Wakulla County Septic Tank Study

Interim Report on Performance Based Treatment Systems

FDEP AGREEMENT NO: WM926

January 2010

Prepared by

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Executive Summary

The Florida State University Department of Oceanography has been working cooperatively with the Florida Department of Environmental Protection in the Wakulla Springs Basin on a year-long evaluation of Performance Based Treatment Systems (PBTS) that are used for the treatment of residential domestic wastewater. A conventional onsite sewage treatment and disposal system (OSTDS) includes a septic tank and drain field to treat wastewater prior to discharge into the groundwater. Under normal conditions, conventional septic tanks provide minimal treatment of nitrogen. Performance based treatment systems are engineered to provide additional removal of nitrogen from the wastewater before it is discharged.

This report was prepared to provide interim results of the study, and to specifically provide information on the total nitrogen (TN) removal effectiveness of PBTS from 7 months of sampling at 8 typical residential sites and the findings of a wider inspection and sampling program of PBTS, which included inspections of over half of the systems installed in Wakulla County as of October 2008 and sampling at 27 of the sites. The final report, to be provided in 2010, will include 5 additional months of data from the study sites as well as environmental fate information from drain fields and drip systems that receive the treated wastewater.

Advanced treatment of nitrogen for new and repaired OSTDS became a requirement for Wakulla County residents when Ordinance 2006-58 went into effect in October 2006. The Wakulla County ordinance states that “only performance-based septic systems that *can* produce a treatment standard of 10 mg/L nitrogen shall be installed in new construction and as replacements when older systems fail or are replaced”. This ordinance applies to the entire county as a springs protection measure. Approved PBTS from the following three manufacturers have been installed in Wakulla County **(Figure ES-1):** MicroFAST by Bio-Microbics, Inc. (60% of the sites), HOOT Series-AND by HOOT Aerobics Inc (10% of the sites), and Singulair by Norweco, Inc (30% of the sites). The sites monitored in this study provide a proportional representation of all three systems. Effectiveness of the systems being monitored in this study was measured as a percent (%) reduction in the TN concentration of the septic tank effluent, comparing average OSTDS influent concentrations obtained in the county against tank effluent concentrations from the PBTS included in the project.

Characterizing the amount of nitrogen going into an individual residential OSTDS (influent) requires multiple samples over a period of time due to the high variability in the

composition of the raw sewage. However, understanding the characteristics of the waste stream is crucial in the design of treatment systems, management decisions, and accessing PBTS performance and environmental impacts. Raw influent data collected as part of this study as well as data from nearby sites from a Colorado School of Mines (CSM) study were used to estimate influent concentrations. In this study, raw sewage from four households served by PBTS was collected and the average influent concentration was 72.8 ± 39.2 mg-N/L, n=17. The CSM study focused on six other households in Wakulla County which produced an average raw TN concentration of 73.1 ± 50.3, mg-N/L n = 24 **(Figure ES-2**). A broad range in influent concentrations is typical of residential septic systems. For ease of subsequent calculations, a value of 70 mg-N/L was chosen to represent raw wastewater input of TN to septic tanks in Wakulla County.

In the CSM study, the average conventional septic tank effluent (STE) concentration was 64 ± 13 mg-N/L **(Figure ES-2).** If 70 mg-N/L is used as a raw wastewater input value, this results in a TN-reduction of 9 ± 19% (Eq. 1) for these conventional septic tanks (Figure ES-3). A conventional OSTDS provides for some attenuation of nitrogen through ammonia volatilization and the removal of solids. According to Anderson (2006), estimates of up to 17% reduction in TN content have been reported by the U.S. Environmental Protection Agency and others. Anderson (2006) as a rule of thumb recommended a figure of 10% reduction for a conventional septic tank. In another study, Xuan et al. (2009) reported a of 24% reduction in TN for a conventional system. The La Pine, Oregon reported median TN concentration of 63 mg-N/L for effluent from conventional septic tanks (La Pine Oregon Demonstration Project, 2006), similar to the CSM value of 64 ± 13 mg-N/L.

Effluent TN concentrations from the primary PBTS study sites sampled monthly for a 7 month period averaged 30 ± 10 mg-N/L. The average TN concentration in effluent samples from the other 27 PBTS systems that were inspected and sampled, was 29 ± 21 mg-N/L. For all 35 PBTS that were sampled, the average TN concentration was 29 ± 19 mg-N/L. This average concentration is roughly 50% lower than the average TN concentration from conventional OSTDS effluent. Using a raw wastewater input concentration of 70 mg-N/L; the primary study sites yield a TN reduction of 56.0 ± 15.9 %. For the 27 sites sampled only once, we calculated a TN reduction of 58.9 ± 28.5 % **(Figure ES-3**). These results are similar to results obtained in the larger La Pine National Demonstration Project conducted in Oregon by the US Geological

Survey (La Pine Oregon Demonstration Project, 2006) and research data compiled by FDOH (2008).

The survey of PBTS in Wakulla County and sampling of the 27 PBTS sites was conducted with the assistance of the Wakulla County Health Department (health department) and FDOH Bureau of Onsite Sewage Programs. All of the PBTS systems visited were installed prior to October 2008, to ensure at least 6 months between installation and sampling. The distribution of types of PBTS in Wakulla County was also taken into consideration while selecting site candidates. The sampling team encountered numerous issues of concern regarding the installation, operation and maintenance of many systems. A total of 59 systems were inspected and 27 of the systems were operating and could be sampled. Out of the total of 59 PBTS inspected, 23 (39%) of them were not operating as designed because they had been turned off by the homeowners, they had no electrical service, or they had not been properly constructed so that effluent could be inspected or sampled **(Figure ES-4).**

Summary of Findings

1. Raw Sewage TN inputs: The total nitrogen (TN) input value was 72.8 ± 39.2 mg-N/L, n=17 from four households served by PBTS. The CSM study focused on another six households, with an average of 73.1 ± 50.3, n = 24. The data indicates that 70 mg-N/L is a reasonable estimate of total nitrogen from households in Wakulla County and is used to calculate percent TN removal by the systems.

2. From the primary study sites, the average PBTS effluent concentration was 30.7 mg-N/L. The average TN concentration for the 27 additional systems was 29.2 mg-N/L, confirming the primary study sites are typical of systems installed in Wakulla County.

3. Performance Based Treatment Systems installed in Wakulla County reduce TN by 50-70% from input concentrations, when properly operated and maintained. Over a 7-month monitoring period, the primary PBTS had reduced nitrogen on average by 56%. The other 27 systems that were sampled only once were found to have reduced nitrogen on average by about 59%.

4. When operated properly, the systems that are currently being installed in Wakulla County meet the manufacturers' and DOH expectations for PBTS in that they achieve 50% or better Nitrogen reduction. However, they cannot, as currently designed, be expected to regularly achieve effluent concentrations of less than 10 mg TN/L under typical homeowner usage scenarios.

5. Operation, maintenance and construction issues are responsible for a very large percentage of PBTS in Wakulla County not being in compliance with their permits and providing less than optimal treatment.

Figure ES-1. The distribution of performance based treatment systems by manufacturer installed in Wakulla County, 10% Hoot, 30% Norweco, 60% Fast.

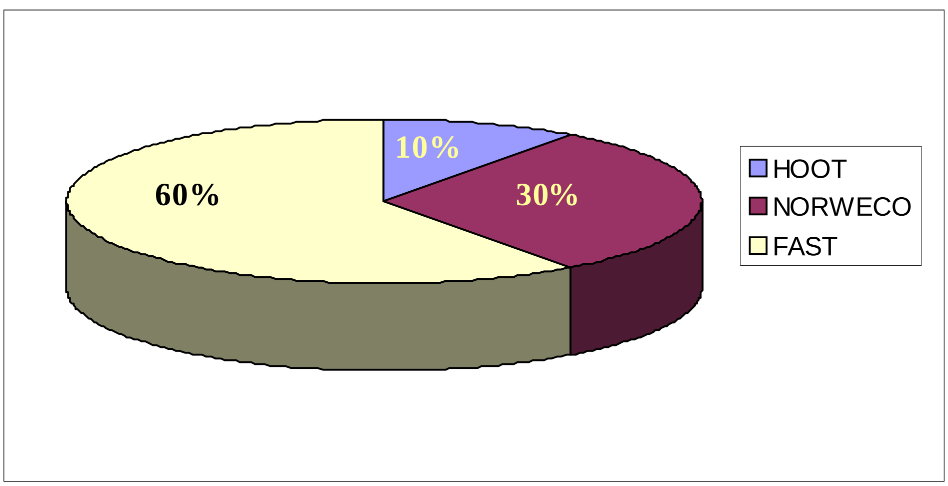


Figure ES-2. Concentration of total nitrogen in septic tank inputs and effluent from conventional and performance based systems.

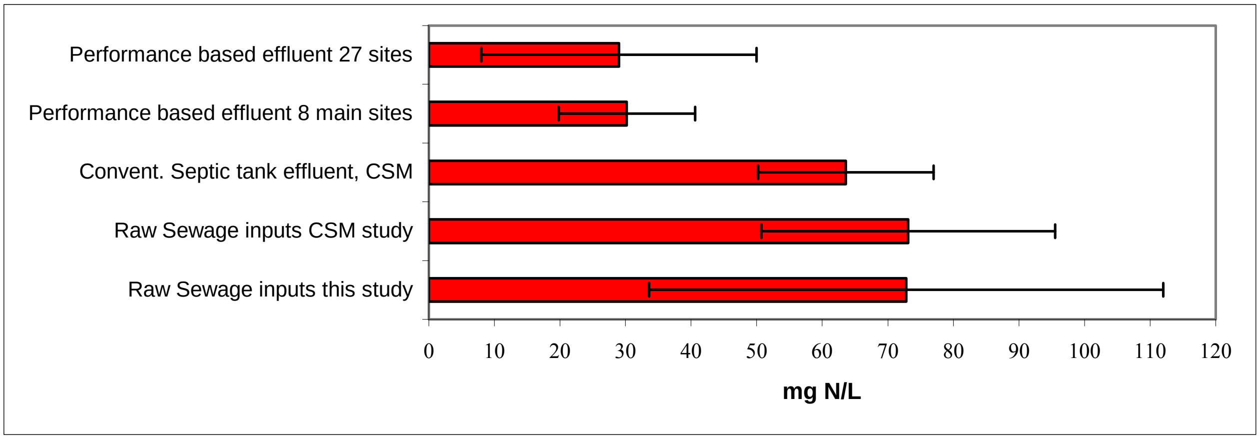


Figure ES-3. Percent Nitrogen reduction from conventional and performance based septic systems. An influent value of 70 mg-N/L was used in the calculations.

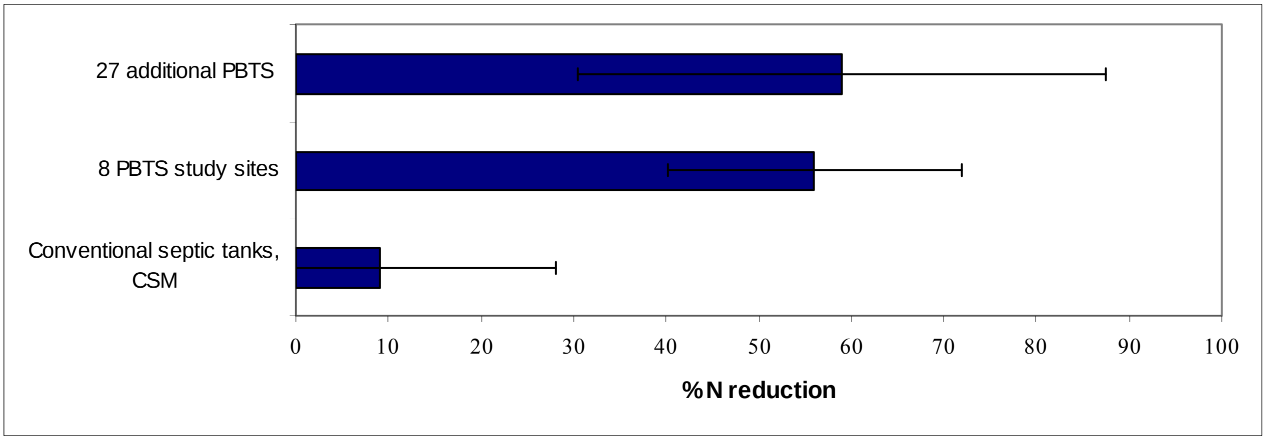
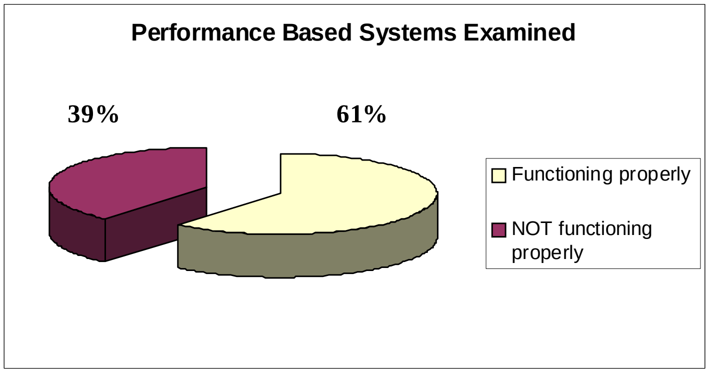


Figure ES-4. Of 59 performance based systems examined in Wakulla County, 36 (61%) were in compliance. 23 systems (39%) were not functioning as performance based systems due to electrical issues, being turned off or other problems.



