

Treatment performance of advanced onsite wastewater treatment systems in the Otsego Lake watershed, 2008 results

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INTRODUCTION

This report serves to document the treatment performance monitored for two of the systems installed as a part of a NYS DEC grant to demonstrate the use of advanced onsite wastewater treatment systems, and one additional system that was installed on BFS property to serve the Upland Interpretive Center (UIC). Treatment performance was assessed based on the following analyses: biochemical oxygen demand (BOD or CBOD), total suspended solids (TSS), nitrate, ammonia, and total phosphorus (TP). An historical overview of Otsego Lake's nutrient loading and onsite wastewater treatment is provided below.

Otsego Lake is located in northern Otsego County, New York. According to the historical overview by Harman, et al. (1997), the monitoring of Otsego Lake's water quality dates back to a 1935 NYS Department of Environmental Conservation (DEC) study. Routine water quality monitoring efforts began subsequent to the establishment of the Biological Field Station (BFS) in 1968 (Harman, et al. 1997). Comparisons to these and other historical datasets had shown overall decreasing water quality conditions, noting in particular increased phosphorous concentrations likely tied to loading from watershed activities (agriculture, road maintenance, onsite wastewater treatment, etc.). Onsite wastewater treatment (septic) systems are estimated to contribute only 7% of the total phosphorus load (Albright 1996), though the combination of the bio-available form and time of greatest loading at the height of the growing season is likely to lead to stimulation of algal production (Harman, et al. 1997). The cascading effects of such nutrient loading on the lake's ecosystem are far-reaching, and began to concern lake users and the Village of Cooperstown, which uses Otsego Lake as its source of drinking water. In 1985, the Village implemented public Health Law 1100 in order to give them legal grounds to protect the lake as their source of drinking water (Harman, et al. 1997). Additional actions to curb further water quality degradation in the lake culminated in the formation of a watershed management plan in 1998, which identified nutrient loading as the greatest threat to the health of Otsego Lake. Wastewater treatment via onsite treatment systems were listed second on a prioritized list of action areas (Anonymous 1998), and efforts to manage the effectiveness of these treatment systems began with a 2004 inventory of all systems in the established Lake Shore Protection District followed by the inception of the inspection program in 2005 (Anonymous 2007). Under this program, any system found to be in failing condition is to be replaced within one calendar year. Such replacement systems generally make use of advanced or enhanced treatment technologies due to conditions that constrain the use of conventional designs, such as setback to the lake or a tributary, soil depth to bedrock or groundwater, percolation rate, etc. Many of these enhanced treatment technologies are new the region, and thus are unfamiliar to industry professionals, regulators, and residents. For this reason, a DEC grant sought and obtained to fund a demonstration project to install and monitor

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the treatment performance of six shared advanced treatment systems. The scope of the grant has since been amended, changing the total number of treatment systems to three, with the last installed in December of 2008.

Biochemical oxygen demand (BOD or CBOD) and total suspended solids (TSS) are typical metrics used to characterize the strength of residential wastewater (Crites and Tchobanoglous 1998). BOD is an analysis used to determine the relative oxygen requirements of wastewater, effluents, and polluted waters, by measuring the oxygen utilized during a given incubation period (APHA 1989). It is expected that organic material is broken down as wastewater progresses through a treatment system, thus decreasing the oxygen requirements of highly-treated wastewater and in turn resulting in lower BOD concentrations over the course of the treatment system. TSS analysis measures the total amount of suspended or dissolved solids in wastewater. Solids may negatively affect water quality for drinking or bathing and potentially clog a drain field. As with BOD, the amount of solids in treated effluent should be lower than that of raw wastewater.

