Investigation of passive nitrogen removal strategies for onsite septic systems at the Massachusetts Alternative Septic System Test Center

(and Continued Operation of the Test Center to Investigate Proprietary Technologies)

Project 14-01 319

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Executive Summary

Nitrogen from septic system constitutes approximately 80% of the nitrogen entering marine embayments on Cape Cod. Reducing nitrogen from this source is essential to maintain water quality that supports both a healthy marine ecosystem and the economic livelihood of Barnstable County.

Techniques were investigated that held promise to reduce nitrogen originating from onsite wastewater generation before reaching groundwater. A large publicly-funded project in Florida served as a basis for investigating passive, economical and sustainable means of modifying the drainfield portion of a septic system to facilitate denitrification in the drainfield itself. Soil column experiments initially showed that unsaturated flow of nitrified percolate through a sand:sawdust mixture produced >80% Total Nitrogen (TN) removal, while saturated flow produced even higher nitrogen removal rates. Following these soil column experiments, one small-scale and two full-scale septic systems were installed and intensely monitored over at least 500 days. The unsaturated design was tested due to its simplicity and projected cost savings in construction. The small-**scale (≈ 16 gallons/day) trial was monitored over 850 days and removed from ≈ 55% to > 90%** of influent Total Nitrogen (TN). One full-scale (220 gallons/day) system modelled after research conducted by the University of Waterloo, Canada[1] **averaged ≈ 85% reduction in** TN over 650 days that it was monitored. Finally, a full scale (200 gallons/day) system monitored over **500 days averaged ≈81%** removal of TN. All systems exhibited significant reduction in performance during the colder months. Decreased performance in colder month may be related to either temperature or the increased availability of dissolved oxygen associated with lower temperatures. Pan lysimeters were validated in the present study as providing a representative sample of nitrogen discharge from soils based systems.

Although questions remain regarding longevity of the cellulosic carbon source and the rate (if any) of settling that might occur, these authors believe that field trials at actual residences is indicated. Accordingly, the authors have convened a collaborative team from the authors of the original work in Florida[2] and researchers from the University of Rhode Island and obtained a grant from USEPA Southern New England Estuary Program to install twelve systems. Using the data from the present project, the team has modified the design to attempt higher levels of nitrogen removal. These design changes are described herein.

Introduction

Nitrogen from septic system constitutes approximately 80% of the nitrogen entering marine embayments on Cape Cod (Cape Cod Commission – Cape Cod Areawide Water Quality Management Plan). Reducing nitrogen from this source is essential to maintain water quality that supports both a healthy marine ecosystem and the economic livelihood of Barnstable County.

Due to the anticipated continued use of septic system in the county, beginning in 2013, Barnstable County Department of Health and Environment began investigating economical and sustainable ways to treat wastewater-derived nitrogen onsite. The emphasis of these efforts is on non-proprietary means to modify soil treatment areas (STA), alternately known as leachfields or soil absorption systems to remove nitrogen. These efforts supplement **the department's ongoing efforts to research and report on** proprietary technologies (https://septic.barnstablecountyhealth.org/category/statistical-analyses). The present project was guided by several publicly-financed projects being conducted in various geographical locations; most notably we derived much design guidance from the Florida Onsite Sewage Nitrogen Reduction Strategies (FOSNRS) Project. The information from this and other projects combined with the test-bed assets of the Massachusetts Alternative Septic System Test Center offered an unprecedented opportunity to apply the emerging findings from Florida and other studies to our area. While design elements are relatively easy to duplicate, it is vital to document the effects of differences in wastewater chemistry such as alkalinity between Florida and our region as well as seasonal differences in temperature that have an anticipated effect on nitrogen removal.

The reader should understand that this and subsequent projects funded under the, the Section 319(b) Nonpoint Source Pollution Competitive Grant Program (Project 15-07/319 and Project17-03/319) have **evolved since their inceptions. Major efforts have been "spawned" by this and subsequent** projects that have reshaped and focused our efforts. Of note is the fact that the newly-established New York State NYS Center for Clean Water Technology (CCWT), whose primary objective is to develop and commercialize wastewater treatment systems for individual onsite (household) used the work from this project and Project 15-07/319 to identify techniques potentially capable of meeting treatment goals for Long Island, New York. In addition to public efforts, since the inception of this project two major manufacturers of septic system products and one new start-up company have invested significant effort to develop passive denitrifying technologies based on principles used in our non-proprietary work funded under this grant.

Inspiration from Albert Einstein

A quote, often attributed to Albert Einstein states "Everything should be made as simple as possible, but **not simpler"**. Designs used in the FOSNER efforts involved an impervious liner beneath a Soil Treatment Area (STA) which essentially made the entire STA a contained filter. The percolate was then directed to a pump chamber and further directed to an additional STA for disposal (figure 1). Close inspection of the data from these Florida systems indicated experiments with a simpler concept might yield benefits for both simplicity in construction, elimination of a second disposal field and significant cost savings. One goal of this project was to determine whether simplification of concepts used in previous work might yield favorable results. Initial discussions with Florida investigators indicated that there was significant reduction of nitrogen in the liner-based systems even when full saturation of the media was not provided. Accordingly, we designed and conducted experiments on soil columns where unsaturated conditions could be produced to simulate what might occur in full scale STA installations. Many of these experiments duplicated those performed in Florida and are reported herein. Our efforts toward this simpler "unsaturated system" design were also informed by a system reported by Robertson and Cherry[1]. Discussions with Florida researchers, Will Robertson, Ph.D. of the University of Waterloo (author of the previously-cited paper) and others suggested that this simpler design might hold promise of, at least, enhanced nitrogen removal compared to standard STA. Unsaturated refers to a condition in the soil where the soil pore space is occupied primarily by air or gasses. The design is placed immediately above the native soil, eliminating the need for a second disposal area (figure 2).

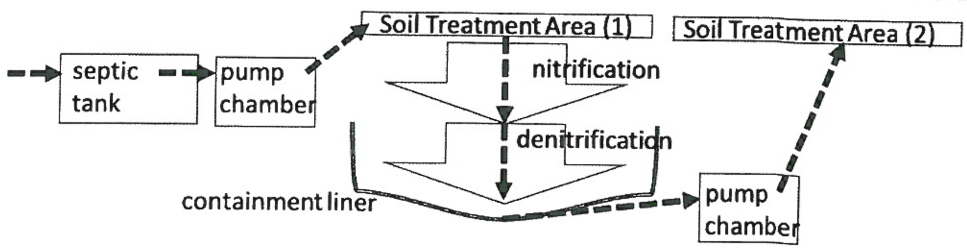

Figure 1. Diagrammatical representation of initial designs used under Florida Onsite Sewage Nitrogen Reduction Strategies (FOSNRS) studies.

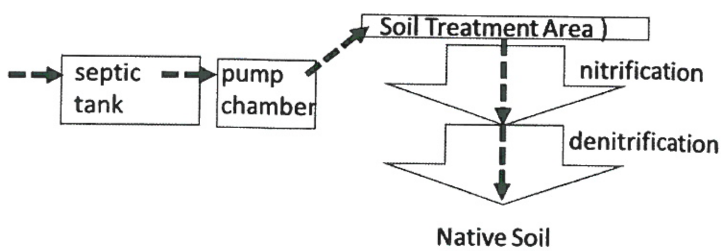

Figure 2 Diagrammatic representation of initial designs in the present project.

Methodology - Soil Column Experiments.

Following upon work in Florida, since June 2014, nitrified effluent (percolate) from a functioning septic leaching area with an 18-inch depth was collected and dispersed to top of seven soil columns containing a 1:1 sand/sawdust mixture. The leaching area used for a source of nitrified percolate simulated the top (surface-most) layers of the complete soil absorption system shown in figure 2. The soil columns (containing 18 inches of a sand-sawdust mixture) simulated the deeper layers (the denitrification layer shown in figure 2) positioned beneath the surface-most layers. The sawdust was introduced to provide a carbon source for the denitrification process. The experimental setup and is illustrated and pictured in figures 3 and 4. Three of the columns were kept saturated by means of standpipes. These saturated columns represented the Florida saturated system designs more closely since the pore space of the sand/sawdust was filled with liquid, much like the condition where an impervious liner would hold the saturated condition by not allowing the water to freely drain. The four remaining columns were maintained in an *unsaturated* condition. One of the unsaturated columns was supplied with only tap water to determine the nitrogen supplied by the sand/sawdust alone. These unsaturated columns simulated the condition where no liner was installed and the wastewater could freely drain and allow gas exchange to some pore spaces. Nitrogen in the percolate supply for these two treatments was generally in the form of nitrate-nitrogen and was diverted by means of small calibrated pumps (figure 4 and 5). The hydraulic loading rate was nominally 0.5 gal/sq. ft./day (2 cm/day) in accordance with the hydraulic loading rate of the soil area providing the percolate.

