Florida Onsite Sewage Nitrogen Reduction Strategies Study

TASK B DRAFT FINAL REPORT

Evaluation of Prototype Full Scale Passive Nitrogen Reduction Systems (PNRS) and Recommendations for Future Implementation

Prepared for:

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Acknowledgements

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1 INTRODUCTION

1.1 Project Background

The Florida Department of Health (FDOH) estimates that over two million onsite wastewater treatment and disposal systems (OSTDS) are currently operating in the State of Florida. Nitrogen loading from onsite systems is a potential concern in the state, depending on the number and density of onsite installations, their proximity to receiving waters, nitrogen removal processes in subsurface soils, and the sensitivity of receiving waters. The great majority of Florida onsite systems are comprised of a septic tank for primary treatment followed by dispersal into the environment using soil treatment units (STUs) commonly referred to as drainfields. Provided these typical systems meet current code requirements, they provide significant treatment of primary effluent, but their ability to remove nitrogen prior to the renovated effluent reaching groundwater is limited relative to other parameters. In 2008, the Florida legislature provided funding to FDOH to develop cost-effective, passive strategies for nitrogen reduction that complement the use of conventional OSTDS, and the Florida Onsite Sewage Nitrogen Reduction Strategies (FOSNRS) project was initiated in 2009. The FOSNRS project implemented a multi-pronged approach to address nitrogen loading from OSTDS to the Florida environment. A central component of the FOSNRS project was the development, design, and field evaluation of onsite wastewater nitrogen reduction technologies at both pilot and full scale. The goal of Task B of the FOSNRS project was to develop, design, install and evaluate prototype treatment technologies that are appropriate for onsite deployment, are relatively passive in operation, and which substantially increase nitrogen reduction over that of conventional OSTDS.

1.2 Previous Passive Nitrogen Reduction Study

FDOH had commissioned an earlier bench scale passive nitrogen removal study to investigate alternative methods to reduce nitrogen from onsite systems. A primary objective was to evaluate systems which operated with limited reliance on pumping, controls and forced aeration (Smith et al., 2008; Smith, 2009a; Smith, 2012). The operational definition for a passive system was established by FDOH in this study, and defined a passive nitrogen reduction system (PNRS) as an OSTDS that contains at most only a single liquid pump, no mechanical aerators or other mechanical devices, and that uses reactive media for denitrification. The bench scale study provided proof-of concept for a two-stage biofiltration process that met the FDOH criteria for a passive system and removed over 95% of Total Nitrogen from septic tank effluent (Smith et al., 2008; Smith, 2009a; Smith, 2009b; Smith, 2012).

1.3 Prioritization and Pilot Testing of Treatment Technologies

The FOSNRS project started in early 2009 with an evaluation of nitrogen reduction options for OSTDS. FOSNRS Task A included a literature review and classification of nitrogen removal technologies (Hazen & Sawyer and AET, 2009a), ranking of nitrogen removal systems, and prioritization of technologies for testing (Hazen & Sawyer and AET, 2009b). Two-stage biofiltration received a high ranking and recommendation. A pilot scale passive nitrogen reduction study was therefore undertaken. Multiple pilot scale two-stage biofilters were designed, constructed, and tested to further document performance and to develop preliminary design criteria for application of the two-stage process to prototype full scale onsite wastewater systems. The pilot study was conducted over a period of 18 months and indicated that two-stage biofiltration was a relatively simple process that was effective in reducing nitrogen concentrations from onsite wastewater primary effluent. Over 22 biofilters were operated in the pilot work and produced definitive track performance data for multiple design variants of the two stage biofiltration process. Total nitrogen removals of over 95% were continuously achieved in several of the pilot two-stage biofiltration units treating primary effluent (Hazen & Sawyer and AET, 2014; Hirst, et al., 2014).

1.4 Full Scale Prototype PNRS Evaluation at Florida Homes

The results of FOSNRS Task A and the pilot scale testing provided guidance for the design and performance testing of prototype full scale PNRS at individual Florida home sites, which was the objective of FOSNRS Task B and the subject of this report. The overall goal of FOSNRS Task B was to perform field evaluations of full scale PNRS under actual operating conditions to critically assess nitrogen reduction technologies that were identified in FOSNRS Task A. FOSNRS Task B included a Quality Assurance Project Plan for field testing (Hazen & Sawyer and AET, 2010), field system installation and monitoring, and a PNRS Life Cycle Cost Analysis template (Hazen & Sawyer and AET, 2015). This report summarizes the results of the full scale PNRS evaluations conducted under FOSNRS Task B and the Life Cycle Cost Analysis (LCCA) of the various treatment systems studied. Finally, the report provides summary recommendations for deploying PNRS treatment technologies as one component of a Florida Onsite Sewage Nitrogen Reduction Strategy.

2 OBJECTIVES AND SCOPE

The overall goal of FOSNRS Task B was to perform field evaluations of full scale PNRS under actual operating conditions to critically assess nitrogen reduction technologies that were identified for testing in FOSNRS Task A. To accomplish this goal several objectives were identified and met during the study through a series of tasks and subtasks:

- Development of a Quality Assurance Project Plan for field testing of PNRS
- Identification of residential test sites and establishment of homeowner agreements allowing use and access to the site
- Detailed design of a prototype PNRS specific to each test site, or identification of any specific proprietary technology vendors and establishment of vendor agreements as necessary
- Permitting and installation of prototype or proprietary treatment systems at test sites and documentation of any installation issues
- Documentation of installation costs of each prototype or proprietary PNRS system
- Monitoring of the performance of each treatment system for nitrogen and other water quality parameters to assess performance
- Monitoring of the energy used and other operational costs associated with PNRS operation
- Monitoring of routine and non-routine maintenance costs to support life cycle economic analysis of each PNRS
- Transfer of PNRS ownership and responsibility to the homeowner for future operation and maintenance or removal of system and restoration of the site, as desired by the homeowner
- Development of this Task B report summarizing the results of the prototype PNRS evaluations and life cycle cost analysis, and providing summary recommendations for deploying PNRS as one component of a Florida Onsite Sewage Nitrogen Reduction Strategy

3 SELECTION OF TREATMENT PROCESSES

The selection of treatment processes for full scale evaluation in Task B resulted from a culmination of FOSNRS Task A activities, which included a multistep process to classify, rank and prioritize candidate nitrogen reduction processes followed by pilot evaluations of the top ranked PNRS technologies and processes.

3.1 Task A Ranking and Prioritization

Task A included a literature review of nitrogen reduction processes and technologies, and a workshop conducted with the FDOH Research Review and Advisory Committee (RRAC) to classify, rank and prioritize treatment technologies. The workshop presented the nitrogen reduction technology and process classifications, ranking criteria, and weighting factors recommended by the project team, and solicited input from the stakeholder members of the RRAC. The objective of the workshop was to gain consensus on the ranking and prioritization methodology to be used for subsequent field testing. The outcome was the recommendations presented in the FOSNRS Task A report (Hazen & Sawyer and AET, 2009b) which are summarized in Table 3-1. Treatment process selection in Task B was guided by the Table 3-1 rankings.

Table 3-1: Process Systems Recommended for Task B Full Scale Testing (Hazen & Sawyer and AET, 2009b)

System Rank	Technology/Process	Comments
1	Two stage (segregated biomass) system: Stage 1: Biofiltration with recycle (nitrification) Stage 2: Autotrophic denitrification with reactive media biofilter	• Top ranked system capable of meeting the lowest TN concentration standard • Suitable for new systems or retrofit
2	Two stage (segregated biomass) system: Stage 1: Biofiltration with recycle (nitrification) Stage 2: Heterotrophic denitrification with reactive media biofilter	• Top ranked system capable of meeting the lowest TN concentration standard • Suitable for new systems or retrofit
3	Natural system: Septic tank/STU (Drainfield) with in-situ reactive media layers	• Lower cost natural system that is untested but appears capable of achieving 75-78% TN removal before reaching groundwater • Suitable for new systems or replacing existing systems at end of useful life

Table 3-1 (cont.): Process Systems Recommended for Task B Full Scale Testing (Hazen & Sawyer and AET, 2009b)

System	Technology	Comments
4	Natural system: Primary or secondary effluent with drip dispersal	• Suitable for reducing TN impacts on groundwater through enhanced TN removal and reduced TN loading on soil • Suitable for new systems or retrofit
5	Mixed biomass fixed film system with recycle followed by heterotrophic denitrification with reactive media biofilter	• High performance aerobic treatment with anoxia for enhanced TN removal followed by second stage heterotrophic denitrification for high nitrogen removal • Suitable for new systems or nitrogen reduction upgrades
6	Mixed biomass fixed film system with recycle followed by an autotrophic denitrification with reactive media biofilter	• High performance aerobic treatment with anoxia for enhanced TN removal followed by second stage autotrophic denitrification for meeting low TN concentration standard • Suitable for new systems or nitrogen reduction upgrades
7	Mixed biomass integrated fixed film activated sludge system: Suspended growth with recycle	• High performance aerobic treatment with recycle for denitrification • Suitable for new systems or nitrogen reduction upgrades
8	Mixed biomass integrated fixed film activated sludge system: Moving bed bioreactor	• High performance aerobic treatment with simultaneous denitrification • Suitable for new systems or nitrogen reduction upgrades
9	Mixed biomass suspended growth system: Suspended growth sequencing batch reactor	• Aerobic treatment • Suitable for new systems or nitrogen reduction upgrades
10	Membrane process system: Membrane bioreactor (MBR)	• Suitable for new systems or nitrogen reduction upgrades
11	Source separation system: Dry toilet (evaporative or composting)	• Eliminates liquid disposal of toilet wastes, eliminating 70-80% of TN from wastewater stream
12	Source separation system: Urine separating (recovery) toilet	• Innovative system that is capable of removing 70-80% of the household TN • Provides potential for sustainable recovery of nutrients

3.2 PNRS Pilot Testing

A pilot test facility was established to evaluate the top ranked PNRS technologies/processes and to develop preliminary design criteria for Task B full scale system prototypes. The pilot facility was located at the University of Florida Gulf Coast Research and Education Center (GCREC) in Wimauma, Florida. Twenty-four in-tank and two in-ground pilot scale biofilters were operated and monitored over a period of 18 months to evaluate nitrogen removal from wastewater primary effluent. The pilot test facility included four groups of two-stage biofiltration systems, with each group encompassing multiple variants of unsaturated biofiltration (Stage 1) followed by saturated biofiltration with reactive media (Stage 2). An overview of the pilot biofilter configuration is shown in Figure 3-1. The results of the pilot testing are summarized here; further details can be found in Hazen & Sawyer and AET (2014).

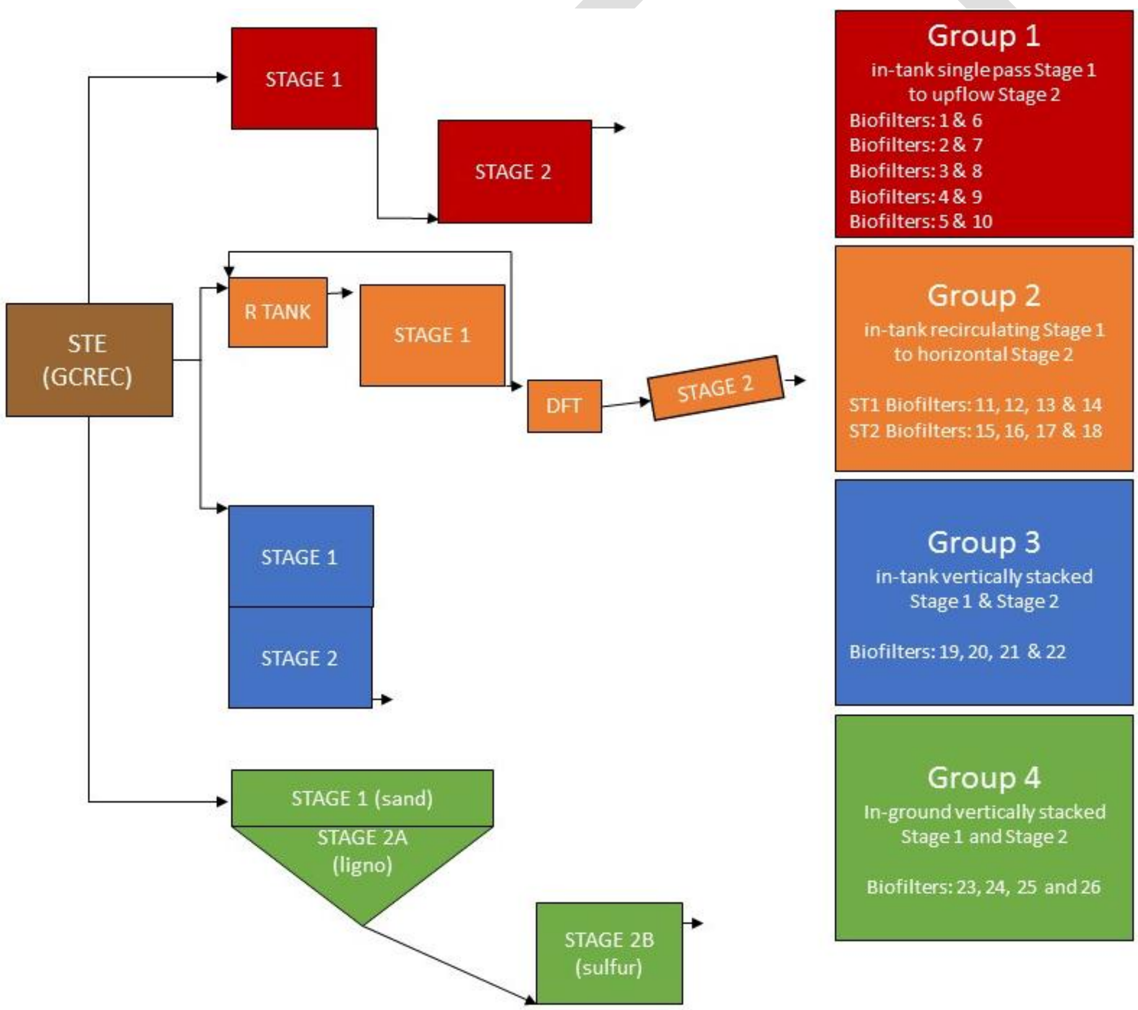


Figure 3-1: **GCREC Pilot Test Facility Groups**
See Table 3-2 for biofilter characteristics

The first group (Group 1) consisted of in-tank single pass Stage 1 biofilters directly coupled to upflow Stage 2 biofilters as depicted in Figure 3-2. Five single pass Stage 1 biofilters were directly connected to five upflow Stage 2 denitrification biofilters.Target hydraulic loading to Stage 1 biofilters was a surface loading of 3 gallons per square feet per day (gal/ft^2-day), which provided a 5.7 gal/ft^2-day surface loading to Stage 2 biofilters. The monitoring points for Group 1 included influent (STE), Stage 1 effluent and Stage 2 (final effluent).