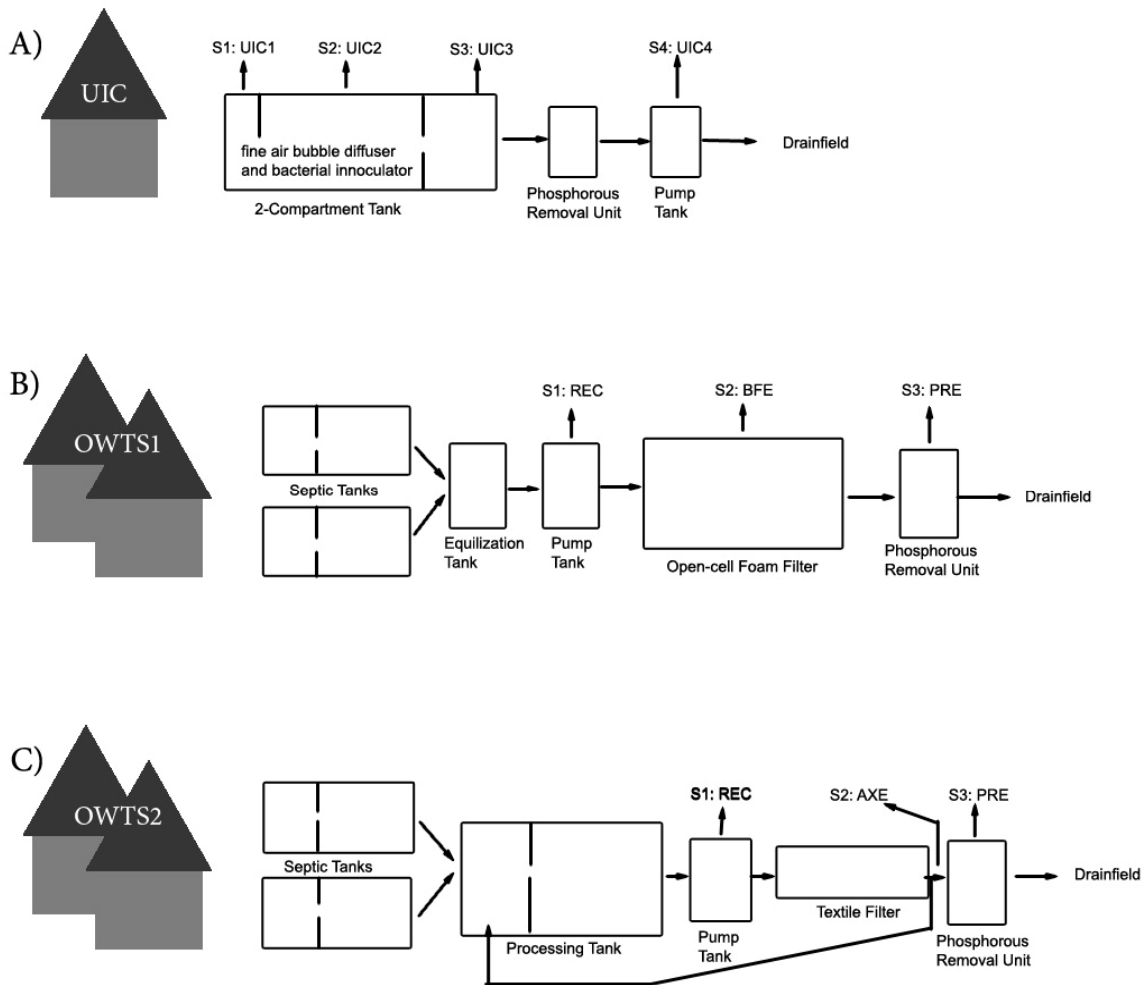
Nitrate and ammonia concentrations provide insight into the physio-chemical conditions along the treatment train, as the transformations between various nitrogen forms are dependent on oxygen availability, alkalinity, temperature, and the presence of specific bacterial populations. Nitrogen is a dynamic component of wastewater treatment systems, which are often designed to facilitate specific transformations of nitrogen species. Advanced treatment systems most often incorporate a secondary treatment step that involves aerating the wastewater in order to create favorable conditions for the bacterial transformation of ammonia to nitrate, called nitrification. Nitrogen can be completely removed from the waste stream through the process of denitrification, during which nitrate is converted to nitrogen gas (N_2), which is released to the atmosphere. Nitrification is generally considered the most limiting step of this overall nitrogen removal process, as it supplies the nitrate that is converted to N_2 gas.

Phosphorus, as previously mentioned, is the nutrient of greatest concern with regards to vulnerable freshwater bodies. The removal of phosphorus from the waste stream prior to subsurface disposal will be of great benefit to lake management efforts should the technologies installed prove to be successful.

