	88.25	90.37	28.91
10	244	28.82	0.00	4.30	5.12	42.12	75.79	88.91	91.67	90.62	
10	260	29.72	0.00	4.55	5.48	29.64	69.50	84.14	86.64	90.93	

10	264	28.70	0.00	2.25	2.26	9.86	26.02	69.85	86.41	89.75	
10	274	29.61	0.00	3.77	4.87	37.68	74.28	87.38	89.93	90.99	
10	241	28.96	0.00	4.16	4.25	30.86	54.20	69.77	86.63	89.99	29.16

content ranged from 98.43 to 99.85 (standard deviation = 0.29, CV = 0.3%), percentages of silt and clay ranged from 0.11 to 1.26 (standard deviation = 0.27 and CV = 44.91%) and 0.01 to 0.53 (standard deviation = 0.17 and CV = 69.17%), respectively.

Based on the USDA textural classification scheme, all of the tested soils have a sand texture. The media used in these artificially created wastewater infiltration cells contained 0.8% gravel (> 2.0 mm), 11.3% very coarse sand (1.0-2.0 mm), 26.3% coarse sand (0.5-1.0 mm), 34.2% medium sand (0.25-0.5 mm), 18% fine sand (0.10-0.25 mm) and 8.5% very fine sand (0.10-0.05 mm). These sand textured soils are "coarse sands", as classified in the USDA system, with an average of 37.6% of very coarse and coarse sand and less than 50% of any other single grade of soil.

An ANOVA was conducted using the student's t-test at an $\alpha = 0.05$ level to test for statistically significant differences in soil physical properties between the 10 cells (table 3.).

Table 3. Summary of statistical analyses of soil characteristics from soil cores taken along the longitudinal axis of test cells where leaching trenches were installed. * Means with the same letters within a row are not significantly different. **Mean values for the physical properties tested decreases from A to C. t-tests performed at $\alpha = 0.05$ level.*

Physical Property	Test Cells										
	1	2	3	4	5	6	7	8	9	10	Avg.
Uniformity coefficient	A[a] 3.22	A 3.04	A 3.19	A 3.08	A 3.20	A 3.13	A 3.17	A 3.10	A 3.10	A 3.16	3.14
Effective grain size ($D_{ef} = d_{10}$)	A 0.30	A 0.30	A 0.26	A 0.30	A 0.28	A 0.26	A 0.30	A 0.28	A 0.30	A 0.30	0.27
Dry bulk density	BC 1.66	A 1.71	A 1.72	ABC 1.68	ABC 1.67	ABC 1.68	AB 1.69	AB 1.68	C 1.63	ABC 1.67	1.68
Hydraulic conductivity	AB 1.91	AB 2.14	AB 2.13	AB 2.08	AB 2.08	AB 2.13	A 2.37	A 2.32	B 1.83	AB 2.21	2.12
Porosity	A 29.22	A 28.46	A 28.22	A 28.29	A 27.90	A 29.17	A 29.33	A 29.38	A 29.74	A 29.39	28.91
% water drained at 30 cm tension	AB 56.71	AB 58.51	AB 58.35	AB 59.16	A 68.80	B 45.23	B 47.26	B 45.21	AB 59.26	AB 60.00	55.84
% water drained at 50 cm tension	A[b] 88.26	A 86.27	A 6.16	AB 84.84	A 88.17	BC 71.02	C 69.48	ABC 75.05	ABC 83.83	ABC 80.01	81.31
% water drained at 200 cm tension	AB 93.46	A 94.71	BC 90.56	ABC 91.84	ABC 92.28	BC 91.05	C 90.11	C 89.88	ABC 91.57	BC 90.46	91.59
% Sand	BC 99.06	ABC 99.13	A 99.45	ABC 99.12	ABC 99.12	BC 99.05	C 98.95	ABC 99.22	AB 99.33	ABC 99.12	99.15
% Silt	B 0.52	AB 0.67	B 0.42	AB 0.60	AB 0.60	AB 0.61	A 0.92	B 0.55	B 0.50	AB 0.62	0.60

% Clay	A 0.42	BC 0.21	C 0.14	ABC 0.28	ABC 0.26	AB 0.34	C 0.14	ABC 0.22	BC 0.19	ABC 0.26	0.24

t-tests performed at $\alpha = 0.05$ level.

[a] Means with the same letters within a row are not significantly different.

[b] Mean values for physical properties tested decreases from A to C.

A statistical analysis conducted using the student's t-test at an $\alpha = 0.05$ level to test for statistically significant differences between the 10 test cells indicated that the uniformity coefficient, effective grain size distribution and soil porosity were not significantly different from cell to cell. There were significant differences between the cells for the other soil properties tested (bulk density, K_{sat}, percentage of water drained at 30 cm, 50 cm and 200 cm tension, percentage of sand, silt and clay). However, all these values are numerically similar excepting the percentage of water drained at 30 cm and 50 cm tensions. Percentage of water drained for seven soil cores (Core ID 288,392,292,293,267,262 and264), at 30 cm tension (table 2) was substantially lower compared to the other 43 soil cores. For instance, the percentage of water draining at 30 cm of tension averaged only 26% for these seven cores. All seven of these cores were collected from the shorter test cells used to assess the gravelless trenches. A similar situation was observed at 50 cm tension. Percentage of water drained at 50 cm tension for two of the cores taken from the shorter trenches were much lower than the average. A statistical analysis was also conducted to test for significant differences between the gravel-laden trenches (test cells 1-5) and gravelless trenches (test cells 6-10) as groupings (table 4.).

Table 4. Comparison of soil physical properties in long versus short cells using the student t-test performed at an $\alpha = 0.05$ level.

Physical Property	Longer cells	Shorter cells
Uniformity coefficient (D_{60}/D_{10})	A[a] 3.15	A 3.13
Effective grain size (D_{10})	A 0.28	A 0.26
Dry bulk density	A 1.69	A 1.67
Saturated hydraulic conductivity	A 2.10	A 2.18
Porosity	A 28.80	A 29.02
% water drained at 30 cm tension	A 60.31	B 51.38
% water drained at 50 cm tension	A 86.74	B 75.89
% water drained at 200 cm tension	A 92.57	B 90.61
% sand	A 99.17	A 99.13
% silt	A 0.56	A 0.64
% clay	A 0.26	A 0.23

[a] Means with the same letters in a row are not significantly different.

The student's t-test at an $\alpha = 0.05$ level showed that there were no significant differences for any of the physical properties tested between the long and short cells as groupings, except for percentage of water drained at 30 cm, 50 cm and 200 cm tension. Percentage of water drained at 30 cm, 50 cm and 200 cm tension was greater in longer cells than in shorter cells (table 2). A small numerical difference was evident in the average percentage of water draining at 200 cm tension (93% vs. 91%); hence, a pragmatic effect in the field is not expected for the differences in moisture retention at 200 cm tension. Conversely, at 30 cm and 50 cm tension, larger variations occurred in the percentages of water draining (60% vs. 51% and 87% vs. 76%, respectively) between the longer and shorter test cells. These differences in average moisture retention between longer and shorter cells are quite large and of pragmatic importance in predicting impacts of physical properties upon performance and function of the test cells. No statistical comparisons were made for percentage of water draining at 3.8 cm, 10 cm and 20 cm of applied tensions, because these tensions are outside the range of typical on-site systems operations once biomats have completely formed. However, the data in table 2 indicate water retention at 20 cm of tension showed trends similar to water retention at 30 cm of tension.

Significant differences in the percentage of water drained at different tensions occurred between the longer and the shorter cells. There were no differences in soil porosity, grain size distribution, particle size distribution and bulk density. Therefore, the observed variation in pore size distributions probably occurred during placement and compaction of the sandy fill material in the test cells. Compaction of filled material using external force can cause soil solid particles and aggregates to move, collapse, or deform thereby changing the size of pores. Inconsistency in pressure applied to compact fill material could be a potential reason for the variations in pore size distribution. During soil compaction most of the changes in pore size distribution occurs in large pores which leads to a reduction in water retention (Bruand and Cousin, 1995).

The long and short test cells have the same porosity and therefore the same total volume of pores. The pore sizes (average pore diameters) are not the same between these two types of test cells. A reduction in the number of large pores or an increase in pore tortuosity could decrease water flow during unsaturated flow conditions at low tensions (i.e. 30-50 cm of tension).

Note that unsaturated hydraulic conductivity(K_{unsat}) could not be measured at any tension due to the costs involved. Hence, the soil moisture retention curves function as a "proxy" to assist with prediction of potential impacts of K_{unsat} upon test cell operations and function. Therefore, the differences observed in soil moisture retention in the 30-40 cm tension range are cause for concern. A confounding result, however, was the lack of any similar significant difference in saturated hydraulic conductivity, which was directly measured. This dissimilarity in results is difficult to explain.

The test cells were constructed in chronological sequences (i.e. cells 1-5 followed by cells 6-10). Test cell construction was observed in the field. Consistent technologies and substantial care during packing and build-up of the sandy fill test cell were observed by the authors during the installation of all 10 test cells. Hence, the variability in physical properties described here is not thought to result from any easily controllable construction process. The problem is not a reflection of poor practices by the contractors building the test cells. Instead it is inherent in any attempts to artificially construct soils that will have consistent pore distribution network from soil to soil.

The cells used to test gravel-laden trenches (cells 1-5) were substantially longer than the test cells used to assess gravelless trench technologies (cells 6-10). The longer test cells (cells 1-5) were also constructed earlier in the day than the shorter cells (cells 6-10). Hence, the treatments (gravel-laden vs. gravelless trenches) were not randomly applied to the test cells and do not represent completely independent observations. As a result it was recommended that NSF consider possible changes to the draft protocol for the proposed ANSI/NSF Standard 240.

One option suggested is to construct all test cells of equal length (i.e. the length needed for the gravel-laden treatment). Test cells for all treatments could be constructed up to the elevation of the infiltrative surface, and the locations of the treatments could then be randomly selected using either a table of random numbers or the random number generator. This is not to suggest that the trenches be of equal length, rather that consideration is given to consistent dimensions of the test cells themselves, (i.e. the experimental units). This would allow the treatments to be randomly applied to the experimental test units. It would randomize any potential effects due to chronological test cell construction. By randomizing systematic construction effects, any potential system performance impacts due to systematic changes in construction technique from morning to evening should be randomized and likely to be reduced.

If it is critical to maintain different test cell lengths dependent upon specific treatments, an alternate randomization strategy could be employed. If shorter test cells for the gravelless trenches and longer test cells for the gravel-laden treatments are required, the locations of the treatments could be randomly selected prior to construction of the test cells, rather than installing the test cells systematically or on the basis of treatment.

Both options would allow for random application of the treatments to the experimental cells. Either option facilitates each test cell being a random and independent replication of the two treatments (i.e. gravelless and gravel-laden). However, standardizing the experimental cells is preferred because it removes the size-related effects upon placement and packing of the sandy fill material. It also randomizes any chronologic systematic variations – the other most controllable source of variations.

To summarize, the sandy fill material used in these test cells was relatively consistent. There are also numerous observations in these data that indicated placement of the sandy fill material was consistent as well. However, there were statistically significant differences in water drained at both 30 cm and 50 cm of tension for the longer vs. shorter cells. This indicates that the average pore size was larger in the longer test cells than in the shorter test cells. Water flow through soils beneath septic systems with mature biomats typically functions at about 30-40 cm of tension. The smaller average pore size observed here in the shorter cells could possibly reduce unsaturated flow rates in them under typical on-site system operation conditions. Therefore, differences in soil physical properties within the test cells as a potential cause of any reductions in wastewater infiltration or increases in ponding in the shorter test cells can not be ruled out.

Ponding Observations. In developing the draft protocol to evaluate gravelless technologies, the prevailing agreement of the task group was to require, at minimum, some evaluation of hydraulic performance, as indicated by effluent ponding at the soil interface. There was little consensus among the task group participants, however, as to what ponding depth indicates "failure" of the system. With agreement of the Idaho DEQ, a pilot test of the draft protocol was conducted to obtain data for determining the ponding criteria to signal the end of a test.

Flow to all trenches was initiated on 22 February 2006, and first incidence of ponding was observed on 22 March 2006 in nine of the ten trenches (figure 3). From this date until late June 2006 an increased ponding was observed in all trenches at the proximal observation port, with the exception of gravel trench 4, which exhibited no significant ponding. Gravelless trenches also exhibited ponding at the distal end of the trench nearly identical to the proximal end. This was expected since the void within the gravelless trenches would produce a level ponding across the entire infiltrative surface. The gravel trenches, however, exhibited no ponding in the distal end of the trench during this period. The rapid reduction in ponding noted on 4-8 May 2006 in all trenches was due to the interruption of influent to the system during the repair of a broken influent line. In mid-late June 2006 all trenches exhibited a precipitous decline in the ponding levels to the point where no ponding was observed until mid-to-late November 2006. One exception to this was gravelless trench 9, which showed renewed and increased ponding beginning in early November 2006. All gravelless trenches exhibited relatively rapid increases in ponding (2-3 mm/day) compared with gravel trenches (<0.5 mm/day) from mid-November 2006 to mid-March 2007. In addition to the differences in rates of ponding increases, only limited ponding (<20 mm) was observed at the distal end of only one of the gravel trenches. This compares with ponding observed at all distal observation ports of the gravelless trenches. Although not confirmed, ponding in the proximal end of the gravel trenches in the absence of ponding at the distal trench end may arise because growth of the biomat material within the gravel in the proximal end of the trenches forms dams or bridges to prevent the equilibrating of liquid level in the entire trench as occurs in the gravelless trenches. If correct, this may indicate that the degree of biomat development could vary positionally within gravel-laden trenches.

The data collected during this trial run has not led to agreement among the task group regarding the endpoint of the test relative to ponding depth. However, the invert elevation of the gravelless system being 279 mm above soil interface may signal the necessary endpoint, if reached. At the time of this manuscript preparation, two of the gravelless trenches had reached a 254 mm ponding depth..

A valid testing protocol for gravelless technologies should be able to demonstrate comparability to a "control" or gravel trench in a number of factors including hydraulic performance. The protocol should also be able to document significant control on all untested variables that might affect the outcome (i.e. soil characteristics). In this pilot test, apparent substantial differences in ponding were observed between the gravel trenches and the gravelless trenches. While the procedures used during construction of the trenches were carefully observed to produce statistically similar cell characteristics among the treatment and control trenches, statistically significant differences did occur in moisture release characteristics at tensions reported to be ambient beneath gravel trench biomats. The differences observed in ponding depths between the gravel and gravelless trenches may raise questions about the significance of the measured moisture release values described above, although there is not agreement between all task group members regarding their significance. A challenge in finalizing the protocol is to resolve this question.

Fecal Coliform. It appears that gravelless trenches remove comparably more fecal coliform compared with gravel trenches, as 31 of the 35 mean values are lower for fecal coliform levels in gravelless trenches (figure 4) Of particular note is the fact that fecal coliform levels are highest in the gravelless trenches during times when ponding in these trenches is absent. This suggests that the unsaturated flow induced beneath the biomat that forms fully across the bottom soil interface is more conducive to removing bacteria.

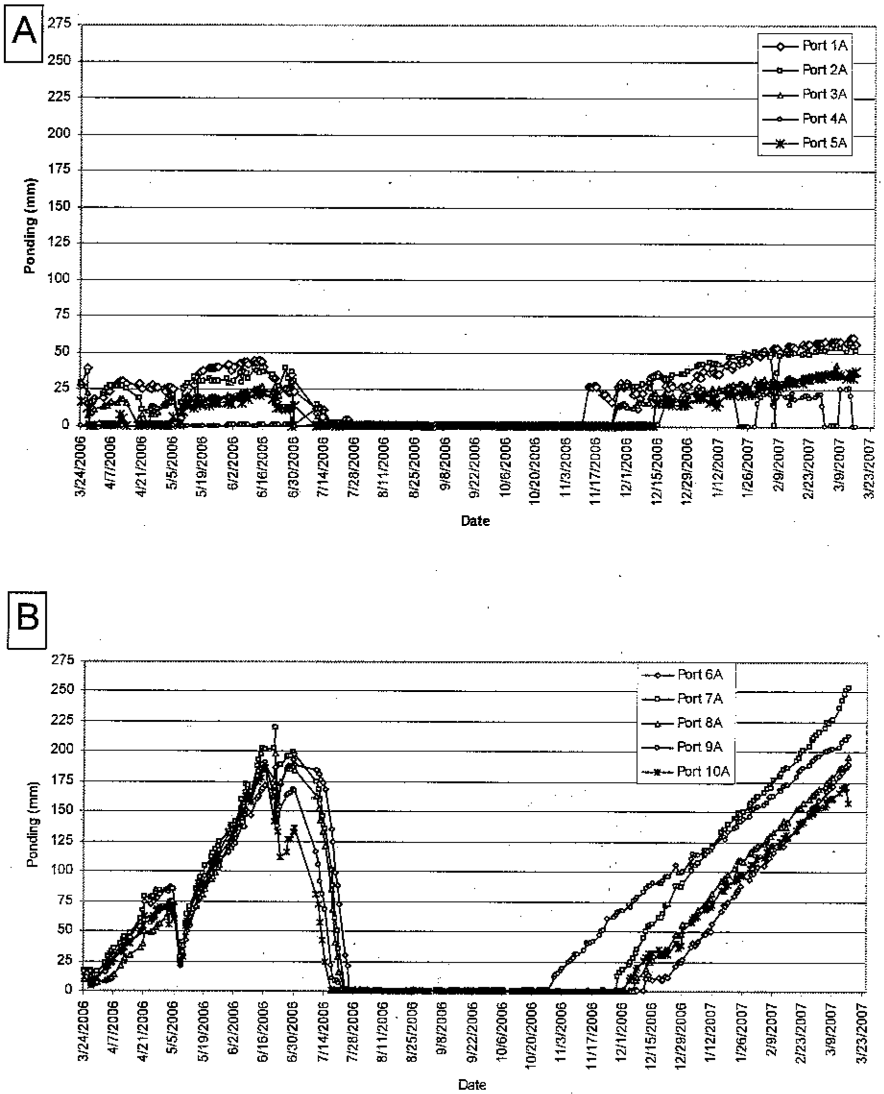

Figure 3. Ponding (in mm) observed in the proximal observation ports of gravel (A) and gravelless (B) trenches. No appreciable ponding was observed in distal observation ports of the gravel systems, while distal observation ports of the gravelless systems exhibited nearly identical levels as the proximal port.

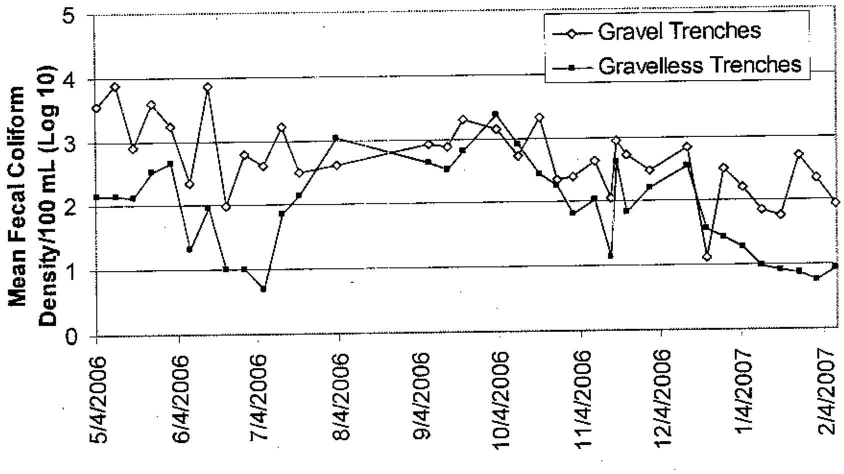

Figure 4. Comparison of fecal coliform levels in the percolate beneath gravel and gravelless trenches.

Conclusions

A draft protocol to evaluate gravelless soil absorption technologies was developed by a panel convened by NSF. A pilot test following the draft protocol was completed to refine protocol elements and to determine the feasibility of the protocol's use. Despite unresolved issues, this exercise of constructing a pilot test and taking selected measurements has shown that a high degree of comparability for tests cells, and control of operational variables (i.e. influent flow volumes, control of evapotranspiration) can be achieved in a test center venue. Data collected has added to our understanding of the performance of gravel-laden and gravelless trenches under controlled conditions.

Among the unresolved issues is determining the importance of differences in moisture release functions of otherwise comparable soils (bulk density, particle size distribution, hydraulic conductivity, uniformity coefficient) constructed soils. Differences in soil moisture release functions were observed in a number of undisturbed cores whose distribution was biased toward the areas beneath the gravelless trenches. Random location of the test and control trenches within the testing site may offset some of the observed differences in construction of the soil system. These efforts hold promise that a valid and reproducible test protocol can be developed and conducted in a test center venue. The onset and characteristics of ponding, indicator bacteria removal, and other measured parameters suggest that discernable performance characteristics of aggregate free and stone aggregate trenches can be observed within a reasonable timeframe of 12-18 months.

Acknowledgments

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Field Comparison of Rock-Filled and Chambered Trench Systems

University of Minnesota Onsite Sewage Treatment Program

Sara Christopherson[1], Dan Wheeler[1], Jessica Wittwer[1] and Tim Haeg[2]

ABSTRACT

Due to actions of the Minnesota State Legislature, systems utilizing chambers and synthetic drainfield distribution media are allowed to be designed and installed up to 40% smaller than the standard or conventional trench system area, under provisions of a special "Warrantied System" category. If approved for "Warrantied System" sizing, manufacturers can receive reduced sizing guidelines in exchange for offering a five-year performance warranty and technical information. There has been debate among regulators, professionals and manufacturers about the long-term hydraulic longevity of systems that use the reduced-area trenches for final treatment and dispersal. A project was designed to identify whether there is a statistical difference in performance between chambered and rock-filled trench systems. This was achieved by a large-scale survey of over 100 selected onsite systems of both rock-filled trenches and chambered trenches across seven Minnesota counties. Each system type was studied within three major soil permeability categories (fast, medium and slow) utilizing soil texture classes. In addition to a general evaluation of the system and homeowner survey including questions on usage and maintenance frequency, the percentage of the system in use at the time of the site visit was determined. This was possible because a majority of trench systems in Minnesota utilize drop box or sequential distribution which loads the trenches in a particular order so that one trench is loaded to a specific level before the subsequent trenches are utilized. Adjusting both types of systems to a standard size datum, the ponding levels were compared. Surprisingly nearly 60% of the systems visited during the study of the ages 5 -10 years did not have any ponding observed at the end of the first trench segment. When the amount of ponding was compared between rock-filled and chambered systems the data was not able to prove the hypothesis that chambered systems of a similar age as rock-filled systems utilize 25% less area than the rock systems at 10% significance level. To the contrary, the results indicate that rock-filled trench systems were utilizing less soil treatment area than the chambered systems due in part to the smaller area per trench of the chamber systems. More mature trench systems of both types need further investigation and analysis to more fully evaluate this issue.