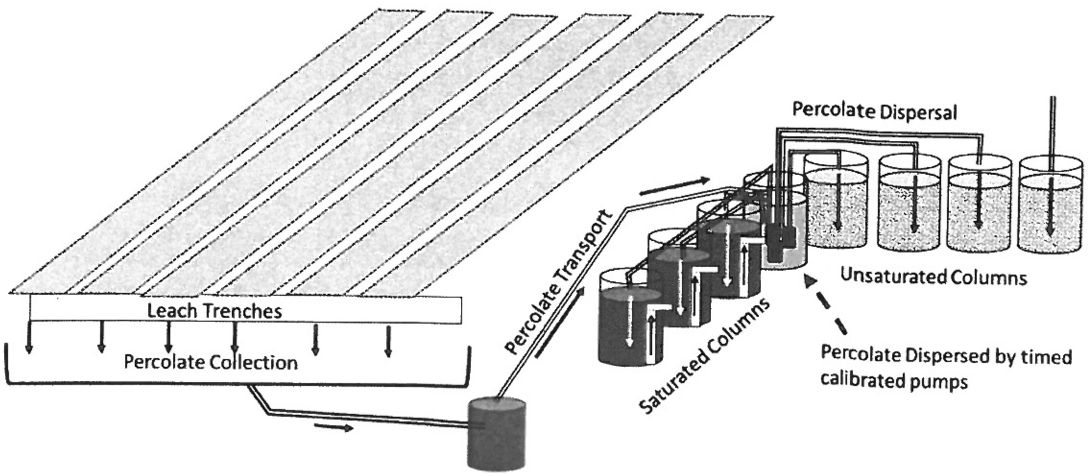

Figure 3. Configuration of soil columns.

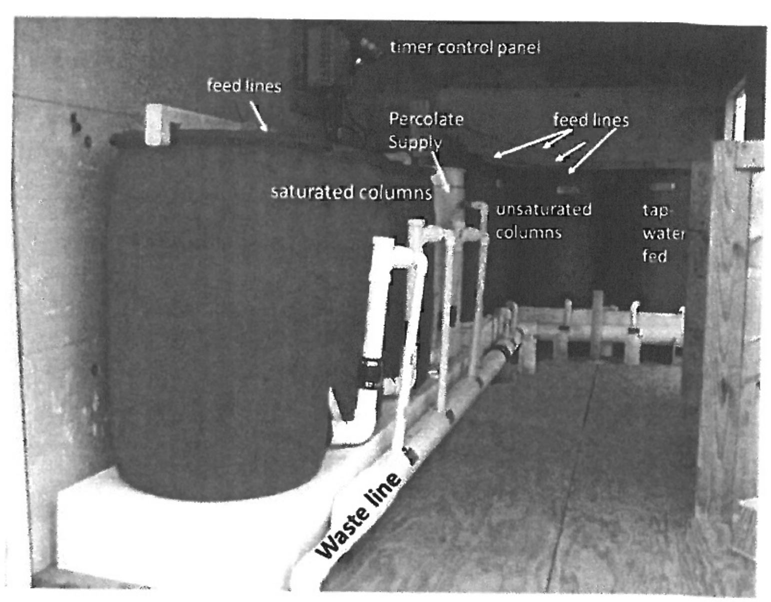

Figure 4. Soil columns located in enclosed trailer.

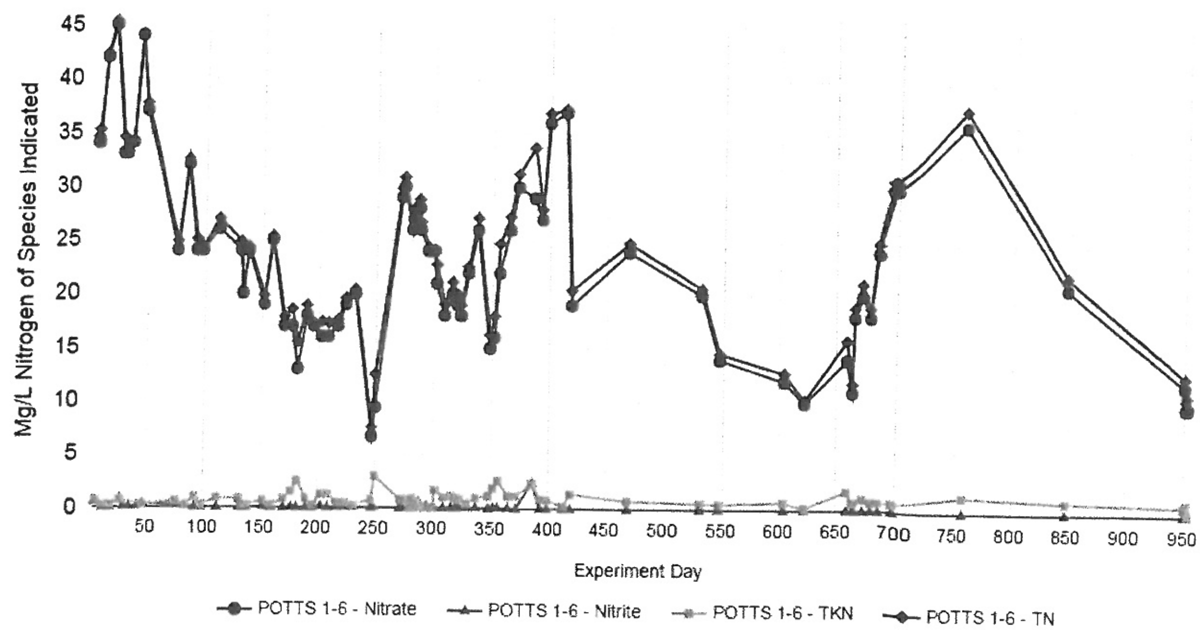

Figure 5 Nitrogen concentrations for source percolate used in column experiments.

Methodology – scaled installations

The systems described in this report contrast with those described in subsequent reports (see Final Project Report Project 15-07/319 *Continued operation of the Massachusetts Alternative Septic System Test Center and the Investigation of passive nitrogen removal strategies for onsite septic systems*) in which an impervious polyethylene liner is placed to maintain an area of saturation in the STA similar to some of the designs from the Florida Project[2]. Installations described herein endeavored to investigate the simplest and least expensive designs to install and operate. Essentially, these **"layered"** designs simply incorporate a mixed carbon-containing layer into a standard STA approximately 18 inches below the wastewater/soil interface. There were no impervious liners used to maintain saturation in the denitrification media. Three installations are described herein:

- A small scale unsaturated STA (≈**16 gallons/da**y), installed October 2014;
- A full scale (220 gallon/day) system using a loamy sand nitrification and sand-silt-sawdust denitrification layer (installed June 2015), and;
- A full-scale (220 gallons/day) system using a loamy sand nitrification layer and a loamy sand-sawdust denitrification layer (installed December 2015).

Small-Scale Unsaturated System

Based on soil column data discussed below, in October 2014 a small-scale system was constructed (≈8 ft. x 4 ft.) and supplied with septic tank effluent. This was the first attempt to place the system in a manner consistent with a standard installation (figures 6 and 7).

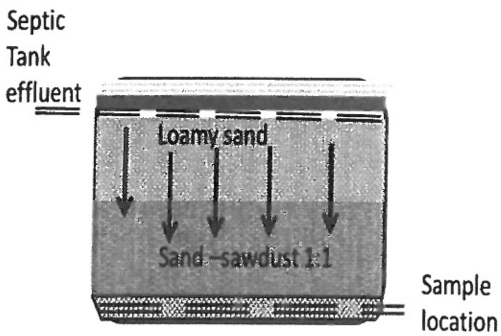

Figure 6. Schemata of small scale layered treatment unit installed at the Massachusetts Alternative Septic System Test Center November 2014.

Understanding the Processes – a brief review of nitrogen removal in soil-based systems.

*Denitrification in soil-based systems can be thought of as following a defined sequence. Ammonia from the septic tank enters the soil profile and is first nitrified (converted by way of biology or microbial transformations to nitrate). As wastewater continues to percolate through the soil profile much of the carbon necessary for denitrifying organisms is removed. In addition, the oxygen transferred along the way inhibits denitrification. **If** we could introduce a carbon source into the pathway and limit the oxygen, then conditions for denitrification (reduction of the nitrate to nitrogen gas) could occur. The sand/sawdust layer is intended to introduce the carbon that is necessary for denitrification and promote low oxygen conditions by maintaining the soil moisture.*

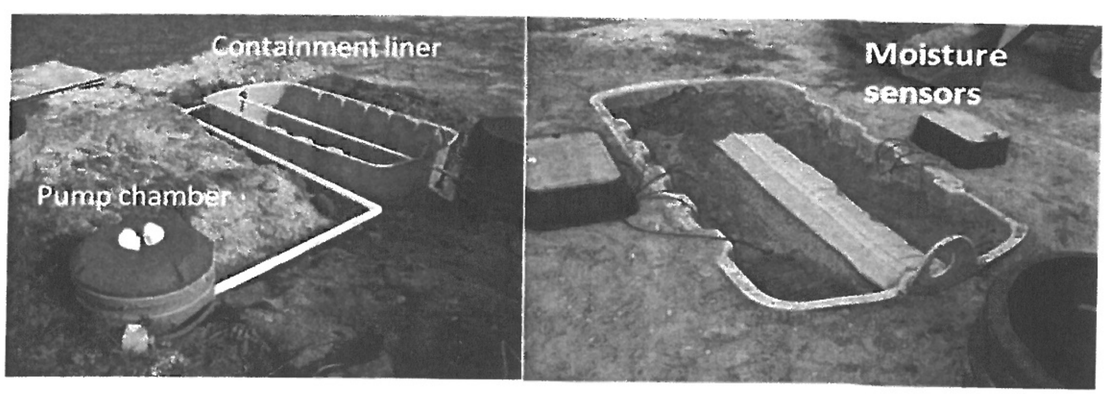

Figure 7 Small layered system prior to filling of containment liner (left). Wastewater distribution lateral placed before final cover (right).