METHODS AND MATERIALS

Three onsite wastewater treatment systems (OWTS) were monitored in this study and are displayed in Figure 1; these include the system serving the SUNY Oneonta BFS Thayer Farm Upland Interpretive Center (UIC) and two homeowner systems, which for the purpose of this study will be called OWTS 1 and 2. The UIC system has relatively high capacity, as the UIC was built to accommodate large groups. However, water usage is relatively low since most events are less than 4 hours in duration; actual flow has not been measured. The system was installed and use commenced in fall of 2005. The system has been in continuous operation, though the main tank was initially not sealed appropriately and as a result proper function did not begin until fall of 2007.

OWTS1 and OWTS2 are located within 100 feet of the western shore of Otsego Lake off of State Highway 80, and are used mainly on weekends during the summer. Each system is shared by two adjacent residences and they are designed to receive daily flows of 440 gallons



and 550 gallons respectively. Actual flow for OWTS1 was not measured. Flow through OWTS2 was measured by the service provider. OWTS 1 has been in use since 1 June 2006. OWTS 2 has been in use since 1 June 2007.

Figure 1. Onsite wastewater treatment system schematics. “S#” indicates a sampling point.

A) The UIC system is comprised of a 2-compartment tank, a phosphorus removal unit, a pump tank, and gravel bed drainfield. Wastewater is circulated and aerated in the first chamber, and settles in the clarification chamber for final solids settling. It then flows to the phosphorus removal effluent (PRE) chamber, on to a pump chamber, from which it is pumped in to the drain field.

B) OWTS1 provides primary treatment in 2 septic tanks which flow into an equalization tank, then to a pump tank where the wastewater is pumped and sprayed over an open-cell foam media filter. In this case the foam media filter aerates the wastewater and provides surface area for beneficial bacteria, increasing organic digestion. 25% of flow is returned to the headworks of each septic tank to facilitate the removal of nitrogen from the waste stream, and 50% flows to the P removal unit and on to the drainfield via gravity.

C) OWTS2 provides primary treatment in 2 septic tanks which flow to a two-compartment processing tank. Effluent flows from the processing tank to a pump tank which periodically doses a textile media filter. Filter-effluent (AXE) is split between the processing tank (REC) and

the P removal unit (PRE). A portion of effluent from the textile media filter is returned to the processing tank to facilitate the removal of nitrogen from the waste stream.

Preliminary sampling efforts were conducted during the summer of 2007 in order to assess the concentrations of various chemical and nutrient parameters. Beginning in May of 2008 on a weekly basis through August 29, 2008, approximately 600 mL of wastewater were taken from all treatment components of each system. Each sample site is shown in Figure 1. Samples were tested for Biochemical Oxygen Demand using methods summarized by Green (2004). This method involves determining initial dissolved oxygen (DO) concentration of the sample and nutrient buffer followed by incubation at 20°C for five days and determination of the final DO concentration. Samples were diluted to obtain target DO values such that the 5-day DO concentration would be lower than the initial by at least 2 mg/L but with a final concentration greater than 1 mg/L. These conditions were not always achieved, thus valid BOD values were not obtained for every sample collected. Because a nitrification inhibitor is used during incubation, results are presented as values of CBOD, as they are associated with the carbonaceous oxygen demand rather than the total oxygen demand (APHA 1992). Overall CBOD reduction rates for each secondary treatment unit (OWTS 1 and 2 filters, UIC 1-3) were calculated based on the average CBOD concentrations observed over the monitoring period, presented in Table 1.

Samples were also tested for total suspended solids (TSS) using the standard methods procedure (APHA 1989). A measured volume of well-mixed sample was filtered through a previously weighed filter and allowed to dry for approximately 12-24 hours in an oven at 103-105°C. The filter was again weighed and suspended sediment is calculated (APHA 1989).

Phosphorus concentrations were determined using the ascorbic acid following persulfate digestion method run on a Lachat QuikChem FIA+ Water Analyzer (Laio and Marten 2001). Total nitrogen (TN), nitrate, and ammonia concentrations were also determined for each sample, using Lachat-approved methods (Ebina, et al. 1983, Pritzlaff 2003, Liao 2001). All reduction and transformation rates are calculated based on average concentrations observed over the monitoring period.