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INTRODUCTION

Trench-type drainfields are a simple method of treating wastewater in settings when proper soil and site conditions exist. In gravity dispersal systems, septic tank effluent flows or is dosed to a drop box or a distribution box. Only systems utilizing drop boxes were evaluated in this study, where effluent flows from an outlet pipe in the lowest position in the box to the first trench in a series. In Minnesota, individual sewage treatment systems (ISTS) can utilize various media for temporary storage of sewage prior to absorption by soil, including drainfield rock, chambers, and other approved products. All of these medias have the same objective: to apply wastewater to the soil in a manner that allows movement into or through the soil, resulting in treatment and dispersal of the wastewater. The media also maintains the excavation to expose the infiltrative surfaces and provides storage. Absorption of effluent by the soil is dependent on a complex series of processes. The factors involved include the initial soil characteristics, hydraulic and organic loading, dosing regime, aeration status of the infiltrative surface and soil biogeochemical properties (Kropf et al., 1977).

In Minnesota, drainfields sized according to Minnesota State Rule (Table 1) are considered "standard". Alternatively, drainfields can be installed at a reduced size, using a special classification created by the Minnesota State Legislature at the request of chamber manufacturers. Under this "warrantied system" classification, drainfield trenches built using chambers and expanded polystyrene can be sized with up to a 40% reduction in soil treatment trench bottom area. In order for a technology to be classified as a warrantied system the system manufacturers are required to submit technical performance and design information, financial assurance documentation to ensure performance on warranties, information showing that at least 50 of its systems were operating successfully for at least three years across all major Minnesota soil classifications and a $1,000 application fee.

The standard system length required is calculated by taking the estimated flow based on bedrooms multiplied by the soil sizing factor divided by the width of the rock trench or chamber. The warrantied sizing is simply 60% of the calculated length or bottom area. When drop boxes are used, the actual loading rate to the first trench in sequence, regardless of distribution media, is often much higher then the design loading rate. This increased loading encourages the formation of a biomat which assists in the treatment process. It was expected that most of the systems visited with ages from 5 -10 years would have an established biomat with some measurable ponding.

Table 1. Soil sizing factors used to design trench systems in Minnesota (MPCA, 2002)

Soil Texture	**Standard Soil Sizing Factor ft²/gpd (loading rate) gpd/ ft²**	**Warrantied/ 40% Downsized Soil Sizing Factor ft²/gpd (loading rate) gpd/ ft²**	**Permeability Class for this Evaluation**
Course, medium or loamy sand	0.83 (1.2)	0.50 (2.0)	Fast
Sandy loam	1.27 (0.8)	0.76 (1.32)	Medium
Fine Sand and Loam	1.67 (0.6)	1.00 (1.0)	Medium
Silt loam and silt	2.0 (0.5)	1.2 (0.83)	Slow
Clay loam, sandy clay or silty clay	2.2 (0.45)	1.32 (0.76)	Slow
Clay, sand or silty clay	4.2 (0.24)	2.52 (0.45)	Slow

There has been debate among regulators, professionals and manufacturers about the hydraulic longevity of systems that use reduced-area trenches versus "standard" trenches (Hall, 2002). Generally, the argument on the part of proponents of the installation of chamber systems at reduced area has been that the infiltration rate in rock-filled trenches compared to chambered systems is reduced due to an embedment layer composed of rocks impressed with the soil at the infiltrative surface. It is argued that the more open nature of chambers, including its larger volume of storage capacity, more open infiltrative soil surface, lower compaction from installation, and the absence of fines are justification for the downsizing (Siegrist, 1987). Regardless of distribution media, the soil has a limited hydraulic capacity which cannot be exceeded regardless of distribution media. In most cases, the most hydraulically restrictive layer will be the biomat at the soil infiltrative surface and not the underlying soil although in heavy textured soil this many not be the case.

METHODS AND MATERIALS

Project Design

This research was coordinated by the University of Minnesota Onsite Sewage Treatment Program working in conjunction with regulators from local county onsite programs. This study attempted to evaluate the issue of system hydraulic performances between the two distribution medias.

System hydraulic performance was evaluated by:

(i.) determining if the system was sized according to state standards and also met a two foot vertical separation requirement,

(ii.) investigating whether sewage was coming or has come to the surface, and

(iii.) the percentage of system in use as indicated by ponding of effluent. Use was determined in this study by verifying ponding occurrence and ponding depth in order to calculate the percentage of system in use. Systems experiencing no ponding at the end of the first trench segment will have a percentage use of zero.

This project was designed as a large-scale survey of onsite systems across Minnesota. Systems sampled were selected based on system type (rock-filled or chamber) and major soil types utilizing three general soil texture classes as the authors expect there may be differences in system hydraulic performance based on the nature of the soil material(s) encountered. Chambered systems that were designed with both standard and warrantied sizing were included because they would be evaluated for comparison by the percentage of system in use compared to standard sizing.

The evaluation was performed independently of the product manufacturers. The month of May was chosen as a target time period to visit the systems, as this period generally coincides wetter soils and with higher seasonal water tables in Minnesota (Minnesota Climatology Working Group, 2006). This period was chosen to test the systems as it is presents the worse case scenario when ponding of systems would be at a peak level. The study was designed to be conducted in its entirety during a 1-month period in the spring of 2006 to minimize climatic variation among the study sites.

Statistical Approach

The hypothesis for this project is that chambered systems of a similar age (5-10 years since installation) as rock-filled systems will utilize 25% less area than the rock-filled systems at a 10% significance level. Thus, for similar soils, we anticipate that a chambered system will accept more wastewater per unit area of trench before ponding, and that chambered systems should take more wastewater per inch per unit area of trench.

This project was designed as a large-scale survey of 220 onsite systems across Minnesota. Our minimum sample sizes were determined to minimize the effect of flow variability in our percent usage data. By utilizing flow per capita and standard deviation data (Mayer et al., 1999), we desired to detect a 25% difference in system area used with a probability of 0.90 at a significance level of 0.10. Factoring in this flow variability along with other key variables of system type and major soil category, we determined that for each system type approximately 33 systems must be evaluated stratified by 1/3 of the systems in each major soil category to minimize flow uncertainties.

Basic statistics were computed for all data collected to develop an understanding of data. Comparison of percentage in use data between system types and stratified by major textural category within each system type (Systat 10, 2000). Significance levels utilized for all analyses is 0.10. Assumptions common to the paired t-test analysis include random equal variance and approximately normal distribution. Non-normally distributed data is common in uncontrolled experiments and may result in the skewing of risk levels, which are chosen arbitrarily (Koch and Link, 1980).

The survey areas were chosen based on three conditions:

1. The systems were spread across Minnesota. This was important to limit the data being biased by a particular region, county or professional.
2. The systems were located in counties with a sufficient number of chambered and rock-filled systems ranging in age from five to ten years which utilize drop boxes as the distribution method.
3. The systems were spread across the soil textural classes. For the purpose of this study all soils were placed into categories of slow, medium, and fast. With "fast" representing coarse sand, medium sand or loamy sand; "medium" representing fine sand, sandy loam, and loam; and "slow" representing silt, silty clay loam and sandy or silty clay with approximately a third of both the chambered and the rock-filled systems in each of the three categories.

Based on historical sales data and known soil conditions, counties with the highest probability of a match to the categories studied were contacted. Working with county staff, approximately 1000 systems were identified that met the criteria. After the systems were identified, permission was obtained from homeowners prior to the evaluation period. Homeowners were provided with a clear outline of the project with assurance that enforcement would not occur as a result of the field evaluation of their system. A short homeowner questionnaire was required to be completed prior to the visit provided including the question from Table 3. The data gained from this questionnaire eliminated some systems from the study and provided information on operational and management issues which may affect the amount of ponding in a system. In general, because a large number of systems were surveyed, one would not expect operation and maintenance to vary by system type, so this factor should not affect the survey results. The questions regarding bedrooms and people living in the home were used to determine estimated and calculated flow values.

Estimated daily flow values, used to design all systems in Minnesota were strictly based on the number of bedrooms (150 gal/bedroom). Actual flows were estimated from the number of persons in each residence. The AWWA Research Foundation's report on Residential Water Use reports a median flow per capita of 60.4 gpd was used with a standard deviation 39.6 gpd (Mayer et al., 1999). The use of this median value is justified by the large number of systems evaluated in this study so the daily flow variability from site to site is averaged out and not considered to be an explanatory variable between the two types of media studied. The number of persons in each residence was multiplied by the reported median flow per capita to obtain the estimated actual daily flow for each residence.

Table 3. Homeowner questionnaire.

Question	Rationale
Is the home used on a seasonal basis?	Used to eliminate seasonal residences
How many bedrooms are in the home?	Used to calculate design flow
How many people live in the house?	Used to calculate estimated actual usage
When was the last time your septic tank was pumped?	Used to determine if a relationship exists between recently pumped tanks and usage.
Do you have a garbage disposal?	Used to determine if a relationship exists between presence of garbage disposal and usage.

There was a concern that with this method of system selection, property owners with surfacing systems would be less likely to allow access to their sites. There are two reasons this is of less concern. First, these systems are relatively young in age, all designed and installed by licensed professionals and inspected by county inspectors, so the number of surfacing systems should be very minimal. Second, surfacing hydraulic failure was not our only parameter to indicate system performance. Instead we focused on determining the percentage of system in use. Additional parameters collected were possible explanations for differences in usage and may be used to add additional insight into our analyses and outcomes.

Field Survey Protocol

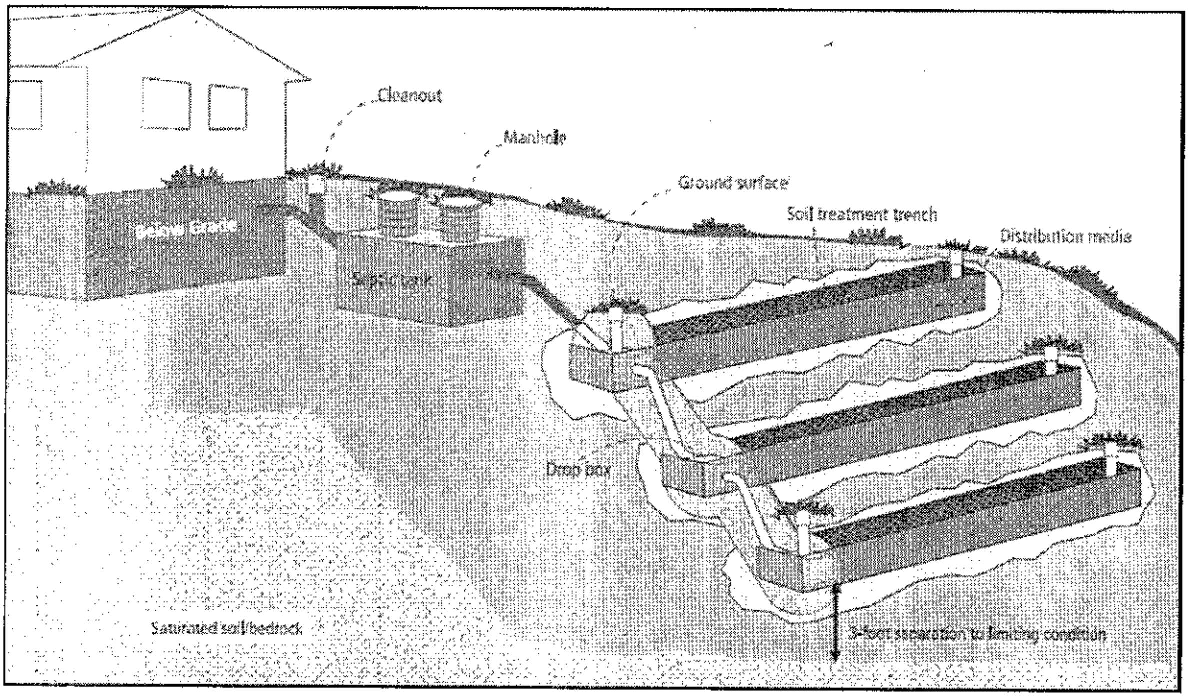
A field survey evaluation form, including the protocol, was designed to serve as a site-specific data collection and compilation guide (See Appendix A). County permit data was used, as available, as a starting point for field evaluation. Typical county permit data available in Minnesota includes the system type, installation date/age, system design, well location, number of bedrooms, design flow, septic tank sizing, use of a pump, type of distribution method, depth to limiting condition, soil sizing factor, system length, depth, and location of trenches, system construction inspection data and as-built drawings. If a subsequent compliance inspection was part of the permit file, it would also be evaluated.

A licensed private inspector visited each site chosen for the survey. A member of the University of Minnesota research team participated in approximately 30% of the site visits to both establish the initial protocol and provide quality assurance throughout the study. The following parameters were evaluated by the inspector:

a. The size of the system installed was confirmed.
b. Surfacing of septic tank effluent or evidence that the system surfaced in the past was investigated.
c. The number, length and depth of trenches was confirmed.
d. The soil texture and vertical separation was identified with in a soil boring performed outside the area of influence along the mid-point contour of the soil treatment system was performed.

e. The width for rock trenches was assumed to be 36" (typical design variable and bucket width in Minnesota and 29" for chambers (inside foot print of chambers). For design purposes most designers use the excavation width of 36" when sizing chambered systems. The actual infiltration area was considered to more accurate for the purposes of this study.
f. The amount of ponding was recorded for each trench. The drop boxes and inspection wells on the ends of the trenches provide a location for monitoring the use and amount of ponding, height above the trench bottom (see Figure 1). This was done by inserting a probe into the inspection port until the bottom was reach, removing the probe and recording the amount of effluent visible on the probe. If inspection ports were absent, the trench media was manually exposed for ponding measurement. If the trench had no measurable ponding it was recorded as having zero inches of ponding even though portions of that trench were accepting the effluent, but had yet to reach the point of building a biomat resulting in ponding. Due to the use of drop boxes, the subsequent trenches will not receive effluent until the first trench is ponding to its maximum potential.

Figure 1. Trench system layout utilizing drop boxes for distribution.



Determining Percentage of System in Use

Based on the data collected in the field, the percentage of system in use was calculated and compared to the datum of a "standard/conventional" sized system so both full and downsized systems were able to be included in the study. This measurement does not indicate life expectancy as the development of biomat is dynamic and is not likely to be a linear process. The calculation allows for a comparison between the two types of media to test the project hypothesis that a smaller percentage of use will exist in chambers compared to rock-filled trenches.

RESULTS AND DISCUSSION

Survey Area

To meet the conditions of geographic spread, sufficient numbers of each system type and soil textural class, seven Minnesota counties were selected for the study: Hubbard, Goodhue, Cottonwood, Olmsted, Wright, Stearns, and Washington. Other factors that influenced the selection of target counties included the level of interest by local government units to participate and the return of the consent form and questionnaire by homeowners. Once a county was identified as having chambered or rock-filled systems that could qualify for the study, that county's offices were visited for research and duplication of records. At that time, a letter explaining the study, a consent form, and a questionnaire were mailed to owners of potential study sites.

Systems Characteristics

In this study, 116 chambered and 104 rock-filled systems were inspected across seven different Minnesota counties, stratified by 3 major soil textural categories. Each system included in the study had to be occupied year round and have at least 2 feet of vertical separation to the seasonally high water table or bedrock. Over the study period, 31 systems were inspected that did not meet this 2 foot separation requirement and were not included in these results. We also removed rock-trench systems (27 systems) from the database that included more than 6" of ponding (where rock-filled trench depths were greater than 6 inches) in order to compare similar systems to chambers. Surfacing during the field visit or indications of past surface discharge were not observed in any of the systems inspected during the survey. Only one system was fully ponded with very limited additional storage capacity.

All systems meeting study criteria (162 systems total) for this study were between 5 and 10 years of age, with 82% of the systems operating for 6 to 7 years. Seventy percent of the systems had been pumped within the last 5 years and 20% had garbage disposals. A trench with 6" of rock beneath the pipe serves as our datum when determining if a system was downsized. The flow for the home multiplied by our soil sizing factor then serves as a "standard" sized system.

The field evaluation was conducted between April 26 and June 24, 2006. The time period of evaluation was lengthened due to problems gaining consent from property owners. 33 systems per category was the goal, but due to study requirements and sample time limitations the number was slightly less for several categories as shown in Table 5. The sample set is statistically valid in size.

Table 5. Number of system per soil type and average age and trench length.

System Type	Soil Type and Number of Systems ( )	Avg. Age in years & Standard Deviation ( )	Avg. Trench Length (ft) & Standard Deviation ( )
Chamber	Fast (33)	6.0 (0.5)	46 (20)
	Medium (28)	6.0 (0.8)	52 (17)
	Slow (31)	7.0 (1.5)	66 (24)
Total/Averages	90	6.3 (1.1)	56 (22)
Rock	Fast (22)	6.4 (0.7)	57 (17)
	Medium (22)	6.5 (0.8)	70 (23)
	Slow (28)	6.7 (0.9)	78 (21)
Total/Averages	72	6.7 (0.9)	68 (22)

System Comparison Evaluation

There were a large number of systems where no ponding was recorded (96 total, 57 rock and 39 chamber) indicating the biomat had not yet matured to the point of causing ponding. Generally speaking a biomat is a positive attribute of gravity trenches receiving septic tank effluent as it assists in unsaturated flow through the soil profile. One likely explanation for less rock systems experiencing measurable ponding is due to the fact that it takes longer for the mature biomat to develop in rock-filled trenches because they are generally longer in length as shown in Table 5. Chambered systems are about 30% shorter (SE 5.1%).

T-test comparisons utilizing the entire database demonstrate a higher usage in systems without garbage disposals (12.9% use versus 3.5%, respectively, $p = 0.002$), while there was no difference in usage between recently pumped systems and those less recently pumped (10.4% use versus 11.8%, respectively, $p = 0.688$). To further investigate these differences, we compared within system types. Analyzing the presence or absence of garbage disposals shows the same trends, at significant levels ($p < 0.10$), within both rock and chambered systems. For the pumping frequency, the statistically insignificant results continued.

T-test results indicate no significant differences between systems (chambered and rock) studied comparing overall system size (assuming Minnesota state standard sizing was utilized) or system age. These findings are important when comparing system types in terms of usage. Since there were no significant differences regarding size or age, these properties are not considered influential variables if differences between system types are observed.

Estimated daily flows were determined by multiplying the number of residents from the homeowner survey by 60.5 gallons per day. The mean estimated flows between chambered and rock trench systems did not vary significantly at the 0.10 level (173 and 185 gallons per day, respectively).

T-test comparisons of all rock-filled trenches versus all chambered systems found chambered systems have a higher percent usage (p = 0.000). Investigating the system types by major soil category shows that for each soil textural category, chambered systems use more system area when compared to rock systems (Table 6). The significant differences between system types even when stratified by soil type may be partially explained by trench length.

Table 6. Comparison of percent use by system type and general soil texture class.

	Percent Use (%)		
Soil Category	**Rock**	**Chambers**	**p value**
Fast	8.7	20.8	0.041
Medium	3.1	16.5	0.003
Slow	1.6	9.6	0.001

To investigate the role of trench length as an explanatory variable in this study, we first needed to develop a metric of comparison between systems. Since length of the systems is not comparing the same square footage per unit length, we chose area as our metric. All systems have varying lengths of trenches so we averaged the trench lengths in order to derive our final variable, which is average area per trench. We found average area per trench (square feet) to vary significantly between system types when data is aggregated and between fast, medium and slow soils (Table 7). Chambered systems have shorter trench segments and therefore are more likely to pond sooner. Since our study evaluated system usage by determining ponding, chambers are likely to have a higher use because of their shorter trench segments. It can also be seen in Table 7 that the actual soil sizing factors based on the estimated flows and average area per trench the loading rates to both systems are quite high since all the wastewater is flowing into the first sequential trench. The data indicated that chambered systems are receiving a higher loading rate which encouraged the formation of a biomat and measurable ponding. These results should not be used to predict system longevity.

Table 7. Comparison of average area per trench by system type and general soil texture class.

	Avg. Area Per Trench (sq ft)			**Average Soil Sizing Factor (ft^2/gpd) (Loading Rate(gpd/ft^2))**	
Soil Category	**Rock**	**Chambers**	**p value**	**Rock**	**Chambers**
Fast	181	139	0.008	0.9 (1.11)	0.8 (1.25)
Medium	219	162	0.006	1.2 (0.83)	0.9 (1.11)
Slow	236	206	0.093	1.3 (0.77)	1.2 (0.83)

To further investigate how much of the variability in percent use to attribute to average area per trench, a linear regression was completed of the percent of soil treatment system use by average area per trench stratified by soil textural class. This data found average area per trench to explain

29, 38 and 46% for slow, medium and fast soils respectively of the variation in percentage of system used. So while trench area plays a role in explaining why this study found chambers using a greater amount of a soil treatment area, it is not a complete explanation. Numerous possible explanations exist to potentially further explain the differences including chamber settling, surface compaction due to foot traffic in the trenches and wastewater application methods, quality of sites and installers on sites utilizing downsized chambers and treatment/biomat development which may occur initially in rock trenches before ponding occurs as effluent travels over the rock similar to a trickling filter. Evidence of these occurrences was not identified in this study as the chambers and trench bottoms were not exposed.

To determine which attributes of the systems measured significantly impacted the percent in use SYSTAT was used to perform a multiple linear regression of all the systems included in the study. Evaluating the percent in use type of system ($p = 0.001$), people in the home/usage ($p = 0.000$) and average area per trench ($p = 0.000$) are all important variables which explain approximately 30% of the variability. Within each system type, number of people (chambers $p = 0.007$, and rock $p = 0.000$) and average area per trench (chambers $p = 0.000$ and rock $p = 0.003$) are statistically significant and garbage disposal use is significant only for chambered systems ($p = 0.061$).

Systems were then divided into three size categories based on average area per trench: small (1), medium (2), large (3). Analysis of percent in use was performed with all the systems and number of people ($p = 0.008$) and size category ($p = 0.000$) are explanatory variables. When the data is grouped into rock-filled and chambered the number of people and the size category were significant in both rock filled ($p = 0.001$ and 0.006) and chambered ($p = 0.008$ and 0.000), respectively.

Summarizing percent in use by area categories was determined for each system type as shown in Table 8. The size categories were chosen based on sample size and natural breaks in system areas. As systems increase in average area per trench the percent in use decreases across the two system types. This holds true for each system type with systems with smaller square footage have higher percent use than medium, and medium higher than large. Even within the same size category rock-filled systems have a smaller percentage of system in use then chambered systems. These differences are significant with the exception of category 3 due to the large area of the trenches and the sampling methods.

Table 8. Percent in Use Results with Systems Categorized by Square Footage Categories.

Size Category - Range in ft^2	Number of Systems	Percent in Use			
		All	Rock	Chambers	p value
1 - (0 – 150)	60	19.6	9.5	24.3	0.011
2 - (150 – 250)	66	7.8	3.9	10.9	0.020
3 - (> 250)	36	1.2	0.6	2.4	0.353

The data collected in this study was unable to prove the hypothesis that chambered systems of a similar age as rock-filled systems will use 25% less area than rock-filled systems at 10% significance level. The data shows the opposite with less ponding in rock-filled systems. Based on the age of systems used in this study this phenomenon may occur because many systems have not yet reached the point of building a mature biomat, which causes ponding. Statistically significant differences were detected by a t-test at the 0.10 level between chamber and rock-filled trench systems when mean percent of system area in use was compared (Table 9). However, it is the rock-filled trenches that are experiencing a lower mean percentage of system use, not chambered systems as stated in our hypothesis. While statistically valid differences do exist, they appear to be small differences and our conclusion from this analysis is that rock-filled trenches and chambered systems act similarly in terms of area used for the age of systems in this study (5-10 years). Therefore, there was no observed advantage of chambered systems over rock-filled systems at this age range in terms of system usage discovered in this study.