Full-Scale Sand-Silt-Sawdust System Installed June 2015.

In June 2015, encouraged by results of the small-scale system described above, a full-scale system was installed using the principles used by Robertson and Cherry (2005)[1](figure 8). The location chosen for installation was a 20 ft. x 40 ft. area that was completely contained so that all percolate passing through the system could be sampled. In addition, two sampling pan lysimeter were placed beneath the STA (figures 8 - 13).

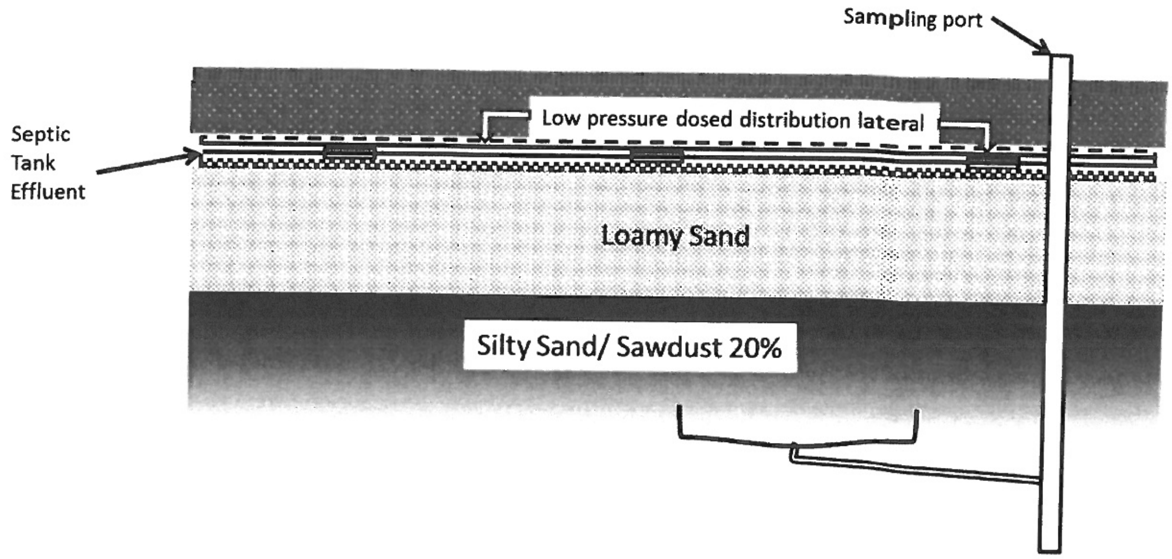

Figure 8 Schemata showing section of full-scale sand-silt-sawdust system installed at the Massachusetts Alternative Septic System Test Center in June 2015. Area was completely contained for representative sampling (containment not shown).

Figure 9 Placement of the sawdust-sand-silt mix which serves as a denitrification layer. Layer is 27 – 45 inches below finish grade and is placed atop the native soil.

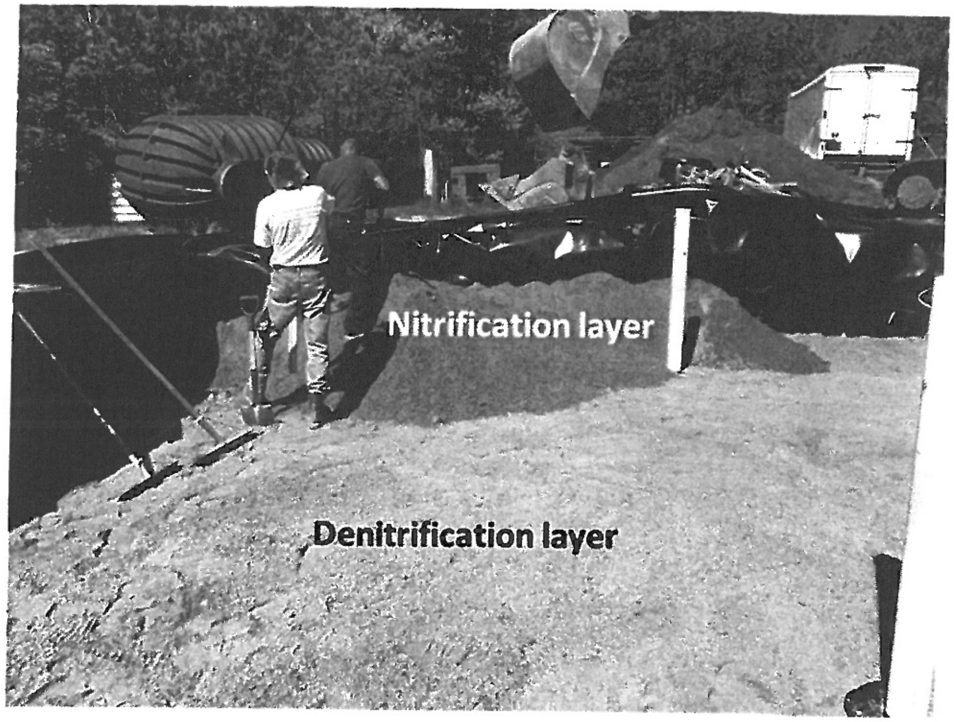

Figure 10 Loamy sand is place atop the denitrification layer. Liner shown is no part of a standard installation. Pipe shown is pan lysimeter installed below denitrification area.

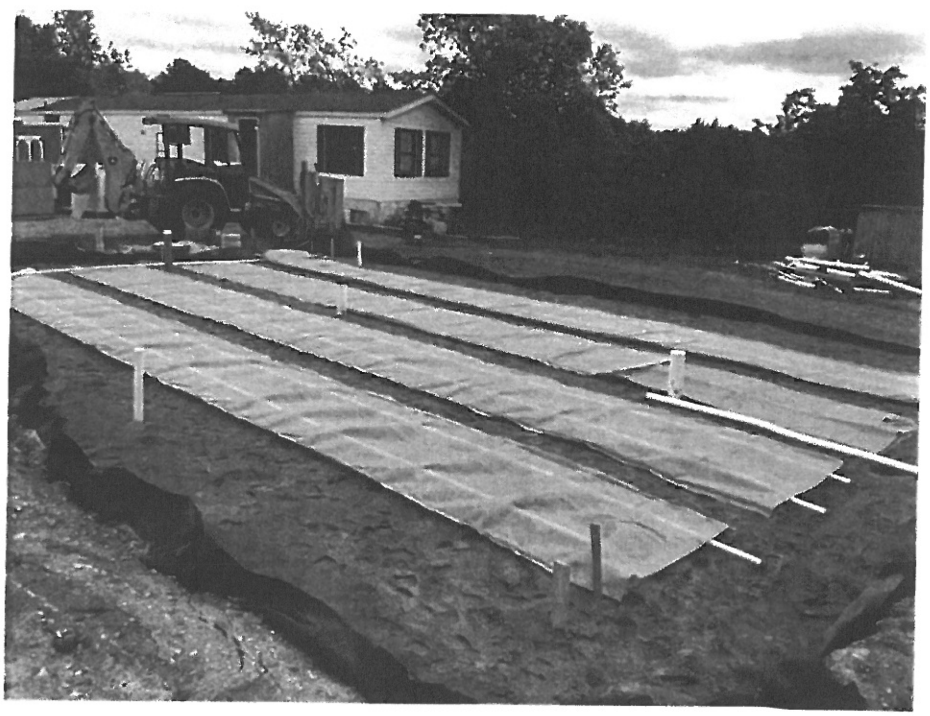

Figure 11 Septic tank distribution piping placed atop nitrification area (supply manifold not shown). Note in this experimental setting extra piping installed to allow flexibility during tests.

Figure 12 Finish grade over system. Note large green risers not typical. Extra valve controls installed to allow flexibility during testing.

Figure 13 Appearance of sand-silt-sawdust system installed at the Massachusetts Alternative Septic System Test Center in June 2015. Picture taken June 2017.

