#2.37

Sand Filter Evaluation in a Northern Climate

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ABSTRACT

Forty-seven single pass sand filters were monitored during winter, spring, and summer. Effluent samples were collected from both the septic tank and sand filter pump chamber. Media samples from the sand filter and soil cover samples and cover depths were also collected or measured. Water meters were installed for each site and the meters were recorded on a monthly basis by the homeowner. All but one of the sand filters had a programmable timer to control dosing.

The median hydraulic loading rate was 1.8 cm/day (0.44 gpd/ft^2), which was lower than the design hydraulic loading rate of 5.1 cm/day (1.25 gpd/ft^2). The median dose volume was 78 L/dose (21 gal/dose), which is higher than the recommended dose volume of 57 to 60 L/dose (15 to 16 gal/dose) for a 33.4 m^2 (360 ft^2) filter. The median orifice loading rate (1.3 L/dose/orifice, 0.34 gal/dose/orifice) was also found to be greater than the recommended rate of 0.95 L/dose/orifice (0.25 gal/dose/orifice), indicating that the dose times need to be adjusted.

The sand filters were found to reduce the concentration of TSS, BOD, and total nitrogen by 96%, 98%, and 37% from the septic tank based on the median values. The fecal coliforms showed a 4-log reduction from the septic tank, with 76% of the samples having a fecal count of 200 col./100 mL or less.

Recommended soil cover types and depths were followed only 18% of the time. The sand media was found to match the recommended effective diameter 59% of the time. Sand from 26% of the filters had sand that exceeded the limits for fines.

INTRODUCTION

On-site wastewater treatment has relied on the septic tank followed by soil absorption. With increased interest in rural development, and with 68% of the land unsuitable for soil absorption of septic tank effluent, other alternatives are needed to supplement the septic tank in pretreating the wastewater prior to soil dispersal. One such alternative is the buried single pass sand filter.

Single pass sand filters treat the wastewater by physical, chemical and biological processes. The main mechanisms of treatment are straining, sedimentation, inertial impaction, interception, adhesion, flocculation, diffusion, adsorption, and biological activity (U.S. EPA, 1985). The most important of these mechanisms is biological activity.

Other studies have evaluated the effluent quality of single pass sand filters for single family housing (Ronayne et al., 1982, Converse and Converse, 1998, McCarthy et al., 1998, Jantrania et al., 1998, Siever, 1998, Cagle and Johnson, 1994, and Moore, 1997). All sources reported sand filters produce a low BOD, low TSS and a highly nitrified effluent.

The objective of this study was to quantify the field performance and construction techniques of 47 single pass sand filters serving residences in a northern climate.

MATERIAL AND METHODS

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Single pass sand filters are contained by a 30-mil PVC membrane. Stone with a diameter of 2 to 2.5 cm (0.75 to 1 inch) is placed on top of the liner, in which a collection pipe is placed. Approximately 7.5 cm (3 in.) of pea gravel is placed on top of the stone to reduce migration of fines into the collection pipe. The treatment media, sand that meets a strict specification, is placed on top of the pea gravel. Pea gravel is placed on top of the treatment media and a distribution system is placed within the gravel. The pea gravel is covered with a breathable geotextile fabric. The filters are then covered with a maximum of 15 cm (6 in.) of sandy loam or loamy sand, and seeded. Decorative stone can be utilized in place of the soil. Figures 1 and 2 show a cross section and plan view of a typical single pass sand filter. Other sizes are available.

All sites, except one, used a timer to control dosing of the septic tank effluent onto the sand filter. Either a turbine or a centrifuge effluent pump was used to dose the sand filter. Forty-four of the 47 sites had sand filters with an area of 33.4 m^2 (360 ft^2), either 3 x 11 m (10 x 36 ft), or 5.5 x 6.1 m (18 x 20 ft). Two other sand filters served larger-sized houses; one filter is 55.7 m^2 (600 ft^2), 6.1 x 9.1 m (20 x 30 ft), and the other was 66.9 m^2 (720 ft^2), 6.1 x 11 m (20 x 36 ft). All of the sand filters were membrane-lined.