RESULTS AND DISCUSSION

Biochemical Oxygen Demand (Carbonaceous)

Average initial CBOD concentrations ranged from 13.90 mg/L at the UIC to 255.11 mg/L at OWTS2. Such variation is expected given the different system inputs described previously. Typical CBOD concentrations associated with raw wastewater vary greatly (100 – 600 mg/L) depending on per capita water usage and inputs of solids to the system (i.e. garbage grinder waste) (Crites 1998). The CBOD concentrations observed in the UIC system (Table 1; Figure 2) are lower than those generally encountered in raw wastewater, and thus the reduction rates are around 40% (Table 2). OWTS 1 has initial CBOD loadings that are at the low end of the typical range, which is consistent with increased per capita water use (Crites 1998), and coincides with evidence of a leaky fixture in one of the residences. OWTS 1 foam filter CBOD reduction is at

34%, which is lower than that of the textile filter in OWTS 2. Initial CBOD loading and overall CBOD reduction are greatest in OWTS 2, at 255 mg/L and 94%, respectively. This system is receiving wastewater of a higher strength than is typically seen in US households (ranging from 110 to 513 mg/L), yet is producing wastewater of very high quality. Third-party data collected at testing centers and field installations present an average CBOD less than 9 mg/L in filter effluent, whereas the textile media filter incorporated in OWTS 2 has higher CBOD concentrations, averaging 24.6 mg/L. Despite this higher final CBOD concentration, the system consistently reduces CBOD by at least 92%, which is consistent with other third-party testing results (Orenco Systems 2008).

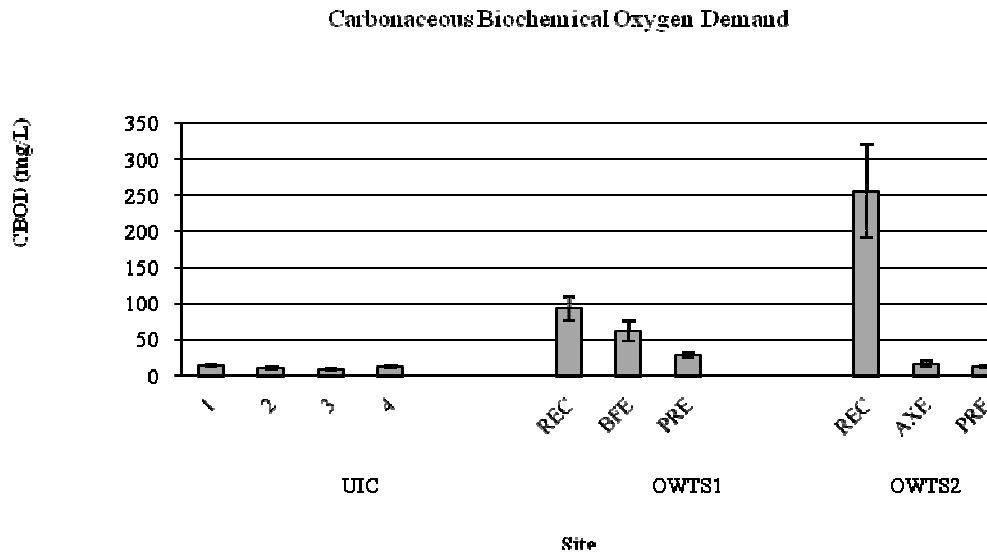


Figure 2. Average CBOD in mg/L across all sampling sites and dates. Error bars indicate standard error, as presented in Table 1.

Total Phosphorus

Initial total phosphorus concentrations ranged from 7.03 mg/L at UIC to 11.70 mg/L at OWTS 1, which is similar to the range typically seen in residential wastewater (Crites 1998). Final effluent concentrations at OWTS 1 and 2 averaged 9.77 and 6.71 respectively (Table 1; Figure 3). In terms of phosphorus removal rates, OWTS 1 and 2 achieved similar results, removing 22 and 26% respectively (Table 2). This removal rate is below the manufacturer's performance claim of 50% removal and substantially greater than the claimed final concentration less than 1 mg/L (Noga 2007). Contrary to the OWTS 1 and 2 systems, the phosphorus removal unit in the UIC system produced final effluent of 0.66 mg/L, removing 90% of the phosphorus on average. The reactive media components in the phosphorus removal units of OWTS 1 and 2 were replaced on September 29, 2008. Samples taken from OWTS 1 subsequent to this replacement resulted in a final TP concentration of 3.7 mg/L and a removal rate of 85%. These values are not included in the summary tables as they reflect a modification of the unit that occurred at the end of the official monitoring period. The removal rate seen here is greater than those recorded for either OWTS 1 or 2 during the summer monitoring efforts, though the final concentration of phosphorus still does not meet the manufacturer's claim and exceeds the desired output for a system in such close proximity to the lake. OWTS2 could not be sampled to provide

comparison, thus no inferences can be made regarding the mechanism for the increased removal, as more than one component of the OWTS 1 P removal unit was replaced.

