Florida Passive Nitrogen Removal Study

Final Report

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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.

Literature Review and Database

A literature review was conducted to evaluate technologies that can potentially be used in passive nitrogen removal systems. The literature review included searches in scientific and engineering databases, peer reviewed literature, conference and journal proceedings, unpublished reports, vendor-supplied information, World Wide Web searches, and personal contacts with experts in the field. A searchable database of 227 citations was compiled and provided as a project deliverable. The literature review and analysis of "passive" system constraints were used to formulate a two-stage filter strategy for removing total nitrogen from septic tank effluent. Evaluation of key media characteristics resulted in recommendations of specific media to use in the Stage 1 unsaturated aerobic nitrification filter, and in the saturated, anoxic Stage 2 denitrification filter. The literature review included recommendations regarding key design factors of hydraulic loading rate, dosing regime and media depth of the unsaturated Stage 1 filter and filter sizing and residence time in Stage 2.

Experimental Evaluation

An experimental on-site wastewater treatment system was operated for sixty days 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. Two of the three 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. 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). The experimental evaluation, though of limited duration, verified the potential of the two-stage filter system for total nitrogen removal using passive technology.

Economic Analysis

A detailed economic analysis was conducted using Life Cycle Cost Analysis (LCCA) to provide equitable evaluation of the cost of alternative passive nitrogen removal systems over their entire life. LCCA included costs for equipment, materials, and installation, energy, scheduled maintenance, and monitoring, media replacement and residuals management. Present Worth (PW) and Uniform Annual Cost (UAC) were developed for twelve alternative configurations of two-stage passive nitrogen removal systems. LCCA results are presented for both total system cost including passive nitrogen removal, primary treatment (i.e. septic tank) and conventional drainfield, and for the passive nitrogen component only. A cost comparison is also provided for a Recirculating Sand Filter, which is a widely applied onsite technology.

Recommendations for System Deployment

Recommendations are presented for deployment of a two-stage passive nitrogen removal system for single family homes which discharge septic tank effluent (STE) with characteristics typical of single family residences in the U.S. The passive nitrogen component is placed following primary treatment and before the drainfield in a conventional onsite system. Specific recommendations are presented for system design, including flow equalization and storage volume, pumping arrangement, aerobic Stage 1 filter dosing system, media, filter sizing, and underdrain, Stage 2 anoxic filter media and sizing, and hydraulic profile development. Recommendations for permitting include innovative status application including NSF testing, and possible evaluation of drainfield size reduction credits. Installation, control and monitoring recommendations are made which share commonality with typical onsite installations; a twice per year maintenance visit and one per year monitoring frequency are recommended. The recommendations for replacement of denitrification media (Stage 2) are dependent on the need for longer term performance verification of sulfur-based denitrification filters. In addition, it is recommended to investigate the reuse of spent denitrification media within the treatment process or for beneficial agricultural land application.

Recommendations for Future Research

Additional studies were recommended to address key issues that have direct implications to two-stage filter process performance, design, feasibility, longevity, and economics. It is recommended to extend operation of the systems to provide longer term operating data, to operated the filter systems at higher loading rates, to employ recycle on Stage 1 filters for pre-denitrification, to more fully examine performance and design issues with the denitrification filters, and to examine treatment parameters other than nitrogen. Full scale testing at a single family residence is recommended for a period of at least two years.

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 (Postma et al.,1992). In a study at Big Pine Key, Florida, the dissolved inorganic nitrogen (DIN) levels in groundwater contiguous to on-site drainfields were greater than DIN levels at a control location (Lapointe et al., 1990). 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 (Corbett et al., 2002). 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 (Siegrist, 2006). 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 (Anderson and Otis, 2000). 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.

Literature Review

Passive Nitrogen Removal

The goal of passive nitrogen removal is to provide on-site systems with relatively simple operation and low life cycle costs. Passive nitrogen removal approaches must be cognizant of the speciation of nitrogen (inorganic vs. organic, particulate vs. soluble, oxidized and reduced), the biochemical reaction sequence needed for complete nitrogen removal, and the use of *Total Nitrogen* as the generally accepted metric of system performance:

Total Nitrogen (TN) = Organic N + Ammonia N + Nitrate N + Nitrite N

In septic tank effluent (STE), nitrogen is present in organic and ammonia forms, with virtually no oxidized N. Other nitrogen relationships and delineations are listed below.

Total Kjeldahl Nitrogen (TKN) = Organic N + Ammonia N

Organic Nitrogen = Filtrable Organic N + Non-filtrable Organic N

Total Inorganic Nitrogen (TIN) = Ammonia N + Nitrate N + Nitrite N

Total Oxidized Nitrogen (TON) = Nitrate N + Nitrite N

TN = TKN + TON

Conventional unmixed septic tanks provide sedimentation and removal of suspended solids and particulate nitrogen. STE contains ammonia, filtrable (dissolved) organic N, and non-filtrable (suspended) organic N that has not been removed within the septic tank by sedimentation. The use of strainers to treat effluent from septic tanks (also termed STE "filters") can enhance removal of non-filtrable organic N. Non-filtrable organic N in STE would be removed in media filters by the standard physical filtration mechanisms of straining, impaction and sedimentation within the filter bed.

Of great importance to the configuration of passive nitrogen removal systems are biochemical nitrogen transformations. The significant biochemical transformations are listed below in the sequence in which they must generally occur. Hydrolysis converts particulate organic N to soluble organic N, which in turn releases ammonia through ammonification. Both processes can occur in the presence or absence of oxygen.

Hydrolysis

Non-filtrable Organic N $\rightarrow$ Filtrable Organic N

Ammonification

Filtrable Organic N → Ammonia N

Removal of total nitrogen in on-site systems requires both nitrification (an aerobic process) and denitrification (an anoxic process). Nitrification must occur first and must be followed by denitrification. Passive denitrification filters cannot treat septic tank effluent without pre-treatment with some type of aerobic treatment. Therefore, if septic tank effluent is considered as the starting point for examining nitrogen reduction strategies, a systems view of nitrification and denitrification may be most beneficial.

Nitrification (requires O_2)

Ammonia N → Nitrite N → Nitrate N

Denitrification (requires electron donor)

Nitrate N → Nitrite N → Di-nitrogen (N_2)

Nitrification requires oxygen, while denitrification requires an electron donor. Oxygen for nitrification can be supplied to liquid in septic tanks, pumping tanks, or other treatment tanks using aeration pumps, or by air ingress (assisted or unassisted) into systems containing unsaturated media, such as packed trickling filters, recirculating sand filters, peat filters, textile filters, and the unsaturated zones of drainfields. Here, the unsaturated media are attachment surfaces for nitrifiers and other microorganisms.

To remove nitrogen, both centralized and decentralized wastewater treatment plants must create the conditions necessary to sustain the biochemical reactions required for nitrogen removal. Several different process trains are used in conventional suspended growth wastewater treatment plants, including "two sludge" systems with separate aerobic and denitrifying microbial populations (Figure 1), and "simultaneous" systems (Figures 2) that accomplish both nitrification and denitrification. "Sludge" in this case refers to the active biomass in the process, which provides the treatment. In the simultaneous process the biomass is a mixture of autotrophs

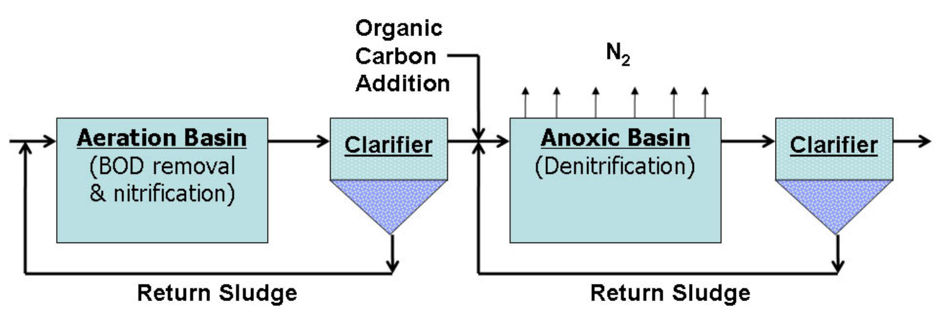

Figure 1. Two Sludge Denitrification System

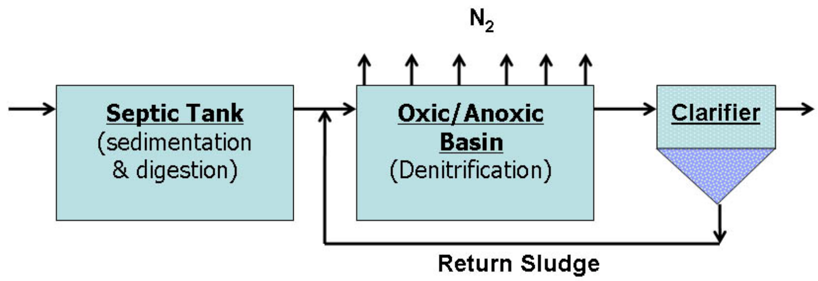

Figure 2. Simultaneous Denitrification System

(nitrifiers) and facultative heterotrophs (organic degraders & denitrifiers) while in the two sludge system, the two groups of microorganisms are separated in different reactors.

The two sludge system can achieve nearly complete nitrogen removal because both the nitrification step and denitrification step can be optimized for removal of organic nitrogen and ammonia (nitrification step) and nitrate and nitrite (denitrification step). However, since the nitrification step removes nearly all the organic carbon, a separate source of organic carbon is required for removal of nitrate and nitrite (Figure 1). Without adequate carbon source, even though removal of ammonia and organic nitrogen may be highly complete, Total Nitrogen removal will be limited. Though the two sludge process has the advantage that it can achieve more complete nitrogen removal, it is very dependent on an external organic carbon source (Bitton, 1994; Degen, et al., 1991; Oakley, 2005).

In the simultaneous system, denitrification is achieved by cycling between oxic and anoxic conditions in a single reactor such that nitrification and denitrification is accomplished "simultaneously" (Figure 2). This process occurs in the filter media when wastewater containing ammonium and biodegradable carbon is applied to aerobic soil. In response to the application, facultative heterotrophs quickly degrade the organic carbon and deplete the oxygen in doing so. The ammonium cannot be nitrified under anoxic conditions, so being a positively charged ion; it may be retained within the filter media depending on the cation exchange capacity. This simultaneous process has the advantages of having a continuous supply of organic carbon from the wastewater for the denitrification step, lower oxygen requirements, and it recycles the alkalinity needed for nitrification. However, the amount of denitrification can be limited depending on the frequency and duration of the oxic/anoxic fluctuations within the filter with respect to the reaction rates. In a field study in soil which investigated OWTS design and operation that would maximize denitrification, Degen, et al. (1991) found that this simultaneous process performed best because carbon is the limiting factor for denitrification in soil.

A third process model that has been recognized only recently is an anaerobic, autotrophic bacterial process called Anammox. This process is possible when both nitrate and ammonium occur together under anoxic or anaerobic conditions (Van de Graaf et al., 1995; 1996; 1997). In this process, the autotrophs reduce the nitrate to nitrogen gas while utilizing the oxygen from the nitrate to oxidize the ammonium to nitrate. Because the bacteria are autotrophs, no organic carbon is required to sustain this process. Anoxic or anaerobic conditions are necessary because if not, the heterotrophs would oxidize the ammonium removing the energy source from the autotrophs.

Regardless of the types of nitrogen transforming biochemical reactions within the treatment system and their spatial locations, total nitrogen in the effluent will consist of ammonia, nitrate and nitrite, and organic nitrogen. The ammonia nitrogen levels in the effluent from the unit operations preceding the denitrification filter must be consistently at or below target levels for final effluent ammonia nitrogen, since ammonia may behave conservatively as wastewater passes through the anoxic denitrification filter. For passive denitrification filters, solid phase electron donors are employed that provide attachment surfaces for denitrifying microorganisms and electron donor supply through a process of continuous dissolution over extended time periods. While numerous potential solid phase electron donors exist, the most commonly applied have been lignocellulosic materials such as wood chips and sawdust that support heterotrophic denitrification and elemental sulfur (autotrophic denitrification). The total oxidized nitrogen levels in the effluent from the denitrification filter must be consistently at or below target levels for final effluent oxidized nitrogen, which can be established either independently or be apportionment of the target effluent Total Nitrogen among the nitrogen species.

The meaning of the term "passive" for nitrogen removal in on-site wastewater treatment systems can then be addressed within the context of overall STE composition, the forms and speciation of nitrogen, and the mechanisms of nitrogen removal. For the Florida Passive Nitrogen Removal Study, a program specific definition for the term "passive" was provided by FDOH:

> **Passive** *A type of onsite sewage treatment and disposal system that* ***excludes the use of aerator pumps*** *and includes* ***no more than one effluent dosing pump*** *in mechanical and moving parts and uses a reactive media to assist in nitrogen removal*

The definition of a "passive" system placed significant restrictions on the types of onsite wastewater treatment systems than can be considered. The definition precludes the use of aeration pumps within any system component: septic tank, dosing tank or other treatment chambers. Oxygen for BOD removal and nitrification must therefore be supplied by unassisted aeration to an unsaturated media filter that operates as a four phase system: solid media, water, gas phase, and attached biofilm. Wastewater is supplied at the top of the media and flows downward by trickle flow or percolation. This very common approach to onsite wastewater systems is applied in sand filters and in other media filters, providing ammonification and nitrification.

Single pass unsaturated media filters can provide some degree of denitrification using wastewater organics. Recirculation of filter effluent to a septic tank chamber or dosing tank can substantially enhance denitrification and produce Total Nitrogen removals of 60% or greater. To achieve higher Total Nitrogen removal percentages and lower effluent TN concentrations, unsaturated filter effluent can be directed to a denitrification filter. Denitrification filters are possibly the only feasible approach to enhancing TN removal in passive onsite systems beyond that achievable by unsaturated filters. Denitrification filters are saturated with water and are three phase systems: solid media, liquid, and biofilm (possible bubble formation from denitrification is considered relatively insignificant). The solid phase contains a reactive solid media that supplies attachment surface and electron donor for denitrifying organisms. The solid phase electron donors that have been most commonly studied are elemental sulfur and cellulosic materials (sawdust and wood chips).

Another stipulation of the "passive" definition is that only a single effluent dosing pump be used. The dosing pump must provide adequate head to convey wastewater from the septic tank effluent elevation, through filter media, and presumably to a soil treatment unit. Wherever the single pump is positioned within the treatment train, the movement of wastewater before and after the pump must be by gravity. In addition to hydraulic conveyance, the pump can provide very important treatment features including the ability to pressure dose, the ability used timed dosing, and the ability to spread wastewater uniformly over the entire area of the filter surface. These features have been exploited numerous unsaturated systems such as intermittent sand filters, and are important for efficient treatment. An additional feature afforded by a pump is the ability to recirculate a portion of filter effluent, using various non-powered splitter devices which do not require power or manual operation. Recirculation of the effluent of an aerobic filter effluent (recirculating sand filter for example) increases denitrification using wastewater organics as carbon source, and can substantially increase TN removal efficiency and decrease effluent TN.

An additional treatment consideration is alkalinity and the need to maintain appropriate pH conditions for biochemical reactions. Nitrification consumes 7.14 grams of alkalinity as $CaCO_3$ per gram ammonia N nitrified, and nitrifying microorganisms are inhibited as pH decreases below neutral. For an STE containing 45 mg/L TN, required alkalinity is 321 mg/L. The alkalinity of the starting water supply, as augmented by the increase in alkalinity through domestic water use (perhaps 60 to 120 mg/L), must be sufficient to prevent pH decrease and inhibition of nitrification. Nitrogen removal performance of a total nitrogen removal system could be affected by alkalinity of STE and the effects of pH conditions on biochemical reaction rates. If the pH drops in an aerobic filter due to nitrification, then nitrification might not proceed to completion, leaving a high residual ammonia concentration. Ammonia in the effluent of the first stage aerobic filter could largely pass through s second stage anoxic filter, thereby lowering the overall TN removal efficiency. A benefit of recycle around the aerobic filter is that the partial pre-denitrification would be accompanied by the additional benefit of restoration of alkalinity. Alkalinity restoration may become more important in the future as water conservation trends exacerbate the potential of alkalinity to limit nitrification in non-recycle aerobic systems. The potential advantages of recycle in aerobic systems are increased as TN levels increase in STE.

The first stage filter must achieve a high degree of BOD and ammonia removal because these components may not be degraded in the second stage anoxic filter environment. Additionally, a high quality first stage effluent will limit the amount of solids and BOD added to the second stage filter. Lower loadings to the anoxic filter should reduce the possibility of channeling and enable better long term performance and lower maintenance needs.

Saturated anoxic filters for passive denitrification have far less studied than unsaturated filters. Anoxic filters are usually fully submerged to preclude ingress of oxygen from air. Oxygen in the incoming flow is probably utilized preferentially near the entrance, enabling anoxic conditions to prevail downstream. Denitrifying microorganisms reduce oxidized inorganic nitrogen, predominantly nitrate, to nitrogen gas. The denitrifying microorganisms grow as biofilms on the reactive media, dissolving the reactive media and using it for nitrate reduction. Nitrate is reduced to nitrogen gas, which leaves the reactor dissolved in the liquid effluent or as small bubbles. The principals of porous media biofilm reactors have been well established. Factors that affect performance include the size, specific surface area, tortuosity and porosity of media, average liquid residence time, superficial flow velocity, linear velocity, uniformity of flow (i.e. channeling), mass transfer and biofilm kinetics. A special feature of the passive anoxic filters is the reactive dissolution of the media. The media must supply enough electron donor for denitrification or nitrate removal may decline. On the other hand, if media dissolution is too rapid, media longevity will be reduced and the reactor effluent will contain excess dissolution product (such as BOD for cellulose based media). A solid phase alkalinity supply, such as limestone or crushed oyster shell, may be required to maintain pH. Over long term continuous operation, flow channeling can result in short circuiting, decreased contact time of with biofilms, and decline in performance.

A "passive" treatment system for nitrogen removal must be seen as an integrated sequence of unit operations/processes that can achieve the treatment goal. If it is assumed that the starting point is septic tank effluent (STE), then the total treatment system must meet the target treatment goal. The treatment goal could be expressed as the Total Nitrogen (TN) concentration "leaving the treatment system," or "entering the environment." Suppose the goal is to achieve a TN of 2.5 mg/L or less before directing the effluent to a soil absorption field. Assuming nitrite levels are negligible, the effluent TN of 2.5 must be apportioned between 1. organic N, 2. ammonia-N, and 3. nitrate-N:

$$\text{Organic-N} + NH_3\text{-N} + NO_3\text{-N} \leq 3.0$$

The biochemical sequence requires ammonification and nitrification before denitrification. For a process with a final treatment step will be an anoxic denitrification filter with reactive media, then attention must be focused on the organic N and ammonia N concentrations in the influent to the denitrification filter. Ammonia levels could increase across the denitrification filter due to ammonification of influent organic N; ammonia levels could decrease across the denitrification filter by nitrification near the inlet using residual dissolved oxygen in the actual denitrification filter influent.

An approach to formulation of process objectives is to estimate the effluent nitrate N achievable in anoxic filters, and allocate the remainder of the target effluent TN to the sum of organic N and ammonia N. For a target effluent TN of 3.0 mg/L:

$$TKN_{allowable} \leq 3.0 - NO_3\text{-}N$$

An achievable effluent NO_3-N of 1.0 mg/L would mandate a TKN of not greater than 2.0 mg/L. The approach would be conservative from the perspective of ammonification in the anoxic filter, which would not change TKN, although some factors such as autolysis could increase TKN.

This discussion points to the important need to reduce TKN in the treatment that occurs before the anoxic denitrification filter. Producing TKN less than $TKN_{allowable}$ should be the first priority of the "first stage" of treatment. For "first stage" systems that accomplish denitrification along with nitrification and ammonification in the same process tank or through recirculation, the critical question is: is the effluent TKN less than $TKN_{allowable}$.

From a knowledge of the functioning of aerobic filter systems treating STE, it is hypothesized that optimization of the aerobic treatment process is the most important factor affecting overall nitrogen reduction. This is speculative, because there is limited experience in the coupled operation of aerobic and coupled anoxic filters in passive configurations. If the aerobic process must be optimized, then the single pump that is allowed should be used to supply STE to the aerobic biofilter. The benefits of more frequent doses of lower volume and more uniform flow distribution will accrue to the aerobic filter, and provide a high quality influent to the anoxic biofilter. Using the pump to supply the aerobic biofilter will enable recirculation, which will lessen the nitrate loading to the denitrification biofilter and reduce alkalinity requirements. For low relief Florida environments, the aerobic filter would be placed above grade to enable gravity flow to and through the anoxic filter and then to a soil treatment unit.

The following points summarize the needs that must be satisfied by the passive nitrogen removal technology, and factors that influence the overall approach and configuration:

- the biochemical requirement for initial aerobic reactions (ammonification and nitrification), followed by anoxic denitrification, likely in two separate filters;
- a first stage unsaturated media filter allowing air ingress without aeration pumps;
- first stage filter to achieve target effluent ammonia and organic nitrogen level;
- second stage saturated denitrification filter with reactive solid phase electron donor and possible alkalinity source;
- second stage design to achieve desired effluent oxidized nitrogen level;
- provide adequate head for passive media filtration, enabled by only one effluent dosing pump;
- preferred alternative considered dosing pump to first stage unsaturated (aerobic) filter that enables timed pressure dosing and uniform effluent distribution;
- possible recirculation around first stage (unsaturated) filter;
- management of any residual materials resulting from filter media replacement, including cleaning and reapplication, land application, soil conditioner, and construction.

Literature Search Methodology

Databases and Search Engines CSA Illumina (http://www.csa.com/) and Science Direct (http://www.science-direct.com/) search engines were used to access multiple data bases, as shown in Table 2. The American Society of Agricultural and Biological Engineers (ASABE) Technical Library was queried, as ASABE has been sponsoring an on-site wastewater treatment symposium every three years. Search terms listed in Table 2 were combined using *and* operator logic in numerous configurations. In addition, Google (http://www.google.com/) and Google Scholar (http://scholar.google.com/) searches were conducted on the World Wide Web, using the same search terms listed in Table 3.

Test Centers The on-site centers listed in Table 4 were contacted regarding information on passive nitrogen removal technologies, experience, and theoretical and practical developments. Site visits were made on May 21, 2007 and October 19, 2007 to the Massachusetts Alternative Septic System Test Center on Cape Cod, MA. During these visits, it was determined that many nitrogen removal technologies were being evaluated at the test center that were subject to non-disclosure by center staff. As a result of the first visit, a memo was prepared and addressed to the test center requesting voluntary information disclosure from technology developers using the test center for evaluation of nitrogen removal technologies. A copy of the memo is included in Appendix A.

Table 1 Search Engines and Databases

CSA Illumina
Biotechnology and Bioengineering Abstracts
Environmental Sciences and Pollution Management
Environmental Engineering Abstracts
Pollution Abstracts
Science Direct (over 2000 peer reviewed journals)
Applied Science and Technology
Civil Engineering Abstracts
American Society of Agricultural and Biological Engineers (ASABE) Technical Library

Table 2 Search Terms

denitrification
wastewater
on site
nitrogen
nitrate
ammonia
nitrification
passive
septic
carbon
wood
sawdust
sulfur
organic
media
filter
filtration
solid
peat filter
recirculating filter
sand filter
coir filter
zeolite filter
soil denitrification

Table 3 On-Site Centers Contacted

Massachusetts Alternative Septic System Test Center
Rhode Island On Site Wastewater Resource Center
Deschutes County Environmental Health Division, Oregon Department of Environmental Quality (La Pine National Demonstration Project)
National Environmental Services Center
Baylor Wastewater Research Program

Personal Contacts Personal contacts were made with individuals who are involved with developing, testing, and evaluating technologies for nitrogen removal in on-site wastewater treatment systems. The individuals contacted are listed in Table 5. Valuable insights were gained through discussions and information transfer, and technical reports and information was obtained that was not otherwise available.

Table 4 Individuals Contacted

Dr. Bruce Lesikar	Texas A & M University
Dr. Robert Siegrist	Colorado School of Mines
George Loomis	University of Rhode Island
George Huefelder	Director, Massachusetts Alternative Septic System Test Center
Damann Anderson	Hazan and Sawyer, Tampa
Barbara Rich	Environmental Health Division, Dechuttes Co, Oregon
Pio Lombardo	Lombardo and Associates
Dr. Sukalyan Sengupta	University of Massachusetts-Dartmouth
Paul Hagerty	Hagerty Environmental
Wesley Brighton	Wastewater Alternatives
Dr. Martin Wanielista	University of Central Florida

Literature Search Results

Database Structure A database was constructed using EndNote software provided by Thomson Research Soft (http://www.endnote.com/). EndNote is a contemporary and fully supported standard software tool for publishing and managing bibliographies on the Windows and Macintosh® desktops. Endnote allows internal searches using keywords, and Endnote files can be exported for use in other software. The Passive Nitrogen Removal database contains 227 references, which are listed in Appendix B. The Endnote entries include keywords and abstracts for most citations, and URL addresses are provided for numerous citations. The attached CD includes numerous PDFs for cited articles, and PDFs and Word files containing descriptive and performance data for numerous citations.

Organization of Reference Electronic Files References were classified according to the nested tree file framework shown in Figure 1. The files in the attached CD are also organized according to the Figure 1 framework. The numbers in the parenthesis of Table 2 are the numbers of citations or supporting documents in each in each folder.

The overall organization includes general nitrogen removal in on-site systems, nitrification processes, denitrification processes, and drainfield modifications. Denitrification processes are classified into heterotrophic and autotrophic processes. Heterotrophic processes are subdivided into citations for general cellulosic, cellulosic sources and other carbon sources. The cellulosic folder includes several separate folders for processes of for studies for which several citations of supporting files are available. The autotrophic citations are dominated by sulfur based systems, testifying to the extensive research in this area. As an example, an internal Endnote search using the single search term *sulfur* extracted 43 entries in the Florida Passive Nitrogen Removal Study Citation List. The search terms *organic* and *carbon* each extracted a similar number of citations. The search terms *sand filter*, *peat*, and *wetland* extracted 29, 14 and 12 citations, respectively.

The assembled Citation List includes nitrification processes, including recirculation systems. A system using a recirculation pump, such as a recirculating sand filter, would not be "passive" in the sense that a one-pass flow through media filter would be "passive." In fact, some state regulatory agencies who are considering the certification of passive denitrification filters are requesting that, as part of the certification process, the provider also specify the aerobic treatment system(s) that would be acceptable to the provider as pretreatments for the denitrification filter (Loomis, 2007). If the treatment system under consideration already includes an aerobic treatment process, then addition of a passive denitrification filter could in itself provide substantially increased total nitrogen removal. The term *recirculating* extracted 26 citations from the Florida Passive Nitrogen Removal Study Citation List.

Some references appears in more than one folder in the attached CD for the reason that they cover more than one subject classification or that they have subject common to more than one area. One example is citations in the Drainfield Modification folder. The organization framework of Table 2 is used in the following section to review the individual citations.

Table 5 Organization of Citations in Electronic Files ( ) number of files

Onsite Nitrogen Removal (10)

Aerobic Unsaturated Filters (Unsaturated)

- Recirculating Sand Filters (6)
- Peat Biofilters (9)
- Open Cell Foam Biofilters (2)
- Textile Biofilters (2)
- Coir Biofilters (4)
- Zeolite Biofilters (2)
- Tire Chip (1)

Anoxic Filters (Saturated)

- Heterotrophic Processes
    - Cellulosics (7)
    - Point (4)
    - Nitrex (5)
    - RI Systems (4)
    - La Pine Study (5)
    - Other Carbon Donors (6)
- Autotrophic Processes
    - Sulfur (38)
    - Sulfide (1)
    - Iron (1)
- Heterotrophic/Autotrophic Processes (3)

Drainfield Modifications (10)

- Point (4)
- Black & Gold (1)

Multi Soil Layers (5)

Soil Denitrification (1)

Review of Passive Nitrogen Removal

Technologies with potential for application in passive on-site nitrogen removal systems are discussed here. Results of field and laboratory performance evaluations and experiments are summarized in Appendix C, *Passive Nitrogen Technology*. Nitrogen in STE occurs in reduced form as organic nitrogen or ammonia. Total nitrogen removal requires aerobic nitrification as a first biochemical reaction followed by denitrification. These must occur within process tanks, in natural systems, or within soil treatment units (drainfields) modified for enhanced nitrogen removal. The complete citation list for the literature review is contained in Appendix B and in the Endnote file that is an integral part of this report. In this section, tables are presented which contain the number designations for citations that refer to the citation list in Appendix B.

Unit Operations

As a biochemical necessity, ammonification and nitrification is required prior to passive denitrification filters. Removal efficiency and effluent concentrations of organic nitrogen and ammonia are of great concern in the initial aerobic stage, as well as the aerobic effluent water quality that could affect operation of the anoxic denitrification filter. Passive denitrification filters operate with lower dissolved oxygen or under completely anoxic conditions, and are limited in their ability to remove reduced nitrogen (i.e. organic and ammonia nitrogen). Initial treatment units that promote nitrification may also denitrify and reduce total nitrogen, and recirculation around the first stage (as in recirculating sand filters for example) can increase total nitrogen removal and lower the nitrate loading on subsequent passive denitrification filters. Recirculation around the aerobic treatment filter also restores alkalinity. In a single pass aerobic system, nitrification could result in a decline in pH due to alkalinity consumption. Inhibition of nitrification at lower pH could result in a deterioration in ammonia removal performance. The increasing emphasis on domestic water conservation could result in higher total nitrogen (TN) levels in septic tank effluent and increases in the TN/alkalinity ratio. The potential for inhibition of nitrification could be increased with water conservation.

Factors that influence the selection of a passive nitrogen removal technology include the water quality characteristics of STE, target effluent nitrogen levels, and the desired treatment reliability. It should be realized that there may be limitations on the concept of a completely passive treatment system for removal of Total Nitrogen from onsite wastewater. For example, an inverse relationship may exist between nitrogen removal effectiveness and treatment system passivity. This relationship is not strongly defined. The literature review was conducted to examine currently employed and possibly new approaches to passive nitrogen removal, and to identify technologies and combinations of systems that could be used.

Aerobic (Unsaturated) Filters

Prominent nitrification processes include intermittent and recirculating sand filters, peat filters, textile filters, and filters with other media. These systems are summarized in Table 6. All systems contain porous media through which wastewater flows downward as a trickle flow over media surfaces. Oxygen is supplied by ingress of air through pore spaces in the media. All systems are capable of substantial reductions of organic nitrogen and ammonia. A feature common to many unsaturated filters is enhancement of total nitrogen reduction by recirculation, which provides pre-denitrification using organic matter in the wastewater as the carbon source/electron donor. Summaries of unsaturated filter technologies have been presented in Jantrania and Gross (2006), Leverenz et al. (2002) and Crites and Tchobanoglous (1998).

Recirculating sand filters (RSF) are capable of achieving ammonia removals of 98% and Total N removals of 40 to over 70% (Kaintz et al., 2004; Louden et al., 2004; Piluk and Peters, 1994; Richardson et al., 2004;). Effluent ammonia levels of 3 mg/L or less can be achieved (Urynowicz et al., 2007). Low temperatures have been suggested to adversely affect RSF ammonia removal performance, but adverse temperature effects should be of limited significance in the Florida climate. Peat filters can achieve ammonia nitrogen removal efficiencies of 96% or greater from septic tank effluent, with effluent NH_3-N in some cases of 1 mg/L or less (Lacasse, 2001; Lindbo and MacConnell, 2001; Loomis et al., 2004; Patterson, 2004; Rich, 2007). TN reductions of 29 to 41% have been reported in modular recirculating peat filters (Monson Geerts et al., 2001a); 44% in peat filters using pressurized dosing (Patterson et al., 2004); and 15 and 21% in two single pass modular peat filters. Recirculating textile filters achieved 44 to 47% TN reduction (Loomis et al., 2004) from septic tank effluent. In some cases, textile filters treating septic tank effluent have produced effluents with NH_3-N levels of less than 1 mg/L (Rich, 2007). Textile filters also produce nitrified effluents (McCarthy, et al., 2001; Rich, 2007; Wren et al. 2004) and are often operated at higher hydraulic loading rates (Table 6). The Waterloo Biofilter is a proprietary treatment system that has been demonstrated to reduce septic tank effluent TN by 62% while also providing over 90% ammonia N removal (132). Aerocell is another open cell foam media filter that operated with recycles and achieves 77% total nitrogen removal (Table 6). Tire crumb or tire chip has been employed as a substitute for gravel in disposal trenches, and has been summarized by Grimes et al (2003).