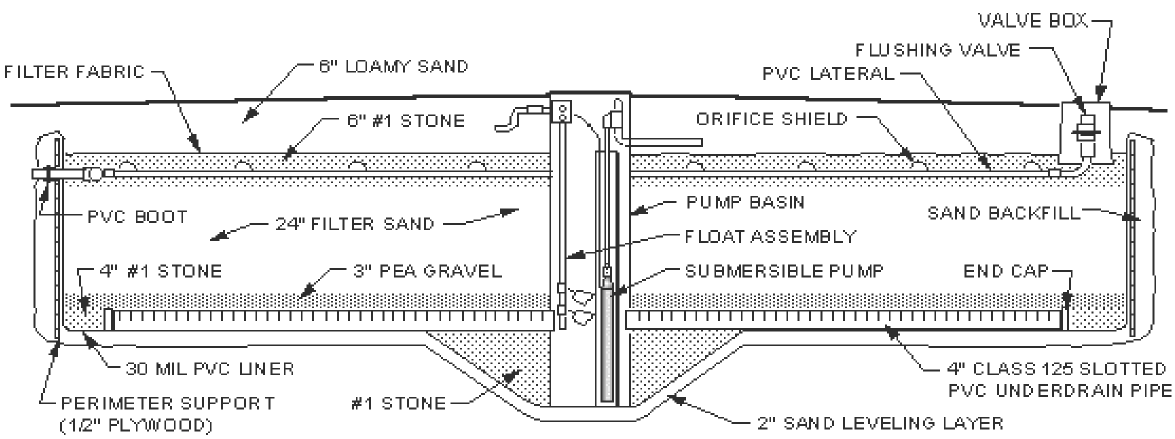

Figure 1: Cross section of sand filter with internal pump chamber (Orenco, 1996)

All effluent analysis, except nitrogen and chloride, followed the procedures as outlined in Standard Methods for the Examination of Water and Wastewater (APHA, 1992). Nitrogen analysis was done according to Methods of Soil Analysis Part 2-Chemical and Microbiological Properties (ASA, 1982). Chloride was measured using a Buchler Instruments Chloride Station, following the procedure outlined in "Methods of Soil Analysis" Part 2, Chemical and Microbiological Properties (ASA, 1982). Samples were analyzed immediately except for nitrogen and TOC. The nitrogen samples were preserved by freezing, and the TOC samples were preserved by acidification and refrigeration in a brown glass bottle until a sufficient number of samples were collected.

Each site was sampled a total of three times, once each in: winter, November through March; spring, April through June 8; and summer, June 22 through September. All samples were collected as grab samples from both the septic tank pump vault and the sand filter pump chamber. Samples were taken by attaching a one liter sample bottle to a sampler and then inserting the sampler below the water surface and allowing it to fill up. Samples for total and fecal coliforms were collected in a sterile bottle, before other samples were taken for the other parameters. Sand filter effluent was collected prior to the septic tank effluent samples. The samples were then placed in a cooler with ice and brought back to the lab. Dissolved oxygen was analyzed using a YSI model 55 DO probe at the site by inserting the probe in the sand filter pump chamber. Effluent temperature and pH were also taken at the site by using a thermometer and a portable Fischer Accument AP 10 pH meter.

Water meter readings were recorded from each site on a monthly basis. A self-addressed stamped, postcard was sent to each residence in the study at the beginning of every month. These cards were then filled out by the homeowner and returned. Not all cards were returned every month, but on the whole most sites returned them consistently.