Table 8. Results of unpaired t-tests comparing system types. P-values were evaluated at a significance level of $p < 0.10$.

System Type	**Age (years)**		**System Size (sq ft)**		**Estimated Flow (gpd)**		**Percent Use (%)**	
	Mean	**p-value**	**Mean**	**p-value**	**Mean**	**p-value**	**Mean**	**p-value**
Chamber	6.3	0.120	853	0.770	173	0.359	15.8	0.000
Rock	6.5		827		185		4.3	

CONCLUSIONS

While direct flow measurements and actual biomat cannot be quantified, our sampling provided non-intrusive methods for collecting data suitable for comparison. Surprisingly, 59.3% of systems included in our study of the ages 5- 10 years did not have any ponding observed during a typical wet time of year for Minnesota climatic conditions. This finding is cause for additional analyses in order to ascertain a suitable explanation, as establishment of a biomat at the bottom of a soil treatment system ensures proper treatment of effluent. Additional data may be required in order to fully understand this unexpected outcome.

Rock-filled trench septic systems between 5-10 years in age were found in our study to be utilizing less soil treatment area than chambered systems. While total area between the two system types did not vary, it is estimated that part of the explanation for why rock systems were found to use less of the soil treatment area is because of the smaller area per trench utilized in many chambered systems (29-46%). Analyses of additional data collected in this study failed to provide further insight into the differences determined. These results should not be used to predict system longevity.

Based on the results of this study, the design parameter used in Minnesota (loading rates and three feet of separation), proper installation and maintenance along with the licensing, permitting and inspection program are resulting in excellent system performance of gravity sequentially loaded trenches. The authors believe the requirements in Minnesota generally result in successful system at relatively low cost due to their proper design and installation. Another large benefit of the trenches in Minnesota is the inspection at both the drop box and end of the trench which allowed us to investigate the amount of ponding and provide a system management component.

FURTHER RESEARCH

This study provides a more detailed protocol to investigate the performance of trench systems. It would be advantageous and informative to either complete this study in a different location with older systems or to rerun this study in 5-10 years to determine if a longer term difference between the system types will exist. This would testing systems for allow longevity and system performance with a higher proportion of systems experiencing measurable ponding.

The development of ponding in gravity trenches needs further investigation. It was assumed when this project was under development that more then 75% of systems with sequential loading would have some measurable ponding at the end of the first trench after five years or more of operation. This lack of biomat development questions our general understanding of biomat formation time lines, identifies our conservative design approach and highlights that shorter trench installation maybe be helpful in the performance of systems.

ACKNOWEDGEMENTS

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Soil Treatment and Even Distribution of Effluent

MPCA

4/20/09

Background

- Since 1978, Chapter 7080 has had a 3 foot separation distance to the periodically saturated soil or bedrock.

Background

- This separation distance provided removal of pathogenic organisms.

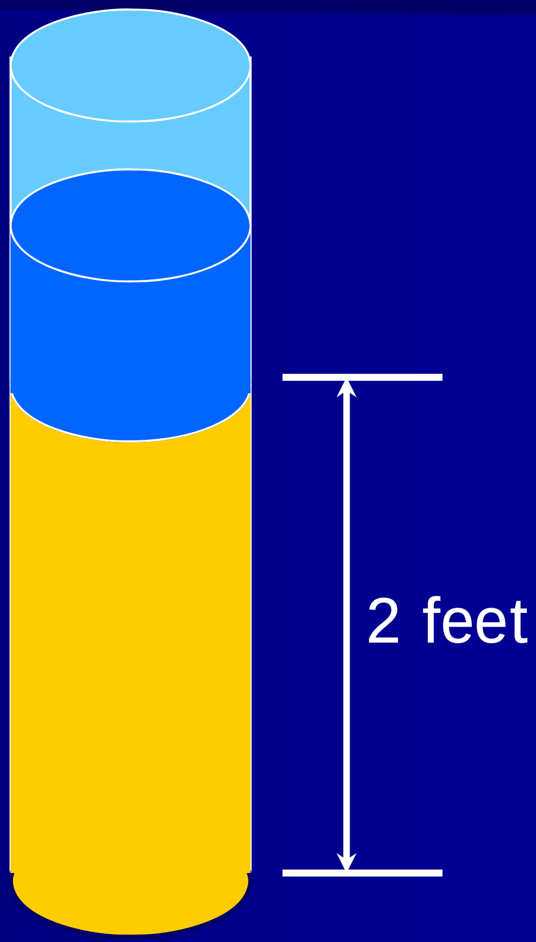
Background

- This separation distance was based on a certain loading rate.

Background

Green and Cliver - 1975

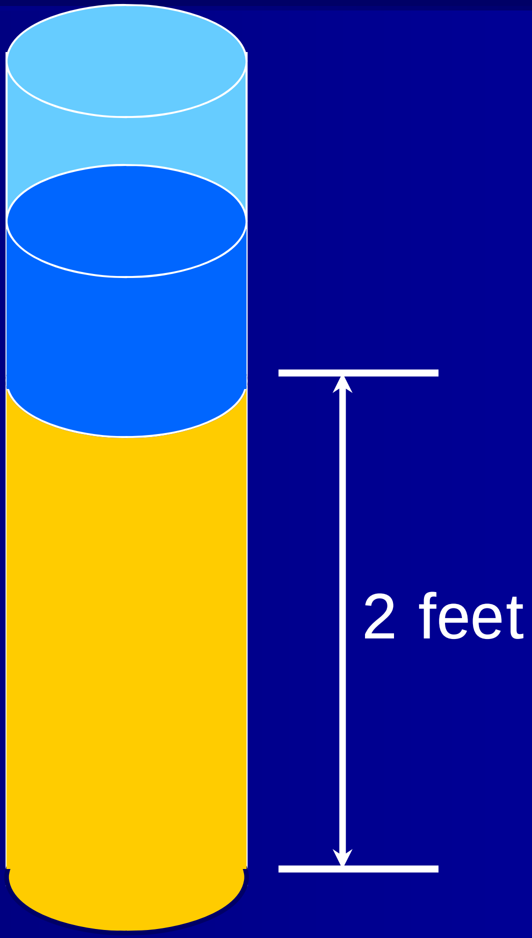
Loading of 1.2 gpd/ft2 –
all polio viruses removed



Background

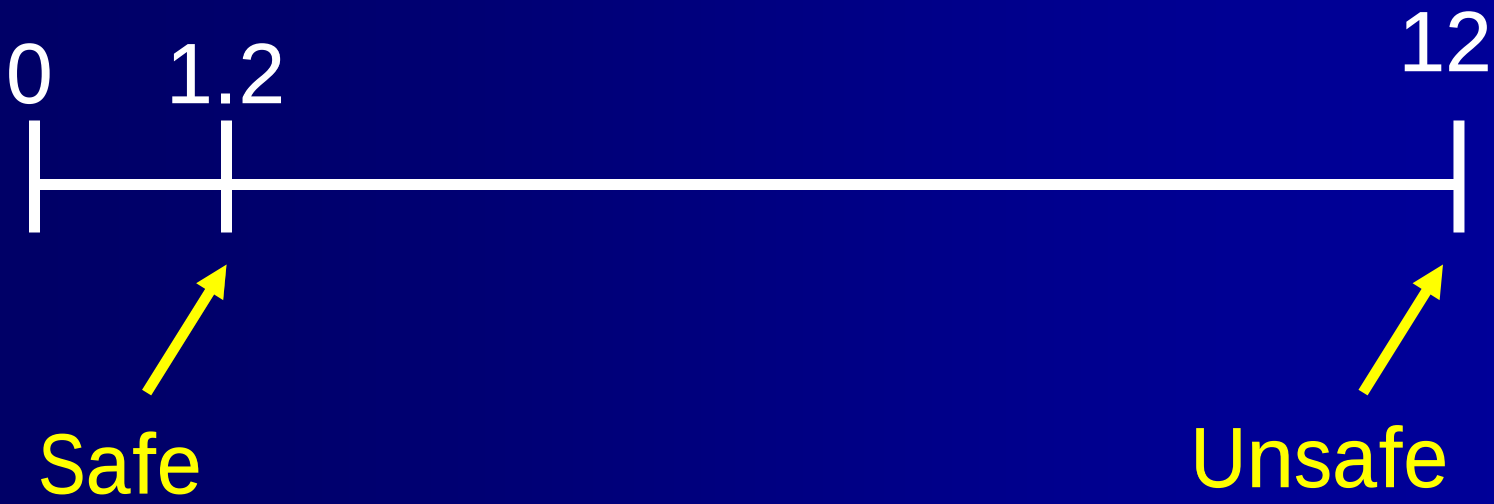
Green and Cliver - 1975

Loading of 12 gpd/ft2 – polio viruses not removed



Background

Loading Rate (gpd/ft2)



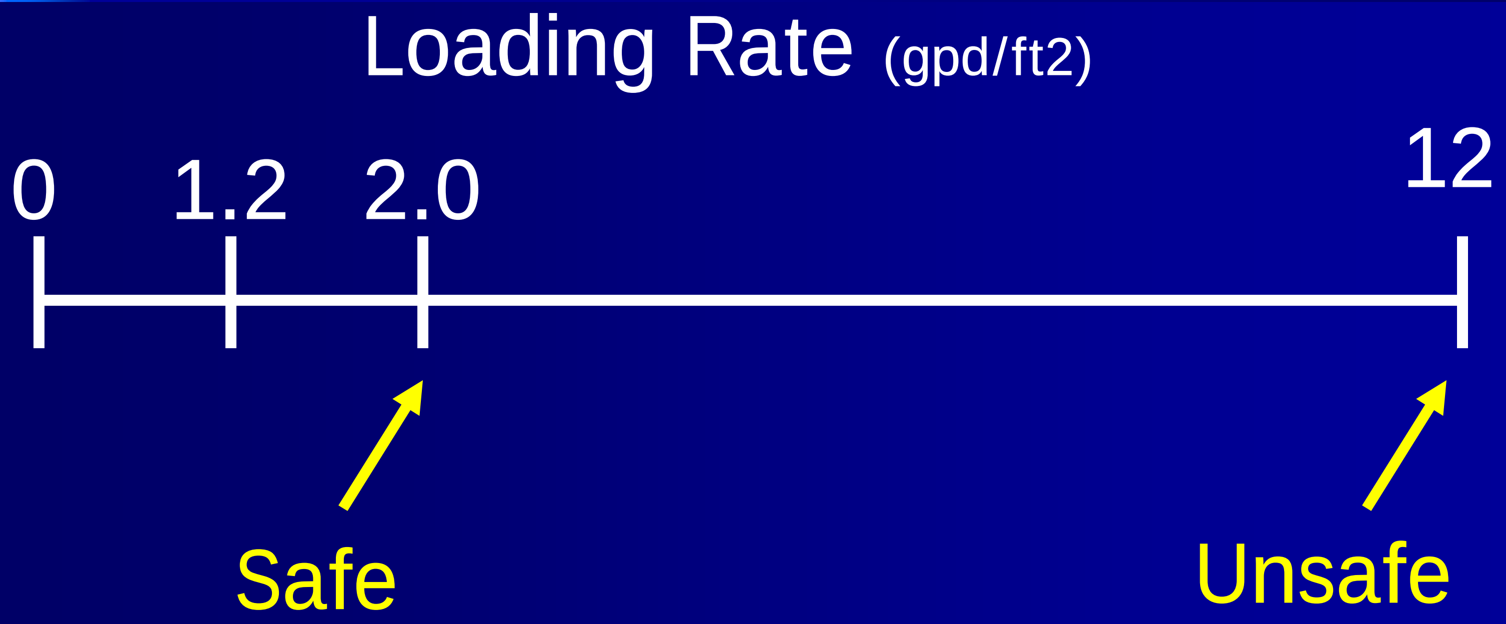
Background

- Chapter 7080's maximum loading rate is based on this research.

Background

- Further Research by VanCuyk et. al. in 2001 showed that a loading rate of 2.0 gpd/ft2 is safe.

Background



Background

- The industry was pushing for a performance based code. The agency did some investigation in this area.

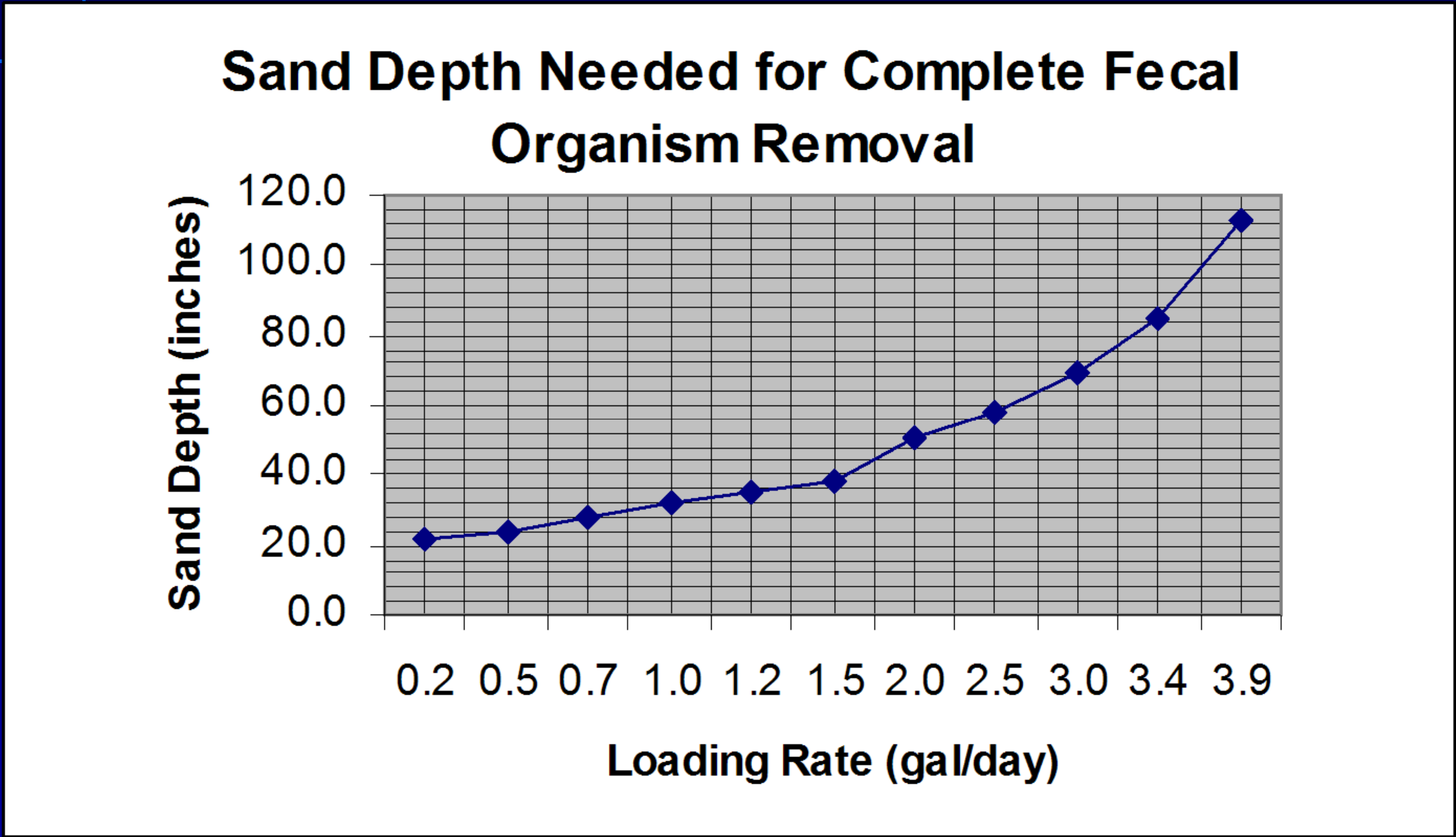
Background

- Treatment is based on many things:
  - – Soil Texture
  - – Loading Rate
  - – Dosing frequency
  - – Temperature
  - – pH
  - – many others……

Background

- The agency review research. Found some research of sand filters and sand columns.

Background



Sand Depth Needed for Complete Fecal Organism Removal
Sand Depth (inches)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0.2
0.5
0.7
1.0
1.2
1.5
2.0
2.5
3.0
3.4
3.9
Loading Rate (gal/day)

Background

- The research showed that there is a relationship between loading rate and the needed separation distance.

Background

- Interestingly, the standard loading rate of 1.2 gpd/ft2 resulted in a 3 foot separation distance.

Background

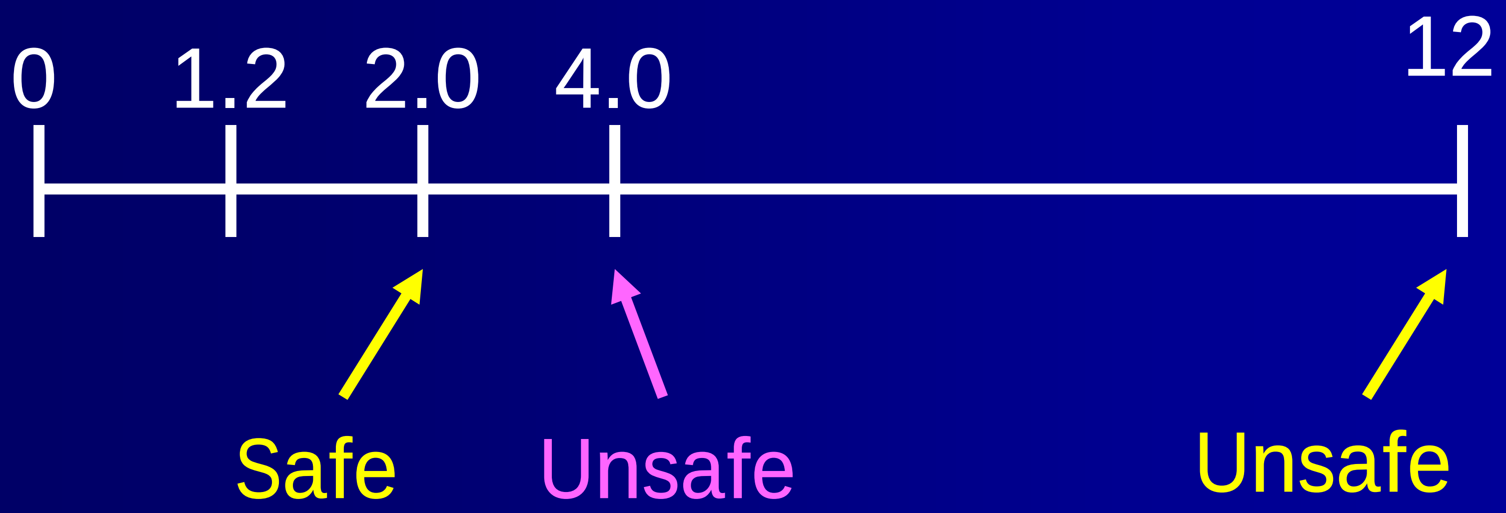
- A more recent study by Standridge et. al. in Wisconsin showed the same relationship

Background

Loading Rate	Fecal Concentration
1.0 gpd/ft2	0
2.0 gpd/ft2	0 to 20
4.0 gpd/ft2	190,000 to 238,000

Background

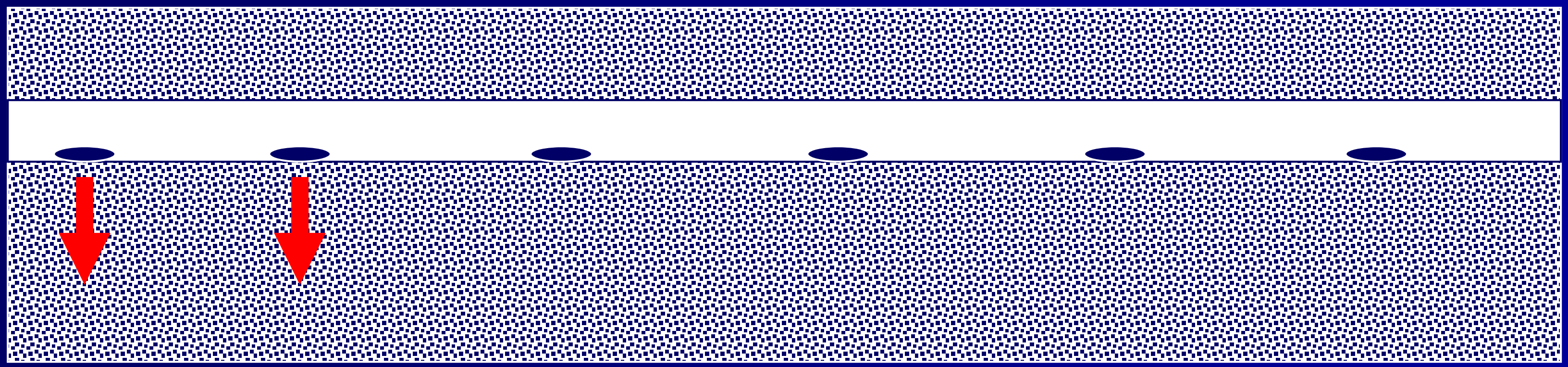
Loading Rate (gpd/ft2)



Background

- Gravity distribution
  - Average effluent velocity from a septic tank is 0.5 gallons per minute.
  - Gravity distribution pipe is 4 inches in diameter with ½ in holes

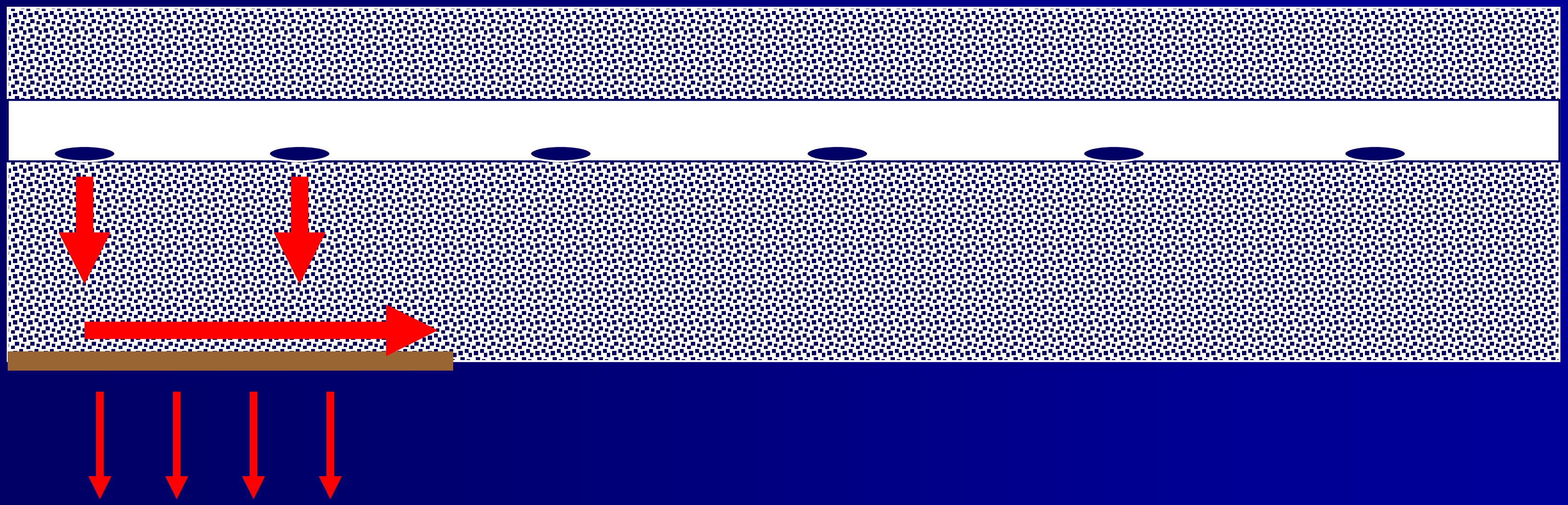
Background



Background

- The soil is initially overloaded and clogs, distributing the effluent along the trench bottom.