Table 6 Summary of Unsaturated Aerobic Media Filters

System Type	Description	Features	Typical Performance Range	Citations (Refer to Appendix B)
Intermittent sand filters	Sand filter Single pass	0.3 to 0.7 mm media 18 to 36 in. depth 0.7 to 1.5 gal/ft^2-day 12 to 48 dose/day	TN Removal: 20 to 50% Effluent: 20 to 20 mg/L NH_3-N Effluent: 1.9 to 9 mg/L	10,12,28,41,49, 58,64,71,88,94,111,134,169
Recirculating sand filters	Sand filter Recirculation	1.5 to 3 mm media 18 to 36 in. depth 3 to 5 gal/ft^2-day 40 to 120 dose/day	TN Removal: 40 to 75% Effluent: 15 to 30 mg/L NH_3-N Effluent: 1 to 5 mg/L	20,24,33,40,41,53, 56,84,88,89,94,111,118,130,131,142, 153,159,166,199, 210,209
Textile biofilters	Textile filter Recirculation	2 to 3 in. cubes 36 to 72 in. depth 8 to 17 gal/ft^2-day 80 to 140 dose/day	TN Removal: 20 to 60% Effluent: 10 to 60 mg/L NH_3-N Effluent: 1.7 to 5.9 NO_3-N Effluent: 11 mg/L	47,84,88,111,117, 123,158,218
Peat biofilters	Peat media filter Single pass or recirculation	246 to 36 in. depth 3 to 6 gal/ft^2-day 12 to 120 dose/day	TN Removal: 10 to 75% Effluent: 10 to 60 mg/L TKN Removal: 90 to 95% NH_3-N Effluent: 1 mg/L NO_3-N Effluent: 20 to 50	20,47,56,84,88,108,117,123,124,126, 127,147-149,158, 163,199,216

Table 6 Summary of Unsaturated Aerobic Media Filters (Continued)

System Type	Description	Features	Treatment Performance	Citations (Refer to Appendix B)
Waterloo biofilter	Open cell foam media, single pass or recirculation	3 to 4 in. cube media 48 in. depth 11 gal/ft^2-day	TN Removal: 62% Effluent: 14 mg/L NH_3-N Effluent: 2.4 mg/L NO_3-N Effluent: 10 mg/L	135
Zeolite biofilters	Zeolite media filter	20 to 30 in. depth 6.1 gal/ft^2-day	NH_3-N Removal: 98.6% Influent: 70 mg/L Effluent: 1 mg/L NO_3-N Effluent: 57 mg/L	151
Coir biofilters	Coir filter bed, with recirculation	Coconut coir media 18 gal/ft^2-day 5.88 gal/ft^3-day	TN Removal: 55% Influent: 38 mg/L Effluent: 17 mg/L TKN Removal: 83% Influent: 38 mg/L Effluent: 6.5 mg/L	137,180,181,196
Aerocell biofilter	Open cell foam media filter, with recirculation	2 in. cube media 18 gal/ft^2-day 5.88 gal/ft^3-day	TN Removal: 77 % Influent: 40 mg/L Effluent: 9.3 mg/L TKN Removal: 87% Influent: 40 mg/L Effluent: 5.4 mg/L	136

As a group, nitrification processes are reasonably well developed technologies. Synthetic media generally have lower footprints and higher areal hydraulic loading rates that traditional sand filters. Issues involved include the use and need for recirculation, effluent levels of organic and ammonia N achievable, and reliability of performance. With some media, recirculation may be more important to maintaining a given level of ammonia removal, which may be related to oxygen ingress into the site of action of attached nitrifying microorganisms. A rational basis for comparison of aerobic media could potentially be developed using the effective media surface area within the filter bed, as perhaps modified by factors effecting oxygen ingress and by recirculation. The overriding requirement for the aerobic treatment performance is to produce low effluent levels of organic N and ammonia N prior to treatment in anoxic reactive media filters.

Factors affecting performance of unsaturated aerobic media filters are listed in Table 7. The hydraulic loading rate and loading rates of organics and nitrogen are important operating characteristics, particularly as they relate to the functioning of the physical and biological processes within the media. Key factors for successful treatment in an unsaturated media filter are surface area for attachment of microorganisms and for sorption of colloidal constituents in the wastewater, the need for sufficient pore space for assimilation of solids materials and their biodegradation between doses, the water retention capacity of the media, and the pore space that is available for aeration. The characteristics of media that influence performance of unsaturated filters are listed in Table 8. The performance of any unsaturated media filter is determined by the interactions of media characteristics (Table 8) with system parameters (Table 7). A significant interaction that occurs between the media and the system is the water retention capacity of media versus the hydraulic application rate. High water retention capacity is desirable to retain wastewater within the filter and achieve low effluent levels. The water retention capacity of media must exceed the hydraulic application rate per dose to prevent rapid movement of applied wastewater through the filter. More frequent doses (lower volume per dose), coupled with high water retention media, represent the most favorable combination.

Another highly critical factor to optimum functioning of unsaturated media filters is the aeration pore space. Unsaturated media filters are four phase systems: solid media, attached microbial film, percolating wastewater, and gas phase. The total porosity (excluding internal pore spaces within the media) must be shared between attached biofilm, percolating water, and gas phase. A media with a high total porosity will more likely allow sufficient oxygen transfer throughout the filter bed, providing more effective utilization of the total media surface area for aerobic treatment. If media size becomes too small, a larger fraction of the pores may remain saturated and become inaccessible to oxygen transfer. For example, sand with a total porosity of 38% could have an aeration porosity of only 2.5% of the total media volume, depending on sand size and the hydraulic application rate. Such conditions could decrease nitrification effectiveness and perhaps also increase denitrification within microzones with limited contact with the

Table 7 Factors Influencing Performance of Unsaturated Aerobic Filters

Feature	Effect
Hydraulic loading rate	Higher rates lower water retention time and treatment
Organic loading rate	Higher loading rates increase rate at which biofilms must process organic matter; nitrification may be inhibited of too high
Nitrogen loading rate	Higher loading rates require higher nitrification rates and higher oxygen utilization rates
Media depth	Deeper beds can give better treatment; uppers layers often more reactive
Specific surface area	Higher values give greater attachment surfaces for microorganisms
Superficial velocity	Effects mass transfer between wastewater and biofilms
Average linear velocity	Effects mass transfer between wastewater and biofilms
Hydraulic application rate per dose	Volume per dose should be scaled to field capacity of media
Organic loading rate per dose	Loading per dose must not exceed processing rate
Nitrogen loading rate per dose	Loading per dose must not exceed processing rate
Average water residence time	Longer residence time gives more time for biochemical reactions and better treatment
Uniformity of Dosing	Promotes full utilization of all elements of the filter media
Wastewater	
Suspended solids	Accumulated within pores, may lead to clogging if not biodegraded
BOD	High values require more room for attached growth and metabolism between doses, particularly in upper filter layers
Organic and ammonia nitrogen	Significant component of total oxygen supply requirement
Alkalinity	Consumed by nitrification and restored by heterotrophic denitrification; adequate supply needed to prevent pH decline by nitrification

Table 8 Media Characteristics Influencing Performance of Filters

Feature	Effect
Particle size distribution	Larger particles less subject to clogging Smaller particles have greater surface area per volume for treatment
Uniformity coefficient	Effects flow uniformity
Specific surface area	Higher values give greater attachment surfaces for microorganisms
Air filled porosity	Oxygen supply throughout media depth for BOD oxidation and nitrification in unsaturated filters
Water retention capacity	Higher water retention in unsaturated media filters provides longer time of contact of water with microorganisms and better treatment; affected by intrinsic porosity that favors capillary water retention
Sinuosity and tortuosity	Affect accessibility of pore spaces to exchange of wastewater and air
Specific weight	Effects compression strength required for support in multi media filters
Ion exchange capacity	Ammonia adsorption may improve performance
Compressibility	Effects material resistance to compression when wetted with biofilm and attached solids
Biodegradation	Biodegradation of organic media will limit longevity
Resilience	Prevents compaction under deployment
Hydrophilicity	Attracts water for wetting and rewetting

gas phase. Denitrification within an unsaturated filter would improve total nitrogen removal but could result in less efficient nitrification and higher effluent ammonia concentrations. By contrast, media with high total porosity would be more likely to have a sufficiently high aeration porosity to allow effective utilization of all media surface area and better ammonia removal performance. If the goal is to achieve total nitrogen removal in an overall system containing an unsaturated filter followed by an anoxic, reactive media denitrification filter, then the goal of low effluent ammonia should take precedence over denitrification in the unsaturated first stage filter. An example media with high total porosity and high water retention capability is sphagnum peat moss. The total porosity of sphagnum peat is greater than 85%, and percolating water might occupy two thirds of this available pores. Under these conditions, pore space available for aeration would be over 25% of the total volume of the filter bed. The very low effluent ammonia levels that peat filters appear capable of producing may be related to these factors.

Media with significant ion exchange capacity may offer a method to superior removal of ammonia nitrogen in flowing systems (Philip and Vasel, 2006; Smith, 2006). Zeolite media are excellent surface for biofilm attachment, and have relatively high porosities. Sorption of ammonium ions onto zeolite media can sequester ammonium ions from the water and provide enhanced contact with attached nitrifying organisms under steady flow conditions. Sorption also provides a buffer when loading rates are high or other factors inhibit nitrifier activity, resulting in increased resiliency of the treatment process. Ammonia ion exchange adsorption onto zeolites is reversible, and microorganisms can biologically regenerate the zeolite media in periods of lower loading. A zeolite filter for onsite wastewater treatment removed 98.6% of ammonia and produced an effluent ammonia nitrogen concentration of 1 mg/L when operated at 6.1 gal/ft^2-day (Philip and Vasel, 2006). Other bench scale and pilot studies have demonstrated the ability of zeolite filters to maintain high ammonia removal under high non-steady loadings of ammonia nitrogen (Smith, 2006).

Coconut coir is a natural, renewable material that is a waste product from coconut production. Coir has many of the same properties of peat that make it a desirable treatment media, including high surface area, high water retention, and high porosity (Talbot, 2006), and has been successfully used as a planting media in greenhouses. While most coir is produced in Asia, Florida contains abundant coconut palm trees that could potentially provide a sustainable material source. A onsite wastewater treatment system using coconut coir has been reported (Sherman, 2006: Sherman, 2007). Synthetic fiber materials could have many of the same advantages as a media as coir.

Candidate media for the unsaturated media filter should possess many of the desirable characteristics that have been discussed above. Zeolite filters also have promise for unsaturated flow filters for passive systems. The interaction of cation exchange media with microbial reactions appears to offer potential for passive treatment with enhanced performance. Other candidate media include expanded clays, expanded shales, and tire crumb.

Anoxic (Saturated) Filters

Anoxic saturated media filters form a second stage in the passive nitrogen removal system. The anoxic filters contain a "reactive" media that provide a slowly dissolving source of electron donor for reduction of nitrate and nitrite by microbial denitrification. Denitrifying microorganisms grow predominantly attached to the media surfaces. Water flows by advection through the media pores, where the oxidized nitrogen species is consumed by attached microorganisms. Water saturation of the pores prevents ingress of oxygen, which could interfere with nitrate reduction. Factors influencing the performance of anoxic denitrification filters are listed in Table 9. Hydraulic and nitrogen loading rates, surface area of media, pore size, and flow characteristics within the reactor are important considerations. The media is consumed by dissolution, and this process must be sufficiently rapid to supply electron equivalents for nitrate reduction and other possible reactions. On the other hand, rapid dissolution would reduce the longevity of the media. Too rapid a dissolution rate could also lead to the presence of excess dissolution products in the effluent (BOD for wood-based filters; sulfate for sulfur based filters). An aerobic process effluent low in BOD and suspended solids would be less likely to lead to channeling within the anoxic filter. Geometry of the column could affect flow patterns and potential channeling; the later effects could be overcome by use of larger systems. The effects of flow channeling on performance deterioration could require maintenance or media replacement at time scales appreciably shorter than longevities based on theoretical stoichiometric requirements of electron donor for denitrification. A summary of performance of passive anoxic denitrification filters is shown in Table 10.

Heterotrophic Denitrification Passive heterotrophic denitrification systems use solid phase carbon sources including woodchips (Cooke et al., 2001; Greenan et al., 2006; Jaynes et al., 2002; Kim et al., 2003; Robertson et al., 2000; Robertson and Cherry, 1995; Robertson et al., 2005; van Driel et al., 2006), sawdust (Eljamal et al., 2007; Greenan et al., 2006; Jin et al., 2006; Kim et al., 2003; van Driel et al., 2006), cardboard (Greenan et al., 2006), paper (Jin et al., 2006; Kim et al., 2003), and agricultural residues (Cooke et al., 2001; Greenan et al., 2006; Jin et al., 2006; Kim et al., 2003; Ovez, 2006; a, 2006b). Limited studies have also been conducted using other carbon sources such as cotton (Della Roca et al., 2005), poly(e-caprolactone) (Horiba et al., 2005), and bacterial polyesters (Mergaert et al., 2001). Cellulosic-based systems using wood are the most developed heterotrophic denitrification filter technology. The Nitrex process uses a proprietary media containing woodchips and other materials (EPA, 2007; NSF, 2003; Lombardo, 2005; Robertson et al., 2000; Robertson and Cherry, 1995; Robertson et al., 2005). Several Nitrex demonstration studies have been conducted, which have followed sand or peat filters, and some have operated for greater than two years (Lombardo, 2005). Combined RSF/Nitrex systems have

Table 9 Factors Influencing Performance of Saturated Anoxic Filters

Feature	Effect
Hydraulic loading rate	Higher rates lower water retention time and treatment
Organic loading rate	Higher loading rates increase rate at which heterotrophic biomass could accumulate
Solids loading rate	Higher loading rates increase rate at which solids could accumulate
Nitrogen loading rate	Higher loading rates require higher denitrification rates and higher rates of electron donor dissolution
Media depth	Deeper beds can give better treatment; uppers layers often more reactive
Specific surface area	Higher values give greater surface area for attachment of microorganisms and dissolution of media
Superficial velocity	Effects mass transfer between wastewater and biofilms
Average linear velocity	Effects mass transfer between wastewater and biofilms
Average water residence time	Longer residence time gives more time for biochemical reactions and better treatment
Wastewater	
Suspended solids	Accumulated within pores, may lead to preferential flow if not biodegraded
BOD	Will create more heterotrophic biomass and may increase potential for preferential flow
Nitrate nitrogen	High loadings require greater surface areas and higher levels of denitrifying activity
Alkalinity	Consumed by autotrophic denitrification; must be balanced by sum of influent alkalinity and alkalinity provided by solid source

Table 10 Summary of Saturated Anoxic Media Filters

System Type	Description	Features	Treatment Performance	Citations (Refer to Appendix B)
Sulfur/oyster shell filter (bench scale)	1 liter bench column synthetic wastewater upflow single pass	Sulphur/oyster shell media (75/25% by volume) Sulphur: 4.7 mm	**anoxic only** NO_3-N Removal: 80% Influent: 50 mg/L Effluent: 10 mg/L	173
Sulfur/oyster shell filter	185 gal. column aerobic effluent upflow single pass	Sulphur/oyster shell media (75/25% by volume) 47 gal/ft^2-day	**anoxic only** TN Removal: 82% Effluent: 4.2 mg/L NO_3-N Removal: 88% Influent: 20 mg/L Effluent: 2.4 mg/L	23
Sulfur/limestone column	237 gal. column groundwater upflow single pass Residence time: 13 hr.	Sulphur/limestone media (67/33% by volume) 63 gal/ft^2-day Sulfur: 2.5 to 3.0 mm Limestone: 2.38 to 4.76 mm	**anoxic only** NO_3-N Removal: 96% Influent: 64 mg/L Effluent: 2.4 mg/L NO_2-N Effluent: 0.2 mg/L	46

Table 10 Summary of Saturated Anoxic Media Filters (Continued)

System Type	Description	Features	Treatment Performance	Citations (Refer to Appendix B)
Nitrex™	aerobic effluent gravity flow upflow single pass	Nitrex wood-based media 24 to 30 inch media depth (est.) 4.6 gal/ft^2-day (est.)	**aerobic+anoxic** TN Removal: 79 to 96% Effluent: 3 to 18 mg/L NO_3-N Effluent: 0.3 to 8 mg/L	54,62,114,116, 158,160,162,203
Black& Gold™	wood-based media single pass downflow gravity	Influent: STE 280 gal. column Sand/tire crumb/woodchip (85/11/5% by volume) 8.3 gal/ft^2-day	**aerobic+anoxic** TN Removal: 98% Influent: 414 mg/L Effluent: 7.1 mg/L NH_3-N Effluent: 4.4 mg/L NO_3-N Effluent: 0.05 mg/L	176

produced average TN removals of 88 to 99% from septic tank effluent, with average effluent NO_3-N concentrations of 1 to 2 mg/L. In another study, a subsurface leaching chamber was installed beneath an active parking lot for on-site sewage treatment, using sawdust as carbon source (St. Marseille and Anderson, 2002). At a loading of 1.22 gallons/ft^2-day; the effluent NO_3-N averaged 0.6 mg/L. Other heterotrophic denitrification systems have been successfully tested at laboratory scale.

Factors that affect the long term success of carbon-based denitrification filters include the long term availability of carbon supply for the wastestream being treated and the physical structure of the biodegradable components of the media. As for any packed bed, biologically active media filter which is deployed over extended periods of time, the long term hydraulics of the unit are a possible issue. Accumulation of biological and inorganic solids could lead over time to the development of preferential flow paths within the filter, reducing average residence time and wastewater contact with the media. The result of flow short circuiting would be performance deterioration. The practical aspects of media replacement and management/disposal must be considered, in light of the frequency with which media must be supplemented or replaced. Another factor is the release of soluble biodegradable carbon as water passes through the filter, which could increase biochemical oxygen demand (BOD) and chemical oxygen demand (COD). It is possible that this material would be readily consumed within tens of feet of release in a groundwater plume, or within a solid treatment unit receiving the effluent of the carbon-based denitrification filter.

Autotrophic Denitrification The autotrophic denitrification systems that have received the most attention are elemental sulfur-based media filters, which are under development. Sulfur-based denitrification filters have employed limestone or oyster shell as a solid phase alkalinity source to buffer the alkalinity consumption of the sulfur-based biochemical denitrification (Brighton, 2007; Darbi et al., 2003a, 2003b; Flere and Zhang, 1998; Kim et al., 2003; Koenig and Liu, 2002; Nugroho et al., 2002; Sengupta and Ergas, 2006; Sengupta et al. 2007; Sengupta et al., 2006; Shan and Zhang, 1998; Zeng and Zhang, 2005; Zhang, 2002; Zhang, 2004).

A pilot scale filter containing elemental sulfur and oyster shell at a 3:1 ratio was operated for 11 months at the Massachusetts Alternative Septic System Test Center (Brighton, 2007). The filter received the effluent from a Clean Solution aerobic treatment system that was receiving septic tank effluent. TN was reduced 82% through the sulfur/oyster shell filter, while the aerobic/sulfur filter system removed 89.5% TN from the septic tank effluent. A pilot scale elemental sulfur/limestone column was operated for 6 months on a well water containing 65 mg/L NO_3-N; nitrate removal averaged 96% and average effluent NO_3-N was 2.4 mg/L (Darbi et al., 2003a). A laboratory sulfur/oyster shell column was operated at an Empty Bed Contact Time of 0.33 to 0.67 days and removed 80% of influent nitrate (Sengupta and Ergas, 2006; Sengupta et al., 2006).

Some factors that affect the long term performance success of autotrophic denitrification filters are similar to those for carbon-based denitrification filters. They include the long term availability of electron donor supply for the wastestream being treated, and the physical structure of the biodegradable components of the media. Versus wood based organics electron donors, elemental sulfur could possibly remain physically intact for longer time periods. As for any packed bed, biologically active media filter deployed over extended periods of time, the long term hydraulics of the unit are a concern. Accumulation of biological and inorganic solids could lead over time to the development of preferential flow paths within the filter, reducing average residence time and wastewater contact with the media. To the extent that these processes occur, deterioration of performance could result. The timescales of media replacement, maintenance and supplementation and the practical aspects of these activities must be considered. Another factor is the release of sulfate as water passes through the filter, and possible odors through hydrogen sulfide generation.

Several candidate media can be suggested for the saturated media filter which forms the second stage of a passive onsite nitrogen removal system for Florida. Media should possess many of the desirable characteristics that have been previously discussed. Both elemental sulfur and wood based treatment systems are readily available and economical candidates. Crushed oyster shell is readily available. These alkalinity sources could also be used in a single pass, unsaturated first stage filter if nitrification would otherwise be inhibited. The interaction of cation exchange media with microbial reactions appears to offer potential for passive treatment with enhanced performance. Expanded shales with anion exchange capacity are commercially available and could be used in mixed media to increase the resiliency and performance of second stage anoxic denitrification filters.

Drainfield Modifications

Modifications to drainfields entail the in-situ addition of a permeable media that supports denitrification through the release of carbon or electron donor. Wastewater (septic tank effluent) would initially pass through an unsaturated layer or zone (of sand for example), where nitrification occurs. Following passage through the unsaturated zone, the wastewater would pass through a permeable denitrification layer or zone. Denitrification media could be placed as an underlayment beneath the unsaturated soil, or as a subdivided treatment zone within a drainfield through which effluent from the aerobic zone must pass.

A modified drainfield design using a sulfur/limestone layer beneath a sand layer provided greater than 95% TN removal in laboratory scale columns receiving primary effluent from a municipal wastewater treatment plant (Shan, 1998). Nitrification occurred in the upper sand layer, and the lower denitrification layer was not maintained in a saturated condition.

A wood based system using a mixture of sand, wood chips, and tire crumb (85/11/4% by mass), was examined in bench scale columns to simulate treatment that would occur in a separate reactive media treatment zone established within a drainfield (Shah, 2007). In this system, septic tank effluent would first pass through an unsaturated sand layer, and then through the treatment zone containing the reactive media. Laboratory column experiments with septic tank effluent supplied at a hydraulic residence time of 24 hours resulted in 98% TN removal. Average effluent ammonia and nitrate nitrogen concentrations were 4.4 and 0.05 mg/L, respectively.

Other studies, conducted in the laboratory for the most part, have demonstrated an increase in total nitrogen removal using modified drainfield designs with carbon substrates (usually wood chips or sawdust) or inorganic electron donors (elemental sulfur). The general concepts are similar to the drainfield modifications presented above. Issues of concern for modified drainfields include media longevity, replacement intervals, and hydraulic issues related to preferential flow paths. Replacement of in-situ denitrification media could require disturbing or removing the entire drainfield, so the life of the reactive media in the denitrification zone would need to be at least as long as the other drainfield components. The consequences of uncertainty in the life of an in-situ denitrification zone located within a drainfield could be relatively more significant than for an in-tank denitrification filter, where media replacement would not require disruption of other treatment system components. Another issue of possible concern is the ability to definitively monitor in-situ nitrogen removal in subsurface locations.

Denitrification in Soil

Biological denitrification is a complex process that requires mineralization and nitrification the nitrogen before denitrification can occur. With the decay of organic matter, nitrogen is released into the environment as organic nitrogen (principally proteins and urea). Bacteria and fungi in the soil quickly "mineralize" the organic nitrogen by converting it to ammonium. The ammonium is nitrified by autotrophic bacteria, which use carbon dioxide for their carbon source instead of organic carbon. These bacteria are obligate aerobes that require an aerobic environment because oxygen is used as the final electron acceptor. Since hydrogen ions are created by this reaction, which can lower the pH to levels that inhibit the biological process, it is essential that sufficient alkalinity be available to buffer the soil solution so that nitrification can be complete. After nitrification, heterotrophic bacteria are able to convert the nitrate to gaseous nitrogen and NO_X as they oxidize available organic matter. However, for this conversion, an anoxic or anaerobic environment is required since the oxygen associated with the nitrate is used as the final electron acceptor in oxidizing the organic matter. If either anoxic conditions or organic carbon are not available, denitrification does not proceed via this pathway. Other pathways exist, but they are far less prevalent.

The heterotrophic bacterial process models were used to define the mechanisms and the necessary conditions for biological denitrification to occur. By understanding these, the literature could be reviewed for the occurrence of the requisite conditions in soils from which the potential for nitrogen removal could be estimated. The most critical conditions for which data are available were selected to investigate. These included the soil's internal drainage, depth to saturated conditions, and the availability of organic materials. Internal drainage provides a measure of the soil's permeability and the extent of time that it may be unsaturated. Unsaturated conditions are necessary to aerate the soil to allow the autotrophs to nitrify the ammonium nitrogen. The shallower the depth to the water table, the more likelihood organic matter will be leached to where the soil moisture is high enough to restrict soil reaeration to the point that aerobic organic matter decomposition is inhibited preserving the carbon for heterotrophic denitrification. The availability of organic carbon determines the occurrence and extent of denitrification that will occur.

Gable and Fox (2000) and Woods et al. (1999) suspect that the Anammox process could explain why nitrogen removal below large soil aquifer treatment systems (SAT) exceeds what can be attributed to heterotrophic nitrogen removal alone because the organic carbon to nitrogen ratio is typically too low to sustain heterotrophic denitrification. Crites (1985) reports that denitrification below seven large scale SAT systems in the US were observed to achieve total nitrogen removals of 38 to 93%. While Anammox quite likely could contribute substantially to the reduction of nitrogen below OWTS, little is known about the conditions under which it is likely to occur. Until the process requirements are better understood, detection of denitrification via the Anammox process would requires actual monitoring data where the nitrogen reduction by the heterotrophic processes can be separated out. Such data were not available so the estimates of nitrogen removal below OWTS reported in this study may under estimate the actual removals.

The extent to which denitrification occurs in soils varies depending on the specific environmental conditions at the particular site, and the design and operation of the OWTS. Numerous investigations into the fate of nitrogen below soil infiltration zones have been undertaken. However, the results are quite variable even for sites that appear similar. Gold and Sims (2000) point out that the dynamic and open nature of soil water infiltration designs results in uncertainties with in-situ studies of the fate of nitrogen in soil. The effects of dispersion, dilution, spatial variability in soil properties, wastewater infiltration rates, inability to identify a plume, uncertainty of whether the upstream and downstream monitoring locations are in the same flow path, and temperature impacts are a few of the problems that challenge the in-situ studies. As a result, even when small differences in concentrations are observed, the spatial and temporal variability can result in large changes in estimates of the mass loss of nitrogen.

Several investigators have performed rather thorough reviews of the fate of nitrogen below soil water infiltration systems. Siegrist and Jennsen (1989) reviewed national and international literature for both laboratory and field studies of nitrogen removal for soil infiltration. Laboratory studies using soil columns showed removals of TN from less than 1 to 84 percent. Hydraulic loadings varied from 5 to 215 cm/day and influent TN concentrations from 16 to 74 mg/L. The field studies were performed on systems installed in sands. As in the case of most field studies, influent flows and TN concentrations were not always accurately known. Estimates of TN removal in these studies ranged from 0 to 94 percent. The investigators noted that high TN removals have been observed but that reasonably comparable studies showed limited removals. Based on their review, they provided a table of what they thought were "achievable nitrogen removal efficiencies" below soil water infiltration zones (Table 11).

Table 11. Total Nitrogen Removals below Soil Infiltration Zones
(after Siegrist & Jennsen, 1989)

Soil Water Infiltration Type	Achievable N Removals	
	Typical	Range
Traditional In-Ground	20%	10 – 40%
Mound/Fill	25%	15 – 60%
Systems with Cyclic Loading	50%	30 – 80%

Long (1995) reviewed studies of nitrogen transformations in OWTS to develop a methodology for predicting OWTS nitrogen loadings to the environment. Long also found that in-situ studies were confounded with many known and unknown variables that made data interpretation complicated. His review of the data indicated that soil treatment removes between 23 to 100% of the nitrogen. He correlated greater removals with finer grained soils because anoxic conditions would be achieved more frequently, which also would help to preserve available organic carbon for denitrification. Using this correlation, he estimated TN removals as shown in Table 12.

In a study investigating the effects of effluent type, effluent loading rate, dosing interval, and temperature on denitrification under soil water infiltration zones, Degen, et al. (1991) and Stolt and Reneau, Jr., (1991) reviewed published results of other studies that measured denitrification in OWTS. They found denitrification removals varied substantially depending on the type of pretreatment and the design of the soil water infiltration system (Table 13).

Table 12. Estimates of TN Removal Based on Soil Texture (Long, 1995)

Soil Texture	Estimated TN Removal	Comments
Coarse grained sands	23%	Soils promote rapid carbon and nitrogen oxidation leaving insufficient carbon for denitrification. If anoxic conditions and a source of carbon is available, such as a high or fluctuating water table, TN removal would increase.
Medium grained sands	40%	Soils restrict gas transfer during bulk liquid flow periods to create anoxic conditions.
Fine grained sands	60%	Soils restrict gas transfer for longer periods after bulk flow periods
Silt or clay	70%	Soils further restrict gas transfer and retain nutrients higher in the soil profile.

The more significant environmental factors that determine whether nitrogen removal occurs and to what extent include the soil's texture, structure, and mineralogy, soil drainage and wetness, depth to a saturated zone and the degree to which it fluctuates, and amount of available organic carbon present. OWTS design and operation factors include the species of nitrogen discharged to the soil infiltration zone, the depth and geometry of the infiltrative surface, the daily hydraulic loading and its method of application, whether it is dosed and, if so its frequency.

Soil drainage class has been found to be a good indicator of a soil' capacity to remove nitrogen (Gold, et al., 1999). The Natural Resources Conservation Service (NRCS) uses seven drainage classes to describe the "quality" of the soil that allows the downward flow of excess water through it (USDA, 1962). The classes reflect the frequency and duration

Table 13. Total Nitrogen Removal Found in Various Studies of OWTS

System Type	TN Removal	Source
Traditional	0-35%	Ritter & Eastburn (1988)
Sand filter	71-97%	Wert & Paeth (1985)
Low Pressure Dosing Shallow	46%	Brown & Thomas (1978)
Low Pressure Dosing At-Grade	98%	Stewart & Reneau, Jr. (1988)
Mound	44-86%	Harkin, et al. (1979)

Table 14. NRCS Drainage Classes and Descriptions

Drainage Class	Description
Excessively drained	Water is removed from the soil very rapidly. The soils are very porous. These soils tend to be droughty.
Somewhat excessively drained	Water is removed from the soils rapidly. The soils are sandy and very porous. These soils tend to be droughty but can support some agricultural crops without irrigation.
Well drained	Water is removed from the soil readily but not rapidly. The soils are commonly intermediate in texture and retain optimum amounts of moisture for plant growth after rains.
Moderately well drained	Water is removed from the soil somewhat poorly so that the profile is wet for a small but significant period of time. The soils commonly have a slowly permeable layer within or immediately beneath the solum and/or a shallow water table.
Somewhat poorly drained	Water is removed from the soil slowly enough to keep it wet for significant periods of time. These soils commonly have a slowly permeable layer within the profile and/or a shallow water table. The growth of crops is restricted to a marked degree unless artificial drainage is provided.
Poorly drained	Water is removed so slowly that the soil remains wet for a large part of the time. The water table is commonly at or near the soil surface for a considerable part of the year. They tend to be mucky.
Very poorly drained	Water is removed from the soil so slowly that the water table remains at or on the surface the greater part of the year. They commonly have mucky surfaces.

of periods of soil saturation with water, which are determined in part, by the texture, structure, underlying layers, and elevation of the water table in relation to the addition of water to the soil. Table 14 provides a brief description of each of the classes.

Poorly drained and very poorly drained soils can have a high capacity for nitrogen removal because the saturated zone is shallow, carbon enriched and anoxic while moderately well and well drained soils have a very limited capacity (Groffman et al., 1992; Hanson et al., 1994a, 1994b; Nelson et al., 1995; Parkin and Meisinger, 1989; Simmons et al., 1992). Moderately to well drained groundwater typically flows deeper within the subsoil and does not intersect the reduced and organic enriched surface horizons. Expected impacts of soil groups on denitrification are given in Table 15.