It is important to consider that the quality of influent to any treatment unit directly affects the treatment performance of that unit. The concentration of wastewater constituents (alkalinity, CBOD, pH, available carbon, etc.) may inhibit or decrease the efficiency of treatment processes within a given unit. In terms of the phosphorus removal units, high concentrations of BOD

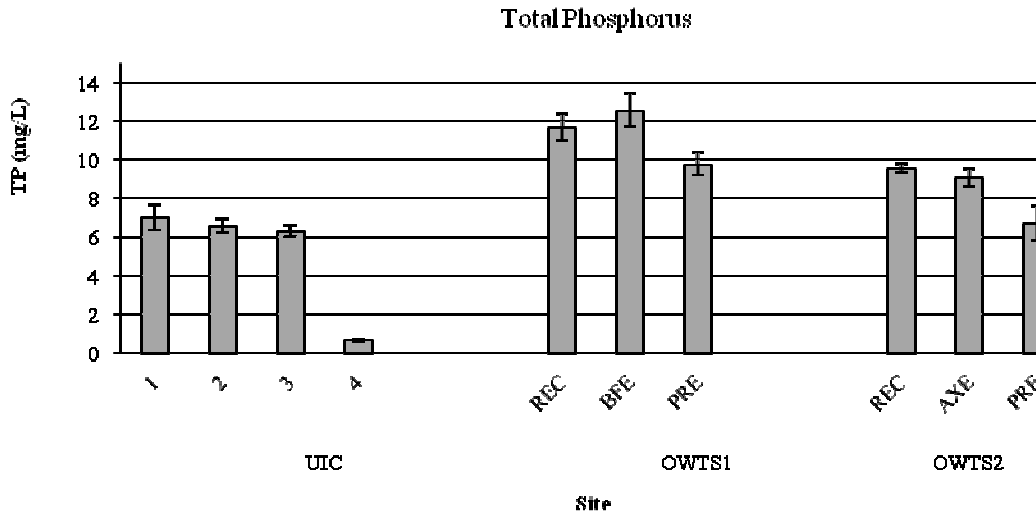


Figure 3. Average total phosphorus concentrations in mg/L for all sampling sites across all sample dates. Error bars indicate the standard error, as presented in Table 1.

coming in may cause growth of a biofilm on the media in the treatment unit, thus coating the reactive surfaces. Theoretically, this could greatly reduce the treatment capacity of the unit, as it isolates the adsorptive surfaces from the wastewater. However, our monitoring results the unit installed at OWTS 2 receives low concentrations of CBOD yet has an average TP removal rate that is only slightly greater than that observed at OWTS 1. Another factor that influences the treatment performance of the unit is the life-expectancy of the media. Given that adsorption of P onto active sites of the media is the mechanism for P removal from the waste stream, the length of time the unit has been in service and the loading that it receives determine its effectiveness at a given point in time. Because of this characteristic, the media's performance decreases over time as active adsorption sites become occupied by phosphorus compounds. The rate at which this decrease occurs is dependent on the use of each system and must be determined. For these reasons it is necessary that additional research and development be focused on the P removal process and means by which to reliably removal phosphorus in active and dynamic onsite treatment systems.

Total Suspended Solids

Solids are being reduced to levels that are consistent with highly treated wastewater (Crites 1998). Incoming solids vary widely between the three systems, as with other parameters, though are consistently treated most effectively by OWTS 2 (Table 1). The wastewater sampled from the pump tank has previously passed through an effluent filter that is designed to remove

solids that may otherwise move with the effluent to the subsequent treatment step. Our results indicate that this design is functioning well, and should be considered for use following the primary treatment step of all onsite treatment applications. The UIC system also includes an effluent filter between UIC3 and UIC4, but the direct impact of it is not reflected in our samples and so TSS reduction rates are not listed for UIC in Table 2.