Background



Background

- This process was suppose to take a relatively short time period.

Background

- Recent research by the U of M on a related issue indicated that the biomat was not forming and the soil was getting overloaded.
- In addition, the agency as receive observations by professionals that the biomat was not forming in sandy soils

On-Site Wastewater Treatment

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DEVELOPMENT AND IMPLEMENTATION OF PERFORMANCE STANDARDS ASSESSING PERFORMANCE DESIGNS

M. S. Wespetal, L. L. C. Frekot*

ABSTRACT

In October 1999, the Minnesota Pollution Control Agency amended its state rule for individual sewage treatment standards to include performance standards. The standards were developed after assessing the outcomes achieved by conventional systems and applying those outcomes to performance standards. The standards are broad in nature to allow maximum design flexibility. The standards are based on protection of public health, safety, the environment, and include provisions for consumer awareness.

A design assessment model for performance systems is based on giving treatment "credit" for known treatment components such as loading rates, soil separation, soil texture and dosing frequency. In this manner, the designer can adjust the various design parameters to conceptually meet performance expectations. This paper describes the process used to develop performance standards, justification for the selected standards, and a method to assess a system design.

KEYWORDS. Performance standards, septic system modeling, design.

INTRODUCTION

In October 1999, Minnesota's Individual Sewage Treatment System (ISTS) rule was revised to include performance standards. Minnesota's rule allows maximum design flexibility to keep the true spirit of a performance standard. The standards are based on public health, safety and environmental protection, and include provisions for consumer awareness.

DEVELOPING PERFORMANCE STANDARDS IN MINNESOTA

In developing performance standards, the Minnesota Pollution Control Agency (agency) assessed the treatment and hydraulic expectations of standard prescriptive designs. This assessment provided the basis to establish comparable performance standards for non-prescriptive designs. The agency solicited input from a technical committee, state licensed ISTS professionals and research findings. A complete description of the process is detailed in the agency's Statement of Need and Reasonableness (MPCA, 1999b). Performance standards are provided for local governmental units who have the option to adopt them into local ordinances and provide local administration and management.

Minnesota's Performance Standards

The following are the main provisions of Minnesota's performance standards (MPCA, 1999a):

Public Health Protection Standards

- Only domestic sewage may be discharged into the system.
- No sewage may be exposed for human or animal contact during treatment and disposal.
- The system must be protective of physical safety (i.e., injuries)
- The system needs to conform to all applicable federal, state and local requirements.
- All devices need to be operated and maintained in accordance with manufacturer's requirements.

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Environmental Protection Standards

- "Some" unsaturated soil must be maintained between the bottom of the soil treatment systems and the seasonally saturated soil or bedrock during loading of effluent (i.e., vertic separation).
- The sewage effluent/groundwater mixture shall be free of viable fecal organisms 7.6 m horizontally from the soil treatment area. This limit cannot be exceeded during typical periods of climatic stress and/or under typical maximum design flow volumes.
- If the system is located on a lot that adjoins a lake, the sewage effluent/groundwater mixture must not exceed a total phosphorus concentration of 1 mg/l.
- Local governmental units may enact nitrogen standards for sewage effluent/ground wat mixture.

Consumer Protection Standards

Designers of performance systems are required to provide a comparison of the performance design with an applicable standard design. The comparison must include estimated costs of construction, operation, monitoring, component replacement and management. The comparison must also include anticipated system life based on hydraulic and organic loading rates. The rule requires performance systems to use the standard design flow of 568 L/bedroom/day (MPCA 1999a).

Monitoring and management are required for all performance systems. Monitoring must be specifi the system. Management must be accomplished through local renewable operating permits.

PERFORMANCE STANDARDS: DESIGN ASSESSMENT MODEL

A design assessment model is needed to conceptually assess whether a proposed system will meet performance expectations. To be complete, all environmental concerns should be addressed such a pathogens, nitrogen, synthetic organic chemicals, heavy metals, and phosphorus. The purpose of th model is not meant to absolutely determine if compliance will be met; but can be a tool for regulators to use to determine if a permit should be issued for the proposed system, and to determ the type and extent of the monitoring.

Performance Design Parameters

The general nature of Minnesota's performance code allows the designer to manipulate all the factors that are known to treat sewage to achieve public health and environmental protection. Factors that affect sewage treatment are described by Sobsey (1982), Yates and Yates (1990), anc Lance and Gerba (1982) and include the following:

- Concentration of pollutants
- Loading rates
- Dosing frequency
- Clogging mat
- Soil treatment (separation distance, amount and type of clay minerals, biological antagonism, temperature, pH, moisture content, salt species and concentrations, organic matter (humic and fulvic acids), pathogen survival (absorbed, non-absorbe aggregated, non aggregated)

Challenges in Determining Treatment Credit

The design assessment model is based on assigning treatment credits for major treatment components identified above. The treatment credits presented in this paper were derived from literature review. However, several challenges were encountered in this process, including:

- Much of the research did not measure or report all the treatment components (i.e., was a clogging mat present, dosing frequency, etc.).
- Wide varieties of test organisms were used.
- Some tests were conducted for short periods of time (i.e., hours). Modeling by Yates et al. (1991) and studies reviewed by Kreissl (1978) showed deeper penetration over longer periods time.
- Soil pH was seldom given. Sobsey (1982) indicates pH as being a very important parameter in virus attenuation.
- Research was lacking on finer textured soils at different loading rates and dosing frequencies.
- Few papers examined the relationships between multiple treatment components.
- Current virus transport models are complex.

The varied research methods in addition to the variation in the natural system itself resulted in numerical treatment credits that cannot be strongly justified.

TREATMENT EXPECTATIONS

Minnesota's performance code does not allow viable fecal contamination to travel farther than 7.6 m horizontally from the system during a "normal" period of climatic and loading stress (e.g., rainfall after snow melt on a peak water using day). This standard was chosen to be consistent with what is expected to occur under a standard system with a 0.9 m vertical separation. However, since it is difficult to model stress situations, the proposed model is based on total fecal organism removal at the seasonally saturated soil or bedrock under normal loading and climatic conditions. In Minnesota, the seasonally saturated soil level is determined by distinct redoximorphic concentrations and/or redoximorphic depletions and is anticipated to have a duration of approximately 20% of the year (Khan and Fenton, 1994; Bell and Richardson, 1997; Thompson and Bell, 1996; Thompson et. al, 1998, Thompson and Bell, 1998).

Treatment expectations for fecal organisms are summarized in Table 1. Concentrations are based on Ziebel et al, (1974), USEPA (1980), Metcalf and Eddy (1972), Kreissl (1982), and England (1972).

Table 1. Concentrations of Fecal Organisms in Raw Domestic Sewage, Compliance Concentrations and Compliance Points.

Organism	Concentration in Raw Sewage	Compliance Concentration	Compliance Point
Viruses	less than 10^4/100ml	zero	seasonally saturated soil or bedrock
Bacteria	10^7 - 10^9/100ml	zero	

Design Parameters and Treatment Credits

The following is a discussion of the design components that can be manipulated to conceptually achieve complete removal of fecal organisms at the non-treating layer under normal loading and climatic conditions.

Design Flow Amounts

Performance systems in Minnesota must be designed using flow estimates for standard systems, 568 L/bedroom/day. However, for design assessments a more realistic flow value of 285 L/bedroom/day should be used to assess real-time soil treatment efficiencies and groundwater mounding. The design assessment flow is based on 170 L/person/day (USEPA, 1980) of actual water use plus a 20 L/day safety factor, and using 1.5 persons/bedroom (99% of Minnesota dwellings, Bureau of the Census, 1990). Therefore, a four-bedroom dwelling would be designed at 2270 L/day, but would be assessed for treatment and groundwater mounding purposes at 1140 L/ day.

Concentration of Pathogens

Typical concentrations of fecal organisms in raw sewage are found in Table 1.

Many pretreatment devices significantly reduce concentrations of fecal organisms. The amount of reduction or chosen fecal concentrations from the device should be based on testing or research of similar designs. It is recommended that an effluent concentration be chosen that can be achieved 95% of the time.

Typically, secondary treatment devices will require the use of septic tanks, therefore primary treatment should not be overlooked if assessing the removal of viruses. Table 2 lists the reduction in viruses from primary treatment. The values are an estimate based on Rao, et al. (1981), USEPA (1980), and Foster and Engelbrecht (1973).

In most cases fecal coliform bacteria will be the only fecal organism where data is available to be used in the model (or can be easily measured for future compliance).

Table 2. Reduction in Fecal Organisms from Septic Tanks (Primary Treatment)

Organism	Reduction (%)
Viruses	50
Bacteria	0

Loading Rates, Groundwater Mounding and Capillary Fringe

There is a correlation between loading rates and treatment efficiencies of soil, Lance (1983). Therefore, the loading rate is one component that should be factored into the design to assess performance.

One of the distinctions sought by using a secondary treatment device is to make the soil dispersal systems smaller because of limited (or no) formation of a clogging mat. Increased loading rates to the soil system will increase the groundwater mound beneath the system. Caution must be exercised. If systems are designed very close to the saturated soil horizon and the loading rate increased, the designed vertical separation may be lost which may cause severe hydraulic problems with the system.

To reduce the potential for hydraulic overloading, some method must be employed to estimate the effects of adjusting the loading rate on groundwater mounding. Table 3 shows estimated heights of groundwater mounding at different loading rates. These heights are based on Kaplan (1991) for perching above slowly permeable layers. Kaplan's calculation predicts a much lower groundwater mound as compared to other mounding calculations investigated. The more conservative calculations were not used because the predictions show excessive mounding, even at standard loading rates and separation distances. Mid to high range conductivity values were used to derive the mound heights in Table 3.

The groundwater mounding values in Table 3 will be added to the needed vertical separation distance. Actual groundwater height should be measured during operation to determine if the designed vertical separation is being met because of uncertain mounding height predictions.

Table 3. Predicted Rise in Groundwater (cm) Based on Hydraulic Soil System Loading

Loading (cm/day)	1	2	4	8	16
Soil Texture					
Sandy	0	1	2	4	8
Loamy	6	13	26	52	-
Clayey	14	28	55	-	-

Along with groundwater mounding the treatment and hydraulic affects of the capillary fringe should be determined. Anderson et. al, (1994) noted the presence of a capillary fringe under an operating system. van Schilfgaard (1974) describes the reduced oxygen diffusion rates in the capillary fringe, while Gillham (1984) describes the unexpected dramatic rise of the watertable due to the addition of a small amount of water to the capillary fringe. Table 4 proposes distances above the watertable which are expected to provide limited treatment or may interfere with hydraulic performance. The table is based on air entry values (Clapp and Hornberger, 1978). The model will add these distances to the needed vertical separation distance.

Table 4. Proposed distances above a watertable that are anticipated to provide limited treatment

Soil Texture	Adverse effect of the capillary fringe (cm)
Sandy	2
Loamy	15
Clayey	30

The Clogging Mat

The literature suggests that the clogging mat removes significant fecal organisms (Brown et al., 1979, Kreissl, 1978, Bouma et al, 1972). Therefore, if a clogging mat is anticipated to form (based on waste strength), a treatment credit is given to the clogging mat (Table 5).

Table 5. Reduction of Fecal Organisms by a Clogging Mat

Mat Formation	Log Reduction
No clogging mat	0
With clogging mat	2.0

Soil Separation, Soil Texture, Hydraulic Loading Rate and Dosing Frequency Credit

The hydraulic loading rate, dosing frequency, vertical separation, and soil texture will affect soil treatment efficiencies. Therefore, these parameters need to be optimized during design to achieve the desired performance.

An attempt was made to develop "treatment credits" from longer duration fecal organism removal studies in sand filters and sandy soils. Table 6 was developed by placing the measured treatment efficiencies from literature into the appropriate table, row, and column. Tables, rows and columns are based on soil texture, loading rates and dosing frequency. Where no data was available, values were interpolated between known values. Values derived from research findings are identified in Table 6 and were acquired from: Anderson et. al, (1994); Rose et al., 2000; Emerick et al. 1997; Higgins et al., 1999; Siegrist et. al., 1999; Siegrist et al. 2000; Gold et al., 1992.

Relatively few studies with complete information (i.e., separation distances, loading rates, dosing frequencies, presence/absence of clogging mat, etc.) were found for non-sand soils (Kreissl, 1978; Converse et. al, 1991 and Reneau 2000). Therefore, treatment tables for finer textured soils was not attempted. Significant research is needed in this area.

A clogging mat will likely not form if secondary treatment is used (Siegrist, 1987; Tyler et al., 1995). Without formation of the clogging mat, gravity distribution should not be used because of poor distribution resulting in high hydraulic loading rates over a small portion of the system (Converse, 1974). Secondary treated effluent must be distributed by pressure distribution.

Interestingly, the limited research on finer textured soils, with pressure distribution, without a clogging mat, indicated less treatment of fecal organisms than on sandy soils (Converse and Tyler, 1998). This may be attributed to a combination of a high dose volume per orifice (Converse and Tyler, 1998) and preferential flow in structured soils. Personal communication with Orenco Systems, Inc. representatives indicate that the wetted area in sand filters is 0.04 m^2 per orifice. Ziebell (1975) (as referenced by Kreissel (1978)) reduced preferential flow and increased treatment with lower loading rates. If preferential flow can be mitigated by the increased number of orifices and lower dose volumes, finer texture soils, with more surface area and absorption capacity should out-perform sandy soils. This has been demonstrated by exceptional removal (7.9 logs/cm) of viruses in repacked columns (without macropores) of silt loam soils (Green and Cliver, 1974 as referenced by Kreissl, 1978).

Due to the threat of preferential flow, the credits assigned in Table 6 restrict the dosing volume to 1 cm/dose for sandy soils. This volume per dose should be further reduced for structured soils. This recommended dose volume is not based on research findings. It is also recommended that pressure distribution systems be designed with one orifice per 0.56 m^2 (Converse and Tyler 1999).

Table 6 shows fecal organism reduction in log removal/cm of soil depth. The blank row and column (above the line) designated in the table indicate loading rates and dosing frequencies that are anticipated to cause preferential flow.

Table 6. Log Reduction of Fecal Organisms per cm of Soil Depth - Sandy Soils.

Dosing Frequency doses/day	Loading Rate, cm/day: 1	2	3	4	5	6	8	10	12	14	16
1			**0.051**[1]		**0.055**[3]	**0.052**[1]		**0.036**[3]			**0.097**[1]
2	0.060	0.056			**0.086**[1]	**0.072**[1]		**0.095**[1]			
4	0.064	0.059	0.054	0.046		**0.079**[1]					
6	0.068	0.063	**0.057**[2]	0.049	0.044	**0.028**[1]	**0.076**[1]				
8	0.072	0.066	0.060	0.051	0.047	0.042	0.033				
10	0.077	0.070	0.063	0.054	0.049	0.044	0.035	0.028			
12	0.081	0.073	0.065	0.056	0.051	**0.046**[2]	**0.036**[2]	0.029	0.022		
14	0.085	0.077	0.068	0.059	0.054	0.048	0.038	0.031	0.024	0.017	
16	0.089	0.080	0.071	0.061	0.056	0.050	0.039,	0.032	0.025	0.019	0.012
18	0.093	0.084	0.074	0.064	0.058	0.052	0.041	0.034	0.027	0.020	0.014
20	0.097	0.087	0.077	0.066	0.060	0.054	0.042	0.036	0.029	0.022	0.016
22	0.101	0.091	0.080	0.069	0.063	0.056	0.044	0.037	0.031	0.024	0.018
24	**0.110**[2]	**0.098**[2]	0.086	**0.074**[2]	0.067	**0.061**[2]	**0.047**[1]	0.041	0.034	0.028	**0.021**[1]

[1] Values derived from research findings [2] Value sligthly modified from research findings. [3] Research values averaged.
Values above the line were used to develop the table, but are not to be used for design due to the increased threat of preferential flow.

ASSESSMENT OF A PROPOSED DESIGN

The following design calculation shows how to use the previous tables to conceptually determine how much vertical separation is necessary to achieve treatment and hydraulic performance. The assessment also attempts to account for the vertical separation distance lost due to capillary fringe and groundwater mounding.

System Design:

Dwelling: *4-bedroom*
Flow for System Sizing: *2270 L/day*
Flow for Groundwater Mounding and Loading Rate Assessment: *1140 L/day*
Fecal Coliform Concentration of Pretreatment Effluent (95% confidence): *10^3 organisms/100 ml. (3 Log);*
Chosen system size: *38 m^2*
Designed Loading Rate: *60 L/m^2/day (6 cm/day)*
Actual Loading Rate: *30 L/m^2/day (3 cm/day)*

Chosen Dosing Frequency: *8x/day*
Soil Texture: *Sand*
Ground Water Mounding estimate (Table 3): *2 cm*
Capillary Fringe Affect (Table 4): *2 cm*
Clogging Mat Reduction (Table 5.): *None (used pretreatment device)*
Log Reduction Based on Texture, Loading Rate and Dosing Frequency (Table 6): *0.060 log/cm*

Calculated Vertical Separation Distance Needed:

3 log / 0.060 log reduction/cm + 2 cm (mounding) + 2 cm (capillary fringe) = 54 cm

CONCLUSION

Although it appears that this approach is technically sound, all the numerical values used are not fully supported by research. Therefore, adequate monitoring of performance systems designed under this model must take place. If it is found that soil or groundwater monitoring is not reliable or cost effective, the use of performance designs may be premature.

It is hoped that more research on soil treatment efficiencies will be conducted that includes the interaction of all (both major and minor) treatment components listed in this report. This research, along with existing data, may be used to develop a sophisticated mathematical model with a user-friendly interface for a personal computer. The ultimate goal would be to have a model accurate to the point where soil monitoring for performance would not be necessary.

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Comparison of 110 gallons per bedroom criteria vs. Type One dwelling flow

Dwellings	Bedroom/Dwelling	Total Bedrooms	110 gallon/bedroom	Type I Dwelling
1	3.3	3.3	363	500
2	3.3	6.6	726	1000
3	3.3	9.9	1089	1500
4	3.3	13.2	1452	2000
5	3.3	16.5	1815	2500
6	3.3	19.8	2178	3000
7	3.3	23.1	2541	3500
8	3.3	26.4	2904	4000
9	3.3	29.7	3267	4500
10	3.3	33	3630	5000
11	3.3	36.3	3993	5225
12	3.3	39.6	4356	5450
13	3.3	42.9	4719	5675
14	3.3	46.2	5082	5900
15	3.3	49.5	5445	6125
16	3.3	52.8	5808	6350
17	3.3	56.1	6171	6575
18	3.3	59.4	6534	6800
19	3.3	62.7	6897	7025
20	3.3	66	7260	7250
21	3.3	69.3	7623	7475
22	3.3	72.6	7986	7700
23	3.3	75.9	8349	7925
24	3.3	79.2	8712	8150
25	3.3	82.5	9075	8375
26	3.3	85.8	9438	8600
27	3.3	89.1	9801	8825
28	3.3	92.4	10164	9050
29	3.3	95.7	10527	9275
30	3.3	99	10890	9500

Comparison of 110 gallons per bedroom criteria vs. Type One dwelling flow

Dwellings	Bedroom/Dwelling	Total Bedrooms	110 gallon/bedroom	Type I Dwelling
1	3	3	330	450
2	3	6	660	900
3	3	9	990	1350
4	3	12	1320	1800
5	3	15	1650	2250
6	3	18	1980	2700
7	3	21	2310	3150
8	3	24	2640	3600
9	3	27	2970	4050
10	3	30	3300	4500
11	3	33	3630	4703
12	3	36	3960	4905
13	3	39	4290	5108
14	3	42	4620	5310
15	3	45	4950	5513
16	3	48	5280	5715
17	3	51	5610	5918
18	3	54	5940	6120
19	3	57	6270	6323
20	3	60	6600	6525
21	3	63	6930	6728
22	3	66	7260	6930
23	3	69	7590	7133
24	3	72	7920	7335
25	3	75	8250	7538
26	3	78	8580	7740
27	3	81	8910	7943
28	3	84	9240	8145
29	3	87	9570	8348
30	3	90	9900	8550

Comparison of 110 gallons per bedroom criteria vs. Type One dwelling flow

Dwellings	Bedroom/Dwelling	Total Bedrooms	110 gallon/bedroom	Type I Dwelling
1	4	4	440	600
2	4	8	880	1200
3	4	12	1320	1800
4	4	16	1760	2400
5	4	20	2200	3000
6	4	24	2640	3600
7	4	28	3080	4200
8	4	32	3520	4800
9	4	36	3960	5400
10	4	40	4400	6000
11	4	44	4840	6270
12	4	48	5280	6540
13	4	52	5720	6810
14	4	56	6160	7080
15	4	60	6600	7350
16	4	64	7040	7620
17	4	68	7480	7890
18	4	72	7920	8160
19	4	76	8360	8430
20	4	80	8800	8700
21	4	84	9240	8970
22	4	88	9680	9240
23	4	92	10120	9510
24	4	96	10560	9780
25	4	100	11000	10050
26	4	104	11440	10320
27	4	108	11880	10590
28	4	112	12320	10860
29	4	116	12760	11130
30	4	120	13200	11400

Is $CBOD_5$ Test Viable for Raw and Settled Wastewater?

By O. E. Albertson,[1] Member, ASCE

Abstract: In recent years, the carbonaceous biochemical oxygen demand ($CBOD_5$) test has been employed to determine the carbonaceous fraction of the biochemical oxygen demand (BOD_5) of final effluents in nitrifying systems. More recently, several states have required plants to analyze influents using the $CBOD_5$ test to determine whether the 85%-removal rule is being attained. The 1989 *Standard for the Examination of Water and Wastewater Methods* does not suggest—nor does the Environmental Protection Agency (EPA) $CBOD_5$ procedure studies justify—the use of the $CBOD_5$ test for raw and settled wastewaters. Analysis of operational data from several plants demonstrates that the $CBOD_5$ test seriously understates the true strength of influent and primary effluent wastewaters as defined by BOD_5 and chemical oxygen demand (COD) tests. The result of using $CBOD_5$ data could result in a 20–40% underdesign as well as cause nonexistent effluent violations of the EPA 85% removal-criteria rule. The conclusion was that $CBOD_5$ is an improper test for influent and settled raw wastewater.

BACKGROUND

The Environmental Protection Agency (EPA) has encouraged state regulatory agencies to use the carbonaceous biochemical oxygen demand ($CBOD_5$) test for measuring the carbonaceous biochemical oxygen demand (BOD_5) fraction of a nitrified effluent. This procedure, which employs adding formulations containing 2-chloro-6-(trichloromethyl)pyridine or nitrapyrin (TCMP) to inhibit nitrification (NOD) in the BOD_5 bottle, has been incorporated into *Standard Methods for the Examination of Water and Wastewater* (1989) and is employed throughout the United States for nitrified effluents. The purported value of this procedure is the ability to separate carbonaceous (C) and nitrogenous oxygen demands and report only the $CBOD_5$ value of the biological effluent wastewater.

