# Florida Passive Nitrogen Removal Study

## Additional Monitoring

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Florida Department of Health
Division of Environmental Health
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## Report Preparation

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# Executive Summary

Approximately 2.5 million onsite wastewater treatment systems (OWTS) are currently permitted in the State of Florida. Population growth, exurban development trends, and the high cost and sustainability of centralized infrastructure make it likely that distributed infrastructure will continue to be used for the management of a large portion of domestic sanitary water generated in Florida. The vast majority of onsite systems include a septic tank for primary treatment, followed by dispersal into the environment using soil adsorption systems. Nitrogen removal in these typical systems is limited. Nitrogen loading from onsite systems is a potential concern in Florida, depending on the sensitivity of the water environments, the number and density of onsite installations, their proximity to receiving waters, and processes in subsurface soil media.

This Florida Passive Nitrogen Removal Study (PNRS) was undertaken to investigate alternative methods to remove nitrogen in onsite systems. A primary consideration was to evaluate systems that were “passive” in nature, with limited reliance on pumping and forced aeration. A guiding principal for the PNRS was the specific definition of a “passive” nitrogen removal system as one that contains only a single liquid pump, no mechanical aerators, and that uses reactive media. The PNRS was specifically intended to perform a literature review of passive nitrogen removal technologies, perform an experimental evaluation of passive systems and candidate media, perform an economic analysis of such systems, and make recommendations regarding deployment of passive nitrogen systems.

## Experimental Evaluation

The Passive Nitrogen Removal Study entailed operation of three two-stage filter systems to evaluate enhanced nitrogen removal using two-stage passive nitrogen removal systems. Experiments were performed using actual septic tank effluent at a field site in Hillsborough County, Florida. In the original study, the three systems were operated for 60 days on septic tank effluent. Two of the two-stage filter systems achieved over 97% total nitrogen removal and 98% total inorganic nitrogen removal, with average effluent ammonia nitrogen and nitrate+nitrate nitrogen concentrations of less than 0.7 mg/L and 0.5 mg/L, respectively (Smith et al., 2008). High nitrogen removal performance was achieved using clinoptilolite and expanded clay media in the unsaturated Stage 1 filter, and elemental sulfur in the anoxic denitrification filter (Stage 2).

This report presents the results of additional operation and monitoring following the original study. Operation of the three two-stage filters was extended by an additional 186 days, for a total duration exceeding eight months. Nitrogen removal performance of the clinoptilolite/ 75% sulfur and expanded clay/ 60% sulfur systems was similar for the extended operation (Days 123 to 245) to the initial 60 day period. The average removal efficiency of these systems for Days 123 through 245was greater than 95% for Total Nitrogen and greater than 97% for Total Inorganic Nitrogen. The granular rubber/40% sulfur system continued to improved prior to Day 210, after which Total Nitrogen removal was greater than 90%.

Five day carbonaceous biochemical oxygen demand was < 2 to < 8 mg/L in all three Stage 1 effluents, with removal efficiencies exceeding 94% for all filters. These results verify the ability of the Stage 1 filter designs to remove organic matter in septic tank effluent in addition to nitrogen species. The experimental evaluation verified the potential of the two-stage filter systems for both total nitrogen removal and organics removal using passive technology over an eight month period.

## Media Examination

At the conclusion of the study, the two-stage filter systems were disassembled and media samples removed from the filters. The media was subjected to several tests to evaluate changes to media through the 246 day operation. Resident water retention in Stage 1 media was from 19 to 41% of mass and was lowest for larger media particle size. Estimated water detention time in Stage 1 filters was 15 to 48 hours and was highest for expanded clay and lowest for granular rubber. Visual and photographic analysis generally showed no gross accumulation of solids in media materials. The entrance regions of the Stage 2 reactors showed gelatinous accumulation on media surfaces, which is a characteristic of biofilm reactors.

## Introduction

As population growth continues in Florida, so do the potential impacts of on-site wastewater treatment systems to surface and groundwater quality. Nitrogen loading from wastewater treatment systems may be a concern where numerous on-site wastewater treatment and disposal systems (OWTS) are located within sensitive environments. Conventional septic tank and soil adsorption systems rely on biological reactions in porous media (setback layer or unsaturated natural soil) to attenuate nitrogen loadings to ground or surface water. Groundwater nitrate concentrations have been shown to exceed drinking water standards by factors of three or greater at distances on the order of several meters from soil adsorption systems. A study at Big Pine Key, Florida found that the dissolved inorganic nitrogen (DIN) levels in groundwater contiguous to on-site drainfields were greater than DIN levels at a control location. Groundwater $NH_3$-N levels at Big Pine Key reached 2.75 millimoles per liter (38.5 mg/L), indicating a high fractional breakthrough of ammonia through the on-site treatment system. In another study, conducted on a sandy Florida aquifer system, groundwater levels of both Total Nitrogen and ammonia were elevated above background levels at a distance of 50 meters from a conventional soil adsorption drainfield. Available setback distances in Florida locations may often be quite limited, which increases the significance of achieving high nitrogen removal percentages within septic tanks, media filters and other in-tank treatment processes, as well as with in soil treatment units. A summary review of a wide variety of on-site treatment approaches showed that systems with some degree of “passive” characteristics exhibited Total Nitrogen removal efficiencies of 40 to 75% and produced effluent TN of 10 to 20 mg/L. FDOH has an interest in exploring the feasibility and practicality of using relatively passive on-site treatment systems to accomplish even higher nitrogen reductions in a cost effective manner.

The mission of the Bureau of Onsite Sewage Programs of the Florida Department of Health (FDOH) is *“Protecting the public health and environment through a comprehensive onsite sewage program*”. FDOH established the Florida Passive Nitrogen Removal Study to identify passive treatment systems that can achieve greater nitrogen reductions than exhibited by conventional septic tank/drainfield configurations. The FDOH is specifically interested in approaches that employ filter media, or reactive filter media, and systems that which eliminate the need for aeration pumps and minimize the need for liquid pumping. The first step of the Florida Passive Nitrogen Removal Study was to identify treatment configurations, reactive and non-reactive media, performance capabilities of new and demonstrated technologies, and factors influencing performance and longevity. The following section describes the results of the literature review and the genesis of the recommended two-stage system for passive nitrogen removal. The experimental evaluation section describes the results of experiments that were performed to verify total nitrogen removal from actual septic tank effluent using passive, two-stage nitrogen removal technology. The economic analysis section presents a detailed life cycle cost analysis of a passive two-stage nitrogen removal system. Finally, the recommendations section provides specific guidance for deployment of passive two-stage nitrogen removal technology for a single family residence.

## Approaches to Passive Nitrogen Removal

The overall approach to passive nitrogen removal is a two stage filter system. The first stage is an unsaturated media filter for ammonification and nitrification. The second stage is a saturated anoxic filter with reactive media (denitrification). This configuration is mandated by the obligatory biochemical sequence of aerobic nitrification followed by anoxic denitrification. The use of an unsaturated media filter for the initial nitrification is necessary because of the constraint that aeration pumps can not be used in the passive system. The first media filter can be established as a downflow filter, similar to a sand filter for example, and can be connected to the second anoxic denitrification filter that operates in the upflow direction. The flow connectivity between the two filter stages would be by gravity.

The first stage filter must be designed to achieve the targeted final effluent ammonia N levels. Ammonia N may behave conservatively in the anoxic second stage filter, and any additional ammonia N removal in the anoxic filter should be viewed as incidental. The first stage filter will also provide additional processes that will remove biodegradable organics (biochemical oxygen demand) and organic N. Although some denitrification may occur in unsaturated filters that are operated on STE under certain conditions (i.e. simultaneous nitrification/denitrification), the predominant design goal of the first stage filter must be to achieve consistent low levels of ammonia N and organic N. Key factors for first stage media are timed dosing, dosing distribution across the filter surface area, ability to supply oxygen supply by maintaining aeration pore volume, ability to retain water, and adequate space within the media to assimilate suspended solids in the wastewater influent and biomass that is synthesized from degradation of influent wastewater constituents. Unsaturated filter performance is governed by the interaction between the filter media and the manner in which septic tank effluent is imposed onto the media surface. Important factors are the average applied hydraulic and organic loading rates, the timing and volume of dosings, and the distribution of wastewater over the entire surface area of the filter. Review of technologies suggests that ammonia nitrogen reductions of 95% and effluent ammonia N levels of 1 mg/L are possible to achieve. Evaluation of specific filter media, hydraulic and organic loading rates, and water quality must be conducted to define the design parameters needed to achieve low effluent ammonia and organic N concentrations. Promising candidate media include zeolites, expanded clays and shales, tire crumb, peat, coconut coir, and synthetic fiber materials. The first stage unsaturated filter should produce and effluent with low TSS and regrowth potential to minimize potential solids accumulation and channeling in the second stage filter.

The second filter must be designed to achieve the targeted final effluent total oxidized N levels, which are expected to be predominantly nitrate N. Considerations for the second stage media involve surface area per volume, propensity for accumulated suspended solids to reduce hydraulic conductivity (clogging) and lead to preferential flow, and operating factors such as the applied hydraulic and organic loading rates. The need to provide a continuous supply of electron donor for denitrification, and to supply it over extended periods of deployment, is central to the purpose of the reactive media. Review of technologies suggests that it should be possible to achieve effluent nitrate levels of 2 mg/L and less. Evaluation of specific filter media, hydraulic and nitrate loading rates, and water quality must be conducted to identify media and define the design parameters needed to achieve low effluent nitrate concentrations. Candidate media include elemental sulfur, woodchips, and sawdust; other cost effective materials may also identified. Literature review suggests two additional considerations that must be addressed for deployment of anoxic reactive media. The first is residuals that are added to water by passage through the reactive media. Wood based materials can add biodegradable organics to water, increasing the chemical and biochemical oxygen demand. Elemental sulfur systems can increase sulfate levels and possibly sulfide. The degree to which residuals are added to the water by the reactive media filters could be reduced to by replacing a fraction of the reactive media with inert filler. However, care must be taken to insure continuous electron donor supply over the target deployment period. Thus, anoxic filter systems must be formulated with sufficient electron donor supply to support denitrification, but with as small an excess release of electron donor as is consistent with achieving the target nitrate removals.