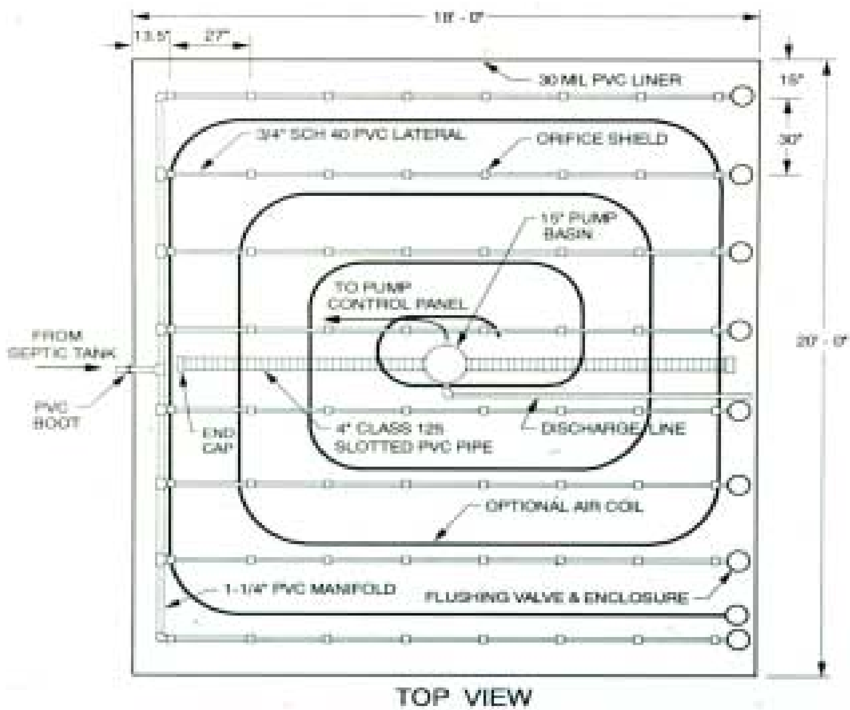

Figure 2: Top view of sand filter with internal pump chamber (Orenco, 1996)

Sand samples from the sand filter were collected by inserting a probe into the flush valve cover and through the aggregate. Part of the probe was then removed, leaving a hollow tube in the sand, through which a probe was inserted to obtain the sand sample. This was repeated until enough sand was collected. Approximately 500 g of the wet sand sample was dried at 104-107 ^oC until the sample obtained a constant weight. The sample was then washed through a 200-mesh sieve. All material retained on the sieve was then placed back in the oven and dried to a constant weight. All of the material passing the 200 sieve was discarded but was accounted for in the calculations. The sample was sieved through 3/8, 4, 8, 10, 16, 30, 50, 100, 200 U.S. standard mesh sieves. The amount passing each sieve was then computed using the initial total weight, and the effective diameter and uniformity coefficient were calculated.

Soil cover samples were taken at four to six locations on top of each filter using an Oakfield probe, and were then consolidated into one. Soil texture was determined by hand texturing. Soil cover depth was determined by inserting a drain tile probe to the top of the gravel layer.

Water use was calculated by taking the difference in water meter readings from the water meter cards, returned monthly by the homeowner, before and after the dates of sampling. The water meter difference was then converted into L/day (gallons/day), L/capita/day (gallons/capita/day), cm/d (gallons/square foot/day), and L/dose (gallons/dose). All metered water was assumed to discharge to the system. For sampling dates that did not have a water meter installed at the time of sampling, the average daily water usage rate during the study was used. Five sites did not have a water meter installed during the study.

About 11 sites had water meters that measured the outside faucet use. Apparently very little water was used from the outside faucet compared to the rest of the household, as a significant difference was not found between months when outside water was used and not used.

Mass loading rates were computed using the daily flow rates calculated above. The flow rates were computed for each of the three samples, and these flow rates were then averaged. The average concentration in the septic tank, of all three samples, was then multiplied by average daily flow rate and converted into kilograms/day (lb/day). The kilograms/day (lb/day) was then used to compute the mass loading per square foot and per capita (Converse, 1999).

RESULTS AND DISCUSSION

Hydraulic Loading Rates

The actual hydraulic loading rates were evaluated and compared with the design loading rate of 5.1 cm/day (1.25 gpd/ft^2). The median and average hydraulic loading rates were both 1.8 cm/day (0.44 gpd/ft^2), with a range of 0.4 to 4.4 cm/day (0.1 to 1.07 gpd/ft^2), all of which were below the design loading rate (Table 1).