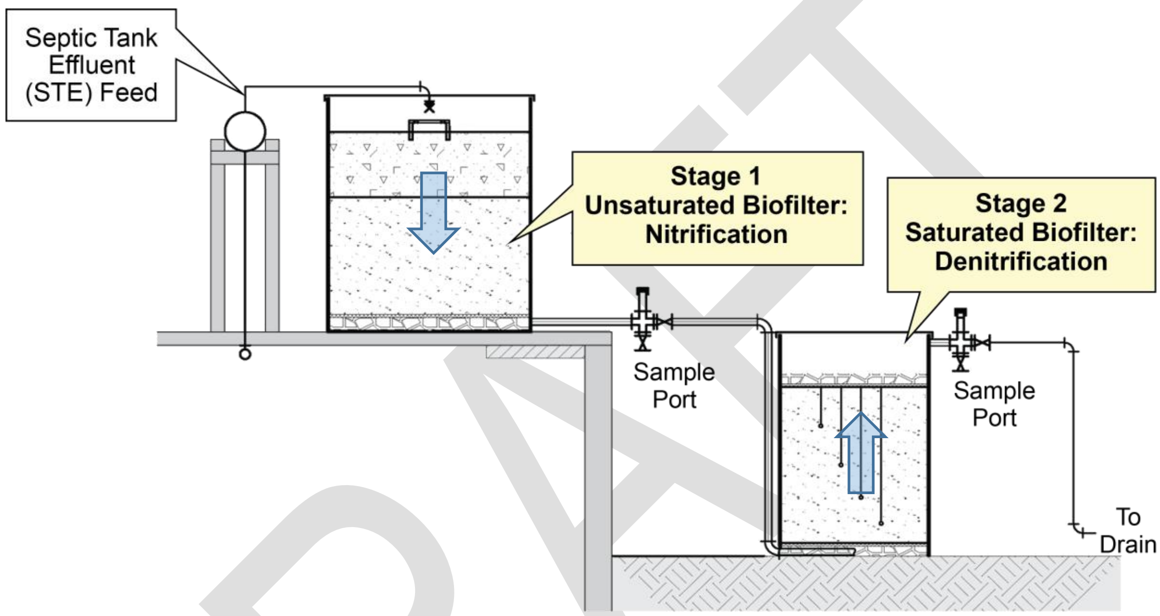


Figure 3-2: **Flow Schematic for a Single Pass Stage 1 Biofilter Directly Coupled to Upflow Stage 2 Biofilter**

The second group (Group 2) consisted of four in-tank recirculating Stage 1 biofilters where the combined Stage 1 biofilter effluents were collected in a denite feed tank (DFT) which fed four horizontal Stage 2 biofilters (Figure 3-3). The setup allowed parallel testing of various media in Stage 2 biofilters which received the same nitrified influent. Target hydraulic loading to the four Stage 1 recirculating biofilters was a surface loading of 3 gal/ft^2-day forward flow with a 3:1 recycle ratio of nitrified biofilter effluent to wastewater forward flow. This provided a 12 gal/ft^2-day surface loading to the Stage 1 biofilters based on total flow. The four horizontal Stage 2 biofilters received composite effluent from the recirculating Stage 1 biofilters, dosed from the DFT. Target hydraulic loading to the horizontal Stage 2 biofilters was a surface loading of 10 gal/ft^2-day. The monitoring points for Group 2 included the influent (STE), recirculation tank effluent, Stage 1 effluent, DFT, and Stage 2 effluent (final effluent).

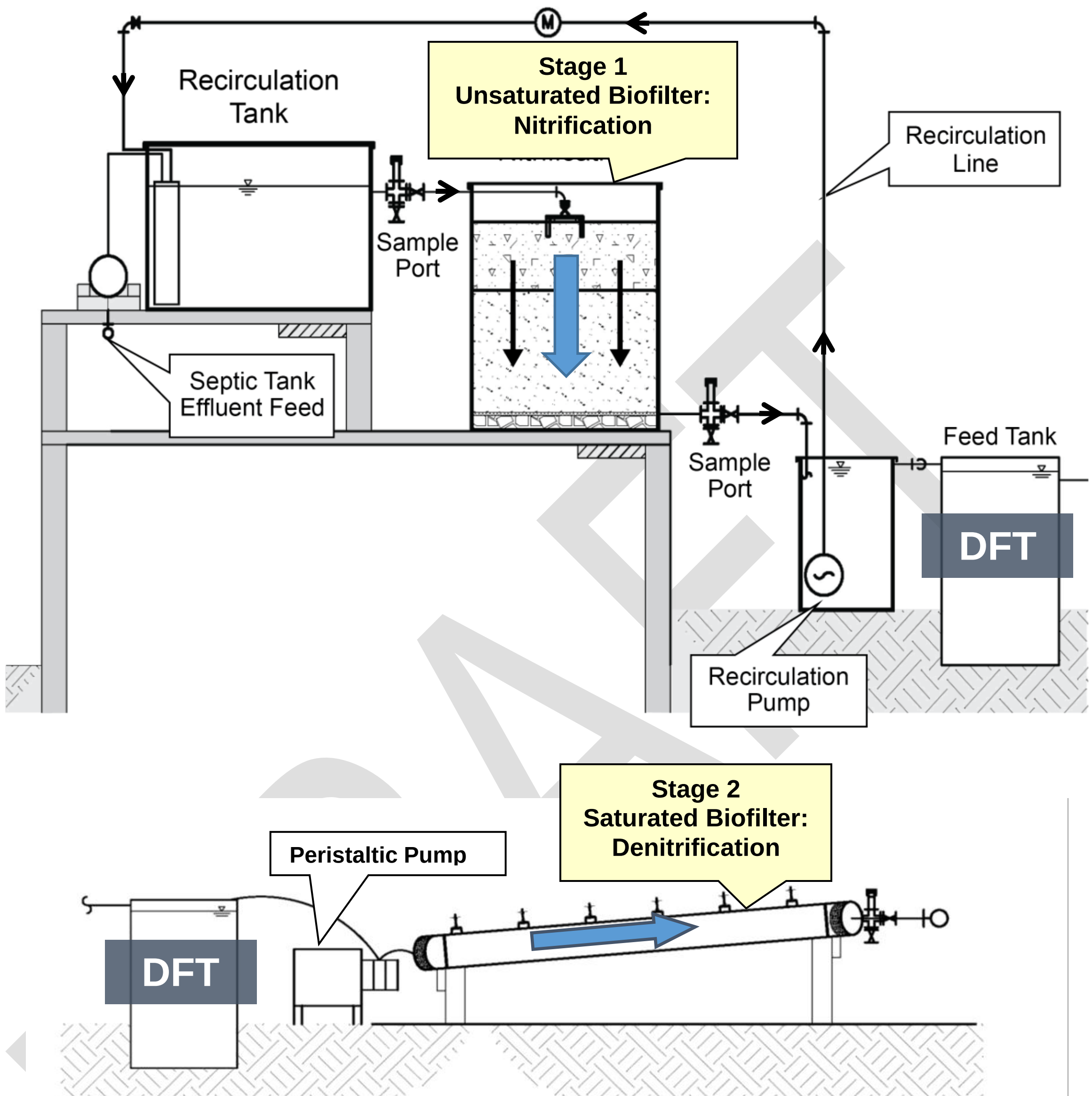


Figure 3-3: **Flow Schematic for a Recirculating Stage 1 Biofilter and Horizontal Stage 2 Biofilter**

The third group (Group 3) consisted of in-tank vertically stacked Stage 1/Stage 2 biofilters which consisted of single pass biofilters with an upper unsaturated Stage 1 media underlain by Stage 2 media as depicted in Figure 3-4. The vertically stacked biofilters were configured with an upper unsaturated Stage 1 layer, a middle mixed media layer of Southern yellow pine and expanded clay, and a saturated lower layer with elemental sulfur media. Three of the vertically stacked biofilters received primary effluent and the fourth (22-VS-SA-12) received nitrified effluent from a Group 1, Stage 1 biofilter. Target hydraulic loading to the four vertically stacked biofilters was a surface loading of 1.1 to 1.2 gal/ft^2-day. Monitoring points for Group 3 included the influent (STE), middle layer effluent, and sulfur effluent (final effluent).

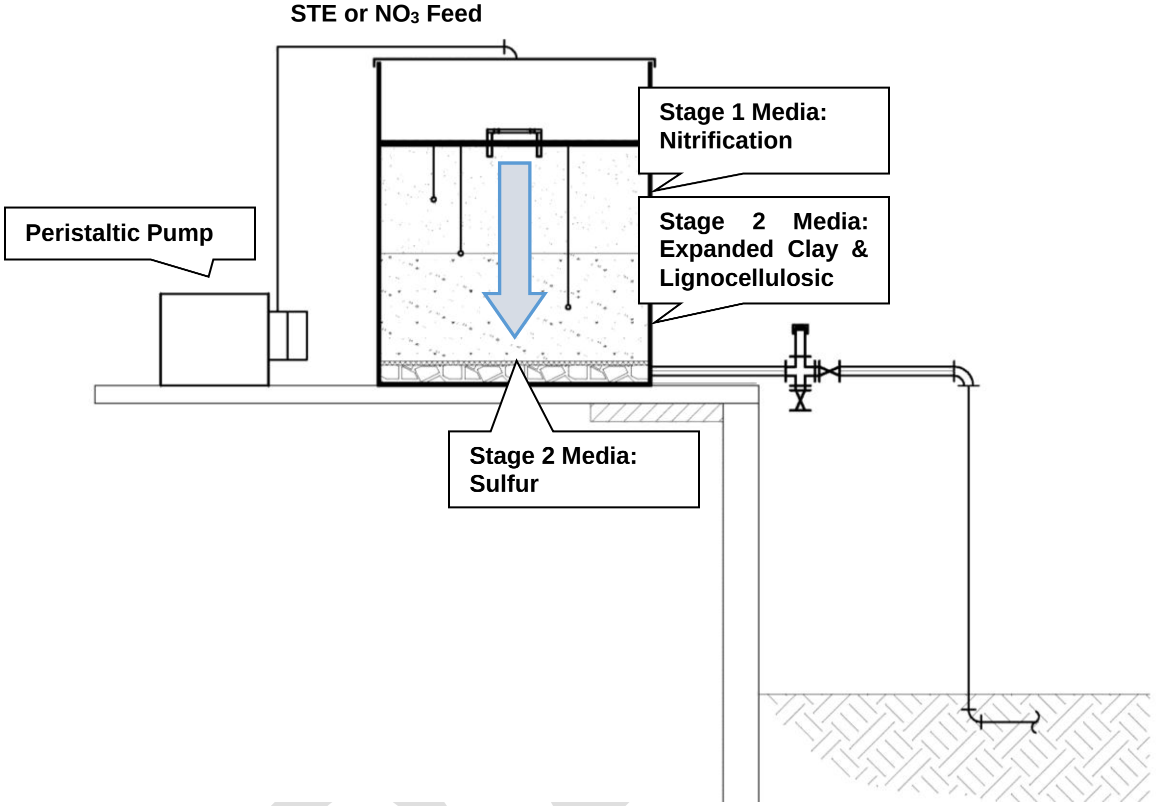


Figure 3-4: **Flow Schematic for an In-tank Vertically Stacked Stage 1/Stage 2 Biofilter System**

The fourth group (Group 4) consisted of in-ground vertically stacked Stage 1/Stage 2 biofilters followed by an additional in-tank Stage 2 biofilter. The single pass in-ground biofilters consisted of an upper unsaturated Stage 1 sand media underlain by Stage 2 lignocellulosic media mixed with sand on an HDPE liner as depicted in Figure 3-5. The effluent collected on the liner was directed to an in-tank saturated Stage 2 sulfur media tank for additional treatment. The denitrified effluent was discharged to the natural soil via an infiltrator trench system. One of the in-ground vertically stacked biofilters received primary effluent and the other received the effluent from an aerobic treatment unit (ATU). Target hydraulic loading to the in-ground vertically stacked biofilters was a surface loading of 0.8 gal/ft^2-day. Monitoring points for Group 4 included the influent (STE or ATU), Stage 1 layer effluent, liner effluent, and sulfur effluent (final effluent).

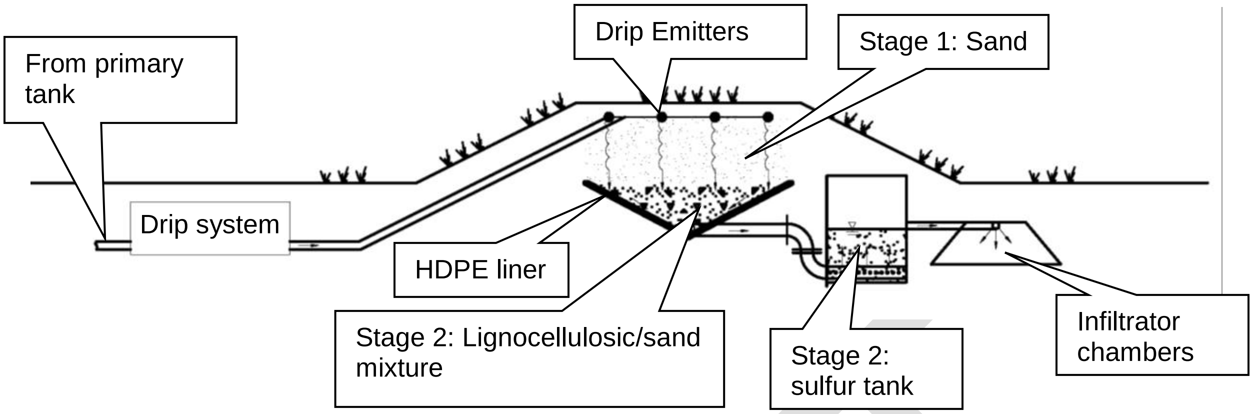


Figure 3-5: **Flow Schematic for an In-Ground Vertically Stacked Stage 1/Stage 2 Biofilter System**

The twenty-six biofilters in the pilot study consisted of nine in-tank unsaturated Stage 1 biofilters, eleven in-tank saturated Stage 2 biofilters, four in-tank vertically stacked biofilters, and two in-ground vertically stacked biofilters characterized in Table 3-2. The unsaturated nitrification (Stage 1) biofilter media tested included expanded clay (EC), clinoptilolite (CL) and sand (SA) in four media depths of 12, 15, 18 and 30 inches. In the Group 1 and 2 tank systems a larger media particle size was used in the upper one third of media depth and smaller particle size in the lower two thirds. The Stage 1 biofilter IDs as summarized in Table 3-2 indicate the biofilter ID (number) type of media (EC, CL or SA) and media depth (12, 15 or 30 inches). The saturated (Stage 2) denitrification biofilters reactive media tested included lignocellulose (LS), from Southern Yellow Pine sawmill waste, and elemental sulfur (SU) in various percentages. In addition, one horizontal Stage 2 biofilter was dosed glycerol (GL) as a liquid electron donor. The Stage 2 biofilter IDs as summarized in Table 3-2 indicate the ID (number) type of electron donor (LS, SU or GL) and reactive media percentage (varies). Other media components included oyster shell and limestone as slow release alkalinity supply (Sengupta et al., 2006), and gravel.

