Chapter 5: Control Systems: Septic tank and sand filter performance

Introduction

The field test program of the La Pine Project included a significant effort applied to sampling conventional onsite systems, including standard gravity tank and drainfields, pressure distribution and sand filter systems. These systems provided a benchmark against which the performance of innovative systems and the monitoring well sampling results can be compared. This work also increased baseline knowledge system performance for comparison against other work performed in the field.

Conventional systems have been found to be contaminating groundwater in the region (Hinkle et al, 2007; Morgan et al, 2007) because these systems provide primary treatment in the septic tank and discharge nitrogen-rich effluent to the drainfield or sand filter where it becomes transformed from ammonium to nitrate and is discharged to the environment. Nitrification process are described in more detail in texts like Burks & Minnis (1994) and Crites & Tchobanoglous (1998). Figure 5-1 provides a simplified illustration of the biochemical processes that occur in a conventional system using trenches or a sand filter for nitrification.

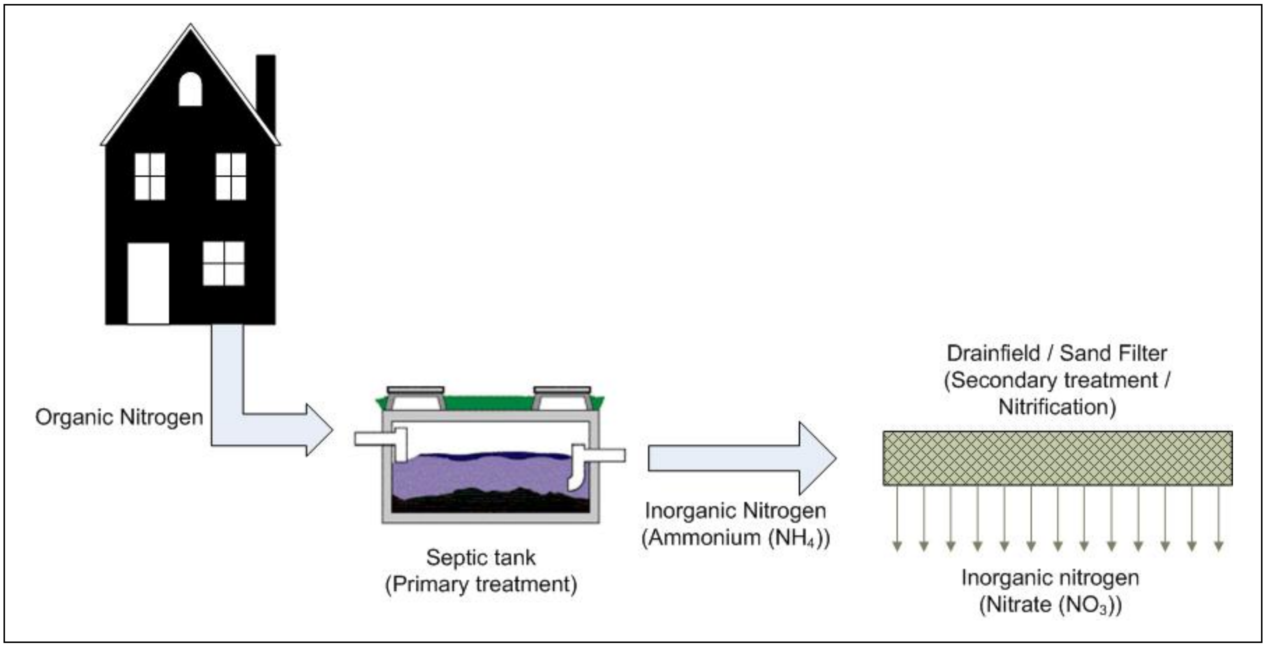

Figure 5-1. Wastewater treatment process in conventional onsite systems.

Septic Tank Performance

The field test program of the La Pine Project included a significant effort applied to sampling septic tank effluent. The septic tank population included 20 single-pass septic tanks that are all 1,500 gallons in volume except for one single compartment tank that is 1,000 gallons in volume. The tank population was evenly split between one compartment and two compartment tanks where the two compartment tanks are configured as a 1000-gallon primary chamber and a 500-gallon discharge chamber.

The data from this study were used to review the waste strength coming from single-family households and to provide a benchmark for the performance of the denitrifying systems in the field test. Several of the denitrifying systems employed a recirculating process to return nitrified effluent to the carbon-rich environment of the primary processing tank for denitrification. As a result, the project team could not easily monitor the influent waste strength and, therefore, directly calculate the percent reduction achieved by these systems. The larger single-pass septic tank population provides a reasonable estimate of waste strength in order to produce this kind of performance review.

In this section, septic tank performance is evaluated using total nitrogen instead of total Kjeldahl nitrogen (TKN). The nitrogen in the septic tank effluent is comprised primarily of TKN with minimal nitrate present. The project team reviewed the total amount of nitrogen leaving the septic tanks to determine if total nitrogen (TN) would be a better representation of effluent quality than TKN. The statistics for TKN are indistinguishable from the statistics for TN because the dominant nitrogen species in septic tanks is TKN. Because there is no statistical difference between TKN and TN in septic tank effluent, the project team decided to use the TN results to be consistent with the performance standards for the denitrifying treatment system study. The data provided in the tables in this paper are a subset of total parameters taken as part of the field test program. The full dataset is provided in Appendix B and C.

In this section, the Oregon residential waste strength definition will be used as an example of the applicability and limitations of a concentration based performance standard. [Note: the analysis lends itself to any pertinent residential waste strength definition.] Oregon's definition, contained in the statewide onsite rule (OAR 340-071-0100(126)) requires:

> *"Residential Strength Wastewater" means septic tank effluent that does not typically exceed five-day biochemical oxygen demand (BOD_5) of 300 mg/L; total suspended solids (TSS) of 150 mg/L; total Kjeldahl nitrogen (TKN) of 150 mg/L; oil & grease of 25 mg/L; or concentrations or quantities of other contaminants normally found in residential sewage. (Oregon DEQ, 2005)*

Table 5-1 provides the summary statistics for the single pass septic tank population in the La Pine Project. Each tank was sampled monthly for the first year and then bimonthly or quarterly for the next two years. Each tank was sampled at the same time that the wastewater treatment unit and/or the lysimeter and/or the drainfield monitoring well was sampled to facilitate the overall performance review of the treatment unit or the receiving environment. (Section 8) Table 5-1 provides the statistics in terms of the total population of tanks sampled and also by number of compartments. The table includes the mean and median values for the total population and the geometric mean. The geometric mean may be a useful tool in this circumstance as the data for the individual tanks is slightly skewed. The geometric mean is also useful to reduce the effect of varying sample sizes. Converse (2004) applied this method in order to better compare data from sample sets with significantly different sample sizes (between 31 and 517). The sample size effect is lessened in this study because the counts are similar.

The discussion in the remainder of this section focuses on the BOD_5, TSS, TN and O&G. The remaining statistics reported in Table 5-1 (total phosphorus, bacteria, and temperature) are provided as a baseline for the denitrifying systems discussion in Section 6 of this report.

On average, the waste strength from the twenty households falls within the Oregon definition for residential septic tank effluent on all parameters except oil and grease (O&G). The maximum concentrations recorded, however, greatly exceed the definition and the magnitude of the mean concentrations for BOD_5 and TSS indicate that a significant number of samples exceed the residential waste strength definition. The statistics for the different tank designs indicates that two-compartment tanks perform significantly better (99% confidence level) than single-compartment tanks for TSS reduction. BOD_5 reduction in two-compartment tanks is slightly better than single-compartment tanks but only to the 70% confidence level. The O&G concentrations in the two-compartment tanks are actually significantly higher than in single-compartment tanks.

Table 5-1. Septic tank effluent quality summary statistics.