Full-Scale (220 gallons/day) System Installed December 2015

In December 2015, an additional full scale unsaturated layered system was installed. This system was constructed with sand into which a small amount (<10%) loamy material was mixed on site for both the nitrification and the denitrification layer. The denitrification layer was comprised of this material mixed 1:1 with sawdust (figures 14 - 16).

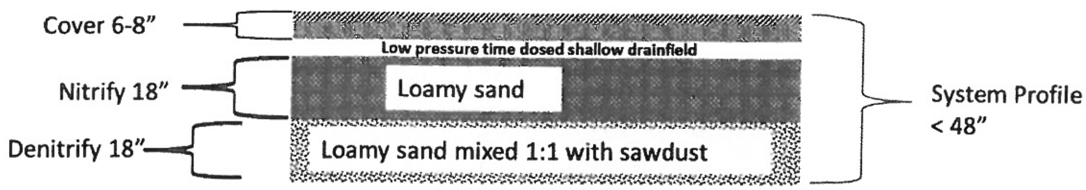

Figure 14 Schemata of layered system installed December 2015 at the Massachusetts Alternative Septic System Test Center

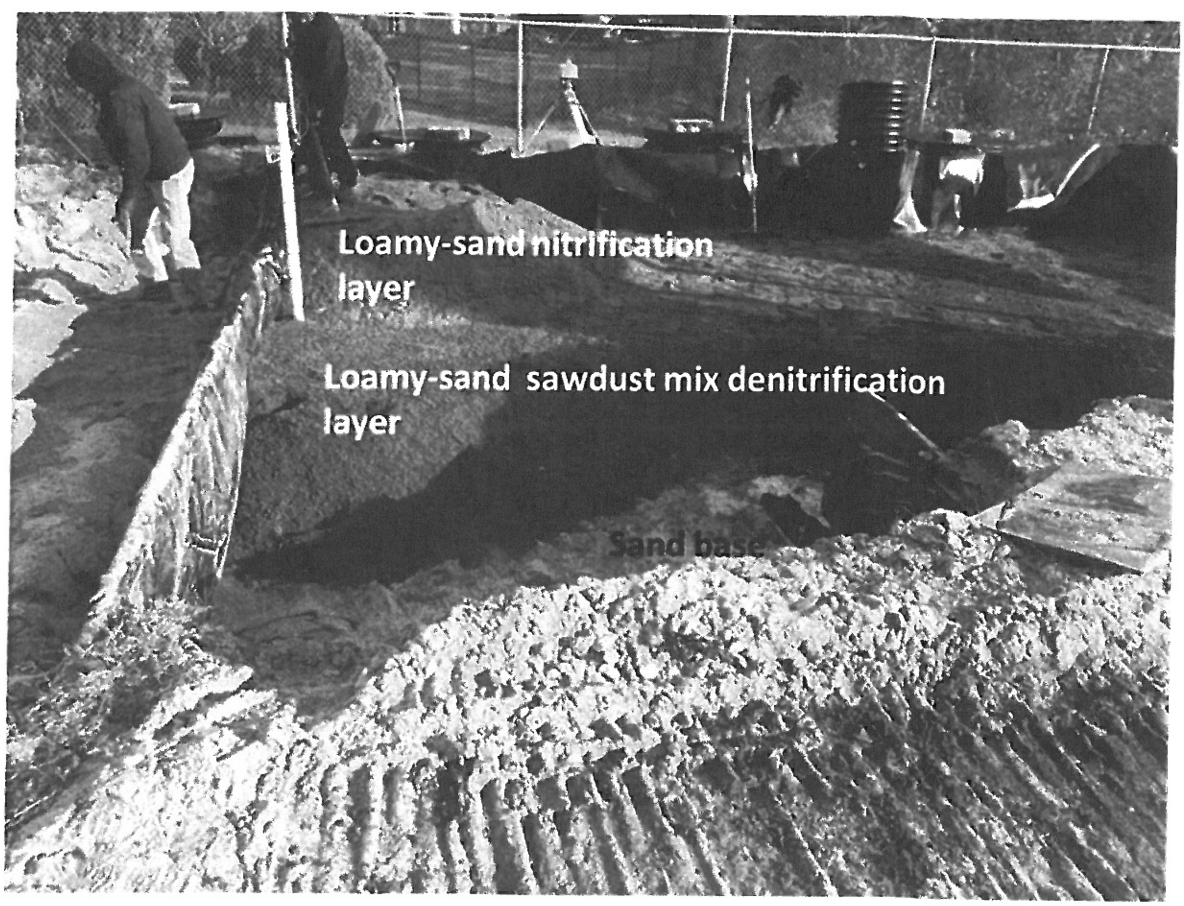

Figure 15 Layered system during installation. Note both nitrification and denitrification layers shown.

This system was also installed atop a large collection containment area that is not typical of standard installation but allows for representative sampling.

Figure 16 Full-scale layered system installed in December 2015. Pictured in June 2017.

Results

Unsaturated Soil Columns

For nearly one year (August 2014 – July 2015) the unsaturated soil column results appeared favorable, generally yielding percolate with Total Nitrogen (TN) concentrations < 10 mg/L – average 5.3 mg/L from August 2015 – July 2015 (figure 17). Following this date however, TN concentrations increased to nearly 20 mg/L from August 2015 – February 2017 when measurements were stopped. The initial encouraging results were the basis for both the small-scale system and the two full-scale systems described below. These later results were perplexing since these later scaled systems did not experience this decline in performance in the short-time period.

In summary, these unsaturated soil columns were intended to simulate the denitrifying soil layer. They were supplied with nitrified percolate from a functioning STA similar to what they would have received if they were positioned beneath the nitrifying layer. The reason that their nitrogen removing capacity declined over time is not known however the dominant form of nitrogen in the percolate was the oxidized form (nitrate – figure 18) and dissolved oxygen levels were typically >25 % saturation. These observations collectively indicate that the anoxic conditions necessary for denitrification did not occur.

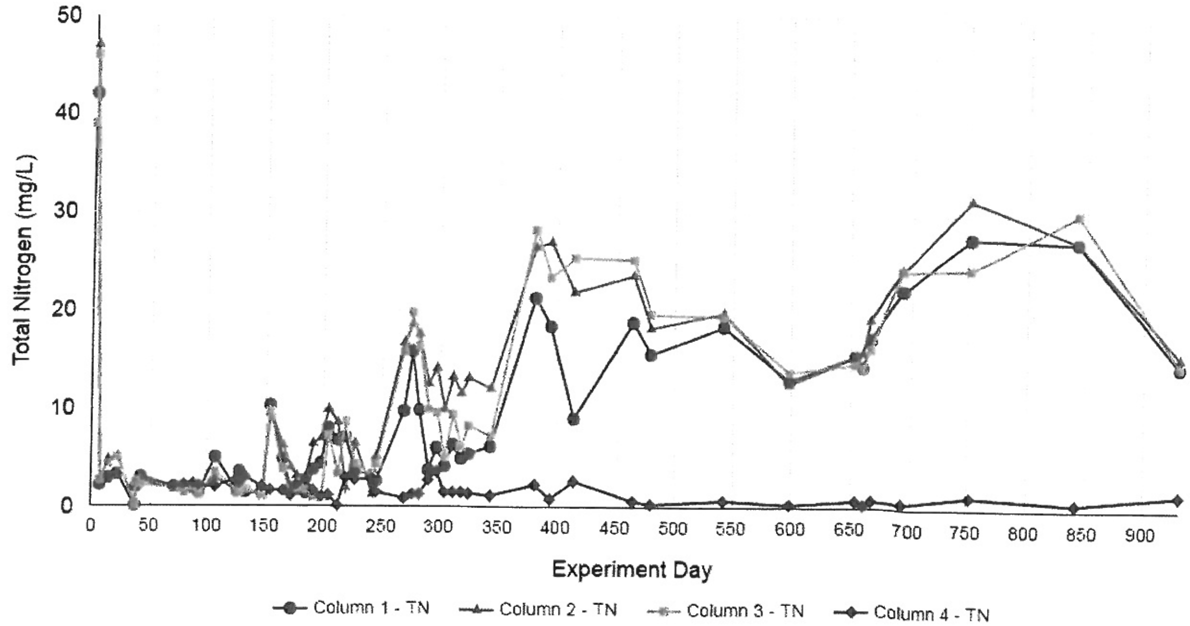

Figure 18 Total Nitrogen (TN) concentrations in mg/L in percolate of unsaturated soil columns July 2014 - February 2017.