Heterotrophic bacterial denitrification is often limited by organic matter (Bradley, et al., 1992; Burford and Bremner, 1975; Christensen, et al., 1990; Gambrell, R.P., et al., 1975). The organic carbon is necessary as an energy source for bacterial metabolism. Sources of organic matter in soil are either natural, which is continuously replenished in the soil from the decay of vegetative materials or supplied by the wastewater itself. Studies indicate that denitrification is inhibited where the nitrate to dissolved organic carbon ratio is below 0.73 to 1.3 (Burford & Bremmer, 1975).

Table 15. Drainage Class and Expected Impacts on Denitrification

Drainage Class Group	Expected Impact on Heterotrophic Denitrification
Excessively/ Somewhat excessively	◆ Well aerated soil capable of achieving complete nitrification of applied TKN ◆ Provides little organic carbon and will likely degrade any added organic matter within the aerobic zone ◆ Short retention time
Well	◆ Sufficiently aerated soil capable of achieving complete nitrification ◆ May allow some organic matter to reach a saturated zone where it would be available for denitrification if a shallow water table is present
Moderately well	◆ Sufficiently aerated soil capable of achieving complete nitrification ◆ Denitrification would be enhanced with a fluctuating water table for a “two sludge” process or with slow drainage for a “single sludge” process
Somewhat poorly/ Poorly/ Very poorly	◆ Ample organic matter for a carbon source and to create anoxic conditions in saturated zones for significant nitrogen reduction ◆ Insufficiently aerated soil to nitrify TKN requiring nitrification of the wastewater prior to application to the soil

The amount of organic matter in the soil is greatest in the root zone and above (Paul and Zebarth, 1997; Starr and Gillham 1993). Roots regularly exude carbonaceous materials and die and decay. Much of the organic carbon is degraded in the vadose zone through natural degradation within 2-3 ft of the ground surface. Organic matter is typically very low (<1%) below about 3 ft in most soils with a deep vadose zone. There are some cases of soil horizons that are lower in the soil profile and that contains organic matter, iron and aluminum. An example is spodic soils which are common in some locations, which contain organic matter that would be available for heterotrophic denitrifiers.

Water tables or perched water saturated zones restrict reaeration of the soil. With organic matter present, the saturated zone will become anoxic or anaerobic. This will inhibit nitrification and if nitrate and organic matter are present, will support denitrification. When the air-filled porosity drops below 11 to 14% or the moisture content is greater than 60 to 75% of the soil's water holding capacity, reaeration is sufficiently restricted that anoxic conditions can result (Bremmer and Shaw, 1956; Christensen, et al., 1990; Cogger, et al., 1998; Donahue et al., 1983; Pilot and Patrick, Jr., 1972; Reneau, Jr., 1977; Singer & Munns, 1991; Tucholke et al., 2007).

If the water table is deep, little denitrification seems to occur. In soils with thick unsaturated zones, organic matter may not reach the saturated zone because it is oxidized before it can leach to the water table. Where the ground water depths exceed about one meter, denitrification is greatly reduced (Barton et al., 1999; Starr and Gillham, 1993). However, a shallow, fluctuating water table can create the conditions for simultaneous denitrification. This occurs when a seasonally high water table prevents nitrification of the ammonium, which will adsorb to negatively charged clay particles in the soil. The ammonium is held by the soil and after draining and reaerating, the ammonium is nitrified. If organic matter is present and the soil nears saturation again, the nitrate can be denitrified and the newly applied ammonium is adsorbed as before, repeating the process. Cogger, 1988; Reneau, 1977, 1979; Walker et al.,1973a).

The type of infiltration system used can affect the soil's potential for nitrogen removal. Traditional in-ground trench systems are installed with their infiltrative surfaces typically below the A horizon and thus below where organic matter can be expected to be the highest. At-grade and mound systems are typically installed above the O and A horizon thereby gaining the advantage of having a high organic layer available to create anoxic conditions with organic carbon available (Converse et al., 1999; Harkin et al., 1979). However, in Florida, the OWTS rules for mound construction require the removal of the O horizon and vegetation, which removes most of the available organic carbon. Also, "digouts", which are systems on sites where a restrictive horizon in the soil profile is removed, can result in reducing a particular soil's nitrogen removal potential because quite often the restrictive horizon removed is a spodic layer, which can have a sufficiently high organic content and be restrictive enough to create a saturated zone where anoxic conditions may be created for denitrification.

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 and pumping would not be required.

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 need for recirculation around the first filter must be considered, the point to which recirculation should be directed (i.e. a pumping tank, external recirculation tank, septic tank chamber), and the recirculation ratio (flowrate in relation to the wastewater flowrate). Recirculation can provide pre-denitrification using wastewater organics, which would lower nitrate loadings to anoxic denitrification filters. Alkalinity recovery would be an accompanying benefit which may be important in the future to prevent nitrification inhibition if water conservation efforts lead to increases the Total Nitrogen of and the TN/Alkalinity ratio in STE. Recirculation around the aerobic filter can be accommodated by using a flow splitting device on aerobic filter effluent, while still keeping within the FDOH definition of “passive.”

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.

Literature Search Conclusions and Recommendations

A review was conducted of passive technologies that enhance removal of nitrogen from on-site wastewater treatment systems. The review included searches of peer reviewed literature and conference proceedings, procuring technical reports, searches on the world wide web, discussions with vendors and national experts, and a site visit to the Massachusetts Alternative System Test Center. These efforts provided the basis for a critical assessment of the present state of technology. The following summarize the significant conclusions of this effort.

- To achieve high nitrogen removals from septic tank effluent using "passive" systems as defined by the study goals, a promising approach is a two stage filter system consisting of an unsaturated first stage media filter followed by a directly connected second stage anoxic filter with reactive media for denitrification; pressure and timed dosing to the first stage; with possible recirculation around the first stage.
- The two stage filter system could be configured in various manners, including an above ground system in separate tanks, as an unsaturated filter stacked above a saturated filter, or with the saturated second stage in the subsurface.
- Filter media that appear promising for passive nitrogen removal include zeolites, expanded clays and shales, peat, coir, synthetic fabrics, and tire crumb (first aerobic stage), and elemental sulfur and cellulosic based materials (sawdust and woodchips) in the second stage.
- As defined by FDOH, a passive system includes only one liquid pump and no aerator pumps. These constraints may limit performance or reduce reliability. Studies of actual field installations are required to ascertain their ability to perform satisfactorily over extended time periods.
- Passive systems to remove nitrogen from septic tank effluent (STE) must consider the entire nitrogen transformation process, including ammonification, nitrification and denitrification, and integration into an overall total system.
- Aerobic, unsaturated filtration technologies have been well studied and in some cases can achieve effluent ammonia nitrogen levels of five milligrams per liter or less. Most prominent current technologies include sand, peat, textile and foam media, and often employ recirculation. Alternative media offer exciting possibilities for improved performance.
- Passive denitrification filters employ solid phase electron donors to produce saturated anoxic environmental. Passive technologies are currently under development or in early stages of deployment. Promising filter systems include cellulosic based media (wood, sawdust), other organic media, and elemental sulfur based systems.
- Passive denitrification technologies have not been deployed for sufficiently long periods of time to fully evaluate longer term performance, operation and maintenance requirements, media longevity, and media replacement requirements.
- The ability of passive denitrification media to maintain a long term supply of carbon or electrons for denitrification is a significant factor affecting their longevity.

Theoretical stochiometric calculations provide an initial estimate of longevity, but longer term studies are needed to verify these results in practice.

- The longevity of passive denitrification filter systems may be affected by the long term accumulation of organic and inorganic solids within the filter media. This could be more important than the duration of the carbon or electron donor supply. Solids accumulation can result in the development of preferential flow paths, reduced contact of wastewater with solid media, and deterioration of performance. Longer term studies are needed to verify continued performance of denitrification filters in practice, and to determine filter maintenance needs and media replacement requirements.
- Constituents released by passive denitrification media include biodegradable organic matter (BOD) from carbon-based systems, and sulfate and possibly sulfide from sulfur-based systems. The environmental acceptability of constituent release must be ascertained.
- The practicality and life cycle costs of media replacement must be evaluated for all systems, including frequency of replacement, site access issues, replacement volumes, and management of used media.
- Modifications to soil treatment units have been evaluated in limited laboratory systems and some field studies are underway, using denitrification media similar to those used in in-tank treatment processes.
- In-soil denitrification is highly dependent on the specific environmental conditions at a particular site and operation of the onsite wastewater treatment and disposal system.

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 16, 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 3. Three filter systems were evaluated, each consisting of an unsaturated filter followed by a saturated filter. Filters were fabricated from PVC pipe, at 3 in. inner diameter 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 listed in Table 17. 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

Table 16 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
Tire Crumb	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

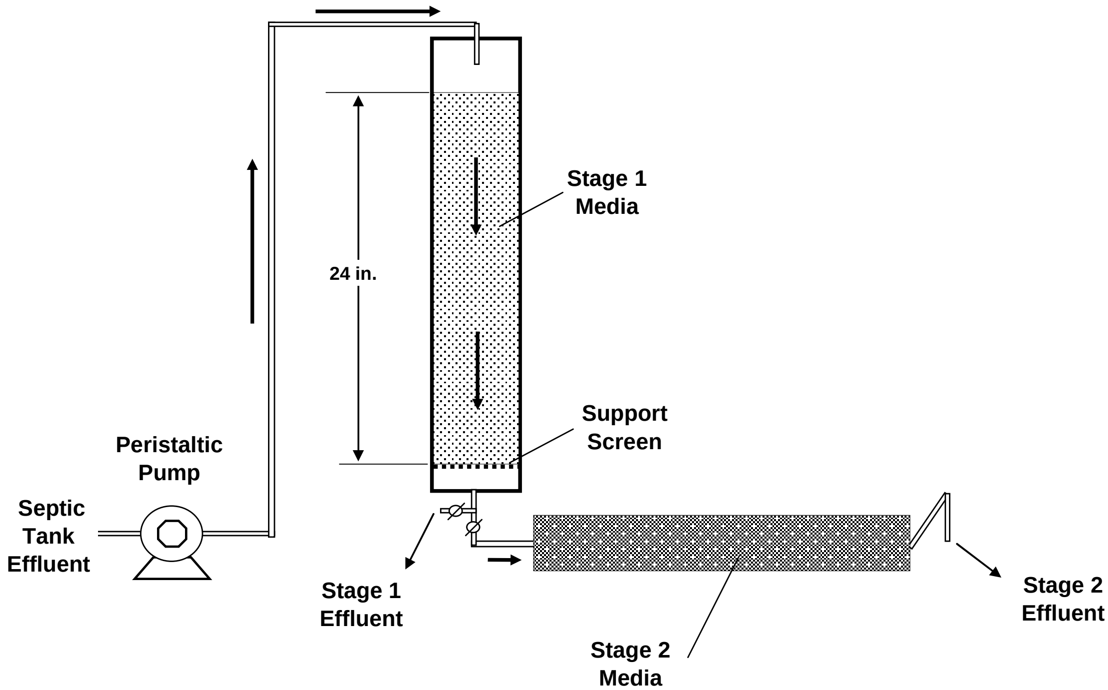

Figure 3 Experimental Filter System Schematic

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. The use of finer particle sizes in lower depths was intended to provide greater surface area for microbial attachment and a finer media for physical filtration, the later which could improve removal of pathogens and other wastewater constituents. The progression of coarser to finer media size through the filter was also intended to enable coarser media to filter out larger particulates and protect the finer media that follows.

Three Stage 2 columns were constructed using unstratified media containing elemental sulfur, crushed oyster shell, and expanded shale (Table 17) 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 3). 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 3). 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 was commenced on 1/2/2008. The hydraulic loading rate to the Stage 1 filters was 3 gallons of septic tank effluent per square foot of surface area per day. Details of operation of the experimental columns are included in the QAPP (Appendix D). Operation of the column systems To allow time for establishment of microbial activity, the systems were operated for three weeks before the first liquid samples were collected. Monitoring for wet chemistry parameters was conducted on five separate occasions, on days 22, 33/34, 42/43, 49/50, and 60/62.

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.

Monitoring was generally conducted in the following sequence:

- Stage 2 effluent: temperature, pH, DO, alkalinity
- Stage 2 effluent: sulfate sample collection
- Stage 2 effluent: nitrogen sample collection
- Stage 1 effluent: nitrogen sample collection
- Field blank: preparation
- STE and Stage 1 effluent: temperature, pH, DO, alkalinity
- STE: sulfate and nitrogen sample collection
- STE: BOD and TSS sample collection

Table 17 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** depth (in.) / diameter (mm) / top 8 / 2.38 - 4.76 8 / 1.19 - 2.38 6 / 0.5 - 1.19 1 / 1.19 - 2.38 1 / 2.38 - 4.76 / bottom
	1B				**Expanded Clay** depth (in.) / diameter (mm) / top 8 / 3 - 5 8 / 1.0 - 2.0 6 / 0.5 - 1.0 1 / 1.0 - 2.0 1 / 3 - 5 / bottom
	1C				**Tire Crumb** depth (in.) / diameter (mm) / top 8 / 3 - 5 8 / 1.0 - 2.0 6 / 0.5 - 1.0 1 / 1.0 - 2.0 1 / 3 - 5 / bottom
Stage 2 saturated anoxic	**2A**	**1.5**	**24.0**	**Nonstratified (1 - 3 mm)**	**75% elemental sulfur** **25% oyster shell**
	2B				**60% elemental sulfur** **20% oyster shell** **20% expanded shale**
	2C				**45% elemental sulfur** **15% oyster shell** **40% expanded shale**

Analytical Methods

Nitrogen and sulfate 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. For each sampling event, nitrogen analysis were performed on a field blank; the maximum field blank N value was 0.073 mg/L (App. A).

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.

Results and Discussion

Applied Hydraulic Loading

Applied hydraulic loadings to Stage 1 filters are summarized in Table 18. 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, while the average flowrate to System 3 (tire crumb/45% sulfur media) was somewhat lower than that to Systems 1 and 2. The applied hydraulic loadings to the Stage 1 filters were reasonably close to the loadings that were targeted in the experimental design.

Table 18 Applied Hydraulic Loading Rate

System	Media	Average gal/ft^2-day	Standard Deviation gal/ft^2-day
1	Clinoptilolite / 75% Sulfur	2.71	0.28
2	Expanded Clay / 60% Sulfur	2.95	0.20
3	Tire Crumb / 45% Sulfur	2.51	0.18

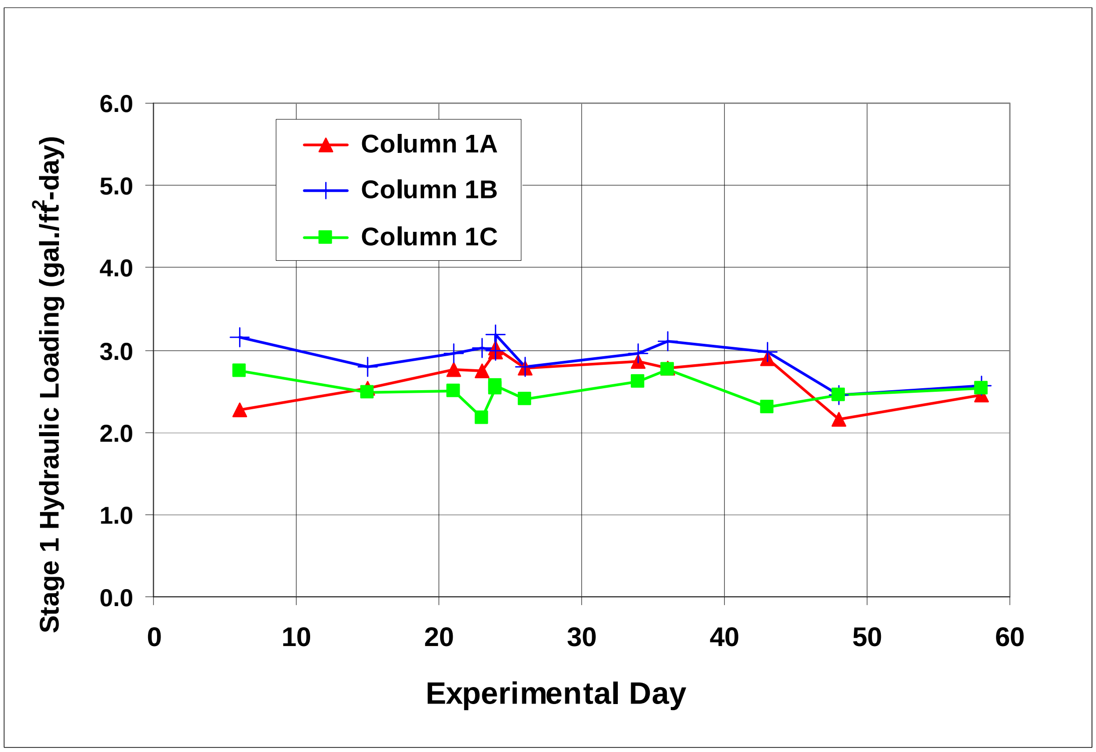

Figure 4 Hydraulic Loading Rate Applied to Stage 1 Filters

Septic Tank Effluent

Septic tank water quality parameters are summarized in Table 19. The average Total Nitrogen (TN) of 77.4 mg/L was somewhat higher than typical for single family residences. The high TN may be a reflection of the contribution of day users to the wastewater; typical short term visitation patterns may result in a relatively high proportion of urine which contains the majority of nitrogen in human waste. The nitrogen speciation results show that the majority of STE was ammonia, with the balance generally organic nitrogen. Single values for NH_3 (2.6 mg/L) and NO_x (21 mg/L) appear to be outliers, as suggested by examination of median values; inquiries with the analytical lab and reanalysis did not resolve this issue. The biochemical oxygen demand may be more characteristic of typical single family Florida residences. The TSS was relatively low, which may have reflected the passage of STE through the effluent screen.

Table 19 Septic Tank Effluent Quality
(all values in mg/L except pH)

System	Average	Standard Deviation	Median	Range	n
Total Nitrogen	77.4	6.2	78	69 - 85	5
Total Kjeldahl N	73.2	14.7	78	48 - 85	5
Organic Nitrogen	20.7	28.6	8	3.0 - 71	5
NH_3-N	52.5	30.2	70	2.6 - 74	5
NO_x-N	4.2	9.4	0.04	.028 - 21	5
Total Inorganic N	56.8	30.8	70	2.7 - 74	5
SO_4-S	23	4.7	22	17 - 29	5
C-BOD_5	203	71	190	140 - 180	3
TSS	18.7	5.5	16	15 - 25	3
Temperature	22.5	6.7	24	14.1-30.9	5
DO	0.008	0.1	0.00	0 - 0.02	5
pH	7.39	0.27	7.33	7.11 - 7.85	5
Alkalinity	416	157	455	140 - 381	5

Applied BOD and Nitrogen Loading

Applied loadings of BOD and Total Nitrogen (TN) are summarized in Table 20. The variations in applied loading of TN with time (Figure 5) reflect both the variations in flowrate applied to each system and variation in TN of the STE influent. The applied nitrogen loading was fairly consistent (Figure 5). The systems were initially operated for three weeks to allow microbial processes to become established; nitrogen was not monitored during this time.

Table 20 Applied BOD and Nitrogen Loading Rates

System	C-BOD$_5$ (n = 3)		Total Nitrogen (n = 5)		
	Average	Average	Average	Standard Deviation	Average
	gram/m^2-day	lbs./ft^2-day	gram/m^2-day	gram/m^2-day	lbs./ft^2-day
1	22.8	0.0064	8.68	0.70	0.0018
2	24.2	0.0068	9.23	0.74	0.0019
3	20.6	0.0058	7.83	0.63	0.0016

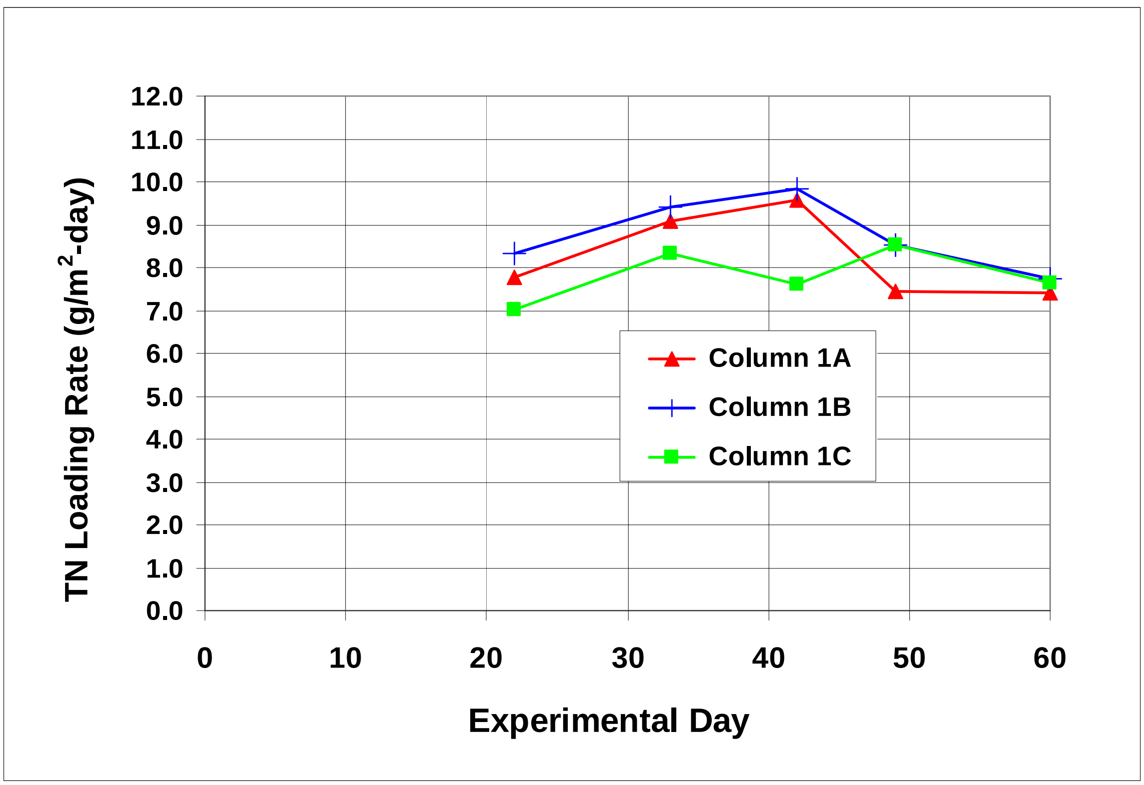

Figure 5 Rate of STE Total Nitrogen Applied to Stage 1 Filters

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 21. Total Nitrogen (TN) removal efficiencies are summarized in Table 22. Total nitrogen oncentrations of the two stage filter systems are plotted in Figure 6. TN removal efficiency of Systems 1 and 2 averaged greater than 97%, while System 3 averaged 33%. The low TN removal efficiency is System 3 was in large part because the tire crumb media was less effective in ammonia reduction than clinoptilolite and expanded clay media. Another factor contributing to lower TN removal efficiency of System 3 was the increase in effluent NO_x concentrations from System 3 Stage 2 that occurred as the test progressed. This is discussed below. The measured total nitrogen (TN) concentration in the final effluent of System 1 (clinoptilolite) and System 2 (expanded clay) two-stage filters was not a strong function of applied TN loading (Figure 7).

Stage 1 effluent ammonia nitrogen concentrations were less than 0.1 mg/l in filters with clinoptilolite and livelite media, and were often near levels of detection. Clinoptilolite and livelite are high water retention media compared to tire crumb, which exhibited higher average effluent ammonia levels (Table 21). It is noted that the average ammonia level for the clinoptilolite column was based on 4 sample results rather than 5. Column 1A effluent ammonia was quite high in the first sample event; this value was considered an outlier and was inconsistent with the fact that ammonia was completely absent in the effluent of anoxic Column 2A which followed the clinoptilolite column. The organic nitrogen in the final effluents from Systems 1 through 3 averaged 1.4 to 2.1 mg/L. For systems with highly efficient removal of Total Inorganic Nitrogen (TIN, the sum of ammonia and NO_x), the effluent nitrogen was dominated by the organic component. The average TIN removal efficiencies of Systems 1 and 2 were 99.8 and 98.1 %, respectively, and effluent nitrogen was predominantly organic N.

Average values of field monitoring parameters are summarized in Table 23. Each of the three Stage 1 media were effective at increasing dissolved oxygen (DO) from virtually zero in STE to over 7 mg/L in Stage 1 effluent (Figure 8). The low values of DO in Stage 1 effluents on Day 23 may have been due to some transient operational condition, perhaps associated with a characteristic of the feed (STE alkalinity was quite low on Day 23). Another possible explanation for low DO in Stage 1 effluent was the DO probe. Although the probe passed all manufacturer recommended testing and troubleshooting measures, it was replaced the following week. 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 9). 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. The highest alkalinity reduction through Stage 1 filters is for Column 1B, which also has the greatest decline in pH. Additionally, Column 1B was highly efficient in removing ammonia. Another factor that affects alkalinity is denitrification. Average NO_x concentrations were lower in Column 1A (clinoptilolite) than in Column 2A (livelite). Trends in average alkalinity changes in Stage 1 filters show some consistency with nitrogen transformation trends.

The STE alkalinity of 1/26/2008 was 140 mg/L (alkalinity/TN of 2.0) and resulted in an effluent alkalinity of zero in all three Stage 1 filters. These zero alkalinity numbers were included in the average values presented in Table 23. The alkalinity results of the 1/26/2008 sampling appear to be valid, and may offer one explanation of high Stage 1 effluent ammonia levels on 1/26/2008. If alkalinity in STE is low, nitrification in Stage 1 filters may be inhibited. In this study, the alkalinity/total nitrogen in STE averaged 5.3 and was greater than the required stoichiometric ratio of 4.57 in all but the first sample event. Nevertheless, alkalinity has the potential to change significantly. The implication to passive nitrogen removal systems are the possible need to supplement alkalinity for one pass systems when the alkalinity/total nitrogen ratio in STE is low. The use of recycle around Stage 1 is also a logical approach that can be integrated into passive nitrogen removal systems.

Table 21 Nitrogen Species In Filter Influents and Effluents
(Average of n=5; all values in mg/L)

Sample Point	Total Nitrogen	Total Kjeldahl Nitrogen	Organic N	NH_3-N	NO_x-N	Total Inorganic Nitrogen
Influent (STE)	77.4	73.2	20.7	52.5	4.2	56.8
Stage 1 Effluent						
1A Clinoptilolite	35.2	8.9	2.2	0.1*	26.3	33.0
1B Expanded clay	56.2	1.0	0.9	0.1	55.2	55.3
1C Tire crumb	65.4	29.0	2.4	26.6	36.4	63.0
Stage 2 Effluent						
2A 75% Sulfur	2.2	2.2	2.1	0.11	0.03	0.14
2B 60% Sulfur	2.1	2.0	1.4	0.61	0.02	0.63
2C 45% Sulfur	43.9	36.6	1.8	34.8	7.3	42.1

*n=4

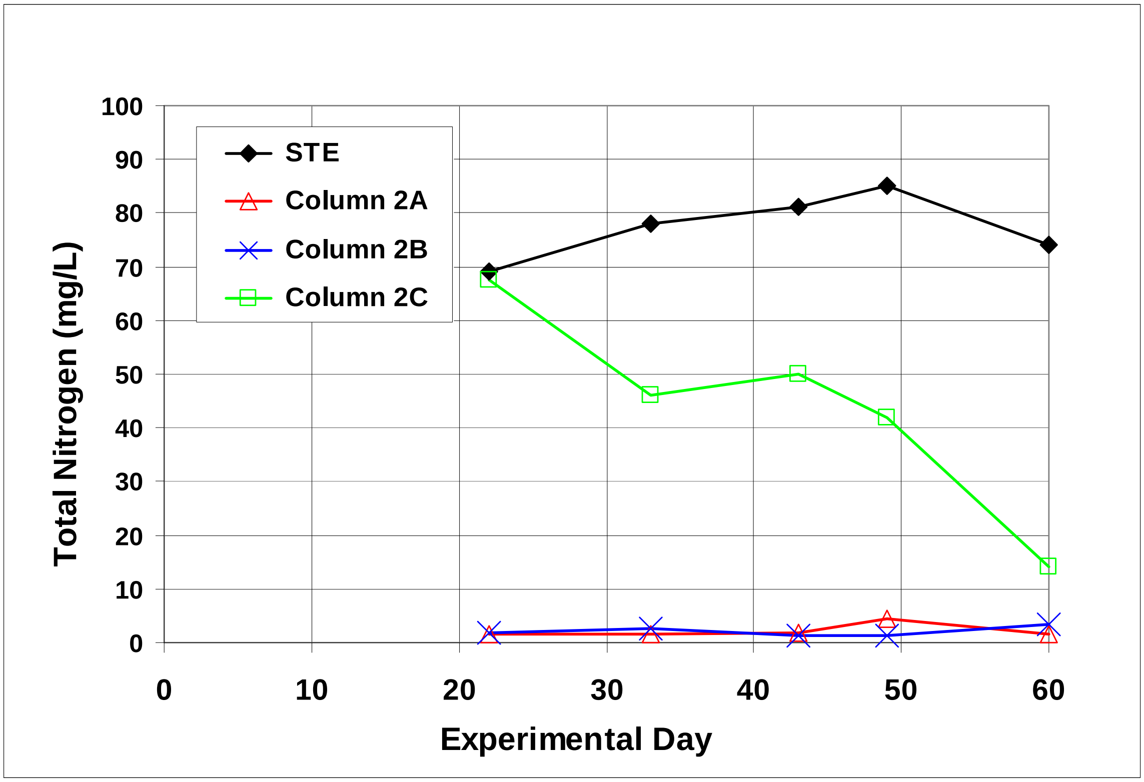

Figure 6 Total Nitrogen in Influent STE and Effluent of Two Stage Filter Systems

Table 22 Two Stage Treatment System Nitrogen Removal Efficiency[1]

System	Media	Total Nitrogen		Total Inorganic Nitrogen	
		Average	Range	Average	Range
1	Clinoptilolite / 75% Sulfur	97.1	94.9 - 97.9	99.8	99.7 - 99.9
2	Expanded Clay / 60% Sulfur	97.7	96.6 - 98.6	98.1	97.5 - 98.7
3	Tire Crumb / 45% Sulfur	33.0	2.2 - 50.6	34.4	2.0 - 52.5

[1]n=5

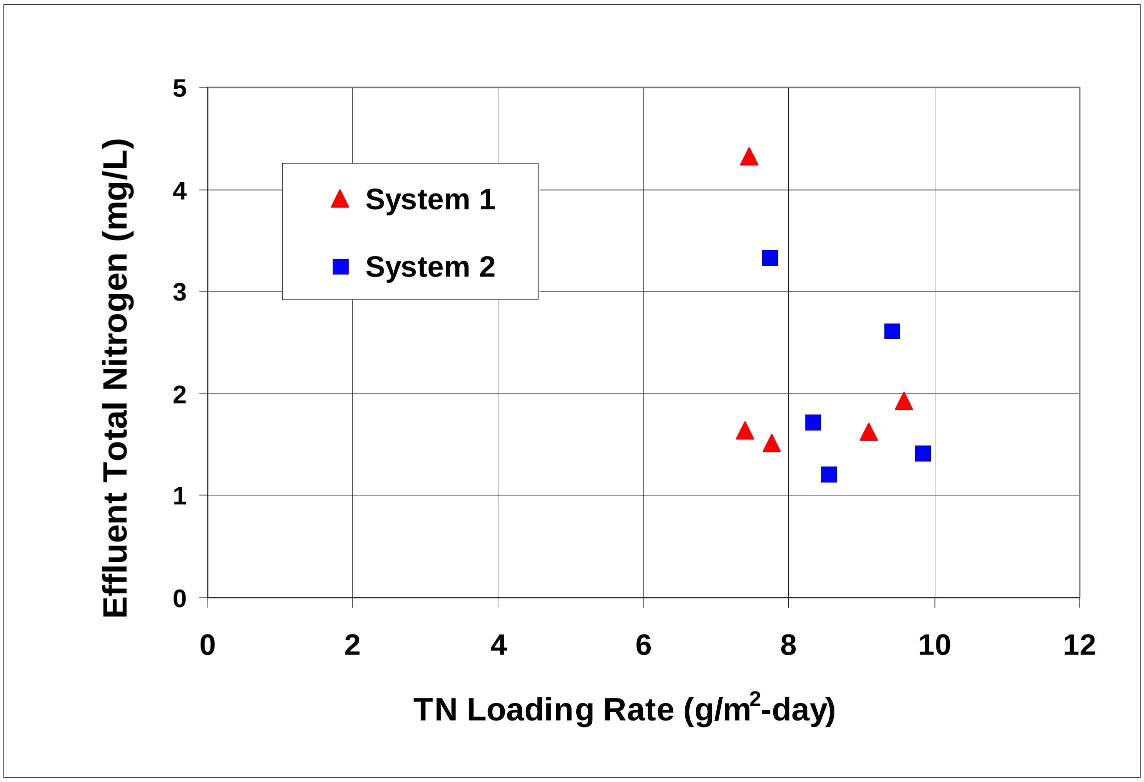

Figure 7 Two-Stage System Effluent Total Nitrogen versus TN Loading

Table 23 Field Parameters In Filter Influents and Effluents[1]