Table 3-2: PNRS Pilot Biofilter Characteristics

Description	Biofilter & Process Designations						
	Biofilter ID	Media Depth (inches)	Surface Loading Rate (gal/ft²-day)	Biofilter ID	Reactive Media (percent)	Media Depth (inches)	Surface Loading Rate (gal/ft²-day)
Group 1: In-tank Single Pass Stage 1 directly connected to Upflow Stage 2	Single Pass Stage 1 Biofilters			Upflow Stage 2 Biofilters			
	1-EC-15	15	3	6-SU-30	30	24	5.6
	2-EC-30	30		7-LS-50	50		
	3-CL-15	15		8-SU-80	80		
	4-CL-30	30		9-LS-25	25		
	5-CL-30	30		10-LS-30	30		
Group 2: In-tank Recirculating Stage 1 with composited ST1 effluent to Horizontal Stage 2	Recirculating Stage 1 Biofilters			Horizontal Stage 2 Biofilters			
	11-SA-30	30	12	15-SU-80	80	72	10
	12-EC-30	30		16-SU-30	30		
	13-CL-15	15		17-LS-50	50		
	14-CL-30	30		18-GL	N/A		
Group 3: In-tank Vertically Stacked Single Pass Stage 1 underlain by Stage 2	Single Pass Stage 1 Biofilters			Underlying Stage 2 Biofilters			
	19-VS-SA-12	12	1.1		LS-40	12	1.1
					SU-100	4	
	20-VS-EC-12				LS-40	12	
					SU-100	4	
	21-VS-CL-12		1.2		LS-40	12	1.2
					SU-100	4	
	22-VS-SA-12				LS-40	12	
					SU-100	4	
Group 4: In-ground Vertically Stacked Singe Pass Stage 1 underlain by Stage 2	Single Pass Stage 1 Biofilters			Stage 2 Biofilters			
	23-VS-SA-18	18	0.8 (STE)		LS-50	9	0.8
				24-SU-80	80	20	
	25-VS-SA-18	18	0.8 (ATU)		LS-50	9	0.8
				26-SU-80	80	20	

EC= expanded clay; CL = clinoptilolite; SA= sand; LS = lignocellulose; SU = elemental sulfur; GL = glycerol

Groups 1 & 2 Results

Stage 1 Performance: The primary effluent supplied to the pilot systems had an average Total Nitrogen of 52.5 mg/L. Nitrogen in primary wastewater effluent is predominately in the form of reduced nitrogen. Total Kjeldahl Nitrogen (TKN) measures reduced nitrogen and is the sum of the two forms of reduced nitrogen: organic nitrogen and ammonia. Aerobic biofilters (Stage 1) convert organic nitrogen to ammonia through ammonification and oxidize ammonia through nitrification. Effluent reduced nitrogen is therefore a good measure of Stage 1 performance. The reduced nitrogen in Stage 1 biofilter effluents are shown in Figure 3-6. Mean TKN levels varied from 2.4 to 4.0 mg/L, with standard deviations of approximately 1 mg/L indicating limited variability in effluent quality. The exception is the 30 inch clinoptilolite recirculating biofilter (14-CL-30), for which the high mean TKN and standard deviation were caused by one TKN result which was possibly a sampling artifact. Mean effluent ammonia nitrogen levels ranged from 0.01 to 0.5 mg/L, with many analyses at or below method detection limits. It is important to achieve low effluent ammonia in the Stage 1 biofilter because ammonia is not expected to be degraded in the anoxic environments of the saturated Stage 2 biofilters. Ammonia in Stage 1 effluent could pass through an anoxic Stage 2 biofilter and contribute to the total nitrogen in the final two-stage biofiltration effluent. Organic nitrogen as well as ammonia in Stage 1 effluent would therefore limit the removal efficiency of total nitrogen in the two-stage system. Verifying low levels of reduced nitrogen species in Stage 1 biofilter effluents is a first step in establishing effective total nitrogen removal with two-stage biofiltration.

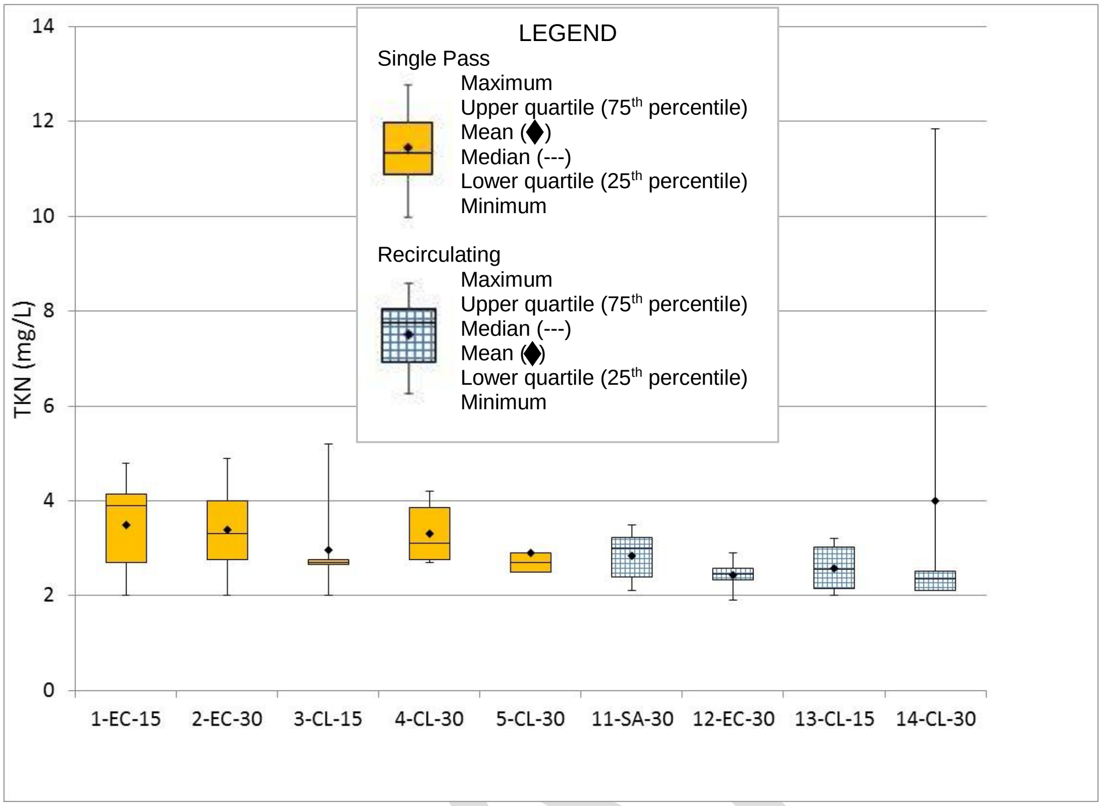


Figure 3-6: Unsaturated Biofilter Effluent Reduced TKN Nitrogen (Stage 1)
Mean Influent TN=TKN=52.5 mg/L

Stage 2 Performance: Saturated denitrification biofilters (Stage 2) contain electron donor media to remove oxidized nitrogen. Oxidized nitrogen is the sum of nitrate and nitrite (NO_x-N), although nitrate typically dominates in biofilter effluents. Effective denitrification biofilters will have low levels of NO_x-N in their effluent. Stage 2 biofilter effluent NO_x-N levels are shown in Figure 3-7. Mean effluent NO_x-N in sulfur biofilter effluents ranged from 0.04 to 0.11 mg/L with standard deviations of similar magnitude. Fluctuations in effluent NO_x-N from the sulfur denitrification process were very limited. The glycerol biofilter provided similar NO_x-N removal performance to the sulfur biofilters. Highly effective NO_x-N removal was also achieved by the horizontal biofilter (17-LS-50) that used Southern Yellow Pine sawmill waste as a lignocellulosic electron donor, producing mean effluent NO_x-N of 0.02 mg N/L. Two upflow lignocellulosic saturated (7-LS-50 and 9-LS-25) biofilters exhibited incomplete NO_x-N removal, with mean effluent NO_x-N of 6.2 and 14.2 mg/L based on three monitoring events. Possible explanations for limited NO_x-N removal in the two upflow lignocellulosic biofilters include low media reactivity, insufficient retention time and biofilter design. Overall, the pilot results verified denitrification biofilter designs that were highly effective in removing NO_x-N.

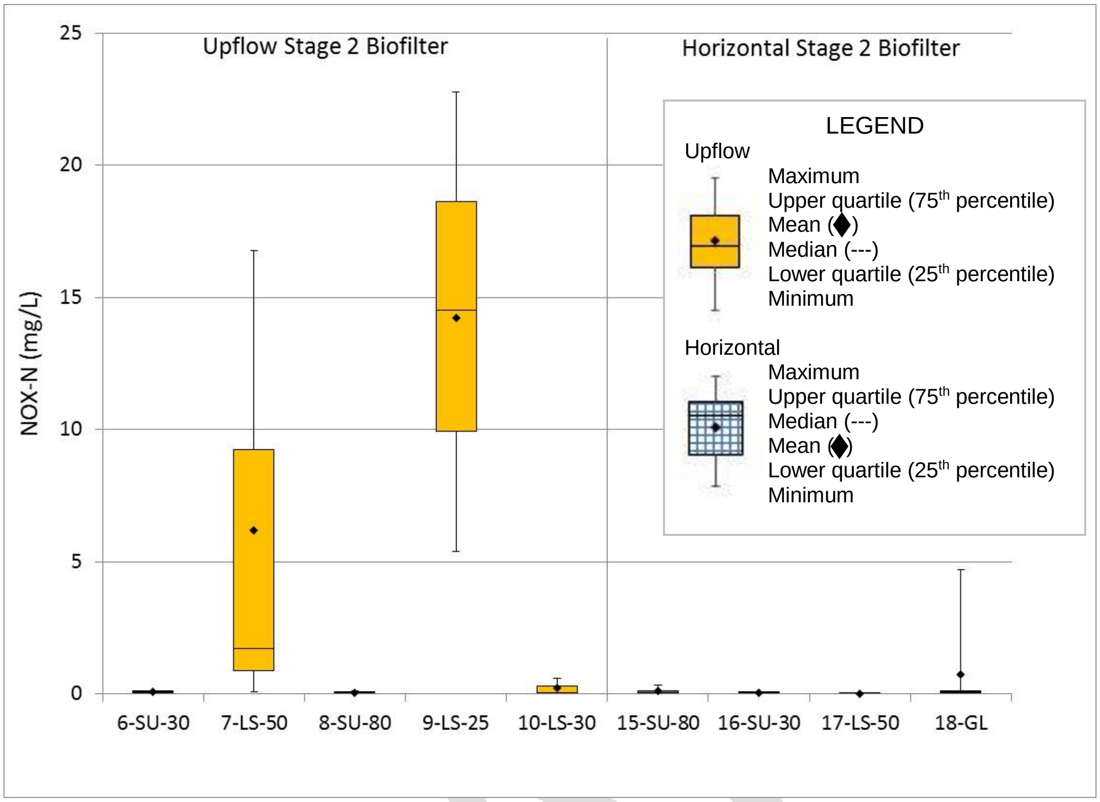


Figure 3-7: Saturated Biofilter Effluent NO_x-N (Stage 2)

The lignocellosic biofilter that achieved very effective NO_x-N removal (17-LS-50) used similar lignocellulosic media as the other lignocellosic biofilters but had a longer retention time. Other investigators have reported highly successful use of *Pinus radiata* (pine softwood) media in denitrification biofilters (Cameron and Schipper, 2010; Schmidt and Clark, 2013; Schmidt and Clark, 2012; Schipper et al., 2010). To further evaluate the effect of retention time, NO_x-N reduction as a function of hydraulic retention time (HRT) for the various saturated lignocellulosic-containing biofilters was plotted to examine any trends (Figure 3-8). While data is limited and the linear correlation is not extremely high, the percent NO_x-N reduction does appear to increase as residence time in the Stage 2 lignocellulosic biofilter increases. These results suggest that lignocellulosic material could be a potential media for saturated anoxic denitrification biofilters, but that designs using the media should incorporate a longer HRT than used in the pilot systems.