A second factor in anoxic filter design is the long term hydraulic performance, which may be even more significant to the longevity of anoxic denitrification filters than the duration of electron donor supply. Preferential flow paths can be initiated through deposition of organic and inorganic solids within the filter media, and by methods used to distribute and withdraw flow into and through the reactive media. Preferential flow paths can lead to channelization, reduced contact with reactive media surfaces, and performance deterioration. The ability to predict a priori the propensity for channelization phenomena is limited, particularly in the anoxic filters, which host biochemically reactive systems with complex water chemistries and which experience a significant transition from a predominantly aerobic to an anoxic redox environment. Approaches to overcoming channelization involve manipulation of media, inlet and outlet arrangements, the provision of a minimum amount of headloss, baffling, the use of long aspect ratio reactors, using large systems that provide acceptable performance over time even with some degree of channelization, or using smaller filters with lower retention times that are changed out more frequently. Continuous deployments of treatment systems over time periods of months and longer are needed to fully examine these factors.

The embodiment of the two stage treatment system as an in-tank process has advantages over a modified drainfield approach. Achieving acceptably low effluent Total N removals over time periods of many years will require access to filter media for effluent monitoring, media maintenance and change out when required, and verification of desired hydraulic operation. Replacement or maintenance of denitrification media could be accomplished without disturbing the first stage media. The use of the two stage in-tank process, passively connected hydraulically, would avoid the vagaries inherent in verifying the continuing performance of subsurface flow systems. The second stage saturated filter could be deployed as a horizontal subsurface filter bed as long as it remained saturated.

# Experimental Evaluation

## Materials and Methods

### Project Site

The experimental studies were conducted at Flatwoods Park, 18205 Bruce B. Downs Boulevard, Tampa FL 33592. The park is a day use public recreational facility operated by Hillsborough County. Wastewater is generated by two sources: a lavatory with two hand washing sinks and two flush toilets, and a continuously occupied single family home (ranger residence). The park was open for public use every day during the study period. Park visitation is highest on weekends and on weekday afternoons. Wastewater from the ranger residence and lavatory is collected in a septic tank before being pumped to a mounded onsite sewage and disposal system. The source water for the ranger residence and lavatory is municipal water supplied by the City of Tampa.

### Experimental Treatment Systems

The filter media that were evaluated are listed in Table 1, along with the estimated bulk density and the range of particle sizes of the material as procured. Stage 1 media included clinoptilolite, expanded clay and tire crumb. These media provided substantial external porosity (> 45%), while clinoptilolite and expanded clay would be expected to exhibit desirable water retention characteristics. Additionally, the clinoptilolite media provides cationic ion exchange capacity (1.5 to 1.8 meq./g) which could enhance sorption and retention of ammonium ions. Tire chips are produced by the cutting up of recycled tires, and are available in particles sized of 5 mm and less that are suitable for use as filter media. Details of column design are included in the QAPP (Appendix D).

Clinoptilolite media was obtained by the supplier in three particle size gradations: 16x50, 8x16, and 4x8. The 16x50 was passed through a No. 35 mesh sieve to remove the smaller particles; materials retained on the screen were particles of 0.50 to 1.19 mm size. The 8x16 (1.19 to 2.38 mm) and 4x8 (2.38 to 4.76 mm) sizes were used as supplied. Each clinoptilolite size fraction was rinsed eight times before placement in the filter. Livlite and tire crumb media were prepared using dry sieving as follows. Media were initially sieved through a 5 mm square mesh wire screen to remove extraneous larger particles. Materials passing through the 5 mm screen were sieved through a 3 mm square mesh screen. Materials that were retained on the 3 mm screen composed the 3 to 5 mm size material that was used in the upper layer of the filter. Materials passing through the 3 mm screen were sequentially sieved through US Sieve Numbers 10, 18 and 35 (openings of 2.00, 1.00 and 0.500 mm), providing media of 1.0 to 2.0 mm size for the middle filter layer and 0.5 to 1.0 mm size for the lower filter layer. While filter media can be more completely characterized using particle size distribution analysis (PSD), effective diameter ($D_{10}$), and uniformity coefficient ($D_{60}/D_{10}$), these data were not available for the materials as procured nor obtained for the size fractions.

The Stage 2 electron donor media was elemental sulfur, which provided an autotrophic denitrification process in the anoxic filter. Crushed oyster shell was used as an alkalinity source, as sulfur-based autotrophic denitrification will consume alkalinity. Expanded shale was included in two Stage 2 columns and provided anion exchange capacity, which would sorb nitrate under non-steady operational conditions.

A schematic of the experimental filter columns is shown in Figure 1. Three filter systems were evaluated, each consisting of an unsaturated filter followed by a saturated filter. Filters were fabricated from at 3 in. inner diameter PVC for Stage 1 (unsaturated) filters and 1.5 in. inner diameter for Stage 2 (saturated) filters. A 1/8 inch square mesh screen was used for media support and retention at the outlet media end of each column.

A single peristaltic pump (Cole Parmer) was used to dose septic tank effluent to the three Two-Stage Filter systems. Each Stage 1 filter was dosed with a separate pump head; the three pump heads were attached to the same pump. STE was supplied through a single tube connected to an intake manifold (3 in. PVC pipe) with 1/16 in. slots located in the septic tank. The STE tube branched into three separate tubes prior to the pump heads; each branch tube supplied one peristaltic pump head. The sizes of pump head and pump head tubing, and the pump speed and run time were identical for all three Two-Stage Filter systems.

The media configuration in the six columns is shown in Table 2. Total media depth in the vertical unsaturated Stage 1 columns was 24 in. The Stage 1 filters employed a stratified media configuration, with particle sizes decreasing in the downward direction, with 2 in. of larger particle sized media on the bottom for particle retention. Stratification of media based on particle size was based on the expected progression of biochemical reactions within the filter media. The processes in the upper media layer include adsorption of wastewater particulates and colloids, hydrolysis and release of soluble organics, aerobic utilization of soluble organics, and biomass synthesis. In this region, the biochemical processing of organic matter between doses must keep up with the newly applied wastewater constituents from each dose. The greatest accumulation of organic and inorganic mass will occur in the upper layer, and the use of larger particle size media will provide greater space for accumulation of solids. Stratified media should enhance to potential for long term operation while maintaining treatment efficiency.

**Table 1 Procured Filter Media**

| Material | Bulk density, lb/ft$^3$ | Particle Size Range |
|---|---|---|
| **Zeo-Pure AMZ Clinoptilolite** | **55** | **0.3 - 4.76 mm** |
| **Livlite Expanded Clay** | **41** | **0.4 - > 5 mm** |
| **Granular Rubber** | **25** | **0.3 - > 5 mm** |
| **Elemental sulfur** | **77** | **2 - 5 mm** |
| **Oyster shell** | **82** | **3 - 15 mm** |
| **ACT-MX ESF-450 Utelite** | **54** | **0.4 - 4.5 mm** |

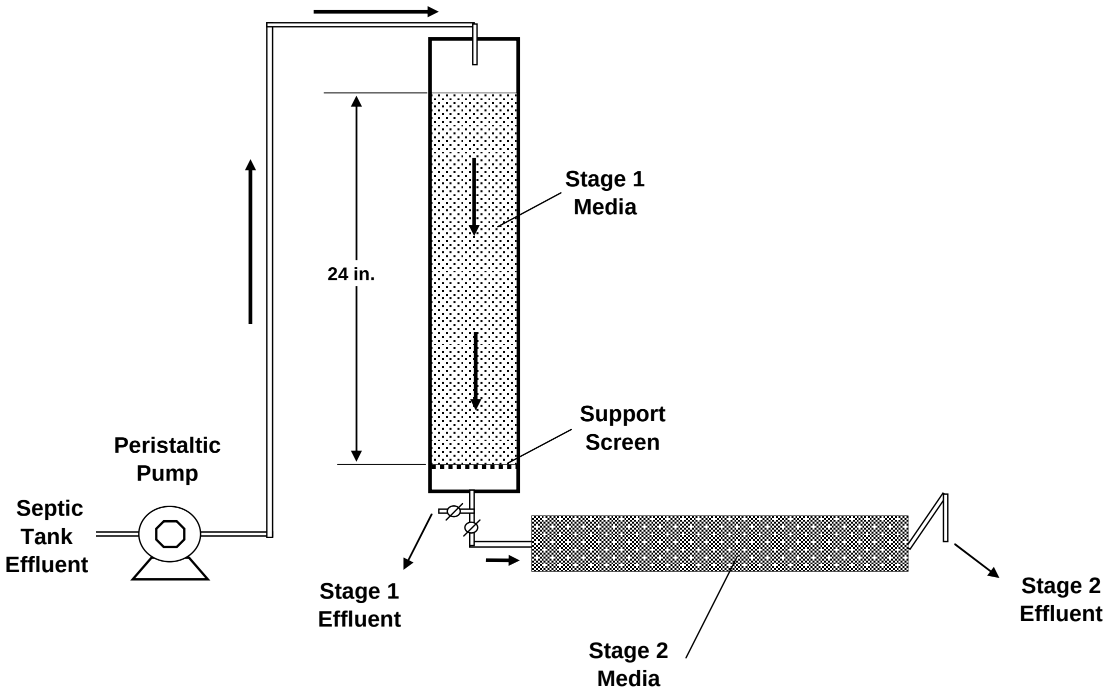

**Figure 1 Experimental Filter System Schematic**

Three Stage 2 columns were constructed using unstratified media containing elemental sulfur, crushed oyster shell, and expanded shale (Table 2) of 24 in. total media depth. Each filter contained a 3:1 vol./vol. ratio of elemental sulfur to crushed oyster shell. The fraction of expanded shale in Stage 2 media ranged from 0 to 40%. Expanded shale contains anion exchange capacity which can bind nitrate ions, potentially enhancing removal. Higher expanded shale fractions were accompanied by lower elemental sulfur fractions, which would reduce the total surface area of elemental sulfur and possibly the overall sulfur oxidation rate. A lower sulfur oxidation rates could have the positive effect of reducing effluent sulfate levels if sulfur oxidation exceeded the amount needed for denitrification.