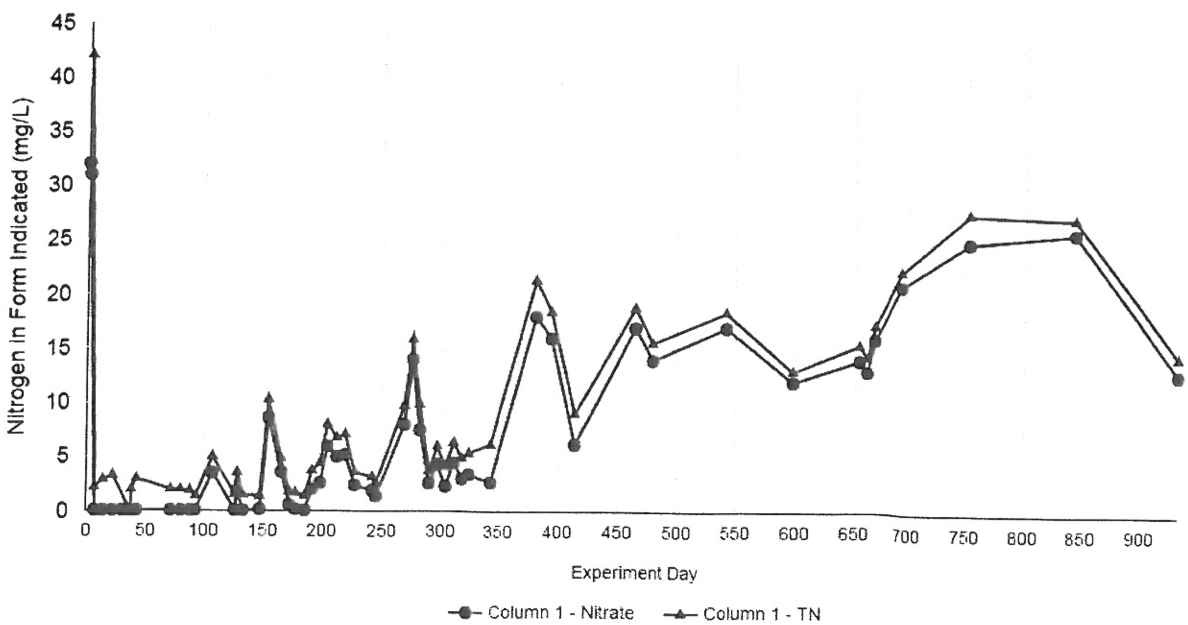

Figure 17 Total Nitrogen and nitrate levels in percolate from unsaturated soil columns supplied with nitrified percolate August 2015 – February 2017 at the Massachusetts Alternative Septic System Test Center showing that the majority of TN is in the nitrate form.

Although the data from these columns were beneficial in informing the design of the field trials, they were of limited continued value and were discontinued in February 2017. In April 2017, they were dissembled and the sawdust was inspected. It no appreciable change in appearance compared with their initial installation.

Saturated Soil Columns

Adjacent to the unsaturated soil columns, we similarly supplied saturated soil columns with nitrified percolate as described above (see figure 4). These columns have been sampled periodically from July 11, 2014 – March 15, 2017. Hydraulic loading rate to the columns was nominally 0.5 gal/sq. ft./day (2 cm/day) which matched the hydraulic loading rate of the STA that supplied the percolate. The dosing mechanisms are presently being redesigned and these columns will be monitored during 2017 to determine sand/sawdust longevity. These saturated columns were to simulate the conditions where a liner is placed under the sand/sawdust layer in a full-scale STA. Report on these full-scale systems is presented under different cover (See Final Report Project 15-07/319). The data from these saturated soil columns predicted substantial nitrogen attenuation (figure 19).

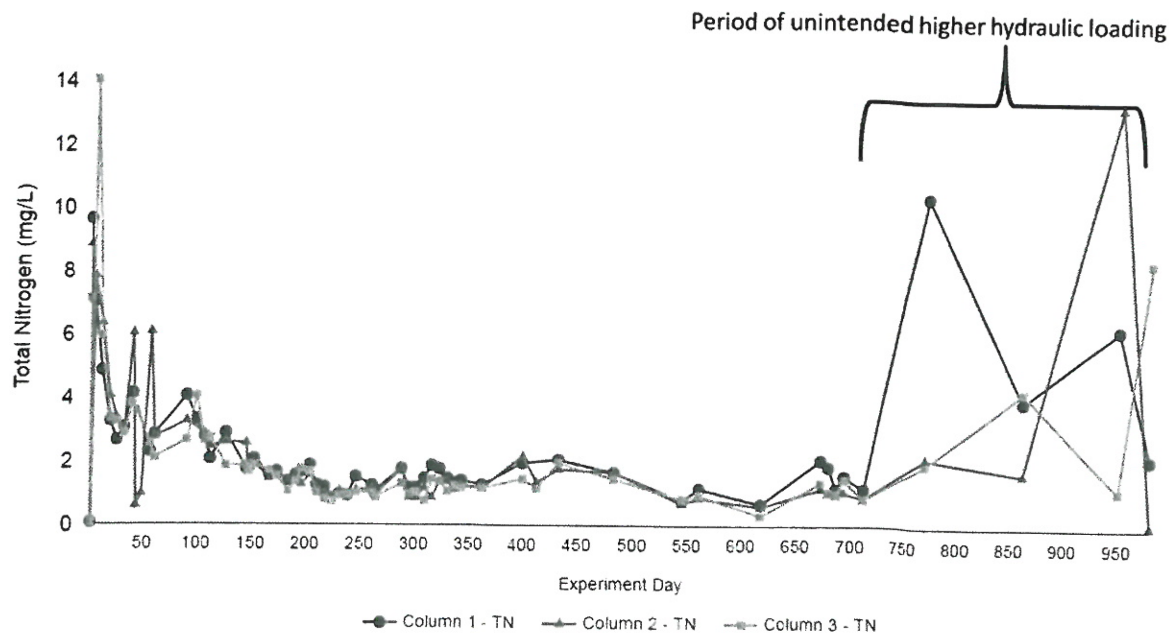

Figure 19 Total Nitrogen levels in percolate from saturated soil columns supplied with percolate from existing STA at the Massachusetts Alternative Septic System Test Center July 2014 - March 2017. Period of unintended increased hydraulic loading was due to siphoning from supply.

Two events explain the relatively-high nitrogen concentrations following circa day 765. Following the sampling on August 8, 2016 we discovered that the percolate from the supply was siphoning into Column 1 presenting a higher hydraulic load/day and hence less residence time in the denitrifying soil column. This lower residence time resulted in less nitrogen removal. In addition, following day 860 when higher total nitrogen levels were observed in all but one column, we discovered that the influent to the columns (percolate from the adjacent STA) contained higher ammonia levels. The major processes of denitrification involve the reduction of the oxidized forms of nitrogen (nitrite or nitrate). Ammonia cannot be transformed to any great extend in this setting. Accordingly, in general, ammonia concentrations of the effluent will approximate those of the influent. The reason for this higher level of ammonia at that time is related to our replacement of one of the percolate-supplying trenches. This newly placed trench was not nitrifying the wastewater completely and hence ammonia from its percolate comprised a portion of the supply for the saturated columns. Examination of the nitrate levels in all columns (figure 20) suggests that all columns retained an ability to denitrify most of the nitrate supplied, except for the period of uncontrolled hydraulic loading.

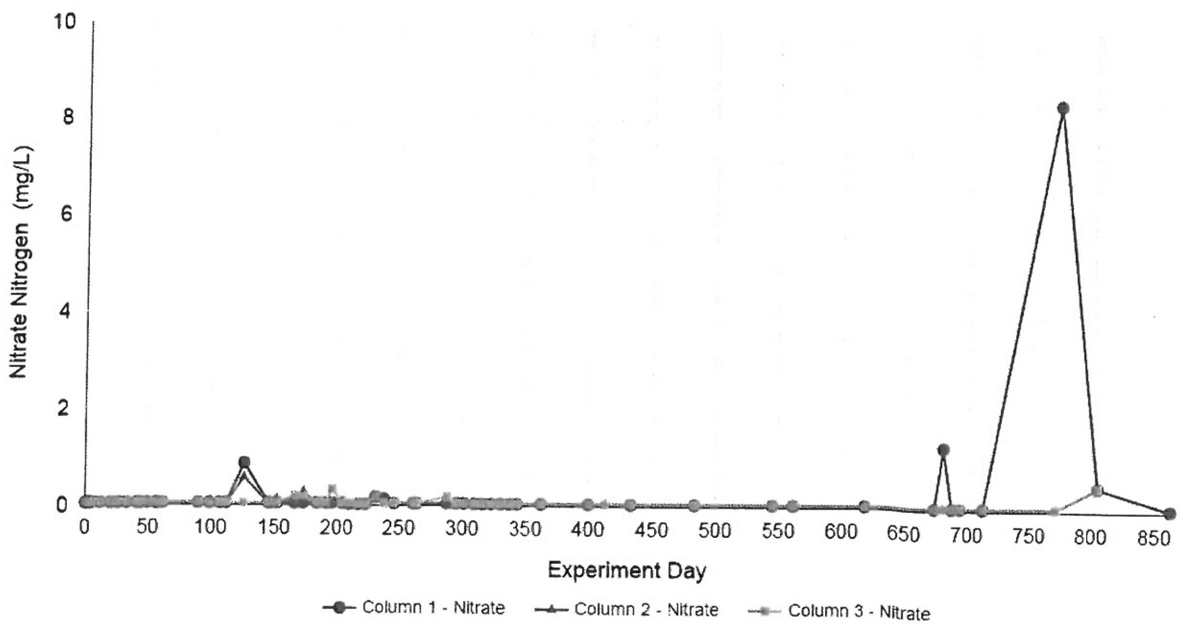

Figure 20 Nitrate levels from percolate of the saturated soil columns (note vertical scale). High levels of nitrate in Column 1 related to periods of uncontrolled dosing.