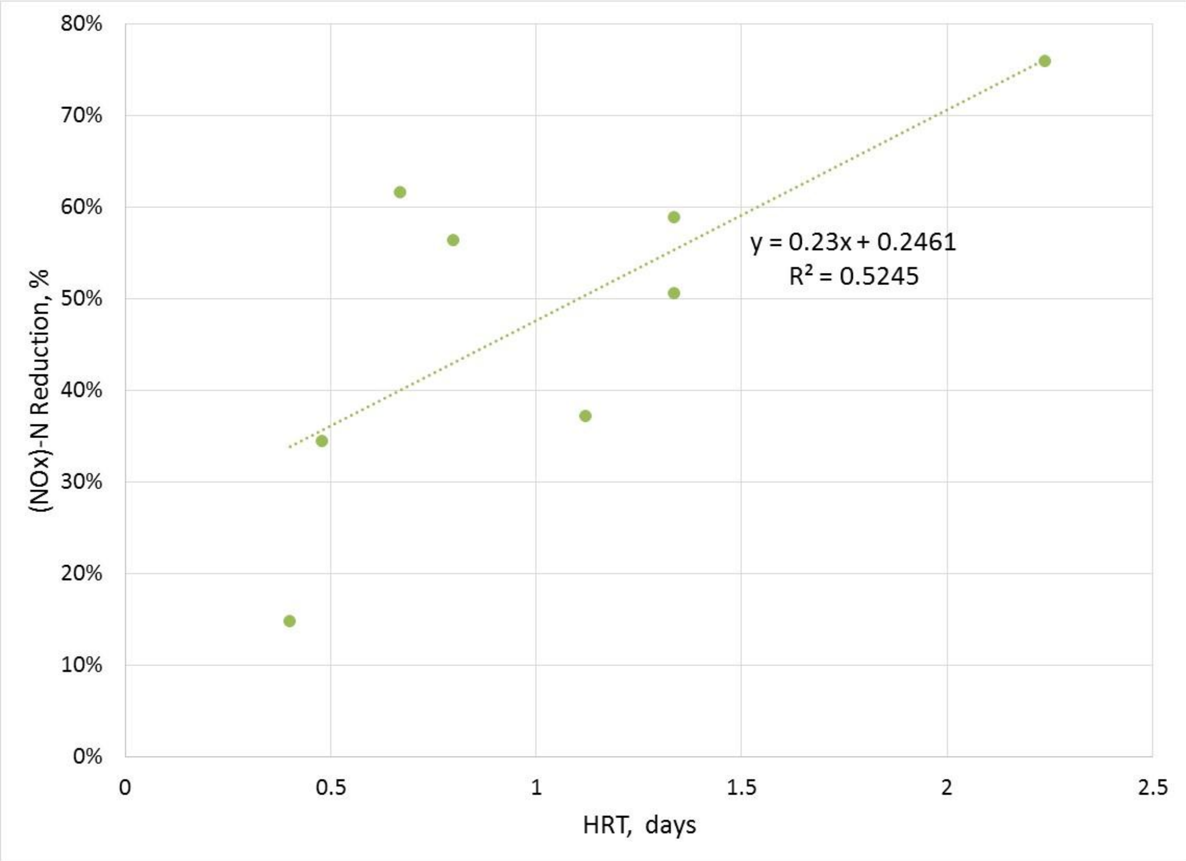


Figure 3-8: Stage 2 Lignocellulosic Biofilters NO_x-N Reduction with Time

Total nitrogen in the denitrification biofilter effluents (Stage 2) are shown in Figure 3-9. The effluent from the Stage 2 biofilters is the final effluent of a two-stage system. Stage 2 effluents include organic nitrogen, ammonia and oxidized nitrogen (NO_x-N). For a two-stage biofiltration system with effective first and second stages, effluent total nitrogen is dominated by dissolved organic nitrogen.

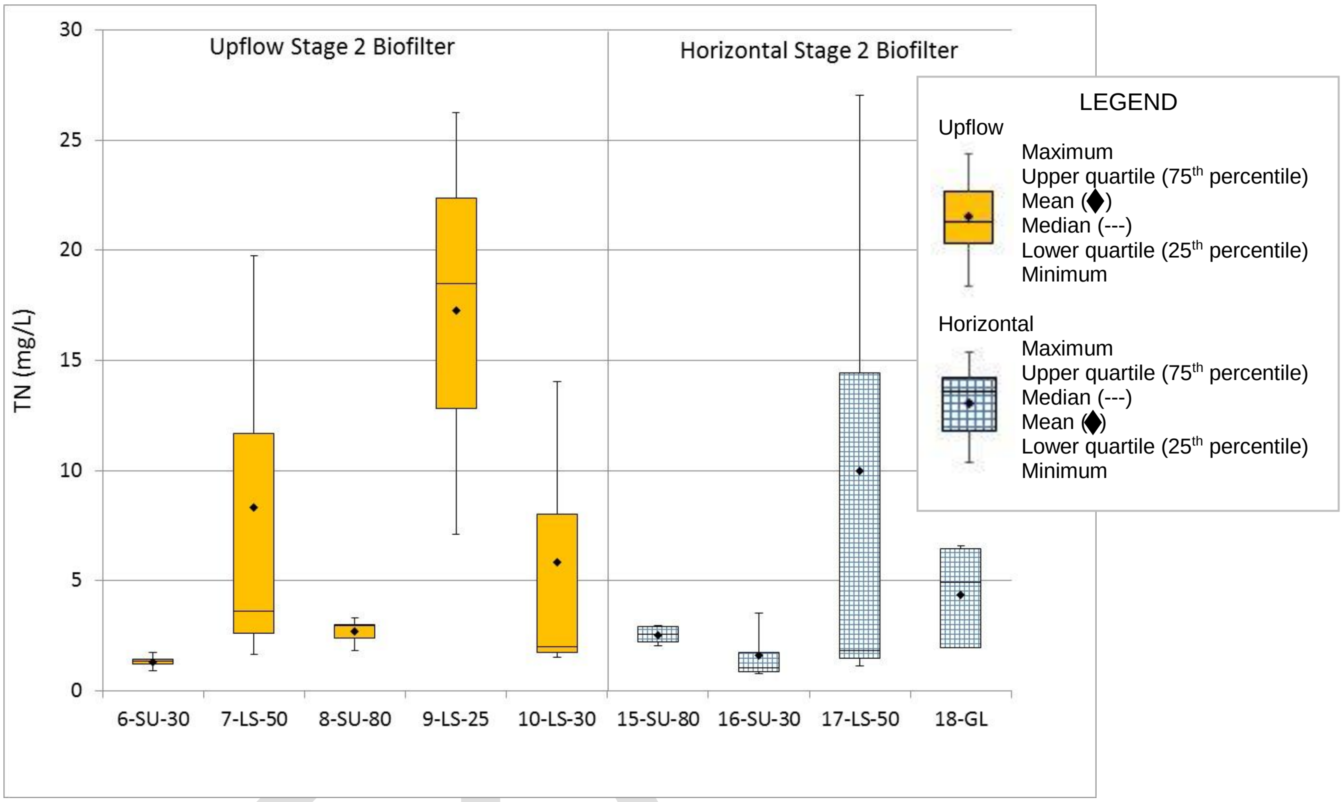


Figure 3-9: Saturated Biofilter Effluent Total Nitrogen (Stage 2)

Overall Performance of Group 1 and 2 Biofilters: The mean total nitrogen removal efficiencies of two-stage biofiltration are shown in Figure 3-10. Mean total nitrogen removal efficiencies of two-stage biofilters employing sulfur media and glycerol were greater than 90%, with effluent nitrogen dominated by dissolved organic nitrogen (Figure 3-10). Total nitrogen removal efficiencies of several lignocellulosic biofilters were limited by incomplete NO_x-N removal, resulting in effluent nitrogen dominated by NO_x-N. The pilot testing results verified that several two-stage biofiltration designs could consistently achieve 95 percent total nitrogen removal.

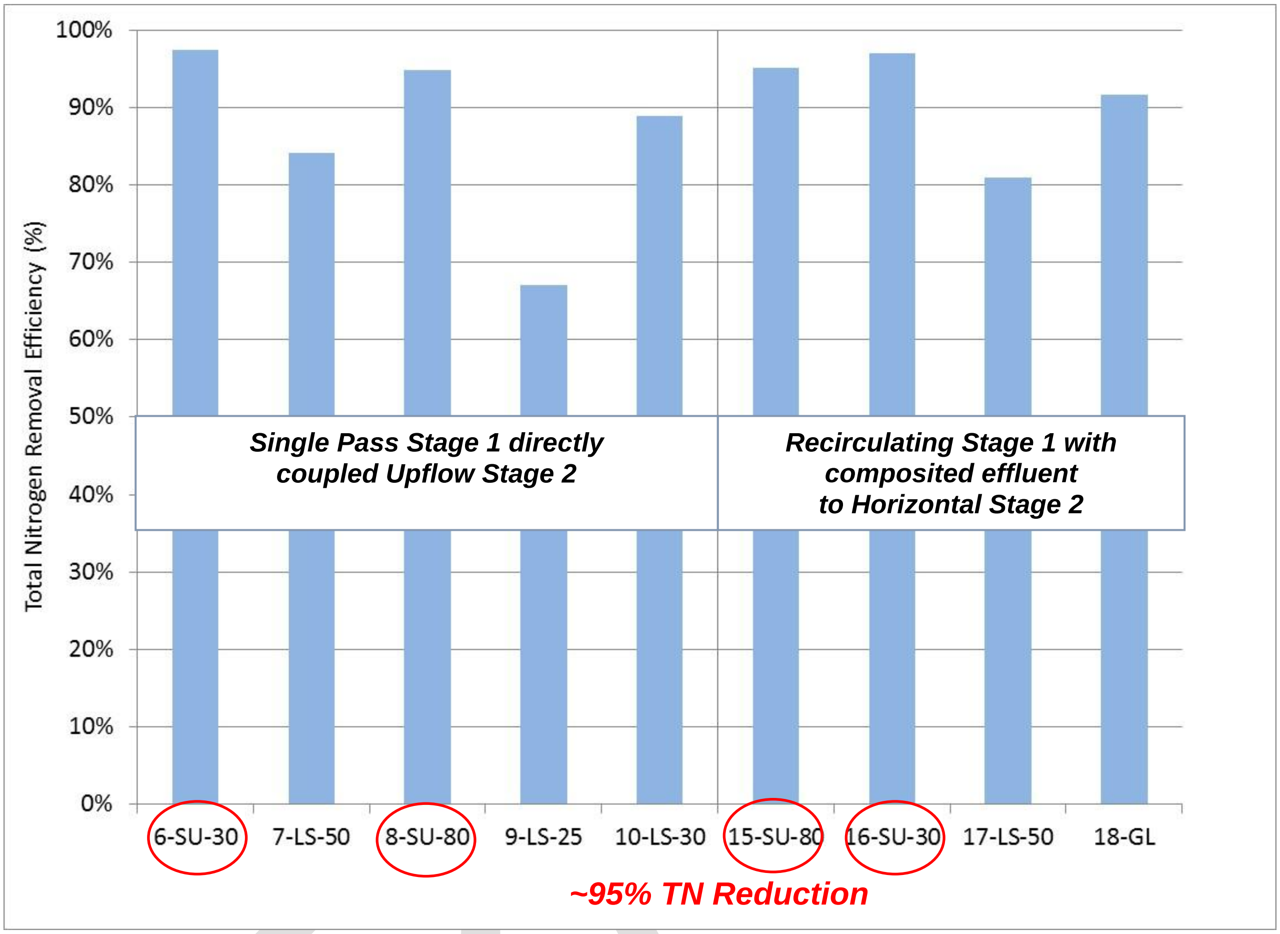


Figure 3-10: Total Nitrogen Removal Efficiency of Various 2 Stage Biofilter Systems, Organized by Stage 2 Biofilter

A concern associated with the use of the sulfur biofilters is the effluent sulfate concentration. The U.S. Environmental Protection Agency has established National Secondary Drinking Water Regulations that set non-mandatory water quality standards for 15 drinking water contaminants. Secondary standards were established as guidelines to assist public water systems in managing their drinking water for aesthetic considerations. The secondary standard for sulfate is 250 mg/L, and is based on taste. Effluent sulfate levels in the four sulfur-containing biofilters are summarized in Table 3-3. Mean effluent sulfate levels were 325 to 482 mg/L and exceeded the secondary drinking water standard.

Table 3-3: Effluent Sulfate

Biofilter	Effluent Sulfate, mg/L				Change in Sulfate Across Biofilter, mg/L			
	Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max
15-SU-80	325	33.8	230	450	266	33.7	184	398
16-SU-30	343	55.1	140	490	284	53.7	94	426
8-SU-80	482	46.9	340	650	427	45.1	303	589
6-SU-30	453	46.0	260	560	396	44.5	214	499

Autotrophic denitrification with elemental sulfur can be represented with the following biochemical reaction (Batchelor and Lawrence, 1978; Smith, 2009a):

$$50\ S^0 + 49.9\ NO_3^- + 11\ CO_2 + 32.8\ H_2O \rightarrow 2.2\ C_5H_7O_2N + 50\ SO_4^- + 23.8\ N_2 + 50.1H^+ \qquad \text{(Eq. 3-1)}$$

Based on this equation, for each gram of NO_3-N removed approximately 2.29 grams of sulfur are oxidized and 6.87 grams of sulfate are generated. Sample ports were installed along the length of the Stage 2 biofilters to enable longitudinal profiling of nitrogen species and other water quality parameters. Solute profiles of the Stage 2 sulfur-containing denitrification biofilters showed a significant decline in NO_x-N concentration and increase in sulfate concentration at the entrance region (see Figure 3-11, 3 inches from inlet). It is significant that the sulfate concentration in the biofilter does not increase substantially after the depletion of NO_x-N (and presumably DO). In addition, as depicted in Figure 3-11, applying a lower NO_3-N concentration (red, Day 242 as compared to green, Day 305) to the sulfur biofilter results in a lower sulfate concentration in the final effluent.