The Stage 1 filters were vertically oriented and Stage 2 filters oriented horizontally (Figure 1). The Stage 1 filters were supplied with septic tank effluent by a multi-head peristaltic pump with a timed dosing of once per one half hour (48 doses/day). Wastewater trickled downward through the Stage 1 media, through the support screen, and into a tube that directed Stage 1 effluent to the Stage 2 filter (Figure 1). The water elevation in the tube below the Stage 1 filter provided hydraulic head for passive movement of water through the Stage 2 filter. A valve and sample port (with another valve) was located in the tube below the Stage 1 filter. In normal filter operation, the sample port valve was closed and the valve leading to Stage 2 open, providing passive flow of Stage 1 effluent to and through the horizontal Stage 2 filter. The design of the two stage filter system minimized internal volume within the connecting piping; liquid volumes in the Stage 1 and Stage 2 filters comprised greater than 90% of the total internal volume.

## Operation and Monitoring

Operation of the experimental treatment systems under the original study was commenced on 1/2/2008. The original study was completed on 3/2/2008, but operation was continued in an identical manner through 9/3/2008. The target hydraulic loading rate to the Stage 1 filters was 3 gallons of septic tank effluent per square foot of surface area per day. The additional sampling events presented in this report were conducted operation Days 123, 152, 196, 208 and 245.

Monitoring was conducted at seven monitoring points, consisting of influent septic tank effluent (STE), effluents from each Stage 1 filter, and effluents from each Stage 2 filter. Temperature, pH, and dissolved oxygen (DO) measurements were performed by inserting probes directly into the Stage 2 effluent port, into Stage 1 effluent collection reservoirs, and for STE in a 1 liter sample container immediately after collection. Sulfate and nitrogen samples from the effluents of Stage 1 and Stage 2 filters were collected by routing effluent from the filters directly into prepared sample containers located in an iced cooler. For STE, samples for sulfate, nitrogen, biochemical oxygen demand (BOD), and total suspended solids (TSS) were collected by directly filling prepared sample containers with pumped STE and immediately placing samples containers on ice in a cooler.

In the additional monitoring study, monitoring was generally conducted in the following sequence:

- Stage 2 effluent: temperature, pH, DO, alkalinity
- Stage 2 effluent: nitrogen sample collection
- Stage 1 effluent: nitrogen sample collection
- STE: nitrogen sample collection
- STE: BOD sample collection
- Stage 1 effluent: BOD sample collection
- STE and Stage 1 effluent: temperature, pH, DO, alkalinity

## Analytical Methods

Nitrogen and C-BOD$_5$ analyses were performed by a NELAC certified laboratory (ELAB Inc.).
Total kjeldahl nitrogen was performed by digestion and colorimetric determination (EPA 351.2).
Ammonia nitrogen was performed by semi-automated colorimetry (EPA 350.1).
Nitrate plus nitrite nitrogen was performed by cadmium reduction and colorimetry (EPA 353.2).
Sulfate was measured by anion chromatography (EPA 300.0). Quality assurance and control procedures were followed by ELAB Inc.

Temperature, pH and dissolved oxygen (DO) were measured using a Hach 40d multimeter with Intellical glass membrane probe and luminescent Dissolved Oxygen probe. Probes were calibrated according to manufacturer's instructions using three standard solutions (4,7,10) for pH, and for DO, an air saturated water solution and a zero DO (sodium sulfide) solution. The Hach LDO probe (LDO 10103) included a temperature sensor that performed automatic temperature compensation for DO. Total alkalinity was measured by titration with 1.6N sulfuric acid to a bromocresol green-methyl red endpoint.

## Table 2 Configuration of Two Stage Filter Media

| Stage | Filter | Column inner diameter, inch | Media depth, inch | Media placement | Media |
|---|---|---|---|---|---|
| **Stage 1 unsaturated aerobic** | **1A** | **3.0** | **24.0** | **Stratified** | **Clinoptilolite**<br>depth (in.) diameter (mm) top<br>8 2.38 - 4.76<br>8 1.19 - 2.38<br>6 0.5 - 1.19<br>1 1.19 - 2.38<br>1 2.38 - 4.76 bottom |
| | **1B** | | | | **Expanded Clay**<br>depth (in.) diameter (mm) top<br>8 3 - 5<br>8 1.0 - 2.0<br>6 0.5 - 1.0<br>1 1.0 - 2.0<br>1 3 - 5 bottom |
| | **1C** | | | | **Granular Rubber**<br>depth (in.) diameter (mm) top<br>8 3 - 5<br>8 1.0 - 2.0<br>6 0.5 - 1.0<br>1 1.0 - 2.0<br>1 3 - 5 bottom |
| **Stage 2 saturated anoxic** | **2A** | **1.5** | **24.0** | **Nonstratified (1 - 3 mm)** | **75% elemental sulfur**<br>**25% oyster shell** |
| | **2B** | | | | **60% elemental sulfur**<br>**20% oyster shell**<br>**20% expanded shale** |
| | **2C** | | | | **45% elemental sulfur**<br>**15% oyster shell**<br>**40% expanded shale** |

# Results and Discussion

## Applied Hydraulic Loading

Applied hydraulic loadings to Stage 1 filters for the additional monitoring period (Day 123 to 246) are summarized in Table 3. Flowrates were measured by collecting and quantifying the cumulative liquid volume exiting the Stage 2 filters (i.e. the final effluent) over time periods of 15 to 40 hours and dividing volume by elapsed time. Hydraulic loading rates over the time of experimental operation are shown in Figure 4. Flowrates were fairly consistent and average hydraulic loading rates were within 10% of the target of 3 gal/ft$^2$-day to Stage 1 filters.

**Table 3 Applied Hydraulic Loading Rate (n=18)**

| System | Media | Average (gal/ft$^2$-day) | Standard Deviation (gal/ft$^2$-day) |
|---|---|---|---|
| 1 | Clinoptilolite / 75% Sulfur | 2.82 | 0.21 |
| 2 | Expanded clay / 60% Sulfur | 2.96 | 0.37 |
| 3 | Tire crumb / 45% Sulfur | 2.83 | 0.33 |

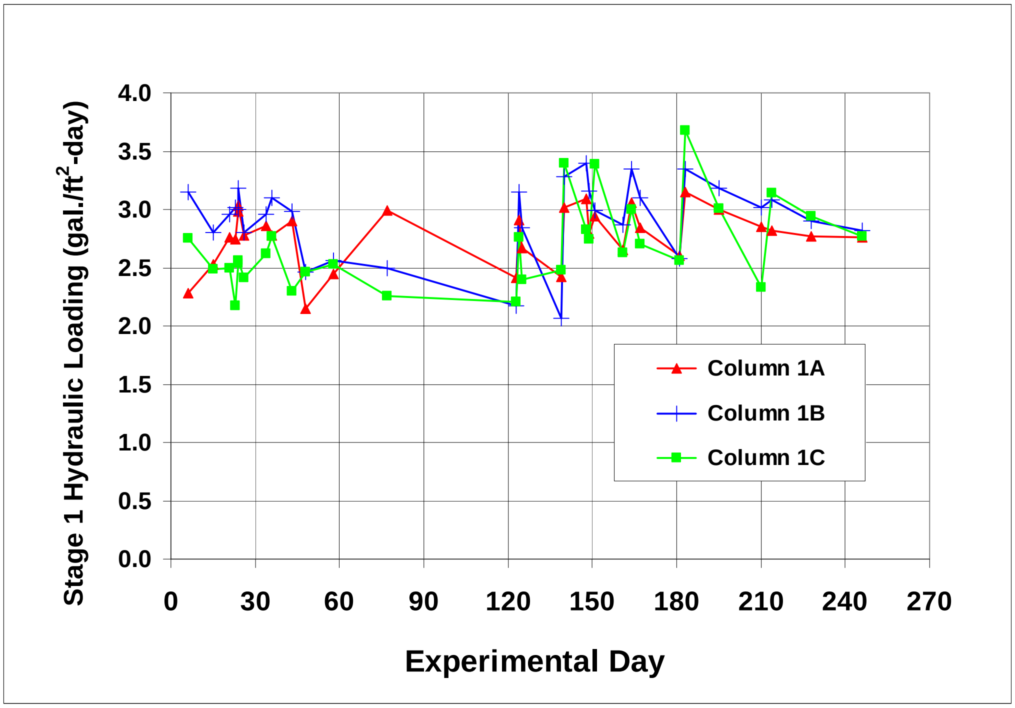

**Figure 2 Hydraulic Loading Rate Applied to Stage 1 Filters**

## Septic Tank Effluent

Septic tank water quality parameters for the additional monitoring period (Day 123 to 246) are summarized in Table 4. The average Total Nitrogen (TN) of 66.9 mg/L was somewhat higher than typical for single family residences and may reflect the contribution of day users to the wastewater. The majority of STE nitrogen was TKN and dominated by ammonia as is characteristic of single family residence STE.

**Table 4 Septic Tank Effluent Quality**
**(n=5; all values in mg/L except pH)**

| Component | Average | Standard Deviation | Range |
|---|---|---|---|
| Total Nitrogen | 66.9 | 21.0 | 50 - 98 |
| Organic Nitrogen | 8.4 | 3.3 | 4 - 13 |
| $NH_3$-N | 58.4 | 20.5 | 41 - 91 |
| $NO_x$-N | 0.09 | 0.10 | .025 - .25 |
| DO | 0.022 | 0.004 | .01 - .03 |
| pH | 7.34 | 0.24 | 7.12 - 7.69 |
| Alkalinity | 526 | 37 | 469 - 569 |

## Applied Nitrogen Loading

Applied loading of Total Nitrogen (TN) is shown in Figure 3. The variations in loading with time reflect both the variations in hydraulic loading rate and variation in STE TN. The applied nitrogen loading varied between 6 and 12 grams per square meter of Stage 1 filter surface area per day and was lower from Day 179 to 245 because of lower STE TN.