Sample Point	Dissolved Oxygen, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Alkalinity Change, mg/L as CaCO3
Influent (STE)	0.008	7.49	416	-
Stage 1				
1A Clinoptilolite	7.28	7.65	283	-133
1B Expanded clay	7.27	7.22	86	-330
1C Tire crumb	7.10	7.42	178	-238
Stage 2				
2A 75% Sulfur	0.06	7.02	437	+154
2B 60% Sulfur	0.05	6.97	225	+139
2C 45% Sulfur	0.93	7.25	294	+116

[1] Average of n=5

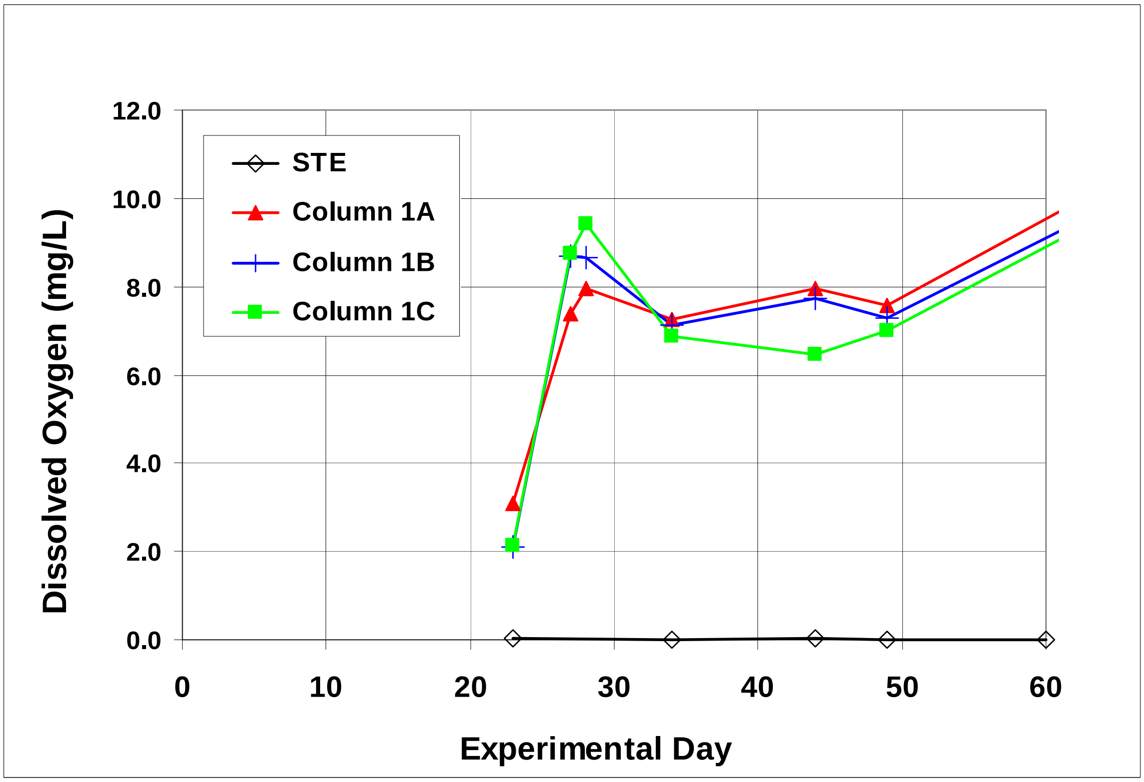

Figure 8 Dissolved Oxygen in Effluent of Unsaturated Filters (Stage 1)

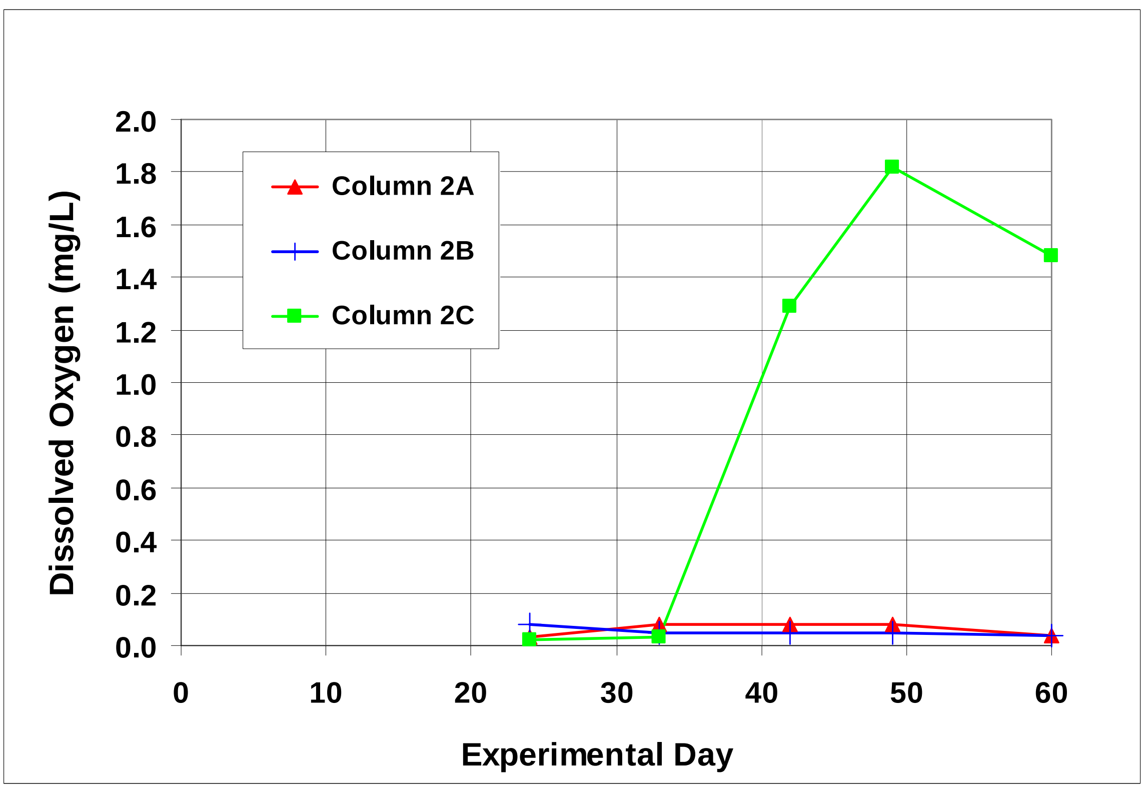

Figure 9 Dissolved Oxygen in Effluent of Denitrification Filters (Stage 2)

Performance of Unsaturated Aerobic Filters (Stage 1)

Nitrogen removal performance of the aerobic, unsaturated (Stage 1) filters is summarized in Table 24. Average TN removal was 50% for clinoptilolite media, which was a quite good and unexpected performance considering that the filter operated as single pass at a loading of 2.7 gal./ft^2-day. The expanded clay media was virtually as efficient as clinoptilolite at ammonia and TKN removal but less efficient at NO_x removal. The tire crumb was less efficient than clinoptilolite of expanded clay at ammonia removal, but performance appeared to be improving as the study progressed (Figure 10). The measured ammonia nitrogen (NH_4^+-N) concentration in the Stage 1 effluent from System 1 (clinoptilolite) and System 2 (expanded clay) was not a strong function of applied TN loading (Figure 11).

Performance of Anoxic Denitrification Filters (Stage 2)

The performance of the three denitrification (Stage 2) filters is illustrated in Figures 12 and 12. For System 1 (clinoptilolite / 75% sulfur) and System 2 (expanded clay/ 60% sulfur), TN removal efficiencies are high and and Stage 2 (final effluent) NO_x concentrations are low. System 3 showed a lower TN removal efficiency, which is partly due to higher Stage 2 effluent NO_x (Figure 13). The System 3 Stage 2 had the lowest fraction of sulfur (45%) of the three Stage 2 filters, which reduced the total sulfur surface area in the filter and may have resulted in insufficient dissolution of electron donor source or contact with wastewater fluid parcels with reactive surfaces. The release of inhibitory materials from the tire media in Column 1C is another possibile explanation for lower NO_x removal efficiency of Column 2C, although this is purely speculative. Dissolved oxygen increased significantly over time of operation in the effluent of the sulfur filter (Column 3B) that followed the tire crumb media. DO remained at levels below 0.1 mg/l in the anoxic filters following clinoptilolite and livelite media. In a sulfur based denitrification filter, consumption of influent DO would be expected to occur preferentially to denitrification. A biochemical equation developed from reaction stoichiometry and energetics indicates that 0.82 grams S are required per removal of 1 gram oxygen, or 5.7 mg/L sulfur for a 7 mg/L influent DO. Although ample sulfur is present in all Stage 2 filters to react with influent DO, the reasons that the one sulfur filter did not reduce DO to very low levesl cannot be explained. More research is needed into sulfur based denitrification filter design and extended operation.

Table 24 Stage 1 Nitrogen Removal Efficiency

System	Media	Total Nitrogen[1]		Ammonia Nitrogen[1]	
		Average	Range	Average	Range
1	Clinoptilolite	50.6	18.8 - 88.1	99.9	99.9 - 99.9
2	Expanded Clay	26.1	10.2 - 32.9	99.9	99.5 - 99.9
3	Tire Crumb	13.0	0 - 28.2	60.5	35.1 - 87.7

[1]Average of n=5

[2]n=4

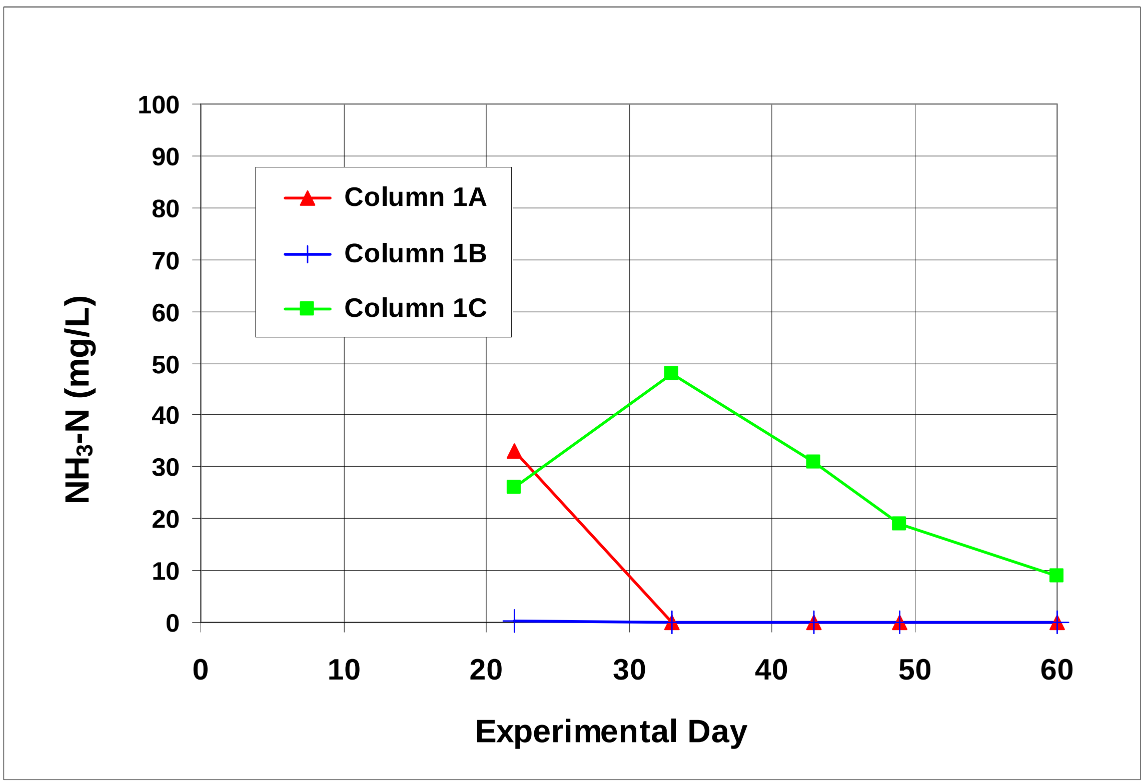

Figure 10 Effluent Ammonia from Unsaturated (Stage 1) Filters

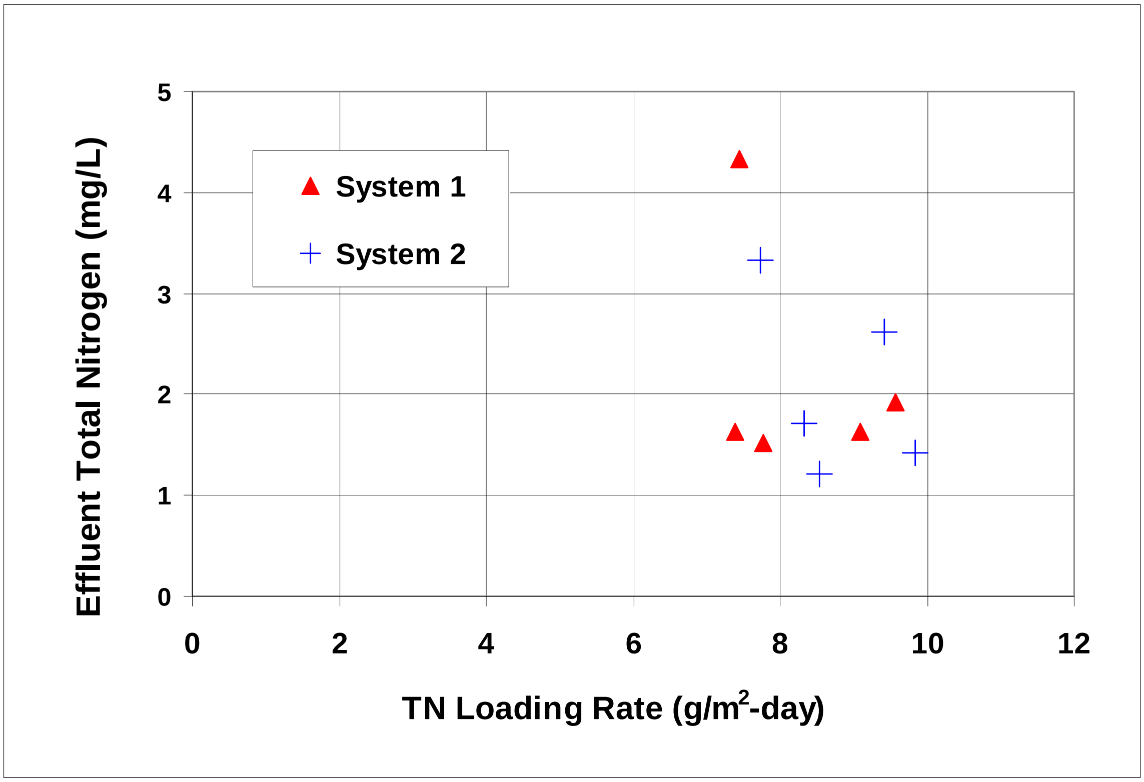

Figure 11 Stage 1 Effluent NH_4^+-N versus TN Loading Rate

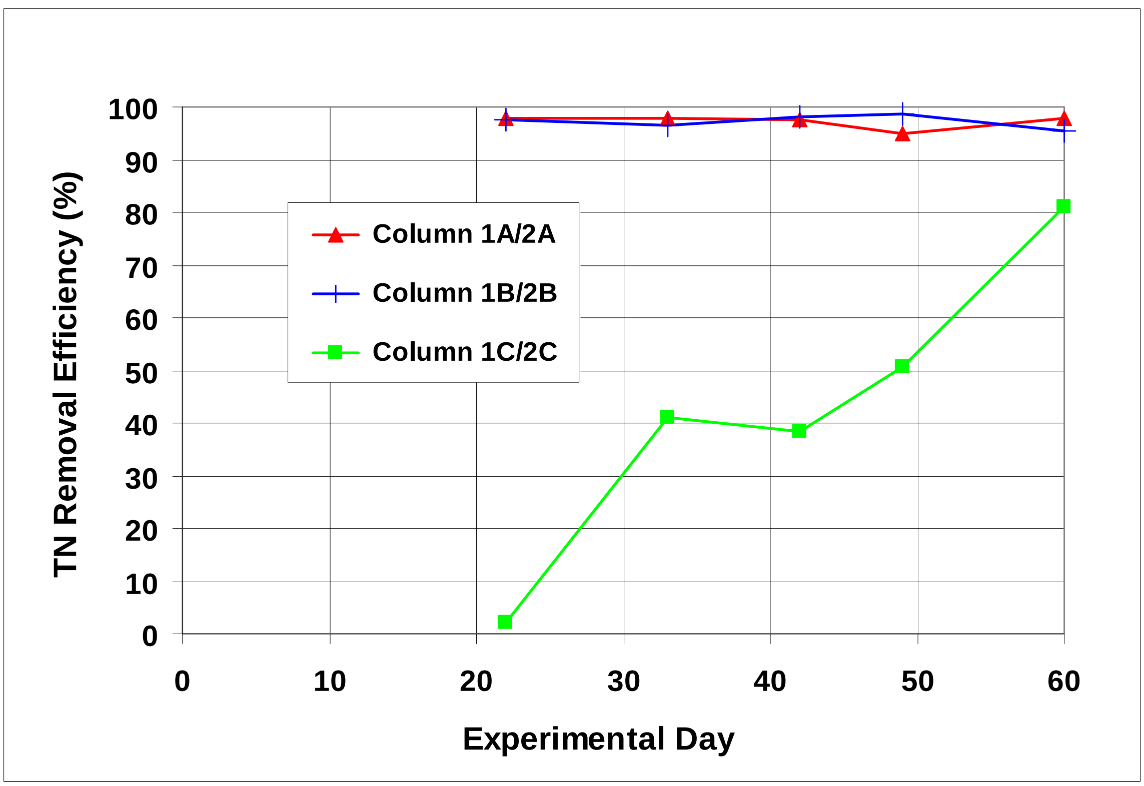

Figure 12 Total Inorganic Nitrogen Removal Efficiencies of Two Stage Systems

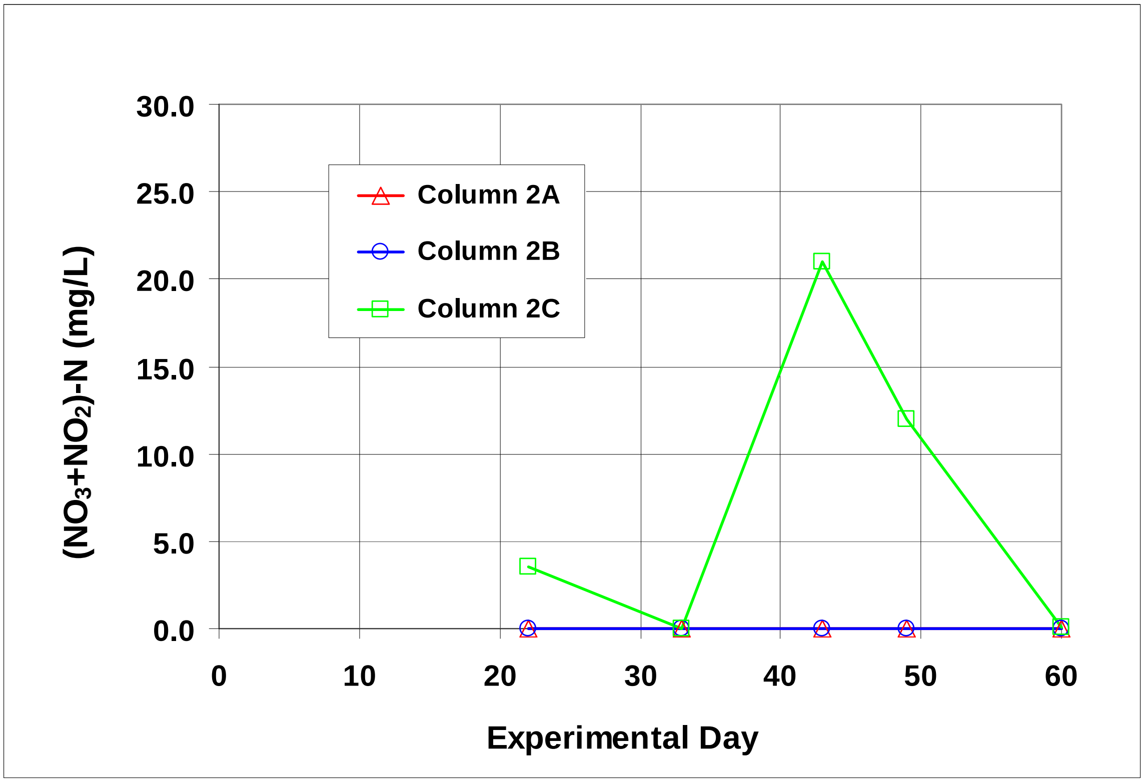

Figure 13 NO_x Concentrations in Stage 2 Filter Effluents

Statistical Tests

Statistical tests were performed to determine if statistical differences existed among the three passive nitrogen removal systems, as summarized in Table 25. The majority of data sets for effluent Total Nitrogen (TN), ammonia nitrogen (NH_4^+-N), and oxidized nitrogen (NO_x-N) were either non-normally distributed or had unequal variances; Kruskall-Wallis and Mann Whitney tests were chosen for multiple or paired comparisions, respectively. The statistical analyses in Table 25 indicate the following:

- Total nitrogen concentrations in the effluent of the two-stage filter systems (i.e. the effluents from the Stage 2 filters) were significantly higher for System 3 than for Systems 1 and 2;
- Total nitrogen concentrations in the effluent of the two-stage filter system were not significantly different between Systems 1 and 2;
- Ammonia nitrogen (NH_4^+-N) concentrations in the Stage 1 filter effluents were not significantly different for System 1 (clinoptilolite) than System 2 (expanded clay);
- Oxidized nitrogen (NO_x-N) concentrations in the effluent of the Stage 1 filters were significantly lower for System 1 (clinoptilolite) than System 2 (expanded clay).

Table 25. Statistical Tests for Effluent Nitrogen Concentrations

Comparison	Systems	Test	Result
Two-Stage System Effluent Total Nitrogen	1, 2, 3	Kruskall-Wallis One Way Analysis of Variance on Ranks	> 99% chance that the differences in the medians of the three systems are statistically significant
	1, 2	Mann Whitney Rank Sum Test	> 99% probablity that there is not a statistically significant difference
Stage 1 Effluent Ammonia-N	1, 2, 3	Kruskall-Wallis One Way Analysis of Variance on Ranks	> 99% chance that the differences in the medians of the three systems are statistically significant
	1, 2	Mann Whitney Rank Sum Test	> 90% probablity that there is not a statistically significant difference
Stage 1 Effluent NO_x-N	1, 2	Mann Whitney Rank Sum Test	> 99% probablity that there is a statistically significant difference

Experimental Conclusions and Recommendations

Three two stage experimental wastewater systems using media filters were operated in a passive mode 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 the sixty day experimental period:

- Average hydraulic loading rates of septic tank effluent applied to Stage 1 filters with clinoptilolite, expanded clay, and tire crumb media were 2.71, 2.95 and 2.51 gallons per square foot per day, respectively.
- Average total nitrogen (TN) loading rates were 8.7, 9.2 and 7.8 grams per square meter per day to Stage 1 filters with clinoptilolite, expanded clay, and tire crumb media, respectively.
- The total nitrogen in septic tank effluent averaged 77.4 mg/L with a standard deviation of 6.2 mg/L.
- Septic tank effluent carbonaceous five day biochemical oxygen demand and total suspended solids averaged 203 and 18.7 mg/L, respectively.
- Total Nitrogen (TN) removal efficiencies for Two Stage Systems averaged 97.1, 97.7 and 33.0%, respectively, for clinoptilolite, expanded clay and tire crumb media.
- Effluent Total Nitrogen (TN) concentrations for Two Stage Systems averaged 2.2, 2.1, and 43.9 mg/L, respectively, for clinoptilolite, expanded clay and tire crumb media.
- Total Inorganic Nitrogen (TIN) removal efficiencies for Two Stage Systems averaged 99.8, 98.1, and 34.4 %, respectively, for clinoptilolite, expanded clay and tire crumb media.

- Effluent Total Inorganic Nitrogen (TIN) concentrations for Two Stage Systems averaged 0.14, 0.63 and 42.1 mg/L, respectively, for clinoptilolite, expanded clay and tire crumb media.
- Total Nitrogen (TN) removal efficiencies for Stage 1 Systems averaged 50.6, 26.1, and 13.0%, respectively, for clinoptilolite, expanded clay and tire crumb media.
- Effluent Total Nitrogen (TN) concentrations for Stage 1 Systems averaged 35.2, 56.2 and 65.4 mg/L, respectively, for clinoptilolite, expanded clay and tire crumb media.
- Ammonia Nitrogen (NH_3-N) removal efficiencies for Stage 1 Systems averaged 99.9, 99.9, and 60.5%, respectively, for clinoptilolite, expanded clay and tire crumb media.
- Ammonia Nitrogen (NH_3-N) concentrations for Stage 1 Systems averaged 0.11, 0.61 and 34.8 mg/L, respectively, for clinoptilolite, expanded clay and tire crumb media.
- Average dissolved oxygen in unsaturated (Stage 1) effluents were 7.28, 7.27 and 7.10 mg/L, respectively, for clinoptilolite, expanded clay and tire crumb media.
- Average dissolved oxygen in anoxic filter effluents (Stage 2) were 0.06, 0.05 and 0.93 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 133 to 330 mg/L, while alkalinity increase in anoxic filters (Stage 2) was 116 to 154 mg/L.
- Clinoptilolite and expanded clay appear to be suitable media for full scale application.

The results from the passive nitrogen removal experimental study suggest that the innovative designs that were employed have potential to be developed into full scale passive nitrogen treatment systems. However, the scope of the ongoing study is quite limited and does not provide the basis for rational engineering design. Significantly more data is needed in order to rationally formulate engineering options for passive nitrogen removal systems. Additional studies are needed to address key issues that have direct implications to process performance, design, feasibility, longevity, and economics.

Based on the results of this study, it is recommended that additional studies be conducted to provide data for rational design of a full scale on-site wastewater treatment process to demonstrate enhanced nitrogen removal using a passive system. Additional studies include:

- **Extend Operation of Current Systems** The time of operation of the experimental systems (60 days) is insufficient and should be extended. Biological systems typically need extended times to fully adapt and establish. Extended operation would provide a longer operational period to ascertain TKN and ammonia removal performance in Stage 1 filters, denitrification that is achieved in Stage 1 single pass filters, and NO_x removal in Stage 2 filters.

- **Operation of Current Systems at Higher Loading Rates** The performance results of the Stage 1 filters with zeolite (Column 1A) and livelite (Column 1B) media suggest that these filters could be operated at higher loading rates. The design loading rate has important implications for Stage 1 filter size, required media volume, and system costs.

- **Operate Unsaturated (Stage 1) Filters in Recycle Mode** Recycle of effluent from the unsaturated filter and mixing with untreated septic tank effluent would increase total nitrogen reduction in Stage 1 by pre-denitrification. The nitrate loading to the anoxic denitrification filter would decrease, affecting the Stage 2 design and media life.

- **Monitoring of Anoxic Denitrification Filters** The operation of anoxic denitrification filters should be examined through more detailed analysis of nitrate levels, including profiles through the columns. Additional analyses for sulfate, pH, alkalinity, and dissolved oxygen should be used to increase understanding of these filters for more rationally based designs as Stage 2 filters.

- **Examine Other Treatment Aspects** Additional treatment issues should be examined, including removal of biochemical oxygen demand, suspended solids, and pathogens, additional types of media, and residuals management.

Economic Analysis

Economic Analysis Objectives The objective of economic analysis is to provide an equitable evaluation of the cost of alternative passive nitrogen removal systems over their entire life. A Life Cycle Cost Analysis (LCCA) was applied (Fuller and Peterson, 1995). LCCA entails estimating all present costs and future costs over the useful life of the system (project life). The LCCA included costs for:

- Equipment, materials, and installation
- Energy, scheduled maintenance, and monitoring
- Media replacement and residuals management
- Salvage and decommissioning values at the end of the project life.

In the LCCA methodology, all present and future costs are combined using the standard accounting techniques of Present Worth (PW) and Uniform Annual Cost (UAC). For the LCCA evaluation of passive nitrogen systems, a standard 30 year project life, a 4% discount rate (Federal Funds interest rate, December 2007), and current Engineering News Record (ENR) published cost factors (ENR, 2008) of 3.7% were used to determine the PW and UAC for each alternative configuration.

Design Criteria To perform a Life Cycle Cost Analysis of passive nitrogen removal systems, it is necessary to specify key design criteria. The experimental evaluation that was conducted as a part of the Florida Passive Nitrogen Removal Study provided the basis for design alternatives. The experimental study evaluated three two-stage nitrogen removal systems, provided proof of concept of the passive two-stage nitrogen removal process, and confirmed that high nitrogen reductions could be obtained. Design criteria were derived from the experimental results and applied to a single family residence with average daily flow of 300 gallons per day, with TN similar to the average applied to the experimental systems (75 mg/L). A definition sketch of two-stage passive nitrogen removal technology for onsite wastewater treatment is shown in Figure 14. The PNRS configuration shown in Figure 14 is an above ground unsaturated filter, followed by a gravity fed horizontal anoxic filter. The single pump is located in a pump chamber built into the primary tank. The PNRS design mandates that the single pump raise the elevation of septic tank effluent sufficiently to provide dosing, downward trickle flow through 2 ft. of Stage 1 media and through the underdrain, and gravity flow through the Stage 2 filter to the drainfield. The hydraulic profile would have to be developed to insure that no more than 18 in. of soil cover would overlie the top of a subsurface drainfield, and such that the bottom of the drainfield would be not greater than 30 in. below grade. Use of 12 to 18 in. diameter enclosures for anoxic denitrification filters would possible enable the Stage 2 filter to be located below existing grade while maintaining a top of drainfield elevation of 18 in. below existing grade. At locations with high seasonal groundwater table elevations where an above-grade mound is required, the

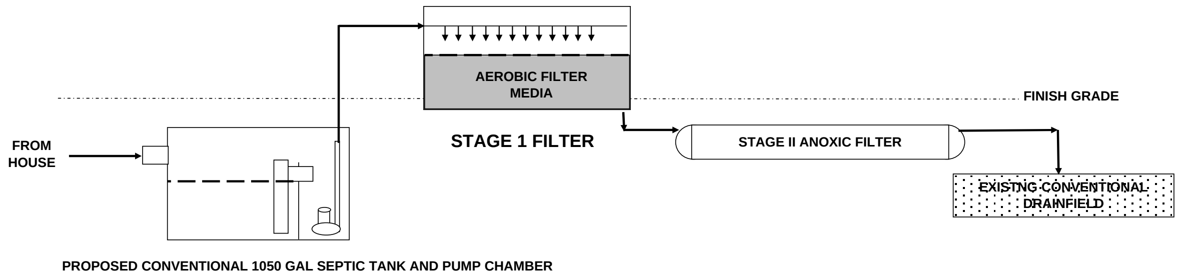

Figure 14 Passive Nitrogen Removal System Schematic

hydraulic profile with a one pump system would require all PNRS system components be moved above ground. This would increase energy costs by perhaps 25%. The alternative would be to use a second pump, following the stage 2 denitrification filter to lift wastewater to the mound surface.