Comparing the hydraulic loading rates with the sand filter effluent BOD, TSS, fecal coliforms, total coliforms, and total nitrogen, no effect in performance was noticed for the observed hydraulic loading rates.

Table 1: Hydraulic Loading Rates

	Capita	*Daily Water Usage LPD*	*Hydraulic Loading Rate Lpd/m^2*	*Dose Volume L/Dose*	*Orifice Loading Rate L/Dose/Orifice*
Median	3.6	601	1.8[1]	78	1.3
Average	3.6	611	1.8	84	1.3
Maximum	7	1455	4.4	235	3.9
Minimum	1	131	0.4	22	1.3
Standard Deviation	1.4	239	0.7	44	0.8
90th Percentile	5[2]	840	2.5	118	2.0
10th Percentile	2	316	0.9	33	0.4
Samples	47	42	42	35	35

[1]Hydraulic loading rate is the average of the averages for all sites that reported water meter readings and had control boxes accessible.

[2]The 90th and 10th percentile refer to percentage of data points that are below that data point.

Orifice Loading Rates

The orifice loading rate is an evaluation of how frequently and in what quantities the sand filter is being dosed. The recommended rate is 0.95 L/dose/orifice (0.25 gal/dose/orifice) (Crites and Tchobanoglous, 1998). The median and average orifice loading rate of 1.3 L/dose/orifice (0.34 gal/dose/orifice) is higher than the recommended rate (Table 1). Out of 36 sites, with both flow and dosing frequency data, only 10 had an orifice loading rate that was equal to or lower than the recommended orifice loading rate. Since the hydraulic loading rate is less than the design loading rate, but the orifice loading rate is higher than the recommended rate, it appears that the sand filters are not being dosed at the recommended frequency. Darby et al, (1996) reported small doses applied frequently improved the performance of the sand filter.

The median and average dosing volumes were 78 and 84 L/dose (21 and 22 gal/dose), respectively, which are higher than the recommended dosing volumes of 57 to 60 L/dose (15-16 gal/dose).

When evaluating the orifice loading rate, a positive correlation was found between the orifice loading rate and the fecal coliforms, BOD, and TN, with P-values of 0.005, 0.005, and 0.0005, respectively (indicating an increase in the sand filter effluent concentration with an increase in the orifice loading rate (Converse, 1999)). Since the model explains only 21%, 20%, and 32% of the variation about the mean; it would be unwise to use the model as a predictive tool.

Effluent Quality

Tables 2 and 3 list the results of sampling from both the septic tank and the sand filter pump chambers. Table 4 lists the percent reduction of various constituents in the sand filter effluent from the septic tank effluent.

Table 2: Septic Tank Effluent Data

	TSS mg/L	*VSS mg/L*	*BOD mg/L*	*COD mg/L*	*TOC mg/L*	*Fecal Coliforms col./100 mL*
Median	69	48	178	445	133	2.3×10^5
Average	87	60	192	458	147	6.0×10^5
Maximum	626	544	548	1600	715	1.0×10^7
Minimum	14	8	32	105	35	4.4×10^2
Standard Deviation	91	51	91	183	81	1.4×10^6
90^{th} Percentile	146	101	300	680	222	1.1×10^6
10^{th} Percentile	30	25	89	270	63	3.5×10^4
Samples	47	101	141	141	139	139

The median BOD value was 3 mg/L with the average slightly higher at 5 mg/L, which represents a reduction from the septic tank of 98% for both the median and average values. Ninety-nine percent of the samples had BOD values less than 20 mg/L (Table 5), with 25 mg/L being a common standard for secondary treated effluent. The TOC in the sand filter effluent ranges from 0 to 132 mg/L, with a median of 13 mg/L and an average of 18 mg/L. Sand filter effluent COD ranged from 7 mg/L to 130 mg/L, with median and average values of 25 mg/L and 30 mg/L, respectively. This represents a decrease in the COD of 94% and 93% based on the median and average values, respectively, from the septic tank effluent.