## Performance of Two Stage Treatment Systems

Nitrogen species in the influents and effluents of each filter in the two stage systems are summarized in Table 5 and removal efficiencies are summarized in Table 6. Total nitrogen concentrations of the two stage filter systems are presented in Figure 4. Average TN removal efficiency of Systems 1 and 2 were 96.8 and 95.1%, respectively, with average effluent TN of 2.2 and 3.2 mg/L. System 3 average effluent TN was significantly higher than Systems 1 and 2, reflecting the decreasing effluent TN pattern prior to Day 210 (Figure 4). Lower ammonia removal in the Stage 1 filter and nitrate removal both contributed to lower TN removal efficiencies in System 3 prior to Day 210.

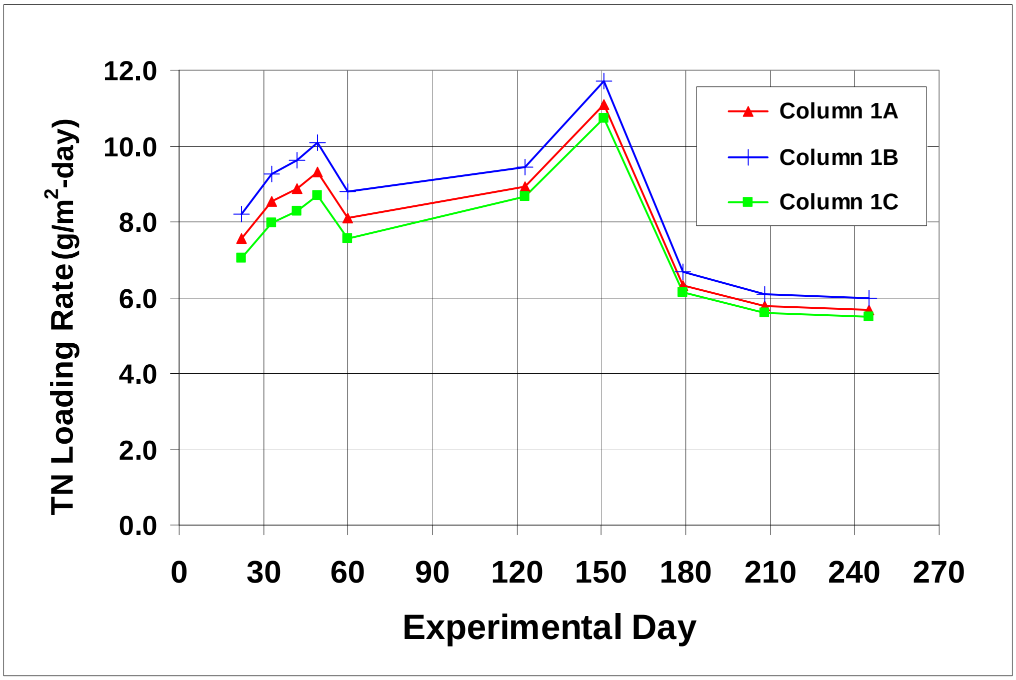

**Figure 3 Areal Nitrogen Application Rate to Stage 1 Filters**

**Table 5  Nitrogen Species In Filter Influents and Effluents**
(Days 123 to 245; Average of n=5; all values in mg/L)

| Sample Point | Total Nitrogen | Organic N | $NH_3$-N | $NO_x$-N | Total Inorganic Nitrogen |
|---|---|---|---|---|---|
| **Influent (STE)** | 66.9 | 8.4 | 58.4 | 0.090 | 58.5 |
| **Stage 1 Effluent** | | | | | |
| 1A Clinoptilolite | 52.0 | 0.72 | 0.028 | 51.2 | 51.2 |
| 1B Expanded clay | 63.2 | 0.39 | 0.17 | 62.6 | 62.8 |
| 1C Granular rubber | 67.8 | 4.6 | 4.2 | 59.0 | 63.1 |
| **Stage 2 Effluent** | | | | | |
| 2A 75% Sulfur | 2.2 | 1.6 | 0.50 | 0.032 | 0.53 |
| 2B 60% Sulfur | 3.2 | 1.9 | 1.3 | 0.041 | 1.3 |
| 2C 45% Sulfur | 10.4 | 4.3 | 4.8 | 1.3 | 6.1 |

**Table 6 Two Stage Treatment System Nitrogen Removal Efficiency**
(Days 123 to 245; Average of n=5)

| System | Media | Total Nitrogen | | Total Inorganic Nitrogen | |
|---|---|---|---|---|---|
| | | Average | Range | Average | Range |
| 1 | Clinoptilolite / 75% Sulfur | 96.8 | 95 - 97.8 | 99.2 | 98.6 - 99.6 |
| 2 | Expanded Clay / 60% Sulfur | 95.1 | 93.7 - 96.7 | 97.0 | 96 - 97.9 |
| 3 | Granular Rubber / 45% Sulfur | 86.6 | 74.5 - 93.6 | 92.2 | 79.4 - 98.6 |

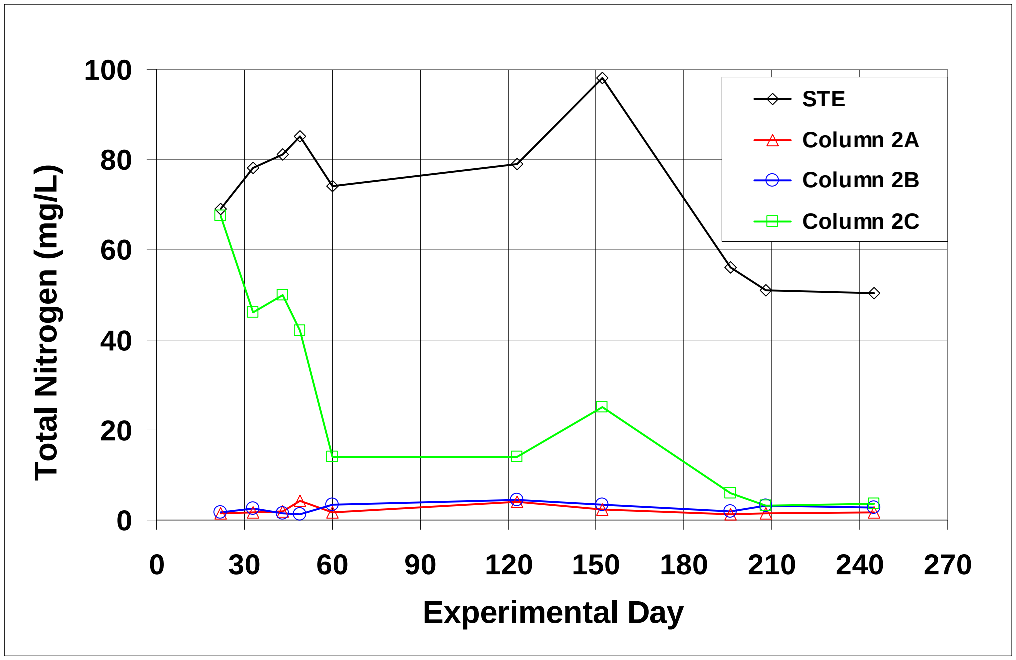

**Figure 4 Total Nitrogen in Influent STE and Effluent of Two Stage Filter Systems**

## Performance of Unsaturated Aerobic Filters (Stage 1)

Ammonia nitrogen levels in effluent from the unsaturated Stage 1 filters are shown in Figure 5. The high ammonia nitrogen reductions observed in the clinoptilolite and expanded clay filters continued throughout the study until Day 245. In the granular rubber filter, ammonia appeared to reach a steady level after Day 210. Stage 1 ammonia removal efficiency is shown in Figure 8 using a highly exaggerated scale. The clinoptilolite (Column 1A) and expanded clay (Column 1B) filters consistently removed greater than 99% ammonia, while the ammonia removal efficiency with granular rubber media reached a similar level after Day 210.