In recent years, several states, including Washington, Arizona, New Mexico, and Virginia, have required that both the raw sewage and final effluents be tested using the $CBOD_5$ procedure. The rationale behind the regulation is to ensure that the minimum 85% removal rule for BOD_5 is also being met for $CBOD_5$. The problem, however, is that the $CBOD_5$ test has shown little consistency in reliably defining the actual strength (BOD_5 or COD) or raw wastewater and primary effluent.

Standard Methods (1989), in its discussion of nitrification in the BOD_5 test, did not suggest that an inhibitor be used for any wastewater other than biological effluents or natural waters. This reference notes that the nitrifying organisms will generally not be present in raw wastewater. Further, if a nitrification inhibitor, like TCMP formulations, is employed in the BOD_5 test, then the term $CBOD_5$ must be used to define the results.

The studies reported in the background literature on the $CBOD_5$ test procedure were primarily oriented to secondary effluent. Furthermore, the evaluations of the $CBOD_5$ procedure did not employ any secondary check procedure such as the COD or total organic carbon (TOC) test. The COD procedure, when chloride interference is neutralized, measures the total carbonaceous oxygen demand of the wastewater by chemical oxidation. [Oxidation of ammonia (NH_4N) does not occur when chloride interference is suppressed.] The value and use of the COD test is widely accepted and the procedures are simple, reliable, and quick to complete. However, its weaknesses are that it cannot distinguish whether toxicity is present nor determine the level of biodegradability of the wastewater organics. For these reasons, BOD_5 tests still have a value.

The $CBOD_5$ of raw and primary wastewater has been found to vary widely and unpredictably in comparison to the BOD_5. However, the coefficient in all design equations are based on BOD_5, not $CBOD_5$, measurements. This represents a serious problem and more study is warranted before $CBOD_5$ measurements are used as a basis of design of wastewater treatment plants (WWTP).

OBJECTIVES

The objectives of this field survey and analysis are twofold. One is to report the disturbing operating results of a number of municipal wastewater treatment facilities that are routinely using the $CBOD_5$ test for all wastewater streams. These data demonstrate that the $CBOD_5$ test is not suitable for raw and settled wastewaters. That is, plant data used in this analysis suggest that the $CBOD_5$ test results are significantly underreporting the wastewater strength based on our current understanding of the COD/BOD_5 ratio and other factors common to domestic and mixed municipal and industrial wastewaters.

A second objective is to further the use and acceptance of the COD test to define the total carbonaceous oxygen demand of wastewater. Use of this test in conjunction with the BOD_5 test to define the relative biodegradability will improve data quality and coherence versus that presently available from either the BOD_5 or $CBOD_5$ tests.

LITERATURE REVIEW

Nitrification in the standard BOD_5 (no inhibitor) tests may cause problems in the interpretation of the results. Ruchhoft et al. (1948) reported on nitrification in the BOD_5 bottle and concluded that oxidation and nitrification occur simultaneously in the 5-day BOD tests. Young (1973) summarized the history of concern for this nitrification problem and the various methods employed to control nitrification in the BOD_5 test without interfering with the $CBOD_5$ measurement. The suppression of nitrification would provide a more uniform measurement of the carbonaceous biochemical oxygen demand. Young modified samples with pasteurization, acidification, and chlorination with reseeding. He found that all procedures were effective, but well-trained and experienced analysts were required for good reproducibility and consistent reseeding practices were equally critical for producing accurate results.

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Young and Baumann (1972), using the electrolytic BOD_5 method and with and without TCMP addition, produced data suggesting that nitrification could be initiated in about 1.5 days in raw sewage and less than one day in primary effluent. However, the results of TCMP versus the control BOD_5 (no TCMP) were quite scattered; from a $CBOD_5$:BOD_5 ratio of 0.84 to 1.0.

Young (1973) also evaluated the effects of three nitrification inhibitors, allylthiourea (ATU), N-Hib, and TCMP, on the biochemical oxygen demand using an electrolytic respirometer. The conclusions of these studies were that the chemical methods were dependable and did not significantly affect the carbonaceous oxygen demand within the 5-day incubation period. Ammonia (NH_4N), nitrite (NO_2N), and nitrate (NO_3N) measurements in the respirometer were conducted on a synthetic wastewater seeded with primary effluent. The seed added to the BOD_5 bottle would have been a likely source of the nitrifiers when nitrification reoccurred.

Slayton and Trovato (1979) studied the use of inhibitors in the BOD_5 test to define the nitrification oxygen demand (*NOD*) of river water, sewage, and industrial effluents. The fate of the nitrogen compounds were measured and the researchers concluded that the use of TCMP provided an accurate determination of the *NOD*.

Young (1983) evaluated the effects of three TCMP inhibitors: reagent grade, technical grade, and Hach Formula 2533, using primary effluent as a test substrate. Using respirometers, the tests showed no statistical difference between samples receiving chemicals nor between chemical and the control (no inhibitor) through 6 days of incubation. In this study, TCMP did not inhibit carbonaceous BOD_5 of the primary effluent tests.

Hall and Foxen (1983) discussed the problem of nitrification in the BOD_5 testing of secondary effluents and concluded that this was a significant factor in many plants' failure to meet secondary effluent critieria. Hall (private discussions, 1992) reportedly found very minor interferences in the $CBOD_5$ measurements in studies conducted for the EPA. The major emphasis in these and earlier studies was the $CBOD_5$ versus BOD_5 of secondary effluent or natural waters, not untreated wastewater.

REVIEW OF WWTP OPERATING DATA

A review of several WWTPs' operating data illustrates the problems encountered with the $CBOD_5$ test when used as a biological measurement of influent and primary-effluent strength. The presentation of plant data and the subsequent discussion relies on the observation that the total suspended solids (*TSS*) and volatile suspended solids (*VSS*) fraction of raw wastewater and primary effluents have coefficients that are relatively narrow in range and provide a means to conduct veracity checks on data. These coefficients are BOD_5 = soluble BOD ($SBOD_5$) + f_b *TSS* (or f_{bv} for *VSS*); and *COD* = soluble COD (*SCOD*) + f_c *TSS* (or f_{cv} for *VSS*) (see Table 1). Complete details of development of the coefficients are available (Albertson and Okey 1992).

TABLE 1. Coefficients

Variable (1)	Influent (2)	Primary effluent (3)
f_b	0.65 ± 0.05	0.83 ± 0.05
f_{bv}	0.87 ± 0.05	1.00 ± 0.05
f_c	1.45 ± 0.15	1.40 ± 0.10
f_{cv}	1.80 ± 0.10	1.70 ± 0.10

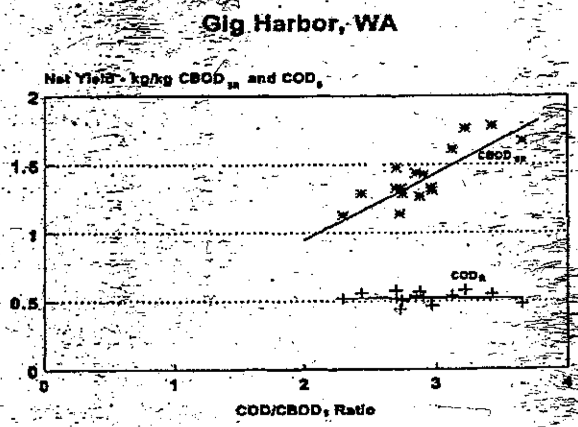

FIG. 1. BOD_5 and COD Sludge Yield—Washington WWTP

Gig Harbor, Washington

Gig Harbor employs an activated sludge process without primary clarifiers and is operating at a 0.5 mgd (21.9 L/s) and a 5–8 day solids retention time (SRT). The net sludge yield on the basis of removal of the contaminants ($CBOD_{5R}$ and COD_R) as a function of the *COD*:$CBOD_5$ ratio is plotted in Fig. 1. The points represent the average monthly values for 15 months of data. The influent *COD*:$CBOD_5$ ratio averaged about 3.0 for this domestic wastewater rather than the expected 1.8–2.2 ratio (Water 1977; Water 1992; Metcalf and Eddy 1991).

The data of Fig. 1 show an abnormal increase in net yield versus *COD*:$CBOD_5$ ratio in view of the reasonable correlation of the net yield on a COD_R basis. There are no recycle flows included in the raw-sewage sample to affect the test. Although the yield could be affected by sludge recycle from the aerobic digesters, the *COD* yield data do not indicate that this occurred. A COD_R net yield of 0.52 lb/lb COD_R would be about 1.0–1.1 lb/lb BOD_{5R} or the normal yield found for this application. The influent *COD*/$CBOD_5$ ratio of 3.0 is another indication that the $CBOD_5$ value does not reflect historical measurements for municipal sewage.

Pierce County, Washington

The 10 mgd (438 L/s) Chambers Creek WWTP is a conventional primary clarifier-activated sludge plant. The activated sludge system routinely operates at 2.0–2.7 day SRT to limit nitrification while producing a good quality secondary effluent: <10 mg/L $CBOD_5$ and <12 mg/L *TSS*. The influent and primary effluent are routinely analyzed for $CBOD_5$, *COD*, and *TSS*. Reduction of several months of data (Albertson 1993) revealed that the influent and primary effluent *COD*/$CBOD_5$ ratio averaged 3.2 and 3.1, respectively.

The primary clarifiers reduce the $CBOD_5$ by 43 mg/L (31%), *COD* by 156 mg/L (35%), and *TSS* by 100 mg/L (63%). The primary clarifier removal of 1.56 mg COD_R/mg TSS_R (f_c) is normal (Albertson and Okey, presentation at Utah WEF meeting; 1992) for domestic wastewater, but the removal of only 0.43 mg $CBOD_{5R}$/mg TSS_R (f_b) is low compared to the expected value of 0.55–0.60 mg BOD_{5R}/mg TSS_R. This could mean that the $CBOD_5$ test is not reporting the total BOD_5 of the *TSS*. Data were available to determine if there were similar effects on the insoluble BOD_5 fraction remaining after clarification.

TABLE 2. USD Measured $CBOD_5$, $SBOD_5$, TSS, and Estimated BOD_5 Values

Period in 1989 (1)	Measured Primary Effluent: Data points (2)	Measured Primary Effluent: $CBOD_5$ (mg/L) (3)	Measured Primary Effluent: $SBOD_5$ (mg/L) (4)	Measured Primary Effluent: TSS (mg/L) (5)	Calculated f_b (mg/mg) (6)	Estimated BOD_5 (mg/L) (7)	Measured $CBOD_5/BOD_5$ ratio (8)
July 7 to July 29	22	179	112	139	0.48	223	0.80
August 1 to August 30	30	183	113	129	0.54	216	0.85
September 4 to September 30	22	161	105	167	0.34	239	0.67
October 1 to October 10	10	168	104	111	0.58	193	0.87
All data	84	174	110	139	0.51	213	0.82
Standard deviation	—	24	15	23	0.14	22	0.10

Note: f_b = 0.80 mg BOD_5/mg TSS (normal value) and estimated BOD_5 = $SBOD_5$ + 0.8 TSS.

Union Sanitary District (USD), Alvarado, California

The 35-mgd USD WWTP is currently operating at 22–25 mgd and an SRT of 1–1.5 days in the aeration basin. Rotating biological contactors (RBCs) and complete mix activated sludge, which follow primary clarification, can operate in series or parallel. The plant can produce a consistently low effluent <20 mg/L $CBOD_5$, <10 mg/L $SCBOD_5$, and <20 mg/L TSS from a mixture of municipal and industrial wastewaters. The average net sludge yield from a process study of the aeration system in 1989 was 1.3 lb $CBOD_{5R}$.

The USD primary effluent had a $CBOD_5/BOD_5$ value of 0.69 in 1988 and 0.90 in the first six months of 1989. Thereafter, the comparative tests were not conducted. Data from the process study are presented in Table 2. The $CBOD_5$ of the $TSS(f_b)$ was determined in the following manner:

$$f_b = (CBOD_5 - SCBOD_5)/TSS \text{ (mg/mg)} \quad (1)$$

The value of f_b for primary effluent TSS was projected to be 0.83 ± 0.05 mg/mg by Albertson and Okey (presentation at Utah WEF meeting, 1992) for domestic wastewater. Periodically, there are BOD_5 inhibitory substances in the USD influent and primary effluent. When this has occurred, BOD_5 and $CBOD_5$ values were similar and the $f_b(BOD_5$ of the $TSS)$ values were even lower than shown in Table 2. Based on these data, an initial premise could be that TCMP formulations reduce the biological oxidation rate of colloidal and suspended solids fractions of the wastewater, like the results exhibited by the Pierce County data.

Santa Fe, New Mexico

The Santa Fe WWTP treats 6 mgd (263 L/s) domestic wastewater in an oxidation ditch preceded by anoxic basins for denitrification using unsettled wastewater. The COD analysis has recently been added to supplement the influent $CBOD_5$ test. The influent COD:$CBOD_5$ ratio for the period April 1991 through January 1992 averaged 2.8 and ranged from 2.26 to 3.20. The average value is unusually high for a plant treating domestic wastewater. As with the Gig Harbor data, there was a high level of data scatter believed to originate with the $CBOD_5$ rather than the COD analysis. The required data were not available for the accurate determination of sludge yield nor were there any BOD_5 data available.

Webster, Massachusetts

The Webster WWTP uses an extended aeration process to treat a 5 mgd (219 L/s) mixture of domestic and industrial wastewater. The industrial fraction is readily biodegradable organics (primarily starch) from a cotton finishing plant. The Webster plant conducts both $CBOD_5$ and BOD_5 tests. Typical daily results of the tests are shown in Fig. 2. The monthly average influent $CBOD_5$:BOD_5 ratio ranged from 0.67 to 0.72 and averaged 0.69 for 6 months of daily data. The nitrified effluent $CBOD_5$/total BOD_5 ($TBOD_5$) averaged 0.54 and 0.62 for the two months of influent data shown in Fig. 2.

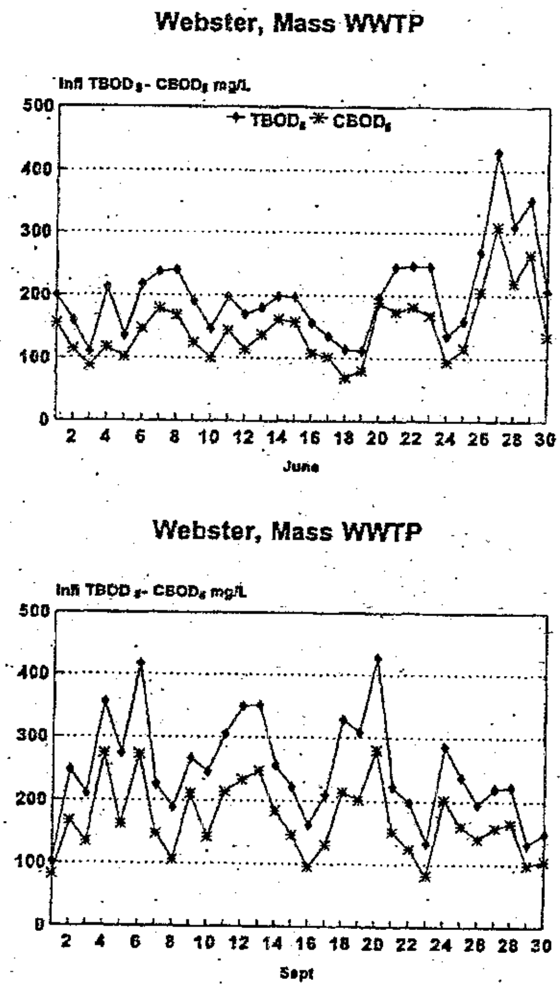

FIG. 2. $CBOD_5$ versus BOD_5 tests—Massachusetts WWTP: (a) June; (b) September

The Webster influent data were also analyzed to determine if the concentration of the BOD_5 in the influent affected the reported ratio of $CBOD_5/BOD_5$ measured. It was found that the $CBOD_5$ was uniformly understating the organic strength

TABLE 3. 23rd Avenue Primary Clarifier Study

Phase—number of samples (1)	$CBOD_5$ Influent (mg/L) (2)	$CBOD_5$ Primary effluent (mg/L) (3)	$CBOD_5$ Removal (%) (4)	TSS Influent (mg/L) (5)	TSS Primary effluent (mg/L) (6)	TSS Removal (%) (7)	Primary effluent COD (mg/L) (8)	$CBOD_{5R}/TSS_R$ (mg/mg) (9)	$COD/CBOD_5$ (mg/mg) (10)
A—62	148	125	15.5	140	53	62.1	361	0.26	2.9
B—61	160	134	16.3	152	53	65.1	397	0.26	3.0
C—61	167	157	6.0	161	62	61.4	399	0:10	2.5
Average	158	139	12.0	151	56	62.9	386	0.20	2.8

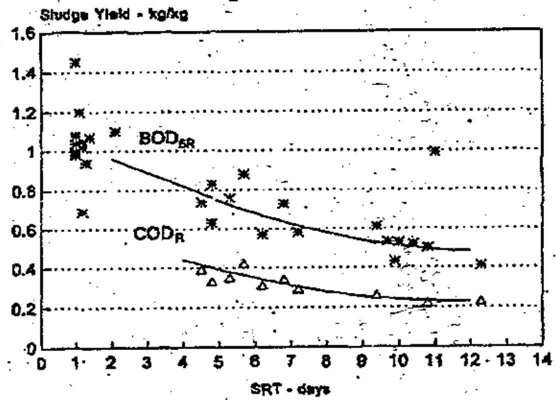

FIG. 3. BOD_5 and COD Sludge Yields—Phoenix 23rd Avenue WWTP

of the wastewater by 30% at all BOD_5 concentrations from less than 100 mg/L up to 450 mg/L.

Salt Lake City, Utah

During a full-scale trickling filter study in 1993, Central Valley WWTP, operating at about 50 mgd (2.2 m^3/s), established that the primary effluent quality was 98 mg/L BOD_5, 77 mg/L $CBOD_5$, 31 mg/L $SBOD_5$, 197 mg/L COD, and 75 mg/L TSS. The respective ratios were: 0.79 $CBOD_5$:BOD_5, 2.6 COD:$CBOD_5$, and 2.0 COD:BOD_5. The f_b of the TSS fraction was in the normal range at 0.89 mg BOD_5/mg TSS [(98 − 31)/75]. However, based on $CBOD_5$, the f_b value was low at 0.61 mg/mg (71 − 31)/75] versus the expected range of 0.83 ± 0.05 mg/mg. The addition of TCMP corresponded to a lower BOD_5 of the TSS fraction (lower f_b) and the high $COD/CBOD_5$ values.

Yuma, Arizona

The 12 mgd (526 L/s) Yuma WWTP, which receives a flow of 7–9 mgd, is a conventional activated sludge design operated at an SRT of less than two days to discourage nitrification. Here, BOD_5 and $CBOD_5$ analyses are conducted on the raw wastewater and final effluent. The average data for 8 months of operation produced a $CBOD_5/BOD_5$ ratio of 0.70 and 0.91 for the influent and final effluent, respectively.

The influent $CBOD_5/BOD_5$ ratios are low and similar to those of Webster, Massachusetts. The effluent $CBOD_5$:BOD_5 was 0.91 or in the range expected for effluent samples. The effluent samples have been chlorinated and primary effluent is used for reseeding the samples for BOD_5 and $CBOD_5$ tests. These tests show that the $CBOD_5$:BOD_5 ratios were lower for raw than for the final effluent samples. The limited impact of TCMP on the carbonaceous fraction of the BOD_5 in biological effluents is consistent with EPA-sponsored studies.

Meadowbrook-Limestone WWTP, New York

Expansion and upgrading of the 7.0 mgd (307 L/s) plant to advanced wastewater treatment (AWT) was required to meet future permit criteria. Due to concern that the $CBOD_5$ tests were not representative of the influent wastewater strength, control tests for COD, BOD_5, and $CBOD_5$ were conducted. The average of 9 samples tested was 264 mg/L COD, 106 mg/L BOD_5, and 73 mg/L $CBOD_5$. The ratios were 0.69 mg $CBOD_5$/mg BOD_5, 2.5 mg COD/mg BOD_5, and 3.6 mg COD/mg $CBOD_5$. The COD test was the only analysis that would provide the proper process design information for this facility.

Phoenix, Arizona

The two Phoenix facilities are monitoring both the $CBOD_5$ and BOD_5 content of their raw wastewater. The $CBOD_5$ is monitored to meet state requirements and the BOD_5 is measured to define the true wastewater strength. The daily data over a 7-month period produced a $CBOD_5/BOD_5$ ratio of 0.85 mg/mg at the 23rd Avenue plant and 0.75 mg/mg at the 91st Avenue plant. Although the ratio is higher at 23rd Avenue, this plant also periodically experiences low levels of toxicity, which impacts nitrification and sometimes causes increased nitrite concentrations. The toxicity occurrences at 23rd Avenue may explain the higher ratio, which was consistent with USD's experiences when there was toxicity.

A clarifier study at the 23rd Avenue WWTP developed additional information in regard to the $CBOD_5$ measurement problems. The results of these studies are summarized in Table 3. The plant operates at 30–32 mgd (1.3–1.4 m^3/s) and, most importantly, there are no in-plant recycle flows back to the influent of the facility. Waste-activated sludge (WAS) and other waste streams are sewered to the 154 mgd (6.75 m^3/s) 91st Avenue WWTP.

The typical primary BOD_{5R}/TSS_R ratio for municipal wastewater is in the range of 0.55 mg/mg, but the $CBOD_{5R}/TSS_R$ value was 0.2 mg/L. For a municipal wastewater with the BOD_5 and TSS approximately the same, a TSS removal of 63% is expected to remove 30–35% of the BOD_5, not 12%. Prior to the use of the $CBOD_5$ test, BOD_{5R} was 30–35% at 60–65% TSS_R.

The 23rd Avenue data add substantial support for the earlier hypothesis that TCMP in some manner blocks the oxidation of the colloidal and suspended solids fraction of the BOD_5.

Like the Gig Harbor data, the reproducibility of net sludge yield based on COD removal was excellent at the Phoenix 23rd Avenue plant. Fig. 3 was developed as the plant was modified to nitrification/denitrification at a higher SRT, and COD was instituted for process control. Primary effluent $CBOD_5$ values were not determined during this period. Based on recent $CBOD_5/BOD_5$ data, $CBOD_5$ yield would be 30–40% higher than that shown in the Fig. 3 BOD_5 plot. The monthly average yield data for BOD_5 (or $CBOD_5$) will usually demonstrate the inability of these procedures to accurately

TABLE 4. Estimated $COD:BOD_5$ Ratios from COD and $CBOD_5$ Data

Plant (1)	Wastewater (2)	Measured $CBOD_5:BOD_5$ (3)	Measured $COD:CBOD_5$ (4)	Estimated/actual $COD:BOD_5$ (5)
Gig Harbor, Wash.	Influent	—	2.9	2.2[a]
Gloucester Co. N.J.	Influent	0.77	—	—
M-L, N.Y.	Influent	0.69	3.6	2.5
Phoenix 23rd Ave, Ariz.	Influent	0.85	—	—
Phoenix 23rd Ave, Ariz.	Primary effluent	—	2.8	2.1[a]
Phoenix 91st Ave, Ariz.	Influent	0.75	—	—
Pierce County, Wash.	Influent	—	3.2	2.4[a]
Pierce County, Wash.	Primary effluent	—	3.1	2.3[a]
Central Valley, Utah	Primary effluent	0.79	2.6	2.0
Santa Fe, N.M.	Influent	—	2.8	2.1[a]
USD, Calif.	Influent	0.80	2.9	2.1
Webster, Mass.	Influent	0.69	—	—
Yuma, Ariz.	Influent	0.70	—	—

[a]Based on an estimated average $CBOD_5/BOD_5$ = 0.75.