Collectively the column experiments suggest that the saturated condition of sand/sawdust is favorable to denitrification to a greater extent than the unsaturated condition.

Researchers at the Clean Water Center of Stony Brook University, Long Island New York have sampled the saturated sand/sawdust and are presently in the process of identifying the functional groups and the microbes responsible for the denitrification.

Small Scale Unsaturated System

From November 3, 2014 through March 3, 2017 (856 days), the small scale unsaturated system was operated and monitored (see figures 6 and 7). The hydraulic loading rate to the system was 0.5 gal/sq. ft./day (2 cm/day). After March 2017, the loamy sand was removed and replaced with sand to make the system comparison with sand-based nitrification layers and to verify that sand alone (ASTM C33 or "Title 5" fill sand) can achieve complete nitrification. The loamy sand used during this first deployment was thought necessary to achieve nitrification while preserving alkalinity levels that were thought necessary to prevent decreased nitrification[3]. This was also based on numerous observations from past study conducted at the Test Center.

Over the study period (approximately 850 days), the average Total Nitrogen (TN) in the percolate was 6 mg/L (5 – 7 mg/L, *p=.05*). Seasonal effects were clearly demonstrated (figure 21 with highest TN values observed during autumn and winter. In general, it appears that as the final effluent temperatures decreased, percolate/effluent TN increased.

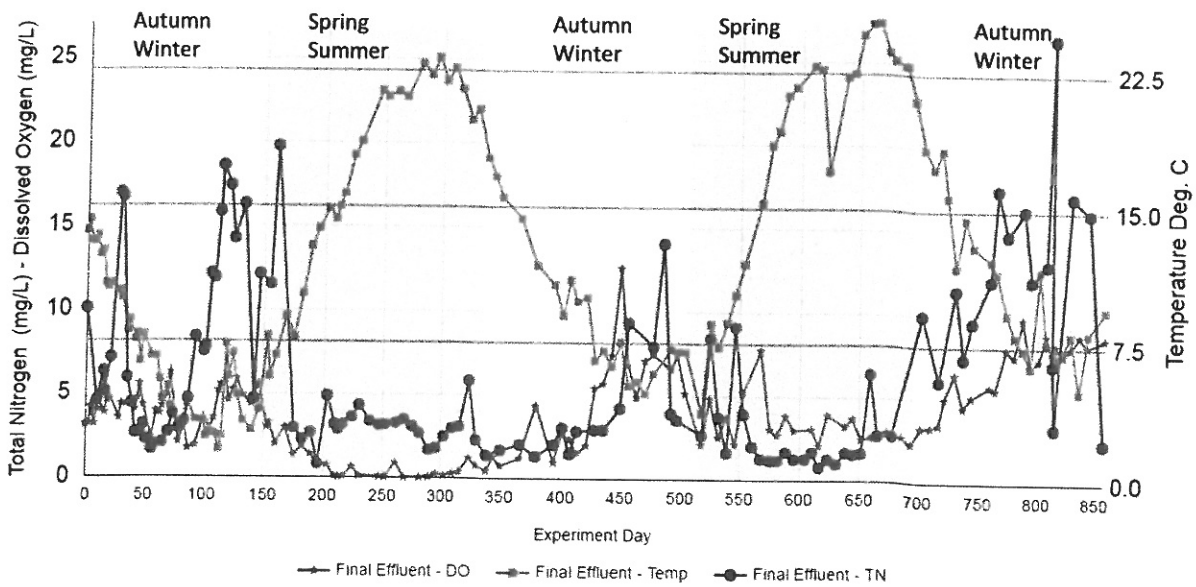

Figure 21 Total Nitrogen (TN) in the percolate beneath a small scale unsaturated Soil Treatment Area (STA) at the Massachusetts Alternative Septic System Test Center operated for 856 days.

We note that in most instances where TN levels were > 5 mg/L, much of the nitrogen was in the oxidized form of nitrate. We also note that periods of higher TN were related to the periods of high dissolved oxygen in the percolate. These data suggest that there are two mechanisms which may be responsible for the higher TN levels. Foremost it is generally accepted that lower temperatures slow biological processes, including denitrification, thus resulting in higher TN levels. In addition, low percolate water temperatures would also allow higher concentrations of oxygen to dissolve in percolating effluent which also might inhibit the denitrification process. In either event, it appears that there are seasonal considerations in applying this configuration.

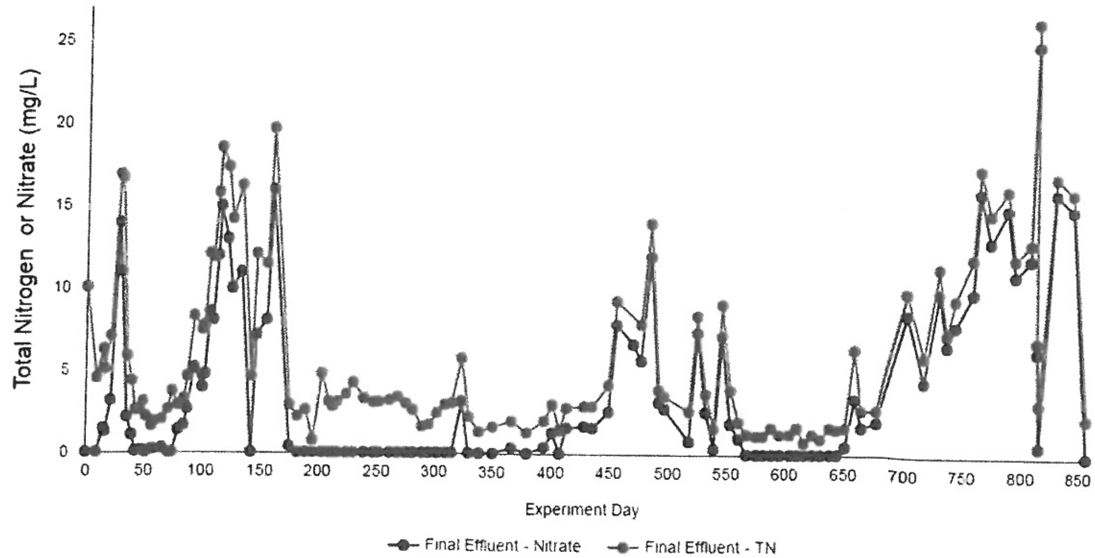

Figure 22 Comparison of Total Nitrogen (TN) and nitrate levels in the percolate beneath a small scale unsaturated Soil Treatment Area (STA) at the Massachusetts Alternative Septic System Test Center operated for 856 days. Note that the majority of TN is in the form of nitrate-nitrogen.

A Full-Scale (220 gallon/day) System Using Loamy Sand Nitrification and Sand-Silt-Sawdust Denitrification Layer.

This system contained three major monitoring points. Since the system was installed within a large **containment area, the bottom of the containment area or "sump" is the most representative sample** that could be obtained. These large containments will not, however, be a part of a normal installation. Since a representative sample will be required in field installations, two pan lysimeters were installed beneath the sand/silt/sawdust layer. The design of the pan lysimeter is presented in figure 23.

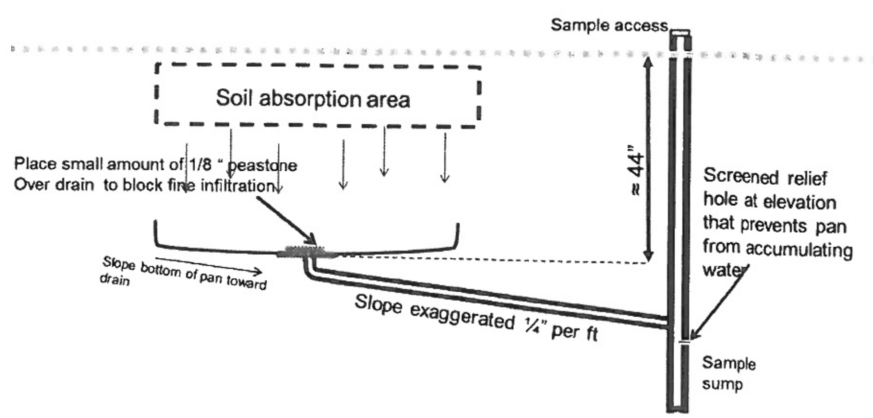

Figure 23 Schemata of a pan lysimeter placed beneath the sand-silt-sawdust layer of the full-scale system at the Massachusetts Alternative Septic System Test Center.