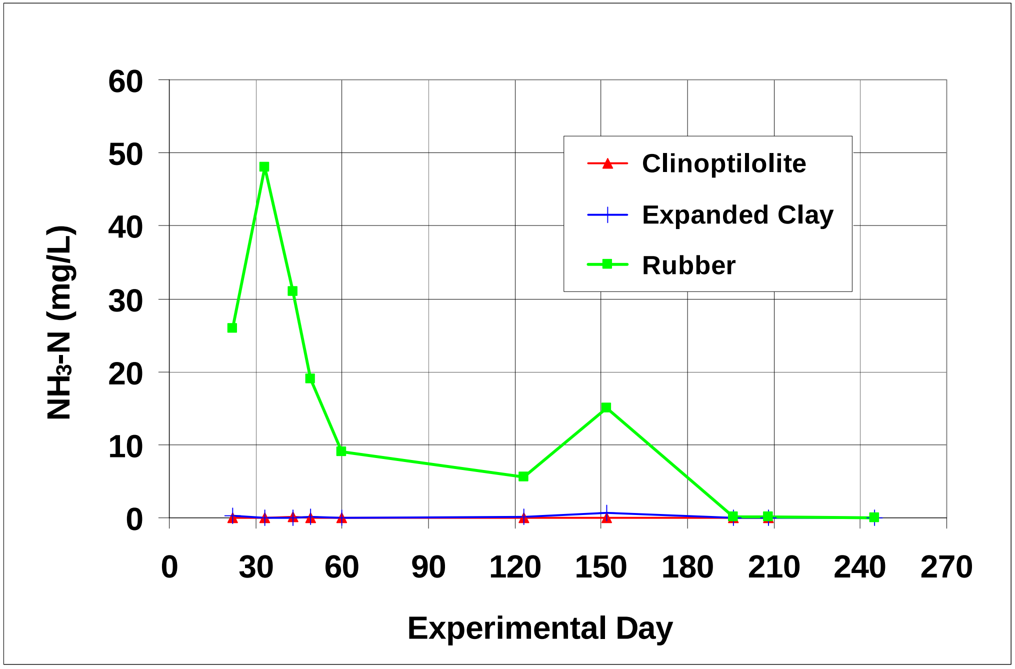

Figure 5 Effluent Ammonia from Unsaturated (Stage 1) Filters

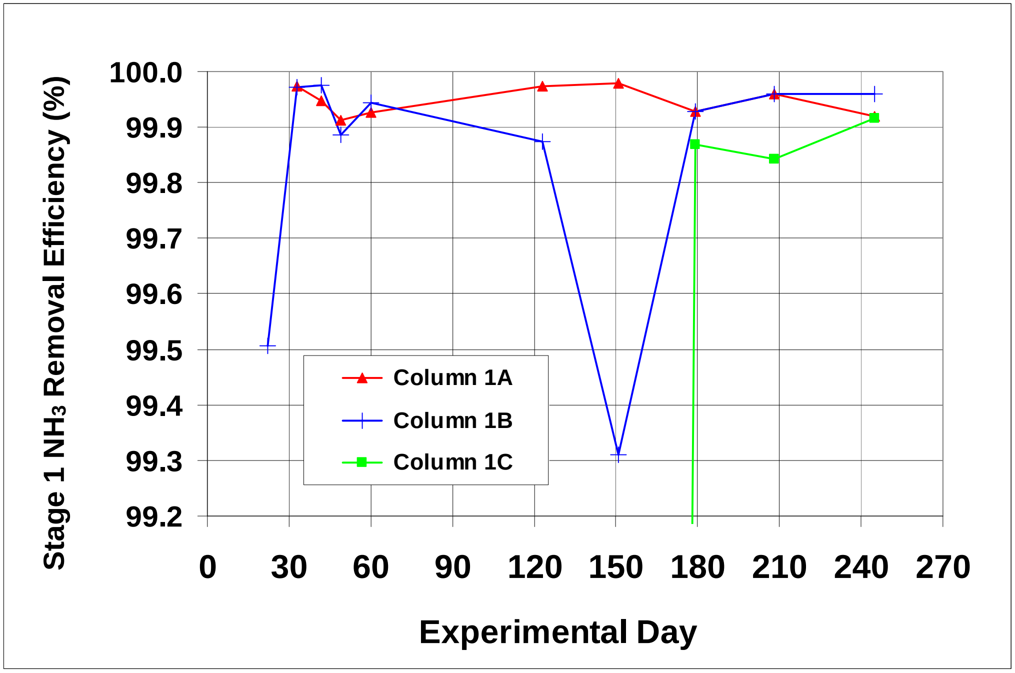

Figure 6 Stage 1 Ammonia Removal Efficiency

## Performance of Anoxic Denitrification Filters (Stage 2)

The performance of the three denitrification (Stage 2) filters is illustrated in Figures 7 and 8. $NO_x$ concentrations were quite low and TIN removal efficiencies high for System 1 (clinoptilolite / 75% sulfur) and System 2 (expanded clay/ 60% sulfur) throughout the study. System 3 (granular rubber/ 40% sulfur) showed less complete NOz removal through Day 210.

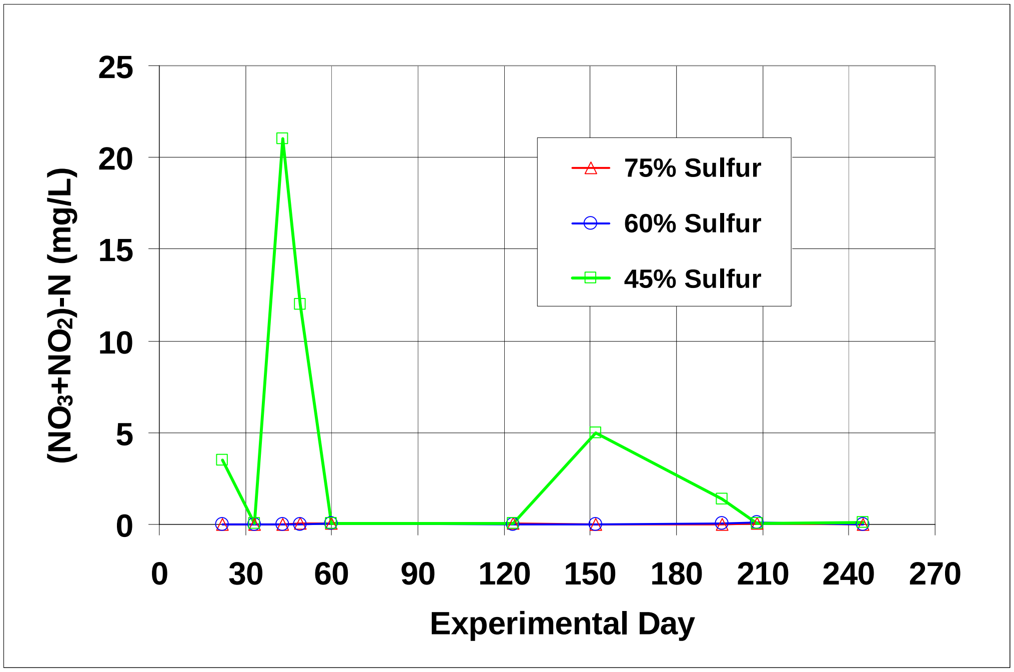

**Figure 7 $NO_x$ Concentrations in Stage 2 Filter Effluents**

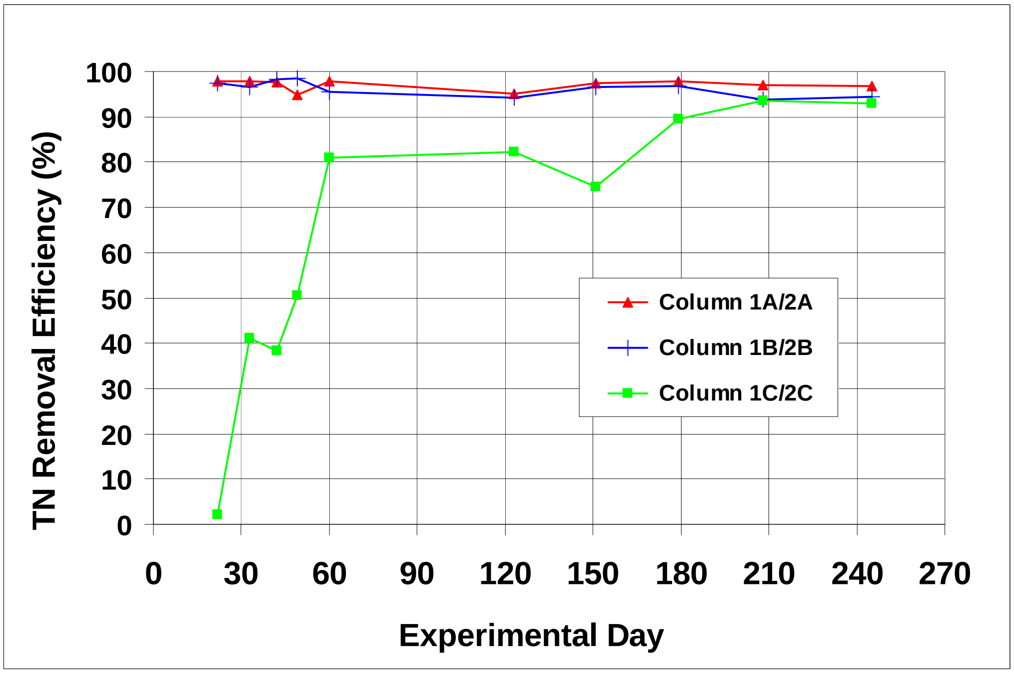

**Figure 8 Total Inorganic Nitrogen Removal Efficiencies of Two Stage Filters**

## Carbonaceous Biochemical Oxygen Demand

The removal of five day carbonaceous biochemical oxygen demand (C-$BOD_5$) was evaluated in three sampling events during which C-$BOD_5$ was analyzed in septic tank and effluents of the Stage 1 filters. The results are shown in Table 7. STE C-$BOD_5$ ranged from 120 to 160 mg/L and ranged from < 2 to < 8 for all three columns. The less than designations in the reported results reflect the different dilutions that were applied on the different sampling events days. C-$BOD_5$ removal efficiency ranged from > 94 to > 98% for all three Stage 1 columns. Based on ammonia removal performance of the Stage 1 filters that was found in the initial 60 day study, a high removal of for C-$BOD_5$ was presumed but not demonstrated. The results shown in Table 7 verified the expectation that C-$BOD_5$ removal efficiency would be high.

**Table 7 Carbonaceous Biochemical Oxygen Demand in STE and Stage 1 Effluent**

| **Date** | **C-$BOD_5$, mg/L** | | | |
|---|---|---|---|---|
| | **Septic Tank Effluent** | **Clinoptilolite** | **Enpanded Clay** | **Granular Rubber** |
| 5/4/2008 | 130 | < 8 | < 8 | < 8 |
| 6/3/2008 | 160 | 4.0 | 3.5 | 8.4 |
| 7/2/2008 | 120 | < 2 | < 2 | < 2 |
| % Removal Efficiency | - | > 94, 98, > 98 | > 94, 98, > 98 | > 94, 95, > 98 |

Field monitoring parameters are listed in Table 8 and summarized in Table 9. Each of the three Stage 1 media was effective in increasing dissolved oxygen (DO) from virtually zero in STE to (Figure 9). While wastewater DO was increased significantly by passage through the unsaturated Stage 1 filters, it was significantly reduced by passage through Stage 2 media (Figure 10). The change in pH in Stage 1 filters appears to be associated with the process of biochemical nitrification, which consumes 4.57 mg/l alkalinity as $CaCO_3$ per gram ammonia nitrogen nitrified.