All single pass septic tank effluent	**BOD$_5$ (mg/L)**	**TSS (mg/L)**	**TN (mg/L)**	**Total Phosphorus (mg/L)**	**Oil & Grease (mg/L)**	**Fecal Coliform**	**Log Fecal**	**E. coli**	**Log E. coli**	**Temp (C)**
Mean	261	94	66	11	35	1.5E+07	5.4	9.5E+06	5.3	15.1
Geometric Mean	225	63	62	10	29	2.3E+05	5.1	1.6E+05	5.0	15.0
Median	240	62	63	10	28	1.9E+05	5.3	1.4E+05	5.1	15.2
Standard Deviation	136	149	22	5.6	28	7.3E+07	1.4	5.2E+07	1.3	4.4
Minimum	22	ND	8.6	0.1	2.5	ND	0.3	ND	0.3	3.1
Maximum	1000	1900	233	96	280	7.7E+08	8.9	7.4E+08	8.9	25.3
Count	428	427	427	429	415	429	429	429	429	430
95% Confidence Level	13	14	2.1	0.5	2.7	6.9E+06	0.1	4.9E+06	0.1	0.4
99% Confidence Level	17	19	2.8	0.7	3.5	9.1E+06	0.2	6.5E+06	0.2	0.6

All 1-compartment septic tank effluent	**BOD$_5$ (mg/L)**	**TSS (mg/L)**	**TN (mg/L)**	**Total Phosphorus (mg/L)**	**Oil & Grease (mg/L)**	**Fecal Coliform**	**Log Fecal**	**E. coli**	**Log E. coli**	**Temp (C)**
Mean	265	119	64	11	33	1.8E+07	5.5	1.2E+07	5.3	15.4
Geometric Mean	222	76	60	9.6	27	2.8E+05	5.2	1.9E+05	5.0	14.8
Median	250	71	62	10	27	2.0E+05	5.3	1.5E+05	5.2	15.6
Standard Deviation	146	195	20	6.9	25	7.8E+07	1.3	6.1E+07	1.3	4.4
Minimum	22	10	8.6	0.1	2.5	ND	0.3	ND	0.3	3.1
Maximum	1000	1900	160	96	280	7.7E+08	8.9	7.4E+08	8.9	25.3
Count	231	231	230	232	223	232	232	232	232	233
95% Confidence Level	19	25	2.6	0.9	3.3	1.0E+07	0.2	8.0E+06	0.2	0.6
99% Confidence Level	25	33	3.4	1.2	4.3	1.3E+07	0.2	1.0E+07	0.2	0.8

All 2-compartment septic tank effluent	**BOD$_5$ (mg/L)**	**TSS (mg/L)**	**TN (mg/L)**	**Total Phosphorus (mg/L)**	**Oil & Grease (mg/L)**	**Fecal Coliform**	**Log Fecal**	**E. coli**	**Log E. coli**	**Temp (C)**
Mean	255	64	69	11	38	1.2E+07	5.3	6.5E+06	5.2	14.8
Geometric Mean	228	52	64	10	32	2.0E+05	5.0	1.4E+05	4.9	14.3
Median	240	53	64	10	30	1.7E+05	5.2	1.3E+05	5.1	14.7
Standard Deviation	124	44	24	3.3	31	6.6E+07	1.4	3.8E+07	1.3	4.4
Minimum	44	ND	27	2.3	2.5	ND	0.3	ND	0.3	3.6
Maximum	730	340	233	23	191	7.2E+08	8.9	5.0E+08	8.7	24.5
Count	197	196	197	197	192	197	197	197	197	197
95% Confidence Level	17	6.2	3.4	0.5	4.4	9.3E+06	0.2	5.4E+06	0.2	0.6
99% Confidence Level	23	8.2	4.4	0.6	5.8	1.2E+07	0.3	7.1E+06	0.2	0.8

Residential Waste Strength Definition	**< 300**	**< 150**	**< 150**		**< 25**					

ND = non detect

A review of the summary statistics for individual residences indicates that some households produce significantly higher waste strength on average. Table 5-2, for example, was a household with a two-compartment tank where the septic tank effluent greatly exceeded the waste strength definition *on average*. It is unclear, based on the homeowner’s survey responses and other observations, what caused the high waste strength in this household. Two possible causes are that one family member was taking up to four different prescription medications during the test period and the water use was extremely low for a household of 5 persons (mean = 124 gpd; median = 97 gpd).

An important policy implication is highlighted here in the situation where property owners could be penalized for practicing good water conservation measures because these practices can cause the onsite system to receive higher than residential strength wastewater. For example, Oregon rule (OAR 340-071-0130(15)(b)(B)) states that an onsite system receiving greater than residential strength wastewater must be permitted using a Water Pollution Control Facilities Permit (WPCF), a process typically used to administer commercial onsite systems. As a result, any home found to be discharging greater than residential waste strength effluent is required to be on a WPCF permit. The property owner would then be subject to significant annual monitoring and reporting requirements and an increased annual compliance fee. However, if we adjust the mass load of the BOD_5 produced by this family (mean = 156 lb/yr, median = 135 lb/yr) to illustrate what the BOD_5 concentration would be if that load were delivered in 225 gallons per day (GPD) on average (225 GPD is the average design flow for a single family residence in Oregon), then the septic tank would be discharging BOD_5 concentrations between 200 and 230 mg/L, well within the residential waste strength definition. This example illustrates the value and the need to examine the mass load and not solely the concentration discharged by a facility in order to obtain a true picture of the treatment system's performance.

Table 5- 2. Household with two-compartment tank with high BOD_5 and O&G.

Innov. Trench-B System-M STE	BOD_5 (mg/L)	TSS (mg/L)	TN (mg/L)	Total Phosphorus (mg/L)	Oil & Grease (mg/L)	Fecal Coliform	Log Fecal	E. coli	Log E. coli	Temp (C)	GPD
Mean	439	97	74	11	108	9.8E+05	5.5	7.7E+05	5.4	17.7	124
Geom. Mean	414	80	74	11	99	3.4E+05	5.5	2.4E+05	5.3	17.4	115
Median	450	85	75	11	108	2.0E+05	5.3	1.3E+05	5.1	16.7	97
Standard Dev.	125	75	11	1.9	43	1.3E+06	0.7	1.1E+06	0.7	3.7	59
Minimum	117	31	54	7.3	29	1.4E+04	4.1	1.5E+04	4.2	12.8	84
Maximum	570	340	96	15	191	5.0E+06	6.7	4.2E+06	6.6	24.5	300
Count	15	15	15	15	15	15	15	15	15	15	14
95% Conf. Level	69	42	6.1	1.1	24	7.4E+05	0.4	6.4E+05	0.4	2.0	34
99% Conf. Level	96	58	8.4	1.5	33	1.0E+06	0.6	8.8E+05	0.6	2.8	47

The twenty septic tanks in the La Pine Project represented a diverse group of residents from single young or retired persons to families of six. The sites included residents on long-term antibiotics or chemotherapy drugs to people who didn't take any prescription drugs or use potent household cleaners. While this diversity creates a difficulty when trying to determine how the one-compartment tank population compares to the two-compartment tank, the La Pine Project team believes that the diversity is representative of the population in general. Given that, Table 5-3 provides another method of showing how the sample population compares to the residential waste strength definition. This table provides the percent of all septic tank effluent samples that exceeded the residential waste strength definition and the percent of the septic tanks that exceed the definition on average.

In general, the two-compartment tanks performed better than the single compartment tanks on a per sample basis on all parameters except O&G. (The 2% of samples exceeding reported for TN in two-compartment tanks is not a statistically significant difference between the two populations.) When the individual septic tanks are compared, however, there is no difference in the performance for BOD_5. When the population of tanks serving households where long-term prescription drugs are used is removed from the data, the statistics change significantly. In all cases, two-compartment tanks perform better than one-compartment tanks on all parameters and none of the tanks exceed the waste strength definition for BOD_5.

Table 5-3. Percent of the samples and septic tanks that exceeded Oregon's residential waste strength definition.