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1. Introduction

1.1 Background and Motivation

Onsite sewage treatment and disposal systems (OSTDS) are an important part of Florida's wastewater infrastructure, serving about a quarter of the state's households (Social Science Data Analysis Network, undated; Florida Department of Health [FDOH], 2007). The proportion of homes served by OSTDS units is much higher in the rapidly growing, formerly rural areas of central and north Florida. These regions include areas where the limestone is close to the surface and characterized by karst features, such as large springs, sinkholes and caves. These karst features have been shown to rapidly transport contaminants to and in the underlying groundwater (e.g. Price, 1988; Paul et al., 2000; Dillon et al., 1999, 2000: Harden et al., 2008).

Springs in most areas have experienced degradation in water quality, particularly exhibiting elevated nitrogen concentrations (Florida Springs Task Force, 2006). While other sources such as fertilizer use, stormwater runoff, atmospheric deposition, and wastewater treatment plant discharge also contribute to nitrogen in ground water, the effects of conventional OSTDS, consisting of a septic tank with a drain field, are a concern because of the recent trend in high-to-medium density residential development in areas not served by sewer. The FDOH is responsible for regulating residential OSTDS in Florida with a goal of preventing adverse health effects, not of protecting water quality. The human health-related target for nitrogen is the drinking water standard for nitrate-nitrogen, which is 10 mg/L. However, to protect sensitive aquatic ecosystems such as those for spring runs, the nitrogen threshold is much lower. FDEP has proposed a nitrogen threshold of 0.35 mg/L for clear water streams, which includes springs (http://www.dep.state.fl.us/water/wqssp/nutrients/index.htm).

In Florida, advanced treatment to reduce nitrogen is required for permanent OSTDS installed in the Florida Keys, where limestone is at the surface, lots are small, and the nearby coral reef system is threatened (FDOH, 2009). Advanced waste treatment is also required by local ordinance in Collier and a coastal area of Franklin County, Florida. Also in some karst areas of Florida, a larger drain field is required when shallow discontinuous limestone is encountered during site evaluation (FDOH, 1999). In most cases, a mounded system is used to raise the disposal point well above the limestone, which is often the more cost effective solution. In October 2006, an ordinance was passed by Wakulla County to require performance based treatment systems (PBTS) for nitrogen removal (Ordinance 2006-58) and similar ordinances have been proposed for Leon and Marion counties. All of these ordinances were put into place to protect sensitive spring fed surface waters and refer to a performance target concentration of 10 mg/L.

In May 2007, the Florida State University Department of Oceanography entered into an agreement with the Florida Department of Environmental Protection (FDEP) Ground Water Protection Section to evaluate the effectiveness and fate of nutrients discharged by conventional OSTDS in the Wakulla Springs Basin. This contract was amended in June 2008 to include a second phase, a 1-year-long field study of the effectiveness of PBTS that were installed under the new Wakulla County ordinance.

Phase I of this study focused on three residential sites with conventional septic tanks and drain fields in or near Wakulla County. Septic tank effluent (STE) samples, pore water samples from lysimeters below the drain fields; and ground water well samples from below the drain fields were collected and analyzed for nutrients, inorganic wastewater tracers, organic wastewater compounds and microorganisms (Katz, et al, 2009). Concurrent with this study, the Department of Oceanography, working with the Colorado School of Mines (CSM), conducted a study characterizing raw sewage inputs into septic tanks in comparison to STE from conventional OSTDS. One of the CSM study areas was in Wakulla County and included one of the Phase I sites.

Phase II of this study is focused on assessing the effectiveness of PBTS that were installed in compliance with the new 2006 Wakulla County ordinance. Phase II included collection and analysis of septic tank effluent samples, pore water samples beneath drain fields and ground water samples from adjacent to drain fields. In addition, influent samples were collected using the same equipment and methodology employed in the CSM study.

This interim report includes a comparison between raw sewage inputs to household septic systems from the three studies and the nitrogen content of effluent from both conventional and performance based treatment systems. Performance of these systems was measured as a percent reduction in total nitrogen concentrations as is shown below:

$$\%\ \text{N-reduction} = (1 - \text{septic tank effluent}/\text{septic tank influent}) * 100 \qquad \textbf{(1a)}$$

Or

$$\%\ \text{N-reduction} = (1 - \text{PBTS effluent}/\text{PBTS influent}) * 100 \qquad \textbf{(1b)}$$

Additionally, Phase II includes an assessment of the environmental fate of wastewater discharged by PBTS to drain fields and drip irrigation systems at the sites and a survey to assess compliance with the ordinance and random sampling to evaluate TN reduction and system efficiency. The findings to date of this survey are also included in this interim report.

1.2 Descriptions of PBTS Installed in Wakulla County

Performance based treatment systems are defined by the Florida Department of Health (FDOH) as "a specialized onsite sewage treatment and disposal system designed by a professional engineer with a background in wastewater engineering, licensed in the state of Florida, using appropriate application of sound engineering principles to achieve specified levels of CBOD5 (carbonaceous biochemical oxygen demand),TSS (total suspended solids), TN (total nitrogen), TP (total phosphorus), and fecal coliform found in domestic sewage waste, to a specific and measurable established performance standard" (FDOH, 2009). PBTS certified by NSF International according to the National Sanitation Foundation/American National Standards Institute (NSF/ANSI) Standard 40 plus Nitrogen Reduction or Standard 245 have been reviewed and approved by the FDOH Bureau of Onsite Septic Systems. Several PBTS had successfully reduced effluent TN concentrations to below 10 mg-N/L during the NSF/ANSI testing and are approved by FDOH for installation in Florida. Consistent with the performance expectation of the FDOH certification process, Wakulla County Ordinance 2006-58 states that "only performance-based septic systems that *can* produce a treatment standard of 10 mg/L TN shall be installed: in new construction and as replacements when older systems fail or are replaced" FDOH-approved systems from the following three manufacturers have been installed in Wakulla County: MicroFAST by Bio-Microbics, Inc., HOOT Series-AND by HOOT Aerobics Inc, and Singulair by Norweco Inc. For simplicity they will be referred to as FAST, HOOT, and Norweco in this report.

This interim report focuses on the reductions of nitrogen occurring in septic tanks and systems and does not address the attenuation of nutrients by drain fields or drip systems, which will be addressed in the final report. Raw sewage (influent) that enters the tanks contains nitrogen in the form of mainly organic nitrogen and ammonia. The organic N component is converted to ammonia and ammonium by bacteria under anaerobic conditions. In the presence of oxygen, ammonia (NH_3) and ammonium (NH_4) are then converted to nitrate (NO_3). Nitrate can be converted to di-nitrogen gas (N_2) under sub-oxic/anaerobic conditions by bacteria in the presence of organic matter. Di-nitrogen gas is an inert form of N; all the other forms are bio-active. Thus denitrification is a goal of performance-based systems to achieve N reduction. To be effective, the septic systems should cycle the wastewater from anaerobic conditions, to aerobic, and then back to sub-oxic/anaerobic conditions.

All three of the PBTS evaluated in this study employ similar processes to reduce the concentration of nitrogen in raw sewage. Raw sewage flows into a pre-treatment chamber, which acts as a small septic tank. Here, solids settle out, and ammonification occurs in the anaerobic conditions as bacteria convert organic nitrogen into ammonia and ammonium ion (ammonification). Total Kjeldahl nitrogen is the combination of ammonia, ammonium and organic nitrogen. The predominant form of nitrogen in the wastewater is ammonia as it flows out of the anaerobic pre-treatment chamber into the treatment chamber. A blower or aerator creates an aerobic environment in the treatment chamber where the proper bacteria convert ammonia into nitrite and then nitrate. This process is called nitrification. Length of treatment time, oxygen levels and the population and health of the nitrifying bacteria determine the extent of nitrification. The design of the treatment chamber is the major difference between the three systems, but they are all engineered so that wastewater will be exposed to both aerobic and anaerobic conditions, allowing for denitrification. Denitrification is the process of nitrate being converted to nitrogen gas in the presence of denitrifying bacteria. These bacteria require high carbon content and low dissolved oxygen. In HOOT, Norweco and some configurations of FAST systems, the effluent then flows into a holding tank where it its then pumped to a conventional drain field or drip irrigation bed. Further denitrification is accomplished by having a portion of the pumped effluent directed back to the pre-treatment chamber. Recirculation is required in HOOT and Norweco systems to achieve their performance objective. Although FAST systems can be installed with recirculation, it is not required. Each system is described in greater detail below.

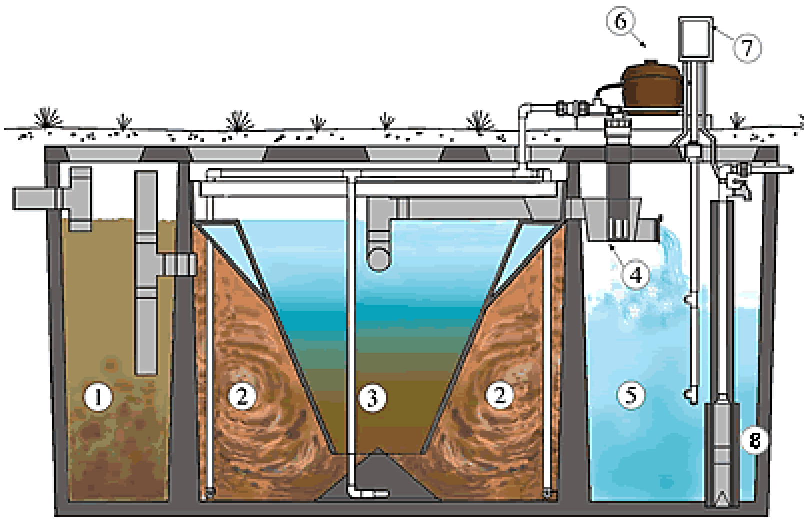
1.21 HOOT Aerobic Treatment System AND series: Models H-500 and H-600 are typical for a residence

Septic influent enters the anaerobic pretreatment chamber where initial settling and anaerobic treatment occurs. The wastewater then flows into the aeration chamber. A blower delivers air into the aeration chamber through bubbler stones. The wastewater enters the clarification chamber, which has an open bottom and is inside the aeration chamber. Sludge settles out of the open bottom clarification chamber back into the aeration chamber. Wastewater flows from the clarification tank into a holding tank. The wastewater is pumped from the holding tank into the drain field (Figure 1). If the drain field is a drip system, the pumped effluent passes through a 120-150 micron filter. A portion of the effluent pumped to the drain field is returned to the pre-treatment tank enhancing denitrification. The recirculation of the effluent back to the pre-treatment tank is necessary in order for the unit to achieve the necessary treatment for it to be classified as PBTS.

Figure 1. Diagram of the HOOT Aerobic Treatment System from HOOT website. Recirculation of the effluent exiting the system back into the pretreatment tank is not shown.