## Table 8 Field Parameters in Influent and Filter Effluents

| May 4/5 2008 | | Temp C | DO mg/L | pH | Alkalinity |
|---|---|---|---|---|---|
| Influent | | 31.2 | 0.02 | 7.69 | 469 |
| Stage 1 | System 1 | 30.5 | 5.75 | 5.75 | 300 |
| | System 2 | 30.1 | 6.39 | 6.72 | 63 |
| | System 3 | 30.5 | 0.73 | 6.00 | 69 |
| Stage 2 | System 1 | 21.6 | 0.08 | 6.72 | 369 |
| | System 2 | 21.6 | 0.08 | 6.68 | 300 |
| | System 3 | 22.2 | 0.05 | 6.68 | 313 |
| | | | | | |
| June 2 2008 | | Temp C | DO mg/L | pH | Alkalinity |
| Influent | | 25.4 | 0.03 | 7.12 | 569 |
| Stage 1 | System 1 | 31.8 | 6.73 | 7.05 | 178 |
| | System 2 | 32.1 | 5.35 | 5.69 | 38 |
| | System 3 | 33.6 | 3.08 | 5.43 | 25 |
| Stage 2 | System 1 | 22.4 | 0.06 | 6.70 | 394 |
| | System 2 | 22.6 | 0.04 | 6.45 | 244 |
| | System 3 | 23.3 | 0.18 | 6.30 | 219 |
| | | | | | |
| July 1 2008 | | Temp C | DO mg/L | pH | Alkalinity |
| Influent | | 31.9 | 0.03 | 7.13 | 519 |
| Stage 1 | System 1 | 29.9 | 6.76 | 7.21 | 113 |
| | System 2 | 30.7 | 6.60 | 5.51 | 44 |
| | System 3 | 29.9 | 6.06 | 5.83 | 44 |
| Stage 2 | System 1 | 23.4 | 0.08 | 6.76 | 363 |
| | System 2 | 23.4 | 0.06 | 6.70 | 250 |
| | System 3 | 23.9 | 0.28 | 6.39 | 144 |
| | | | | | |
| July 28/29 2008 | | Temp C | DO mg/L | pH | Alkalinity |
| Influent | | 33.8 | 0.01 | 7.44 | 544 |
| Stage 1 | System 1 | 27.9 | 7.71 | 7.18 | 6 |
| | System 2 | 27.9 | 7.33 | 7.33 | 6 |
| | System 3 | 27.9 | 6.93 | 6.93 | 6 |
| Stage 2 | System 1 | 33.1 | 0.07 | 6.84 | 369 |
| | System 2 | 33.6 | 0.08 | 6.71 | 238 |
| | System 3 | 32.9 | 0.07 | 6.62 | 144 |
| | | | | | |
| September 3 2008 | | Temp C | DO mg/L | pH | Alkalinity |
| Influent | | 32.3 | 0.02 | 7.33 | 531 |
| Stage 1 | System 1 | 28.2 | 7.54 | 7.21 | 113 |
| | System 2 | 27.7 | 7.57 | 6.88 | 81 |
| | System 3 | 27.5 | 7.52 | 6.64 | 75 |
| Stage 2 | System 1 | 24.4 | 0.03 | 6.89 | 369 |
| | System 2 | 24.5 | 0.04 | 6.82 | 238 |
| | System 3 | 24.7 | 0.04 | 6.77 | 144 |

**Table 9 Summary of Field Parameters**
(Days 123 to 245; Average of n=5)

| Sample Point | Dissolved Oxygen, mg/L | pH | Alkalinity, mg/L as $CaCO_3$ | Alkalinity Change, mg/L as $CaCO_3$ |
|---|---|---|---|---|
| **Influent (STE)** | 0.02 | 7.34 | 526 | - |
| **Stage 1** | | | | |
| **1A Clinoptilolite** | 6.92 | 6.97 | 164 | - 362 |
| **1B Expanded clay** | 6.65 | 6.31 | 55 | - 471 |
| **1C Granular rubber** | 4.86 | 6.24 | 58 | - 469 |
| **Stage 2** | | | | |
| **2A 75% Sulfur** | 0.06 | 6.78 | 370 | + 206 |
| **2B 60% Sulfur** | 0.06 | 6.67 | 265 | + 210 |
| **2C 45% Sulfur** | 0.12 | 6.55 | 205 | + 148 |

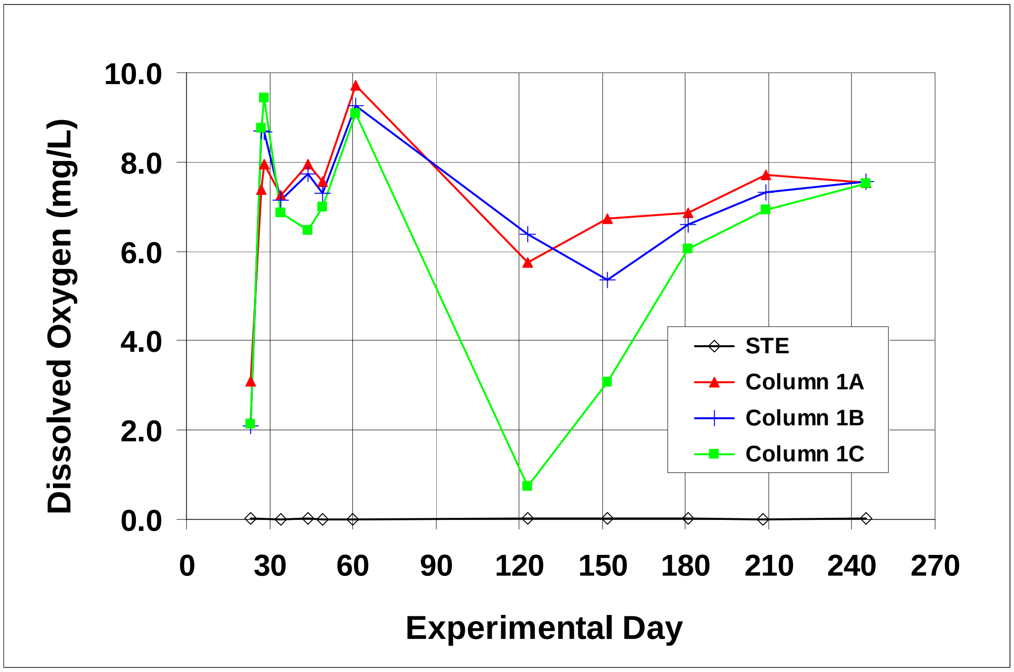

**Figure 9 Dissolved Oxygen in Effluent of Unsaturated Filters (Stage 1)**

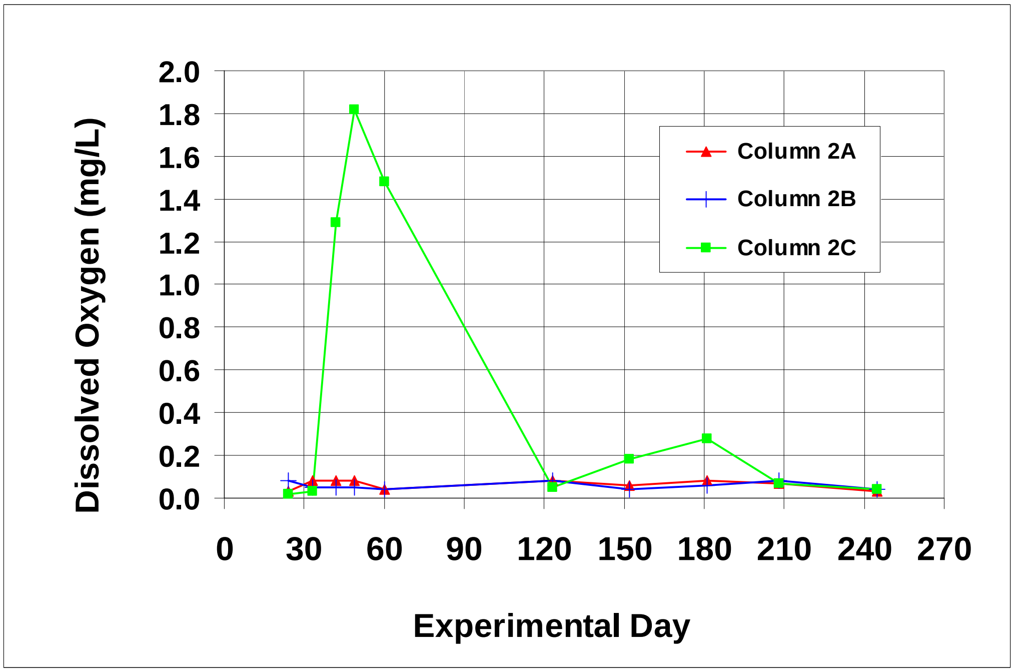

**Figure 10 Dissolved Oxygen in Effluent of Denitrification Filters (Stage 2)**

## Statistical Tests

Statistical tests were performed to compare STE composition and two-stage filter performance for the additional monitoring events (Period 1, Day 133 to 245) with the original PNRS study (Period 2, Day 20 to 60). Additional statistical tests were performed to compare the performance of the three filter systems to each other during Period 2. The central focus was on BOD and nitrogen levels in STE and nitrogen levels in filter effluents.

A comparison of STE composition between Period 1 (Day 22 to 62) and Period 2 (Days 123 to 245) is presented in Table 10. The two data sets for C-BOD$_5$ and for TN were both compared using the unpaired t-test, since all were normally distributed with equal variance. Although mean STE C-BOD$_5$ in Period 2 was 1/3 lower than in Period 1, the difference was not significant statistically, reflecting the limited number of analyses in each data set. Mean STE TN in Period 2 was 14% lower than in Period 1, but was also not statistically significant.

A comparison of effluent nitrogen concentrations between Period 1 and Period 2 is shown in Table 11. For each comparison, the unpaired t-test was performed when the statistical criteria for normal distribution and equal variance were met by both data sets; otherwise, the Mann Whitney rank sum test was employed. For Systems 1 and 2, the final effluent (Stage 2) TN in Period 2 was not significantly different than in Period 1, effluent TN was significantly lower for System 3. This was due to the improvement in performance in System 3 prior to Day 210. For Systems 1 and 2, both Stage 1 effluent ammonia and Stage 2 effluent NO$_x$ in Period 2 were not significantly different than in Period 1. Ammonia removal in Stage 1 and NO$_x$ removal in Stage 2 are central operative features of Passive Nitrogen Removal Systems, and these results indicate that these key features continued to function successfully through eight months of operation.