Entire septic tank population	Percent of all samples exceeding				Percent of tanks exceeding			
	BOD_5	TSS	TN	O&G	BOD_5	TSS	TN	O&G
All STE (20 tanks)	33%	11%	1%	58%	30%	5%	0%	70%
1-compartment STE (10 tanks)	39%	17%	0%	54%	30%	10%	0%	30%
2-compartment STE (10 tanks)	27%	4%	2%	63%	30%	0%	0%	80%

Septic tanks with no prescription drugs	Percent of all samples exceeding				Percent of tanks exceeding			
	BOD_5	TSS	TN	O&G	BOD_5	TSS	TN	O&G
All STE (9 tanks)	24%	16%	1%	37%	22%	11%	0%	44%
1-compartment STE (5 tanks)	31%	25%	1%	59%	40%	20%	0%	60%
2-compartment STE (4 tanks)	13%	4%	1%	6%	0%	0%	0%	25%

Overall, it appears that the two-compartment septic tanks performed better than single compartment tanks on total suspended solids even when considering the median or geometric mean values. The BOD_5 reduction is slightly better but the difference is not statistically significant. A large number of septic tanks served residences where at least one person in the household is taking prescription medication for a long period of time.

The only parameter for which the Oregon residential waste strength definition appears to be consistently valid is for total nitrogen or total Kjeldahl nitrogen. This result was unexpected because one hypothesis was that the waste strength was greater because of water conserving fixtures. If that were the case, however, the TN results would have been much higher because of the lack of dilution. It appears that the waste strength may be more strongly influenced by chemically or biologically reactive inputs to the systems than water conserving fixtures. Also, given that eleven of the twenty single-pass septic tanks included in the project serve residents taking some kind of long-term prescription drug (four are families with children or young couples and seven are retired persons), chemically or biologically reactive inputs may be present in a significant proportion of the population in general.

Sand Filter performance

The La Pine Project monitored the performance of three bottomless and two lined sand filters as part of the field test program. The sampling for these systems occurred at the same frequency as the denitrifying systems in order to create a baseline of information for the performance of sand filters and as a benchmark for the performance of the denitrifying systems. The septic tank and sand filter effluent were sampled for chlorides in order to be able to correct for the effects of dilution from precipitation or irrigation. The sample location for the bottomless sand filter consisted of a 10 to 12 foot long and 10 to 12 inch diameter half-pipe placed at the sand/soil interface to intercept the effluent percolating through the sand bed below one of the distribution laterals. The sample location for the lined sand filter consisted of an access port in the discharge pipe of the sand filter where a small sump collected effluent for sampling purposes.

Table 5-4 provides the hydraulic and organic loading rates for the three bottomless sand filters in the La Pine Project. Table 5-5 provides the hydraulic and organic loading rates for the two lined sand filters in the study. The sand filters are designed for a hydraulic loading rate of 1.25 gpd/ft^2 and the actual mean and median loading rates are 0.3 gpd/ft^2, with even the range of hydraulic loading rates from 0.02-0.6 gpd/ft^2 staying well below the design rate.

The organic loading rate, however, is more difficult to discuss because there are few standards for organic loading. The Oregon onsite rule, for example, does not explicitly state an organic loading rate. A hydraulic loading rate is provided in terms of a maximum number of gallons that may be applied to a unit of land (0.5 to 1 acre depending on soil type) but an organic load is not specified for any wastewater treatment systems other than proprietary treatment devices. Some onsite professionals try to derive an organic loading standard based on the residential waste strength definition and the design flow rates for single family residences (DEQ, 2005). Using total nitrogen as an example, if the residential waste strength definition and the average and maximum design flow rates are applied, the maximums provided in Table 5-6 result. When these results are compared to the actual TN loading rates measured in the bottomless sand filters studied in the La Pine Project, the calculated TN mass load becomes meaningless, because rather than providing a minimum standard for performance, it could be construed as allowing an increase in the mass load applied to an individual lot.

Summaries of bottomless sand filter performance are provided in Tables 5-7 and 5-8, an example of a performance curve is provided in Figures 5-2 though 5-5, and the reductions achieved by lined sand filter are provided in Table 5-9. The data provided in Tables 5-8 and 5-9 and Figure 5-3 show that bottomless sand filters achieved large reductions in BOD_5 and TSS concentrations from septic tank effluent. Lined sand filters (Table 5-9) performed comparably for BOD_5 but the TSS results were significantly higher. These results are produced by sampling error because the design of the sampling port for the lined sand filter allowed soil and other detritus from the top of the sand filter to contaminate the samples.

The bacteria reductions were also high overall despite two individual high results (>100,000 CFU/100 ml) reported for System-B and System-A. These two extremely high results were not replicated and, therefore, it is unclear whether this is an indication of actual performance or the result of a sampling error. Table 5-10 provides the frequency with which the sand filters in the La Pine Project discharged various concentrations of fecal coliform. In general, the sand filters perform well as 94% of samples were less than 400 CFU/100 ml.

The phosphorus data shows that these sand filters achieved approximately 70% reduction on average. This may be a result of the sand used in sand filter construction in the La Pine region and this level of reduction may not be achievable in other regions where the sand used is of a different composition.

The nitrogen species data for the three bottomless sand filter systems are provided in Figures 5-1, 5-3 and 5-4. Overall the systems produced completely nitrified effluent from the beginning of the sample record. System-H3 (Figure 5-5) provided one exception in December 2002 and February 2003 when it discharged elevated ammonium and lowered nitrate concentrations. This effluent quality coincided with a field observation during the December 2002 sampling event that the sand filter effluent was tinged blue. The project team contacted the homeowners shortly after this sampling event to remind them not to use “every flush” toilet bowl cleaners/deodorizers and the sand filter effluent returned to normal over the next two to four months. These products contain potent anti-bacterial agents that affect the biological organisms that treat wastewater.

There is little nitrogen reduction achieved by bottomless sand filters in this study, between 7 and 12%, based on the mean and median values, respectively. Lined sand filters appeared to have higher denitrification rates (Table 5-9) but the differences in TN in the sand filter effluent from the two types of sand filters is not statistically significant (99% confidence level). This result is different than the results commonly quoted by onsite professionals in Oregon because an early study of sand filter performance in the state indicated that sand filters achieved nearly 50% reduction in total nitrogen (Oregon DEQ, 1982; also referred to in Ronayne et al, 1984). There are two fundamental differences between the study reported in 1982 and the La Pine Project: the geographical and climate conditions and the sampling program design. Both of these factors have an influence on the reported nitrogen reduction from the 1982 study and which were accounted for in the La Pine Project.

An early hypothesis for the difference in performance between the two studies is the difference in climate and physical conditions of the test sites. The 1982 study involved four sand filters installed in Douglas County in Western Oregon. The general climate conditions of the two areas are presented in Table 5-11. The weather data for the La Pine Project study area represents the years during which the sand filters were sampled (beginning late 2000 and ending in late 2003) while the weather information from Douglas County was taken from the county website because the 1982 report does not provide the weather or ambient conditions during that study period. In general, the La Pine Project study area experienced lower temperatures during the winter months and comparable summer high temperatures than Douglas County. The diurnal temperature range is also greater in the La Pine region, representing lower overnight temperatures, even in the summer months. Total precipitation is nearly three times greater in Douglas County than in the La Pine study area. (Douglas County, 2005; Sunriver weather station, *written communication*)

The first hypothesis as to why sand filters perform better in Douglas County vs. the La Pine Project area is that the climate differences adversely impact denitrification. The literature shows that denitrification rates are temperature dependent in that denitrification declines when the temperature declines (Sutton et al, 1975; Lewandowski, 1982; Crites et al, 1998). Figure 5-2 plots the high and low temperatures against the nitrogen species concentrations in the effluent for a bottomless sand filter in the La Pine Project. The figure shows an apparent correlation between the temperature fluctuations and the nitrogen concentrations although the calculated correlation is relatively poor (r = 0.6). On closer review, however, the nitrogen concentrations decline when the temperatures decline which implies that nitrogen concentrations in the effluent are reduced more at low temperatures rather than at higher temperatures as would be expected. Given the body of work performed on the temperature relationship for denitrification, denitrification does not appear to be the operative mechanism affecting the change in seasonal nitrogen concentrations in these systems.