TABLE 5. Nitrification versus Suppression of Carbonaceous Oxidation

Component (1)	Domestic wastewater (2)	Nitrification		Oxidation ($CBOD_5$) (5)
		NOD (3)	$CBOD_5$ (4)	
COD (mg/L)	420		420	420
$SCOD$ (mg/L)	140		140	140
BOD_5 (mg/L)	200	50	—	—
$SBOD_5$ (mg/L)	66	50	16	66
TSS BOD_5 (mg/L)	134		134	84
$CBOD_5$ (mg/L)			150	150
TSS (mg/L)	200		200	200
f_b (mg/mg TSS)	0.67		0.67	0.42
f_c (mg/mg TSS)	1.40		1.40	1.40
COD/BOD_5	2.1		2.8	2.8
$SCOD/SBOD_5$	2.1		8.8	2.1

define the organic content of the wastewater, which can be biologically removed or accumulated as excess sludge.

COMMENTS

These cited plant results raised concern regarding the use of $CBOD_5$ tests for raw and primary effluent when designing wastewater treatment plants. The $COD:BOD_5$ ratio of domestic wastewater and primary effluent is reported to be in the range of 1.8 to 2.2:1.0. However, when the $CBOD_5$ procedure was used, the $COD:CBOD_5$ ratio is 2.8 to 3.6:1.0 in the data discussed. The Gloucester, Webster, USD, Phoenix, Meadowbrook-Limestone, and Yuma results indicate an average $CBOD_5:BOD_5$ ratio of about 0.75. If this ratio were applied to the wastewaters for which there are COD and $CBOD_5$ data, the estimated $COD:BOD_5$ ratio would be lower and consistent with historical data, as indicated in Table 4.

The Phoenix 23rd Avenue and USD WWTPs have higher $CBOD_5/BOD_5$ ratios, but both plants are known to have toxicity problems. If toxicity is present in the wastewater, it could explain why these ratios were higher, because toxicity effects of more than one compound are not necessarily additive.

The Gig Harbor, Gloucester County, Phoenix, Pierce County, Salt Lake City, Santa Fe, and USD data had wide variations in the $COD:CBOD_5$ ratio. Based on the respective test procedures and this analysis, it is reasonable to suspect that much of the variations originated from the $CBOD_5$ values. That is, the $CBOD_5$ test was a less reliable measure than the BOD_5 and COD of the organic strength of the wastewater. This is reflected in the net yield graphs of COD, $CBOD_5$, and BOD_5 (Figs. 1 and 3).

Alternatively, is it possible that much of our historical data for BOD_5 is invalid? Are sludge production values of 1.0–1.4 kg/kg $CBOD_{5R}$ fact or artifact? Does this mean that the background literature containing design equations, rate and yield coefficients, and so on, which were all developed from uninhibited BOD_5 data, constituted an unknown and variable amount of NOD? Because $CBOD_5$s were not employed for development of coefficients for our basic design equations, what are the ramifications? Or, is it possible that the TCMP provides a site-specific inhibitory effect that may significantly, but unpredictably, reduce the level of carbonaceous oxidation?

The questions were pertinent because there were literature references that indicate that nitrification occurs in the 5-day BOD_5 testing of influent wastewater and primary effluent. Also, there was limited testing of a primary effluent comparing TCMP formulations and a control suggesting no impact on the BOD_5 of the nonbiological wastewater. However, the extensive field results demonstrate significant differences in the $CBOD_5$ and BOD_5 values. If the cause was nitrification in the BOD_5 test, then the plant data can be examined on that premise.

If nitrification occurs in the BOD_5 test, then the $SBOD_5$ fraction of the wastewater would be proportionally reduced by the $CBOD_5$ procedure. Based on the average value of $CBOD_5:BOD_5$ ratio of 0.75, the two alternatives of nitrification in the BOD_5 test versus the observation of suppression of the BOD_5 of nonsoluble fraction has been developed. A typical fresh domestic wastewater of 200 mg/L BOD_5 and TSS and a soluble fraction equal to 33% of the BOD_5 was used in the analysis. The results are shown in Table 5.

If the problem is nitrification in the test, the influent wastewater would have been only 16 mg/L carbonaceous $SBOD_5$, or the impossible 8.8 mg $SCOD$/mg $SBOD_5$. The BOD_5 of the suspended solids fraction (f_b) would remain unchanged. However, the data reveal that there is a suppression of the f_b values and further, that the 0.42 mg/mg value is consistent with the data. Other supporting evidence is that net yield values of 1.1–1.5 kg excess solids/kg $CBOD_5$ removed are not consistent with our experiences nor supported by our literature. Lastly, $COD:CBOD_5$ ratios of 2.6:3.6 on domestic influents and primary effluents would then indicate the presence of a nonbiodegradable fraction about 40–60% higher than normal.

In the extensive data examined from the facilities listed in Table 4, there is no support for nitrification as a significant factor for the large differences in the $CBOD_5$ and BOD_5 test values. The suppression of the BOD_5 of the suspended solids fraction is the primary cause for the difference.

It is time to reexamine all of our measurement tools. Even the BOD_5 test has many limitations and an equal number of detractors. It is not an acceptable quantitative measurement for advanced wastewater treatment (AWT) designs where about 96–98% of the influent soluble organics as defined by COD are transformed either to biomass or oxidized. A municipal wastewater with a $COD{:}BOD_5$ ratio of 1.8 will require a significantly different design than one with a ratio of 2.6. Yet a BOD_5(or $CBOD_5$) determination does not disclose this fact. This fact has been long known to process engineers and designers of industrial wastewater plants, but currently not understood by many of the designers of municipal plants.

The $CBOD_5$ test has a value, but should be limited to biological effluents as defined by *Standard Methods* (1989). However, it is equally important to recommend that the more reliable COD test be an integral part of our quantification of wastewater characteristics for design and to aid plant operations. As a control parameter, it can be timely, whereas the BOD_5 test records only history.

SUMMARY AND CONCLUSIONS

- The $CBOD_5$ test was developed, approved by *Standard Methods* (1989) for natural waters and biological effluents where the presence of nitrifying organisms will interfere with laboratory measurement of the carbonaceous fraction of the BOD_5 and should be retained for those streams.
- The $CBOD_5$ procedure, although suitable for biological effluents, was not thoroughly evaluated nor recommended by *Standard Methods* for raw wastewater and primary effluents.
- Many wastewater treatment plants are reporting unusually high $COD/CBOD_5$ ratios and high excess sludge yields based on $CBOD_5$ measurements. This indicates that the $CBOD_5$ test is understating the actual wastewater strength by 20–40%. Also, $CBOD_5$ analysis of influent wastewater could result in a violation of the 85% EPA rule, when in reality it didn't occur.
- Serious errors in the design of biological and sludge-handling systems will result as $CBOD_5$ values of raw and settled wastewater much lower than the corresponding BOD_5 values. Thus, $CBOD_5$ should not be used in design equations developed for the BOD_5 analysis.
- The data reveals that the TCMP formulations suppress the level of oxidation (BOD_5) of the nonsoluble fraction. Nitrification in raw and settled BOD_5 samples was not the major cause of low $CBOD_5{:}BOD_5$ ratios in the plant data.
- COD measurements are more useful and reliable than either the BOD_5 or $CBOD_5$ measurements and should be used to quantify the wastewater strength. The value of BOD_5 measurements in conjunction with COD is its determination of the nonbiodegradable fraction and/or toxic conditions.
- Controlled laboratory studies are needed to better understand the field observations and the mechanisms involved.

APPENDIX I. REFERENCES

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APPENDIX II. NOTATION

The following symbols are used in this paper:

BOD_5 = Biochemical Oxygen Demand;
BOD_{5R} = BOD_5 removed or removal;
C = carbonaceous fraction of BOD_5, $CBOD_5$;
COD = chemical oxygen demand;
COD_R = COD removed or removal;
f_b = BOD_5 of TSS = $(BOD_5 - SBOD_5)/TSS$;
f_c = COD of TSS = $(COD - SCOD)/TSS$;
N-Hib = nitrification inhibitor, Salsbury Laboratories;
NOD = nitrification oxygen demand;
$SCBOD_5$ = soluble $CBOD_5$;
SRT = solids retention time;
$TBOD_5$ = total BOD_5;
TOC = total organic carbon;
TSS = total suspended solids;
TSS_R = total suspended solids removed or removal; and
VSS = volatile suspended solids.

SSTS Mentoring Program Questionnaire Preliminary Results

Summer, 2009

Water Resources Center
University of Minnesota
Driven to Discover[SM]

Do you work on septic system designs, installations, or inspections?

543___ YES (Please continue with survey)
55 ___ NO (Thank you for your time, but our survey focuses on design, installation and inspection practitioners. Please return survey in the prepaid envelope.

Instructions:
Please read each question entirely and select the answer that best matches your opinion. Certain questions allow multiple responses, while others are limited to one response—please refer to the prompts at the end of each question if you are unclear about whether or not to mark multiple answers.

1. Background Questions:

1. What endorsement categories do you hold and when did you obtain them? (choose all that apply)

Endorsement Category	1996 or earlier	1997 - 2005	2006 - 2008	Currently Restricted
Installer	**227**	**135**	**37**	**12**
Designer	**166**	**118**	**20**	**18**
Inspector	**86**	**94**	**34**	**15**
Pumper/Maintainer	**39**	**31**	**08**	**06**

2. When did you begin working in the SSTS Industry? (choose one)

1996 or earlier 328
1997-2005 170
2006-Present 39
9 error

3. Why are you in the SSTS Industry? (choose all that apply)

I enjoy being self-employed 291
I take pride in protecting the health of my customers 271 (45.32%)
I like working outdoors 370
I take pride in protecting the health of Minnesota's environment 344 (57.53%)
I don't have any other options 12
It is a family business 124 (20.74%)
Other: ________________ 110 (available upon request)

4. Which septic system BEST protects public health and the environment? (choose one)

A septic tank to an in ground soil treatment with 36″ vertical separation 459 (85.16%)
A septic tank to a mound with 18″ vertical separation 22
A septic tank to a seepage pit with no vertical separation 0
All of these systems protect public health and the environment 20
None of these systems protect public health and the environment 13
25 provided multiple answers

5. What statement best describes human exposure to sewage and septic tank effluent? (choose one)

Sewage and septic tank effluent is always safe to come into contact with humans	0
Sewage and septic tank effluent is usually safe to come into contact with humans	12
Sewage and septic tank effluent can cause infectious disease in humans	396
Sewage and septic tank effluent can cause death in humans	100
	24 provided multiple answers

6. How important is the proper design, installation and inspection of a septic system to protect the health of people near the system? (choose one)

Avg. 1.12

Very important	487
Important	41
Of little importance	3
Not important	0
	2 provided multiple answers

7. How well do you think MN Rules Chapter 7080-7083's design, installation and inspection requirements protect public health and the environment? (choose one)

Avg. 1.37

Very well	356
Adequately	166
Poorly	6
Not well at all	3
	1 provided multiple answers

2. Professional Preparation Questions

8. When did you submit your experience documentation to the Minnesota Pollution Control Agency (MPCA) for the first time? (choose one)

1996 or earlier	249
1997-2005	181
2006-2008	46
I am in the process of completing my first required experience documentation	33
I do not recall ever submitting official experience documentation	17
	5 provided multiple answers

9. Rank, in order of importance, the value of each component of the SSTS Program's professional preparation: (choose one box per line)

	Preparation Component	1 Most Important	2 Somewhat Important	3 Least Important
Avg. 1.39	A. Pre-Certification Course and Exams	**351**	**147**	**29**
Avg. 1.55	B. Required Experience Component	**309**	**151**	**63**
Avg. 1.98	C. Continuing Education	**174**	**194**	**154**

10. To be considered an expert, how important is it for septic system professionals to hold multiple endorsement categories (Installer, Designer, Inspector, Pumper/Maintainer)? (choose one)

Avg. 2.12

Very important	159
Important	208
Of little importance	122
Not important	39

11. How important is it that system designers install systems before they design systems? (choose one)

Avg. 1.75

Very important	260
Important	183
Of little importance	63
Not Important	22

12. How important is it that system inspectors install and design systems before they inspect systems? (choose one)

Avg. 1.77

Very important	258
Important	168
Of little importance	82
Not important	20

13. How well does the current Experience Program differentiate between high and low quality mentors? (choose one)

Avg. 2.57

Very well	25
Adequately	261
Poorly	137
Not well at all	86

14. How important is it for the MPCA to differentiate between high and low quality mentors? (choose one)

Avg. 1.90

Very important	141
Important	319
Of little importance	44
Not important	18

15. How important is it that new septic system professionals have guaranteed access to a qualified mentor? (choose one)

Avg. 1.65

Very important	248
Important	234
Of little importance	30
Not important	16

16. Should someone make sure that all new septic system professionals have access to opportunities to complete their required experience? (choose one)

Yes	346 (66.03%)
No (skip to #18)	113
I don't know (skip to #18)	65

17. If yes, who should make sure that new professionals have access to opportunities to complete their Experience Program? (choose one)

Local Units of Government	113
Minnesota Pollution Control Agency	104
University of Minnesota	43
Professional/Trade organization, such as the Minnesota Onsite Wastewater Association	53
Other ________	15 (available upon request)

3. Local Permitting and Inspection Questions

		1 Strongly Agree	2 Agree	3 Disagree	4 Strongly Disagree
Avg. 1.73	18. I believe that differences in local permitting and inspection programs influence septic system professionals' practices. (choose one)	**203**	**262**	**54**	**4**
Avg. 1.80	19. I believe that tough and thorough local programs result in high quality septic system installations and decreased risks to public health. (choose one)	**192**	**262**	**57**	**14**
Avg. 1.79	20. I believe that there should be a uniform SSTS program across the state of Minnesota (choose one)	**234**	**188**	**79**	**22**

4. Working With Your Official Mentor Questions

For the next questions, please think about your individual encounter with your mentor. If you had more than one, please refer to the mentor that signed off on the greatest number of experience instances. If you have not yet obtained a mentor or do not remember working with a mentor to prepare and submit your experience documentation, please skip to #33.

21. How often was your mentor on the job with you? (choose one)

All of the time	163
Most of the time	102
Some of the time	58
Little of the time	39
None of the time	15
	(219 did not answer)

22. Please choose the options that best describe your mentor's behavior:	1 All of the time	2 Most of the time	3 Some of the time	4 Little of the time	5 None of the time
A. My mentor showed me the correct way to do each specific task. (choose one) Avg. 1.89	175	112	54	24	11
B. My mentor criticized me when I did something wrong. (choose one) Avg. 3.03	82	63	77	61	88
C. My mentor complimented me when I did something correctly. (choose one) Avg. 2.46	92	122	80	44	32
D. My mentor corrected me when I did something wrong. (choose one) Avg. 1.70	224	80	40	15	14
E. My mentor provided me with other resources to help me do a better job (showed me examples or other sources of information). (choose one) Avg. 2.47	103	108	86	40	37
F. My mentor taught me practices that I later found to be incorrect. Avg. 4.37	4	5	45	128	189

	1 Strongly Agree	2 Agree	3 Disagree	4 Strongly Disagree
23. My mentor instilled a high level of confidence that I maintain in my current work. (choose one) Avg. 1.68	172	157	33	10
24. My mentor taught me tasks or concepts that helped me to avoid making mistakes in later work. (choose one) Avg. 1.71	143	191	28	5

25. Overall, how satisfied were you with your mentor? (choose one)

Very satisfied	231
Somewhat satisfied	103
Somewhat unsatisfied	23
Very unsatisfied	9
I didn't have a mentor	9

26. Please rate the difficulty of documenting your Experience Plan and submitting it to the MPCA. (choose one)

Very easy	91
Fairly easy	222
Fairly difficult	45
Very difficult	9

27. How did you obtain your mentor? (choose one)

Someone at work provided me with a mentor	114	30.73%
A local unit of government performed mentoring duties for me	81	21.83%
I found a certified person to provide mentorship for me	113	30.46%
A professional organization helped me find a mentor	4	1.08%
Other: ______________________	53	14.29% (available upon request)

28. Where did you complete your required experience? (choose all that apply)

In my core work area	363
I traveled outside my core work area	33

29. Did you have to pay your mentor or accept a reduced wage while you were obtaining your required experience? (choose one)

Yes	52	
No	315	83.55%
I don't know	10	

30. What about the mentoring program was MOST valuable to your development as a practitioner?

270 responses, available upon request

31. What about the mentoring program was LEAST valuable to your development as a practitioner?

184 responses, available upon request

32. How could the mentoring program be changed to improve the hands-on training experience of new practitioners?

212 responses, see attached document.

5. Other On-the-job Training Questions

33. Have you received on-the-job training from someone BESIDES an official mentor? (choose one)

Yes	239	39.97%
No (skip to Section 6)	359	

34. How often was this person (or people) on the job with you? (choose one)

All of the time	48
Most of the time	75
Some of the time	67
Little of the time	35
None of the time	7

35. Please choose the options that best describe this person's (or peoples') behavior:

		1 All of the time	2 Most of the time	3 Some of the time	4 Little of the time	5 None of the time
Avg. 1.84	A. Those that provided me with on-the-job training showed me the correct way to do each specific task. (choose one)	102	83	32	8	4
Avg. 2.90	B. Those that provided me with on-the-job training criticized me when I did something wrong. (choose one)	56	38	58	36	40
Avg. 2.51	C. Those that provided me with on-the-job training complimented me when I did something correctly. (choose one)	45	74	72	25	11
Avg. 1.72	D. Those that provided me with on-the-job training corrected me when I did something wrong. (choose one)	121	71	27	7	3
Avg. 2.46	E. Those that provided me with on-the-job training provided me with other resources to help me do a better job (showed me examples or other sources of information). (choose one)	60	66	60	26	15
Avg. 4.09	F. Those that provided me with on-the-job training taught me practices that I later found to be incorrect.	8	6	34	94	86

		1 Strongly Agree	2 Agree	3 Disagree	4 Strongly Disagree
Avg. 1.61	36. Those that provided me with on-the-job training instilled a high level of confidence that I maintain in my current work (choose one)	109	110	12	3
Avg. 1.61	37. Those that provided me with on-the-job training taught me tasks or concepts that helped me to avoid making mistakes in subsequent work (choose one)	107	113	13	1

38. Overall, how satisfied were you with your other sources of on-the-job training? (choose one)

Very satisfied	134
Somewhat satisfied	89
Somewhat unsatisfied	6
Very unsatisfied	2

39. If you did not submit official experience documentation, please explain why.
41 responses, available upon request

6. Specific Endorsement Questions

If you hold multiple endorsement categories, please answer all questions that apply.

Please answer the questions in the following sections based on your certification with the MPCA:

Installers or those working towards becoming an installer, please answer questions 40- 45

Designers or those working towards becoming a designer, please answer questions 46 – 51

New System Inspectors or those working towards becoming a new system inspector, please answer questions 52 – 56

Existing System Inspectors or those working towards becoming an existing system inspector please answer questions 57 - 61

Installers, please answer questions 40-45: 411 Responses

40. True or False: A watertight septic tank is not critical to the proper functioning of a septic system. (choose one)

True	27	
False	382	92.94%
I don't know	2	

41. True or False: Preventing compaction in and around the soil treatment area can increase the longevity of a septic system. (choose one)

True	387
False	22
I don't know	1

42. Rank the TWO most important practices that you follow to ensure that septic tank installations are watertight (write 1 next to the most important and 2 next to the second most important).

_____ Check tank for cracks before installation and reject if tank is cracked	248 marked #1	44 marked #2
_____ Apply bedding below tank, building sewer, AND supply pipe	19 marked #1	85 marked #2
_____ Check the plastic limit of soil around the septic tank	1 marked #1	5 marked #2
_____ Use of mastic and/or boots at tank penetrations	53 marked #1	162 marked #2
_____ Pressure or vacuum test each tank after installation	9 marked #1	12 marked #2
_____ Fill tank with water and run a hydrostatic test	9 marked #1	17 marked #2
_____ Other _____	8 marked #1 or #2 (upon request)	
I do not follow any of these practices	3	

43. Select all the practices that you commonly follow to prevent compaction around a soil treatment area. (choose all that apply)

Mark the area with flags and/or string to route construction equipment away from soil treatment area	371
Use tracked excavation equipment instead of wheeled equipment	373
Delay installation if soil meets or exceeds the plastic limit	279
Use a soil penetrometer to classify the soil	17
Other _____	12 (upon request)
I do not follow any of these practices	1

44. How do you know where to set the floats to ensure the correct pump cycle? (choose one)

The manufacturer settings are adequate	9
Calculate the gallons per inch in the pump tank and refer to the designer's recommended dose to set the float distance	390
This is the homeowner's responsibility	0
Other: _____	5

45. Has an inspector ever required you to improve or redo your work? (choose one)

Yes	119	29.53%
No	281	69.73%
I don't remember	3	

Designers, please answer questions 46-51: 319 Responses

46. True or False: The depth to the limiting condition is the most important factor in determining the appropriate type of septic system (trench, mound, or at-grade). (choose one)

True	305
False	13
I don't know	

47. True or False: Landscape features influence the design of a system (choose one)

True	300
False	18
I don't know	1

48. Select the MOST important practice that you follow to determine which type of septic system you will design. (choose one)

Determine the system type based on types of systems installed nearby	2
Conduct one or two soil observations (borings or pits)	98
Conduct three or more soil observations	190
Consult the USDA Soil Survey	0
Other ______________________________	5
I do not follow any of these practices	1
	19 marked multiple answers

49. In what way does the soil texture MOST affect the design of a septic system? (choose one)

The type of system to be designed (trench, mound, or at-grade)	59	
The size of the septic tank	0	
The size of the soil treatment area	247	78.41%
None of the above	1	
	8 marked multiple answers	

50. How much does competition from other designers influence the type of system (trench, mound, or at-grade) that you design? (choose one)

Significantly	16	5%
Somewhat	27	
Not much	63	
Not at all	207	

51. How often has a local permitting agency denied you a permit or required a change in your design because they stated that you chose the incorrect system type (trench, mound, or at-grade)? (choose one)

Avg. 1.35

Never	231	75.74%
Rarely	63	
Sometimes	7	
Frequently	0	
Often	0	
	9 marked multiple answers	

Inspectors- please choose ONE set of questions to answer:

Answer questions 52-56 if you primarily inspect new systems.	154 Responses
Answer questions 57-61 if you primarily inspect existing systems.	161 Responses

52. True or False: The depth to the limiting condition is the most important factor in determining the appropriate type of septic system (trench, mound, or at-grade). (choose one)

True	144	
False	8	5%
I don't know	2	

53. How often have you denied a permit or required a change in design based on an incorrectly chosen system type (trench, mound, or at-grade)? (choose one)

Avg. 2.24

Never	31
Rarely	57
Sometimes	52
Frequently	2
Often	1

54. True or False: Preventing compaction in and around the soil treatment area can increase the lifespan of a septic system. (choose one)

True	149
False	2
I don't know	1

55. Select all practices that you follow when conducting a new system inspection (choose all that apply).

Ensure that soil treatment area and reserve soil treatment area are marked with flags and/or string to divert construction equipment away from soil treatment areas.	107	about 69%
Ensure that soil does not meet or exceed the plastic limit	107	about 69%
Lift inspection pipes to ensure they are secured	85	about 55%
Request delivery records from Installer to ascertain the use of clean sand and rock	39	about 25%
Perform a jar test to ascertain the use of clean sand	76	about 50%
I do not follow any of these practices	5	

56. How often do you require installation contractors to redo their work? (choose one)

Never	9	
Rarely	74	54%
Sometimes	54	
Frequently	1	
Often	0	

Existing system inspectors, please answer questions 57-61.