Significant differences obtained for System 3 for TN, TIN, and ammonia, reflecting the performance improvement up to Day 210. Stage 2 TIN in Period 2 was higher for both Systems 1 and 2, and statistically significant for System 1 even though Period 2 TIN in system 1 was lower than for System 2. The reason for this is an increase in ammonia nitrogen through the Stage 2 columns, which is greater in Period 2 than in Period 1. A possible contributing factor is an increase in microbial biomass and endogenous respiration in the Stage 2 filters, which could lead to the release of ammonia.

A comparison of effluent nitrogen concentrations of the three two-stage filter systems during Period 2 (Days 123 to 245) is shown in Table 12. The Kruskall-Wallis rank sum test was employed for comparison of the effluent nitrogen data sets. Statistically significant differences were found among the three systems for Total Nitrogen and $NO_x$, and were subsequently determined to be due to the higher levels in System 3.

**Table 10. Septic Tank Effluent: Statistical Comparison between Periods 1 and 2**

| **Analyte** | **Average (mg/L)** | | **Stastically Significant Difference** |
|---|---|---|---|
| | **Period 1** | **Period 2** | **Yes / No** |
| **C-BOD$_5$** | 203 | 137 | No (T) |
| **Total Nitrogen** | 77.4 | 66.9 | No (T) |

Period 1: Day 22 - 62

Period 2: Day 123 - 245

T: Unpaired t-test (a=0.05)

**Table 11 Effluent Nitrogen: Statistical Comparison between Periods 1 and 2**

| | **System 1 Clinoptilolite 60% Sulfur** | | | **System 2 Expanded Clay 75% Sulfur** | | | **System 3 Granular Rubber 45% Sulfur** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Effluent Source/ Analyte** | **Average N (mg/L)** | | **Stastically Significant Difference** | **Average N (mg/L)** | | **Stastically Significant Difference** | **Average N (mg/L)** | | **Stastically Significant Difference** |
| | **Period 1** | **Period 2** | | **Period 1** | **Period 2** | | **Period 1** | **Period 2** | |
| **Stage 2 TN** | 2.2 | 2.2 | No (M) | 2.1 | 3.2 | No (T) | 43.9 | 10.4 | Yes (T) |
| **Stage 2 TIN** | 0.14 | 0.53 | Yes (T) | 0.63 | 1.29 | No (M) | 42.1 | 6.1 | Yes (M) |
| **Stage 1 $NH_3$-N** | 0.047 | 0.028 | No (T) | 0.082 | 0.172 | No (W) | 26.6 | 4.2 | Yes (T) |
| **Stage 2 $NO_x$-N** | 0.027 | 0.032 | No (M) | 0.021 | 0.041 | No (M) | 7.3 | 1.3 | No (T) |

Period 1: Day 22 - 62

Period 2: Day 123 - 245

T: Unpaired t-test (a=0.05)

M: Mann Whitney rank sum test (P=0.05)

**Table 12  Statistical Comparison of Two-Stage Filter Effluent Nitrogen for Period 2**

| Analysis | Clinoptilolite 60% Sulfur | Expanded Clay 75% Sulfur | Granular Rubber 45% Sulfur | Stastically Significant Difference |
|---|---|---|---|---|
| **Total Nitrogen** | 2.2 | 3.2 | 10.4 | Yes (K) |
| **Total Inorganic Nitrogen** | 0.53 | 1.29 | 6.1 | No (K) |
| **Stage 1 $NH_3$-N** | 0.028 | 0.172 | 4.2 | No (K) |
| **Stage 2 $NO_x$-N** | 0.032 | 0.041 | 1.3 | Yes (K) |

K: Kruskal-Wallis One Way Analysis of Variance on Ranks

## Media Examination

### Dissambly of Columns and Subsample Collection

Filter columns were removed from the column field assembly and transported to the laboratory. The filters and media were maintained as intact units, with Stage 1 filter columns in vertical position and Stage 2 columns in horizontal position and saturated with water. Stage 1 media was removed by inverting each column and dispensing media onto a clean polyethylene sheet while moving the column along a straight line. The procedure resulted in a line of media approximately two feet long, in which the media was deposited in positions corresponding to depths in the filter columns. Stage 1 filter subsamples were collected at locations corrsesponding to depths of approximately 2, 12 and 19 in. depth from each column. For each column, after the three subsamples were collected, a portion was placed into pre-tared aluminum pans for gravimetric analysis and the remainder was set aside for visual observation and photographic recording. The Stage 1 sampling procedure was completed approximately 2 hours after the STE flow to the columns was terminated.

The Stage 2 media samples were then collected. End covers were removed and the columns placed in a vertical position to drain pore water. Media samples were then collected at three locations, in order of 3, 12 and 19 in. from the entrance to the media zone. Media samples were collected by cutting open the column at the target sample location and collecting approximately 2 in. of media in prepared beakers. Media subsamples were removed for gravimetric analysis, and the balance set aside for visual observation and photographic recording. The Stage 1 sampling procedure was completed approximately 3.5 hours after the STE flow to the columns was terminated.

### Observations of Filter Media

The media was visually observed and photographic images were taken. Stage 1 media surfaces at the termination of the study are shown in Figures 11 to 18. Gross solids accumulation at the media surface was not observable, suggesting that oxidative biochemical processes were able to assimlate influent organic materials over the 246 day period of operation.   Samples of media removed from the upper layer 2 inch of each Stage 1 Stage 1 filter are shown in Figures 14 to 16. These media contained water and accumulated solids, and the general shape and appearance of new media was preserved.  The visual difference between new clinoptilolite and clinoptilolite from the upper two in. of Stage 1 Column 1A dried at 103C, is shown in Figure 17.  Deployment for 246 days has darkened the surface.   Organic matter accumulation on the surface an expected feature of biofilm reactors, and organic matter would not be removed from the media surface by drying at 103C.  In Figure 18 are shown Stage 1 media samples from the upper 2 in. of the filter column after drying at 103C.  All media shown details of geometry and illustrate no gross solids accumulation.


**Figure 11 Surface of Clinoptilolite Filter (Day 246).**


**Figure 12 Surface of Expanded Clay Filter (Day 246).**


**Figure 13 Surface of Granular Rubber Filter (Day 246).**

**Figure 14 Clinoptilolite Media from Upper Layer (Day 246).**

**Figure 15 Expanded Clay Media from Upper Layer (Day 246).**

**Figure 16 Granular Rubber Media from Upper Layer (Day 246).**

**Figure 17 Clinoptilolite: New and Column 1A Upper Layer Dried at 103C (Day 246) (Left: new)**

**Figure 18 Stage 1 Media, Upper Layer Dried at 103C (Day 246).**
**Left to right: clinoptilolite, expanded clay, granular rubber.**

Stage 2 media surfaces at the termination of the study are shown in Figures 19 to 21. The cutaway section of column 2A at 21 in. from the entrance is shown in Figure 19. There is no observable meterial accumulation on the media or within the column. The white material in Figure 19 is shavings that resulted from cutting open the pipe. Sulfur media in Figure 19 appeared similar new sulfur as was originally placed into the column at startup. This observation was true for Stage 2 media from all three filters from the sampling point in middle and towards the downstream end. In Figure 20 is shown Column 2A media from entrance region, with media nearer the entrance to the right in the figure. This was media as it appeared before drying. Inspection of the media reveals what appears to be a gelatenous coating of media near the entrance, which is less pronounced farther from the entrance (i.e. to left in photo). The “slime layer” is characteristic of biofilm reactors and was also observed in the other Stage 2 columns. The gelatenous layer material near the entrance suggests that the entance region of the Stage 2 columns is the site of active microbial processes. Photographs of of Stage 2 media after drying at 103C are shown in Figure 21. Media after drying show no obvious observable differences with position in the filters. Note that the darker appearance in media from filters 2B and 2C is due to increasing percentages of expanded shale. **T**he mass of sulfur needed to denitrify the total $NO_x$ supplied to each Stage 2 column over 246 days of operation was estimated using stoichiometric analysis. The resulting fractional consumptions of sulfur for Systems 1, 2 and 3 were 1.8, 3.5 and 3.5, respectively, corresponding to a longevity of 19 to 39 years.

**Figure 19 Filter 2A, 21 in. (Day 246).**

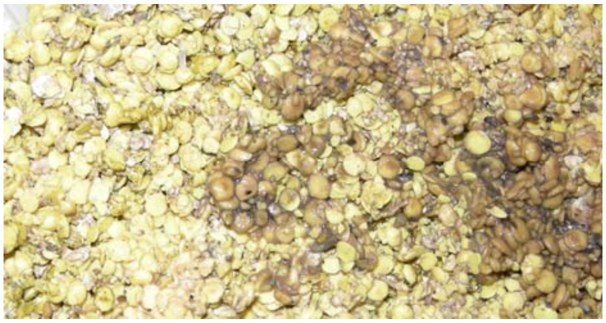

**Figure 20 Filter 2A, 2 in. (Day 246).**

**Figure 21 Stage 2 Media Dried at 103C (Day 246).**
**Left to right, Column 2A, 2B, 2C.**
**Top to bottom in direction of column entrance to exit.**

## Gravimetric Analysis

Gravimetric analyses were conducted to provide measurements of water in the filter media (Table 13). Stage 1 media samples from 2, 12 and 19 in. locations corresponded to large, medium and small media particle sizes (Table 2). In the Stage 2 columns, the samples from 3, 12 and 19 in. locations represented media near the inlet, midpoint, and downstream section of the filter column. Water content for Stage 1 media are expressed as percent of the total mass of media sample (solids + water); the % water content deoends on the dry bulk density of the media. On this basis, the water content similar for clinoptilolite and granular rubber, and higher for expanded clay. For all three media, water fraction was lowest for the large particle size media located at the top of the filter. For Stage 2 media, water content was lowest for the column with the greatest sulfur content. The 60 and 45% sulfur filters contained expanded shale, which may have contributed to higher water contents though its lower bulk density and higher water retention.