1. Pretreatment tank where influent enters.
2. Aeration chamber where oxygen is pumped into the wastewater.
3. Clarifier chamber where the clear, odorless effluent rises.
4. Chlorinator where the clear effluent passes through for disinfection. *
5. Holding tank for disinfected* effluent ready for discharge (optional).
6. Aerator and pump.
7. HOOT Control Center monitors and controls the system.
8. Discharge Pump

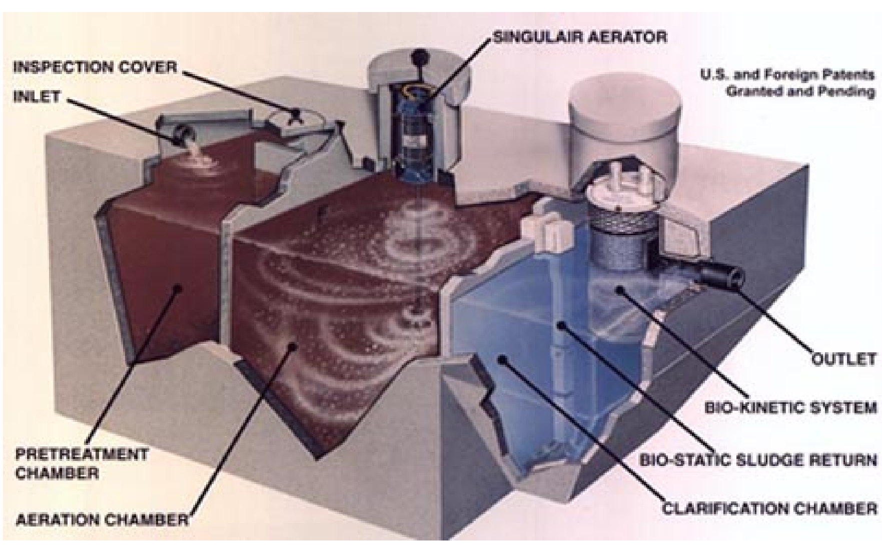
* Not used in the Wakulla Springs basin.



1.22 Singulair Bio-Kinetic Wastewater Treatment System, Model 960, a product of Norweco, Inc.

With the Norweco system, wastewater enters an anaerobic pretreatment chamber where settlement and ammonification occur. Wastewater then flows into the aeration chamber, where aeration is achieved by a specifically designed aerator. Air enters the aerator through four vents and is drawn down into the treatment tank through the spinning aerator shaft. A control box monitors and turns the aerator on and off at adjustable time intervals, allowing for a mix of aerobic and anaerobic conditions. Wastewater flows from the aeration chamber to a clarification chamber. The inlet has a pipe that delivers the aerated wastewater near the bottom of the clarification chamber and sludge settles and flows back into the aeration chamber through an opening between the chambers. The remaining wastewater flows into a "Bio-Kinetic" filter, which has optional chlorination and dechlorination (Figure 2). This filter provides non-mechanical flow equalization achieved by a small hole into the filter container, which reduces incoming hydraulic surges form periods of high wastewater flow. Wastewater flows out into a separate pump tank, where it passes through another 120-150 micron filter and is pumped into the drain field system. If the system employs a conventional drain field for treated wastewater disposal, then there is no secondary filter. As with the HOOT system, circulation back to the pre-treatment chamber is necessary for the Norweco system to be classified as a PBTS.

Figure 2. The Singulair Wastewater Treatment System by Norweco, Inc. From the Norweco website. In Wakulla County a post tank housing a pump is required to allow recirculation back to the pretreatment chamber.

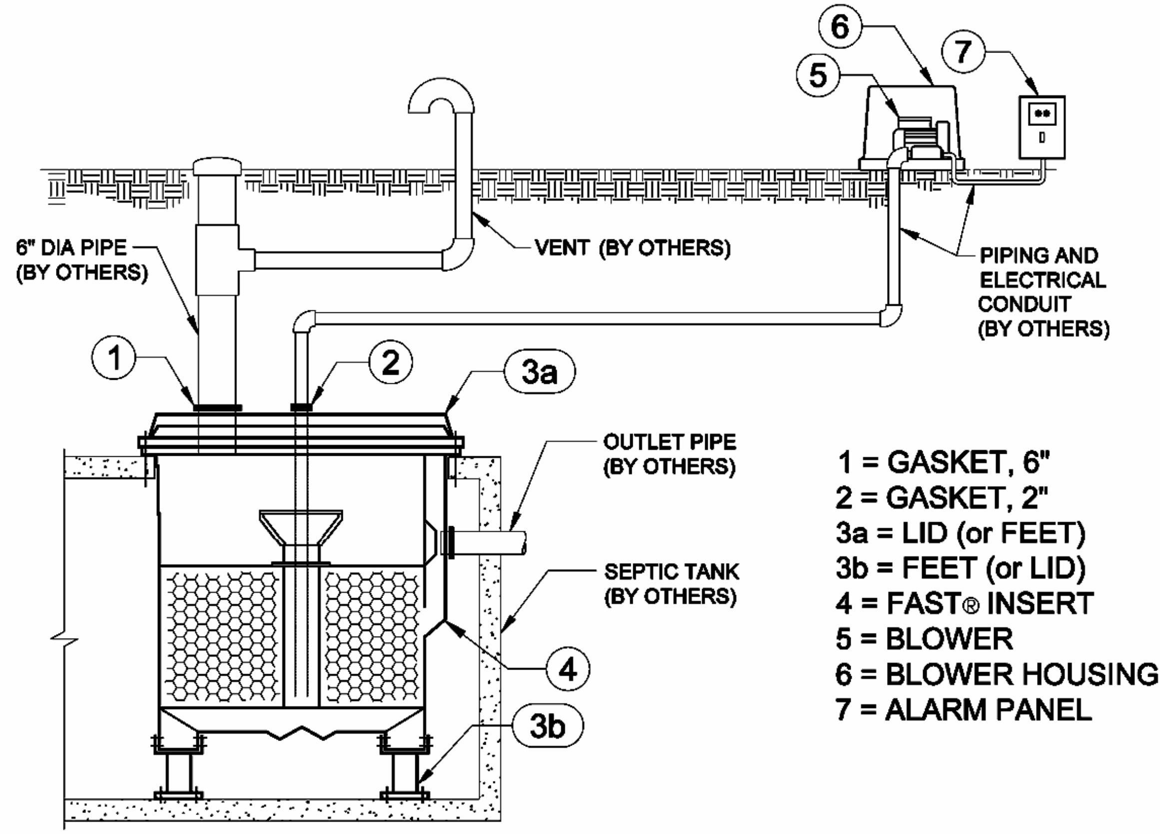


1.23 FAST: Fixed Activated Sludge Treatment, Model MicroFAST 0.5 or 0.75 for typical residence, lager sizes available, a product of Bio-Microbics, Inc.

The FAST system differs from the Norweco and HOOT systems in two major ways. The FAST System has fixed media on which the nitrifying bacteria grow, whereas bacteria in the Norweco and HOOT systems are suspended in the wastewater. Another major difference is that a FAST system typically includes a two-chambered concrete tank from a local source whereas the chambered tanks for the HOOT and Norweco systems are supplied by the manufacturers.

Influent flows into an anaerobic settling chamber (pre-treatment chamber) in a two compartment tank or in a separate “trash” tank. The septic water then flows into a second chamber or tank that has the FAST treatment unit installed. The treatment unit sits above the bottom of the tank either on legs or suspended from the top. An above ground blower blows air into the FAST chamber, drawing water up into the treatment unit and splashing water and air up and over the fixed media. An outlet vent allows for air to escape the system, preventing pressurization of the tank. Bacteria adhere to the media and consume nutrients as the water circulates through the media. As the bacterial mat ages and accumulates, material sloughs off and settles to the bottom of the tank to be removed by periodic pump outs. An outlet pipe in the treatment unit sends effluent out to the drain field system or a holding tank (Figure 3).

Figure 3. Cross section of the FAST treatment unit installed in the second chamber of two chamber tank or in a single chamber tank that is after a separate pre-treatment tank. The blower, vents and controls are also shown. From the Bio-Microbics website.

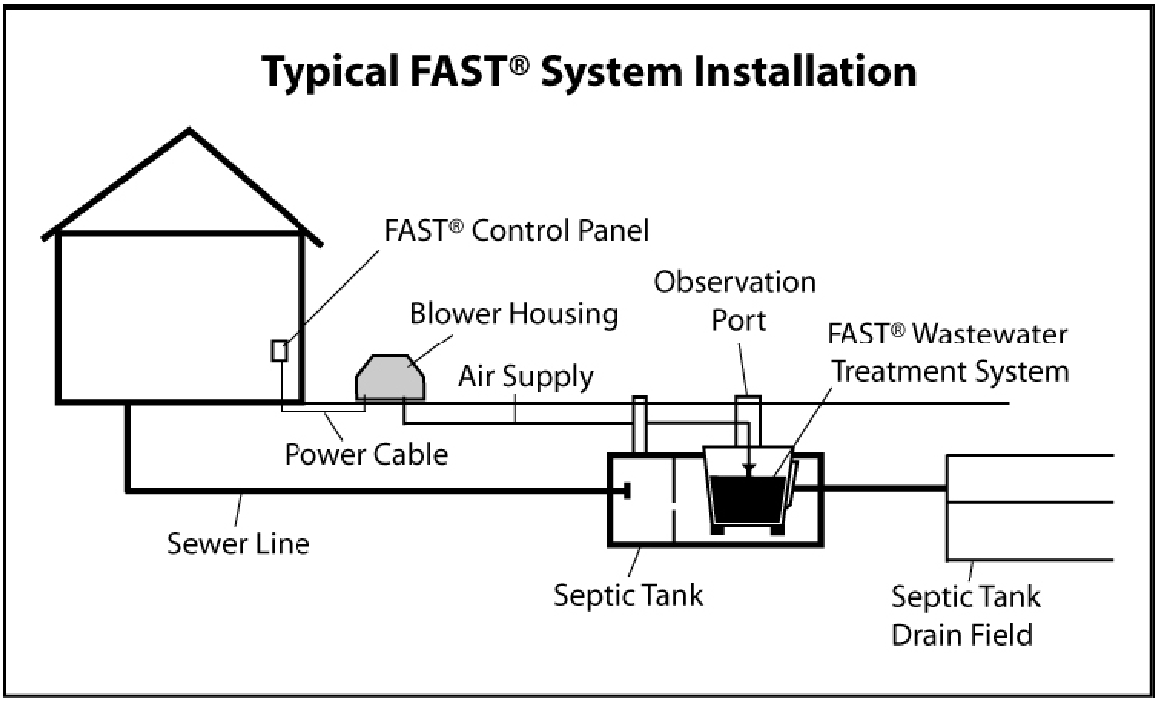


The recirculation required in HOOT and Norweco systems is not necessary in the FAST system. A narrow spill tray allows water splashing up over the fixed media during the treatment to flow back outside the treatment unit but still within the treatment chamber. The water outside the treatment unit in the treatment chamber is anaerobic, providing an environment for denitrification of the aerated wastewater form the spill tray (Figure 4).

***Figure 4. A picture of FAST treatment unit being installed into the treatment chamber of a dual chambered tank. The blue fixed media and spill tray are shown*.**

Not having to recirculate a system's effluent back to a pretreatment chamber allows for the FAST system to be installed without a post chamber or tank housing a pump, as with the HOOT and Norweco systems. This reduces the electrical usage, maintenance, and installation cost of a typical FAST system (Figures 4 and 5). If a drip or mounded drain field systems is necessary, a separate holding tank or pump tank is added and the engineer can decide whether recirculate the effluent back to the pretreatment tank. A holding tank can also be added without the pump to increase the capacity of the system. Because of the added expense of the extra tank and/or pump, most FAST systems have a conventional drain field that is fed by gravity flow (Figure 5).

Figure 5. The most common FAST system configuration installed in Wakulla County. From the Bio-Microbics website.



Earlier FAST systems installed in Wakulla County included a single 1050-gallon septic tank followed by a 350-gallon pump tank. Since these systems were not engineered with an anaerobic tank, they were in a different configuration than those certified by NSF/ANSI Standard 40 and Nitrogen Reduction. The FDOH recommended that the systems be installed with pre-treatment chambers or tanks. As a result, FAST systems are now installed into two chamber 850-900 gallon tanks, each with a chamber for anaerobic treatment and an aeration chamber. In homes needing a higher capacity, separate holding tanks are added post treatment unit. This is also done when drip irrigation is used for effluent disposal and there is need for an effluent pump. The most elaborate configuration of a FAST PBTS uses three separate tanks, a pretreatment tank, a treatment tank with the FAST unit installed, and a post treatment or pump tank.