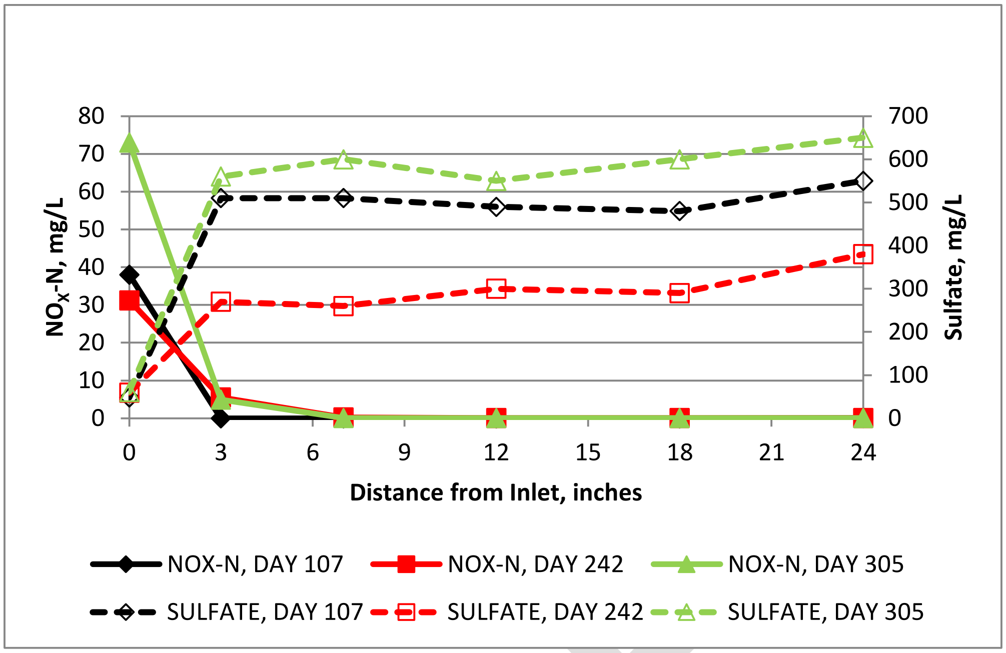


Figure 3-11: Solute Profile for Stage 2 Biofilter 8-SU-80

Group 3 Results

The performance of the in-tank vertically stacked Stage 1/Stage 2 biofilters was highly variable. Three of the systems treated primary effluent: 19-VS-SA, 20-VS-EC and 21-VS-CL (Table 3-2). The vertically stacked biofilters had variable effectiveness in treating primary effluent, with mean effluent $CBOD_5$ of 2.5 to 13 before the sulfur layer and 4.5 to 62 mg/L in final effluent. Mean TN was 10 to 27 mg/L before the sulfur layer and 2.6 to 21 mg/L in final effluent. Mean NH_3-N was 0.28 to 0.55 mg/L before the sulfur layer and 1 to 20 mg/L in final effluent. Reduced nitrogen forms comprised the most significant components of effluent TN in the vertically stacked Stage 1/Stage 2 biofilters treating primary effluent, indicating incomplete nitrification in the unsaturated upper media mean NO_x-N was 7 to 24 mg/L before the sulfur layer and 0.1 to 2.8 mg/L in final effluent. The sulfur layer was highly significant to NO_x-N reduction in the in-tank vertically stacked Stage 1/Stage 2 biofilters testing both primary effluent and nitrified effluent.

Group 4 Results

The in-ground vertically stacked Stage 1/Stage 2 biofilters with additional denitrification tanks were operated separately from the Group 1, 2, and 3 biofilters, as part of a soil and groundwater monitoring task of the FOSNRS project (Task C). These systems were installed and monitored for 523 days. The primary effluent and aerobic treatment unit effluent which were the influent to the systems had mean total nitrogen concentrations of 65.4 mg/L and 37.3 mg/L, respectively. The system that treated primary

effluent produced a mean effluent total nitrogen concentration of 3.5 mg/L, NO_x-N of 0.06 mg/L, $CBOD_5$ of 14.3 mg/L, and sulfate of 293 mg/L. Mean NO_x-N was 3.6 mg/L from the in-ground stacked Stage 1/Stage 2 biofilter prior to the sulfur tank. The system that treated aerobic treatment unit effluent mean effluent total nitrogen was 2.6 mg/L, NO_x-N was 0.07 mg/L, $CBOD_5$ was 6.2 mg/L, and sulfate was 151 mg/L. Mean NO_x-N was 1.4 mg/L from the stacked Stage 1/Stage 2 biofilter prior to the sulfur tank. Both systems indicated that the lignocellosic and sand mixture underlying the Stage 1 biofilter significantly removed nitrogen prior to the denitrification tank containing the sulfur media.

Summary

Two-stage biofiltration is aerobic biofiltration followed by anoxic biofiltration. The pilot study results indicated that the two-stage biofiltration process was effective in nitrogen removal from wastewater primary effluent. Ammonia nitrogen was consistently reduced to less than 1 mg/L by the unsaturated in-tank (Stage 1) biofilters in single pass and recirculation mode using expanded clay, clinoptilolite and sand media. Anoxic in-tank (saturated Stage 2) biofilters were operated in upflow and horizontal modes using elemental sulfur and lignocellulose (Southern Yellow Pine sawmill waste) media and glycerol as electron donors. Oxidized nitrogen (NO_x-N) was consistently reduced to less than 1 mg/L in sulfur containing biofilters, however sulfate concentration in the final effluent in these biofilters at times exceeded the recommended secondary drinking water standard. Anoxic biofilters with lignocellulosic media did not consistently remove NOx-N under the conditions of this study, however hydraulic retention time in some of these biofilters appeared to be insufficient. In several of the pilot units, two-stage biofiltration continuously achieved total nitrogen removals of over 95% from primary effluent. The performance of the in-tank vertically stacked Stage 1/Stage 2 biofilters was variable but also demonstrated capability of achieving high total nitrogen reductions in some configurations. The in-ground vertically stacked Stage 1/Stage 2 biofilters with supplemental denitrification tank were effective in nitrogen removal. Oxidized nitrogen (NO_x-N) was consistently reduced to less than 1 mg/L, and the sulfate concentration in the final effluent was very close to the recommended secondary drinking water standard.

Overall, the pilot study indicated that two-stage biofiltration appeared to be a viable technology for nitrogen reduction at individual home sites. The results of this pilot study provided guidance for the design of prototype full scale systems at individual Florida home sites, discussed below.

3.3 Recommended PNRS for Full Scale Evaluation

3.3.1 Two Stage Process

"Two-stage biofiltration", utilizing Stage 1 and Stage 2 biofilters have their basis in the general sequence of biochemical reactions that are utilized for biological reduction of wastewater nitrogen in the classical context: i.e., nitrification followed by denitrification as shown in Figure 3-12.

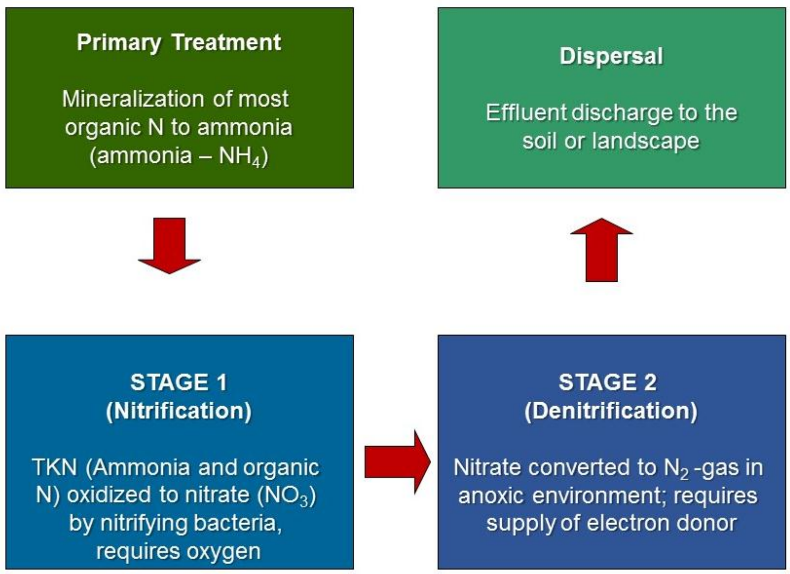


Figure 3-12: Biological Removal of Wastewater Nitrogen

3.3.2 Stage 1 Nitrification

In the two-stage biofilter process, a Stage 1 porous media biofilter is unsaturated (pore spaces not filled with water) for nitrification. Nitrification is the term used to describe the two-step biological process in which ammonia is oxidized to nitrite and nitrite is oxidized to nitrate. Septic tank effluent (primary effluent) is applied to the top of the first stage media, resulting in a downward percolation of wastewater over and through the porous media biofilter bed. The unsaturated pore spaces in the first stage media allow air to reach microorganisms attached to the media surfaces, enabling aerobic biochemical reactions to occur. The significant target reactions in Stage 1 are hydrolysis of particulate matter, aerobic oxidation (by heterotrophic microorganisms that oxidize organic material and reduce biochemical oxygen demand), ammonification of organic nitrogen (releasing ammonia), and nitrification (biochemical conversion of

ammonia to nitrite and nitrate by autotrophic bacteria). The goal of Stage 1 biofiltration is to oxidize the reduced forms of nitrogen, (i.e. organic nitrogen and ammonia), and the concentrations of organic and ammonia nitrogen in Stage 1 effluent are the primary metric by which to assess performance. The goal of Stage 1 is to produce an effluent where most of the wastewater nitrogen has been converted to nitrate, and where organic nitrogen and ammonia levels are low. The Stage 1 effluent with its high nitrate concentration is then passed on to the Stage 2 biofilter as shown in Figure 3-13.

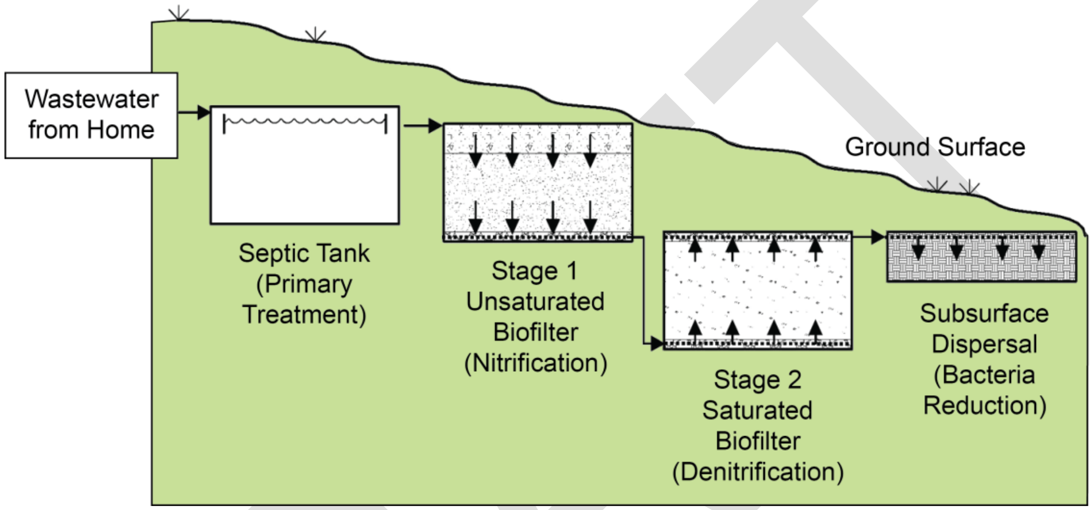


Figure 3-13: Stage 1 Single Pass Process Flow Diagram

3.3.3 Stage 1 Pre-Denitrification with Recirculation

Stage 1 biofilters with recirculation provide an opportunity for pre-denitrification. As discussed in the previous section, most of the wastewater nitrogen has been converted to nitrate in the Stage 1 effluent. With recirculation of Stage 1 effluent, nitrified effluent produced in the Stage 1 biofilter is recirculated back to an anoxic holding tank where it is mixed with incoming wastewater (Figure 3-14) providing an opportunity for biological denitrification to occur. The organic substrate in the influent wastewater provides the electron donor (organic carbon) for oxidation reduction reactions using nitrate. The biological reduction of nitrate to nitrogen gas is termed denitrification. The removal of oxidized nitrogen (nitrate and nitrite) in the recirculated nitrified effluent by biological denitrification contributes to the removal of nitrogen prior to Stage 2.

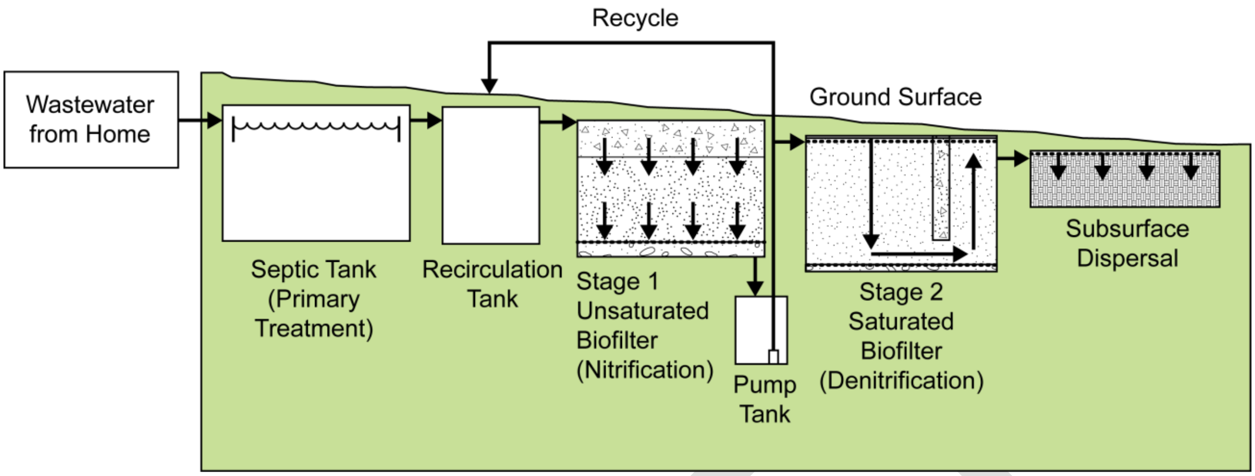


Figure 3-14: Stage 1 Recirculation Process Flow Diagram

3.3.4 Stage 2 Denitrification

The goal of the Stage 2 biofilter is to remove oxidized nitrogen (nitrate and nitrite) by biological denitrification. The Stage 2 biofilter contains "reactive media" which provides the electron donor needed for denitrification, and it is saturated (pore space is filled with water) to prevent oxygen ingress and promote anoxic conditions. Denitrification in the Stage 2 biofilter occurs by two general biochemical classifications, depending on the electron donor and the microorganisms involved. Autotrophic denitrifying bacteria utilize inorganic electron donors such as iron or sulfur for denitrification, while heterotrophic denitrifying bacteria utilize organic carbon as the electron donor. Stage 2 media must satisfy numerous objectives including: reactivity, longevity, physical integrity, availability and cost. Literature reviews identified candidate media that were well suited for Stage 2 media as elemental sulfur and lignocellulosic materials from growth of woody plants (Hazen & Sawyer and AET, 2009a; Smith et al., 2008).

Various process designs for Stage 2 biofilters were evaluated based on the pilot work including: simultaneous nitrification/denitrification in unsaturated or partially unsaturated biofilters, use of denitrification biofilters with mixed heterotrophic and autotrophic media, use of sequential heterotrophic and autotrophic denitrification biofilters, use of vertically stacked single pass biofilter systems with upper unsaturated layers, underlying saturated layers with denitrification media, and partially saturated intermediate layers containing denitrification media.