The results of all three sampling ports are presented in figure 24.

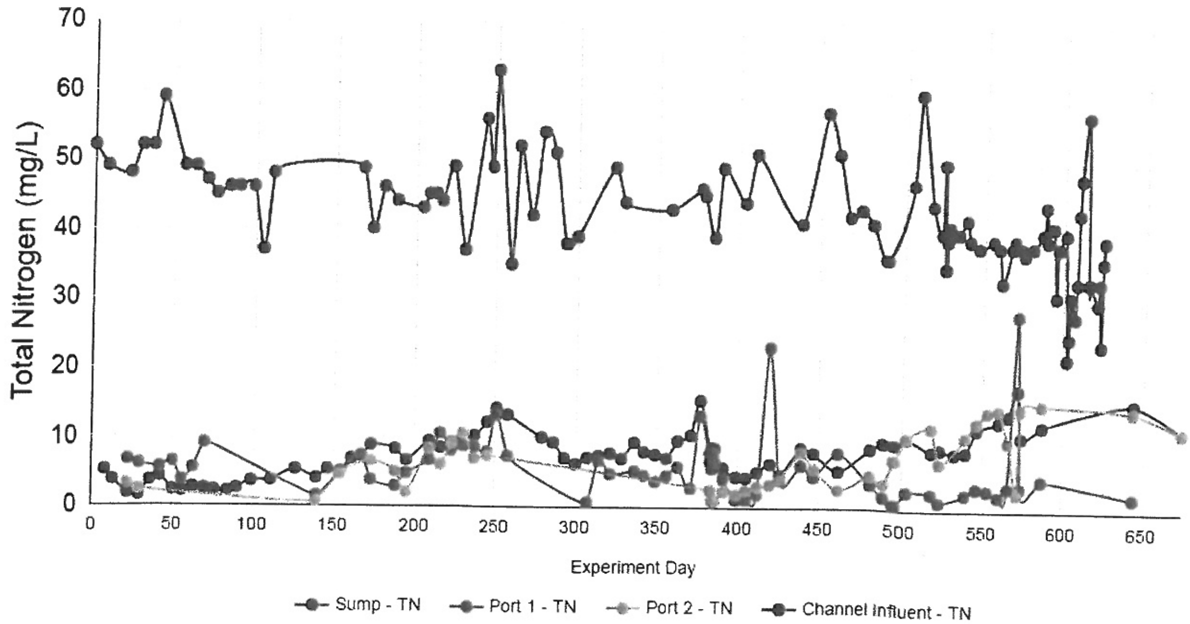

Figure 24 Total Nitrogen (TN) concentrations at selected sampling locations beneath a full-Scale (220 gallon/day) system using loamy sand nitrification and sand-silt-sawdust denitrification layer.

Observations made at sampling locations selected discharge locations of this system (n=176) indicates a mean TN concentration of 6.8 mg/L (6.2 – 7.4, *p= .05*). This represents an approximate 85% reduction in the total nitrogen concentration entering the system. A comparison of the individual sampling points indicates no significant difference between TN concentrations from Port 2 (mean TN 6.7 mg/L, SD = 4.5, n= 42) and the Sump concentrations (mean TN 7.7 mg/L, SD = 3.5, n=76 – no significance *p= .05*). In addition, there was no significant difference between sampling Port 1 (mean TN 5.8, SD = 4.7, n=59) and Port 2 (p= .05). There was, however a significant difference between the sampling Port 1 and the Sump. We conclude however that the assays taken from lysimeter samplers are a reasonable representation of the system performance.

Similar to the small-scale system previously described, there is a general trend for increased nitrogen levels (decreased efficiency of nitrogen removal) in colder weather, coincident with higher dissolved oxygen levels (figure 25). Compared with the small-scale system previously discussed, this system was less subject to the low temperature extremes. The low temperature observed at this system was 7.1° C, while for the three cold seasons observed, the small-scale system was consistently below 5°C, and was observed as low as 1.6°C. This may account for less extreme fluctuations in TN concentrations. The large thermal mass of this system coupled with the much deeper location of the sampling locations is likely the reason for this moderated response to atmospheric temperature fluctuations and is likely a more comparable situation to normal installations. Similar to the small-scale system, most of the nitrogen present in the percolate in the colder months was in the form of nitrate.

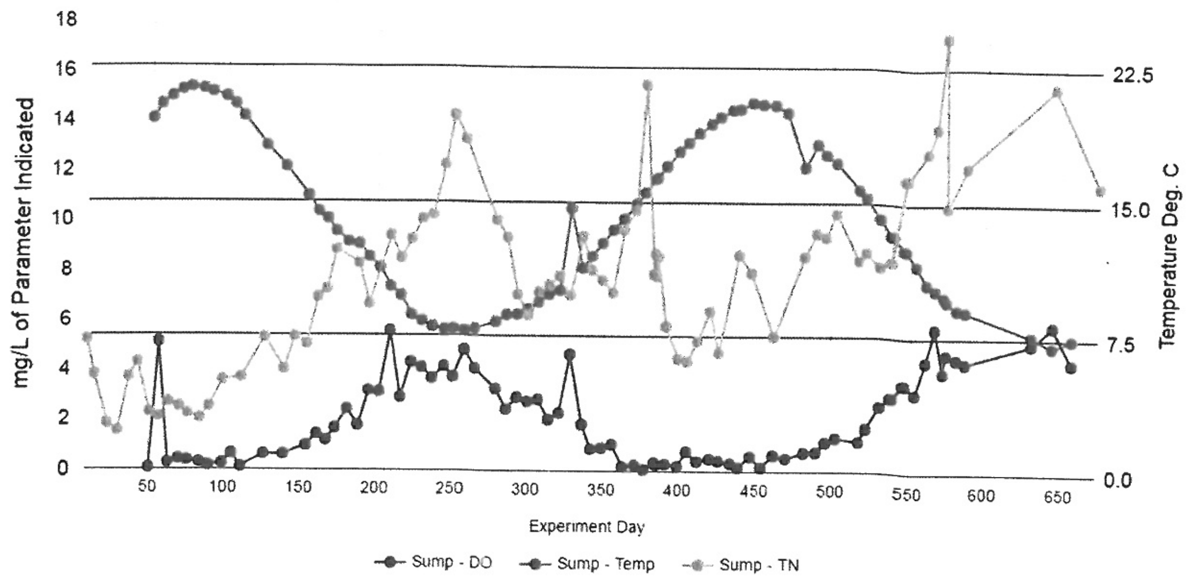

Figure 25 Total Nitrogen (TN) concentrations with temperature and dissolve oxygen levels in sump samples taken beneath a full-Scale (220 gallon/day) system using loamy sand nitrification and sand-silt-sawdust denitrification layer.

A Full-scale (220 gallons/day) System Using a Loamy Sand Nitrification Layer and a Loamy Sand-Sawdust Denitrification Layer

The winter start of this system was thought to be a potential a challenge to treatment during the initial operating months due to the low temperatures. Although the data suggest some start-up difficulties, the mean TN concentration over the 500+ days was 8.4 mg/L (6.9 – 9.9 mg/L, p=.05). Again, to validate the use of pan lysimeters for representative sampling, a comparison was made between the final discharge beneath the full containment liner and the pan lysimeter itself. The mean TN concentration in the single pan lysimeter placed beneath the denitrification layer was 6.7 mg/L (4.7 – 8.8 mg/L, p= .05). This value was not significantly different from the full-area sample at the 0.5 level of significance. This provides further evidence that pan lysimeters can serve as a representative sample at field installations which are not totally contained in a liner.

The performance of this system differed from the other two unsaturated systems in one significant aspect. The increase in nitrogen following approximately day 275 was due to elevated levels of ammonia (figure 27). This contrasts with other systems reported here since the major nitrogen species in the small-scale system and the large-scale sand-silt-sawdust system during periods of higher TN was nitrate (see figure 22). The reason for this difference is unknown, however incomplete nitrification is indicated. The extremely low nitrate levels suggest that any ammonia that is nitrified is subsequently denitrified in the passage through the denitrification layer. Oxygen levels, although below 5 mg/L in the percolate, would generally be adequate for further nitrification. Unfortunately, we have no alkalinity measures during this period to verify whether that parameter is limiting.