Table 3: Sand Filter Effluent Data

	TSS mg/L	*VSS mg/L*	*BOD mg/L*	*COD mg/L*	*TOC mg/L*	*Fecal Coliforms col./100 mL*	*DO mg/L*
Median	3	0.8	3	25	13	20	3.4
Average	4	1.9	5	30	18	1,300	3.8
Maximum	34	19	31	130	132	68,000	11
Minimum	0	0	0	7	0	0.5	0
Standard Deviation	6	3.9	5	18	18	7,000	2.9
90^{th} Percentile	8	4	12	52	42	1,800	8.2
10^{th} Percentile	1	0	1	14	2	0.5	0.5
Samples	47	47	140	141	140	139	133

Table 4: Reductions in Concentration Due to Sand Filtration

	TSS	*VSS*	*BOD*	*COD*	*TOC*	*TN*	*Fecals*
Average	95%	97%	98%	93%	88%	31%	3 log
Median	96%	98%	98%	94%	90%	37%	4 log

The sand filter total suspended solid (TSS) had a median value of 3 mg/L and an average of 4 mg/L, which corresponds to a reduction in the median and average values of 96% and 95%, respectively, for TSS from the septic tank effluent. All but one of the samples for TSS were below 30 mg/L which is a common standard for secondary treated effluent (Table 5).

Fecal coliforms are an important indicator of fecal contamination of water. The drinking water standard is 0 col./100 mL and the body contact standard is 200 col./100 mL. The median and average sand filter effluent fecal coliforms counts were 20 and 1,300 col./100 mL, respectively (Table 3). The average is higher because of the inclusion of several sites that consistently produced higher fecal concentrations. Seventy-six percent of the samples had a fecal coliform count of 200 col./100 mL or less, with 21% of the samples having a fecal count of 1 col./100 mL or less (Table 6).

Table 5: Frequency of Sand Filter Effluent Concentrations of BOD and TSS

Concentration in SFE (mg/L)	*Percent TSS samples less than concentration*	*Percent BOD samples less than concentration*
≤1	23%	31%
5	85%	71%
10	94%	89%
20	96%	99%
25	98%	99%
30	98%	99%
>30	100%	100%
Number of Samples	47	140

Table 6: Frequency of Sand Filter Effluent Concentrations for Fecal Coliforms

Concentration in SFE (mg/L)	*Percent of Fecal Coliform samples less than concentration*
≤1	21%
100	71%
200	76%
1,000	89%
10,000	98%
>10,000	100%
Number of Samples	140

The sand filter effluent total nitrogen median and average values were 38 and 40 mg/L, resulting in a 37% and a 31% reduction respectively. Nitrate accounted for 82% and 83% of the total sand filter effluent nitrogen based on median and average values, respectively (Table 7), with the rest being either organic nitrogen or ammonia. For optimum nitrification to occur, the dissolved oxygen level must be 2 mg/L, pH between 7.2 and 8.2, and 7.14 mg/L of alkalinity as $CaCO_3$ for every milligram of NH_4^+ nitrified (Britton, 1994). Since 31% of the samples had a pH out side the optimum and 16% of the samples had insufficient alkalinity, nitrification might have been inhibited (Converse, 1999).

Table 7: Nitrogen Concentration in Septic Tank and Sand Filter Effluent

	Septic Tank Effluent			***Sand Filter Effluent***		
	TKN mg-N/L	*NH_4^+ mg-N/L*	*NO_3^- mg-N/L*	*TKN mg-N/L*	*NH_4^+ mg-N/L*	*NO_3^- mg-N/L*
Median	55	42	0.5	1.7*	1.0	31*
Average	62	50	0.7	7.6	6.2	33
Maximum	209	179	8.5	77	68	81
Minimum	22	11	0	0	0	0
Standard Deviation	29	26	1.0	13	12	18
90th Percentile	93	81	1.4	25	18	57
10th Percentile	37	28	0.1	0.4	0.2	7

Samples	139	139	139	139	139	139

*Total nitrogen reported in the text was computed from the TKN and NO_3^- for each site individually and then the median and average value were calculated.