3.4 Full Scale Prototype Design Concepts

The results of the pilot work provided a preliminary basis for the design of the full scale prototype biofiltration systems to be evaluated at individual home sites in Task B. Design recommendations for the single family home prototype biofiltration systems generally followed the applied loading rates, media

types, media particle sizes, and depth and size configurations of the most successful biofilters used in the pilot work. Several modifications were recommended based on the pilot scale results, including:

- Stage 1 media grain size recommendations were increased due to the clogging experienced at the end of the pilot study at the higher applied hydraulic loading rates;
- Biofilter volume was increased for Stage 2 lignocellulosic biofilters to increase water residence time and denitrification performance; and
- A combined lignocellulosic/sulfur Stage 2 biofilter design was recommended to lower effluent sulfate concentrations,

The recommendations are process based and focus on factors and parameters that provide effective biological treatment in varied biofilter configurations. The pilot work results were also used to evolve prototype system designs to address secondary treatment objectives. The effluent sulfate levels in elemental sulfur-containing denitrification biofilters may be of concern in some locations. Therefore, the concept of using combined media in Stage 2, with lignocellulosic media preceding sulfur, evolved in an attempt to lower effluent sulfate levels. The design recommendations can also be used to derive hybrid designs that couple biofilters in a manner not specifically tested in the pilot study. Table 3- 4 provides the basic design recommendations used for the full scale prototype PNRS designs.

Table 3-4: Preliminary Recommendations Used for Full Scale Prototype PNRS Design

Stage 1 Unsaturated Recirculating Biofilters

Media	Hydraulic Loading Rate, gal/ft^2-day		Recycle Ratio R:Q	Total Media Depth, inch	Media Stratification and Particle Size Distribution		
	Metered Flow	Code Flow			Layer	Depth, inch	Particle Size Spec, mm
Expanded Clay	≤ 3.0	≤ 6.0	3:1	≥ 24	Upper	≥ 10	≥6 (1/4")
					Lower	≥ 14	≥4 (3/16")
Sand	≤ 3.0	≤ 6.0	3:1	≥ 24	Upper	≥ 10	E.S. ≥ 2 U.C.≤3
					Lower	≥ 14	E.S. ≥ 1 U.C.≤3

Stage 1 Unsaturated Single Pass Biofilters

Media	Forward Flow Hydraulic Loading Rate, gal/ft^2-day		Total Media Depth, inch	Media Stratification and Particle Size Distribution		
	Metered Flow	Code Flow		Layer	Depth, inch	Particle Size Spec, mm
Expanded Clay	≤ 3.0	≤ 4.0	≥ 24	Upper	≥ 10	≥6 (1/4")
				Lower	≥ 14	≥4 (3/16")
Sand	≤ 3.0	≤ 4.0	≥ 24	Upper	≥ 10	E.S. ≥ 2 U.C.≤3
				Lower	≥ 14	E.S. ≥ 1 U.C.≤3

Table 3-4 (cont.): Preliminary Recommendations Used for Full Scale Prototype PNRS Design

Stage 2 Saturated Biofilters

Media	%	Total Media Depth, inch	Empty Bed Residence Time, hour	Media Particle Size Distribution Particle Size Spec, mm
Elemental Sulfur	≥ 50	≥ 24	≥ 30	2.0 - 3.36 <0.5% fines
Limestone or oyster shell	0-20[1]			0.5 - 5
Lignocellulosic media	80-100	≥ 24	≥ 120	1 - 30

Vertically Stacked Biofilters

Influent	Hydraulic Loading Rate, gal/ft^2-day	Media Layer	Media Layer Depth, inch	Media	Media Stratification and Particle Size Spec, mm
Septic tank effluent	In-ground 0.8 - 1.2 (depending on soil)	Upper	≥ 18	Slightly Limited Sand	Clean sand < 1% fines
		Lower	≥ 8	50% Ligno 50% Sand	Ligno = 1 - 30
	In-tank ≤ 3.0	Upper	≥ 24	Expanded Clay or filter sand	≥6 (1/4") E.S. ≥ 2 U.C.≤3
		Lower	≥ 8	100% Ligno	1-30

[1]As needed for alkalinity adjustment

E.S. = effective size; U.C. = uniformity coefficient

3.4.1 Surface Hydraulic Loading Rates

Two-stage biofiltration conducted in the pilot work demonstrated the capability to consistently achieve total nitrogen removals of over 95 percent from primary effluent at the tested design loading rates which were used as the basis for design of the full scale systems. The rates in the pilot studies were actual measured wastewater flows, so a hydraulic loading rate adjustment was recommended when using flows

derived from Florida code, which are typically higher than actual flows. Table 3-4 lists recommended loading rates for both metered flows and code flows for the prototype Stage 1 biofilters.

3.4.2 Media Type

The pilot work demonstrated the capability of Stage 1 aerobic biofilters to continuously achieve TKN removals of over 95% from primary effluent using expanded clay, clinoptilolite and sand media. Expanded clay was the least expensive and most readily available Stage 1 media evaluated and was recommended for in-tank Stage 1 biofilters, either as separate a Stage 1 biofilter or as the top layer of in-tank vertically stacked Stage 1/Stage 2 biofilters.

Anoxic biofilters with elemental sulfur media consistently reduced oxidized nitrogen (nitrate and nitrite) to less than 1 mg/L and appeared to provide a suitable electron donor media for full scale Stage 2 denitrifying biofilters. Anoxic biofilters containing lignocellulosic media (Southern yellow pine) were also capable of achieving high NO_x-N reductions in the conditions of the pilot work, but overall performance was variable and not equal to the sulfur biofilter performance. NO_x-N reductions appeared to be limited by water retention time in denitrification biofilters containing lignocellulosic media. The pilot studies also demonstrated that biofilters with vertically stacked Stage 1/Stage 2 media configurations were capable in some configurations of achieving high total nitrogen reductions. Lignocellulosic media is relatively inexpensive and a readily available waste byproduct. Elemental sulfur is used as a fertilizer and sold in agricultural supply stores. It is more expensive than lignocellulosic media, but very effective in smaller volumes.

In-ground stacked Stage 1/Stage 2 biofilter systems will typically use native soil materials as media, if suitable. The Stage 1 layer should consist of a slightly limited sand with less than 1% fines. The Stage 2 layer can be lignocellulosic media or a mixture of lignocellulosic media and the same sand.

3.4.3 Tankage

Tankage specifically designed for biofiltration is not readily available in Florida. The Stage 1 biofilter tank typically requires an outlet positioned near the bottom of the tank to allow unsaturated operation. In addition, for long term operation and maintenance, easy access to the surface of the biofilter for maintenance activities is required. A tank with a hinged, lightweight cover which provides access to the entire upper surface area of the biofilter is recommended.

4 Prototype Full Scale PNRS Evaluations: Materials and Methods

Activities prior to installation of full scale prototype PNRS systems included: site identification and selection, wastewater characterization, process technology identification and selection, completion of final design, and notification including applicable permitting to DOH. Operation and monitoring included: monitoring of flowrate or volume treated; energy, media consumption, chemical and microbiological analyses; and routine and non-routine maintenance.

4.1 Full Scale PNRS Demonstration Sites

Over sixty sites were evaluated to identify individual homeowner sites for their suitability for establishing full scale PNRS technology testing. Criteria considered in the suitability analysis included: homeowner willingness to host treatment system, site access, number of residents and continuousness of occupancy, power supply, site security, adequate space, access for monitoring and maintenance, participation in previous or concurrent studies, and pre-existing treatment technologies. The homeowner and/or system users were surveyed on home occupancy and use characteristics. Table 4-1 provides a summary by County of the number of sites evaluated and agreements established.

Table 4-1: Site Evaluation by County

County	No. of Sites Evaluated	No. of Agreements Established
Charlotte	12	0
Hernando	1	0
Hillsborough	4	3
Lake	1	0
Lee	4	1
Marion	8	3
Orange	2	0
Polk	3	1
Sarasota	13	0
Seminole	8	6
Wakulla	4	4
Total	**60**	**18**

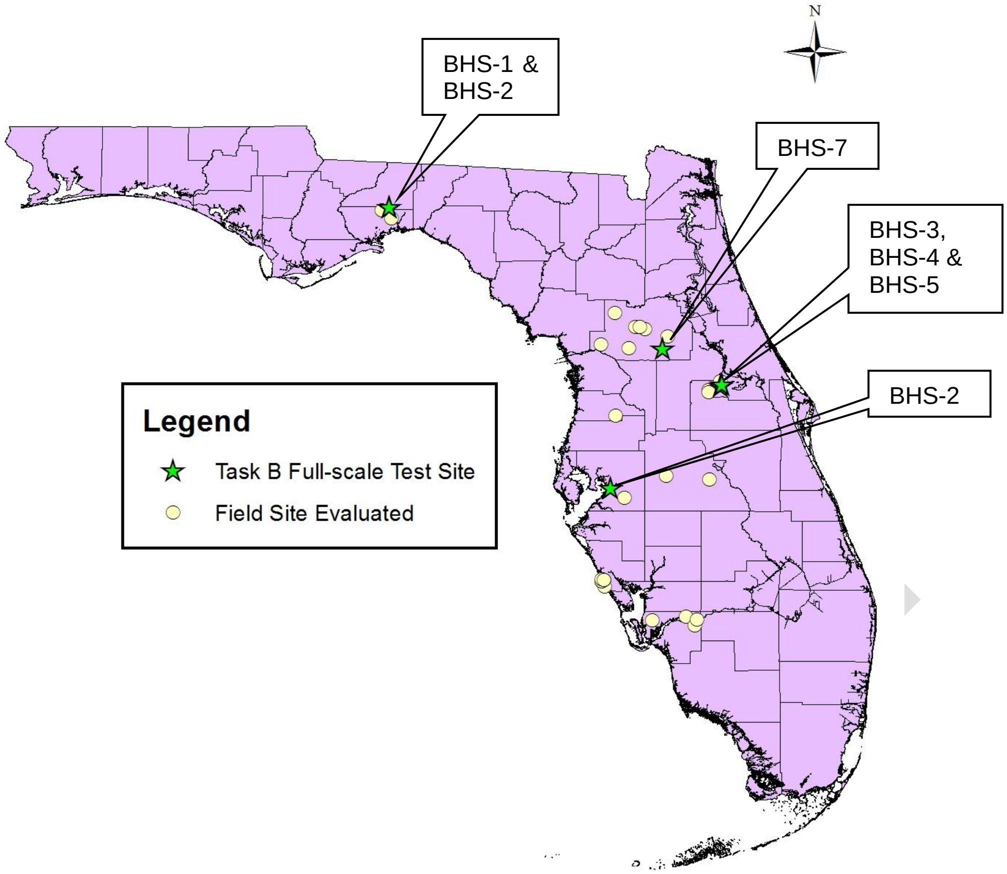


Figure 4-1: Map of Evaluated Field Sites

Installation of prototype full scale PNRS technologies for nitrogen reduction of onsite wastewater was completed at seven of the evaluated sites (see Figure 4-1). The Task B Quality Assurance Project Plan (Hazen & Sawyer and AET, 2010) documents the objectives, monitoring framework, sample frequency and duration, and analytical methods to be used at the test sites. Table 4-2 summarizes the characteristics of each test site.

Table 4-2: Test Site Characteristics

Test Site	County	Age of Existing System (yrs.)	No. of Residents	No. of Bedrooms	Building Area (ft^2)	FAC[1] Design Flow (gpd)
BHS-1	Wakulla	14	4	3	1200	300
BHS-2	Hillsborough	13	2	3	2542	400
BHS-3	Seminole	23	2	5	4940	580
BHS-4	Seminole	40 & 6	5	4	2517	400
BHS-5	Seminole	33	3	5	3315	500
BHS-6	Wakulla	2	4	3	1200	300
BHS-7	Marion	5	2	2	1112	300

[1]per FAC 64E-6.008 Table I

4.2 System types and Configurations

The seven installed prototype PNRS systems for full scale evaluation included both in-tank and in-ground two stage biofilter systems. Various hydraulic configurations for Stage 1 biofilters were tested including: Stage 1 single pass (SP), Stage 1 with internal recirculation flow to spray nozzles located above the Stage 1 media (R internal), and Stage 1 with recirculation to a recirculation tank (R tank). Stage 2 configurations included lignocellulosic media biofilters alone or dual media biofilter configurations where lignocellulosic media was followed by sulfur media. In the dual media Stage 2 biofilters, the lignocellulosic media was referred to as Stage 2a and the sulfur media was referred to as Stage 2b. Table 4-3 summarizes the full scale prototype system design characteristics. Process flow diagrams (Figure 4-2 through Figure 4-8) are provided for each of the seven prototype systems.

Design and construction details were presented previously in the FOSNRS Task B.6 System Installation Reports, and the system monitoring results were presented previously in the FOSNRS Task B.7 Field Systems Monitoring Reports; additional details can be found in these documents. The main section of the System Installation Report for each prototype PNRS system is included in Appendix A. The main section of the final Field System Monitoring Report summarizing the results for each system is included in Appendix B.