Figure 5-2 also provides the sand filter effluent temperature (taken from the half-pipe lysimeter at the sand/soil interface). The sand filter effluent temperature parallels the ambient temperatures reported for the overall study area, possibly because the collection time required (24-72 hours) to obtain sufficient sample volume for analyses is long and thus allowed the sample to be strongly influenced by ambient temperatures. A better indicator of the temperature within the sand filter might be the septic tank effluent temperature as this is the temperature of the effluent that is dosed to the sand filter. However, when the charted data is reviewed, the septic tank temperature also parallels the ambient temperatures but moderates the low values so that the effluent rarely cooled to less than 50˚F. This is a temperature at which denitrification rates should be extremely low; however, the lowest temperature periods still coincide with the lowest nitrogen concentrations of the sample record. Figures 5-4 and 5-5 provide the nitrogen species and temperature plots of the data for System-H3 and System-A respectively, which are similar to the chart for System-B.

This data does not appear to support the hypothesis that the colder overall climate conditions adversely affect denitrification in the La Pine Project sand filters. Hinkle et al (2008) describes additional La Pine Project work on the characterization of nitrogen reduction processes in sand filters. This work included an evaluation of the nitrogen isotopes contained in septic tank and sand filter effluent samples, which indicates that denitrification, rather than ammonium adsorption, occurs in mature sand filters; ammonium adsorption may dominate the nitrogen reduction capacity of sand filters during the sand filter maturation period. Further investigation is required to define the reasons why sand filters would appear to perform better during the cold periods of the year.

The second difference between the two studies is influenced by the interplay between precipitation and sampling program design. The 1982 DEQ study took place in a region that receives an average of 34 inches of precipitation, primarily rainfall, per year. The La Pine Project study area received an average of 13 inches per year during the study period, most of which fell in the form of snow. The USGS estimates (Morgan et al, 2008) that between 1-2 inches of the total annual precipitation reaches the water table, which indicates that most of the precipitation evaporates, transpires or discharges to surface water. As a result, onsite wastewater system effluent is not greatly diluted as it is dispersed in the soil absorption field. The sand filters in both the La Pine Project and the 1982 DEQ study were designed and installed so that the filter is unprotected from rainfall or snowmelt infiltrating the sand bed. In order to account for any dilution (or evaporation) effects, the La Pine Project sampling program required chloride analyses for the septic tank and treatment process effluent samples. The 1982 DEQ study did not include chloride analyses in the sampling plan and so any dilution effects cannot be accounted for in the reported results. Other commonly used references for nitrogen reduction in sand filters (Crites et al, 1998; US EPA, 2002) do not indicate whether the compiled data is corrected for dilution effects, therefore it is difficult to directly compare other warm climate installations with the 1982 study results. Other studies of sand filter performance in the Midwest (Converse et al, 1999) indicate that chloride samples were taken in conjunction with the other parameters in the study. This study in particular used the chloride results to define increased dilution in the winter and spring months over the summer months. However, no correction for dilution in the sand filter or soil absorption data was reported.

The La Pine project data indicate that sand filters achieve some denitrification. The effect of seasonal temperature changes on denitrification is unclear and the effects of dilution can be corrected to define the actual concentration of TN discharged to the environment. The 1982 DEQ study implies that sand filters achieve nearly 50% nitrogen reduction, but without correcting these results for dilution it is impossible to say whether the reduction is due to dilution or denitrification.

Table 5-4. Hydraulic and organic loading rates for the bottomless sand filters in the La Pine Project.

All bottomless sand filters	Daily flow rate (gpd)	Hydraulic loading rate (gpd/ft^2)	BOD$_5$ (mg/L)	BOD$_5$ (lb/yr)	TN (mg/L)	TN (lb/yr)	Total Phosph. (mg/L)	Total P (lb/yr)
Mean	122	0.3	3.0	0.9	51	19	3.5	1.2
Geometric Mean	102	0.3	N/A	N/A	56	13	3.1	1.0
Median	109	0.3	1.5	0.6	50	19	3.1	1.2
Standard Deviation	54	0.1	6.6	1.6	29	10	1.5	0.7
Minimum	6.5	0.02	ND	0.0	ND	0.4	0.9	0.1
Maximum	223	0.6	50	12	151	37	8.2	3.5
Count	60	60	60	56	66	60	64	59
95% Confidence Level	14	0.04	1.7	0.4	7.0	2.6	0.4	0.17
99% Confidence Level	19	0.005	2.3	0.6	9.3	3.5	0.5	0.23

System-H3	Daily flow rate (gpd)	Hydraulic loading rate (gpd/ft^2)	BOD$_5$ (mg/L)	BOD$_5$ (lb/yr)	TN (mg/L)	TN (lb/yr)	Total Phosph. (mg/L)	Total P (lb/yr)
Mean	175	0.5	1.7	0.9	48	25	3.0	1.5
Geometric Mean	172	0.5	N/A	N/A	46	22	2.8	1.4
Median	179	0.5	1.3	0.7	50	27	2.8	1.5
Standard Deviation	30	0.1	1.3	0.7	12	8.7	1.3	0.5
Minimum	75	0.2	ND	0.0	26	0.7	1.7	0.4
Maximum	223	0.6	4.3	2.8	66	37	8.2	2.8
Count	24	24	21	22	23	24	23	24
95% Confidence Level	12	0.03	0.6	0.3	5.2	3.7	0.6	0.2
99% Confidence Level	17	0.05	0.8	0.4	7.1	5.0	0.8	0.3

System-B	Daily flow rate (gpd)	Hydraulic loading rate (gpd/ft^2)	BOD$_5$ (mg/L)	BOD$_5$ (lb/yr)	TN (mg/L)	TN (lb/yr)	Total Phosph. (mg/L)	Total P (lb/yr)
Mean	98	0.3	1.5	1.2	44	13	3.5	1.1
Geometric Mean	85	0.2	N/A	N/A	45	10	3.3	0.9
Median	97	0.3	1.1	0.4	46	14	3.1	1.0
Standard Deviation	35	0.1	1.5	3.0	16	7.8	1.3	0.5
Minimum	6.5	0.02	ND	0.0	ND	1.0	1.8	0.1
Maximum	153	0.4	6.2	12	68	27	6.2	2.1
Count	16	16	17	15	19	16	18	15
95% Confidence Level	19	0.05	0.7	1.7	7.9	4.2	0.7	0.3
99% Confidence Level	26	0.07	1.0	2.3	11	5.8	0.9	0.4

System-A	Daily flow rate (gpd)	Hydraulic loading rate (gpd/ft^2)	BOD$_5$ (mg/L)	BOD$_5$ (lb/yr)	TN (mg/L)	TN (lb/yr)	Total Phosph. (mg/L)	Total P (lb/yr)
Mean	78	0.2	2.6	0.8	81	15	3.5	1.0
Geometric Mean	73	0.2	N/A	0.5	76	9.3	3.2	0.8
Median	67	0.2	1.7	0.4	79	18	3.5	0.9
Standard Deviation	31	0.1	3.4	0.7	29	9.3	1.5	0.8
Minimum	41	0.1	ND	0.07	45	0.4	0.9	0.1
Maximum	162	0.5	14	2.4	151	27	7.1	3.5
Count	20	20	15	19	17	20	17	20
95% Confidence Level	14	0.04	1.9	0.3	15	4.4	0.8	0.4
99% Confidence Level	20	0.06	2.6	0.5	21	5.9	1.1	0.5

Hydraulic loading rate based on 360 ft^2 sand filter
ND = non detect; N/A = statistic not calculable

Table 5-5. Hydraulic and organic loading rates for the lined sand filters in the La Pine Project.