Table 1. Average Biochemical Oxygen Demand (CBOD) in mg/L, Total Phosphorus in mg/L, and Total Suspended Solids in mg/L with standard error (SE) and sample size (n) for samples collected from May through August 2008, grouped by treatment system.

Site	CBOD			Total Phosphorus			Total Solids		
	Avg mg/L	SE	n	Avg mg/L	SE	n	Avg mg/L	SE	n
UIC1	13.90	1.62	12	7.03	0.66	12	18.73	3.35	4
UIC2	9.98	1.06	12	6.60	0.37	12	58.29	42.82	4
UIC3	8.29	0.93	11	6.34	0.32	12	39.21	29.28	4
UIC4	12.05	1.54	10	0.66	0.09	12	5.29	2.15	4
OWTS1 RAW	93.02	16.47	12	11.70	0.69	13	116.42	73	4
OWTS1 BFE	61.61	14.64	9	12.57	0.85	13	46.27	11.35	4
OWTS1 PRE	28.17	3.53	8	9.77	0.60	11	13.09	5.89	4
OWTS2 Recirc	255.11	64.90	7	9.55	0.22	8	75.13	23.21	4
OWTS2 AXE	16.18	3.99	5	9.07	0.44	5	5.1	1.96	4
OWTS2 PRE	12.18	1.78	6	6.71	0.90	6	7.05	2.06	4

Table 2. Average percent reduction and sample size (n) of biochemical oxygen demand (CBOD), total phosphorus (TP), percent of nitrogen converted to nitrate (Nitrification), and percent of nitrogen removed (via denitrification) from the waste stream for each treatment system sampled from May through August 2008. Sample sizes “n/n” indicate sample numbers of influent and effluent.

Site	CBOD		TSS		TP		Nitrification		N Reduction	
	%	n	%	n	%	n	%	n	%	n
UIC	40	12/11	-	-	90	12	97	7	52	7
OWTS 1	34	12/9	60	4	22	13/11	40	15	13	15
OWTS 2	94	7/5	93	4	26	5/6	55	9/7	38	9/7

Nitrate and Ammonia

Nitrate concentrations in OWTS 1 and 2 primary treated effluent were very low (Table 3), as would be expected for raw wastewater given that nitrogen enters the system in the ammonium form (NH₄) (Crites 1998). UIC nitrate concentrations were much higher in the first chamber, with 97% of nitrogen occurring in the nitrate form. This difference is due to the configuration of the system; the chambers of the tank are not hydraulically isolated, and so water can circulate between the first two sampling points, resulting in aeration and thus nitrification of ammonia. From inlet to final effluent, the UIC system achieved greater than 50% removal of nitrogen from the waste stream, though removal occurred beyond the main treatment tank

(Tables 2 and 3). The secondary treatment steps of OWTS 1 and 2 nitrified 40 and 55% of the incoming nitrogen, and completely removed 13 and 38% of the nitrogen from the waste stream through denitrification (Table 2). Final effluent from OWTS 1 contained an average of 32.2 mg/L of nitrate and 42.4 mg/L of ammonia, while OWTS 2 contained 22.8 mg/L of nitrate and 26.9 mg/L of ammonia. Third-party nitrogen data for textile filters are not currently available for comparison.

Table 3. Average nitrate and ammonia concentrations in mg/L with standard error (SE) and sample size (n) for samples collected from May through August 2008, grouped by treatment system.

Sample	Nitrate (mg/L)			Ammonia (mg/L)		
	average	+/- SE	n	average	+/- SE	n
UIC1	57.82	2.48	13	1.70	0.75	7
UIC2	59.29	2.33	13	1.59	0.71	6
UIC3	60.51	4.04	13	1.36	0.74	7
UIC4	25.54	0.95	13	3.02	0.78	10
OWTS1 RAW	2.39	1.53	6	87.71	5.79	15
OWTS1 BFE	31.95	3.95	14	46.34	3.91	15
OWTS1 PRE	32.19	5.45	12	42.44	2.89	13
OWTS2 REC	0.05	0.01	6	85.43	2.60	9
OWTS2 AXE	29.54	6.38	6	23.35	8.66	7
OWTS2 PRE	22.78	4.88	7	26.93	7.95	7