Table 4-3: Summary of Prototype PNRS Design Characteristics

System ID	Location (County)	System Description	Hydraulics	Design Flow (STE)	Stage 1 Biofilter Design Characteristics						Stage 2 Biofilter Design Characteristics							Dispersal
					Design HLR (gal/ft^2-d)	Recirculation Rate	Tankage	Media	Media Size	Media Depth	Design HLR (gal/ft^2-d)	Tankage	Media	Media Size	Media Depth	Media Volume (ft^3)	% Reactive Media	
BHS-1	Wakulla	Proprietary: Stage 1 Aerocell Stage 2 Nitrex	Pumped with Stage 1 internal recirculation	300		R:Q = 10:1	Aerocell Model# ATS-SCAT8-AC-C500; 1050 gallon fiberglass	Open Cell Foam Cubes	8 in^3 each 85 ft^3 total	~28"	5.1	1500 gallon concrete tank	Nitrex	Wood chips and sawdust	~40"	195	100%	STU with Chambers
BHS-2	Hillsborough	In-tank two stage biofilter with stage 1 recirculation, dual media stage 2; lignocellulosic (2a) followed by elemental sulfur (2b)	Pumped with both Stage 1 recirculation to tank and Stage 1 internal recirculation tested	400		R:Q = 3:1	300 gallon recirculation tank	None	NA	NA	11.1	2 compartment 1500 gallon concrete tank	Lignocellulosic; Southern Yellow Pine sawmill waste	Sawdust	42"	126	100%	STU with PTI bundles
					10.8		1050 gallon concrete tank	Expanded Clay	1/4" top layer	10"	22.2		Elemental Sulfur	0.1" Pastille pellets	24"	36	90%	
									3/16" bottom layer	20"								
BHS-3	Seminole	In-ground stacked biofilter, single pass stage 1 over stage 2a with supplemental stage 2b tank; stage 2a lignocellulosic/sand mixture; stage 2b elemental sulfur tank	Pumped with subsurface drip irrigation STE application	580	0.8	N/A	none, in-ground	fine sand, typical mound fill	fine sand	18"	0.8	in-ground liner underlying Stage 1	Lignocellulosic; blended waste wood	Wood chips	9"	273	50%	subsurface drip irrigation of zoysia turfgrass
											15.1	1050 gallon concrete tank	Elemental Sulfur	0.1" Pastille pellets	12"	38.5	90%	
BHS-4	Seminole	In-tank two stage biofilter with single pass stage 1, dual media stage 2; lignocellulosic (2a) followed by elemental sulfur (2b)	Gravity	400	3.5	N/A	2800 gallon concrete tank	Expanded Clay	1/4" top layer	10"	11.1	2 compartment 1500 gallon concrete tank	Lignocellulosic; blended waste wood	Wood chips	42"	126	100%	STU with Chambers
									3/16" bottom layer	20"	22.2		Elemental Sulfur	0.1" Pastille pellets	18"	27	90%	
BHS-5	Seminole	In-tank two stage biofilter with recirculation stage 1, dual media stage 2;lignocellulosic (2a) followed by elemental sulfur (2b)	Pumped with both Stage 1 internal recirculation and single pass tested	500	6.4	R:Q = 3:1	1500 gallon plastic tank	Expanded Clay	1/4" top layer	12.8"	13.9	2 compartment 1500 gallon concrete tank	Lignocellulosic; blended waste wood	Wood chips	42"	126	100%	STU with standard gravel bed (perforated corrugated pipe)
									3/16" bottom layer	21"	27.8		Elemental Sulfur	0.1" Pastille pellets	18"	27	90%	
BHS-6	Wakulla	In-tank vertically stacked biofilter, single pass stage 1 over stage 2a with supplemental stage 2b tank; stage 2a lignocellulosic; stage 2b elemental sulfur tank	Pumped with spray nozzle application (no recirculation)	300	4.5	N/A	1650 gallon concrete tank	Expanded Clay	1/4"	30"	4.5	underlying Stage 1	Lignocellulosic; blended waste wood	Wood chips	12"	67	100"	STU with Chambers
											15	1500 gallon concrete tank with wall	Elemental Sulfur	0.1" Pastille pellets	12"	20	90%	
BHS-7	Marion	In-ground stacked biofilter, single pass stage 1 over stage 2 lignocellulosic	Pumped low pressure distribution	300	0.83	N/A	none, in-ground	native Candler sand	fine sand	24"	0.83	in-ground liner, underlying Stage 1	Lignocellulosic; blended waste wood	Wood chips	12"	362	100"	Around the perimeter of the liner

The BHS-1 system (Figure 4-2) consisted of a 1,500 gallon two chamber concrete tank with a 1,000 gallon primary treatment tank (primary chamber) and a 500 gallon pump chamber (pump chamber); an Aerocell™ unsaturated foam media filter; and a 1,500 gallon single chamber up-flow tank containing Nitrex™ media. Treated effluent from the Nitrex™ unit is discharged to a soil treatment unit (drainfield) consisting of four Infiltrator trenches. The Aerocell™ effluent flows into an adjustable split recirculation device which allows for a portion (up to a 10:1 recycle ratio R:Q) of the effluent to recycle back to the pump chamber. While this system consisted of proprietary components, it was considered a prototype as a PNRS system.

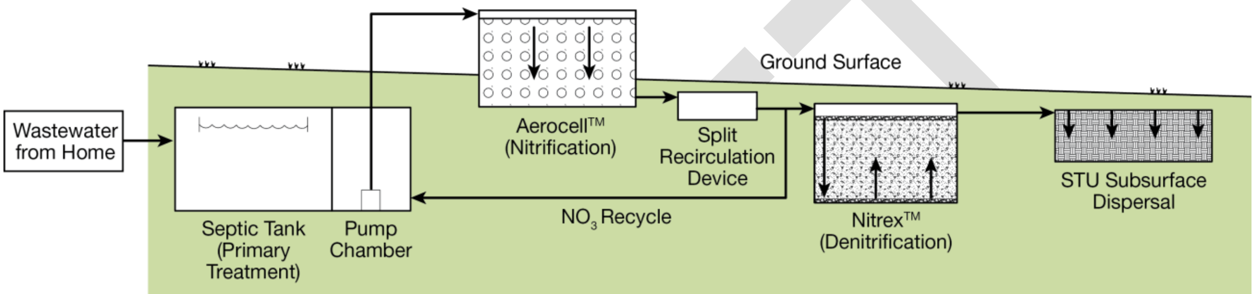


Figure 4-2: BHS-1 Process Flow Diagram

The BHS-2 prototype PNRS (Figure 4-3) consisted of a 1,050 gallon two chamber concrete primary tank; 300 gallon concrete recirculation tank; 900 gallon concrete Stage 1 unsaturated expanded clay media biofilter; 300 gallon concrete pump tank; and 1,500 gallon two chamber concrete Stage 2 saturated media (lignocellulosic followed by sulfur) biofilter. The treated effluent is discharged into the existing mounded drainfield (P.T.I.™ bundles). The Stage 1 effluent flow splits, which allows for a portion (3:1 recycle ratio R:Q) of the effluent to recycle back to a recirculation tank. The system was tested with two modes of recycle operation: Stage 1 with recirculation to the recirculation tank and Stage 1 with internal recirculation to spray nozzles located above the surface of the Stage 1 media.

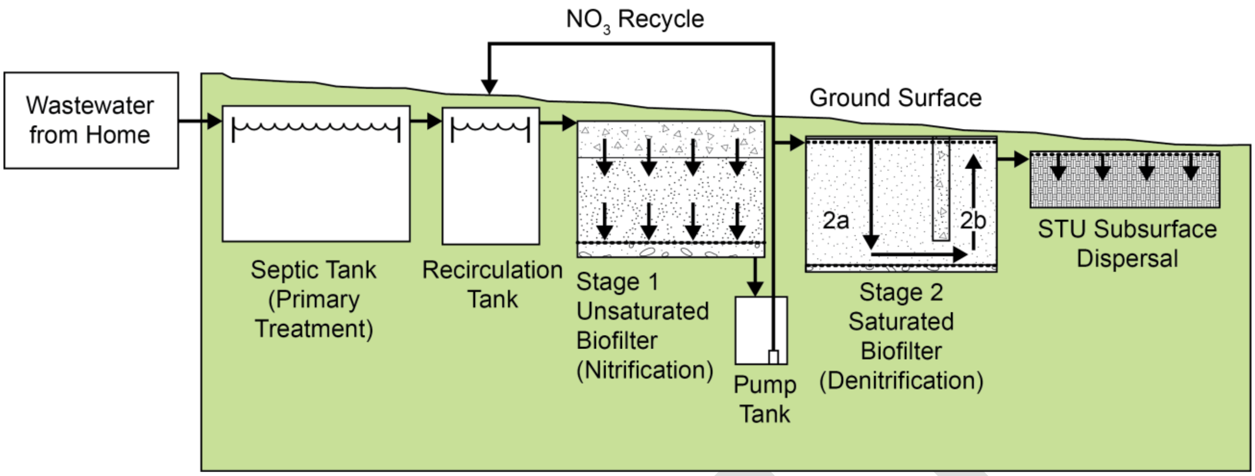


Figure 4-3: BHS-2 Process Flow Diagram (R tank)

The BHS-3 prototype system (Figure 4-4) consisted of a 1,500 gallon two chamber concrete primary treatment tank; a 600 gallon concrete septic tank effluent (STE) dose tank; a two zone Perc-Rite™ drip application system; and a 1,050 gallon concrete tank enclosing a Stage 2 saturated sulfur media biofilter. The first zone of the drip system applied primary effluent to the top of a Stage 1&2a lined drip zone (STE Zone) consisting of fine sand (Stage 1) overlying a 50/50 mixture of lignocellulosic/sand (Stage 2a) on a sloped liner with an underdrain for effluent collection and discharge to the Stage 2b sulfur biofilter. The second drip zone received final treated effluent from Stage 2b for landscape irrigation and dispersal.

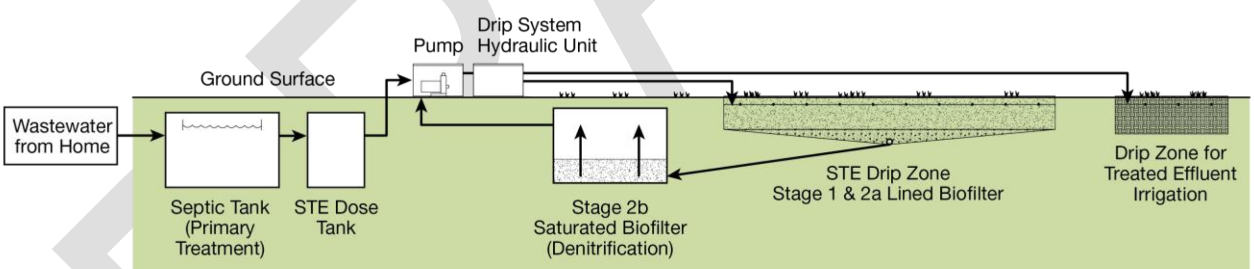


Figure 4-4: BHS-3 Process Flow Diagram

The BHS-4 prototype PNRS (Figure 4-5) consisted of a 1,200 gallon concrete primary tank; a 2,800 gallon concrete tank that houses a Stage 1 unsaturated expanded clay media biofilter; and 1,500 gallon two chamber concrete tank that houses a Stage 2 saturated dual media (2a & 2b) biofilter. The treated effluent is discharged into a new soil treatment unit consisting of four Infiltrator chamber trenches. The 1,200 gallon primary tank is located on the west side of the dwelling and also received flow from a second primary tank serving the east side of the dwelling. Because of the topography at this site, wastewater flow through the PNRS was accomplished by gravity.

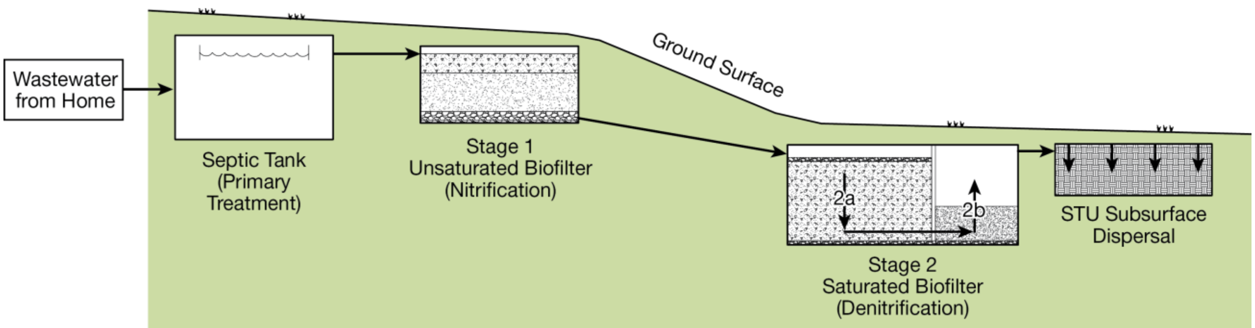


Figure 4-5: BHS-4 Process Flow Diagram

The BHS-5 PNRS (Figure 4-6) consisted of a 1,350 gallon concrete primary tank; a 1,500 gallon plastic tank housing a Stage 1 unsaturated expanded clay media biofilter; a 300 gallon concrete pump tank; and a 1,500 gallon two chamber concrete tank housing a Stage 2 saturated dual media (2a & 2b) biofilter. The treated effluent is discharged into the existing soil treatment unit which is of standard gravel bed geometry. The Stage 1 effluent flow splits, which allows for a portion (3:1 recycle ratio R:Q) of the effluent to recycle. The system was tested with two modes of operation: Stage 1 single pass and Stage 1 with internal recirculation to spray nozzles located above the surface of the Stage 1 media.

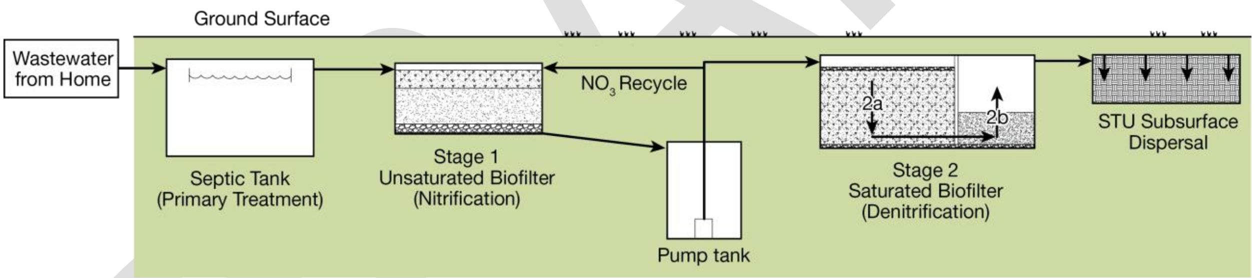


Figure 4-6: BHS-5 Process Flow Diagram (R Internal)

The BHS-6 prototype system (Figure 4-7) consisted of a 1,500 gallon concrete primary tank; 275 gallon pump tank; a 1,650 gallon concrete tank housing a vertically stacked Stage 1 over a Stage 2a media biofilter (expanded clay over lignocellulosic); and a 1,500 gallon single chamber tank housing a Stage 2b saturated sulfur media biofilter. The treated effluent is discharged into the existing soil treatment unit, four Infiltrator chamber trenches.