2. Methods

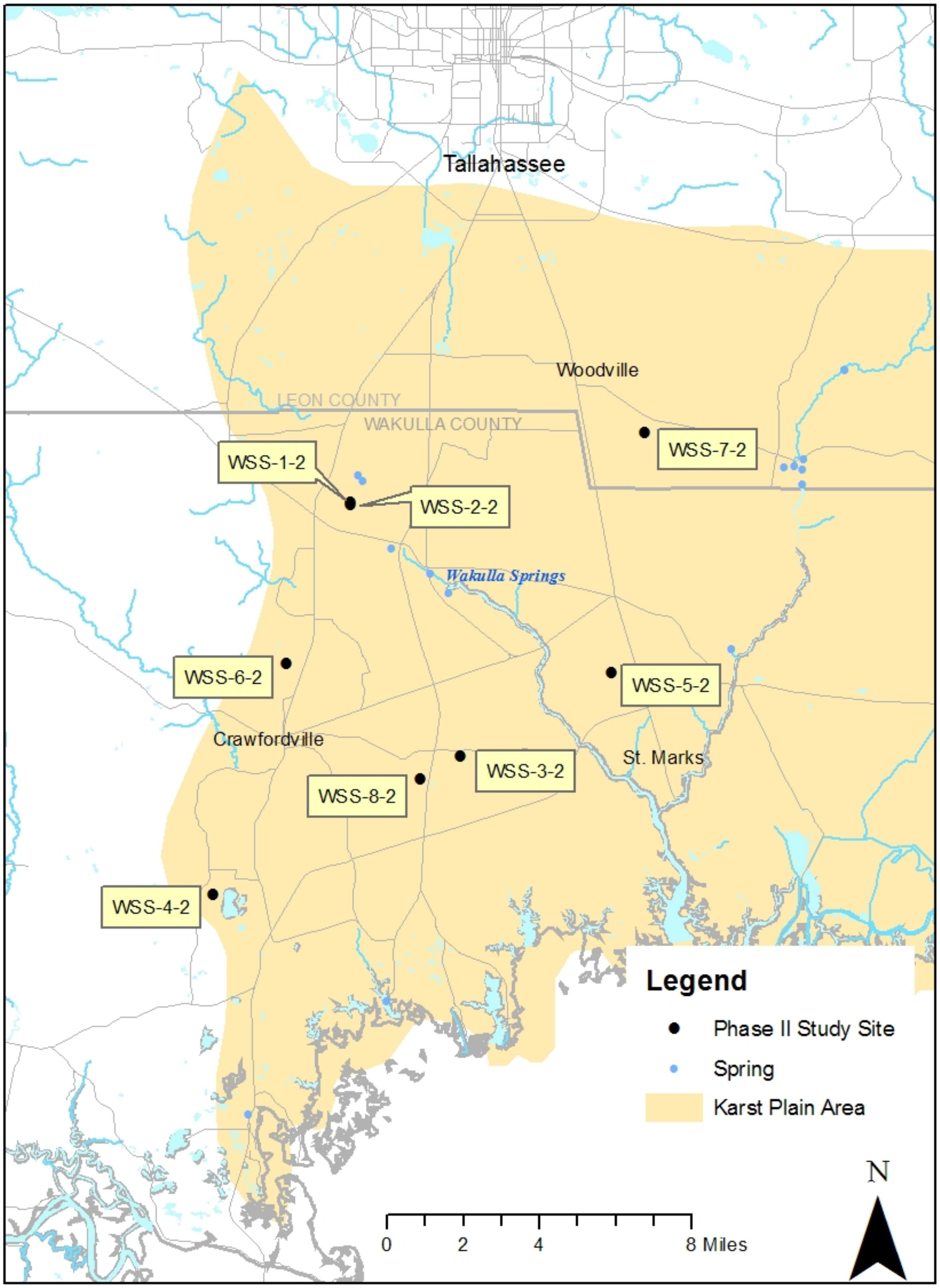
2.1 Phase II Study Sites.

Study sites were chosen from a permit survey which identified 105 PBTS systems installed as of 10/27/08 in Wakulla County, Florida. The locations of the 8 sites in Wakulla County are shown in Figure 6. Sites were chosen so that all three types of PBTS installed in the county were represented. The drain field type was also considered in site selection, with four having conventional drain fields and four having pressurized drip systems.

Table 1. Site information for the Phase II sites, including system type, drain field, installation date.

Site ID	PBTS	Drain field Type	Final Inspection	Household
WSS-1-2	HOOT	Drip, Small Mound	07/03/07	2 adults, 3 children
WSS-2-2	FAST -Dual Chamber	Conventional, gravity	02/02/08	2 Adults, 1 child
WSS-3-3	Norweco	Conventional, dose	04/10/08	2 Adults
WSS-4-2	FAST- 3 Tanks	Drip, Large Mound	08/18/05	2 adults, 1 child
WSS-5-2	Norweco	Mounded conventional	08/20/07	2 Adults
WSS-6-2	HOOT	Drip	8/20/07	2 Adults, 2 Children
WSS-7-2	Norweco	Drip	08/28/08	2 Adults, 1 Child
WSS-8-2	FAST-Dual & Post Tank	Conventional, gravity	02/08/08	5 Adults, 5 Children

Figure 6. Study Site Locations.



2.2 Raw Sewage Sampling

Flow-weighted 24-hour composite samples of the raw sewage were collected at each of the Phase II study sites to determine the nutrient input. Raw sewage was homogenized by the sampling pump that was triggered using a water sensor to capture each flow event.

Prior to the first sampling event, the raw wastewater line between the house and septic system was exposed and a collection vessel and associated plumbing installed. Two vertical PVC pipes extended from the collection vessel to the ground surface. One access port was for placement of a float switch which triggered the sampling pump and the other port was for the raw wastewater input to the pump. An additional PVC line extended to the ground surface for the return of wastewater to the septic tank (Figure 7). After backfilling each site, two irrigation boxes were placed over the access.

Figure 7. Plumbing for sampling raw wastewater about to be installed between the house and septic tank at site WSS-4-2. The water sensor is placed in the 4 inch opening of the 4-way PVC piece. Note the inlet clean out.

The raw sewage sampling device consists of a fabricated system mounted on a wagon that includes an in-line macerating vacuum pump, a power converter, and the waste stream return line with ball valve, which is use for sample collection (Figure 8). The entire raw wastewater flow from the home passes through the collection vessel and sampling pump. A float switch in the collection vessel triggers the in-line macerating vacuum pump (Jets Standard As, vacuumerator 15MB). The pump, commonly used in Europe, is designed for collection of toilet waste and is capable of operating either continuously or intermittently at flow rates up to approximately 83 L/min. The ball valve, installed in the discharge line to control wastewater flow to the sampling container, is adjusted to collect approximately 75-150 mL of sample from each 7.5-liter sample event (1-2% of the total flow). The remainder of the homogenized wastewater flow returns to the wastewater line prior to discharge into the septic tank. Before collecting raw wastewater samples, the solids in the collection vessel are purged and the vessel is flushed with clean water. This system flush also served to decontaminate the homogenization apparatus between sites. Finally, prior to sample collection, up to four exchanges of wastewater from the 7.5-L collection vessel are passed through the system.

Figure 8. The sampling pump wagon set up at a residence to sample raw sewage. The clear hose is the inlet to the pump and the white hose is the return line. The blue cooler holds a glass 2 gallon jar on ice. On the far right, the wire coming out of the PVC pipe is from the water sensor.

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2.3 PBTS Effluent Sampling

The technique for sampling effluent varies depending on the type of system. Ideally, effluent is sampled while flowing in the pipe that leads from the PBTS to the drain field. In systems that have drip drain fields, the pump has a 120-150 micron filter and the sample is taken post filter. Sites WSS-4-2 and WSS-5-2 both had sampling ports installed in the correct location. For these sites, the pump is turned on and after waiting at least 1 minute, the sample taken using the installed valve. At sites WSS-2-2 and WSS-8-2, both with gravity fed drain fields, the vent pipe is used as the sampling port. If effluent is not flowing prior to sampling systems without an effluent pump, then flow was induced by adding water to the cleanout in the inlet pipe to the system. Site WSS-3-2 is sampled from a cleanout installed in the pipe from the pump tank to the conventional drain field. The pump was turned on and the sample taken from then cleanout after flow was established. The remaining sites, WSS-1-2, WSS-6-2, and WSS-7-2, have pumps with filters. Besides the inlet and outlet of the filter, there is a small (1/4 inch) line that is used to re-circulate the filtered effluent back to the pretreatment tank. To sample these systems, the line is disconnected, the pump turned on and after allowing the effluent to flow at least 1 minute, the sample taken.

Analyses and analytical methods for raw sewage and PBTS effluent samples are shown in Table 2.

Table 2. Analytical Methods for Raw Sewage and Septic Tank Effluent Samples

Analysis	Analytical Method	Laboratory Detection Limit
Ammonia Nitrogen	EPA 350.1 Rev. 20.	0.010 mg/L
Total Kjeldahl Nitrogen	EPA 351.2 Rev. 2.0	0.20 mg/L
Nitrate+Nitrite Nitrogen	EPA 353.2 Rev. 2.0	0.004 mg/L
Total Phosphorus	EPA 365.1 Rev. 2.0	0.012 mg/L

3. Results and Discussion

Nitrogen in raw wastewater is predominately in the reduced forms of organic-nitrogen and ammonium-nitrogen. Conditions in septic tanks, as well as the pretreatment tanks in PBTS, are generally anaerobic, causing ammonification, the rapid conversion of organic-nitrogen to ammonium-nitrogen, the predominate form of nitrogen in STE. Nitrification occurs with sufficient oxygen and the proper microbial population, converting ammonium-nitrogen to nitrite-nitrogen then nitrate-nitrogen. In a conventional septic system, nitrification occurs in the unsaturated soil within and beneath the drain field. In a PBTS, the purpose of the blower or aerator is to create an aerobic environment in the treatment chamber so microbial nitrification can occur. Subsequently, if the system provides the proper anaerobic conditions for the nitrified wastewater and the required microbial populations are then present, denitrification converts nitrate-nitrogen to inert nitrogen gas. The denitrifying bacteria require a carbon source and limited dissolved oxygen.

Denitrification may be somewhat limited underneath a drain field in the soil and the subsurface aquifer in the Wakulla County. Denitrification requires nitrate and organic matter. Beneath a thin topsoil layer, the soils are sandy and low in organic content. As currently installed, conventional systems and most drip drain fields are below the carbon rich layer and the root zone of plants that could utilize the nitrate. In a PBTS, denitrification may occur in the treatment tank and perhaps in the post treatment tank. Further denitrification occurs as a portion of the effluent is recirculated back to the anaerobic pretreatment tank. These nitrogen transformations are critical to reduce environmental nitrogen loading.

3.1 Raw wastewater nitrogen inputs to residential OSTDS in Wakulla County

To gauge the effectiveness of septic system in reducing TN, input concentrations as well as system effluent concentrations must be known. In Phase I of this study, raw wastewater was not sampled. However, during that time period, CSM choose Wakulla County as one of their three study regions and 6 sites were sampled quarterly for a year for both raw wastewater and STE. Phase II of this study employed the same equipment (contributed by CSM), sampling techniques, and personnel to sample the wastewater inputs at 5 of the 8 study sites. Unfortunately, site WSS-8-2 had to be abandoned after three of the monthly sampling events and only one raw wastewater sample was obtained from the PBTS installed at it. The PBTS at Site

WSS-4-2 was then outfitted with the raw wastewater sampling apparatus as a replacement. As expected, nitrogen in the raw wastewater was predominately total Kjeldahl nitrogen (TKN), mostly in the form of organic nitrogen with a smaller component of ammonium (Table 3). Although the TKN percentage of TN was consistently close to 100%, there was a large variability in the TN concentrations (Table 4).

Table 3. Phase II Study Results. Raw sewage TN-inputs to septic tanks. Units of N are in mg-N/L.