The experimental investigations confirmed the ability of a passive two-stage filter system to reduce TN. The experimental studies were of limited duration not capable of fully resolving all of the issues needed to provide a definitive design for a Passive Nitrogen Removal System. Key design features that were not fully delineated in the experimental studies include:

- sizing of the aerobic unsaturated Stage 1 filter
- Stage 1 filter media
- media composition of anoxic denitrification filter (Stage 2)
- sizing of the anoxic denitrification filter
- Stage 2 media replacement interval

Multiple alternative designs of were configured and LCCA was used to evaluate the alternative designs.

The application of passive nitrogen removal technology relies on use of readily available materials, labor skills, and minimal operational controls. The basic design elements of primary treatment, pump, dosing and the Stage 1 filter are shown in Figure 15. The system requires installation of a conventional septic tank and pump chamber with 1 day pump holding capacity. For this evaluation, conventional pre-cast concrete septic tanks, pumps, effluent filters, readily available high density polyethylene (HDPE) corrugated drainage piping products and a conventional drain-field were considered for determining costs. Two Stage 1 filter enclosures are shown in Figure 15, but one filter enclosure could be used depending on the total plan area of the Stage 1 filter and available enclosure options. The cost analysis did not include any specialty landscaping or other improvements for the system. It should be noted that the researchers believe that other non-conventional equipment and materials may be incorporated within the design elements to allow for a more site specific customized treatment system. These elements may be defined as more research results and materials investigations are completed.

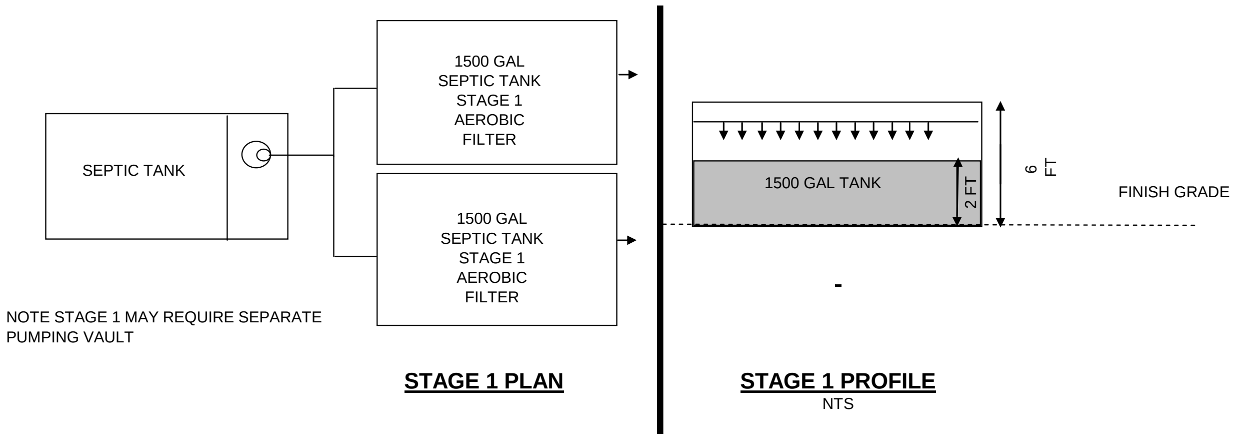

Figure 15 Basic Design Elements of Primary Treatment and Stage 1 Filter

Design of the Stage 2 filter was evaluated based on the anticipated life expectancy of the media and filter size. Several combinations of Stage 2 filter size and media replacement intervals were evaluated. The basic design elements for one Stage 2 filter alternative are shown in Figure 16.

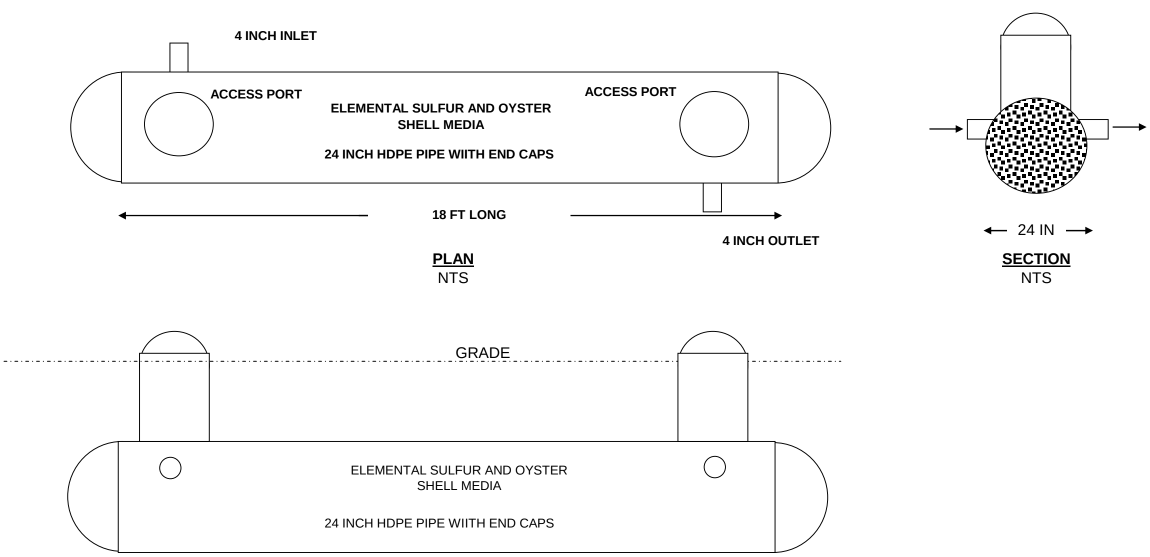

Figure 16 Basic Design Elements of Stage 2 Filter

Life Cycle Cost Analysis The Life Cycle Cost Analyses (LCCA) were performed for 12 candidate design configurations that included all possible combinations of the three individual factors of a. Stage 1 filter plan area, b. Stage 1 media, and c. Stage 2 filter volume/media replacement interval. Alternatives that were considered for each factor are listed in Table 26. All designs were based on a single family residence with a flowrate of 300 gallons per day. The listed options were considered reasonable and feasible based on the results of the experiments. Present worth and annualized cost estimates were prepared for each case. A 30 year project life and a 4% annual discount rate were used in all analyses. In addition, all future costs were adjusted using the 3.7% annual ENR cost increase cited above.

The options for Stage 1 filter plan area and media are based on the experimental results described in the previous section. Complete nitrification and high TKN removal were obtained with both clinoptilolite and livlite media at a hydraulic loading rate (HLR) of 3 gal/ft^2-day under timed pressure dosing of 48 times per day (30 minute cycle). Both clinoptilolite and livlite media are candidate media for Stage 1. The experiments were of limited duration; it is difficult to discern a difference in performance between clinoptilolite and livlite in terms of ammonia and TKN removal. It is judged that, with either media, higher HLR could be applied to the Stage 1 filters while still achieving very high ammonia and TKN reductions. The Stage 1 filter area of 100 ft^2 provides

Table 26 Design Factor Options of Alternatives

Stage 1 Filter Plan Area, ft^2

- 100
- 75

Stage 1 Media

- Clinoptilolite
- Expanded clay

Stage 2 Filter volume/media replacement interval

- 750 gallon, 15 year
- 375 gallon, 5 year
- 75 gallon, 1 year

3 gal/ft^2-day, while the second option of 75 ft^2 filter area increases the average HLR to 4 gal/ft^2-day. While it may be possible to increase HLR even further, definitive design guidance should properly be based on actual operating data. For perspective on the Stage 1 filter plan area, a primary treatment tank (i.e. septic tank) meeting Florida code (F.A.C. 64E6) for a 300 gpd flowrate would have a footprint on the order of 60 ft^2, or 60 to 80% that of the Stage 1 filter.

Stage 2 media composition was specified as sulfur and oyster shell at a 3:1 vol./vol. ratio, as was applied in all of the Stage 2 columns in the experimental investigation. The economic analysis cases did not include utelite (expanded shale) in the Stage 2 filter media. Incorporating additional media components in any Stage 2 design reduces the space available for the reactive sulfur and theoretically reduces the run time. Since the experimental results did not provide definitive evidence of enhanced performance with the expanded shale component, utelite was not included. It should be noted that the experiments were not designed to elucidate all possible operating conditions under which expanded shale could have advantageous properties. Longer term operation of treatment systems would be needed to fully explore this question.

Three options were specified for Stage 2 filter size/media replacement combinations (Table 26). Options range from low volume, frequent media replacement strategy to a designs with larger filter size, longer run time and longer media replacement interval. These options reflect the uncertainty in Stage 2 design due to the lack of demonstrated NO_x removal performance over extended time periods. The smaller filter design with frequent media replacement would be advantageous if performance deterioration was caused by factors such as preferential flow paths (channeling) or chemical precipitation which could occur in shorter times than the useful life of the media. In this case, the NO_x removal effectiveness of the Stage 2 filter would decline, even though the sulfur media was largely unused. Modular media replacement systems could be developed with perhaps renovation and reapplication of spent media.

Hardware Costs Costs for hardware were based on estimates of the installed costs of system components in Florida, including: primary treatment tank (i.e. septic tank), septic tank effluent pump, control system, pressure distribution system to Stage 1 filter, Stage 1 filter enclosure and underdrain, and Stage 2 filter enclosure. The estimated costs of treatment hardware are listed in Table 27.

Primary Treatment and Final Effluent Disposal All alternatives include identical primary treatment (septic tank) installation of $2,800 and identical final disposal system of a non-mounded drainfield that is gravity fed from the Stage 2 filter. If a mound system is required to meet current Florida rule requirements, then installation costs would be greater.

Table 27 Estimated Costs of Treatment Hardware (2008$)

Item	Description	Cost/Unit	No Units	Total
PRIMARY SEPTIC TANK INSTALLATION				
1	1050 GALLON SEPTIC TANK/PUMP CHAMBER	$1,250.00	1	$1,250.00
3	PUMP	$750.00	1	$750.00
3	EFFLUENT FILTER	$300.00	1	$300.00
4	PLUMBING	$500.00	1	$500.00
Subtotal				**$2,800.00**
STAGE I INSTALLATION COST				
5	STAGE I TANKS (2 -1500gal -100 SF)[1]	$1,250.00	2	$2,500.00
6	PUMP TIMER	$300.00	1	$300.00
7	PLUMBING	$150.00	1	$150.00
Subtotal				**$2,950.00**
STAGE II INSTALLATION COST (15 YR OPTION)				
8	STAGE II PIPE TANKS (24IN X 18 FT)	$864.00	2	$1,728.00
9	ACCESS PORTS	$200.00	2	$400.00
10	PLUMBING	$300.00	1	$300.00
Subtotal				**$2,428.00**
STAGE II INSTALLATION COST (5 YEAR OPTION)				
11	STAGE II PIPE TANKS (18IN X 18 FT)	$576.00	2	$1,152.00
12	ACCESS PORTS	$200.00	2	$400.00
13	PLUMBING	$300.00	1	$300.00
Subtotal				**$1,852.00**
STAGE II INSTALLATION COST (1 YEAR OPTION)				
14	STAGE II PIPE TANKS (12IN X 18 FT)	$432.00	2	$864.00
15	ACCESS PORTS	$200.00	2	$400.00
16	PLUMBING	$150.00	1	$150.00
Subtotal				**$1,414.00**

Media Costs Media costs were based on contacting media suppliers and gathering data for at-dock media prices. Shipping costs were obtained from cost estimates provided by shipping firms for whole truckload quantities; whole truckloads would apply for the case of numerous installations of passive nitrogen removal in Florida. Costs were included for media size gradation and bulk storage and handling. Media costs are summarized in Table 28.

Table 28 Estimated Costs of Filter Media (2008$)

Media	Cost at dock	Shipping[1]	Total	Bulk density
	$/lb.	$/lb.	$/lb.	lb/ft^3
Clinoptilolite	$0.25	$0.10	$0.35	55
Livelite	$0.05	$0.05	$0.10	41
Sulfur	$0.35	$0.05	$0.40	77
Oyster shell	$0.35	$0.05	$0.40	82

Operations and Maintenance Costs Operations and maintenance were:

- Two maintenance site visits per year at $150 per visit;
- One PNRS effluent monitoring per year at $100;
- Operating permit at $100 every two years;
- Power: 1209 kW-hr per year at $ 0.103 per kW-hr., based on projected pump efficiency, power efficiency, and run times;
- Septic tank pumping, once per five years at $225; and
- Cost of media replacement and residual management at specified intervals.

Estimated costs for operations and maintenance items are shown in Table 29. Energy use was estimated by assuming one ¾ hp pump operating for 2 minutes every one half hour. Stage 2 effluent monitoring included annual analyses for C-BOD_5, TKN, NO_x, pH and dissolved oxygen.

Table 29 Estimated Costs of Operations, Maintenance and Stage 2 Media (2008 $)

Item	Unit Cost (2008 $)	Uniform Annual Cost[1] (2008 $)	Present Worth[1] (2008 $)
Operations and Maintenance			
Annual Maintenance, yearly	300	287	8,609
Monitoring Analyses, yearly	100	96	2,870
Electricity, yearly	124	119	3,558
Operating Permit, 2 year interval	100	48	1,437
Septic Tank Pumping, 5 year interval	225	43	1,284
Stage 2 Media Replacement[2]			
100 ft^3, once per 15 years	4,304	173	5,198
50 ft^3, once per 5 years	2,152	361	10,844
11 ft^3, once per year	473	452	13,573

[1] 30 year project life, i = 4%.

[2] Includes media, labor, materials, and spent media disposal at $0.05/lb.

LCCA Results The complete treatment system cost of the 12 alternatives was compared on a Present Worth (PW) and Uniform Annual Cost (UAC) basis. PW and UAC for the 12 alternatives are listed in Table 30 for the total system including primary treatment and standard drainfield, and for the Passive Nitrogen Removal Component only (i.e. the Stage 1 and Stage 2 filters). UAC and PW are plotted in Figures 17 and 18, respectively. Uniform Annual Costs of the total treatment system, including all O&M items listed in Table 29, range from $2,262 to $2,728 (Figure 17). The PNRS costs listed in Table 30 include installation with media, as well as media replacement over the project life. The life cycle cost of total treatment systems with two-stage passive nitrogen removal was about 6% higher with clinoptilolite as Stage 1 media versus livlite. The UAC of the Passive Nitrogen Component range from $813 to $1,279, or 36 to 47% of the total system cost. The UAC per volume of effluent treated is shown in Figure 19 and ranges between $0.021 to $0.025 per gallon.

A cost breakout for a single PNRS system is presented in Table 31 for a 100 ft^2 Stage 1 filter with expanded clay media and a 375 gallon Stage 2 filter with a 5 year media replacement interval (System ID 5 in Table 30). The Present Worth of O&M is 41% of the total life cycle cost, illustrating the limitations costs estimates for on-site systems that include installation only but not the continuing costs needed to insure that treatment objectives are being met. Media replacement represents 25% of the total life cycle cost, which is perhaps the greatest source of uncertainty in the total life cycle cost. The cost of primary treatment and pumping to a drainfield (Table 31) represents 58% of the total life cycle cost; this includes all O&M items listed in Table 29 except media replacement. The rationale for fully including theses costs is that an onsite system, with or without PNRS, should be subjected to the same standards of monitoring and inspection. Another assumption is that pumping is necessary for a non-PNRS treatment system, as is the case in many Florida locations with flat topography and high seasonal groundwater tables. The PNRS component represents 41.8% of the total system life cycle cost: this number represents the total cost fraction for installation of PNRS installation with initial media, and media replacement over the project life. The PNRS cost as a percentage of total system cost ranged from 36 to 47% for the alternatives evaluated.

A full summary if the LCCA for all alternatives is shown in Table 32.

Economic analyses for onsite systems have not often used full Life Cycle Cost Analysis, and the costs estimated by LCCA for passive nitrogen technology appear higher than what are often expected for onsite wastewater treatment systems. For comparative purposes, life cycle costs were estimated for an onsite system using a recirculating sand filter (RSF) designed with an average hydraulic loading of 4 gallon/ft^2-day with pressure dosing, including a septic tank and drainfield, but without Stage 2 nitrogen removal. The average costs of the two-stage passive nitrogen removal systems with clinoptilolite and livlite media are compared to the RSF system in Table 33. The cost of the RSF without Stage 2 denitrification ranged from 66 to 80% of the cost of the passive two-stage nitrogen removal system alternatives.

Table 30 Uniform Annual Cost and Present Worth of Alternatives

SYSTEM ID	STAGE 1		STAGE 2		PASSIVE NITROGEN REMOVAL COMPONENT LIFE CYCLE COST 30 year,i=4%,ENR=3.7%		TOTAL SYSTEM LIFE CYCLE COST 30 year,i=4%,ENR=3.7%	
	Media	Plan Area	Media Volume	Replace	Uniform Annual Cost	Present Worth	Uniform Annual Cost	Present Worth
	Type	ft^2	ft^3	Years	2008 ($)	2008 ($)	2008 ($)	2008 ($)
1	Clino	100	100	15	1,015	17,556	2,463	42,614
2	Clino	100	50	5	1,217	21,061	2,666	46,119
3	Clino	100	11	1	1,279	22,131	2,728	47,189
4	Clay	100	100	15	840	14,526	2,288	39,584
5	Clay	100	50	5	1,042	18,031	2,491	43,089
6	Clay	100	11	1	1,104	19,101	2,552	44,159
7	Clino	75	100	15	945	16,343	2,393	41,401
8	Clino	75	50	5	1,147	19,849	2,596	44,907
9	Clino	75	11	1	1,209	20,919	2,657	45,977
10	Clay	75	100	15	813	14,071	2,262	39,129
11	Clay	75	50	5	1,016	17,576	2,464	42,634
12	Clay	75	11	1	1,078	18,646	2,526	43,704

Notes: Stage 1 Media: Clino: Clinoptilolite AMZ Clay: Livlite Expanded Clay
Stage 2 Media: 3:1 Elemental Sulfur & Oyster Shell
Total System Costs includes base septic tank and drainfield installation

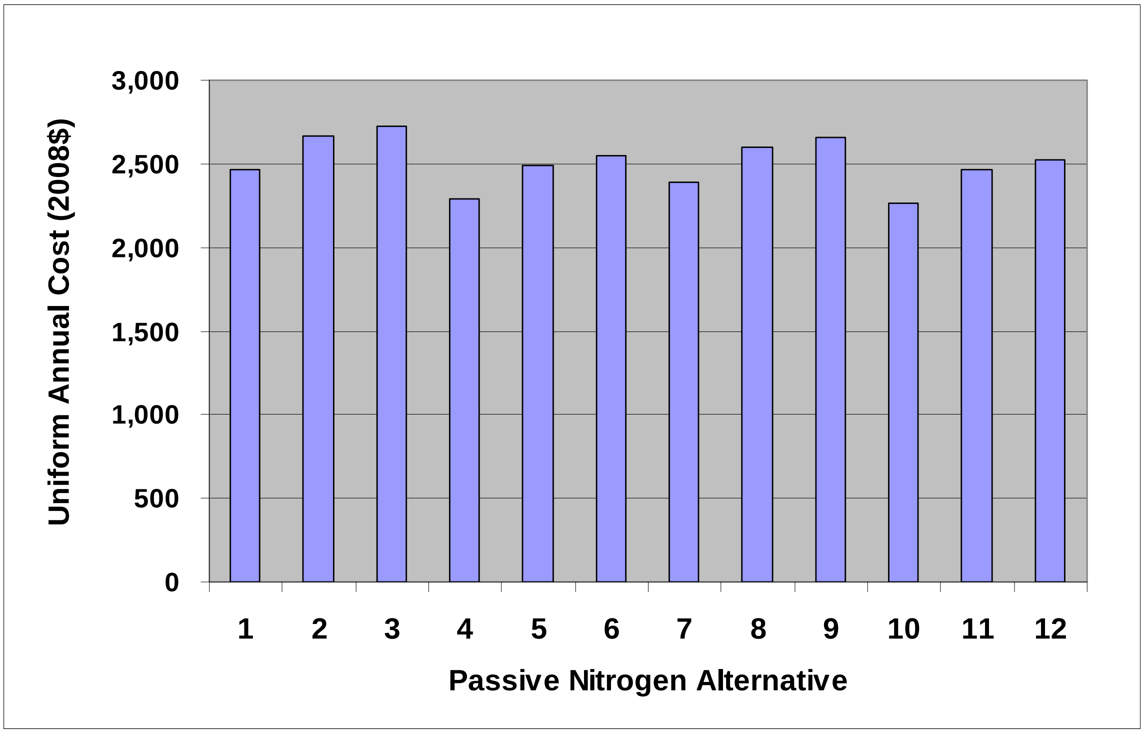

Figure 17 Uniform Annual Cost of Alternative Systems (Refer to Table 30 for alternatives).

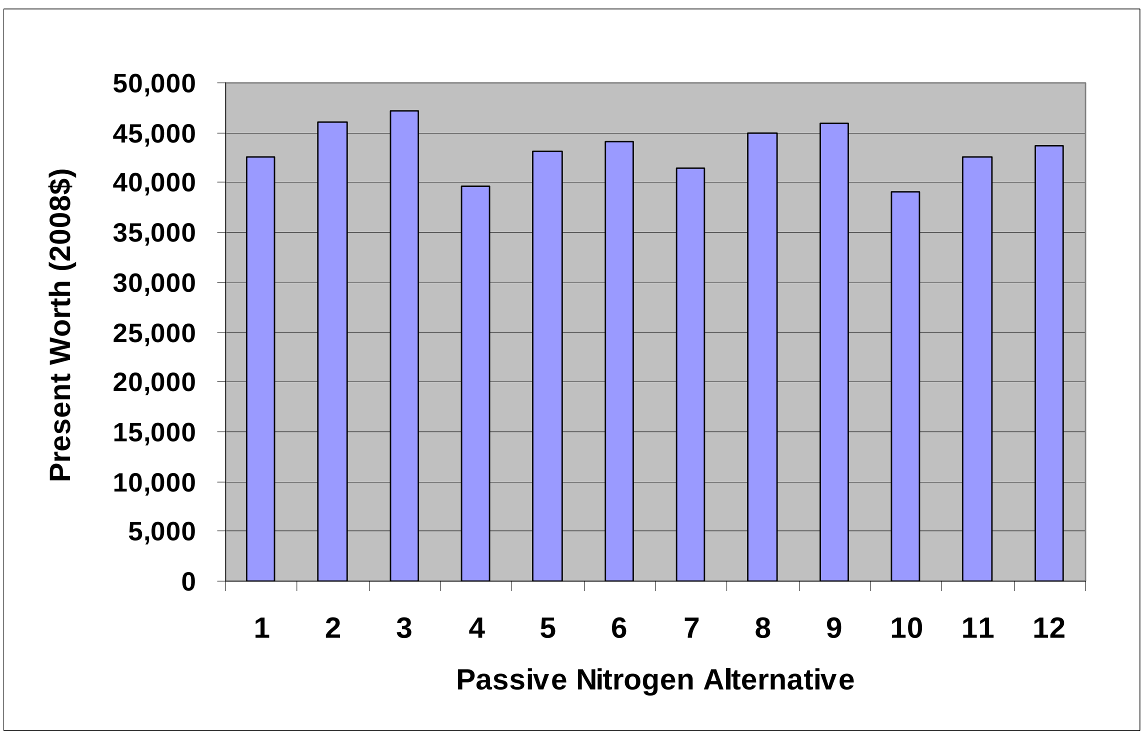

Figure 18 Present Worth of Alternative Systems (refer to Table 30 for alternatives).

Table 31 Passive Nitrogen Removal System Cost Breakout

	PW, 2008 $	% of Total
Installation		
Primary Treatment / Pumping	2,800	6.5
PNRS Stage 1 with Media	3,770	8.7
PNRS Stage 2 with Media	3,417	7.9
Drainfield	4,500	10.4
Total	14,487	33.6
O & M		
Annual Maintenance, yearly	8,609	20.0
Monitoring Analyses, yearly	2,870	6.7
Electricity, yearly	3,558	8.3
Operating Permit, 2 year interval	1,437	3.3
Septic Tank Pumping, 5 year interval	1,284	3.0
Total	17,758	41.2
Stage 2 Media Replacement	10,844	25.2
Total System Life Cycle Cost	43,089	100.0
Primary Treatment/ Pumping/ Drainfield		
Installation	7,300	16.9
O & M	17,758	41.2
Total	25,058	58.2
PNRS Component		
Installation	7,187	16.7
Media Replacement	10,844	25.2
Total	18,031	41.8

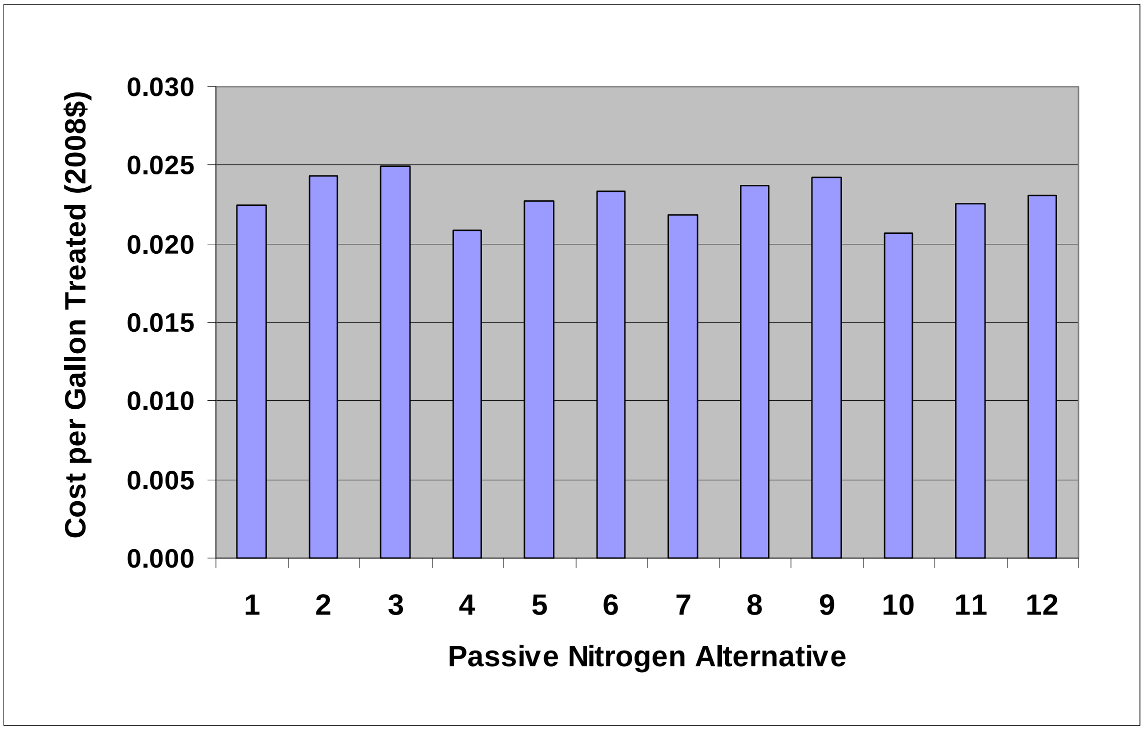

Figure 19 Uniform Annual Cost per Volume Treated (Refer to Table 30 for alternatives).

The treatment cost per mass of nitrogen removed was calculated for the two-stage passive nitrogen removal systems and RSF. The analysis was conducted using a 300 gallon per day flowrate and the average TN concentration (77.4 mg/L) measured in STE the experimental PNRS studies. The average TN removal efficiencies in the PNRS experimental studies were employed. A 50% TN removal efficiency was used for RSF. Nitrogen removal costs for total systems the included PNRS were $33 to $40 per pound and were over $50 for the RSF (Figure 20). The higher unit cost for RSF was affected by lower TN removal efficiency employed in the calculation.

Life cycle costs are compared in Table 34 for treatment systems that include PNRS Stage 1 filters and RSF. The costs include primary treatment and all operating and maintenance items listed in Table 29 and table 32, except media replacement. O&M costs comprise 70 to 81% of the total life cycle costs for clinoptilolite and expanded clay filters. The O&M cost fraction for RSF is higher (87%) due to higher energy costs of recirculation pumping. The PW is higher for larger Stage 1 filters due mostly to greater media costs. The one pass filters with clinoptilolite and expanded clay have higher media costs but lower O&M due to lower energy use; the net effect is roughly similar life cycle costs. RSF can reduce TN by pre-denitrification (with septic tank organic carbon) and by denitrification within the sand media. The one pass clinoptilolite filter can also reduce TN by denitrification within the clinoptilolite media. TN reduction in aerobic filters would reduce the NO_x loading to a subsequent denitrification filter and possibly enable smaller denitrification filter sizes, longer media replacement intervals, and lower life cycle costs for denitrification.