Dissolved Oxygen (DO) in the sand filter is a little harder to judge as the DO was measured only in the sand filter pump chamber. The median and average DO in the sand filter pump chamber was 3.4 and 3.8 mg/L, respectively. As long as the effluent has a low BOD, TSS, fecal coliform concentration and was highly nitrified, it can be assumed that the filter is getting enough oxygen.

Chloride is a conservative ion, and as such the concentration of the chloride should not change as the water proceeds through the treatment process, unless dilution occurs. For both winter and spring sampling periods a significant difference was found between the septic tank effluent and the sand filter effluent chloride concentrations, determined by Wilcoxon's sign rank test for a P-value of 0.05 (Table 8). For summer there was not a significant difference in the Cl^- concentration between the septic tank effluent and the sand filter effluent.

Table 8: Seasonal Chloride Data

	Septic Tank			***Sand Filter***		
	Winter (mg/L)	*Spring (mg/L)*	*Summer (mg/L)*	*Winter (mg/L)*	*Spring (mg/L)*	*Summer (mg/L)*
Median	94	88	83	81	77	80
Average	343	304	398	295	262	375
Maximum	1696	1786	2400	1130	1852	2103
Minimum	35	26	22	27	21	21
Standard Deviation	437	409	583	347	373	530
90^{th} Percentile	816	801	1050	879	827	1008
10^{th} Percentile	42	37	31	33	34	28
Samples	47	47	47	47	47	47

There were significant seasonal differences in effluent quality for BOD, NH_4^+, and total nitrogen (Table 9). There was not a significant difference between the spring and summer NH_4^+ and total nitrogen data. The fecal coliforms do not seem to be heavily influenced by the different seasons, as Wilcoxon's sign rank test did not show a significant difference between the three different sampling periods (Converse, 1999).

Table 9: Seasonal Variations

	Winter		***Spring***		***Summer***	
Pollutant	*Median*	*Average*	*Median*	*Average*	*Median*	*Average*
BOD (mg/L)	5	6	3	5	1	3.5
NH_4^+ (mg-N/L)	2	9	0.7	6	0.6	3.9
TN (mg-N/L)	36	81	38	42	38	41
Fecal Coliforms (col./100 mL)	31	870	9	420	21	2500
Temperature (^oC)	5	6	11	11	18	18

Mass Loading Rates

Mass loading rates were calculated based on BOD, COD, and TOC concentrations (Table 10). The median BOD mass loading rate on the sand filter for all sites is 1.8 x 10^{-3} kg/m^2-day (5.8 x 10^{-4} lb/ft^2-day), while the average is slightly larger at 7.9 x 10^{-3} kg/m^2-day (6.8 x 10^{-4} lb/ft^2-day). Most sites, especially those that are above the 90^{th} percentile, are capable of functioning at the current mass loading rates. There was a significant relationship between the BOD mass loading (kg/m^2-day) on the sand filter, and the sand filter effluent BOD (mg/L), for a P-value of 0.05

indicating that as the BOD mass loading rate increased so did the BOD concentration in the sand filter effluent. However, the model explained only 25% of the variation about the mean.

Table 10: Mass Loading Rates

	BOD *kg/m^2-day*	*COD* *kg/m^2-day*	*TOC* *kg/m^2-day*
Median	1.8×10^{-4}	4.0×10^{-4}	1.3×10^{-4}
Average	7.9×10^{-4}	2.0×10^{-3}	6.1×10^{-4}
Maximum	6.8×10^{-3}	1.4×10^{-2}	4.4×10^{-3}
Minimum	4.1×10^{-5}	1.2×10^{-4}	2.9×10^{-5}
Standard Deviation	1.5×10^{-3}	3.7×10^{-3}	7.7×10^{-4}
90th Percentile	1.8×10^{-3}	7.6×10^{-3}	6.8×10^{-4}
10th Percentile	6.9×10^{-5}	1.8×10^{-4}	2.5×10^{-5}
Samples	42	42	42