Site ID	TN Average (mg/L)	n	%TN as TKN (includes ammonia)	%TKN as $NH4^+$
WSS-1-2	**55.1 ± 28.2**	**4**	**99**	**20**
WSS-2-2	**96.5 ± 56.2**	**5**	**100**	**20**
WSS-4-2	**39.1 ± 20.7**	**2**	**96**	**16**
WSS-7-2	**77.4 ± 26.1**	**5**	**99**	**5**
WSS-8-2	**70.2**	**1**	**100**	**6**
All Samples	**72.8 ± 39.2**	**17**	**99**	**14**

Notes: Average with standard deviation and number of samples (n) for TN measured at each site. The percentage of TN in the form of TKN and the percentage of TKN in the form of ammonium ion and ammonia is also presented. TKN is the sum of organic nitrogen and ammonia species components of TN. TN is the combination of TKN and nitrate plus nitrite.

Table 4. Phase II Study Results. TN statistics from the 5 sites at which raw sewage inputs were measured. Units are in mg-N/ L or percent, where noted.

Site ID	Average	Std. Dev.	Low	25th %	Median	75th %	High	IQR	n
WSS-1-2	**55.1**	28.2	**30.4**	32.0	**51.5**	74.6	**87.1**	42.6	**4**
WSS-2-2	**96.5**	56.2	**42.6**	51.0	**78.3**	140.3	**170.2**	89.2	**5**
WSS-4-2	**39.1**	20.7	**24.5**	31.8	**39.1**	46.4	**53.7**	14.6	**2**
WSS-7-2	**77.4**	26.1	**54.7**	59.6	**61.6**	100.7	**110.4**	41.1	**5**
WSS-8-2	**70.2**								**1**
All Samples									
	72.8	39.2	**24.5**	51.0	**61.6**	87.1	**170.2**	36.1	**17**
Statistics for Averages of 3 sites: WSS-1-2, WSS-2-2, WSS-7-2									
	76.3	20.7	**55.1**	66.3	**77.4**	87.0	**96.5**	20.7	**3**

Notes: Only one sample was taken at site WSS-8-2 and only two samples collected at site WSS-4-2. Due to the high variability in TN values found in raw wastewater, the data from these sites was not used in calculating the statistics of the averages of each site. The bottom row is the average of the means of each of the three sites where the most data was obtained. Each site is counted once in this mean, n=3.

The large range in raw wastewater TN values is not surprising due to variety of daily water use activities that can dilute or strengthen the waste stream concentration for a particular household. Additionally, a household's number and age of members and their life style can affect the TN concentration in the wastewater. For example, an elderly retired couple's waste stream may be very different than that of a younger couple with children. The CSM data shows a similar wide range in TN concentrations within sites (Table 5).

Table 5. CSM Wakulla Results for Raw Wastewater. Statistics for the TN concentrations from the 6 sites at which raw sewage inputs were measured during the portion of the Colorado School of Mines study in Wakulla County. One of the quarterly samples for site F2 is an average of 6 samples taken over a one week period. Units of N are in mg-N/ L.

Site ID	**Average**	**Std. Dev.**	**Low**	**25th %**	**Median**	**75th %**	High	**IQR**	**n**
F1	**51.1**	29.1	**22.0**	28.8	**50.3**	72.6	82.0	43.9	**4**
F2	**43.5**	30.31	**10.5**	28.9	**40.0**	54.6	83.4	25.7	**4**
F3	**96.9**	51.4	**37.0**	66.3	**97.8**	128.4	155.0	62.1	**4**
F4	**70.3**	15.1	**50.0**	65.0	**72.5**	77.8	86.0	12.8	**4**
F5	**81.8**	105.8	**23.0**	23.0	**32.0**	90.8	240.0	67.8	**4**
F6	**95.3**	15.5	**74.5**	88.0	**99.3**	106.5	108.0	18.5	**4**
All Samples									
	73.1	50.3	**10.5**	36.5	**72.3**	87.6	240.0	51.1	**24**
Statistics for Averages of 6 Sites									
	73.2	22.4	**43.5**	55.9	**76.1**	91.9	96.9	36.0	**6**.

Notes: The bottom row is the average of the means of each of the six sites where the most data was obtained. Each site is counted once in this mean, n=6. Units of N are in mg-N/ L.

The Phase II and CSM data for raw wastewater are in good agreement in regard to the averages of the means of each site where 4 or more samples were taken, 76.3 ± 20.7 mg-N/L n=3 and 73.2 ± 22.4. mg-N/L n=6, respectively. This very strong correlation is also seen if the statistics are done using all the samples taken in the Phase II study to date, 72.8 ± 39.2 mg-N/L, n=17 and 73.1 ± 50.3 mg-N/L, n=24 from the CSM study. Both studies also show the high degree of variability in samples. The low value in the Phase II data to date is 24.5 mg-N/L and the high value is 170.2 mg-N/L. The range of values was greater in the CSM study, 10.5 mg-N/L and 240.0 mg-N/L. The higher range and standard deviation of the TN values in the CSM study may be a result of the greater number of samples taken. One of the CSM sites in each region was sampled for 7 consecutive days to access daily variations. The statistics for 6 samples taken over a one week period are summarized Table 6.

Table 6. CSM 7 Day Intensive Results. Statistics for the raw wastewater TN inputs to the CSM site F2 which included a 7 day sampling event during the week of April 15 through 21, 2008. Units of N are in mg-N/L.

	Average.	**Standard Deviation**	**Median**	**n**
Tuesday	71.0	0.0		2
Wednesday	**No sample**			**0**
Thursday	94.0	0.0		2
Friday	44.0	2.8		2
Saturday	38.5	0.7		2
Sunday	149.0	0.0		2
Monday.	104.0	4.2		2
April, 2008 6 days	**83.4**	41.4	**82.5**	**6**
F2-Fall	10.5	0.5		**2**
F2-Winter	35.0	0.0		**2**
F2-April, 2008	**83.4**			**6**
F2-July, 2008	45.0	0.0		**2**
Quarterly Total	**43.5**	30.3	**40.0**	**4**
All F2 samples	**65.7**	43.1	**45.0**	**9**

Notes: The sewage pump was set up on a Monday and first sample was on Tuesday. The Wednesday sample was not taken due to equipment malfunction. The statistics are presented for all samples taken at site F2 as well as the 4 quarterly events, using the average of the 6 daily samples taken during the 3rd quarterly sample even for that value.

The results presented in Table 6 show a wide range of TN values during the weeklong daily sampling and further illustrate the necessity of repeated sampling to accurately assess a household's waste stream. It is difficult to sample raw wastewater on a large number of systems due to having to install special plumbing and the time and labor involved, yet having a realistic and reliable wastewater input value is crucial to evaluating the effectives of treatment

3.2 Septic tank effluent (STE) from conventional septic tanks in Phase I Sites.

Little nitrogen reduction occurs in a conventional septic tank. The primary processing of nitrogen is ammonification, the bacterial conversion of organic nitrogen to ammonia and ammonium ion (Washington State DOH, 2005). Some of the ammonia species are reconverted back to organic nitrogen via cell growth, but a net increase in ammonium concentration occurs in the septic tank (Table 7).

Table 7. Phase I Study Results. The STE Average (Ave.) and standard deviation (Std. Dev.), number of samples (n) for TN measured at each site. Units of N are in mg-N/L.

Site ID	TN Average.	TN Std. Dev.	TN Median	n	%TN as TKN	%TKN as $NH4^+$
HK	**30.1**	10.4	**35.0**	3	100	87
LT	**57.2**	4.6	**55.0**	3	100	94
YG (F1)	**47.8**	13.5	**43.5**	3	100	96
All Samples						
	45.0	14.8	**43.5**	9	100	93

Notes: The percentage of TN in the form of TKN and the percentage of TKN in the form of ammonium ion and ammonia is also presented. TKN is the organic nitrogen and ammonia species component of TN. TN is the combination of TKN and nitrate plus nitrite.

The nitrogen removal from wastewater in a conventional septic tank occurs through ammonia volatilization and sedimentation of undigested organic matter, which is removed by periodic septic pump outs (Washington State DOH, 2005). The low concentrations or absence of nitrate in raw wastewater and the anaerobic conditions unfavorable to nitrification result in the TN in STE to be virtually 100% TKN (Table 7).

The TN concentration in STE is less variable than the TN in raw wastewater due to temporal averaging that occurs in the tank. One of the primary functions of a conventional septic tank is to equalize the flow of the wastewater stream and allow for the digestion and sedimentation of wastewater solids. The statistics for the TN concentrations found in the three sites with conventional septic tanks studied in Phase I of this study are summarized below in Table 8.

Table 8. Phase I Study Results. Septic tank effluent (STE) TN statistics for the 3 sites with conventional systems at which STE were measured at the Phase I sites. Site YG and F1 are the same. These samples are grab samples. Units of N are in mg-N/L.

Site ID	**Ave.**	**Std. Dev.**	**Low**	**25th %**	**Median**	**75th %**	**High**	**IQR**	**N**
HK	**30.1**	10.4	**18.1**	26.6	**35.0**	36.0	**37.0**	9.4	**3**
LT	**57.2**	4.6	**54.0**	54.5	**55.0**	58.8	**62.5**	4.2	**3**
YG (F1)	**47.8**	13.5	**37.0**	40.3	**43.5**	53.3	**63.0**	13.0	**3**
Statistics for Means of 3 Sites									
	45.0	13.8	**30.1**	39.0	**47.8**	`52.5	**57.2**	13.6	**3**
All Samples									
	45.0	14.8	**18.1**	37.0	**43.5**	55.0	**63.0**	18.0	**9**

Notes: The second to bottom row is the average of the means of each of the three sites, where each site is counted once, n=3. The bottom row includes the statistics for all samples taken from the three sites

In Phase I, the STE samples were grab samples. In the CSM study the STE samples were 24-hour composite samples. Site YG from Phase I is the same residence as site F1 in the CSM study. In the CSM study (Table 9) the average septic tank effluent was 64 ± 13 mg-N/L. Due to the larger sample size, we consider the CSM study results for STE for conventional septic tanks to be the more representative values. This assertion is supported by the results of the much more comprehensive La Pine study, 66 ± 22, n=427 (La Pine Oregon Demonstration Project, 2006).

Table 9. CSM Study Results. TN statistics of STE measured at the 6 CSM Wakulla County sites with conventional systems. Site YG from Phase I and F1 of the CSM study are the same septic system. Units of TN are in mg-N/L

Site ID	Average.	Std. Dev.	Low	25^{th} %	Median	75^{th} %	High	IQR	n
F1 (YG)	**43.9**	5.3	**38.0**	41.0	**43.5**	46.4	**50.5**	5.4	**4**
F2	**72.8**	7.0	**64.0**	68.1	**71.0**	78.0	**85.5**	9.9	**10**
F3	**68.3**	5.4	**61.0**	66.3	**69.0**	71.0	**74.0**	4.8	**4**
F4	**67.5**	7.9	**59.0**	62.0	**67.5**	73.0	**76.0**	11.0	**4**
F5	**44.3**	4.3	**38.0**	43.3	**45.5**	46.5	**48.0**	3.3	**4**
F6	**70.9**	5.5	**65.0**	68.0	**70.3**	73.1	**78.0**	5.1	**4**
Statistics for Averages of 6 Sites									
	61.3	13.4	**43.9**	50.1	**67.9**	70.3	**72.8**	20.2	**6**
All Samples									
	63.6	13.4	**38.0**	52.6	**68.0**	72.0	**85.5**	19.4	**30**

Notes: The second to bottom row is the average of the means of each of the six sites, where each site is counted once, n=6. The bottom row is the statistics for all samples taken from the six sites

If 70 mg-N/L is used as an input value, this results in an N-reduction of 9 ± 19% in these conventional septic tanks (using Equation 1). The results of Table 8 with an STE of 45 ± 15 mg-N/L indicate a 36 ± 21% reduction. However, the total CSM study found that on average the mean of both raw influent (n=63) and STE (n=61) was ≈ 60 mg-N/L, suggesting little removal of N by a conventional septic tank (Lowe et al, 2009).