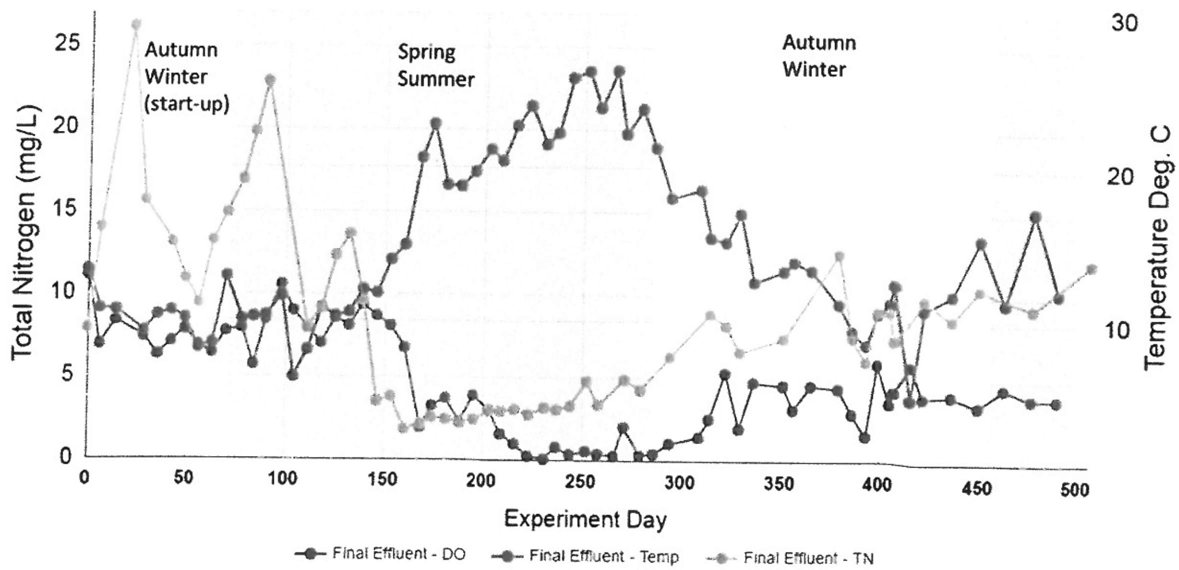

Figure 26 Total Nitrogen (TN) and temperature in the percolate beneath a full-scale (220 gallons/day) system using a loamy sand nitrification layer and a loamy sand-sawdust denitrification layer (installed December 2015).

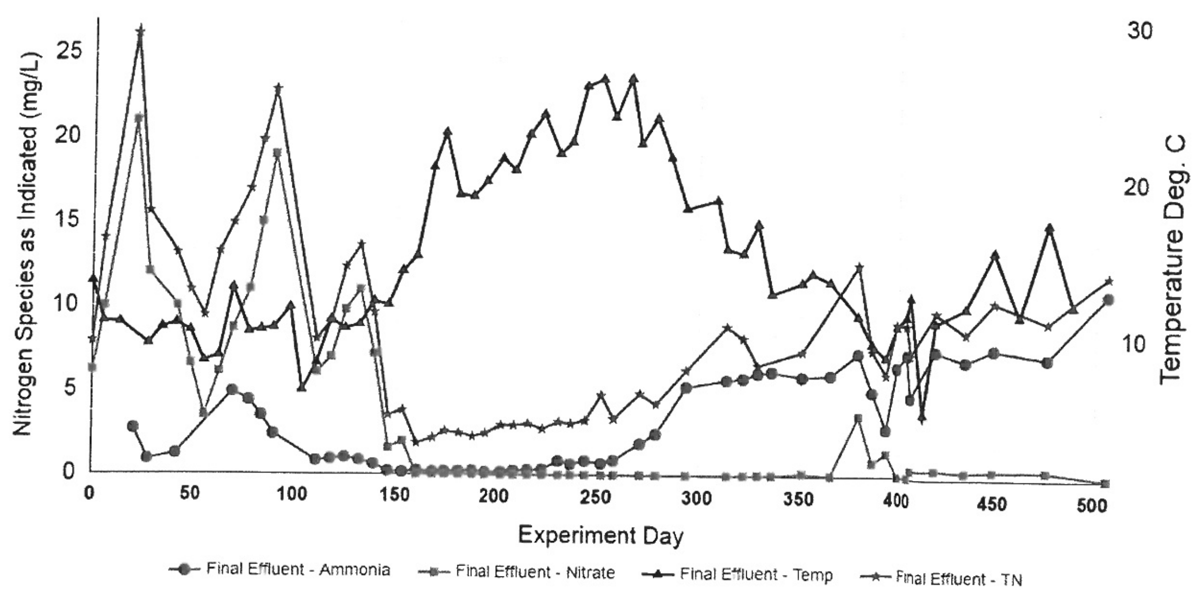

Figure 27 Nitrogen species present in percolate of a full-scale (220 gallons/day) system using a loamy sand nitrification layer and a loamy sand-sawdust denitrification layer (installed December 2015). Note dominance of ammonia fraction of TN following day 275.

Discussion and Conclusions

As early as 1979 investigators wishing to remove nitrogen using onsite wastewater systems have sought to intercept nitrified percolate beneath a soil absorption system to supply a carbon source for denitrification[4]. This principle was used widely in the FOSNER efforts previously cited which incorporated the use of an impervious liner to maintain a level of saturation in a layer of carbon-rich media located beneath a nitrification zone. This project endeavored to examine whether these designs could be simplified by placing a carbon-containing layer of material beneath the nitrification layer without the placement of an impervious barrier (see figure 2). This project more closely follows efforts conducted in Canada dating back to 1995 where no liner was used but denitrification of percolating wastewater was achieved. In that situation, a carbon source was imbedded or mixed with a modified permeable material placed below the nitrification zone. Based on results from that study and results from unsaturated soil columns reported herein, two variations of this "unsaturated" flow design were constructed and tested. The first modification, where sand mixed with sawdust was used as the denitrifying layer was tried in small scale (≈ 16 gallons/day) and full-scale (220 gallons/day). The second modification was a full-scale (220 gallons/day) system and more closely followed the Canadian work by further modifying the sand: sawdust layer with silt. The purpose of the silt addition was to provide more moisture retention in the denitrification layer to limit the oxygen transfer that is thought to inhibit denitrification.

The results to date suggest that 50 – 80% of the nitrogen from onsite wastewater can be removed by a simple layering of a sand/sawdust layer beneath the soil strata where nitrification takes place. The data show clear seasonal impacts on the performance of the systems with performance declining (nitrogen increasing) in the colder months. Contrary to the conventional wisdom which indicates that nitrification (conversion of NH_3 to NO_3^-) is most affected by cold temperatures, we found that the denitrification step (reduction of NO_3^- to $N_{2(gas)}$) was most affected. The reasons for this were not clear, but may be related to the increased oxygen levels allowed by the diffusion of more oxygen into the percolate at the lower temperatures. Facultative denitrifying organisms will use free oxygen when available prior to using denitrifying energy pathways, resulting in reduced denitrification.

Although these results are promising, questions remain. Foremost is the question of longevity. Using estimates provided in the Canadian study a longevity of at least 20 years when silt is mixed with the sand to encourage saturation is indicated. It is unknown if this figure applies to a mixture of just sand and sawdust. In addition to longevity, we do not know whether the system area will appreciably settle as the carbon in the wood material in the denitrification layer is expended.

Following a discussion of results with collaborators George Loomis and Jose Amador from the University of Rhode Island and Damann Anderson from Hazen and Sawyer who was a Principle Investigator on the FOSNR Project, certain design modifications are suggested for future installations. These modifications have also been incorporated into an EPA-Funded effort which will make possible the installation of twelve "unsaturated" systems throughout southeastern New England. This EPA Project was a direct result of research and development of the techniques conducted during this project. Thus project 14-01 319 was leveraged to a demonstration project of regional significance.

Encouraging Innovation

The public inspection of this project has resulted in two existing treatment-technology companies investing resources to integrate cellulose-based matrices into their system designs. Both companies are presently testing at MASSTC these configurations. In addition, one start-up company is investigating a "boxed" version using cellulose as a carbon source for denitrification. Thus, this project is encouraging innovation with the methods that may yield results in the near future.

Education and Outreach

Numerous national, regional and local presentations of this material have occurred during the grant period including:

- Water Environmental Federation – Nutrient Symposium June 12, 2017
- New England Interstate Water Pollution Control Commission – 5th Northeast Onsite Wastewater Treatment Short Course April 2016
- The 54th Annual Yankee Conference on Environmental Health September 2016
- The 49th Annual Health Conference for Massachusetts Health Officers – October 2016
- National Onsite Wastewater Recycling Association – October 2016 (joint authorship)
- Two Technical Seminars on Massachusetts Title 5 Approved Technologies
- Cape Cod Water Protection Collaborative
- Westport River Alliance Annual Meeting
- May 7, 2017 Brewster Pond Coalition – May 9, 2017
- Center for Life Long Learning May 2, 2017
- EPA Nonpoint Source Pollution Conference – April 2017
- One Cape Conference sponsored by the Cape Cod Commission 2016
- 4th Annual Cape Coastal Conference
- Board of Health Meetings to review results – Dennis, Brewster, Eastham, Wellfleet
- Design Charrette with Stony Brook University and the Suffolk County Health Department
- **Meeting with all Martha's Vineyard engineers and health department May 1, 2016**
- Indiana Onsite Wastewater Association Meeting Presentation – January 2016

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