Table 32 Full Life Cycle Economic Analysis for Passive Nitrogen Removal Systems

SYSTEM ID	STAGE 1							STAGE 2							TOTAL LIFE CYCLE COSTS (30 YRS, i=4%)										
	Media	Plan	Hardware (includes septic tank)	Media Qty.	Cost Opinion	Media Cost	System Cost	Replace	Media Vol.	Hardware	Media Qty.	Cost Opinion	Media Cost	System Cost	Installed System	Standard Drainfield	**Total System Installed**	Maintain, Monitor, Permit	Energy	Septic Pumping	**Total O&M**	**Stage II Media Replace**	Salvage Value	Total Life Cycle Cost: Present Worth	Total Life Cycle Cost: Uniform Annual Cost
	Type	ft^2	2008 ($)	lbs	$/lb	2008 ($)	2008 ($)	Years	ft^3	2008 ($)	lbs	$/lb	2008 ($)	2008 ($)	2008 ($)	2008 ($)	2008 ($)	2008 ($)	2008 ($)	2008 ($)	2008 ($)	2008 ($)	2008 ($)	2008 ($)	2008 ($)
1	Clino	100	5,750	11,000	0.35	3,850	9,600	15	100	2,428	7,825	0.40	3,130	5,558	15,158	4,500	19,658	12,916	3,558	1,284	17,758	5,198	0	42,614	2,463
2	Clino	100	5,750	11,000	0.35	3,850	9,600	5	50	1,852	3,913	0.40	1,565	3,417	13,017	4,500	17,517	12,916	3,558	1,284	17,758	10,844	0	46,119	2,666
3	Clino	100	5,750	11,000	0.35	3,850	9,600	1	11	1,414	861	0.40	344	1,758	11,358	4,500	15,858	12,916	3,558	1,284	17,758	13,573	0	47,189	2,728
4	Clay	100	5,750	8,200	0.10	820	6,570	15	100	2,428	7,825	0.40	3,130	5,558	12,128	4,500	16,628	12,916	3,558	1,284	17,758	5,198	0	39,584	2,288
5	Clay	100	5,750	8,200	0.10	820	6,570	5	50	1,852	3,913	0.40	1,565	3,417	9,987	4,500	14,487	12,916	3,558	1,284	17,758	10,844	0	43,089	2,491
6	Clay	100	5,750	8,200	0.10	820	6,570	1	11	1,414	861	0.40	344	1,758	8,328	4,500	12,828	12,916	3,558	1,284	17,758	13,573	0	44,159	2,552
7	Clino	75	5,500	8,250	0.35	2,888	8,388	15	100	2,428	7,825	0.40	3,130	5,558	13,946	4,500	18,446	12,916	3,558	1,284	17,758	5,198	0	41,401	2,393
8	Clino	75	5,500	8,250	0.35	2,888	8,388	5	50	1,852	3,913	0.40	1,565	3,417	11,805	4,500	16,305	12,916	3,558	1,284	17,758	10,844	0	44,907	2,596
9	Clino	75	5,500	8,250	0.35	2,888	8,388	1	11	1,414	861	0.40	344	1,758	10,146	4,500	14,646	12,916	3,558	1,284	17,758	13,573	0	45,977	2,657
10	Clay	75	5,500	6,150	0.10	615	6,115	15	100	2,428	7,825	0.40	3,130	5,558	11,673	4,500	16,173	12,916	3,558	1,284	17,758	5,198	0	39,129	2,262
11	Clay	75	5,500	6,150	0.10	615	6,115	5	50	1,852	3,913	0.40	1,565	3,417	9,532	4,500	14,032	12,916	3,558	1,284	17,758	10,844	0	42,634	2,464
12	Clay	75	5,500	6,150	0.10	615	6,115	1	11	1,414	861	0.40	344	1,758	7,873	4,500	12,373	12,916	3,558	1,284	17,758	13,573	0	43,704	2,526
RSF	SEPTIC SAND	100	5,000	19,800	0.014	277	5,277	na	na	na	na	na	na	na	5,277	4,500	9,777	12,916	7,116	1,284	21,316	na	0	31,093	1,797

Notes: Stage 1 Media: Clino: Clinoptilolite AMZ Clay: Livlite Expanded Clay
Stage 2 Media: 3:1 Elemental Sulfur & Oyster Shell
Total System Costs includes base septic tank installation and drainfield

Table 33 Comparison of Total System LCCA for PNRS and RSF

System	Uniform Annual Cost (2008 $)[1]	Present Worth (2008 $)[1]
Two Stage Filter with Clinoptilolite[2]	2,584	44,701
Two Stage Filter with Expanded Clay[2]	2,430	42,050
Recirculating Sand Filter, One Stage	1,797	31,093

[1]30 year life, i=4%

[1]Average of 6 alternatives

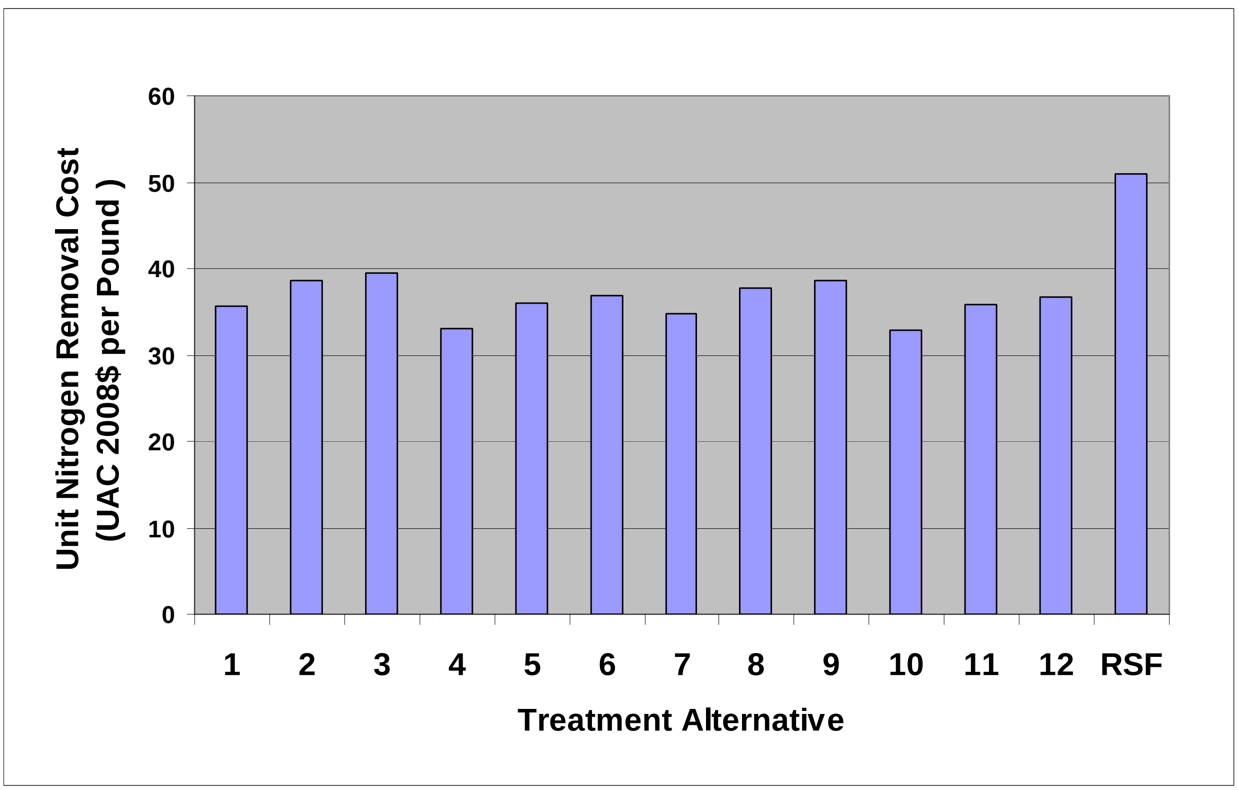

Figure 20 Unit Nitrogen Removal Costs of Passive Nitrogen Systems and RSF (Refer to Table 30 for alternatives).

Table 34 Present Worth Cost Comparison of One Pass Aerobic Filters and RSF (includes primary treatment)

Media	Filter Area	Installation PW (2008$)	O & M PW (2008$)	Total PW (2008$)
Clinoptilolite	100 ft^2	9,600	17,758	27,358
	75 ft^2	8,388	17,758	26,146
Expanded clay	100 ft^2	6,570	17,758	24,328
	75 ft^2	6,115	17,758	23,873
RSF	75 ft^2	5,277	21,316	26,593

Passive Nitrogen Removal Recommendations

Passive Nitrogen Removal System

The objective of the Passive Nitrogen Removal Study was to identify “passive” onsite treatment systems that can achieve greater nitrogen reductions than exhibited by conventional septic tank/drainfield systems yet are relatively simple to operate and have low life cycle costs. In this context, “passive” was defined by the Florida Department of Health as employing biological nitrogen removal processes that were configured in such a way as to eliminate the need for mechanical aeration equipment, require no more than one pump, and employ reactive media.

The study’s focus was only on Passive Nitrogen Removal Systems (PNRS) that would be suitable for single family homes, which discharge septic tank effluent (STE) with characteristics typical of single family residences in the U.S. (U.S. Environmental Protection Agency, 2002). From the literature review of passive biological nitrogen removal processes conducted in Task 1, and evaluation of equipment and issues important to practical implementation of PNRS technology, candidate PNRS were identified. What appears to be the most promising type of PNRS is embodied by a two stage system that consists of an above ground, unsaturated (aerobic) gravity nitrification fixed-film reactor (Stage 1) and a horizontally configured saturated (anoxic/anaerobic) fixed-film denitrification reactor (Stage 2). This PNRS is envisioned as a sequence of operations inserted between the septic tank and the drainfield of a conventional onsite treatment system as shown in Figure 21.

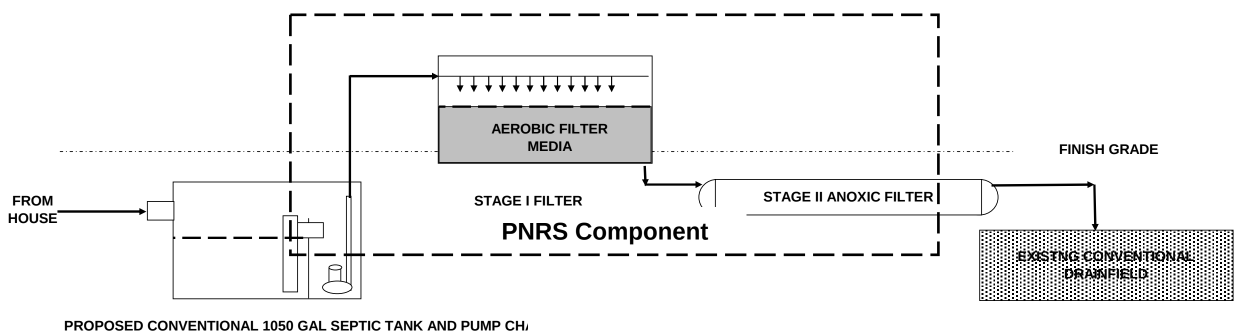

Figure 21 Conceptual PNRS Component Placed within Conventional Onsite System

Wastewater from the home would flow through a septic tank after which the STE enters a flow equalization tank or chamber, the first component of the PNRS. A small pump would be set to operate on regular timed intervals to provide flow equalization. The pump would be used to lift the STE to the Stage 1 filter, which contains a specified granular media. The Stage 1 filter is set at an elevation that achieves gravity flow through the entire PNRS process train and into the subsurface infiltration trenches. This use of the pump, which is the one single pump that is allowed by the criteria established by FDOH, provides the benefits of equalizing the daily flow throughout the day and pressurized distribution to achieve uniform application of the STE over the Stage 1 filter. Uniform areal distribution of limited volume doses is critical to maintaining unsaturated and aerobic conditions in the filter media and effective process performance. These conditions are necessary to support autotrophic bacteria that can nitrify the organic and ammonium nitrogen (Total Kjeldahl N or TKN) in the wastewater and maximize the residence time of the STE as it percolates downward through the filter media. The nitrified filtrate collects at the filter bottom where it flows by gravity into the Stage 2 filter. The Stage 1 filtrate flows through the Stage 2 filter media. The Stage 2 filter media is specific mixture that is submerged below the water surface (i.e. pores are water saturated), which provides the necessary anoxic/anaerobic biochemical conditions to support denitrification of the Stage 1 filtrate. The nitrogen gas produced in this stage is vented to the atmosphere and denitrified filtrate leaves the PNRS and continues to flow by gravity to the subsurface infiltration trenches for dispersal into the soil.

In addition to nitrification and denitrification, the PNRS also would substantially reduce biochemical oxygen demand, suspended solids, and other constituents such as pathogens. Thus, PNRS would have the effect of "lightening the load" to a soil dispersal system. The soil system would shift from a role of a principal treatment component to one of dispersal of the advanced treatment effluent, and in addition, of providing polishing treatment, backup protection and other options for effluent dispersal and reuse.

PNRS can also be configured to be adaptable for a number of additional treatment requirements, some of which are mentioned here. Phosphorus can be reduced by sorption on media with high P affinity. PNRS can be evolved into a Passive Nutrient Removal System (PNuRS) by incorporating P removal media. Since both P removing media and reactive denitrification media have some limited life and will eventually have to be replaced, one logical approach would be to incorporate P sorbing media into the Stage 2 filter. Other options include a separate P removal filter following the Stage 2 denitrification filter, or placing P removal media in a modified soil dispersal system. It is noted that the experimental studies that were conducted included two Stage 2 denitrification filters that contained expanded shale (utelite) as a media component, which is reported to have an appreciable affinity for inorganic P.

Reduction of pathogens from onsite wastewater is a high priority for environmental and public health protection. The ability of PNRS to remove target pathogens or indicator organisms has not been measured, so there is no specific data with which to support reductions in soil system size. However, the PNRS configuration employs biological filtration through 24 in. of unsaturated filter media (Stage 1) followed by biological filtration through saturated, anoxic filter media (Stage 2). Physical, chemical and biochemical processes within PNRS would reduce the levels of pathogen and indicator organisms. Since PNRS will reduce pathogens, it is possible that the size of soil systems that receive PNRS effluent could be reduced. Measurement of pathogen and indicator organism reductions in PNRS are needed before specific design recommendation can be made for reduction in drainfield area.

PNRS can de adapted for enhanced pathogen destruction using other technologies such as ultraviolet disinfection. PNRS compatible UV systems are available that feature low energy consumption, long life, and minimization of fouling through management of lamp surface temperature. A logical placement of UV in PNRS would be after the anoxic denitrification filter (Stage 2), although placement between the Stage 1 and Stage 1 filters may offer unique advantages.

PNRS effluent is low in dissolved oxygen. Introduction of PNRS effluent into an unsaturated media, such as a sand filled soil treatment layer located above the water table, would result oxygen transfer into the PNRS effluent stream. The same process would occur in natural soil provided that PNRS effluent was introduced into unsaturated media; rate of oxygenation would depend on the aeration capacity of the soil media. In addition, sulfate is a product of sulfur based autotrophic denitrification and the possible effects of sulfate in the treated water would require evaluation.

PNRS may have an inherent ability to address emerging contaminants, including a wide variety of substances such as chemical components of personal care products, pharmaceutical products and their metabolic derivatives, consumer food items and their breakdown products, and hormonally active substances. PNRS treatment systems host a great surface area with a highly varied ensemble of microenvironment niches with specific chemical conditions, microbial transformations, and redox environments. A variety of microbial biofilm actions can be brought to bear on specific emerging contaminants, leading potentially to phenomena such as cometabolism and secondary substrate utilization. The ability of PNRS to remove the numerous emerging contaminants is unknown. The use of oxidation technologies, such as ozone, could be incorporated in PNRS for enhanced removal of specific contaminants. Incorporating advanced technologies with PNRS would perhaps be more feasible for cluster treatment and larger systems.

Recommendations

The following sections address pertinent issues of PNRS for onsite treatment and make recommendations for:

- Design
- Permitting
- Installation
- Control
- Maintenance and monitoring
- Replacement of passive treatment media.

Design

The PNRS consists of three components; Lift Pump/Flow Equalization, Stage 1 Filter, and Stage 2 Filter. The individual component design requirements are discussed below. However, because the PNRS relies primarily on gravity flow through the process train, these relative elevations of the assembled components of the PNRS and the septic tank and subsurface infiltration trenches are critical. It is essential that the engineering design develop a full, site specific hydraulic profile for the entire onsite treatment system, including the house wastewater drain invert, primary treatment (septic tank), the PNRS components, and the subsurface infiltration trenches (drainfield).

Flow Equalization

The flow equalization component of the PNRS should provide the following:

- Screened septic tank influent
- Wet well
- Dosing pump and programmable controls and optional telemetry
- Daily flow measurement
- Securable access

The wet well is a watertight vault that is downstream of the septic tank. It may be a separate chamber within the septic tank or a separate tank. The influent to the vault (assumed to be STE) should be screened to remove larger particulates in the STE. The screen should be attached to septic tank outlet.

The vault must have a sufficient "working volume" (volume between the pump off level control and the high water alarm level control) to provide storage of wastewater between pumping events to equalize the flow to the PNRS throughout the day. For single family home systems, the volume provided is typically 50% or greater of the average daily wastewater flow.

The dosing pump is a submersible pump that is elevated off the vault floor on a low pedestal to prevent solids that accumulate on the vault floor from being drawn into the pump volute. The pump must be sized to be capable of providing the design discharge rate of the pressure distribution network in the Stage 1 filter and the static lift and force main losses between the pump and the Stage 1 filter distribution network. A 3 or 4 level control system should be used. The level controls include 1) pump off (redundant to the timer), 2) dose enable (level at which a full dose is ensured (volume between the dose enable and pump off control), which is necessary for filling and pressurizing the distribution network), 3) optional override to pump out wastewater in excess of assumed normal operating flow, and 4) high water alarm. A 3 level control system does not include the override control. In addition to the level controls, a timer is used to operate the pump on regularly spaced timed intervals throughout the day.

Daily flow measurement is important to diagnosing performance problems with the PNRS. The capability to record daily flows should be provided. The most simple devices that can provide adequate accuracy are a running time meters for the pump and counter to record the total number of pumping events.

Easy access to the vault and pump must be provided. The vault access should be above grade and securable to prevent unauthorized entry.

Stage 1 Filter

Unsaturated filtration is a well established onsite wastewater treatment technology that is widely applied. General design principals used in current onsite practice also apply to the unsaturated PNRS Stage 1 filter. The most widely applied unsaturated filter systems that would meet the FDOH "passive" definition are single pass, intermittent sand filters. Recirculating media filters that can achieve recirculation by gravity would also meet the "passive" definition. PNRS design can employ much of the knowledge and techniques of sand filter designs, which can be found in sources including Anderson, et al., 1985, Crites and Tchobanoglous (1996), Commonwealth of Massachusetts (2002), Jantrania and Gross (2006), and US EPA (2002).

The Stage 1 Filter should provide the following:

- Filter housing that is structurally suitable for above grade installation
- Filter size that can accommodate a minimum of 100 ft^2 of surface area, 24 in. depth of select filter media, and underdrain
- Underdrain
- Select media
- Pressurized distribution system for applying STE over the media
- Removable filter cover providing ports for air ingress;
- Accessible filtrate monitoring port at outlet;
- Gravity flow conveyance to the Stage 2 filter.

The filter housing can consist of a number of materials, but is typically concrete or constructed of landscaping timbers above grade over an impermeable liner below grade. Underdrain piping consisting of a minimum of two 4-in perforated DWV (non-pressurized drain, waste, vent pipe) with 0.5 in holes at the 5 and 7 o'clock positions, will be used to collect Stage 1 effluent; pipes are laid on the tank floor or impermeable liner. These drains are connected to a common outlet drain that leads to the Stage 2 filter. The underdrain is covered with 6-in of 0.75 to 1.5 in. gravel, which in turn is covered with 3 to 4-in of pea gravel. The select filter media used is clinoptilolite or livlite, which is washed before placement, and placed in stratified configuration as described in the experimental section and QAPP which is included in Appendix D.

The elevation of the filter housing underdrain outlet invert is a critical to gravity flow within the PNRS. This invert elevation must provide sufficient elevation to maintain complete submergence of the Stage 2 filter media and maintain flow to the infiltration system without backing up into the Stage 1 filter. Fiction losses in the Stage 2 filter media must be considered.

STE is applied to the surface of the filter media by a pressure distribution network (see Converse and Tyler, 2000; Otis, 1982; US EPA, 1980; US EPA, 2002). Small diameter pipe that is perforated with small orifices is used. The goal of the network design is to provide the highest density of orifices as reasonable. However, there is a trade-off; the greater the number of orifices, the larger the pump required. Also, more orifices can mean more piping, which in turn means that dose volumes must increase to achieve pressurization of the network if the distribution is to be uniform. Therefore, the distribution network design must depend on the desired number of daily doses and rate of application. For single pass filters, doses will be limited to 6 or 8 per day. It will be difficult to achieve uniform distribution with a larger number of daily doses without making the orifices very small, which makes them susceptible to plugging. If more doses per day are required, the Stage 1 filtrate should be recirculated (see recirculation below).

The filter surface and distribution piping must not be open and directly exposed to the atmosphere; direct human contact must be prevented. The filter surface may be covered with pea gravel and left open to the atmosphere. Odors typically are not a problem. However, rainfall on the filter surface must be accounted for in design. A flat fiberglass cover works well, (if designed to support foot traffic). Venting is required to provide aeration, which can be provided by elevating the cover to create a small gap between the cover and the tank wall. If security is an issue, external vents can be used so that the cover can be locked down.

Recirculation is an option for the Stage 1 filter design. Recirculation offers several advantages. Because doses can be larger, the number of doses per day can be increased to a maximum of 48 per day, thereby increasing residence time of the STE in the filter for more complete nitrification. The increased number of doses maintains a moist environment in the filter to enhance biochemical activity. With recirculation, other studies have shown that 50% of the total nitrogen (TN) in the STE will be removed. If the filtrate is recycled back to the septic tank to utilize the organic carbon in the STE as an electron donor in the biochemical process, the removals can increase to 70%. This will lower the NO_x loading to the Stage 2 filter and theoretically increase the longevity of the reactive denitrification media. Recycling of Stage 1 filter effluent to promote pre-denitrification will also recover alkalinity that is removed during nitrification, allowing nitrification to proceed without excessive pH decline. This is an important advantage where the STE has a high ratio of TN to alkalinity.

The Stage 1 filtrate can be recycled back to either the flow equalization component or to the septic tank. In either case, the sizing of the tanks must be reviewed to ensure adequate storage for flow equalization and hydraulic residence time in the septic tank is provided. A one day residence time within the primary tank including recirculation flows can be used as initial guidance to evaluate the extent to which recirculation rate can be increased with existing tankage, or if additional pumping tanks capacity is warranted. Similarly, flow equalization may require assessment of flow variations on a weekly and longer timescale.

To properly evaluate the recirculation option, additional experimental studies should be performed. The filters in the experimental studies were operated in single pass mode, and this remains the basis of the present recommendations.

Stage 2 Filter

The Stage 2 filter should provide the following:

- Stage 2 filter housing of fiberglass or plastic pipe with a horizontal orientation
- Select media with a total volume of 50 ft^3 (375 gallon)
- Gas venting
- Accessible monitoring point at outlet

The Stage 2 filter housing is envisioned as a watertight, horizontal fiberglass or plastic 24-in diameter pipe. Its total length is 18 ft to provide a length to width ratio of at least 10:1. The total media volume should be at least 50 ft^3. Header plates, perforated with 0.25-in diameter holes on square matrix at 2 in. centerline spacing, are placed inside the filter housing at the inlet and outlet ends. Their purpose is to secure the media and facilitate uniform distribution of flow within the Stage 2 filter.

The media consists of a 3:1 volumetric ratio of granular elemental sulfur/oyster shell, as specified in the QAPP for the experimental studies (Smith, 2008). Friction losses through this media must be determined to set the Stage 1 filter outlet invert elevation so that flow through the Stage 2 filter and to the infiltration trenches can be maintained at all flow rates without flooding the Stage 1 filter outlet.

The elevation of the Stage 2 filter outlet invert to the infiltration trenches should be set such that a small air gap is maintained at the crown of the pipe to vent the off-gases from the media. This gap should be vented into a short length of a buried rock filled trench to scrub odors from the venting gases.

It is recommended that an alternative configuration be tested consisting of short segments, which are loaded in parallel by a common header to reduce the total headloss through the system so the Stage 1 filter can be lowered in elevation. The short segments also would simplify media replacement. However, the parallel configuration will reduce the length to width ratio, which may increase the potential for preferential flow through the media with a concomitant reduction in media contact and residence time that could reduce nitrogen removal performance.

PNRS can be configured using a modular type design approach that is adaptable for larger applications, such as cluster systems, or that is expandable as the required treatment capacity increases. It is envisioned that, with the creation of a sufficient market, vendors would establish regional media inventory, reducing shipping costs and preparing material according to required size gradations. Alternative sources of alkalinity, perhaps local sources, could be explored for their possible advantages in terms of cost, process efficacy, and residuals management.

Permitting

Regulation of onsite systems in Florida is governed by the Florida Administrative Code, Chapter 64E-6, *Standards For Onsite Sewage Treatment And Disposal Systems,* and also in Chapter 381 of the Florida Statutes. These rules allow innovative and alternative systems to be used but require testing and evaluation of the systems prior to general approval. PNRS could be developed as modular components of total treatment systems, using specific PNRS materials and components, with standardized models that can treat specific flows and loadings and meet established effluent water quality specifications. Nothing in these rules would seem to prohibit PNRS, nor does it appear that special rule provisions are needed to allow PNRS.

Possible routes to enhance acceptance of the technology and regulatory approval include further testing and evaluation of full scale units; application for an Innovative System Permit; application for System Construction Permit; and certification testing under protocols established by the National Sanitation Foundation (NSF) Environmental Technology Verification (ETV) Program. In addition, the consumables would have to be in compliance with the additive rules; for PNRS, the only possible consumable would be the Stage 2 denitrification media.

The PNRS provide a high level of treatment low in TN, BOD, and TSS, which should qualify for reductions in drainfield size or increases in drainfield hydraulic loadings as allowable for Performance Based Treatment Systems.

Installation

Installation and construction of PNRS share common procedures with traditional onsite treatment systems including the location of the residence, locations of other structures and wells, property boundaries, trees and vegetation, topography and elevations, seasonal high groundwater table elevations, and aesthetic and environmental constraints. Other considerations include available area and elevation differences, electrical supply for the dosing pump, and access for system construction, system maintenance and periodic media replacement. The following installation items are the most critical to the PNRS performance:

- System layout and system hydraulic profile
- Media preparation and placement
- Watertightness testing of all components and piping

A system layout plan that ensures an efficient use of the available area and available elevation must be developed. This includes a hydraulic profile of the complete system from the either the house plumbing stub out or the septic tank outlet invert to the inlet invert of the infiltration system. It is critical to establish the hydraulic profile before construction commences to ensure that flow through the system from the Stage 1 filter outlet can occur by gravity. An important aspect of this profile is to determine the headloss through the Stage 2 filter. If too great for the available hydraulic "fall" across the system, other configurations of the Stage 2 filter should be considered including deep bury to create a high driving head through the filter, multiple modules laid horizontally and plumbed to operate in parallel, multiple modules installed vertically and plumbed in series, or other configurations to allow gravity flow. The one pump PNRS system would require the stage 1 filter to be above grade. Depending on the seasonal high groundwater table elevation, a one pump PNRS system would require from all to none of the Stage 2 filter to be above grade. Use of a second pump could reduce or eliminate above grade components.

Both the Stage 1 and Stage 2 filter media should be repeatedly rinsed with clean water on-site to remove fines prior to placement in the filter housings. Fine particles within virgin filter media can consist of fines particles of the media itself or other materials, and their presence within granular media can lead to clogging and hydraulic failure. Placement of the media must follow the specifications as described in the experimental study QAPP (Appendix D). In the Stage 1 filter, the clinoptilolite or livlite filter media, must be well sorted by size and placed on level within one inch in the specified stratified configuration. The Stage 2 filter sulfur and oyster shell media, must be mixed after rinsing to achieve spatially homogeneity before placement.

Control

The rate at which well operating treatment performance is established in a biological treatment system depends on the establishment of microbial populations. Treatment with PNRS should be established at least as quickly as for a suspended growth system. Startup should be rapid and can be accomplished using full strength wastewater and normal hydraulic operation. Control methods are covered previously in the Flow Equalization section.

In the future, distributed treatment infrastructure may be operated and maintained by Responsible Management Entities (RMEs). An RME would have responsibility for managing multiple systems for single family residences, cluster systems, and larger systems. Remote monitoring of onsite treatment systems is one tool which may be used by future RMEs. The PNRS is compatible with remote monitoring, which could transmit signals for power failure, level alarms, or pump failure.

Maintenance and Monitoring

Maintenance recommendations for PNRS include:

- Once per six month checking of counters and elapsed-time meters;
- Once per year inspection and servicing of all electrical and mechanical parts, including pump, filters, float assembly, and control panel;
- Once per year flushing and testing of flow distribution system by manual operation and visual observation;
- Once per year process testing by sampling the Stage 2 filter effluents for BOD, DO, and TKN and Nitrate analyses.

Replacement of Passive Treatment Media

Stage 2 media composition is specified as sulfur and oyster shell with a 3:1 volumetric ratio, as was applied in all of the Stage 2 columns in the experimental investigation (Appendix D). The filter design cases evaluated in the economic analysis did not include utelite (expanded shale) in the Stage 2 filter media since experimental results did not provide definitive evidence of a benefit. Incorporating additional media components in any Stage 2 design reduces the space available for the reactive sulfur and the theoretical longevity of media. Utelite was not included in the recommended Stage 2 media since the experimental results did not provide definitive evidence of a benefit.

The economic analysis included three options for Stage 2 filter size/media replacement combinations, as listed in Table 35. These options span a spectrum from a low reactor volume, frequent media replacement strategy to one of larger filter size with longer run time and less frequent media replacement. These options reflect the lack of continuous operating data for sulfur based denitrification systems, particularly for long term deployment in field conditions. The smaller filter design with frequent media replacement would be advantageous if shorter term performance deterioration was caused by factors such as preferential flow paths (channeling) or chemical precipitation. In this case, the NO_x removal effectiveness of the Stage 2 filter would decline, even though the sulfur media was largely unused. Modular media replacement systems could be developed with perhaps renovation and reapplication of spent media. To fully explore Stage 2 filter design, longer term operation of treatment systems is needed to demonstrate continued NO_x removal performance. The recommended design is the intermediate filter size case, which provides a relative Stage 2 volume and empty bed residence time similar to that of the Stage 2 filters that were operated in the experimental study.

Media replacement recommendations for PNRS include:

- Full media replacement at five year interval;
- Biannual NO_x monitoring of PNRS effluent for possible variation in media replacement intervals;
- Disposal of media in landfill;
- Investigate possible processing of removed media for reapplication;
- Investigate alternative beneficial uses for removed media.

Table 35 Stage 2 Design Options

Stage 2 Design Option	Filter volume, gallon	Replacement interval, year
High volume, infrequent media replacement	750	15
Intermediate volume and media replacement	375	5
Low volume, frequent media replacement	75	1

Operating experience with sulfur based passive nitrogen removal processes for denitrification of onsite wastewater is limited, as is the exploration of residuals management options. For this reason, the landfill disposal option is included in the economic analysis and recommendations. While landfill disposal represents is expedient, it should actually be considered to be last on the preferred hierarchy of management options.

At the top of the management hierarchy is minimizing the production of residuals by regenerating or restoring the media so it can be reused in the process. Preferential flow paths could result in deterioration of denitrification filter performance as evidenced by increasing effluent NO_x concentrations. In this case the sulfur media could retain much of its electron donor capacity, resulting in only partial use of sulfur. The media could be reused by simple removal from the filter followed by washing or scouring. Further treatment by acid washing could restore media if chemical precipitates (e.g. calcium carbonate) were coating media surfaces. Either procedure would enable media to be reused and lower net residuals generation. Replacement media would consist of restored media with some new media makeup.

The next level on the residuals management hierarchy is application of used sulfur or carbonate media for a beneficial purpose. One example is in agriculture. Elemental sulfur can be used as a soil amendment to lower the pH of soils used for the cultivation of acid loving plants. Additionally, sulfur deficiency is a problem that has been noted in Florida citrus, particularly when non-sulfur containing fertilizers are applied (*Macronutrient Deficiencies in Citrus: Calcium, Magnesium, and Sulfur***,** Fact Sheet SL 202, Soil and Water Science Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. January 2003. http://edis.ifas.ufl.edu). Elemental sulfur residuals could be suitably applied as soil amendments. Currently in Florida, reclaimed wastewater and biosolids residuals are widely used beneficially in citrus production, so a history already exists of reusing wastewater treatment residuals.

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APPENDIX A

MEMO TO MASSACHUSETTS ALTERNATIVE SEPTIC SYSTEM TEST CENTER

TO:

George Heufelder, Director
Keith J. Mroczka, Test Center Operator
Massachusetts Alternative Septic System Test Center

FROM:

Daniel Smith, PhD, PE Applied Environmental Technology (AET)
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DATE: 5/29/2007

RE: Florida Passive Nitrogen Removal Study

The Florida Passive Nitrogen Removal Study is a literature review being conducted by AET for the Florida Department of Health (FDOH). The object is to identify and characterize "passive" systems to enhance nitrogen removal in on-site wastewater treatment systems. Florida DOH requests a literature summary and database of available passive nitrogen removal technologies, which can include in-tank systems or modifications to soil treatment units (drainfields). FDOH is interested in technologies that treat influents ranging from septic tank effluent (STE) (i.e. organic and ammonia N, no nitrate) to substantially nitrified effluent. The overall goal is enhanced Total Nitrogen removal: performance, life cycle cost, and permitability, for new or retrofit systems.

During a recent visit to the Massachusetts Alternative Septic System Test Center, it was indicated that systems that are being tested at the center may be of interest to the Florida Passive Nitrogen Removal Study. Vendors with appropriate technologies may be interested in having their technologies included in the Florida DOH study. This memo is to request information from such vendors that describes their technology and characterizes the treatment process, its mode of application within on-site treatment systems, nitrogen removal performance, longevity, operations and maintenance, economics, and any special considerations for deployment.

Vendors are encouraged to contact Dr. Smith directly to discuss this study or to provide the technology information (contact information is listed above). The following list contains some specific information that would be useful to include in the database. It is realized that not all of this information may be available or compiled, or may be included within documents or reports.