All lined sand filters	***Daily flow rate (gpd)***	***Hydraulic loading (gpd/ft^2)***	***BOD_5 (mg/L)***	***BOD_5 (lb/yr)***	***TN (mg/L)***	***TN (lb/yr)***	***Total Phosphorus (mg/L)***	***TP (lb/yr)***
Mean	148	0.4	3.8	2.0	52	23	4.6	2.1
Geometric Mean	141	0.4	N/A	N/A	50	21	4.2	1.8
Median	151	0.4	2.1	0.9	52	25	4.6	1.9
Standard Deviation	47	0.1	4.6	3.0	12	8.2	1.7	1.2
Minimum	36	0.1	ND	0.0	8.3	2.6	1.7	0.5
Maximum	243	0.7	25	17	78	40	8.4	4.8
Count	47	47	48	47	48	47	48	47
95% Confidence Level	14	0.04	1.3	0.9	3.6	2.4	0.5	0.3
99% Confidence Level	19	0.05	1.8	1.2	4.8	3.2	0.7	0.5

System-F	***Daily flow rate (gpd)***	***Hydraulic loading (gpd/ft^2)***	***BOD_5 (mg/L)***	***BOD_5 (lb/yr)***	***TN (mg/L)***	***TN (lb/yr)***	***Total Phosphorus (mg/L)***	***TP (lb/yr)***
Mean	125	0.3	2.8	1.0	54	20	4.8	1.8
Geometric Mean	118	0.3	N/A	N/A	50	18	4.4	1.6
Median	132	0.4	2.1	0.8	56	18	5.0	1.7
Standard Deviation	37	0.1	2.7	1.0	16	9.2	1.8	0.9
Minimum	36	0.1	ND	0.0	8.3	2.6	1.9	0.6
Maximum	189	0.5	11	3.7	78	39	8.4	4.0
Count	24	24	24	24	24	24	24	24
95% Confidence Level	16	0.04	1.1	0.4	6.8	3.9	0.8	0.4
99% Confidence Level	21	0.06	1.5	0.6	9.2	5.3	1.1	0.5

System-S	***Daily flow rate (gpd)***	***Hydraulic loading (gpd/ft^2)***	***BOD_5 (mg/L)***	***BOD_5 (lb/yr)***	***TN (mg/L)***	***TN (lb/yr)***	***Total Phosphorus (mg/L)***	***TP (lb/yr)***
Mean	172	0.5	4.8	2.9	51	26	4.3	2.5
Geometric Mean	164	0.5	N/A	N/A	50	25	4.1	2.1
Median	175	0.5	2.1	1.3	51	27	4.4	2.4
Standard Deviation	45	0.1	5.9	4.1	7.2	6.2	1.6	1.4
Minimum	67	0.2	ND	0.0	38	12	1.7	0.5
Maximum	243	0.7	25	17	64	40	6.8	4.8
Count	23	23	24	23	24	23	24	23
95% Confidence Level	20	0.05	2.5	1.8	3.0	2.7	0.7	0.6
99% Confidence Level	27	0.07	3.4	2.4	4.1	3.6	0.9	0.8

ND = non detect N/A = statistic not calculable

Table 5-6. Potential and actual mass loading from bottomless sand filters in the La Pine Project.

Mass loading from bottomless sand filters (lb/yr)	**Design TN (@ 150 mg/L)**	**Actual BSF TN loading (@ 51 mg/L)**
Average = 225 gpd	103	35
Max = 450 gpd	205	70
Actual BSF average = 122 gpd	56	19

Table 5-7. Bottomless sand filter effluent statistics.

All bottomless sand filter effluent (SFE) after maturation	BOD$_5$ (mg/L)	TSS (mg/L)	TN (mg/L)	TN without dilution	Total Phosphorus (mg/L)	Fecal Coliform	Log Fecal	E. Coli	Log E. coli	GPD
Mean	3.0	4.7	51	56	3.5	3.2E+04	1.2	2.6E+04	1.1	115
Geometric Mean	N/A	N/A	56	48	3.1	15	N/A	12	N/A	
Median	1.5	2.0	50	54	3.1	10	1.0	6	0.8	99
Standard Deviation	6.6	8.1	29	17	1.5	2.4E+05	1.1	2.0E+05	1.1	54
Minimum	ND	ND	ND	29	0.9	ND	0.0	ND	0.0	71
Maximum	50	47	151	92	8.2	1.9E+06	6.3	1.6E+06	6.2	175
Count	60	60	66	49	64	64	64	64	64	3
95% Confidence Level	1.7	2.1	7.0	5.0	0.4	5.9E+04	0.3	5.0E+04	0.3	133
99% Confidence Level	2.3	2.8	9.3	6.7	0.5	7.9E+04	0.4	6.6E+04	0.4	308

System-H3 SFE after maturation	BOD$_5$ (mg/L)	TSS (mg/L)	TN (mg/L)	TN without dilution	Total Phosphorus (mg/L)	Fecal Coliform	Log Fecal	E. Coli	Log E. coli	GPD
Mean	1.7	5.8	48	55	3.0	67	1.2	58	1.0	175
Geometric Mean	N/A	N/A	46	30	2.8	16	N/A	11	N/A	
Median	1.3	2.5	50	50	2.8	20	1.3	10	1.0	179
Standard Deviation	1.3	8.2	12	17	1.3	161	0.8	150	0.7	30
Minimum	ND	ND	26	31	1.7	ND	0.0	ND	0.0	75
Maximum	4.3	37	66	92	8.2	760	2.9	680	2.8	223
Count	21	22	23	18	23	23	23	23	23	24
95% Confidence Level	0.6	3.6	5.2	8.3	0.6	69	0.3	65	0.3	12
99% Confidence Level	0.8	5.0	7.1	11	0.8	94	0.4	88	0.4	17

System-B SFE after maturation	BOD$_5$ (mg/L)	TSS (mg/L)	TN (mg/L)	TN without dilution	Total Phosphorus (mg/L)	Fecal Coliform	Log Fecal	E. Coli	Log E. coli	GPD
Mean	1.5	1.9	44	55	3.5	6.6E+03	1.4	4.6E+03	1.3	99
Geometric Mean	N/A	N/A	45	50	3.3	23	0.9	22	1.0	
Median	1.1	1.0	46	53	3.1	11	1.0	12	1.1	95
Standard Deviation	1.5	2.1	16	15	1.3	2.9E+04	1.2	2.0E+04	1.1	37
Minimum	ND	ND	ND	29	1.8	ND	0.3	ND	0.3	6.5
Maximum	6.2	9.0	68	85	6.2	1.3E+05	5.1	9.0E+04	5.0	167
Count	17	17	19	15	18	20	20	20	20	19
95% Confidence Level	0.7	1.1	7.9	8.5	0.7	1.4E+04	0.6	9.4E+03	0.5	18
99% Confidence Level	1.0	1.5	11	12	0.9	1.9E+04	0.8	1.3E+04	0.7	25

System-A SFE after maturation	BOD$_5$ (mg/L)	TSS (mg/L)	TN (mg/L)	TN without dilution	Total Phosphorus (mg/L)	Fecal Coliform	Log Fecal	E. Coli	Log E. coli	GPD
Mean	2.6	6.5	81	60	3.5	9.0E+04	1.0	7.6E+04	0.9	71
Geometric Mean	N/A	N/A	76	72	3.2	9	N/A	8	N/A	
Median	1.7	3.0	79	59	3.5	2	0.3	2	0.3	66
Standard Deviation	3.4	12	29	20	1.5	4.1E+05	1.3	3.5E+05	1.3	37
Minimum	ND	ND	45	31	0.9	ND	0.0	ND	0.0	0
Maximum	14	47	151	91	7.1	1.9E+06	6.3	1.6E+06	6.2	162
Count	15	14	17	16	17	21	21	21	21	23
95% Confidence Level	1.9	6.9	15	11	0.8	1.9E+05	0.6	1.6E+05	0.6	16
99% Confidence Level	2.6	9.7	21	15	1.1	2.6E+05	0.8	2.2E+05	0.8	21