The water content data were used along with dry bulk density of media and filter empty bed volume to estimates the mass of resident water within each of the Stage 1 filters (Table 14). The expanded clay media had the highest calculated water mass and the granular rubber the lowest. The average retention time of water within the Stage 1 columns, calculated using 3 gal/ft$^2$-day areal loading, was lowest for granular rubber (15.3 hr) and highest for expanded clay (48 hr.). These results provide some consistency with the concept, elucidated in the PNRS literature review, that superior performance can be provided by unsaturated media filters that empoly high water retention media. A calculation of water layer thickness on the media surface was made by assuming uniform film thickness and idealized spherical particle geometry. Results provided water layer thicknesses of 37 to 350 μm. This theoretical result is limited and does not account for water contained within internal pores in the media and held between particels by capillary forces,

Biofiltration is conducted by microbial biofilms that colonize media surfaces. To estimate organic matter content, the Stage 1 media samples used for water analyses were subject to further analysis by combustion at 500 to 600C. It was not possible to determine organic matter in granular rubber and Stage 2 filter media because of the lower vaporization temperature of media components. Organic matter as a fraction of the dry mass was 0.3 to 2.3% (Table 15). Organic matter includes actively metabolizing biomass, products of endogenous decay, microbial exudates such as polysaccharides and other constituents forming a “slime layer”, as well as particulate and colloidal organic materials from the STE that are retained on the filter media through straining, sedimentation, and Brownian diffusion. Theoretical calculations suggest that the accrued biomass would form a thickness of 10 to 150 μm if present as a uniform film on idealized spherical particles.

## Table 13 Gravimetric Analysis of Filter Media

| Filter | Media | Distance from Entrance (in.) | % Solids | % Water |
|---|---|---|---|---|
| **Stage 1** | **clinoptilolite** | 2 | 80.8 | 19.2 |
| | | 12 | 75.5 | 24.5 |
| | | 19 | 76.7 | 23.3 |
| | **expanded clay** | 2 | 64.5 | 35.5 |
| | | 12 | 61.1 | 38.9 |
| | | 19 | 59.1 | 40.9 |
| | **granular rubber** | 2 | 80.7 | 19.3 |
| | | 12 | 75.9 | 24.1 |
| | | 19 | 69.4 | 30.6 |
| **Stage 2** | **75% S** | 3 | 90.4 | 9.6 |
| | | 12 | 91.9 | 8.1 |
| | | 19 | 89.2 | 10.8 |
| | **60% S** | 3 | 78.4 | 21.6 |
| | | 12 | 86.7 | 13.3 |
| | | 19 | 87.7 | 12.3 |
| | **45% S** | 3 | 83.4 | 16.6 |
| | | 12 | 83.1 | 16.9 |
| | | 19 | 84.2 | 15.8 |

## Table 14 Derived Residence Time in Stage 1 Filters

| Stage 1 Media | Mass Resident Water (gram) | Water Retention Time (hour) |
|---|---|---|
| **clinoptilolite** | 30.3 | 30.3 |
| **expanded clay** | 48.7 | 48.7 |
| **granular rubber** | 15.3 | 15.3 |

## Table 15 Organic Matter in Stage 1 Filter Media

| Stage 1 Media | Distance from Media Entrance (in.) | Organic mass/ dry mass (gram/gram) |
|---|---|---|
| **clinoptilolite** | 2 | 0.018 |
| | 12 | 0.023 |
| | 19 | 0.020 |
| **expanded clay** | 2 | 0.016 |
| | 12 | 0.003 |

## Conclusions

Three two-stage passive media filters were operated through eight months to treat septic tank effluent. The systems used no aerators, a single wastewater pump, and otherwise operated in passive mode. The following conclusions are based on five monitoring events conducted over 122 days from Day 123 to day 245.

- Average hydraulic loading rates of septic tank effluent applied to Stage 1 filters with clinoptilolite, expanded clay, and tire crumb media were 2.82, 2.96 and 2.83 gallons per square foot per day, respectively.
- Total nitrogen in septic tank effluent averaged 66.9 mg/L with a standard deviation of 6.2 mg/L.
- Total Nitrogen (TN) removal efficiencies for Two Stage Systems averaged 96.8, 95.1 and 86.6%, respectively, for clinoptilolite, expanded clay and tire crumb media.
- Effluent Total Nitrogen (TN) concentrations for Two Stage Systems averaged 2.2, 3.2, and 10.4 mg/L, respectively, for clinoptilolite, expanded clay and tire crumb media.
- Total Inorganic Nitrogen (TIN) removal efficiencies for Two Stage Systems averaged 99.2, 99.0, and 92.2 %, respectively, for clinoptilolite, expanded clay and tire crumb media.
- Effluent Total Inorganic Nitrogen (TIN) concentrations for Two Stage Systems averaged 0.53, 1.3 and 6.1 mg/L, respectively, for clinoptilolite, expanded clay and tire crumb media.
- Effluent ammonia nitrogen ($NH_3$-N) concentrations for Stage 1 filters averaged 0.028, 0.17 and 4.2 mg/L, respectively, for clinoptilolite, expanded clay and tire crumb media.
- Average septic tank effluent carbonaceous five day biochemical oxygen demand was 137 mg/L.
- C-$BOD_5$ removal efficiencies for Stage 1 filters were greater than 94% for clinoptilolite, expanded clay and granular rubber media.
- Effluent C-$BOD_5$ concentrations in Stage 1 filters were less than 8 mg/L for clinoptilolite, expanded clay and granular rubber media.
- Average dissolved oxygen in unsaturated (Stage 1) effluents were 6.92, 6.65 and 4.86 mg/L, respectively, for clinoptilolite, expanded clay and tire crumb media.
- Average dissolved oxygen in anoxic filter effluents (Stage 2) were 0.06, 0.06 and 0.12 mg/L, respectively, for sulfur media percentages of 75, 60, and 45%.
- For systems 1,2 and 3, the average decline in total alkalinity as $CaCO_3$ in aerobic filters (Stage 1) was 362 to 471 mg/L, while alkalinity increase in anoxic filters (Stage 2) was 148 to 210 mg/L.
- Media from Stage 1 and 2 columns exhibited a generally similar appearance to new filter media after 246 days of operation.

## References

Smith, D. et al. (2008) Florida Passive Nitrogen Removal Study Final Report. Submitted to the Research Review and Advisory Committee, June 26, 2008.

# APPENDIX A

# NELAC CERTIFIED LABORATORY WATER QUALITY DATA

**Sample Event 1**

| Sample Point | Influent | System 1 | | System 2 | | System 3 | |
|---|---|---|---|---|---|---|---|
| | | Stage 1 Effluent | Stage 2 Effluent | Stage 1 Effluent | Stage 2 Effluent | Stage 1 Effluent | Stage 2 Effluent |
| TKN | 79 | 1.9 | 3.9 | 0.05 | 4.5 | 9.5 | 14 |
| $NH_3$-N | 66 | 0.02 | 0.75 | 0.10 | 2.3 | 5.5 | 7.1 |
| $(NO_3+NO_2)$-N | 0.04 | 28 | 0.044 | 73.00 | 0.025 | 60 | 0.079 |
| C-$BOD_5$ | 130 | <8 | - | <8 | - | <8 | - |

**Sample Event 2**

| Sample Point | Influent | System 1 | | System 2 | | System 3 | |
|---|---|---|---|---|---|---|---|
| | | Stage 1 Effluent | Stage 2 Effluent | Stage 1 Effluent | Stage 2 Effluent | Stage 1 Effluent | Stage 2 Effluent |
| TKN | 98 | 0.046 | 2.4 | 0.05 | 3.4 | 26.0 | 20 |
| $NH_3$-N | 91 | 0.020 | 0.61 | 0.68 | 1.1 | 15.0 | 14 |
| $(NO_3+NO_2)$-N | 0.025 | 79 | 0.025 | 91 | 0.025 | 90 | 5 |
| C-$BOD_5$ | 160 | 4 | - | 3.50 | - | 8.4 | - |

**Sample Event 3A**

| Sample Point | Influent | System 1 | | System 2 | | System 3 | |
|---|---|---|---|---|---|---|---|
| | | Stage 1 Effluent | Stage 2 Effluent | Stage 1 Effluent | Stage 2 Effluent | Stage 1 Effluent | Stage 2 Effluent |
| C-$BOD_5$ | 120 | < 2 | - | <2 | - | <2 | - |

**Sample Event 3B**

| Sample Point | Influent | System 1 | | System 2 | | System 3 | |
|---|---|---|---|---|---|---|---|
| | | Stage 1 Effluent | Stage 2 Effluent | Stage 1 Effluent | Stage 2 Effluent | Stage 1 Effluent | Stage 2 Effluent |
| TKN | 56 | 0.120 | 1.2 | 0.450 | 1.8 | 3.0 | 4.5 |
| $NH_3$-N | 47 | 0.040 | 0.33 | 0.04 | 0.64 | 0.07 | 1.7 |
| $(NO_3+NO_2)$-N | 0.025 | 54 | 0.025 | 56 | 0.03 | 52 | 1.4 |

**Sample Event 4**

| Sample Point | Influent | System 1 | | System 2 | | System 3 | |
|---|---|---|---|---|---|---|---|
| | | Stage 1 Effluent | Stage 2 Effluent | Stage 1 Effluent | Stage 2 Effluent | Stage 1 Effluent | Stage 2 Effluent |
| TKN | 51 | 0.87 | 1.5 | 1.30 | 3.1 | 3.3 | 3.2 |
| $NH_3$-N | 47 | 0.02 | 0.15 | 0.02 | 1.1 | 0.075 | 0.56 |
| $(NO_3+NO_2)$-N | 0.025 | 55 | 0.041 | 52 | 0.10 | 53 | 0.062 |

**Sample Event 5**

| Sample Point | Influent | System 1 | | System 2 | | System 3 | |
|---|---|---|---|---|---|---|---|
| | | Stage 1 Effluent | Stage 2 Effluent | Stage 1 Effluent | Stage 2 Effluent | Stage 1 Effluent | Stage 2 Effluent |
| TKN | 50 | 0.82 | 1.6 | 0.96 | 2.8 | 2.1 | 3.4 |
| $NH_3$-N | 41 | 0.04 | 0.67 | 0.02 | 1.1 | 0.04 | 0.40 |
| $(NO_3+NO_2)$-N | 0.25 | 40 | 0.025 | 41 | 0.025 | 40 | 0.13 |