Soil Cover

Both soil cover depths and textures were evaluated with these parameters varying greatly between sites. The median and average soil depth for all sites was 20.3 cm (8.0 in.) and 19.1 cm (7.5 in.), respectively, which is higher than the suggested soil cover of 15.2 cm (6.0 in.) (Orenco, 1996). Out of the 47 sites that were sampled only 9 had a soil depth of 15.2 cm (6.0 in.) or less, with depths ranging from 0 to 38 cm (0 to 15 inches). Since diffusion through the soil cover is the only source of oxygen for the filter, the depth of soil over the filter may be a factor in some sand filters having a relatively low DO concentration in the sand filter pump chamber.

The recommended cover types are gravel (no cover), loamy sand, or sandy loam (Orenco, 1996). Out of the 47 sites studied, 21 of the sites had one of the three recommended soil types. The remaining soil types tended to have a fairly high clay content, which was probably typical of what was excavated from the site. When considering both the cover soil types and the depth, only 18% of the sites met soil type and depth recommendations, indicating that contractors were not following specifications and inspectors were not enforcing specifications.

Sand Media

Sand size, based on effective size and uniformity coefficient, and loading rates are interrelated. Table 11 lists the recommended gradation for sand filter sand used at the time of construction of the sand filter. Out of the 47 sites that were sampled, 59% of them had an effective diameter that fell within the recommended sand specification. When evaluating the whole gradation curve only 24.5% of the sites had sand that fell within the recommended limits. An additional 49% of the sites had sand that was coarser than the gradation limits and another 26% had a media that was finer than recommended (Converse, 1999). Sands that had both coarse and fine sections were classified as fine sand. Sands with too many fines have a greater chance of failing than sand coarser than recommended, assuming similar loading rates. Treatment from coarse sand may not be as good as with fine sand, although for this study there was not a significant difference in treatment quality between fine and coarse sands.

Table 11: Recommended Sand Media Gradation (Orenco, 1996)

US Standard Sieve	*Particle Size (mm)*	*Limit (%)*
3/8	9.5	100/100
4	7.8	95/100
8	2.4	80/100
16	1.2	45/85
30	0.60	15/60
50	0.30	3/15
100	0.15	0/4
200	0.075	0/0

SUMMARY AND CONCLUSIONS

The average hydraulic loading rate was 1.8 cm/day (0.44 gpd/ft^2), which was 35% of the design loading rate of 5.1 cm/day (1.25 gpd/ft^2).

Sand filters are capable of consistently producing an effluent with TSS of 30 mg/L or less and BOD less than or equal to 25 mg/L. They are also capable of producing an effluent with a fecal count of 200 col./100 mL or less 76% of the time, and reducing the TKN in the septic tank by 98% based on the median values, with a loss in total nitrogen of 37%.

The median and average orifice loading rates were 1.3 L/dose/orifice (0.33 gal/orifice/dose), which were higher than the recommended rate of 0.95 L/dose/orifice (0.25 gal/orifice/dose). Since the orifice loading rate is higher than the recommended rate and the hydraulic loading rate is below the recommended rate, it appears that the sand filters are not being dosed frequently enough. The dosing volumes observed during this study were 24 to 30% higher than recommended dosing volumes based on the median and average values, respectively.

The recommended soil cover depth and type specification was only being followed 18% of the time. Out of 47 sites 21 had one of the three recommended soil cover, while only 9 out of 47 sites had the recommended soil cover thickness.

The sand quality used for the sand filter was meeting or exceeding the recommended effective diameter 59% percent of the time. Twenty five percent of the time the sand fell within the recommended gradation with an additional 49% that were slightly coarser than the recommended gradation curve. There was not a significant difference in effluent quality between the coarse and the fine sand for this study. Since the average age of the systems was 14 months there are still some concerns about sites with finer sands producing a biomat and failing.

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