Florida Passive Nitrogen Removal Study Technology Description and Characterization

- Name of technology or process
- Name and contact information of provider
- Process description
  - Treatment principal
  - Treatment goals
  - Unit operation sequence; where unit fits in to treatment sequence
  - Operational methods: passive, dosed, other
- Performance evaluation
  - Testing entity
  - Location and duration
  - Operation and monitoring methods
- Provide references for performance evaluations, certifications
  - email reports, documents, papers, citations
  - web links
  - hard copies of reports, documents, papers
- Performance data
  - Physical description of test unit
    - o Location within treatment sequence
    - o Unit dimensions: plan area, depth, other
    - o Operational method: passive, dosed, other
  - Operational history
  - Influent and effluent flowrates
  - Influent and effluent monitoring data
    - o Temperature
    - o pH
    - o Alkalinity
    - o BOD, COD, TOC
    - o TSS, VSS
    - o Nitrogen: Total N, TKN, Organic N, NH_4-N, NO_2-N, NO_3-N
    - o Other parameters
- Full scale operations and maintenance
  - regular operation
  - inspection and maintenance requirements
  - media replacement intervals
- Longevity
  - the life of passive media (for denitrification for example) for a typical application based on field data or theoretical calculation; list all assumptions
- Economics
  - installation cost
  - specific breakout of media cost
  - operation
  - maintenance
  - media replacement
  - life cycle cost including all of above
- Special Issues relation to permitting and deployment

APPENDIX B

PASSIVE NITROGEN REMOVAL CITATION LIST

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APPENDIX C

PASSIVE NITROGEN TECHNOLOGY

Nitrification Processes

Description/Name of Technology	Reference(s)	General Description	Method of Deployment	Pumps and Recirculation	Test Data	Test System	Influent	Test Information	Water Quality														
Recirculating Sand Filters	20,24,33,40,41,53,56,84, 88,94,111,118,130,131, 142,153,159,166,199,210,209	Sand media	Septic tank effluent treatment	With or without recirculation					**Influent (STE)**							**Effluent**							% Total N removal
									BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	
					Urynowicz, 2007	Field scale recirculating sand filter	Septic tank effluent												15.2/18.2				72.0/63.0
					Loomis, 2004	Field scale single pass sand filter	Septic tank effluent																15/21
					Loudon, 2004	Over 40 field scale recirculating sand filters	Septic tank effluent																27 to 76
					Osesek, 1994	Two field scale recirculating sand filters	Septic tank effluent																60 to 70
					Richardson, 2004	Field scale recirculating sand filter	Septic tank effluent																54
					Costa, 2003	Field scale recirculating sand filter, 0.74 gal/ft^2-day	Septic tank effluent																40
Intermittent Sand Filters	10,12,28,41,49,58,64,71, 88,94,111,134,169	Sand media		Single pass	Mancl and Peeples, 1991	Loading rate: 0.9 to 2.8 gal/ft^2-day Influent BOD_5: 82 to 321 mg/L Effluent BOD_5: 6.2 to 13.1 mg/L % NH_3-N removal: 65 to 96 % Total nitrogen removal: 55 to 77																	
Textile Filters	47,84,88,111,117,123,158,218	Textile media	Septic tank effluent treatment	With recirculation					**Influent (STE)**							**Effluent**							% Total N removal
									BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	
		135			Wren, 2004	Field scale recirculating textile filters	Septic tank effluent																
					Loomis, 2004	Field scale recirculating textile filters	Septic tank effluent																41 to 44
					Rich, 2007	Field scale recirculating textile filters	Septic tank effluent																
					McCarthy, 2001	Field scale recirculating textile filter	Septic tank effluent	Summer	171			69	6	63	0.01	3.2			59	-	1.7	61	14
								Winter	247			81	6	75	0	5.4			64	8	5.9	50	21
Eliminite	59	Metarocks, proprietary trickle filter media	Septic tank effluent treatment						**Influent (STE)**							**Effluent**							% Total N removal
									BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	
																							65 to 85

Nitrification Processes (Continued)

Description/Name of Technology	Reference(s)	General Description	Method of Deployment	Pumps and Recirculation	Test Data	Test System	Influent	Test Information	Influent (STE) BOD$_5$, mg/L	Influent pH	Influent Alkalinity, mg/L as $CaCO_3$	Influent Total N, mg/L	Influent Organic N, mg/L	Influent NH_3-N, mg/L	Influent NO_3-N, mg/L	Effluent BOD$_5$, mg/L	Effluent pH	Effluent Alkalinity, mg/L as $CaCO_3$	Effluent Total N, mg/L	Effluent Organic N, mg/L	Effluent NH_3-N, mg/L	Effluent NO_3-N, mg/L	% Total N removal	
Peat Filters	20,47,56,84,88,108, 111,117,123,124,126,127,147-149,158,163,199,216	Peat media	Septic tank effluent treatment	With or without recirculation																				
					Monson Geerts, 2001b	Modular recirculating peat filters, individual households	Septic tank effluent																29 to 41	
					Patterson, 2001	Peat filter beds, individual households, pressure dosing	Septic tank effluent																44	
					Rich, 2007	Peat filter beds, individual households, pressure dosing	Septic tank effluent																	
					Lacasse, 2001	Peat filter	Septic tank effluent																	
					Monson Geerts, 2001a	Modular recirculating peat filters, individual households	Septic tank effluent	Recirculating, Irish peat, summer	262	7.2		92	7	85	0.02	11	5.5		57	-	4.4	55	38	
								Recirculating, Irish peat, winter	335	7.29		104	10	94	0.04	13	6.5		69	2	33	34	34	
								Recirculating, Minnesota peat, summer	262	7.2		92	7	85	0.02	9	6.0		51	-	19	33	45	
								Recirculating, Minnesota peat, winter	335	7.29		104	10	94	0.04	20	6.6		72	-	55	19	31	
								Single pass, Irish peat, summer	236	7.28		82	11	71	0.02	5.1	6.6		62	0	2.9	59	24	
								Single pass, Irish peat, winter	262	7.19		76	6	70	0.02	6.4	6.2		49	0	11	38	36	
								Single pass, Minnesota peat, summer	236	7.28		82	11	71	0.02	4.9	6.3		52	0	1.8	50	37	
								Single pass, Minnesota peat, winter	262	7.19		76	6	70	0.02	13	5.8		49	-	6.3	47	36	
								Single pass, Minnesota + Irish peat, summer	236	7.28		82	11	71	0.02	6.7	6.6		52	0	1.1	51	37	
								Single pass, Minnesota + Irish peat, winter	262	7.19		76	6	70	0.02	6.3	6.2		52	-	5.9	47	32	

Description/Name of Technology	Reference(s)	General Description	Method of Deployment	Pumps and Recirculation	Test Data	Test System	Influent	Test Information	BOD$_5$, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	BOD$_5$, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	
Zeolite Filter	151,190	Fixed film reactor with zeolite media	Media bed		Philip, 2006	6.1 gal/ft^2-day	Septic tank effluent					70							1			57	

Description/Name of Technology	Reference(s)	General Description	Method of Deployment	Pumps and Recirculation	Test Data	Test System	Influent	Test Information	Influent (STE) BOD$_5$, mg/L	Influent pH	Influent Alkalinity, mg/L as $CaCO_3$	Influent Total N, mg/L	Influent Organic N, mg/L	Influent NH_3-N, mg/L	Influent NO_3-N, mg/L	Effluent BOD$_5$, mg/L	Effluent pH	Effluent Alkalinity, mg/L as $CaCO_3$	Effluent Total N, mg/L	Effluent Organic N, mg/L	Effluent NH_3-N, mg/L	Effluent NO_3-N, mg/L	% Total N removal	
Waterloo Biofilter	134	Fixed film, patented foam cubes	Septic tank effluent treatment		ETV							37							14				62	

Nitrification Processes (Continued)

Description/Name of Technology	Reference(s)	General Description	Method of Deployment	Pumps and Recirculation	Test Data	Test System	Influent	Test Information
Aerocell Biofilter	136	Fixed film, 2 inch open cell foam cubes	Septic tank effluent treatment	Recirculation from dosing chamber	NSF		Septic tank effluent	
Coir Biofilter	137	Fixed film reactor with coconut coir media, 16 µm x 3-5 inch	Media bed	Recirculation from headwords of septic tank	NSF		Septic tank effluent	
Eliminite	59	Metarocks, proprietary trickle filter media	Septic tank effluent treatment					

Water Quality

Description/Name of Technology	Influent (STE)							Effluent							% Total N removal	% TKN removal
	BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L		
Aerocell Biofilter	240	7.0		40	21	19.1	0.36	2	7.0		9.3	3.0	2.0	4.2	77	86
Coir Biofilter	160	7.4		38	38.1	23.6		9	6.9		17	2.1	0.3	11.3	55	84
Eliminite															65 to 85	

Denitrification Processes: Cellulosic Systems

Description/Name of Technology	Reference(s)	General Description	Method of Deployment	Pumps and Recirculation	Test Data	Test System	Test Duration	Influent
Nitrex (wood based denitrification filter)	57,63,114,116,135,156 ,160,200	Woodchip based denitrification filter; media loaded into septic tank	Following nitrified efflu	Passive gravity flow; no recirculation				
	156				Fleming Residence, La Pine, Oregon	Individual residence	27 months	Septic tank effluent, pretreated with sand filter
	156				Stone Residence, La Pine, Oregon	Individual residence	29 months	Septic tank effluent, pretreated with sand filter
	55				Polson, Montana	Single family residence	23 months	Septic tank effluent, pretreated with sand filter
	114				Massachusetts Alternative Septic System Test Center	Test center; 330 gpd	16 months	Septic tank effluent, pretreated with recirculating sand filter
	116				Rhode Island On Site Wastewater Resources Center			Septic tank effluent, pretreated with one pass peat filter
					Rhode Island On Site Wastewater Resources Center			Septic tank effluent, pretreated with one pass peat filter

Water Quality

Influent (STE)							Effluent							% Total N removal
BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	
333	7.3	352	68	16	54	0.02	66	6.6	262	3	1.5	0.3	1.0	96

Influent (STE)							Effluent							% Total N removal
BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	
210	7.9	295	56.5	11.0	45.5	0	36	6.8	239	4.4	1.2	1.0	2.0	92

Influent (STE)							Effluent							% Total N removal
BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	
			46.1	4.0	42	0.1				3.4	0.8	1.0	1.6	89

Influent (STE)							Effluent							% NO_3-N removal
BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	
4.1	6.9	63.8	17.5	2.0	2.9	12.6	42.75	6.91	111.9	4.28	1.71	1.5	1.1	88

Influent (Peat filter effluent)							Effluent							% Total N removal
BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	
2		0	58	2	3	53	18		205	7?		4	8?	88

Influent (Peat filter effluent)							Effluent							% Total N removal
BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	
9		5	84	9	23	52	49		220	18	1.75	16	0.250	79

Denitrification Processes: Cellulosic Systems (Continued)

Description/Name of Technology	Reference(s)	General Description	Method of Deployment	Pumps and Recirculation	Test Data	Test System	Test Duration	Influent	Water Quality
Cellulosic Carbon Sources									
Sawdust	60	82 to 92% nitrate removal	Laboratory columns						
Wood chips, cornstalks, cardboard	72		Laboratory batch reactor						
Wood chips	90	Nitrate reduction from 25 to 10 mg/L N	Field plots						
Alfalfa, newspaper, sawdust, wheat straw, wood chips, leaf mulch compost	98	> 80% reduction in stormwater	Laboratory columns						
Liquorice (Glycyrrhiza glabra), giant reed (Arundo donax)	143,144	87 to 100% nitrate removal	Laboratory flow reactor						
Sawdust	192	Effluent nitrate N = 0.6 mg/L	Subsurface leaching chambers						

Denitrification Processes: Other Carbon Sources

Description/Name of Technology	Reference(s)	Method of Deployment
Other Carbon Sources		
Solid household organic waste hydrosylate	1	Laboratory columns
Poplar, hornbeam, pine shavings and wheat straw	9	Laboratory batch reactors
Cotton	50	Laboratory batch reactors
Poly(e-)caprolactone	85	Laboratory batch reactors
Bacterial Polyester	125	Upflow laboratory reactor
Soluble starch	97	In-situ groundwater treatment

Denitrification Processes: Autotrophic Sulfur Systems

Description/Name of Technology	Reference(s)	General Description	Method of Deployment	Pumps and Recirculation	Test Data	Test System	Test Duration	Influent	Water Quality
Sulfur based denitrification	8,15,24,44-47,64,66, 76,82,87, 96-102, 104-106,111,129, 130,139, 141,142,146,155, 174 176,178,186, 197,217,212,220,221,223,224-227	Elemental sulfur denitrification filter; solid phase alkalinity source	Following nitrified eff	Passive gravity upflow; no recirculation					
Upflow sulfur/ oyster shell column	23	Elemental sulfur denitrification filter; solid phase alkalinity source	185 gal. column, following nitrified effluent	Passive gravity upflow; no recirculation	Massachusetts Alternative Septic System Test Center	Test center; 330 gpd	11 months	Septic tank effluent, pretreated with Clean aerobic treatment system	see below
Upflow sulfur/ oyster shell column	173, 175	Elemental sulfur denitrification filter; solid phase alkalinity source	1 liter laboratory column, following nitrified effluent	Passive gravity upflow; no recirculation	Laboratory column, 1 liter		8 months	Septic tank effluent, pretreated with Clean aerobic treatment system	see below
Nitrification/denitrification column	100	Lower level elemental sulfur denitrification and solid phase alkalinity source; upper nitrification layer	0.88 liter column	Passive gravity downflow; no recirculation	Laboratory column			Septic tank effluent, pretreated with recirculating sand filter	see below
Upflow sulfur/oyster shell column	24	Elemental sulfur denitrification filter; solid phase alkalinity source	Radial packed reactor; effluent upflow column following aerobic treatment	Passive gravity upflow; no recirculation	In development; no test data				
Upflow sulfur/ limestone filter	46	Elemental sulfur denitrification filter; solid phase alkalinity source; 2:1 ratio of S to limestone	200 gallon pilot column column, groundwater	Single pass, upflow, 16 hr. EBCT			12 months	Groundwater	see below

Water Quality — Upflow sulfur/ oyster shell column (23):

Influent (Aerobially treated STE)							Effluent							% Total N removal
BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	
		74	23		2	20				4.2		0.9	2.4	82

Water Quality — Upflow sulfur/ oyster shell column (173, 175):

Influent (Aerobially treated STE)							Effluent							% NO_3 removal	
BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L		
						50							8	80	< 2 mg/L effluent NO_2-N

Water Quality — Nitrification/denitrification column (100):

Influent (Aerobially treated STE)							Effluent							% Total N removal
BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	
														45

Water Quality — Upflow sulfur/ limestone filter (46):

Influent (Aerobially treated STE)							Effluent							% NO_3 removal	
BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L		
						64							2.4	96	0.2 mg/L effluent NO_2-N

Denitrification Processes: Autotrophic Iron Systems

Description/Name of Technology	Reference(s)	General Description	Method of Deployment
Iron			
Iron	198	Iron reactive media	Following nitrified effluent

Denitrification Processes: Heterotrophic/Autotrophic Systems

Description/Name of Technology	Reference(s)	General Description	Method of Deployment	Pumps and Recirculation	Test Data	Test System	Test Duration	Influent	Water Qualit y
Cotton/Zero valent Iron	51	Mixed solid media	Laboratory columns						
Methanol Elemental Sulfur Denitrification	98		Laboratory reactors						
Solids blanket reactor	183	Mixotrophic UASB	Laboratory reactors						

Drainfield Modification

Description/Name of Technology	References	General Description	Method of Deployment	Pumps and Recirculation	Test Data	Test System	Test Duration	Influent	Water Quality
Black and Gold (wood based media)	113,176	Sand, tire crumb, and woodchip filter (85/11/4% by mass)	Subdivided drainfield with initial aerobic zone followed by denitrification zone	Passive gravity flow; no recirculation	UCF Laboratory	280 gallon bench columns, "continuous batch" operation, 6 gal/day, 8.32 gal/ft^2-day, 24 hr HRT	6 months	Septic tank effluent	See table A
POINT System	76	Sawdust based denitrification media	Sawdust amended infiltrative layer						See table B
Multi Soil Layers	31,121,122,167, 168		Infiltrative beds with mixed layers of greater and lesser permeability	Infiltrative flow; no recirculation					
Organic layer in leachfield (sawdust)	15		Leachfield lower layer	Infiltrative flow; no recirculation		Laboratory drainfields	10 months		See table C
Fine-grained denitrification layer	119		Leachfield lower layer	Infiltrative flow; no recirculation		Mathematical simulation			
Carbon based denitrification wall (permeable barrier; reactive barrier)	170,171,172						5 years		See table D
Permeable reactive barrier, carbon based (Nitrex)	203		Reative wall to intercept groundwater	Groundwater flow; no recirculation					
Permeable reactive barrier, sulfur/limestone	177		Sulfur/limestone layer underneath sand drainfiled	Infiltrative flow; no recirculation		Laboratory columns	100 days	Municipal primary effluent	> 95% TN removal in some columns

Table A – Black and Gold (wood based media)

Influent (STE)							Effluent							% Total N removal
BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	
1972			414.5	363	49.73	1.564	144			7.08	2	4.37	0.047	98

Table B – POINT System

Influent (STE)							Effluent							% Total N removal
BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	
														>90

Table C – Organic layer in leachfield (sawdust)

Influent (Synthetic STE)							Effluent							% Total N removal
BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	
													1.0	67

Table D – Carbon based denitrification wall

Influent (Groundwater)							Effluent							% NO_3 removal
BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	BOD_5, mg/L	pH	Alkalinity, mg/L as $CaCO_3$	Total N, mg/L	Organic N, mg/L	NH_3-N, mg/L	NO_3-N, mg/L	
						5 to 15							1.0	> 95%

APPENDIX D

QUALITY ASSURANCE PROJECT PLAN

Florida Passive Nitrogen Removal Study

Laboratory Media Evaluation

Quality Assurance Project Plan

Prepared for:

Florida Department of Health
Division of Environmental Health
Bureau of Onsite Sewage Programs
4042 Bald Cypress Way Bin #A-08
Tallahassee, FL 32399-1713

FDOH Contract CORY6

Prepared by:

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Prepared and Approved by:

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11/16/2007

Daniel Smith, P.E., Principal Investigator — Date

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Section 1 Project Organization

The Florida Department of Health has contracted with Applied Environmental Technology to perform a literature review and assemble a database of passive nitrogen removal technologies for onsite wastewater treatment, and to perform experimental evaluations of candidate reactive media to be used in treatment filter systems. Applied Environmental Technology will perform overall project management, will establish and conduct the experimental studies, and will deliver samples to ELAB Inc., a NELAC Certified Analytical laboratory, for water quality analyses. Applied Environmental Technology will review and interpret the resultant data, adjust the experimental program as warranted, and generate a summary report.

Prudent project management will help minimize changes, ensure project continuity, and avoid delays in the project schedule. This type of project is highly specialized, requiring unusual equipment and services. Therefore it is crucial that adequate project management be used to ensure the success of the project.

Section 2 Problem Definition and Background

A. Project Background

The Florida Department of Health (FDOH) has provided funding to evaluate methods that can be used to enhance nitrogen removal in onsite wastewater systems in a passive and cost effective manner. The Florida Passive Nitrogen Removal Study Task 2 entails an experimental evaluation of candidate filter media that can be used to remove nitrogen from septic tank effluent in passive systems. The purpose of the study is to perform small scale testing to identify candidate media for subsequent evaluation using full scale onsite wastewater treatment systems.

The *Florida Passive Nitrogen Removal Study Literature Review and Database, September 26, 2006,* proposed the development of a two stage filter system for passive removal of total nitrogen from septic tank effluent. The two stage system consisted of an initial unsaturated media filter for ammonification and nitrification, followed in series by a saturated anoxic denitrification filter. The system would be deployed between the septic tank and the soil treatment unit (drainfield) or soil dispersal system of new or existing facilities. Nitrogen in septic tank effluent would be substantially removed before wastewater was directed to the soil for treatment or dispersal.

To perform the media evaluations, it is desired to conduct studies in a manner that closely resembles the functioning of an actual onsite system. The actual candidate media should be used, placed in appropriate depth and distribution. Continuous and dosed filter operation is preferable, where microbial populations will establish their metabolic activities and perform desired biochemical transformations in response to conditions similar to an operating system. The use of actual septic tank effluent (STE) as feed source is deemed preferable to use of a synthetic analog STE. This Quality Assurance Project Plan (QAPP) describes the methods and procedures that will be used to conduct the media evaluations.

B. Candidate Study Sites

Four candidate sites have been identified and approvals are being sought for their use. All sites are considered acceptable and a single site will be used. Each site has a source of actual septic tank effluent and has an available power supply for pumping STE to test columns or to STE reservoirs for transport to test facility. Each site location is isolated from public access and would cause minimal disruption to any activity, and each site has reasonable security. The individual residences are considered preferable to the visitor center. All of the residences have continuous occupancy, and a possible basis for preference is the number of occupants. Further evaluation will determine if the operation of the filter columns will be conducted at the site of STE collection or in the AET facility.

1. **Flatwoods**
   Ranger residence, septic tank, county operated park administered by the Southwest Florida Water Management District, 14302 Morris Bridge Road, Thonotosassa FL 33592, Hillsborough County.
2. **Morris Bridge**
   Ranger residence, septic tank, county operated park administered by the Southwest Florida Water Management District, 13330 Morris Bridge Road, Thonotosassa FL 33592, Hillsborough County.
3. **Hillsborough River State Park**
   Visitor center, septic tank, state park, 15402 US 301 North, Thonotosassa FL 33592, Hillsborough County.
4. **Branchton**
   Private residence, septic tank effluent pumping chamber, 11809 Cedar Cove Drive, Thonotosassa, FL 33592, Hillsborough County.

Section 3 Project Description

A. Project Purpose

To evaluate candidate media for use in passive nitrogen removal systems for onsite wastewater treatment.

B. Project Objectives

The objective is to establish small scale experimental systems to evaluate the effectiveness of media in removing total nitrogen from septic tank effluent. The experimental systems will consist of three two-stage filter systems, each consisting of a first stage unsaturated filter followed in series by a second stage filter saturated with wastewater. Septic tank effluent will be applied to the top of the first stage media, resulting in a downward percolation of wastewater over and through the media filter bed. The unsaturated pore spaces in the first stage media will allow air to reach microorganisms attached to the media surfaces, enabling aerobic biochemical reactions to occur. The significant target reactions are aerobic heterotrophic oxidation (by microorganisms that oxidize organic material and reduce biochemical oxygen demand), hydrolysis and ammonification (releasing ammonia), and nitrification (biochemical conversion of ammonia to nitrate and nitrite). Of particular interest are the organic and ammonia nitrogen concentrations in first stage effluent, as well as nitrate and nitrite.

Effluent from the bottom of the first stage filter will be passed through a saturated anoxic upflow filter that contains a reactive media that supplies electron donor for denitrification (reduction of nitrate and nitrite to N_2 gas). The column systems will be operated for two months and monitored for nitrogen species and other water quality parameters. Of particular interest are the concentrations of nitrate, nitrite and total nitrogen in the second stage effluent.

The interaction of media with applied wastewater governs the treatment process. Key features affecting nitrogen removal performance include:

1. The effects of hydraulic and nitrogen loading rates, on average daily and per dose basis, on first stage effluent nitrogen concentrations.
2. The effects of first stage media on effluent nitrogen levels.
3. Alkalinity consumption in the first stage and its possible effects on nitrification.
4. The effects of hydraulic and nitrogen loading rates, on average daily basis, on second stage effluent nitrogen concentrations.
5. The effects of second stage media on effluent nitrogen levels.
6. Second stage effluent total nitrogen concentrations and speciation into organic, ammonia, and oxidized nitrogen forms.
7. Alkalinity consumption in the second stage and its possible effects on denitrification.
8. Possible use of first stage recycle.

C. Project Tasks

Project tasks are shown in Table 1. The start dates are contingent upon review and approval by FDOH.

Table 1 Scheduled Tasks

Task/Activity	Start	Projected Completion
Task 1 Select study site	Week 1	Week 1
Task 2 Procure media	Week 1	Week 1
Task 3 Construct media filter testing apparatus	Week 1	Week 1
Task 4 Operate and monitor experiments	Week 2	Week 10
Task 5 Prepare draft report (CORY 6 Task 2c)	Week 8	Week 10
Task 6 Prepare final report (CORY 6 Task 2d)	Week 10	Week 12

Task 1 Select study site

Four study sites have been identified, each of which are acceptable for this research (see Section 2B). A final site will be selected based on receiving approval from the agencies with responsibility for the locations and other factors. The study could be conducted at one of the septic tank locations, or alternatively at the test facility. If conducted at AET, the septic tank effluent supply will be changed at least every third day and will be specifically changed one day before sample collection day.

Task 2 Procure media

Candidate media for evaluation in Stage 1 (unsaturated) filters and Stage 2 (saturated) filters are listed in Table 2, with physical properties and their sources. All media offer high water retention and porosity, and the clinoptilolites additionally provide ion exchange capacity. Media will be procured from vendors for use. For Stage 1 media, four clinoptilolite media are listed with particle sizes of 0.3 to 4.8 mm. These have greater than 45% porosity and high water retention. The clinoptilolites have cation exchange capacities of 1.5 to 1.8 meq./g, and will act to retain ammonia ions for enhanced ammonia removal under non-steady flows and higher loading rates. Livlite is an expanded clay with high water retention characteristics. Tire chips are produced by the cutting up of recycled tires, and are available in particles sized of 5 mm and less suitable for use in filter media.

The Stage 2 electron donor media is elemental sulfur, which will result in an autotrophic denitrification process in the anoxic filter. Crushed oyster shell will be used as an alkalinity source, as sulfur-based autotrophic denitrification will consume alkalinity. Expanded shale is included for its anion exchange capacity, which will bind nitrate and enhance performance under non-steady conditions or higher flowrates.

Table 2 Filter Media

Material	Bulk density, lb/ft^3	Particle Size Range	Supplier
ZK406H Clinoptilolite	59	0.8 - 1.7mm	GSA Resources, Tuscon, AZ
AMZ 4/8 Clinoptilolite	55	2.3 - 4.8 mm	Ash Meadows, Armagosa, NV
AMZ 8/20 Clinoptilolite	55	0.8 - 2.3 mm	Ash Meadows, Armagosa, NV
AMZ 16/50 Clinoptilolite	55	0.3 - 1.1 mm	Ash Meadows, Armagosa, NV
Livlite Expanded Clay	41	3 to 5 mm	Big River, Alpharetta, GA
Elemental sulfur	77	2 - 4 mm	Georgia Sulfur, Valdosta, GA
Oyster shell	82	3 - 15 mm	Harold's Farm Supply, Dover, FL
ACT-MX ESF-580 Utelite	54	4 -20 mm	ES Filter, Ogden, UT
ACT-MX ESF-416 Utelite	54	2 - 10 mm	ES Filter, Ogden, UT
ACT-MX ESF-450 Utelite	54	0.4 - 4.5 mm	ES Filter, Ogden, UT
Tire Crumb	25	0.3 - 5 mm	Global Tire Recycling, Wildwood, FL

Task 3 Construct media filter testing apparatus

A schematic of the experimental filter columns is shown in Figure 1. Three filter systems will be evaluated, each consisting of an unsaturated filter followed by a saturated filter. A total of six filters will be fabricated. Filters will be fabricated from 3 in. diameter tubing (unsaturated filters) and 1.5 in. diameter tubing (saturated filters), using a 1/8 inch screening for media support and retention. Filter columns will be constructed of PVC or Lucite. These materials have high contact angles for water sorption versus the filter media, indicating that media wetting characteristics will render wall effects minimal. Additionally, the surface area of the filter media will be twenty to fifty times that of wall area, again rending wall effects minimal.

The media in the six columns are listed in Table 3. Three Stage 1 columns will be constructed, two using stratified layers of clinoptilolite and expanded clay, and a third using tire crumb. Total media depth will be 24 in. in each Stage 1 column. Stratification of media based on particle size is 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

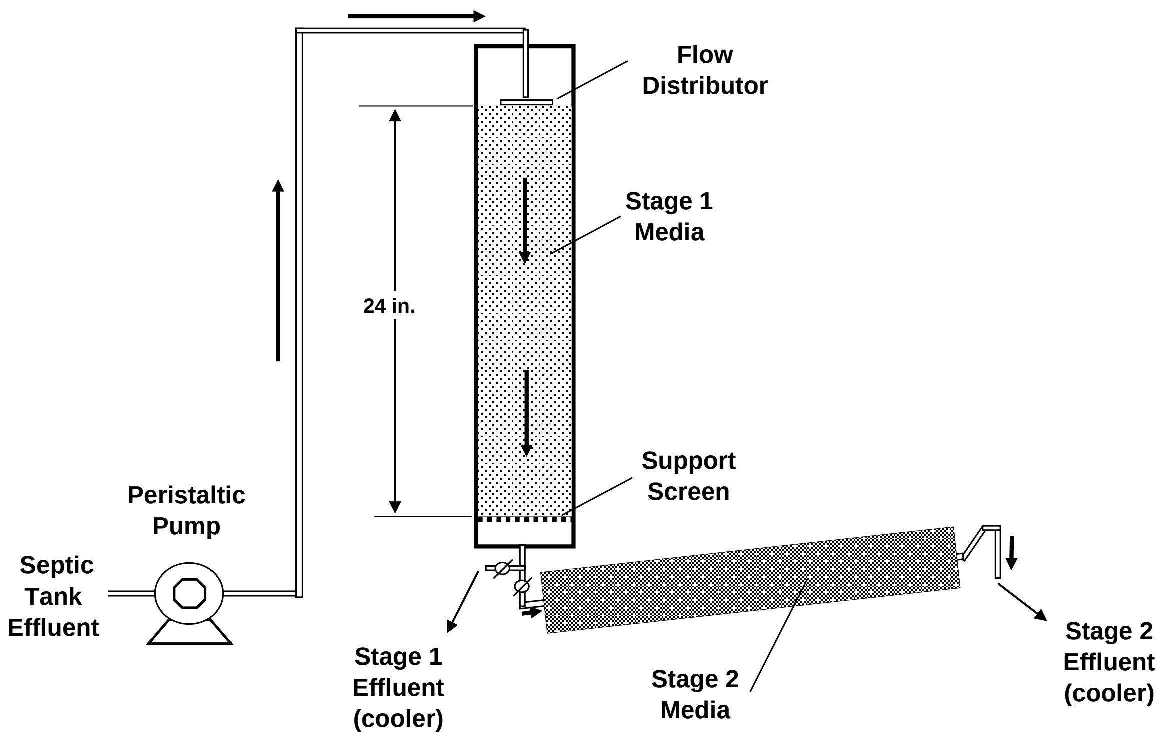

Figure 1 Schematic of Experimental Filter Systems

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. The use of an expanded clay in the upper and lower layers of Filter 1B (Table 3) is based on the supposition that the ion exchange is not necessarily critical to the functioning of the aerobic biochemical processes within the unsaturated aerobic filter. The use of finer particle sizes in lower depths will provide greater surface area for microbial attachment and a finer media for physical filtration, the later which could improve removal of pathogens and other wastewater constituents. The progression of coarser to finer media size through the filter will also enable coarser media to filter out larger particulates and protect the finer media that follows.

Three Stage 2 columns will be constructed or unstratified media containing elemental sulfur, crushed oyster shell, and expanded shale (Table 3) of 24 in. media depth. Each filter will contain a 3:1 ratio of elemental sulfur to crushed oyster shell (vol./vol.), which has previously been shown to provide adequate alkalinity. The difference in the Stage 2 media composition is the fraction of expanded shale, which ranges from 0 to 40%. Expanded shale contains anion exchange capacity which can bind nitrate ions, potentially enhancing removal. In addition,

Table 3 Configuration of Two Stage Filters

Stage	Filter	Column ID, inch.	Total depth, inch	Media placement	Media
Stage 1	1A	3.0	24.0	Stratified	8 in. clinoptilolite (2.3-4.8 mm) 8 in. clinoptilolite (0.8-2.3 mm) 8 in. clinoptilolite (0.5-1.1 mm)
	1B	3.0	24.0	Stratified	8 in. expanded clay (3-5 mm) 8 in. expanded clay (0.8-2.3 mm) 8 in. expanded clay (0.5-1.1 mm)
	1C	3.0	24.0	Stratified	8 in. tire crumb (3-5 mm) 8 in. tire crumb (1-3 mm) 8 in. tire crumb (0.4-1 mm)
Stage 2	2A	1.5	24.0	Nonstratified	75% elemental sulfur 25% oyster shell
	2B	1.5	24.0	Nonstratified	60% elemental sulfur 20% oyster shell 20% expanded shale
	2C	1.5	24.0	Nonstratified	45 % elemental sulfur 15% oyster shell 40% expanded shale

higher expanded shale fractions are accompanied by lower elemental sulfur fractions. Lower sulfur fractions 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. If the sulfur fraction was too low, denitrification could be starved for electron donor and cause nitrate breakthrough in the effluent. The use of three sulfur fractions will allow this issue to be examined.