ND = non detect N/A = statistic not calculable

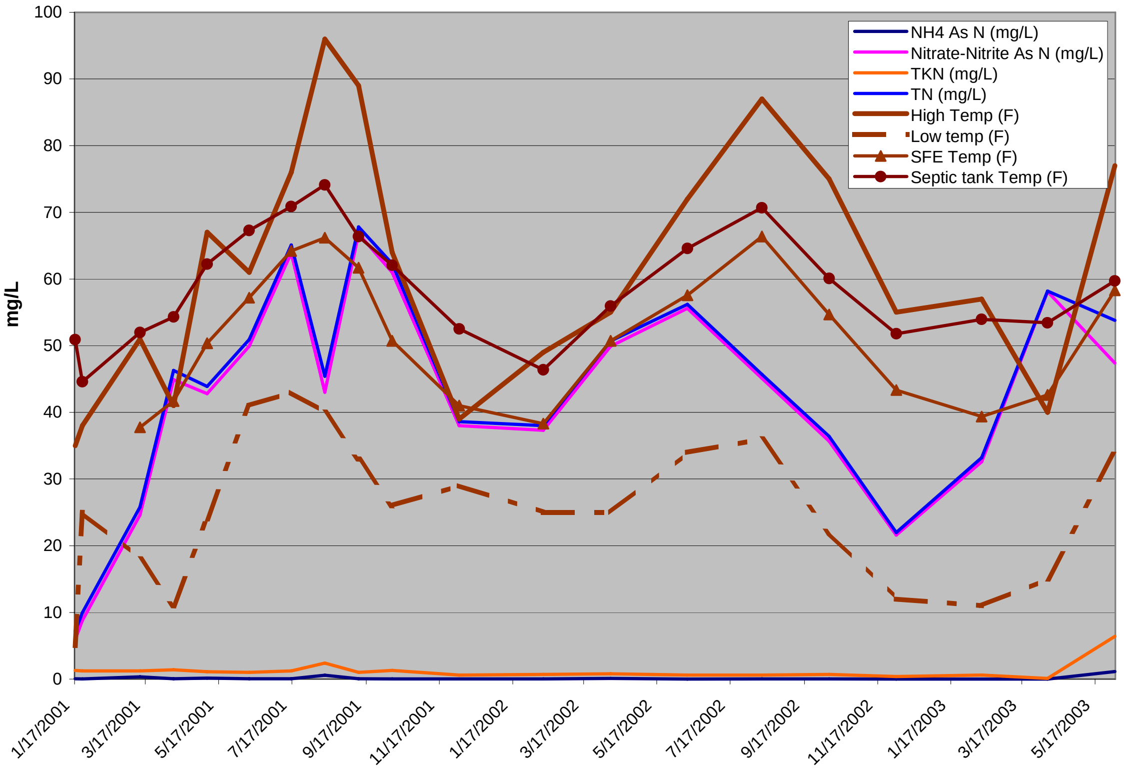

Figure 5-2. System-B bottomless sand filter nitrogen species over time.

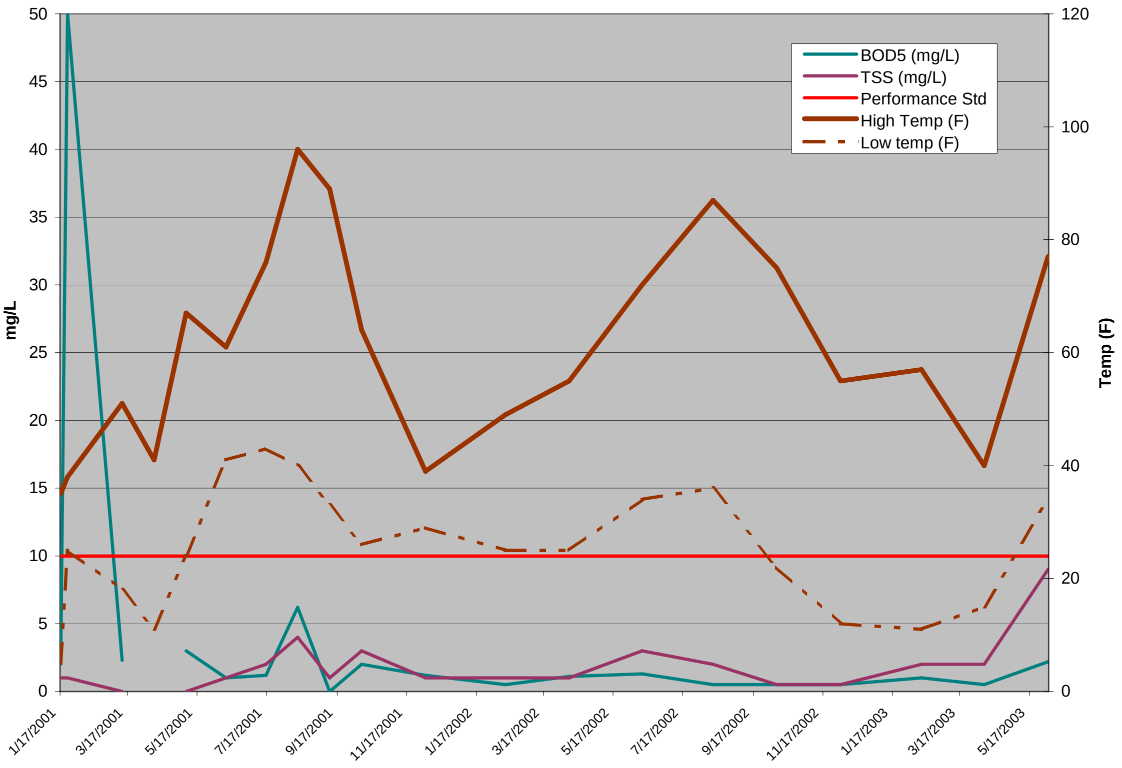

Figure 5-3. System-B bottomless sand filter BOD_5 & TSS over time.

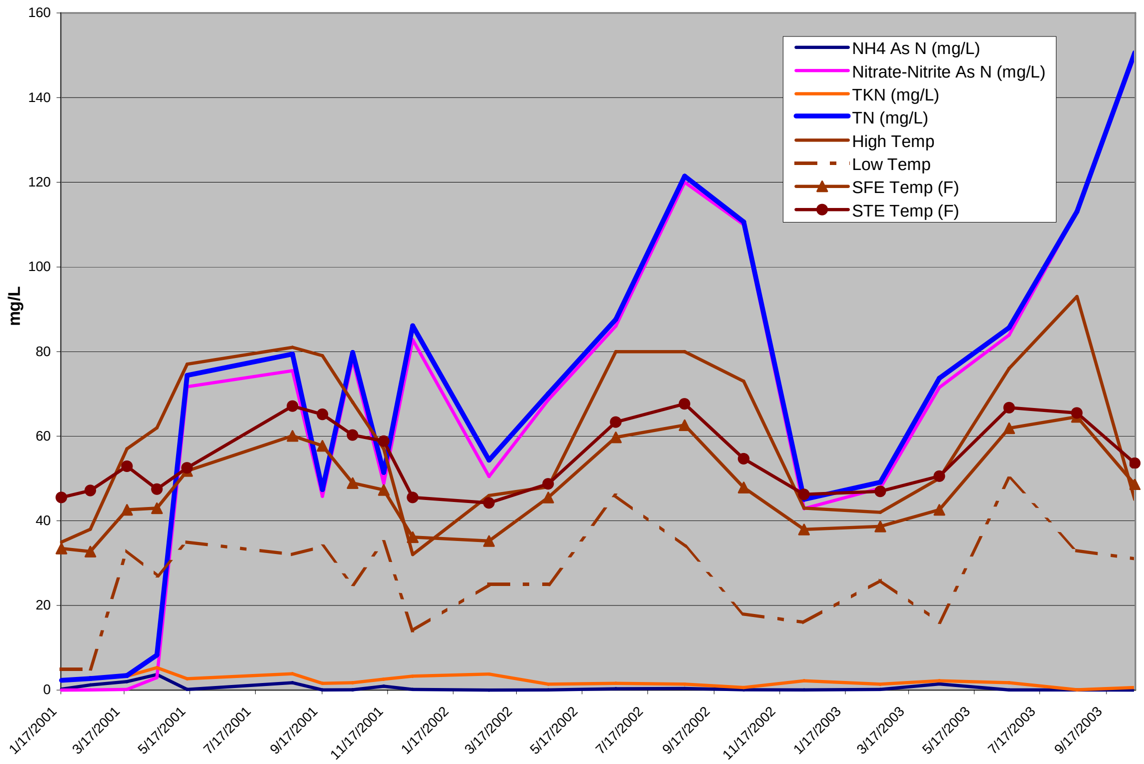

Figure 5-4. System-A bottomless sand filter nitrogen species over time.