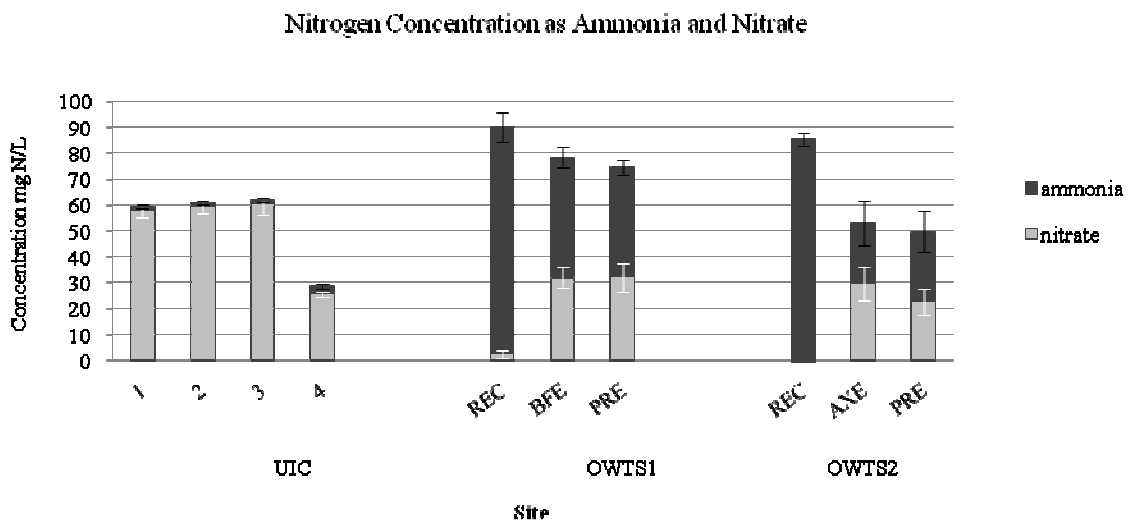


Figure 4. Proportion of the average nitrogen concentration reported as ammonia and nitrate. Error bars indicate standard error, as presented in Table 3.

Environmental Technology Verification (ETV) testing was conducted by the US EPA and National Sanitation Foundation (NSF) on the type of foam filter unit incorporated in the OWTS 1 system (ETV 2003). In comparison with the results presented in the Verification

Report, similar performance issues were encountered during the start-up period; namely that CBOD was not effectively reduced and that the nitrification process was not being performed at the anticipated rate. Due to the seasonal use of the OWTS 1, the system must go through a “start-up” period once use begins again in the spring. During the start-up period, bacterial communities become established and grow to sufficient populations to effectively process the wastewater. Depending on system use and loading, this start-up period could be expected to take more than 5 weeks (ETV 2003). For these seasonal systems, this start-up period could comprise the majority of the summer vacationing season, resulting in less-than-desired treatment performance during peak system activity.

The ETV report associates poor nitrification rates following a cold-weather start-up test with settling of the foam media, which seemed to inhibit growth of the nitrifying bacterial community. Following adjustment of the media, nitrification rates improved dramatically (ETV 2003). This should be considered when system maintenance is performed each fall and spring, as the system remains inactive during the winter months and has demonstrated relatively low nitrification rates. Also of note is the greater average ammonia concentration in effluent entering the OWTS1 foam filter (87.7 mg/L) than that received by the unit during the ETV testing (23 mg/L). It seems possible that the nitrifying bacteria may not be at sufficient populations to effectively nitrify high concentrations of ammonia given the contact time between the wastewater and the filter media, though this contact time has not been measured directly.

Nitrate and ammonia compounds are highly mobile in the groundwater environment, and ammonia is toxic to aquatic organisms. Increasing the nitrification rates within advanced treatment systems would prove to be beneficial for the function of the treatment systems and limit potential ammonia toxicity issues in receiving waters.

CONCLUSIONS

Inputs of nitrogen and phosphorus to the monitored systems at times are at concentrations higher than those that typify US household waste. This is most likely due to the implementation of water conservation practices by homeowners. When considering the potential for nutrient loading from such systems, the total mass of nutrient (either N or P) must be assessed by taking the volume of water used into account. A low volume of water containing a high concentration of nutrients may equal less total mass than moderate water use with moderately high concentrations. Overall, the onsite treatment systems are producing high-quality effluent with a portion of the total phosphorus removed, though the TP concentrations remain within the range expected from primary treated residential wastewater. Additional research into effective phosphorus removal units should be conducted.

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