3.3 Effluent Nitrogen data from PBTS installed in Wakulla County, Florida 8 main sites.

Effluent from 8 PBTS was sampled on an approximately monthly basis for the first 6 months of the study and analyzed for the nitrogen species, as well as TP and chloride. For this report, nitrogen is the focus. Table 10 summarizes the TN concentration in the effluent, measured at the 8 sites. Site WSS-8-2 was abandoned after the first three samples.

Table 10. Phase II Study Results. TN in effluent from 8 PBTS study sites in Wakulla County, Florida. Units of TN are in mg-N/L.

Site ID	Average	Std. Dev.	Low	25th %	Median	75th %	High	IQR	n
WSS-1-2	**35.6**	16.5	10.5	25.3	**41.6**	45.4	53.0	20.1	**6**
WSS-2-2	**26.3**	2.1	23.1	25.1	**26.9**	27.4	28.9	2.4	**6**
WSS-3-2	**31.6**	15.3	12.7	20.5	**31.8**	39.8	54.2	19.3	**6**
WSS-4-2	**17.4**	9.1	4.6	11.0	**19.2**	25.0	25.9	14.0	**6**
WSS-5-2	**34.4**	9.5	22.3	29.3	**33.3**	38.7	49.4	9.4	**6**
WSS-6-2	**19.2**	9.8	9.0	11.7	**16.8**	27.0	**32.1**	15.3	**6**
WSS-7-2	**47.5**	18.2	16.3	44.8	**47.6**	55.5	71.3	10.7	**6**
WSS-8-2	**33.7**	3.8	31.0	31.5	**32.0**	35.0	38.0	3.5	**3**
Statistics for Averages of 8 Sites									
	30.7	**9.7**	**17.4**	24.5	32.7	34.7	47.5	10.2	8.0
All Samples									
	30.5	**14.7**	4.6	20.3	28.0	40.4	71.3	20.1	45.0

Notes: The second to bottom row is the average of the means of each of the eight sites, where each site is counted once, n=8. The bottom row is the statistics for all samples taken from the eight sites

3.4 Effluent Nitrogen data from Performance Based Treatment Systems installed in Wakulla County, Florida, Sampling and survey of additional sites.

In an effort to ascertain if the results from the 8 intensive sites were representative of PBTS installed in the study area, an additional 27 PBTS systems were sampled in cooperation with the Wakulla County Health Department and FDOH Bureau of Onsite Sewage Programs. Candidate systems were selected from a survey of PBTS permits finalized as of 10/27/08. This survey indicated that of the 105 PBTS installed approximately 10% were HOOT systems, 30% were Norweco systems and 60% were FAST systems. Sample sites were chosen to reflect this ratio and to also sample each variety of FAST system that was installed.

Of the 27 additional sites sampled during April, 2009, 3 sites had samples with TN concentrations lower than 10 mg-N/L total nitrogen and while 5 sites had TN effluent concentrations of 60 mg-N/L or greater, similar to conventional septic system effluent (STE). The TN concentrations and the percent TKN in these systems are presented in Table 11. The average TN effluent concentration for all 27 sites was 29.2 ± 20.8 mg-N/L.

Table 11. Phase II Study Results. TN in effluent from 27 additional PBTS sites in Wakulla County, Florida sampled in April 2009. Units of N are in mg-N/L.

Sample ID	System type	TN.	%TKN
WS-11	HOOT	20.2	6
WS-25	HOOT	40.5	11
WS-26	HOOT	18.1	23
WS-1	Norweco	**72.0**	**86**
WS-10	Norweco	19.2	22
WS-12	Norweco	21.1	100
WS-20	Norweco	23.0	74
WS-24	Norweco	**8.6**	**94**
WS-3	FAST Dual Chamber	26.4	68
WS-5	FAST Dual Chamber	26.1	4
WS-7	FAST Dual Chamber	**67.0**	**21**
WS-8	FAST Dual Chamber	**3.6**	**64**
WS-9	FAST Dual Chamber	**59.5**	**100**
WS-22	FAST Dual Chamber	29.3	8
WS-23	FAST Dual Chamber	14.1	22
WS-14	FAST Dual Chamber + Post Tank	**2.6**	**38**
WS-18	FAST Dual Chamber + Post Tank	20.0	98
WS-21	FAST Dual Chamber + Post Tank	16.2	7
WS-6	FAST Single Chamber +Pre Tank	37.0	100
WS-13	FAST Single Chamber +Pre Tank	**60.0**	**27**
WS-16	FAST Single Chamber +Pre Tank	13.2	24
WS-17	FAST Single Chamber +Pre Tank	32.1	19
WS-2	FAST Single Chamber +Post Tank	20.3	98
WS-15	FAST Single Chamber +Post Tank	**8.6**	**2**
WS-19	FAST Single Chamber +Post Tank	26.4	80
WS-4	FAST Three Tanks	**78.1**	**3**
WS-27	FAST Three Tanks	24.0	8
	Average	**29.2 ± 20.8**	

Notes: ***Data are grouped by system type. The FAST system with a single chamber with the treatment unit plus a post tank is no longer allowed by the FDOH. The FAST Dual Chamber configuration is the most common installation. The TN values below 10 mg-N/L and those above 60 mg-N/L, an estimate TN for conventional systems, are in bold.***

The results from the 27 additional sites confirm that the TN data from the 8 PBTS study sites are representative of functioning systems installed in Wakulla County. Table 12 compares the results from all PBTS sampled to date and also gives statistics for the three types of systems studied. The average effluent concentration for the 35 sites was **29.4** ± 18.8 mg-N/L.

Table 12. Phase II Study Results. TN in effluent from the 8 PBTS sites of Phase II and the 27 additional PBTS sites in Wakulla County, Florida sampled in April 2009. Units of N are in mg-N/L.

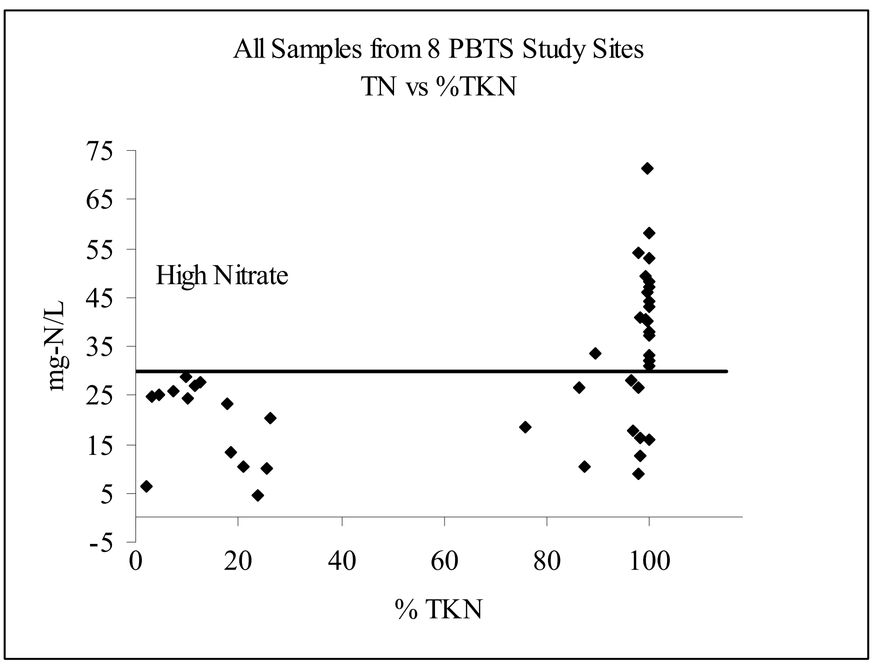
Sample Group	Ave.	Std. Dev.	Low	25th %	Median	75th %	High	IQR	n
24 Current Code	**30.5**	21.5	2.6	17.6	**23.5**	37.9	78.1	20.3	**24**
27 Survey Sites	**29.2**	20.8	2.6	17.2	**23.0**	34.6	78.1	17.4	**27**
8 Main sites	**30.7**	9.7	17.4	24.5	**32.7**	34.7	47.5	10.2	8.0
HOOT	**26.7**	10.5	18.1	19.2	**20.2**	35.6	40.5	16.4	**5.0**
Norweco	**32.2**	19.9	8.6	20.6	**27.3**	37.7	72.0	17.1	**8.0**
FAST	**29.2**	20.2	2.6	16.5	**26.2**	33.3	78.1	16.8	**22.0**
Average of 35 Sites									
Total	**29.5**	18.7	2.6	18.1	**26.1**	35.0	78.1	16.9	**35.0**

Notes: Three of the sites have the FAST unit in a single chamber tank with a post tank, which is no longer allowed by WDOH. These sites are excluded from the 27 Survey Sites in the line 24 Current Code.

3.5 Evidence of Nitrification and Denitrification in PBTS Effluent

In a properly functioning PBTS, the nitrogen in the wastewater flowing out of the pre-treatment chamber into the treatment chamber approaches 100% organic nitrogen+ammonia (TKN) (Table 6). In the treatment chamber, TKN is converted to NO_3 with oxygen through bacterial nitrification. The extent of this process is dependent on the amount of dissolved oxygen present as well as the health and vigor of the nitrifying bacteria. Since nitrification of the TKN to NO_3 is necessary before denitrification can occur, the extent of nitrification determines the amount of denitrification. Denitrification occurs as the nitrate encounters anaerobic conditions in the presence of organic matter. The percentage of nitrogen as TKN in the PBTS effluent is not an indicator of system performance but can provide insight to how system is functioning. Samples from the 8 PBTS study sites with relatively low TN concentrations typically have either very low or high percentages of nitrogen as TKN. Samples with relatively high TN concentrations consistently have high percentages of nitrogen as TKN (Figure 9).

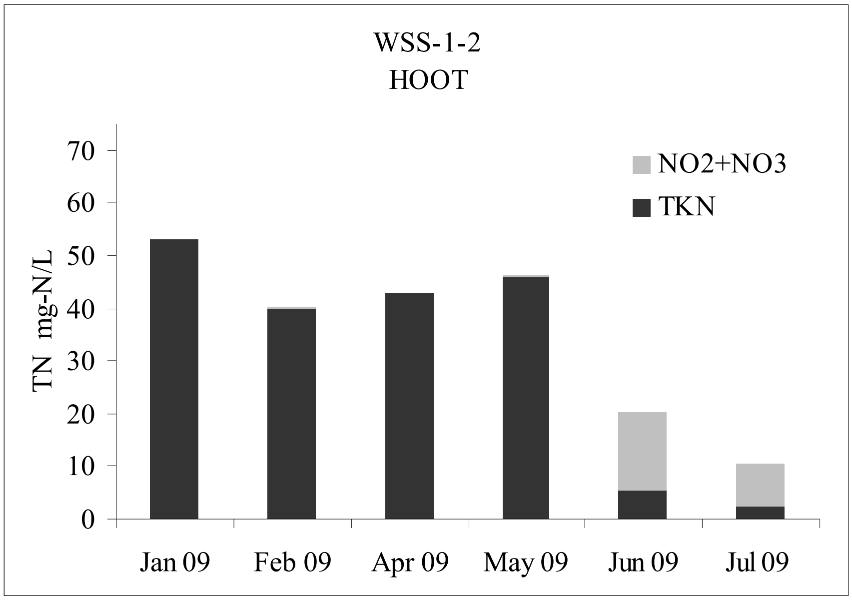
***Figure 9. The TN concentrations (y-axis) of all samples form the 8 PBTS study sites plotted against the percentage of nitrogen as TKN. The samples with TN concentrations below 30 mg-N/L had TKN percentages that were either low or high. Samples with TN concentrations above 30 mg-N/L always had a high percentage of nitrogen as TKN*.**



Effluent samples from systems with low TN concentrations and a high percentage of the nitrogen as nitrate indicate that they are achieving a high rate of nitrification. Most of the nitrogen is converted into NO_3 and as denitrification occurs, lowering the TN, the remaining effluent is predominately NO_3. Samples with low TN concentrations and a high percentage of the nitrogen as TKN indicate systems that have incomplete nitrification followed by denitrification. As denitrification occurs in the partially nitrified wastewater, the NO_3 is consumed resulting in effluent with a high percentage of nitrogen as TKN. Samples with high TN concentrations and a high percentage of the nitrogen as TKN indicate systems that have limited or no nitrification. Any NO_3 that is formed is consumed by denitrification. Since nitrification is limited, denitrification is also limited and the resulting effluent has a high TN that is mostly TKN.