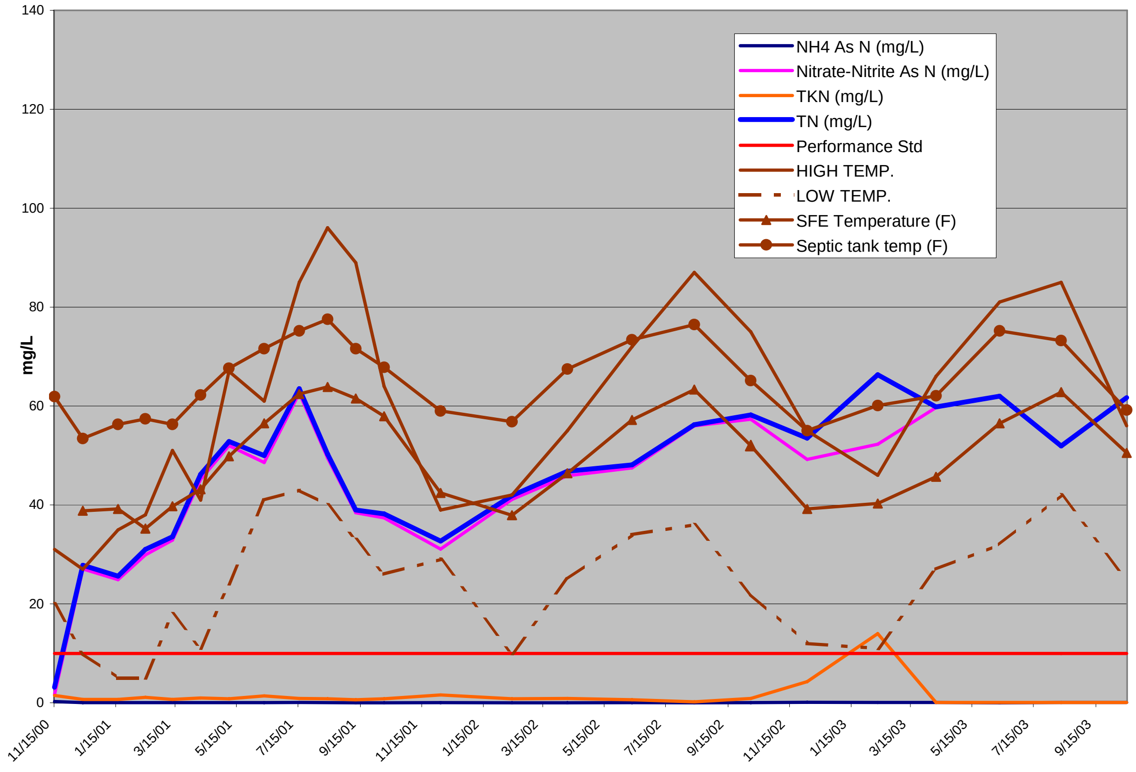

Figure 5-5. System-H3 bottomless sand filter nitrogen species over time.

Table 5-8. Reductions achieved by bottomless sand filters in the La Pine Project.

All bottomless sand filter effluent after maturation	***BOD_5 (mg/L)***	***TSS (mg/L)***	***TN without dilution***	***Total Phosphorus (mg/L)***	***Fecal Coliform***	***Log Fecal***	***E. coli***	***Log E. coli***
Mean	3.0	4.7	56	3.5	3.2E+04	1.2	2.6E+04	1.1
Geometric Mean	N/A	N/A	48	3.1	15	N/A	12	N/A
Median	1.5	2.0	54	3.1	10	1.0	6	0.8
Standard Deviation	6.6	8.1	17	1.5	2.4E+05	1.1	2.0E+05	1.1
Minimum	ND	ND	29	0.9	ND	ND	ND	ND
Maximum	50	47	92	8.2	1.9E+06	6.3	1.6E+06	6.2
Count	60	60	49	64	64	64	64	64
95% Confidence Level	1.7	2.1	5.0	0.4	5.9E+04	0.3	5.0E+04	0.3
99% Confidence Level	2.3	2.8	6.7	0.5	7.9E+04	0.4	6.6E+04	0.4

All BSF systems' septic tank effluent	***BOD_5 (mg/L)***	***TSS (mg/L)***	***TN (mg/L)***	***Total Phosphorus (mg/L)***	***Fecal Coliform***	***Log Fecal***	***E. coli***	***Log E. coli***
Mean	288	112	61	11	9.9E+05	4.5	8.2E+05	4.4
Geometric Mean	257	71	59	10	5.1E+04	4.2	4.1E+04	4.2
Median	270	66	62	9.8	4.0E+04	4.6	2.7E+04	4.4
Standard Deviation	140	204	20	11	4.5E+06	1.2	3.7E+06	1.2
Minimum	22	10	8.6	4.2	ND	ND	ND	ND
Maximum	710	1600	120	96	3.3E+07	7.5	2.8E+07	7.4
Count	70	70	70	70	70	70	70	70
95% Confidence Level	33	49	4.8	2.5	1.1E+06	0.3	8.8E+05	0.3
99% Confidence Level	44	65	6.4	3.4	1.4E+06	0.4	1.2E+06	0.4

Reduction achieved by Bottomless Sand Filters - All systems	***BOD_5 (mg/L)***	***TSS (mg/L)***	***TN (mg/L)***	***Total Phosphorus (mg/L)***	***Fecal Coliform***	***Log Reduction Fecal***	***E. coli***	***Log Reduction E. coli***
Calculated from Mean	99%	96%	7%	70%	96.79%	3.3	96.77%	3.3
Calc. from Geom. Mean	N/A	N/A	18%	70%	99.97%	N/A	99.97%	N/A
Calc. from Median	99%	97%	12%	69%	99.98%	3.6	99.98%	3.6

ND = non detect N/A = statistic not calculable

Table 5-9. Reductions achieved by lined sand filters in the La Pine Project.

Two Systems SFE	BOD$_5$ (mg/L)	TSS (mg/L)	TN (mg/L)	TN without dilution	Total Phosphorus (mg/L)	Fecal Coliform	Log Fecal	E. coli	Log E. coli
Mean	3.8	154	52	51	4.6	718	1.1	516	1.0
Geometric Mean	1.0	117	50	49	4.2	13	0.7	10	0.6
Median	2.1	125	52	50	4.6	4	0.6	ND	0.3
Standard Deviation	4.6	154	12	15	1.7	2.8E+03	1.1	2.0 E+03	1.0
Minimum	ND	19	8.3	9.2	1.7	ND	0.3	ND	0.3
Maximum	25	750	78	92	8.4	1.7 E+04	4.2	1.2 E+04	4.1
Count	48	48	48	36	48	48	48	48	48
95% Confidence Level	1.3	45	3.6	5.2	0.5	826	0.3	591	0.3
99% Confidence Level	1.8	60	4.8	7.0	0.7	1.1E+03	0.4	789	0.4

Two Systems STE	BOD$_5$ (mg/L)	TSS (mg/L)	TN (mg/L)		Total Phosphorus (mg/L)	Fecal Coliform	Log Fecal	E. coli	Log E. coli
Mean	264	88	63		12	5.2E+07	6.2	4.0E+07	5.9
Geometric Mean	249	76	62		12	7.1E+06	6.1	3.3E+06	5.8
Median	250	75	61		12	7.8E+05	5.9	4.6E+05	5.7
Standard Deviation	111	56	11		2.4	1.5E+08	1.3	1.3E+08	1.4
Minimum	130	19	43		9.0	1.6E+03	3.2	370	2.6
Maximum	680	340	96		19	7.7E+08	8.9	7.4E+08	8.9
Count	47	47	46		47	47	47	47	47
95% Confidence Level	33	17	3.4		0.7	4.5E+07	0.4	3.7E+07	0.4
99%Confidence Level	44	22	4.5		0.9	6.0E+07	0.5	5.0E+07	0.5

Reduction over two systems	BOD$_5$ (mg/L)	TSS (mg/L)		TN w/o dilution (mg/L)	Total Phosphorus (mg/L)	Fecal Coliform	Log Fecal	E. coli	Log E. coli
Calculated from Mean	98.6%	N/A		18.3%	62.9%	99.9986%	5.1	99.9987%	4.9
Calc. from Geo. Mean	99.6%	N/A		21.5%	65.3%	99.9998%	5.4	99.9997%	5.2
Calc. from Median	99.2%	N/A		17.7%	60.8%	99.9995%	5.3	100.000%	5.4

ND = non detect N/A = statistic not calculable

Table 5-10. Frequency of sand filter effluent concentrations for fecal coliforms.