57. True or False: The depth to the limiting condition is the most important factor in determining the appropriate type of septic system (trench, mound, or at-grade). (choose one)

True	154
False	4
I don't know	2

58. Do you obtain all septic system records available at the local unit of government before conducting an inspection? (choose one)

Never	0
Rarely	1
Sometimes	16
Frequently	34
Always	106

59. True or False: A watertight septic tank is not critical to the proper functioning of a septic system. (choose one)

True	8
False	152
I don't know	

60. Which ONE practice do you most commonly follow to determine the treatment media depth when inspecting for vertical separation? (choose one)

I use a laser to assist in this determination	10
I probe the area to determine this depth	105
I reference existing design records	14
Other ______________________________	14
I do not follow any of these practices	0

61. Because of extenuating circumstances, have you ever passed a system that might have been non-compliant? (choose one)

Yes	19	about 12%
No	130	
I don't know	11	

Thank you for your participation! Please return the completed survey in the business reply envelope. Your response will help us assess and improve the SSTS Program. If you have questions about the survey, please contact:

Nick Haig, Lead Investigator, 612-625-9797
University of Minnesota
1985 Buford Avenue
173 McNeal Hall
St. Paul, MN 55108

_32_MentorChanges	Frequency	Percent
?	3	1.42
A mentor needs to be able to do more than spell ethics and integrity	1	0.47
A person can get out of it what they put into it	1	0.47
A requirement of two or three systems would be sufficient	1	0.47
A separate training program for mentors	1	0.47
A training center would be ideal. That way there would be consistency. LGUs do not like the liability of training and other contractors do not want to help their competition. The contractors willing to mentor are not the ones that should be.	1	0.47
All work together	1	0.47
As a county inspector, I feel working with an individual designer/installer other than county employee would be helpful to get different perspective	1	0.47
Be more valuable to see all sides of the process (U.S. designing and gov't inspector)	1	0.47
Better cooperation between certified persons	1	0.47
Better or longer soils classes	1	0.47
Better soils training. Better preparation of plans	1	0.47
By having hands-on classes new practitioners could take to avoid the mentoring program all together. The cost of the course may not be cheap but could speed up their restirictions and may still be cheaper than the mentor	1	0.47
By leaving my core work area, I experienced different types of systems and areas	1	0.47
Certify or designate mentors	1	0.47
Check list of things that need to be done	1	0.47
Closer monitoring- I've seen many people just signed off without doing any real training	1	0.47
Competetors don't like to mentor	1	0.47
Competition factor results in difficulty in finding mentors	1	0.47
Consistent mentor requirements, practicum exam at the end, state wide availability	1	0.47
Designate good designers only, 5 to 10 designs	1	0.47
Develop a central training center	1	0.47
Do not know	1	0.47
Don't change.	1	0.47
Don't know	3	1.42
Double the amount of mentoring required	1	0.47
Double the number of required experiences and require oral and practical confirmation that the new person knows what they are doing.	1	0.47
Eliminate! Your work is inspected to be correct. If you have a question call the Inspector.	1	0.47

Everybody should work with their LUG	1	0.47
Feedback from third party that is not competing with my business to provide periodic checks on work quality.	1	0.47
Focus on teaching for the betterment of society	1	0.47
Get everyone to do installations, designs and inspecting the same.	1	0.47
Give an incentive to mentors to work with new people	1	0.47
Good mentors willing to help new people	1	0.47
Good question	1	0.47
Hands on has to be a part of it.	1	0.47
Hands on installation for inspectors.	1	0.47
Have U of M study the mentor before he mentors someone	1	0.47
Have a course for mentoring strictly for people to get credit for continuing education and teach things to know for mentoring new people.	1	0.47
Have a test for mentors before they can mentor	1	0.47
Have good mentors available for required mentoring	1	0.47
Have one job for experience be inspected by LUG official to make sure mentor is at least on the job with them	1	0.47
Have only certain SSTS professionals be licensed as mentors. They should be licensed in all categories to be a mentor.	1	0.47
Have practioners have experience with Dave Gustafson, Dan Weaver and/or MPCA	1	0.47
Have retiring SSTS Professionals help individuals get their license. Pay mentors and help with cost of continuing education. Get feedback from mentor for new professional's qualifications.	1	0.47
Have the main testing part hands on	1	0.47
Have the new practitioners go along with LGU inspectors. By doing this they learn how their LGU functions as inspectors and what they expect from designs and installations	1	0.47
Having a hands on installation course	1	0.47
Having all types of systems are designed or installed under mentor program	1	0.47
Having regional employees to help with mentoring, competitors will not mentor nor should they be required to do so	1	0.47
Having someone at the UMN of MPCA actually be there to answer questions	1	0.47
Help finding mentors in rural areas, not enough work to be spread around	1	0.47
Highly qualified mentors	1	0.47
I am not very excited about being a mentor due to the issue of basic training and helping your direct competition in the area. I was fortunate to find a mentor. Our company has done mentoring for a few others that became competitors and then	1	0.47

I believe a mentor should be on the job site at all times until the person is no longer restricted.	1	0.47
I believe the program is there, he must want it	1	0.47
I don't know	2	0.94
I guess I really don't know. I have mentored a person in our company and consider him to be an expert.	1	0.47
I had access to a mentor with no problem but others I can't speak for so maybe ease of access to mentors.	1	0.47
I had more mentor issues than program issues	1	0.47
I have seen a lot of baloney in the field. Mentors have to come from a pool of qualified, trustworthy and honest individuals. Also, its difficult to get a mentor because people are not likely to train their competition.	1	0.47
I learned through trial and error, explaining things better	1	0.47
I think its good!	1	0.47
I think the number of classes to renew licensing is a joke. They should be more flexible on the renewing if they can't offer better/more classes.	1	0.47
I would like to see inspectors have to be involved in the installation of so many systems also before getting their license.	1	0.47
Identify certified SSTS professionals that want to be mentors by creating a sign up list. New practitioners need to prove that they are qualified and diligent in their work.	1	0.47
If mentors could be compensated for their time so they would spend more time with the trainee	1	0.47
If the state mandates a mentorship program it needs to provide mentors. The current system is very difficult because you are asking a competitor to help you.	1	0.47
In school we should experience what is the right way to do things. We don't know if our mentor is doing things right because we have nothing to compare to	1	0.47
In some respects, a mentor is training their own competition	1	0.47
In sure that new practitioners have to help in intall and design of all types of systems, less work with mounds and drainfields	1	0.47
Inform professionals of need, ask for volunteers to mentor someone out of core area, or if ok in core area	1	0.47
Install a system of guidelines for the mentor to use	1	0.47
It is difficult to find a mentor	1	0.47
It works well but I am considering getting more endorsements but with the economic times it is hard to find a mentor that won't look at me as a future competitor	1	0.47
Just assuring reputable, experienced individuals are available	1	0.47
Just have them explain better the best and right way to do the job	1	0.47
LUG could be of more help	1	0.47

LUGs could offer some assistance or offer expertise/time/experience with new business owners/inspectors/installers, etc.	1	0.47
Less paperwork (forms)	1	0.47
Less rule changes	1	0.47
Less systems needed together	1	0.47
Let the LUGs do the inspection and approval	1	0.47
Let them teach the classes	1	0.47
MPCA paperwork forms to fill out onsite	1	0.47
MPCA should monitor progress- demand accountability. Too many mentors sign off for money!	1	0.47
MPCA writes the rules, MPCA needs to provide mentoring: one on one or group	1	0.47
Make designers and inspectors install systems before they get a liscense	1	0.47
Make it easier to find a mentor	1	0.47
Make sure everyone has one- a good one- a willing one	1	0.47
Make sure mentor is a good contractor and not a fly by night business	1	0.47
Make sure mentors have experience, not LUGs with none.	1	0.47
Make sure the mentor is a reliable person with no past issues or violations	1	0.47
Make sure the mentors are involved with all aspects of the project, not just occasionally or for parts of the project.	1	0.47
Make sure there are plenty of opportunities and a variety of different systems	1	0.47
Make the new person do enough work with the mentor to really learn	1	0.47
Make the trainee work with installer before becoming a "professional"	1	0.47
Make them "hands-on"	1	0.47
Make volunteering mentors more accessable via LUS, MPCA, and UMN	1	0.47
Making sure mentors are credible and are showing proper ways of installing and designing	1	0.47
Making sure the practitioner has the experience to do every standard system (more than once), if possibly some hands on with non-standard	1	0.47
Making sure they are doing different systems, i.e. mound, at-grade, chambers, instead of just one type.	1	0.47
Maybe an aprentice school where you could be taught the correct way, similar to other trades where teaching is standardized.	1	0.47

Maybe being able to work with different mentors at times. When the more complex systems are being installed a new practitioner could learn as much as possible (agreement between mentors)	1	0.47
Maybe current practitioner should get continuing ed credits for mentoring or get paid, or what is the benefit to teach your competition on how you do your work. Why should any of us travel and teach if we don't get paid for it?!	1	0.47
Maybe going to two or three different mentors for more training, seeing different ways each company does the training experience	1	0.47
Maybe having multiple mentors would help. The more people one can learn from the better. If one bad mentor spreads his/her ways then more and more practitioners will turn out bad.	1	0.47
Meeting with mentor to upgrade	1	0.47
Mentor must be able to provide info and communicate it effectively	1	0.47
Mentor should be paid for time	1	0.47
Mentor training: what is expected from the mentor, goal of mentor, mentor own personal experience	1	0.47
Mentoring went good. Keep up the requirements	1	0.47
Mentoring/pay increases	1	0.47
Mentors present more often, requiring LUG inspections during construction and pictures	1	0.47
Mentors should be qualified: i.e work in the field, have at least five years experience, not be LUG employees	1	0.47
Minimum standards for mentor	1	0.47
More county inspection with new practitioners	1	0.47
More experience	1	0.47
More group visits to sites with different systems and materials used	1	0.47
More hands on experience with UMN	1	0.47
More hands on training classes	1	0.47
More mentoring experience	1	0.47
More mentors	1	0.47
More mentors for inspector certification	1	0.47
More oversight by PCA or specific training for LGO inspectors	1	0.47
More people to agree in mentoring	1	0.47
More soils training. Should require inspectors to also do a number of installations as a part of their training.	1	0.47
More time on the job	1	0.47
Most people might not ask a question because they feel that they should know the answer. If there was a web based Q/A system that you could search for the answer would be great. Like when you google a search topic.	1	0.47

Move site programs by MPCA personnel in place of regular site work	1	0.47
Multiple mentors	2	0.94
Must be more involved.	1	0.47
My county seems very good	1	0.47
My mentoring was fine, but I have seen other guys that never had a mentor- they just paid the mentor to sign off. Then they go and give a bad name to the rest of us.	1	0.47
N/A	1	0.47
NA	2	0.94
Need to identify mentors who are quality and willing to train, could provide organized opportunities to get experienec	1	0.47
Needs to be shorter	1	0.47
New persons should ride with local unit of government for a day or two to see what is going on.	1	0.47
New practitioners need to work with a licensed professional prior to being licensed	1	0.47
No idea	1	0.47
No one wants more competition in their area so it is hard to get a mentor. I am not sure.	1	0.47
Non	1	0.47
None	3	1.42
Not expect field professionals to train their competition	1	0.47
Not just anyone should be allowed to mentor. There needs to be a state reviewed mentor list. There are too many "just enough to meet the minimum standard" guys out there.	1	0.47
Not sure	3	1.42
Nothing	2	0.94
Offer it free	1	0.47
Ok	2	0.94
On the job training for the first several systems	1	0.47
On the job training is very important	1	0.47
Organized, run, and supervised by MPCA, UMN, or another party	1	0.47
Possibly through the education process	1	0.47
Professional Mentor	1	0.47
Provide a list of available mentors	1	0.47
Provide mentors	1	0.47
Provide the experience	1	0.47
Provises by state or UMN	1	0.47
Reduce the required number of instances- you either get it or you don't	1	0.47
Require 3 of each type of system installed (trench, at-grade, pressure bed, mound)	1	0.47

Require all areas of Inspector to install system as part of training required	1	0.47
Require at least one witness to an installation.	1	0.47
Require experience in several levels- basic- advanced holding tank-type 5	1	0.47
Require fewer inspections but make sure more types of systems are included, ideally it should be a part of normal training, field trips to partially installed systems	1	0.47
Require more experience in all categories	1	0.47
Require more than one mentor	1	0.47
Require more than one person to be your mentor to give you different views	1	0.47
Require that individuals perform all aspects of the job	1	0.47
Required amount of installs should vary (inground-above ground) to cover all types of systems	1	0.47
Requirement of having mentors who have worked in the trade for 1-3 years before being able to install systems	1	0.47
SSTS professionals are not willing to mentor a new competitor. A mentor must be someone who is not in competition and is qualified to mentor.	1	0.47
Scoot wasn't first choice, but we quickly changed our minds after meeting our first mentor	1	0.47
Send me some money	1	0.47
Skill sets for common and specific installations	1	0.47
Some mentors are way better than others	1	0.47
Some organized method of training for mentors- a "checklist"	1	0.47
Somehow make sure the mentor is following the rules	1	0.47
Spend a few days with LUGS	1	0.47
State should audit evaluations and designs to insure everyone is doing a complete job and design	1	0.47
Take the class out on the job site	1	0.47
Take time to train, not just read and look at drawings	1	0.47
The Mentoring Program should not be required. Additional training by the UMN or local trade schools.	1	0.47
The existing plan is a good experience	1	0.47
The experience requirement does not get a high enough standard. We are not going to raise the standards in the industry by making it easier for new practitioners to get in.	1	0.47
The mentor could have additional training from SSTS Program	1	0.47
The mentor has to go by the book.	1	0.47
There are good and bad mentors	1	0.47
Time tracking methods should be easier	1	0.47
To better police the amount of supervision that mentors give mentees	1	0.47
To make sure that mentors are teaching correct practices	1	0.47

To observe the installation of all different types of systems	1	0.47
Too many individuals are simply signing off on contractors, inspectors shouldn't be allowed to mentor	1	0.47
Valuable quality mentors = quality ISTS professionals	1	0.47
Who would mentor the competition? Why would you?	1	0.47
Work for someone longer before being allowed to apply!	1	0.47
Work with multiple installers and designers and inspectors	1	0.47
Work with two or more mentors	1	0.47
You could control who can mentor. Have a list of interested and qualified people.	1	0.47

Mentoring Work Group

2009 Recommendations to the SSTS Advisory Committee

Investigation History

- Comparison to other trades
- Focus Groups
- Survey Instrument

Positive steps, inherent difficulties

- Changes made for latest MN Rules 7083 were positive
- Changes made to one area of concern have potential to counteract or worsen another area of concern

Simple changes . . .

1. Even the playing field
2. Explore incentives for Mentors, beginning with written guidance for both Mentors and Apprentices

Even the playing field . . .

- Proposed change to 7083.1050 subp 5 Item C:

  An applicant for certification as a basic inspector must have co-completed with a mentor a minimum of 15 inspections of Type I, II, or III systems, as defined under parts 7080.2200 and 7080.2300 with a flow of 2,500 gallons per day or less, <u>with a minimum of one aboveground system inspection, and a minimum of one belowground system inspection. An applicant must observe five soil evaluations, system designs and management plans being developed. An applicant must also observe five system installations, and five service or operational instances, with mentorship not required.</u> No additional experience is required to qualify for the advanced inspector certification.

Explore incentives for Mentors

- Written guidance for both Mentors and Apprentices
  - Define purpose and context of Experience Program
  - Identify what is expected of an Apprentice
    - Define actual value of gaining experience
    - Identify steps in acquiring a Mentor
  - How to provide sound Mentorship
    - Checklist of critical activities where presence is required
    - Limiting liability as a business that provides Mentorship
  - Define “observation”
    - Encourage observation of a variety of SSTS practitioners.

On-Site Wastewater Treatment

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SOIL ACCEPTANCE OF ONSITE WASTEWATER AS AFFECTED BY SOIL MORPHOLOGY AND WASTEWATER QUALITY

E. Jerry Tyler, James C. Converse*

ABSTRACT

Maximum possible soil acceptance of on-site septic tank effluent is less than the saturated hydraulic conductivity or infiltration rate of the natural soil. Reduced wastewater infiltration rates are caused by alteration of soil porosity or pore size distribution from construction activities, soil swelling and dispersion from added wastewater, and the plugging of soil pores by organisms and their metabolic byproducts. Soil without free drainage or with high groundwater has reduced hydraulic gradient and reduced infiltration but is not considered in this report. Reducing organic materials with wastewater pretreatment systems reduces soil pore plugging and has the potential for higher long-term infiltration or loading rates. Loading rates of pretreated wastewater in sands can be increased more than in clayey soil. Wastewater loading rates are suggested considering wastewater quality and soil factors. Rates for highly pretreated wastewaters might be 2 to 16 times greater than rates recommended for septic tank effluent. Higher loading rates, however, reduce the wastewater retention time and therefore wastewater treatment in soil. In the event a pretreatment system fails to deliver highly pretreated wastewaters to the soil, it is likely that a rapid hydraulic failure of the soil systems will occur.

Keywords: Soil acceptance, septic tank effluent, pretreated effluents

INTRODUCTION

Soil wastewater infiltration systems receiving septic tank effluent commonly form a layer of material at the soil infiltrative surface with pores finer than the underlying soil. This layer may be partly due to alteration of the soil by construction or materials used in construction and by soil swelling, but is primarily the result of accumulation of biological substances. This fine-pored layer, often referred to as *crusting* or *clogging*, resists wastewater infiltration. The net flux of wastewater through the clogged soil system is much lower than for soil without clogging.

Careful construction procedures with good materials, along with methods to highly pretreat wastewater prior to soil infiltration, can reduce or eliminate clogging. Higher wastewater loading rates can be applied to soil when the potential for clogging is eliminated.

Although on-site wastewater treatment methods can achieve drinking or surface water standards without soil infiltration, there is reluctance to discharge these effluents to surface waters or to recycle the treated water for reuse on-site. This reluctance may result from a belief that treatment will not be adequate or that intermittent failures will occur. Therefore, highly pretreated wastewaters are added to land through soil infiltration and the soil remains the buffer to the environment and insurance against the spread of disease. Wastewater infiltration systems sized to receive highly pretreated effluent have a greater risk of failure due to rapid development of a

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severe clogging mat if the pretreatment unit fails and delivers low-quality wastewater to the soil. Also, high loading rates lead to reduced wastewater retention time in soil, reducing treatment of wastewater pollutants and allowing pollutants, such as coliforms, to move outside the treatment boundaries of the system.

This paper discusses the implications of soil clogging, the potential for increased loading rates using highly pretreated wastewaters, the need for careful construction, and the consequences should wastewaters of higher than design pollutant concentration be added to the soil.

WASTEWATER FLOW IN SOIL

Water moves in soil from a point of higher potential energy to a point of lower potential energy. In saturated soil, the gravity potential is the significant component of energy driving the water. Water moves toward the center of the earth in response to the gravity potential. During unsaturated flow, as around many clogged wastewater infiltration systems, both gravity and matric or capillary forces define potential energy differences in the soil. Matric potential energy differences can move water in all directions depending on the moisture gradient. Usually, matric forces move water from wetter to drier soil.

The constant between the flow rate, Q, and the potential energy gradient is the hydraulic conductivity or K as defined by Darcy's Law,

$$Q=KA\frac{d\psi}{dZ}$$

where Q is flow rate, K is hydraulic conductivity, A is cross-sectional flow area and $d\psi/dZ$ is hydraulic gradient. The hydraulic conductivity is a constant for a given soil and moisture status. When the soil is saturated and all pores are water filled, K is higher than for the same soil unsaturated. The relationship of the hydraulic conductivity and soil moisture potential for a sandy soil and a clayey soil is shown in Fig. 1. Unsaturated soils have fewer water-filled pores to conduct water and therefore a lower K; the drier the soil, the lower the K. Each soil has a unique saturated and unsaturated hydraulic conductivity for each moisture potential. When defining K values for soil, the moisture conditions must be defined.

As wastewater infiltrates the soil, a thin layer of material may develop that has pores finer than the underlying soil. This layer restricts wastewater infiltration and induces unsaturated soil conditions. The more intense the clogging the lower the pressure potential and hydraulic conductivity of the soil (Fig. 1). Wastewater infiltration rates depend on both the clogging layer and the soil. Flow through a clogging layer in a given soil depends on the height of ponding in the aggregate or chamber above the clogging layer, the thickness of the clogging layer, the hydraulic conductivity of the clogging layer, and the moisture pressure in the soil beneath the clogging layer (Bouma, 1975). Assuming steady infiltration, the flux through the clogging (q_c) is equal to the flux in the soil (q_s). Therefore:

$$q_s=q_c=K_{s(\psi m)}=K_c\left(\frac{H_o+\psi_m+Z_c}{Z_c}\right)$$

where $K_{s(\psi m)}$ is the hydraulic conductivity of the soil at the unsaturated moisture potential of the soil beneath the clogging mat, K_c is the hydraulic conductivity of the clogging layer, H_o is the wastewater ponding height in the aggregate or chamber, ψ_m is the matric potential of the soil next

to the clogging, and Z_c is the thickness of the clogging layer. Omitting some of the equalities gives

$$q_s=K_c\left(\frac{H_o+\psi_m+Z_c}{Z_c}\right)$$

Decreasing Z_c or increasing K_c, or both, increases the flux of wastewater or the wastewater loading rate that can be applied to the soil. Therefore, assuming free drainage of the surrounding soil, factors reducing clogging in the soil allow an increase in the loading rate. Lack of a clogging layer allows wastewater application rates equal to the saturated hydraulic conductivity of the soil, assuming the soil is free draining. This discussion will not consider cases of shallow groundwater or shallow restricting horizons that prevent free drainage.

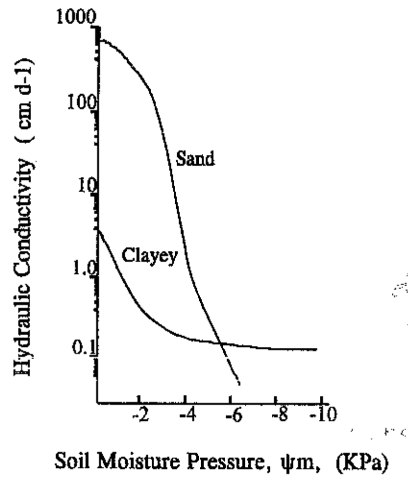

Figure 1. Hydraulic Conductivity vs. Soil Moisture Pressure for a Sandy and Clayey Soil (adapted from Bouma, 1975).