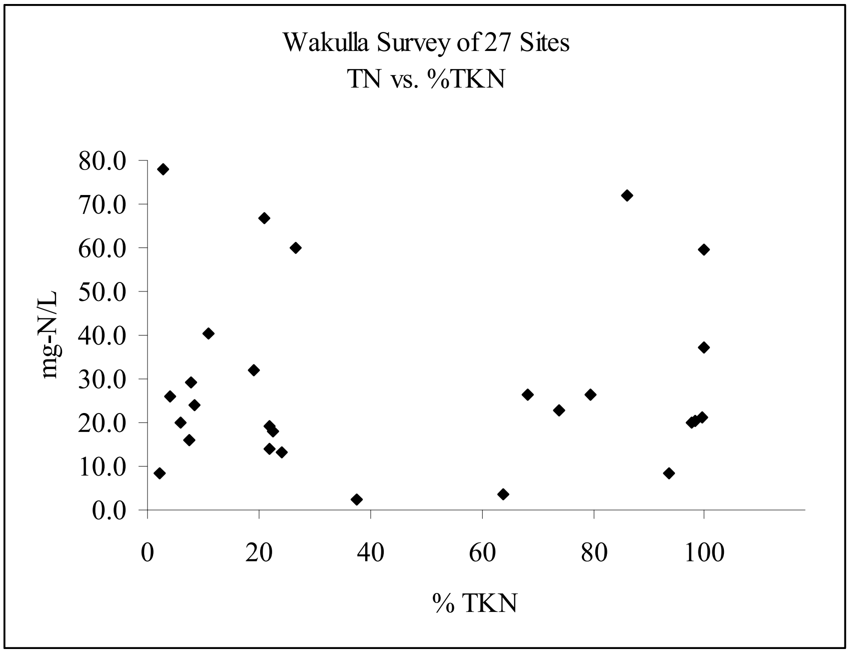
The data from site WSS-1-2 illustrates how the performance of a system may be improved with monitoring and subsequent adjustments to the system. After the May, 2009 sample event, the pressure in the drain field and recirculation system was reduced. Nitrification was thought to be limited as the recirculation was flushing wastewater through the system too fast. After this adjustment, the TN values were lower with a greater percentage of (NO_3 in the effluent (Figure 10).

Figure 10. The TN concentrations plotted against the percentage of nitrogen as TKN at site WSS-1-2. In the first 4 samples with relatively high TN values, the nitrogen was mostly TKN. In the last two samples nitrification was apparently much more extensive and the TN values were lower and predominately in the form of NO_3.



The data from the 27 additional sites sampled showed a greater degree of variability in the percentage of TKN in the TN of the systems effluent. As with the data form the 8 PBTS study sites, there are: (1) low TN concentrations with low percent as TKN indicating extensive nitrification and denitrification, (2) low TN concentrations with high percent as TKN indicating incomplete nitrification and denitrification, and (3) high TN concentrations with a high percentage as TKN indicating limited nitrification and thus denitrification. Additionally, the data from the additional 27 sites show a fourth category, systems with samples with high TN with a low percentage as TKN indicating a system that is nitrifying the waste stream without the subsequent denitrification (Figure 11).

Figure 11. The TN concentrations (y axis) of all samples from the 27 PBTS study sites plotted against the percentage of nitrogen as TKN (x-axis).



3.6 Nitrogen Reduction in PBTS

The reduction of nitrogen by a system can be calculated if both the raw sewage inputs and the effluent output nitrogen concentrations are known. The nitrogen content of raw sewage is highly variable depending on varying water use and lifestyle of the occupants of a household. The recent measurements suggest that a reasonable estimate for the average TN input from raw sewage in residences in Wakulla County is 70 mg-N/L (Tables 4 and 5). The percent reduction is calculated using this estimate and the actual input values for the study sites where the data is available (Table 13).

The results of the Phase II study on performance based units are as follows. Effluent from eight Wakulla County PBTS units was sampled repeatedly through 2009. STE from these 8 sites averaged 30 ± 10 mg-N/L (Figure ES-2, Table 10). Of the additional 59 surveyed sites, the effluent of 27 performance based units was sampled. Their average value was 29 ± 21 mg-N/L (Figure ES-2, Table 11). The average of the 35 total sites was 29 ± 19 mg-N/L (Table 12). These values are roughly half of the N-output from conventional septic systems.

For the 5 sites where the TN of the raw sewage was measured, the percent reduction is calculated using both the measured input TN concentrations and the estimate of 70mg-N/L (Table 13). For the 27 sites sampled once, we calculate a %N-reduction of 58.9 ± 28.5 (Figure ES-3, Table 14).

Table 13. Phase II Study Results. The percent reduction in TN achieved by the PBTS systems at sites where raw sewage inputs were measured is calculated using both the measured raw sewage values and the estimate of 70 mg-N/L. Units of N are in mg-N/L.

Site ID	**Input TN Average.**	**Effluent TN Average.**	**Average % Reduction**	**% Reduction 70 Input**
WSS-1-2	55.1 ± 28.2, n=4	35.5 ± 16.5, n=6	35.4	49.1
WSS-2-2	96.5 ± 56.2, n=5	26.3 ± 2.1, n=6	72.7	62.4
WSS-4-2	39.1 ± 20.6, n=2	17.4 ± 9.1, n=6	55.5	75.1
WSS-7-2	77.4 ± 26.0, n=5	47.5 ± 18.2, n=6	38.6	32.1
WSS-8-2	70.2, n=1	33.7 ± 3.8, n=3	52.0	51.9
5 Sites with Input Measurements				
	67.7 ±21.8, n=5	**32.1 ± 11.2, n=5**	**50.8± 14.9, n=5**	**54.1 ± 16.0, n=5**
All Samples				
	72.8 ± 39.2, n=17	31.9 ± 15.8, n=27	56.2	54.4
WSS-3-2	NA	31.6 ± 15.3, n=6	NA	54.9
WSS-5-2	NA	34.4 ± 9.5, n=6	NA	50.9
WSS-6-2	NA	19.2 ± 9.3, n=6	NA	72.6

Notes: The second to bottom row is the average of the means of each of the five sites, where each site is counted once, n=5. The bottom row is the statistics for all samples taken from the five sites

Table 14. Phase II Study Results. Nitrogen reduction at the survey sites. Percentages assume an input TN concentration of 70 mg-N/L. For samples with effluent values greater than 70 mg-N/L, the % reduction was assumed to be zero. Units of N are in mg-N/L.

Sample ID	System type	TN.	%Reduction 70 mg-N/L Input
WS-11	HOOT	20.2	71
WS-25	HOOT	40.5	42
WS-26	HOOT	18.1	74
WS-1	Norweco	**72.0**	**0**
WS-10	Norweco	19.2	73
WS-12	Norweco	21.1	70
WS-20	Norweco	23.0	67
WS-24	Norweco	**8.6**	**88**
WS-3	FAST Dual Chamber	26.4	62
WS-5	FAST Dual Chamber	26.1	63
WS-7	FAST Dual Chamber	**67.0**	**4**
WS-8	FAST Dual Chamber	**3.6**	**95**
WS-9	FAST Dual Chamber	**59.5**	**15**
WS-22	FAST Dual Chamber	29.3	58
WS-23	FAST Dual Chamber	14.1	80
WS-14	FAST Dual Chamber + Post Tank	**2.6**	**96**
WS-18	FAST Dual Chamber + Post Tank	20.0	71
WS-21	FAST Dual Chamber + Post Tank	16.2	77
WS-6	FAST Single Chamber +Pre Tank	37.0	47
WS-13	FAST Single Chamber +Pre Tank	**60.0**	**14**
WS-16	FAST Single Chamber +Pre Tank	13.2	81
WS-17	FAST Single Chamber +Pre Tank	32.1	54
WS-2	FAST Single Chamber +Post Tank	20.3	71
WS-15	FAST Single Chamber +Post Tank	**8.6**	**88**
WS-19	FAST Single Chamber +Post Tank	26.4	62
WS-4	FAST Three Tanks	**78.1**	**0**
WS-27	FAST Three Tanks	24.0	66
	Average and Standard Deviation	**29.2± 20.8**	**58.9 ± 28.5**

The average TN value of near 30 mg-N/L may seem high for systems in comparison to the 10 mg-N/L expectation in FDOH and Wakulla County documentation, but the percent reduction value of near 60% indicates these systems are working as designed. This technology has been shown to consistently achieve 50-70% nitrogen reduction when installed and maintained correctly, however to achieve the 10 mg-N/L expectation the influent concentration must be much lower. It appears that this expectation comes as a result of the influent concentrations used in the NSF/ANSI testing, which were much lower than the TN concentration in typical domestic wastewater influent. Under the NSF/ANSI testing, these systems were tested with sewage having TN concentrations of 25-35 mg-N/l, less than half of real world measurements (Table 15). It is apparent that in field settings the systems generally achieve or exceed 50% N-reduction, but they rarely achieve 10 mg-N/L because of the higher influent concentrations.

Table 15. Influent and effluent TN concentrations of systems during NSF/ANSI standard testing. Percent reduction of TN is also calculated. Units of N are in mg-N/L

NSF/ANSI Testing	Input TN Average	Effluent TN Average	Average % Reduction
FAST	34.5	9.4	73
HOOT	26.3	9.63	63
Norweco	25	6.8	73

3.7 Survey Results: Frequent non-compliance of PBTS systems.

To determine if the primary residential PBTS included in this study were representative of others in Wakulla County, a survey was conducted in April 2009 and effluent samples were collected from a larger population of systems. The survey included 59 (or about 60%) of the 100+ PBTS that were permitted and installed in Wakulla County at the time. During the course of inspecting and sampling these additional PBTS, we encountered issues of concern regarding the operation, maintenance and/or construction of many of them. The most widespread problem was that a large number of systems were turned off or otherwise not receiving power. Also, several sites lacked sampling ports or other access to enable inspection or sampling of the system effluent. Out of a total of 59 PBTS inspected, 23 (39%) of these systems were not functioning as PBTS. At 22 of those systems, the treatment units were turned off or not powered. At three locations, the electrical wires were not even connected to the control boxes (Figures 12 and 13). At the other non-compliant site, the pump tank was empty due to a missing plug on the bottom and effluent was draining into the ground (Figure 14). Since the purpose of these inspections was to collect effluent samples, many more homes with inoperative systems were identified by county health department staff but not visited.

Figure 12. Picture taken on 04/16/09 of a FAST system with the unwired control box lying on the exposed tank. The system was in use with sewage, but no electricity.

Figure 13. Picture taken on 04/16/09 of Norweco system with the wiring to the control box not connected. There was power to the pump, but not to the aerator control box.

Figure 14. Pictures of the inside of an empty pump tank attached to a functioning FAST system. The installer indicated that a plug at the bottom of the tank came out and has encountered this problem at other sites.

Once a functioning system was found, it was not always possible to sample the effluent. This was unexpected as the biannual maintenance contracts call for visual inspection of the PBTS effluent. Gaining access to the effluent during this sampling survey was often difficult. At several sites the pump tank lid was dug up and opened to obtain a sample. At some sites, the vent pipe had to be cut and then repaired in order to take a sample (Figure 16). In other instances a sampling port was installed, but not in the correct place in the system to obtain a sample complying with the manufacturer's recommendations. With three systems, the sampling team could find no way to access the effluent. At one of the sites, there was no sample port and when the lid was dug up, the electrical wires were found strung across the pump tank lid making it impossible to open without, cutting or disconnecting the wires (Figure 15).

Figure 15. Picture taken on 04/20/09 of Norweco system with wires strung across the pump tank lid preventing access. No sampling port was installed. Maintenance records indicate the effluent was visually inspected.

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Due to the difficulty in obtaining samples, it became obvious that the effluent at some sites was not being inspected as required by permit. However, maintenance records indicate the effluent from these systems has been visually inspected.

Figure 16. Picture taken on 04/14/09 of a vent pipe typical of FAST installations. Note the coupler at ground level. In order to take a sample, the pipe was cut and repaired with the coupler. The black piece is a charcoal filter installed due to odor complaints. This site is in a high density neighborhood with 10 PBTS in a 1.25-acre area, which are apparently creating an odor problem.