Counts in SFE (CFU/100 ml)	Percent of Fecal Coliform samples less than count
ND	40%
100	83%
200	90%
400	94%
1,000	95%
10,000	97%
>10,000	100%
Number of Samples	112

ND = non detect

Table 5-11. Climate conditions in Douglas County and the La Pine Project study area, Oregon.

	Douglas County	La Pine Project Study area
Average annual precipitation (in)	34	13
January low temp	34	22
January high temp	48	40
April low temp	39	25
April high temp	63	55
July low temp	53	42
July high temp	84	87
October low temp	43	24
October high temp	67	62

USGS study

Mass balance and isotope effects during nitrogen transport through septic tank systems with packed-bed (sand) filters (2008)

S.R. Hinkle, U.S. Geological Survey
J.K. Böhlke, U.S. Geological Survey
L.H. Fisher, U.S. Geological Survey

Several studies of sand filters have been published over the past several decades. In most of these studies, nitrogen concentrations leaving sand filters were shown to be lower than those entering the sand filters. These apparent losses have usually been attributed to denitrification. However, although dilution (with precipitation) and (ammonium) adsorption may explain these apparent losses, these processes generally have not been considered. Furthermore, no evidence to support denitrification in these macroscopically oxic environments, other than nitrogen concentration data, has been provided to support the hypothesis of denitrification.

Nitrogen loss in sand filters, from denitrification or ammonium sorption, may have significance beyond just sand filters in and of themselves, because processes controlling nitrogen movement and fate in sand filters may also occur in unsaturated zones in sand above aquifers. Thus, in an effort to generate an improved understanding of nitrogen movement and fate in sand filters, and through analogy, in unsaturated sand, a study of nitrogen fate in sand filters was undertaken. This work, which focuses on sand filter and other unsaturated-zone processes, complements other USGS work in the La Pine study area, which focused on saturated-zone processes.

The sand filter work involved three components. One component was a network of five non-recirculating sand filters in the La Pine area that were monitored over a period of about three years as part of the NDP La Pine project. Septic tank and sand filter effluent nitrogen species and chloride concentration data from the NDP La Pine project were complemented with occasional sampling for nitrogen isotopes. This network of sand filters is referred to as the maturing sand filter network. The resulting data set provides temporal characterization of sand filter effluent from early in their operation into a period of apparent maturity.

A second component was a network of 12 existing, non-recirculating mature sand filter systems sampled by DCEHD and ODEQ in October, 2001. Samples of septic tank effluent and sand filter effluent were analyzed for N and Cl^- concentrations, and isotopes of N. This part of the study is referred to as the mature sand filter synoptic. The data provide characterization of mature sand filter effluent, complementing data from the maturing sand filter network.

A third component consisted of laboratory column experiments to investigate adsorption characteristics of ammonium to La Pine sand filter sediment. These laboratory data complemented field investigations.

Differences between N concentrations in septic tank effluent (sand filter input) and sand filter effluent (sand filter output) were found to be affected by evaporative concentration. The net evaporative effect, opposite of a dilutive effect, apparently was a response to evaporative effects exceeding dilutive effects in this semiarid study area. Chloride concentrations were used to normalize sand filter effluent samples for effects of evaporation. Chloride-normalized nitrogen concentrations indicated nitrogen losses in these sand filters, consistent with observations in most other studies of sand filters. Nitrogen isotopic data indicated fractionation of nitrogen isotopes, with residual nitrogen isotopically enriched relative to septic tank nitrogen. This isotopic effect is consistent with denitrification, and opposite in effect to that expected for ammonium adsorption. These data thus support a hypothesis of denitrification in mature sand filters.

Early-time data (early stages of maturing sand filters) were sparse because of an absence of chloride data in some early-time samples. The early-time data do show some hints of ammonium adsorption, and the column experiments demonstrated a strong adsorption capacity in the volcanic sand used in some La Pine sand filters. These data suggest that sand filters might lose some ammonium to adsorption during early use, but ammonium adsorption capacity likely becomes saturated after an initial period of use. However, early-time data were not sufficient to draw definitive conclusions regarding ammonium adsorption.

These findings have been published by Hinkle, et al, 2008 and the USGS incorporated these results into the groundwater and nitrate transport model.

Conclusion

The La Pine Project monitored the septic tank effluent of nineteen 1,500 gallon and one 1,000 gallon septic tanks for approximately 3 years each. The septic tank population included 10 one-compartment and 10 two-compartment tanks. Residential waste strength appears to have increased since the Oregon onsite rules established a definition to delineate permitting jurisdictions within the state with some portion of the increases in waste strength possibly resulting from concentration due to low water use either from water conserving practices within the home or water conserving plumbing fixtures. The greater effect on waste strength appears to stem from the common use of prescription drugs, including long-term antibiotics and chemotherapy medications. Over 50% of the residences participating in the La Pine Project used prescription medications and, when these households were removed from the dataset, the performance of the septic tanks is better than the total sample population, particularly the performance of two-compartment tanks. The results from this study indicate that residences can be the source of high waste strength.

Sand filter performance in the La Pine Project area is different from the performance of sand filters in Western Oregon reported by Oregon DEQ in a study published in 1982. Seasonal temperature fluctuations do not appear to affect the La Pine Project sand filter systems because the higher summer temperatures do not correlate to higher denitrification rates. The study area for the 1982 DEQ report received a quantity of rainfall that could significantly dilute onsite system effluent as it dispersed in the soil absorption unit. Given the lack of a correction for dilution in the 1982 study and the apparent lack of temperature effects in the La Pine Project systems, it appears that the nitrogen reduction reported in the La Pine Project may be more representative of the sand filters' actual denitrification capability.

In general, the sand filters in the La Pine Project reduced septic tank effluent concentrations for BOD_5 and TSS to levels well below 10 mg/L. Reductions achieved in fecal and E. coli counts exceeded a 3-log reduction based on median values. The nitrogen in sand filter effluent was almost completely transformed from TKN to NO_3 and TN reductions ranged between 7% and 22%, including corrections for the diluting effects of precipitation or irrigation. Based on this information, single-pass intermittently dosed sand filters can be relied upon for nitrogen transformation but not reduction.

References

Burks, B.D. and M.M. Minnis. 1994. *Onsite Wastewater Treatment Systems*. Hogwarth House, Limited, Madison, WI.

Crites, R., G. Tchobanoglous, 1998. *Small and decentralized wastewater management systems*. McGraw-Hill, Boston, MA.

Douglas County, 2005. *Douglas County Oregon e-Government.* http://www.co.douglas.or.us/overview.asp, downloaded 8/28/05.

Hinkle, S.R., J.K. Bohlke, J.H. Duff, D.S. Morgan, R.J. Weick, 2007. *Aquifer-scale controls on the distribution of nitrate and ammonium in groundwater near La Pine, Oregon, USA.* Journal of Hydrology, 333, 486-503.

Hinkle, S.R., J.K. Böhlke, L.H. Fisher, 2008. *Mass balance and isotope effects during nitrogen transport through septic tank systems with packed-bed (sand) filters*. Science of the Total Environment, 407 (2008), 324-332.

Lewandowski, Z., 1982. *Temperature dependency of biological denitrification with organic materials addition.* Water Research, 16, 12-22.

Ronayne, M.A., R.C. Paeth, and S.A. Wilson, 1984. *Oregon Onsite Experimental Systems Program, EPA/600/2-84-157*. Oregon Department of Environmental Quality. US Environmental Protection Agency, Office of Research and Development, Washington, DC.

Morgan, D.S., S.R. Hinkle, R.W. Weick, 2007. *Evaluation of Approaches for Managing Nitrate Loading from On-Site Wastewater Systems near La Pine, Oregon.* Scientific Investigations Report 2007-5237, 66 p.

Oregon Department of Environmental Quality, 1982. *Final Report: Oregon On-Site Experimental Systems Program.* Oregon Department of Environmental Quality, Portland, OR.

Sutton, P.M, KL Murphy, RN Dawson, 1975. *Low temperature biological denitrification of wastewater.* Journal of Water Pollution Control Federation, 47, 122-134.