The unclogged infiltration rate or saturated hydraulic conductivity, $K_{s(\psi m=0)}$ of sandy soil, as seen at ψ_m = zero in Fig. 1, is much higher than the unclogged infiltration rate or saturated hydraulic conductivity of clayey soil. However, the clogged infiltration rates or hydraulic conductivities near ψ_m= -5 kPa are very similar for the two soils. The difference between the saturated flow rate and the clogged soil flow rate is much greater in sandy than clayey soil; therefore, the potential increase in loading rate in sandy soil using pretreated wastewater is greater than in clayey soil when compared to applying septic tank effluent.

CLOGGING

A clogging layer, or zone of lower porosity than the underlying soil, may develop at the infiltrative surface from smearing and compaction of soil by machines, the impact of falling aggregate, dust from dirty aggregate, swelling of soil minerals, suspended solids from wastewater, or biomass from organisms living on wastewater constituents. Products of bacterial growth in a carefully installed wastewater disposal system are probably the primary cause of soil clogging. Entrapment of gases may contribute to reduced flow around systems.

Soil smearing at an infiltration surface results from machine shear forces in moist or wet fine textured soil. Schoenemann (1980) showed that careful excavation of soil from over an infiltration surface using a tractor mounted backhoe resulted in infiltration rates similar to surfaces prepared carefully by hand. In that study, the use of machinery to prepare infiltration surfaces was determined to be an acceptable procedure.

Compaction forces, primarily from the weight of the machinery, results in decreased porosity if applied when soil moisture is at an intermediate level. Reduced infiltration resulted from driving a tractor on a soil infiltration surface in silt loam and clayey soils (Schoenemann, 1980). Removal of the top 10 cm of compacted soil recovered the initial infiltration rate in some cases.

In a study of falling aggregate and the dust often found attached to the aggregate, infiltration rates were significantly reduced in sandy and silt loam soils when all factors of falling aggregate, dust, and shadowing of gravel on the soil were combined (Amerson et al., 1991). In that study it appeared that the dust from aggregate used in the preparation of infiltration surfaces was a major factor in changes in infiltration. Salts, such as those from water softener backwash, are unlikely to reduce infiltration rates in clogged wastewater infiltration systems but reduced infiltration is possible in unclogged soil (Corey et al., 1978).

Organic materials, measured as biological oxygen demand (BOD) and suspended solids (SS) in wastewater, is substrate for microorganisms. The more organic substrate provided by the wastewater, the more cells and associated fibers and slimes are produced. Cells of microorganisms have been shown to physically fill the pores in the soil reducing the porosity and hydraulic conductivity (Vandevivere and Baveye, 1992). The processes of biological soil clogging formation including the natural environmental conditions and those induced by the addition of wastewater have been reviewed by Otis (1985) and Siegrist (1987b).

Although formation of clogging from construction practices and material, or swelling of soil clays may reduce the initial infiltration, the reduction is not as great as that induced by biological clogging. However, if biological clogging is eliminated, as with highly pretreated effluent, and wastewater loading rates are increased, then the importance of these factors increases. At high loading rates more attention needs to be paid to construction practices and material and the addition of hydrolyzable cation loading from water softener backwash.

LOADING RATE

As a volume of wastewater is added over time to soil, infiltration rates decrease to a percentage of the initial rates and remain at that level for an extended period. The relationship of wastewater application and infiltration rate is shown in Fig. 2. Line A represents wastewater with very high BOD and SS. As clogging initiates, infiltration rates decrease, Phase II, and continue to decrease to a very small percentage of the initial rate, Phase III, and then finally decrease to failure, Phase IV (Otis, 1985). These stages of clogging development are related to infiltration rates in Fig. 2.

Line B depicts these phases of clogging development for domestic septic tank effluent. Wastewater may continue to infiltrate for long periods of time at low rates in Phase III and is often referred to as the *long-term loading rate*. The higher the rate of application of organic matter, the faster the clogging mat develops. High organic matter application rates could occur from additions of a low volume of wastewater with high amounts of organic matter or a high volume of wastewater with lower amounts of organic matter.

The combination of wastewater quality, initial soil infiltration rate, actual loading rate, soil infiltration rate measured periodically, and final infiltration rate are seldom all reported in one study. Therefore, it is very difficult to determine the relationships among all soil conditions, wastewater characteristics, and infiltration rates. In a review, Tyler and Converse (1989) discussed the influence wastewater quality has on long-term infiltration rates. They concluded that very highly pretreated wastewater effluents could be applied at higher loading rates than septic tank effluent and possibly at rates equal to the soil saturated hydraulic conductivity. However, it was impossible to predict effluent loading rates for intermediate strengths of pretreated wastewaters. Loading could be as high as Phase I infiltration for clean wastewaters but for all other wastewaters Phase III infiltration rates would be needed.

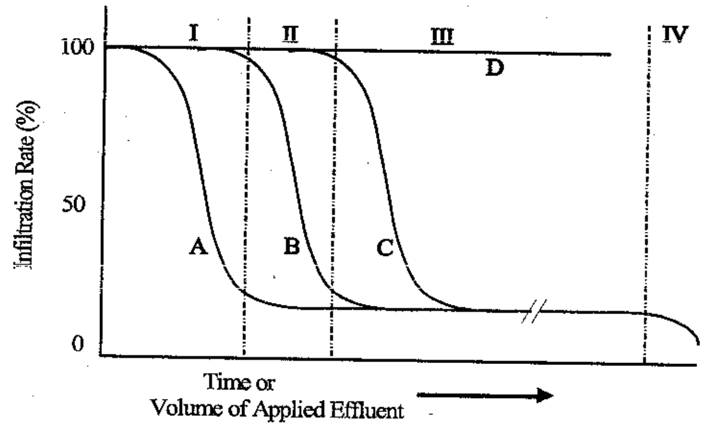

Figure 2. Infiltration vs. Time for Restaurant Effluent (A), Graywater (C), and Tap Water (D). Roman numerals refer to System B phases. (adapted from Siegrist, 1987).

Siegrist (1987a) found that septic tank effluent and graywater, as depicted by Curves B and C in Fig. 2, caused reduced infiltration rates as a clogging layer developed. Although the time of initiation of Phase II clogging was different for the wastewater types, the decrease in infiltration rates was similar. When based on BOD and SS loading instead of wastewater volume loading, the curves are more similar, suggesting that changes in infiltration are also related to cumulative BOD and SS loading and not just hydraulic loading. Results agree with findings of Laak (1976).

Long-term infiltration rates for septic tank effluent are usually in the range of the loading rates prescribed by administrative rules and codes. For example, for sandy soil in central Wisconsin infiltration rates of about 1.7 cm d^{-1} have been measured in trenches ponded with wastewater (Tyler et al., 1991b). This value is similar to the loading rate of 2.5 cm d^{-1} used in administrative code. In silt loam soil, infiltration rates of ponded systems were about 2.5 cm d^{-1} (Hargett et al. 1982). In the southern United States, higher loading rates are reported, probably because of the warmer temperatures.

Recently, wastewater loading rates have been based on soil morphology descriptions. Table 1, adapted from Tyler et al. (1991a), provides a procedure for estimating septic tank effluent wastewater loading rates. Question A identifies those soils offering little treatment and which therefore would not be used for the infiltration of septic tank effluent as indicated by the 0.0 cm d^{-1} loading rate. Questions B through F identify those soils that have very slow vertical conductivity and cannot accept precipitation and therefore additional water cannot be added. These soils frequently are seasonally saturated with natural waters and have morphological features associated with wetness.

Questions G through N identify those soil horizons that will accept the natural precipitation and have additional capacity to accept wastewater. Soil horizons within categories G through I can accept low loading rates. During wet periods these soils are naturally very wet. With a clogging mat, as might develop with the application of septic tank effluent, infiltration is reduced but by a relatively small amount compared with the saturated hydraulic conductivity. This would be similar to changes in K as the moisture pressure decreased from 0 to about -5 kPa represented by the clayey soil line in Fig. 1. For a clogging mat in a sandy soil and other soils of categories K through N in Table 1, inducing a soil moisture pressure of -5 kPa can reduce hydraulic conductivity or infiltration rate a great amount from the initial high saturated values. Therefore, there is some hydraulic advantage to reducing the clogging in soils of categories G through I. The potential for increased loading rate in soils of categories L and N is much greater than for categories G through I. Those soils in categories J, K and M would have intermediate increased loading rates.

Wastewater effluent from treatment units that result in reduced organic materials or pure water, as used as a control in research, do not have reduced infiltration rates. For example, in the study of Siegrist (1987a) tap water did not reduce the initial infiltration rate after 6 yr of application. This is similar to Line D in Fig. 2. Sand filter and aeration unit effluent may have similar results since such units produce effluents of very low organic matter. Maintenance of high infiltration rates for extended periods of time suggests the lack of clogging and higher loading rates.

Based on wastewater pollutant loadings, Siegrist (1987b) proposed adjusting wastewater loading volume rates to soil depending on the concentration of BOD and SS. Using septic tank effluent and a soil with an estimated loading rate of 1.0 cm d^{-1}, he proposed factors of 0.4 for restaurant septic tank effluent, 4.5 for aeration effluent, and 7.5 for sand filter effluent. Line A in Fig. 2 represents the restaurant system, Line B the septic tank system, Line C a graywater system, and Line D clear water or highly pretreated wastewaters. For a soil with a design infiltration rate for septic tank effluent other than 1.0 cm d^{-1}, the proportional amount would be used.

Using only the factor of 7.5 proposed by Siegrist (1987b), loading rates for sand filter effluent with BOD and SS of less than 10 mg L^{-1} each are shown in Table 1. He cautioned that factors for establishing loading rates for sand filter effluent should not be used if the determined loading rate would approach the saturated hydraulic conductivity of the soil. Soils whose loading rate would approach saturated hydraulic conductivity with septic tank effluent would be those in categories G through I in Table 1. Siegrist (1987b) also suggested that the loading rates be only 2 to 3% of the saturated hydraulic conductivity of the soil. Using this criterion on the saturated hydraulic conductivity estimated from USEPA (1991), loading rate estimates would be too high for some soil categories. It should be noted that saturated hydraulic conductivity estimates are intended to represent a possible conductivity. Soil hydraulic conductivities are highly variable.

Table 1. Loading rate from soil morphological descriptions for septic tank effluent (Tyler et al., 1991a), sand filter effluent based on Siegrist (1987b) and this paper, and estimated maximum saturated hydraulic conductivity (K) from USEPA (1991). Values have not been tested and should be confirmed before use. *Instructions*: Read questions in sequence beginning with A. The maximum loading rate in cm d^{-1} is the value corresponding to the first yes response to the questions.

	Question	Loading Rate[a]			
		Septic	Sand Filter		
		Tyler et al. (1991a)	Siegrist (1987b)	This work	Sat. K USEPA (1991)
		------ cm d^{-1} ------			
A	Is the horizon gravelly coarse sand or coarser?	0	0	0	>1000
B	Is the structure of the horizon moderate or strong platy?	0	0	0	<5
C	Is the texture of the horizon sandy clay loam, clay loam, silty clay loam or finer and structure weak platy?	0	0	0	<5
D	Is the moist consistence stronger than firm or any cemented class?	0	0	0	<5
E	Is the texture sandy clay, clay or silty clay of high clay content and structure massive or weak?	0	0	0	<5
F	Is the texture sandy clay loam, clay loam, silty clay loam or silt loam and structure massive?	0	0	0	<5
G	Is the texture of the horizon loam or sandy loam and the soil structure massive?	0.8	6	2	5
H	Is texture sandy clay, clay or silty clay of low clay content and structure moderate or strong?	0.8	6	2	5
I	Is texture sandy clay loam, clay loam or silty clay loam and structure weak?	0.8	6	2	5
J	Is texture sandy clay loam, clay loam or silty clay loam and structure moderate or strong?	1.7	13	6	50
K	Is texture sandy loam, loam, or silt loam and structure weak?	1.7	13	6	50
L	Is texture sandy loam, loam or silt loam and structure moderate or strong?	2.5	19	20	50
M	Is texture fine sand, very fine sand, loamy fine sand, or loamy very fine sand?	1.7	13	6	100
N	Is texture coarse sand, loamy sand or sand?	3.3	25	53	1000

[a]Does not account for soil with appreciable amounts of swelling clays.

It might be better to establish the ideal moisture content of the soil surrounding an operating wastewater infiltration system and then estimate the unsaturated hydraulic conductivity and therefore the loading rate. This would provide assurance of aeration. Unfortunately, the ideal moisture content would be as low as possible increasing retention time and treatment. Possibly all systems should be designed to operate at a soil matric pressure -2 kPa at 1 cm from the infiltration surface. The *K*, and therefore the loading rate, might be estimated from curves in Fig. 1. Maintaining unsaturated soil enhances aeration and increases retention time. Since soil hydraulic characteristics are so variable, however, it is very difficult to establish a loading rate based on this.

Using the logic of -2 kPa of soil matric pressure, the loading rate for soil in category N would be 200 cm d^{-1}, estimated from Fig. 1. This is very high and much greater than suggested by Siegrist (1987b). A rate between these values is suggested in Table 1 (column 3). Rates using the factor of Siegrist may be too high for soils in categories G through I which act more like clay in Fig. 1. Using -2 kPa or 3% of the saturated hydraulic conductivity would result in very low loading rates, lower than experience would suggest is necessary even for application of septic tank effluent. Some modest increase in loading rate should be possible and is suggested in Table 1. A factor of 2 was used for categories G through I, 4 for categories J, K, and M; 8 for category L; and 16 for category N (Table 1, column 3).

The third column of values in Table 1 is a possible set of loading rates to consider for highly pretreated wastewaters. These values consider the logic and suggestions of Siegrist (1987b) based on wastewater and soil characteristics procedures of Tyler et al (1991). The greatest reduction in infiltration area for using highly pretreated effluent is for the coarser soils and the least reduction in area is for the more slowly permeable soil. However, the reductions are substantial in all cases.

The analysis of these loading rates assumes that the soil is uniform to considerable depth and that shallow groundwater or flow-restricting horizons are not present. Should there be any flow restrictions within several meters of the infiltration surface, a linear loading rate should be considered. Linear loading rates have been discussed in Tyler and Converse (1984) and are incorporated in design for mounds and at-grades.

The proposed loading rates of Siegrist (1987b) and this paper have not all been tested. Field verification needs to be done before using these values. Siegrist (1987b) stated that even considering the potential for size reductions, caution should be used since wastewater and soils are highly variable. He suggested using conservative design and including a replacement area.

TREATMENT CONSIDERATIONS

The primary reason for discharging pretreated wastewaters to soil is for treatment of wastewater pollutants. Increasing loading rates when using wastewaters that are not likely to cause clogging will decrease wastewater retention times in the soil and could reduce treatment efficiencies. Because of the pretreatment, not only are constituents resulting in clogging reduced, but many of the environmental and health pollutants are reduced. Therefore, the soil is required to do less treatment than if untreated septic tank effluent were applied to the soil. Treatment needs should be assessed for each type of wastewater and a balance attained between the treatment capabilities of the soil and the goals of treatment.

CONSEQUENCES OF PRETREATMENT FAILURE

Using design loading rates higher than domestic septic tank effluent following pretreatment units is logical. Maintaining the wastewater infiltrative surface in the soil is dependent on never exceeding the design hydraulic or BOD and SS loading rate. Design and maintenance procedures must assure that only the highly pretreated wastewaters reach the soil. Although rejuvenation of clogged and failed infiltration systems has been noted (Converse and Tyler, 1994), this has been accomplished with pretreated wastewater loaded at rates of septic tank effluent. Rejuvenation of a soil infiltration surface following clogging due to severe overloading may be difficult.

CONCLUSIONS

Reducing organic materials with wastewater pretreatment systems reduces soil pore plugging and has the potential for higher long-term infiltration or loading rates. Loading rates of pretreated wastewater in sands can be increased more than in clayey soil. Rates for highly pretreated wastewaters might be 2 to 16 times greater than rates recommended for septic tank effluent. The higher the loading rate the more attention needs to be paid to construction practices and materials, and the addition of hydrolyzable cations. Higher loading rates, however, reduce the wastewater retention time and therefore wastewater treatment in soil. In the event a pretreatment system fails to deliver highly pretreated wastewaters to the soil, it is likely that a rapid hydraulic failure of the soil system will occur.

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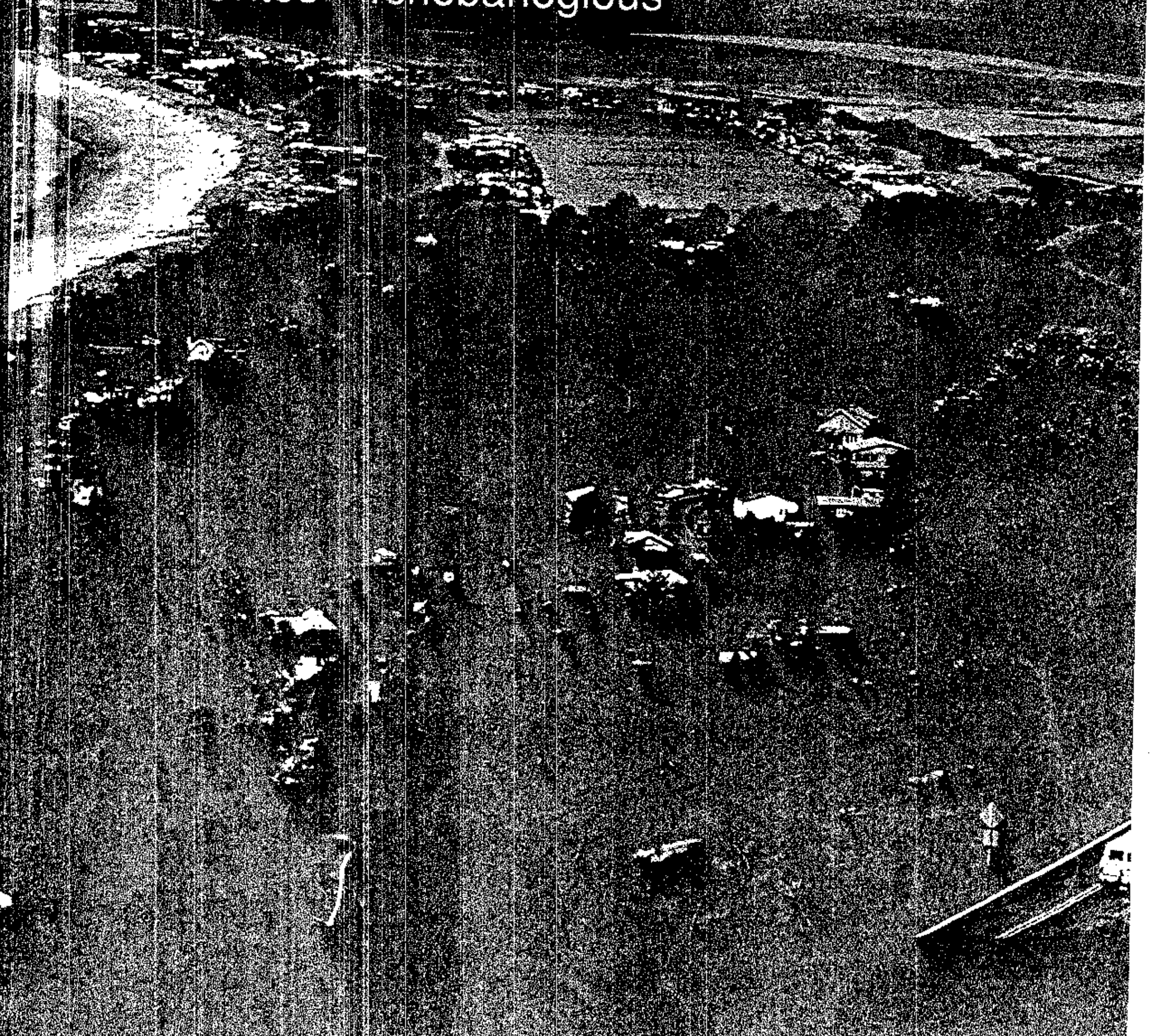

wn in Table 4-14, constituents. Rec- st be emphasized *a guide*. The con- developed from the waste amounts e values given in Table 4-14. It is -12 correspond quite closely to the r.

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astewater resulting from water use, rage system, are especially impor- ter. Typical data on the incremental in municipal wastewater resulting ncreases in the mineral content of ddition of highly mineralized water

tic water use*

crement range, mg/L†	
ptic tank fluent	In municipal wastewater
0–200	50–100
2–20	0–10
0–100	20–50‡
0–60	15–30
0–20	6–16
8–16	4–10
0–20	7–15
0–100§	40–70§
.2–0.3	0.1–0.2
.1–0.4	0.1–0.4
.2–0.4	0.2–0.4
.2–0.4	0.2–0.4
2–10	2–10
0–120	60–120
0–400	150–380

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TABLE 4-16
Typical data on the expected effluent wastewater characteristics from a residential septic tank without and with an effluent filter vault*

		Concentration, mg/L					
		Without effluent filter			With effluent filter		
Constituent (1)	Typical complete mix value† mg/L (2)	Range (3)	Typical without ground up kitchen waste (4)	Typical with ground up kitchen waste (5)	Range (6)	Typical without ground up kitchen waste (7)	Typical with ground up kitchen waste (8)
BOD_5	450	150–250	180	190	100–140	130	140
COD	1050	250–500	345	400	160–300	250	300
TSS	503	40–140	80	85	20–55	30	30
NH_3 as N	41.2	30–50	40	44	30–50	40	44
Org. N as N	29.1	20–40	28	31	20–40	28	31
TKN as N	70.4	50–90	68	75	50–90	68	75
Org. P as P	6.5	4–8	6	6	4–8	6	6
Inorg. P as P	10.8	8–12	10	10	8–12	10	10
Total P as P	17.3	12–20	16	16	12–20	16	16
Oil and grease	164	20–50	25	30	10–20	15	20

*With assistance from Bounds (1997).
†Data from Table 4-12, column 4. Concentration if waste constituents were mixed completely.

from private wells and groundwater, and from industrial use. Domestic and industrial water softeners also contribute significantly to the increase in mineral content and, in some areas, may represent the major source. Occasionally, water added from private wells and groundwater infiltration will (because of its high quality) serve to dilute the mineral concentration in the wastewater.

Composition of Septic Tank Effluent

Typical data on the composition of septic tank effluent, based in part on the data given in Tables 4-11 and 4-12, are presented in Table 4-16 for septic tanks without and with effluent filter vaults (see Sec. 5-7, in Chap. 5) and with and without kitchen food-waste grinders. The beneficial effect of using an effluent filter vault, in terms of reduced constituent concentrations, is clearly evident by comparing columns 4 and 5 and 7 and 8. For the purpose of comparison, the constituent concentrations that would have been expected if the wastes discharged to the septic tank had been mixed completely are reported in column 3. The importance of the septic tank as a pretreatment process can be appreciated by comparing column 2 to columns 4 and 5, or to columns 7 and 8. Here again, because of the significant variations observed in the constituent concentrations in septic tank effluent, the values given in Table 4-16 *should be used only as a guide.*