The highest TN value measured in any sample of the survey of 27 samples and the 8 main study sites was at site at WS-4, 78.1 mg-N/L. This system was a FAST system configured with three separate tanks with recirculation and a mounded drip irrigation system. This configuration typically has a separate pretreatment tank, treatment tank, and pump tank and is the ideal FAST configuration for nitrogen reduction if cost is not considered. During site selection of the Phase II PBTS, this system was inspected by FDEP and FSU staff in September, 2008. A pipe in the drain field was found not connected, resulting in the system effluent filling the control box and not going to the drain field (Figure 17). During this inspection of the broken system, the pump turned on resulting in both personnel being sprayed in the face with effluent. Another health hazard was evident as the treatment tank lid was removed and the mound showing evidence of fresh digging. The home owner, Wakulla County Health Department, and the installer, who also has the maintenance contract, were notified of the situation.

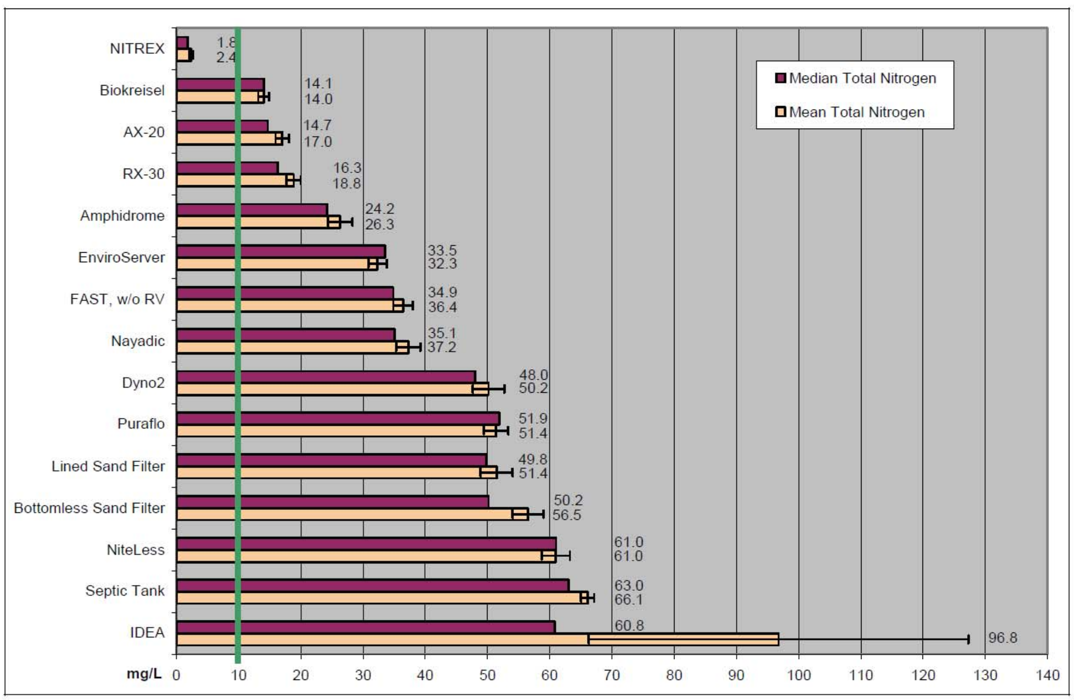
Figure 17. Pictures of site WS-4 taken on April 14, 2009. The broken plumbing evident in this picture was also reported in September 2008. The broken pipe causes the effluent to fill the control box instead of going to the drain field.

Seven months later, during the Wakulla PBTS survey, this system was again inspected on April 14, 2009. The tank lid was in place, but the drain field plumbing was still broken and in the same condition as it was 7 months prior. During this time between these inspections, the system should have had an additional inspection as required by the maintenance contract.

3.8 Observed nitrogen reductions in other research

A large-scale study of nitrogen impacts to ground water from septic tanks was conducted in the town of La Pine, Oregon. This study also included a detailed evaluation of PBTS. This project, conducted by the U. S. Geological Survey, evaluated 15 different designs and demonstrated the difficulty of attaining an effluent TN goal of 10 mg-N/L using most PBTS (Figure 18, La Pine Oregon Demonstration Project, 2006).

Figure 18 Results of La Pine Oregon Demonstration Project, 2006. Only one of the nitrogen reducing systems examined achieved levels of 10 mg-N/L.



Notes. The median TN concentration of 63 mg-N/L for effluent from conventional septic systems (STE) shown above is very similar to the values presented in this study. The FAST effluent TN mean concentration of 35 mg-N/L in the La Pine study compares to the FAST effluent results of this study, 26.2 mg-N/L.

Raw sewage inputs were not measured in the La Pine study; instead conventional septic tank effluent and sand filters were used as controls. The TN concentrations in the La Pine study for both conventional septic tanks and the FAST system are very similar to results in this report (Figure 18). For the La Pine study, the 5 systems that consistently produced effluent concentrations lower than 30 mg-N/L used different technologies than the PBTS installed in Wakulla County. The NITREX system, the only system to meet the 10 mg-N/L goal, uses a different treatment strategy which involves the addition of a carbon source in another treatment chamber after nitrification.

In their compilation of PBTS nationwide data, FDOH found that PBTS and innovative systems provided TN reductions ranging from 44% to 77% (FDOH, 2008). This excludes NITREX and Puraflo systems, both which utilize an added carbon source for denitrification. The Washington State Health Department also released a study on nitrogen reducing systems reporting reductions of 51% to 64% (WDOH, 2005).

The passive nitrogen removal systems being evaluated by the FDOH and University of Central Florida (under contract to FDEP) also utilize an added carbon source. Pin the FDOH-funded study, preliminary results showed TN reduction from 77 mg/L in the septic tank effluent to 2 mg/L prior to discharge into the drain field (Smith et al, 2008). This represents a TN removal of 97%. At the University of Central Florida passive treatment system demonstration site, TN removal of greater than 85% was observed (Chang et al, 2009). These results suggest that if a passive system could be made commercially viable, it may provide a higher level of treatment while eliminating some of the homeowner concerns such as energy cost and noise.

Summary of Findings

1. Raw Sewage TN inputs: The total nitrogen (TN) input value was 72.8 ± 39.2 mg-N/L, n=17 from four households served by PBTS. The CSM study focused on anther six households, with an average of 73.1 ± 50.3, n = 24. The data indicates that 70 mg-N/L is a reasonable estimate of total nitrogen from households in Wakulla County and is used to calculate percent TN removal by the systems.

2. From the main study sites monitored monthly, the average PBTS effluent concentration was 30.7 mg-N/L. The average TN concentration for the 27 additional systems was 29.2 mg-N/L, confirming the 8 main study sites are typical of systems installed in Wakulla County.

3. Performance Based Treatment Systems installed in Wakulla County reduce TN by 50-70% from input concentrations, when properly operated and maintained. Over a 7-month monitoring period, the primary PBTS monitored in the study had reduced nitrogen on average by 56%. The other 27 systems that were sampled only once were found to have reduced nitrogen on average by about 59%.

4. When operated properly, the systems that are currently being installed in Wakulla County meet the manufacturers' and DOH expectations for PBTS in that they achieve 50% or better Nitrogen reduction. However, they cannot, as currently designed, be expected to regularly achieve effluent concentrations of less than 10 mg TN/L under typical homeowner usage scenarios.

5. Operation, maintenance and construction issues are responsible for a very large percentage of PBTS in Wakulla County not being in compliance with their permits and providing less than optimal treatment.

References

Anderson D. A Review of Nitrogen Loading and Treatment Performance Recommendations for Onsite Wastewater Treatment Systems (OWTS) in the Wekiva Study Area. Hazen and Sawyer, P.C. February 2006

Chang, N., Wanielista, M., Daranpob, A., Hossian, F., Xuan, Z,. 2009. Nutrient and Pathogen Removal with an Innovative Passive Underground Drain field for On-site Wastewater Treatment. Presented at the World Environmental and Water Resources Congress, May 17-21, 2009 Kansas City, Missouri.

Dillon, K., Corbett, D.R., Chanton, J.P., Burnett, W.C., Furbish, D.J., 1999. The use of sulfur hexafluoride as a groundwater tracer of septic tank effluent in the Florida Keys. J. Hydrol. 220, 129-140.

Dillon, K., Corbett, D.R., Chanton, J.P., Burnett, W.C., Kump, L., 2000. Bimodal transport of a wastewater plume injected into saline ground waters of the Florida Keys, USA. Ground Water, 38, pages 624-634, 2000.

EPA 625/R-00/008, 2006. Establishing treatment system performance requirements Chapter 3, http://www.epa.gov/ord/NRMRL/pubs/625r00008/html/625R00008chap3.htm. National Risk Management Research Laboratory.

FDOH, 2009. Chapter 64E-6, Florida Administrative Code, Standards for onsite sewage treatment and disposal systems, effective June 25, 2009

FDOH, 2008. Average Testing Performance Data for Components of Performance-Based Treatment Systems (PBTS)11/03/2008 by E. Roeder http://www.myfloridaeh.com/ostds/pdfiles/forms/PBTS_components.pdf

FDOH, 2007. Onsite sewage treatment and disposal systems installed in Florida. Document created 05/24/2007. http://www.doh.state.fl.us/environment/ostds/statistics/newInstallations.pdf

FDOH, 1999. Department Policy for drain field sizing in areas with discontinuous limestone, August 1999. http://www.doh.state.fl.us/environment/ostds/index.html.

Florida Springs Task Force, 2006. Florida's Springs: Strategies for Protection and Restoration May 2006. Prepared for Florida Department of Environmental Protection Office of Ecosystem Projects.

Harden, H., M. Hooks, E. Roeder, J. P. Chanton, 2008. Evaluation of Onsite Sewage Treatment and Disposal Systems in Shallow Karst Terrain. Water Research 42 2585– 2597.

Katz B., Dale W. Griffin, Peter B. McMahon Harmon Harden, Edgar Wade, Richard W. Hicks, Jeffrey Chanton; 2009. Fate of Nitrogen, Organic Wastewater Compounds, Pharmaceuticals, and Microorganisms in the Unsaturated Zone and Groundwater Beneath

Septic Tank Drain fields in the Woodville Karst Plain, Florida. Deliverable for FDEP Contract WM929.

La Pine Oregon Demonstration Project, 2006. http://www.deschutes.org/deq/

Lowe, K., M. B. Tucholke, J. Tomaras, K. E. Conn, C. Hoppe, J. Drewes, J. E. McCray, and J. Munakata-Marr. 2009. *Influent Constituent Characteristics of the Modern Waste Stream from Single Sources*. Final Project Report Project No. 04-DEC-1. Prepared for Water Environment Research Foundation, Alexandria, VA, by Colorado School of Mines, Golden CO.

Paul, J.H., McLaughlin, M.R., Griffin, D.W., Lipp, E.K., Stokes, R., Rose, J.B., 2000. Rapid movement of wastewater from onsite disposal systems into surface waters in the Lower Florida Keys. Estuaries. 23 (5): 662-668.

Price, D.J., 1988. Contamination problems and siting considerations associated with septic tanks in Karst areas of Missouri. IN: Proceedings of the International Symposium on Class V Injection Well Technology, September 13-15, 1988, Las Vegas, NV., 99-117

Social Science Data Analysis Network, undated. Census household and population information. http://www.censusscope.org/us/s12/chart_house.html, http://www.censusscope.org/us/s12/chart_popl.html

Smith, D.P. Otis, R. and Flint M., 2008. Florida Passive Nitrogen Removal Study Experimental Media Evaluation Final Report http://www.doh.state.fl.us/environment/ostds/zip/PassiveNFinal.zip

USGS website, 2009. USGS 02327022 Wakulla River Near Crawfordville. http://waterdata.usgs.gov/fl/nwis/uv/?site_no=02327022&PARAmeter_cd=00065,00060

Xuan, Z., Change,N., Daranpob,A., Wanielista, M. Initial test of a subsurface constructed wetland with green sorption media for nutrient removal in on-site wastewater treatment systems. Water Qual. Expo Health, DOI.10. 1007/s 12403-009-0014-6. published online October 29, 2009.

Wakulla County Ordinance 2006-58.

Washington State DOH, 2005. Nitrogen Reducing Technologies for Onsite Wastewater Treatment Systems. June, 2005.