The Stage 1 filters will be vertically oriented and Stage 2 filters placed at an angle of approximately 15 degrees from horizontal (Figure 1). The Stage 1 filters will be supplied with septic tank effluent by a multi-head peristaltic pump with a timed dosing of once per one half hour (48 doses/day). A perforated plate will be used to distribute effluent over the surface of the Stage 1 media. Water will percolate downward through the Stage 1 media, through the support screen, and into a tube that connects to the Stage 2 filter (Figure 1). The water elevation in the tube below the Stage 1 filter will provide hydraulic head for passive movement of water through the Stage 2 filter. A valve and sample port (with another valve) will be located in the tube below the Stage 1 filter. In normal filter operation, the sample port valve will be closed and the valve leading to Stage 2 will be open. The design of the filter system minimizes internal volumes within the connecting piping, and enables the liquid volumes in the Stage 1 and Stage 2 filters to comprise greater than 90% of the total internal volume.

Operation will be conducted at a hydraulic loading to the Stage 1 filters of 3 gal./ft^2-day. Operating characteristics of Stage 1 and Stage 2 filters are shown in Tables 4 and 5. At 48 doses per day, a single dose will add a volume that is 6% of the water retained within the Stage 1 filter bed. The estimated average water residence time in the Stage 1 filter is 9 hr. (Table 4). An average water residence time of 12 hr. is provided in the Stage 2 filter (Table 5). Due to the limited duration of the initial experimental program outlined in Table 1, no modification of operation is anticipated throughout the current study. All treated effluent from the two stage filter systems will be collected and disposed of into a septic tank system.

Table 4 Operating Characteristics of Unsaturated Column

Flow, gpd/ft^2	3.0
Diameter, inch	3.0
Media depth, inch	24.0
Flow, gal/day	0.147
Flow, ml/day	557
Flow, ml/hour	23.2
Time for 150 ml sample, hour	6.5
Doses/day	48
Flow, ml/dose	11.6
Empty bed volume, liter	2.8
Resident water volume, liter[1]	0.21
Single dose volume / resident water volume	0.06
Average water residence time, hour	9.0

[1]Assumes 50% external porosity, 15% filled with water

Table 5 Operating Characteristics of Saturated Column

Diameter, inch	1.5
Media depth, inch	24.0
Flow, gal/day	0.147
Flow, gpd/ft^2	12.0
Flow, ml/hour	23.2
Time for 150 ml sample, hour	6.5
Empty bed volume, liter	0.69
Pore volume, liter[1]	0.28
Average residence time, hour	12.0

[1]Assumes 40% porosity

Monitoring sample points are septic tank effluent, three Stage 1 effluents, and three Stage 2 effluents (total of seven points). For each monitoring point, separate samples will be collected for field analyses and for laboratory analyses. Field analyses will be performed immediately upon sample collection. Samples for laboratory analyses will be collected by directing samples directly into sample collection containers that are located within iced coolers and that contain any required sample preservatives. Influent and effluent samples will have no contact with any intermediate sample devices. Effluent samples will be maintained in iced coolers and transported to the lab with 24 hr. of collection.

For STE sampling (influent), an influent pipe from the STE pump will be directed to a sample container and the pump speed increased during collection. Sampling of the hydraulically connected Stage 1 and Stage 2 filters will be conducted as follows. Stage 2 will be sampled first. The Stage 2 effluent line will be directed to the sample container and effluent collection will initiate. During Stage 2 sampling, the system will be in normal flow through both Stage 1 and Stage 2 filters. When Stage 2 sampling is completed, the valve will be closed in the line connecting Stage 1 to Stage 2. The Stage 1 sampling valve will be opened and sample will flow directly to a sample container with an iced cooler. When Stage 1 sampling is completed, the position of the valves will be reversed, restoring flow through Stage 2. Stages 1 and 2 will then operated in normal flow through mode until the next sample event. During Stage 1 sampling, the Stage 2 filter will not receive flow. The total volume treated in the Stage 2 filters will be reduced on the order of 5% due to the Stage 1 sampling procedure. The flow reduction will be accounted or in the analysis of results.

Effluent from Stage 1 filters will be applied to stage 2 filters, using 1A to 2A, 1B to 2B, and 3A to 3B. There is not a specific reason for this flow routing scenario, and the resulting data should allow adequate interpretation of performance results. Future studies could examine alternative filter configurations (media, diameter, media depth) based on the results of these tests, but the duration of the present study will not enable evaluation of different cases. Another potential factor that could be examined is the effects of recirculation around the Stage 1 filters, which would have a host of affects: on Stage 1 loadings, Stage 1 effluent TKN levels, the degree of denitrification achieved, the effect on alkalinity across Stage 1, and reduction in the size of the Stage 2 filter. These issues cannot be addressed within the scope of the present investigation.

The apparatus will be fabricated in the AET laboratory and flow tested with clean water. Pump flowrate calibrations will be performed. Media will be screened if necessary, washed repeatedly to remove fines, and placed to appropriate depths in the columns using a funnel and water transport technique. The denitrification column will be filled with a clean water source and water will be applied to fill the tube below the unsaturated column. A line will be connected to the septic tank effluent source and secured in place. The pump will be started and flow hydraulics checked. Initial flowrates will be measured and adjusted 24 hr. later.

Task 4 Operate and monitor experiments

The filter systems will be operated for 60 days. The analytical template is shown in Table 6. Field parameters include temperature, pH, and dissolved oxygen. Laboratory parameters include the nitrogen series of total kjeldahl nitrogen, ammonia, and oxidized nitrogen, as well as sulfate in the Stage 2 column influent and effluent. Alkalinity will also be measured. Flowrate checks will be performed as needed, and tubing at the peristaltic pump head also changed several times through the study. Monitoring will also be conducted for carbonaceous biochemical oxygen demand in influent STE and Stage 1 effluents and total suspended solids in STE.

Task 5 Prepare Draft Report

A draft report will be prepared describing experimental methods and procedures, results of the research, discussion and conclusions, and all monitoring data.

Task 6 Prepare Final Report

A final report will be prepared including comments on the draft report.

Table 6 Analyses Template

	Septic tank effluent	Effluent from unsaturated filters	Effluent from saturated anoxic filters	Sampling Days
Temperature	5	5	5	16,27,38,49,60
pH	5	5	5	16,27,38,49,60
DO	5	5	5	16,27,38,49,60
TKN	5	5	5	16,27,38,49,60
NH_3-N	5	5	5	16,27,38,49,60
(NO_3+NO_2)-N	5	5	5	16,27,38,49,60
Sulfate	5	0	5	16,27,38,49,60
C-BOD_5	3	0	0	27,38,60
TSS	3	0	0	27,38,60

Section 4 Quality Objectives and Criteria

The objective of this monitoring program is to evaluate media for passive nitrogen removal from septic tank effluent. The following will be performed:

- Three two stage filter system will be constructed and operated on septic tank effluent for 60 days.
- The flowrate to each filter system will provide a hydraulic loading of 3 gal/ft^2-day to the first stage.
- Monitoring will be conducted five times of septic tank effluent, effluent from the Stage 1 (unsaturated) filters, and effluent from the Stage 2 (saturated) filters.
- Field parameters will be monitored at the site. Sample will be collected and transported to the laboratory for analysis of nitrogen species and sulfate.
- Operation or configuration of the columns may be modified based on analysis of results and adaptive management.

The monitoring data will be used to calculate:

1. average concentrations and standard deviations of water parameters in septic tank effluent, Stage 1 effluent and Stage 2 effluents;
2. percent removal nitrogen and nitrogen species in Stage 1 filters, Stage 2 filters, and two stage filter systems;
3. changes to dissolved oxygen and pH through treatment stages; and
4. average applied hydraulic loading rate, applied loading rates of total nitrogen and nitrogen species.

A. Precision and Accuracy

Precision describes the reproducibility of results. Accuracy is the degree of agreement between an observed value and an accepted reference value. Accuracy will be evaluated through the analysis of surrogate spikes, Laboratory Control Samples (LCS), Laboratory Control Sample Duplicates (LCSD), matrix spike samples (MS/MSD) and laboratory internal blind audit samples. Precision and accuracy information is tracked by the laboratory, with acceptable ranges updated periodically. In addition, NELAC requirements include the analysis of proficiency test samples to evaluate precision and accuracy. Precision and accuracy requirements for the target analytes and matrices are provided in Table 10. Sampling and analyses and QC procedures are described in Section 7C.

B. Representativeness

Representativeness refers to the relationship of a sample taken from a site to be analyzed to the remainder of the sample matrix at the site. The samples will be taken directly from the influents and effluent of the filters and will provide representativeness.

C. Comparability

The use of NELAC approved procedures and consistent approved methodologies ensure the comparability of data sets generated by different laboratories.

D. Completeness
Completeness is defined as a measure of the extent to which the data fulfill the data quality objectives of the project. The completeness of the data will be determined during the data validation and verification process.

Section 5 Certifications

ELAB Inc. is located in Tampa, Florida and is FDOH NELAP certified laboratory # E84973. ELAB's Tampa certification documentation is provided in Appendix A. ELAB Inc. also maintains a facility in Ormond Beach, Florida that is FDOH NELAP certified laboratory # E83079. The Ormond Beach certification documentation is also provided in Appendix A

Section 6 Documentation and Records

All documentation archives will be kept for a minimum of 5 years after the date of project completion (Table 7). Reports and deliverables will be submitted in Word or Excel format.

A. Field Documentation

1. Field Notes

Field notes will be documented and maintained by field staff.

2. Field Parameters

Field staff will record specific sample point, date and time of sample collection, parameter name, result and units

3. Sample Collection, Preservation and Transport

Chain of custody forms and sample tags attached to sample bottles will be supplied by the laboratory. A copy of the chain of custody from is provided as Figure 1. Legal or evidentiary chain of custody as defined in the NELAC standards will be executed.

B. Laboratory Documentation and Reporting
Laboratory deliverables will be submitted in Word or Excel format. Laboratory reports will be issued in accordance with NELAC requirements. Certificates from vendors will be retained, whether from a laboratory or commercial vendor. Records of the lot numbers of reagents and other cleaning supplies, with the inclusive dates for use, will be recorded. Pre-cleaned container packing slips, lot numbers of shipments, and certification statements provided by the vendor will be retained by ELAB. All local, state and federal requirements pertaining to waste storage and disposal will be followed.

C. Archival of Electronically Stored Data
Analytical reports generated will be retained by AET and ELAB.

Table 7 Documentation and Records Storage

Document/Record	Location	Retention Time	Format
QAPP and revisions	AET	5 years after project completion	Paper, electronic
Field notes	AET	5 years after project completion	Paper
Chain of custody	AET, ELAB	5 years after project completion	Paper
Laboratory QA manual	ELAB	5 years after project completion	Paper, electronic
Laboratory SOPs	ELAB	5 years after project completion	Paper, electronic
Laboratory data reports	ELAB	5 years after project completion	Paper, electronic
Laboratory equipment maintenance logs	ELAB	5 years after project completion	Paper
Laboratory calibration records	ELAB	5 years after project completion	Paper

Figure 2 Chain of Custody Form

Jupiter
Environmental Laboratories, Inc.

150 S. Old Dixie HWY
Jupiter, FL 33458
PH 561-575-0030
FX 561-575-4118

FILL IN THE ORANGE AREAS-CLIENT

CHAIN OF CUSTODY RECORD

DATE:
PAGE: ____________ OF ____________

LABORATORY CLIENT:	CLIENT PROJECT NAME / NUMBER:	Client P/O or P.O. #:
ADDRESS:	PROJECT CONTACT:	QUOTE #:
CITY:	SAMPLER(S): (SIGNATURE)	LOG #
TEL: FAX: E-MAIL:		

TURNAROUND TIME
☐ SAME DAY ☐ 24 HR ☐ 48HR ☐ 3 DAYS (some analytes CANNOT be <3 days)

SPECIAL REQUIREMENTS-pricing/QC package
☐ SFWMD ☐ FDEP ☐ QAQC Level : 1 2 3 see price list for fees

SPECIAL INSTRUCTIONS | Temp Control C | Matrix

REQUESTED ANALYSIS and preservative code

Code
Analysis

LAB USE ONLY	SAMPLE ID	LOCATION/ DESCRIPTION	SAMPLING DATE	SAMPLING TIME	Matrix	#Cont

Relinquished by: (Signature) LAB/Client	Date:	Time	Received by: (Signature) CLIENT/Lab	Date:	Time:
Relinquished by: (Signature) Lab/Client	Date:	Time	Received by: (Signature)	Date:	Time:
Relinquished by: (Signature)	Date:	Time	Received by: (Signature)	Date:	Time:

Matrix Codes:
*Preservation Codes: *C=chilled S=Sulfuric acid N=Nitric acid H=hydrochloric acid O=Other (fill in)*
*ALL SAMPLES MUST BE ON ICE EXCEPT ultra-trace Hg
Please print name of samplers here:

Section 7 Sampling Process Methodology

A. Site Location

The project will be conducted at one of the sites listed in Section 2B or at the AET experimental facility in Hillsborough County.

B. Monitoring and Sampling Frequency and Duration

The filter systems will be monitored five times over a duration of 60 days.

C. Number of Samples and Matrices

All sampling will be aqueous samples. On each monitoring date, seven samples will be collected: septic tank effluent, the effluents from three Stage 1 columns, and the effluents from three Stage 2 columns. Field analysis will be performed upon sample collection. Aqueous samples for laboratory analysis will be collected in sample containers prepared by ELAB, maintained in an iced cooler during collection and transport, and transported to ELAB. Samples will arrive at ELAB within twenty four hours after the completion of collection activities. Field analysis will be performed at the same date and for the sample locations as aqueous laboratory samples. Samples for field analyses will be collected in separate containers from laboratory samples. Stage 1 and 2 filed parameter analyses will be measured in-situ by placing probes directly into collected samples. Shipping coolers will be supplied and decontaminated by the laboratory. Sample preservation and holding times are provided in Table 8. ELAB will follow all local, state and federal requirements pertaining to waste storage and disposal. No equipment except the sample container will be used to collect the samples and the sampling equipment will be certified clean by the laboratory providing the equipment. A field blank will be collected for TKN, NH_3 and NO_3+NO_2 for a minimum of 5% of samples collected over the life of the project using distilled water supplied by ELAB. As a part of its QC, ELAB performs sample duplicates for a minimum of 5% of samples. ELAB's QC also includes matrix spikes, percent recovery on QC standards, and method blanks.

Table 8 Aqueous Matrix Containers, Preservation, and Holding Times

Parameter	Container	Preservation	Holding Time
Nitrate + Nitrite	150 ml HDPE	4°C, H_2SO_4 to pH<2	28 days
TKN			28 days
Ammonia			28 Days
Sulfate	50 ml HDPE	4°C	28 Days

Section 8 Analytical Methodology

Analytical methods, precision and accuracy, method detection and practical quantification limits are shown in Table 9.

Table 9 ELAB Inc. Aqueous Methodology, Precision and Accuracy, Detection Limits

Parameters	Method	Precision (% Diff.[1])	Accuracy (% Recovery)	MDL, ppm	PQL, ppm
Nitrate + Nitrite	EPA 353.2	20	90 - 110	0.0050	0.050
Total Kjeldahl Nitrogen	EPA 351.2	20	90 - 110	0.046	0.5
Ammonia	EPA 350.1	20	90 - 110	0.0063	0.05
Sulfate	EPA 300.0	20	90 - 110	0.085	0.5

[1]% Diff. = (Result 1–Result 2)/((Result 1+Result 2)/2) x 100

Section 9 Inspection/Acceptance of Supplies and Consumables

A. Sample Containers
To be provided by the laboratory prior to each sampling event.

B. Sample Coolers
To be provided by the laboratory prior to each sampling event.

Section 10 Data Review, Verification and Validation

A. Data Verification

Data verification is the process for evaluating the completeness, correctness, and conformance of the data set against the methodology. This evaluation is integral to the final report.

B. Data Validation

Data validation is an analyte and sample specific process that determines the quality of the data set relative to the end use. Any data deemed to be unusable for the stated objectives will be identified as such in the final report.

Appendix A

ELAB Certification Documentation

FLORIDA DEPARTMENT OF

HEALTH

State of Florida
Department of Health, Bureau of Laboratories

This is to certify that

E84973
ELAB, INC. - TAMPA
1211 TECH BLVD. SUITE 106
TAMPA, FL 33619

has complied with Florida Administrative Code 64E-1,
for the examination of Environmental samples in the following categories

DRINKING WATER - MICROBIOLOGY, DRINKING WATER - PRIMARY INORGANIC CONTAMINANTS, DRINKING WATER - SECONDARY INORGANIC CONTAMINANTS, NON-POTABLE WATER - GENERAL CHEMISTRY, NON-POTABLE WATER - MICROBIOLOGY

Continued certification is contingent upon successful on-going compliance with the NELAC Standards and FAC Rule 64E-1 regulations. Specific methods and analytes certified are cited on the Laboratory Scope of Accreditation for this laboratory and are on file at the Bureau of Laboratories, P. O. Box 210, Jacksonville, Florida 32231. Clients and customers are urged to verify with this agency the laboratory's certification status in Florida for particular methods and analytes.

EFFECTIVE August 03, 2007 THROUGH June 30, 2008

Max Salfinger, M.D.
Chief, Bureau of Laboratories
Florida Department of Health
DH Form 1697, 7/04
NON-TRANSFERABLE E84973-04-8/3/2007
Supersedes all previously issued certificates

Charlie Crist
Governor

FLORIDA DEPARTMENT OF HEALTH

Ana M. Viamonte Ros, M.D., M.P.H.
State Surgeon General

Laboratory Scope of Accreditation

Page 1 of 3

Attachment to Certificate #: E84973-04, expiration date June 30, 2008. This listing of accredited analytes should be used only when associated with a valid certificate.

State Laboratory ID: E84973 **EPA Lab Code: FL01241** **(386) 672-5668**

E84973
ELAB, Inc. - Tampa
1211 Tech Blvd.
Suite 106
Tampa, FL 33619

Matrix: Drinking Water

Analyte	Method/Tech	Category	Certification Type	Effective Date
Alkalinity as CaCO3	SM 2320 B	Primary Inorganic Contaminants	NELAP	3/22/2006
Chloride	EPA 325.3	Secondary Inorganic Contaminants	NELAP	7/30/2007
Chloride	SM 4500 Cl- C	Secondary Inorganic Contaminants	NELAP	7/30/2007
Color	EPA 110.2	Secondary Inorganic Contaminants	NELAP	3/22/2006
Conductivity	SM 2510 B	Primary Inorganic Contaminants	NELAP	3/22/2006
Fluoride	EPA 340.2	Primary Inorganic Contaminants	NELAP	7/30/2007
Fluoride	SM 4500 F-C	Primary Inorganic Contaminants	NELAP	7/30/2007
Heterotrophic plate count	SM 9215 B	Microbiology	NELAP	3/22/2006
Nitrate	SM 4500-NO3 E	Primary Inorganic Contaminants	NELAP	3/22/2006
Nitrate as N	EPA 353.2	Primary Inorganic Contaminants	NELAP	7/30/2007
Nitrate-nitrite	SM 4500-NO3 E	Primary Inorganic Contaminants	NELAP	3/22/2006
Nitrite	SM 4500-NO2 B	Primary Inorganic Contaminants	NELAP	3/22/2006
Odor	EPA 140.1	Secondary Inorganic Contaminants	NELAP	3/22/2006
Odor	SM 2150 B	Secondary Inorganic Contaminants	NELAP	3/22/2006
Orthophosphate as P	SM 4500-P E	Primary Inorganic Contaminants	NELAP	3/22/2006
pH	EPA 150.1	Primary Inorganic Contaminants,Secondary Inorganic Contaminants	NELAP	3/22/2006
Residual free chlorine	SM 4500-Cl D	Primary Inorganic Contaminants	NELAP	3/22/2006
Residue-filterable (TDS)	EPA 160.1	Secondary Inorganic Contaminants	NELAP	3/22/2006
Residue-filterable (TDS)	SM 2540 C	Secondary Inorganic Contaminants	NELAP	3/22/2006
Sulfate	EPA 375.4	Secondary Inorganic Contaminants	NELAP	7/30/2007
Sulfate	SM 4500 SO4-E	Secondary Inorganic Contaminants	NELAP	7/30/2007
Total coliforms & E. coli	SM 9223 B	Microbiology	NELAP	3/22/2006
Total nitrate-nitrite	EPA 353.2	Primary Inorganic Contaminants	NELAP	7/30/2007
Total residual chlorine	SM 4500-Cl D	Primary Inorganic Contaminants	NELAP	3/22/2006
Turbidity	EPA 180.1	Secondary Inorganic Contaminants	NELAP	3/22/2006
Turbidity	SM 2130 B	Secondary Inorganic Contaminants	NELAP	3/22/2006

Clients and Customers are urged to verify the laboratory's current certification status with the Environmental Laboratory Certification Program. **Issue Date: 8/3/2007** **Expiration Date: 6/30/2008**

Charlie Crist
Governor

FLORIDA DEPARTMENT OF HEALTH

Ana M. Viamonte Ros, M.D., M.P.H.
State Surgeon General

Laboratory Scope of Accreditation

Page 2 of 3

Attachment to Certificate #: E84973-04, expiration date June 30, 2008. This listing of accredited analytes should be used only when associated with a valid certificate.

State Laboratory ID: E84973 **EPA Lab Code: FL01241** **(386) 672-5668**

E84973
ELAB, Inc. - Tampa
1211 Tech Blvd.
Suite 106
Tampa, FL 33619

Matrix: Non-Potable Water

Analyte	Method/Tech	Category	Certification Type	Effective Date
Alkalinity as CaCO3	EPA 310.1	General Chemistry	NELAP	3/22/2006
Alkalinity as CaCO3	SM 2320 B	General Chemistry	NELAP	3/22/2006
Ammonia as N	EPA 350.3	General Chemistry	NELAP	7/30/2007
Ammonia as N	SM 4500NH3-D	General Chemistry	NELAP	7/30/2007
Biochemical oxygen demand	EPA 405.1	General Chemistry	NELAP	3/22/2006
Biochemical oxygen demand	SM 5210 B	General Chemistry	NELAP	3/22/2006
Carbonaceous BOD (CBOD)	SM 5210 B	General Chemistry	NELAP	3/22/2006
Chemical oxygen demand	EPA 410.4	General Chemistry	NELAP	7/30/2007
Chloride	EPA 325.3	General Chemistry	NELAP	7/30/2007
Chloride	SM 4500 Cl- C	General Chemistry	NELAP	7/30/2007
Chromium VI	SM 3500-Cr D (18th/19th Ed.)COLOR	General Chemistry	NELAP	7/30/2007
Color	EPA 110.2	General Chemistry	NELAP	3/22/2006
Color	SM 2120 B	General Chemistry	NELAP	3/22/2006
Conductivity	EPA 120.1	General Chemistry	NELAP	3/22/2006
Conductivity	SM 2510 B	General Chemistry	NELAP	3/22/2006
Fecal coliforms	SM 9222 D	Microbiology	NELAP	3/22/2006
Fluoride	EPA 340.2	General Chemistry	NELAP	7/30/2007
Fluoride	SM 4500 F-C	General Chemistry	NELAP	7/30/2007
Heterotrophic plate count	SM 9215 B	Microbiology	NELAP	7/30/2007
Nitrate	SM 4500-NO3 E	General Chemistry	NELAP	3/22/2006
Nitrate as N	EPA 353.2	General Chemistry	NELAP	7/30/2007
Nitrate-nitrite	SM 4500-NO3 E	General Chemistry	NELAP	3/22/2006
Nitrite	SM 4500-NO2 B	General Chemistry	NELAP	3/22/2006
Orthophosphate as P	EPA 365.2	General Chemistry	NELAP	3/22/2006
Orthophosphate as P	SM 4500-P E	General Chemistry	NELAP	3/22/2006
pH	EPA 150.1	General Chemistry	NELAP	3/22/2006
Phosphorus, total	EPA 365.2	General Chemistry	NELAP	7/30/2007
Phosphorus, total	SM 4500-P E	General Chemistry	NELAP	7/30/2007
Residue-filterable (TDS)	EPA 160.1	General Chemistry	NELAP	3/22/2006
Residue-filterable (TDS)	SM 2540 C	General Chemistry	NELAP	3/22/2006
Residue-nonfilterable (TSS)	EPA 160.2	General Chemistry	NELAP	3/22/2006
Residue-nonfilterable (TSS)	SM 2540 D	General Chemistry	NELAP	3/22/2006
Residue-total	EPA 160.3	General Chemistry	NELAP	3/22/2006
Residue-total	SM 2540 B	General Chemistry	NELAP	3/22/2006
Sulfate	EPA 375.4	General Chemistry	NELAP	7/30/2007

Clients and Customers are urged to verify the laboratory's current certification status with the Environmental Laboratory Certification Program. **Issue Date: 8/3/2007** **Expiration Date: 6/30/2008**

Charlie Crist
Governor

FLORIDA DEPARTMENT OF HEALTH

Ana M. Viamonte Ros, M.D., M.P.H.
State Surgeon General

Laboratory Scope of Accreditation

Page 3 of 3

Attachment to Certificate #: E84973-04, expiration date June 30, 2008. This listing of accredited analytes should be used only when associated with a valid certificate.

State Laboratory ID: E84973 **EPA Lab Code: FL01241** **(386) 672-5668**

E84973
ELAB, Inc. - Tampa
1211 Tech Blvd.
Suite 106
Tampa, FL 33619

Matrix: **Non-Potable Water**

Analyte	Method/Tech	Category	Certification Type	Effective Date
Sulfate	SM 4500 SO4-E	General Chemistry	NELAP	7/30/2007
Total coliforms	SM 9222 B	Microbiology	NELAP	3/22/2006
Total nitrate-nitrite	EPA 353.2	General Chemistry	NELAP	7/30/2007
Turbidity	EPA 180.1	General Chemistry	NELAP	7/30/2007

Clients and Customers are urged to verify the laboratory's current certification status with the Environmental Laboratory Certification Program. **Issue Date: 8/3/2007** **Expiration Date: 6/30/2008**

FLORIDA DEPARTMENT OF

HEALTH

State of Florida
Department of Health, Bureau of Laboratories

This is to certify that

E83079
ELAB, INC.
8 EAST TOWER CIRCLE
ORMOND BEACH, FL 32174

has complied with Florida Administrative Code 64E-1,
for the examination of Environmental samples in the following categories

DRINKING WATER - GROUP I UNREGULATED CONTAMINANTS, DRINKING WATER - SYNTHETIC ORGANIC CONTAMINANTS, DRINKING WATER - GROUP II UNREGULATED CONTAMINANTS, DRINKING WATER - OTHER REGULATED CONTAMINANTS, DRINKING WATER - GROUP III UNREGULATED CONTAMINANTS, DRINKING WATER - MICROBIOLOGY, DRINKING WATER - PRIMARY INORGANIC CONTAMINANTS, DRINKING WATER - SECONDARY INORGANIC CONTAMINANTS, NON-POTABLE WATER - EXTRACTABLE ORGANICS, NON-POTABLE WATER - GENERAL CHEMISTRY, NON-POTABLE WATER - METALS, NON-POTABLE WATER - MICROBIOLOGY, NON-POTABLE WATER - PESTICIDES-HERBICIDES-PCB'S, NON-POTABLE WATER - VOLATILE ORGANICS, SOLID AND CHEMICAL MATERIALS - EXTRACTABLE ORGANICS, SOLID AND CHEMICAL MATERIALS - GENERAL CHEMISTRY, SOLID AND CHEMICAL MATERIALS - METALS, SOLID AND CHEMICAL MATERIALS - MICROBIOLOGY, SOLID AND CHEMICAL MATERIALS - PESTICIDES-HERBICIDES-PCB'S, SOLID AND CHEMICAL MATERIALS - VOLATILE ORGANICS, BIOLOGICAL TISSUE - METALS, BIOLOGICAL TISSUE - PESTICIDES-HERBICIDES-PCB'S

Continued certification is contingent upon successful on-going compliance with the NELAC Standards and FAC Rule 64E-1 regulations. Specific methods and analytes certified are cited on the Laboratory Scope of Accreditation for this laboratory and are on file at the Bureau of Laboratories, P. O. Box 210, Jacksonville, Florida 32231. Clients and customers are urged to verify with this agency the laboratory's certification status in Florida for particular methods and analytes.

EFFECTIVE July 01, 2007 THROUGH June 30, 2008

Max Salfinger, M.D.
Chief, Bureau of Laboratories
Florida Department of Health
DH Form 1697, 7/04
NON-TRANSFERABLE E83079-08-7/1/2007
Supersedes all previously issued certificates

APPENDIX E

NELAC CERTIFIED LABORATORY WATER QUALITY DATA

Sample Event 1

Sample Point	Influent	System 1		System 2		System 3		Field blank
		Stage 1 Effluent	Stage 2 Effluent	Stage 1 Effluent	Stage 2 Effluent	Stage 1 Effluent	Stage 2 Effluent	
TKN	48	37	1.5	1.6	1.7	29	64	0.046
NH_3	45	33	0.02	0.23	0.092	26	68	0.020
(NO_3+NO_2)-N	21	19	0.022	47	0.020	48	3.5	0.042
SO_4	88	-	230	-	810	-	150	-
C-BOD_5	-	-	-	-	-	-	-	-
TSS	-	-	-	-	-	-	-	-

Sample Event 2

Sample Point	Influent	System 1		System 2		System 3		Field blank
		Stage 1 Effluent	Stage 2 Effluent	Stage 1 Effluent	Stage 2 Effluent	Stage 1 Effluent	Stage 2 Effluent	
TKN	78	1.7	1.6	1.2	2.6	52	46	0.046
NH_3	70	0.020	0.062	0.022	0.63	48	42	0.020
(NO_3+NO_2)-N	0.039	33	0.024	52	0.019	12	0.027	0.046
SO_4	52	-	430	-	570	-	160	-
C-BOD_5	280	-	-	-	-	-	-	-
TSS	15	-	-	-	-	-	-	-

Sample Event 3

Sample Point	Influent	System 1		System 2		System 3		Field blank
		Stage 1 Effluent	Stage 2 Effluent	Stage 1 Effluent	Stage 2 Effluent	Stage 1 Effluent	Stage 2 Effluent	
TKN	81	1.7	1.9	0.8	1.4	35	29	0.07
NH_3	74	0.042	0.089	0.020	0.2	31	26	0.020
(NO_3+NO_2)-N	0.028	47	0.026	72	0.021	32	21	0.054
SO_4	61	-	590	-	720	-	220	-
C-BOD_5	190	-	-	-	-	-	-	-
TSS	16	-	-	-	-	-	-	-

Sample Event 4

Sample Point	Influent	System 1		System 2		System 3		Field blank
		Stage 1 Effluent	Stage 2 Effluent	Stage 1 Effluent	Stage 2 Effluent	Stage 1 Effluent	Stage 2 Effluent	
TKN	85	2.5	4.3	0.046	1.2	19	30	0.06
NH_3	71	0.072	0.24	0.097	0.12	19	27	0.020
(NO_3+NO_2)-N	0.04	7.6	0.03	57	0.017	42	12	0.073
SO_4	78	-	590	-	620	-	200	-
C-BOD_5	-	-	-	-	-	-	-	-
TSS	-	-	-	-	-	-	-	-

Sample Event 5

Sample Point	Influent	System 1		System 2		System 3		Field blank
		Stage 1 Effluent	Stage 2 Effluent	Stage 1 Effluent	Stage 2 Effluent	Stage 1 Effluent	Stage 2 Effluent	
TKN	74	1.4	1.6	1.3	3.3	10	14.0	0.046
NH_3	2.6	0.053	0.14	0.041	2.0	9	11.000	0.020
(NO_3+NO_2)-N	0.051	25	0.035	48	0.028	48	0.066	0.040
SO_4	66	-	510	-	630	-	350	-
C-BOD_5	140	-	-	-	-	-	-	-
TSS	25	-	-	-	-	-	-	-