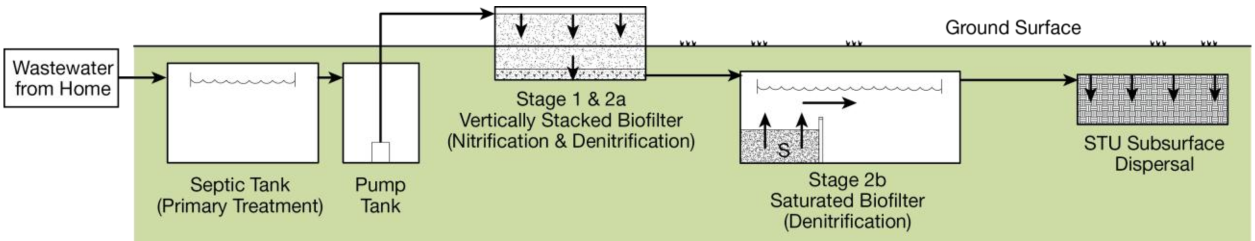


Figure 4-7: BHS-6 Process Flow Diagram

The BHS-7 PNRS prototype (Figure 4-8) consisted of a 900 gallon concrete primary tank; 300 gallon concrete pump tank; low-pressure distribution network; and an in-ground Stage 1 unsaturated sand biofilter directly above a lined Stage 2 lignocellulosic media biofilter. The primary treated effluent was expected to percolate through the Stage 1 native fine sand media for nitrification into the liner filled with lignocellulosic media for denitrification, and then discharge into the soil around the perimeter of the liner by overflowing the liner. As will be explained further in the Section 5, effluent movement did not appear to occur as expected with this system.

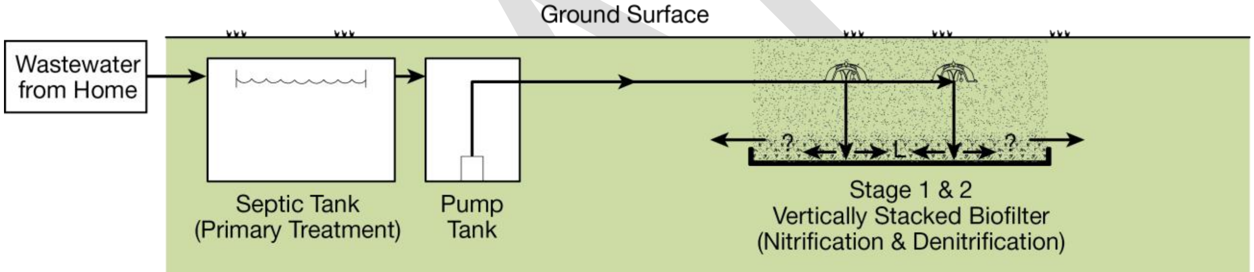


Figure 4-8: BHS-7 Process Flow Diagram

4.3 Monitoring

Each of the seven prototype PNRS demonstration systems were evaluated over an approximately 18 month period, with formal sampling events occurring bi-monthly. This section presents the monitoring methods utilized in the PNRS system evaluations.

4.3.1 Flowrate Measurement

The source of wastewater supplied to each of the PNRS prototype systems was primary effluent (STE) from the single family residence. The household daily wastewater flow was estimated from the potable water meter and system process flow meters (as applicable). Table 4-4 summarizes the location(s) of the flow measurement devices for each system. Flow rates for the systems with timed dosing were calibrated at initial start-up. The flow rates were measured and recorded at each monitoring event.

Table 4-4: Flow Measurement Devices

System	Meter 1 Household water use (Q)	Meter 2 Stage 1 Forward Flow (Q)	Meter 3 Stage 1 Recycle (R)	Meter 4 Stage 2 Forward Flow (Q)
BHS-1	Private well, meter installed on water line prior to entering residence		Combined Aerocell Flow (Q+R), meter installed on pump tank discharge line	
BHS-2	Private well, meter installed on water line prior to entering residence		Combined pump flow (Q+R), meter installed on pump tank discharge line prior to Q and R flow split	Stage 2 forward flow (Q), meter installed on pump tank discharge line following Q and R flow split
BHS-3	Public utility, meter located on water line to property	Combined pump flow (STE + BIO drip zones), meter installed in drip system hydraulic unit prior to zone split		Treated effluent drip zone flow (Q), meter installed on zone 2 feed line following hydraulic unit
BHS-4	Private well, meter installed on water line prior to entering residence			
BHS-5	Private well, meter installed on water line prior to entering residence		Stage 1 recirculation flow (R), meter installed on pump tank discharge R line	Stage 2 forward flow (Q), meter installed on pump tank discharge Q line
BHS-6	Private well, meter installed on water line prior to entering residence	Stage 1 forward flow (Q), meter installed on pump tank discharge line		
BHS-7	Private well, meter installed on water line prior to entering residence	Stage 1 forward flow (Q), meter installed on pump tank discharge line		

4.3.2 Water Quality

The prototype PNRS systems were designed to include sampling of the system influent, Stage 1 biofilter effluent and Stage 2 biofilter effluent as a minimum. The BHS-1 and BHS-2 systems included an additional sampling location which was the holding tank for Stage 1 recirculated effluent which provided the opportunity for pre-denitrification. BHS-2, -3, -4, -5 and -6 included dual Stage 2 media. Therefore the lignocellulosic media (Stage 2a) effluent which preceded the sulfur media (Stage 2b) was also sampled.

Table 4-5: Water Quality Monitoring Locations

Sample ID	**A**	**B**	**C**	**D**	**E**
System	System Influent	Recirculation Tank Effluent	Stage 1 Biofilter Effluent	Intermediate Stage 2a Effluent	Stage 2b Final Effluent
BHS-1	X	X	X		X
BHS-2	X	X	X	X	X
BHS-3	X		X	X	X
BHS-4	X		X	X	X
BHS-5	X		X	X	X
BHS-6	X		X	X	X
BHS-7	X		X		X

In addition, stainless steel drivepoint samplers were installed along the vertical depth of some of the Stage 2 biofilters to enable vertical profiling of nitrogen species and other water quality parameters. Solute profiles of Stage 2 denitrification biofilters were collected intermittently throughout the study period in conjunction with the sample events.

Sampling was performed using a peristaltic pump to collect sufficient sample volume into analysis-specific containers which were supplied by the certified analytical laboratory and contained the appropriate preservatives. These containers were labeled, placed in coolers and transported on ice to the analytical laboratory. Each sample container was secured in packing material as appropriate to prevent damage and spills, and was recorded on chain-of-custody forms supplied by the laboratory.

Field parameters were measured using a HACH 40D multimeter and portable electronic probes and included temperature (Temp), dissolved oxygen (DO), oxidation-reduction potential (ORP), pH, and specific conductance (Table 4-6).

Table 4-6: Field Parameter Analyses

Analyte	**Method**
Temperature	Hach temperature probe and meter
pH	Hach pH electrode and meter
Specific Conductance	Hach specific conductance probe and meter
DO	Hach luminescence DO probe and meter
ORP	Hach ORP probe and meter

The influent, intermediate and effluent samples were analyzed by the laboratory for the parameters listed in Table 4-7. Sulfate (SO_4) and hydrogen sulfide (H_2S) analyses were only conducted on influent and effluent samples for the Stage 2 biofilters containing sulfur media. Analytical methods, and detection

limits for these analyses are also listed in Table 4-7. Additional details of sampling methods and QA/QC can be found in Hazen & Sawyer and AET (2010) and in the system monitoring reports (Appendix B).

Table 4-7: Laboratory Analyses Methods

Analytical Parameter	Method of Analysis	Laboratory Detection Limit
Total Alkalinity as $CaCO_3$	SM 2320B	2 mg/L
Total Kjeldahl Nitrogen (TKN)	EPA351.2	0.05 mg/L
Ammonia Nitrogen (NH_3-N)	EPA350.1	0.01 mg/L
Nitrate/Nitrite Nitrogen (NO_x-N)	EPA353.2	0.01 mg/L
Carbonaceous BOD ($CBOD_5$)	SM 5210B	2 mg/L
Total Suspended Solids (TSS)	SM 2540D	1 mg/L
Volatile Suspended Solids (VSS)	EPA 160.4	1 mg/L
Total Organic Carbon (TOC)	SM5310B	0.06 mg/L
Chemical Oxygen Demand (COD)	EPA 410.4	10 mg/L
Total Phosphorus (TP)	SM 4500PE	0.01 mg/L
Orthophosphate as P (Ortho P)	EPA 300.0	0.01 mg/L
Fecal Coliform (fecal)	SM9222D	1 ct/100mL
E.coli	SM9223B	2 ct/100mL
Sulfate (SO_4)	EPA300.0	0.2 mg/L
Hydrogen Sulfide Unionized (H_2S)	SM4500S F	0.01 mg/L
Sulfide	SM4500S F	0.1 mg/L

4.3.3 Energy Consumption

Energy consumption was monitored for each prototype PNRS using an electrical meter as detailed in Table 4-8. The electrical meter records the cumulative power usage of the system in kilowatt-hours. The power usage of the system is primarily due to the single pump, although a small amount of power is used by the control panel itself. Flow through the BHS-4 PNRS system was accomplished by gravity due to the topography at that site, so no power was used by the PNRS. However, the home originally had two OSTDS, and a small pump was used to transfer flow from the second system to the PNRS.

Table 4-8: Energy Consumption Monitoring Location

System	Meter Location
BHS-1	Installed on the electrical line dedicated to the system control panel
BHS-2	Installed on the electrical line dedicated to the system control panel
BHS-3	Installed on the electrical line dedicated to the system control panel
BHS-4	PNRS flow was by gravity, small pump used to transfer flow from second OSTDS
BHS-5	Installed on the electrical line dedicated to the system control panel
BHS-6	Installed on the electrical line dedicated to the system control panel
BHS-7	Installed on the electrical line dedicated to the low pressure distribution pump

4.3.4 Operation and Maintenance

Overall, the prototype PNRS treatment systems are passive and required little operation and maintenance (O&M). The systems with Stage 1 recirculation require slightly more O&M than single pass systems. The dual drip system requires greater O&M than any of the other systems. Performance verification and monitoring should be performed routinely, as required by permitting agencies and summarized in Table 4-9. The Stage 2 media are reactive, and therefore must be replenished when depleted.

Table 4-9: General Operation & Maintenance

System Component	General Maintenance Action	General Frequency
Primary (septic) tank	Pump-out to remove solids	3-5 years
	Effluent screen cleaning	1-2 times annually
	Water level within the tank	1-2 times annually
Pump tank	Pump-out to remove solids	Same frequency as septic tank
	Water level within the tank	1-2 times annually
Distribution box	Check for debris, equalized flow, pipe placement	1-2 times annually
	Water level within the box	1-2 times annually
Stage 1 biofilter	Check for clogging or ponding (raking if required)	1-2 times annually
	Water level within the biofilter	1-2 times annually
Pump	Check dose volume	1-2 times annually
	Grease, etc. (follow manufacturer's guidelines)	1-2 times annually
Float switches	Check register within control panel	1-2 times annually
Stage 2 biofilter	Reactive media consumption (replenish as needed)	Check Annually
	Water level within the biofilter	1-2 times annually
Soil Treatment Unit (drainfield)	Check for odors, ponding, etc.	1-2 times annually

5 Full Scale Prototype PNRS Evaluations: Results

Flow rate, temperature, water quality, operation and maintenance, energy use, and media consumption results for the seven installed PNRS prototypes for full scale evaluation are presented in this section. Table 5-1 summarizes the operating period for each system.

Table 5-1: Test System Operating Periods

System	Stage 1 Mode of Operation[2]	System start-up date	Monitoring end date	Experimental days	Period of days
BHS-1[1]	R tank	Jun 10, 2011	Jan 24, 2013	594	594
BHS-2	R tank	Sep 25, 2012	Aug 7, 2013	0 through 316	316
	R internal	Aug 7, 2013	Mar 14, 2014	316 through 535	219
	Study period	Sep 25, 2012	Mar 14, 2014	535	535
BHS-3	Drip SP	Jul 12, 2013	Dec 17, 2014	523	523
BHS-4	Gravity SP	Jul 9, 2013	Dec 16, 2014	525	525
BHS-5	Single pass	Jul 9, 2013	Apr 25, 2014	0 through 290	290
	R internal	Apr 25, 2014	Dec 15, 2014	290 through 524	234
	Study period	Jul 9, 2013	Dec 15, 2014	524	524
BHS-6	SP	Nov 14, 2013	Jan 29, 2015	441	441
BHS-7	In-ground LP	Nov 19, 2013	Feb 4, 2015	442	442

[1] BHS-1 split recirculation device was replaced on experimental day 181; recirculation ratio was increased to a target of 10:1 from 5:1

[2] R tank = recirculation to tank
R internal = recirculation to top of Stage 1 media
SP = single pass
LP = low pressure distribution

5.1 Flowrates

System monitoring included the measured household daily wastewater flowrate to each system and any additional process specific flowrates as summarized in Table 4-4. The average and standard deviation for each systems flowrate over the study period is summarized in Table 5-2. Additional details and results on flow monitoring can be found in the System Monitoring Reports in Appendix B. Based on the flow monitoring results in Table 5-2, the actual hydraulic loading rate to the PNRS processes can be calculated. These results are presented in Table 5-3.

Table 5-2: Flowrate

System	Mode of Operation[2]	Period of flow data	Metered Household Water Use (Q)		Metered Stage 1 Forward Flow (Q)		Metered or Calculated Stage 1 Recycle (R)			Metered Stage 2 Forward Flow (Q)	
		# days	Mean (gpd)	SD (gpd)	Mean (gpd)	SD (gpd)	Mean (gpd)	SD (gpd)	Mean Recycle Rate R:Q	Mean (gpd)	SD (gpd)
BHS-1[1]	R tank	398	111.9	6.9			1,037.1	151.9	9.3		
BHS-2	R tank	314	97.6	24.4			377.5	84.4	3.5	109.1	22.3
	R internal	219	107.5	42.0			305.4	157.4	2.7	112.4	56.8
	mean	533	100.9	31.2			344.2	126.3	3.1	110.7	41.0
BHS-3	Drip SP	523	118.9	65.9	145.0	64.8				144.6	62.8
BHS-4	SP	525	297.0	70.3							
BHS-5	SP	290	123.9	36.1						114.1	39.5
	R internal	234	159.1	98.9			392.8	68.9	3.2	123.5	21.3
	mean	524	135.0	64.0						116.5	35.6
BHS-6	SP	441	125.5	21.8	152.6	22.8					
BHS-7	In-ground LP	421	157.9	18.7	125.4	32.7					

[1] After replacement of split flow recirculation device
[2] R tank = recirculation to tank
R internal = recirculation to top of Stage 1 media
SP = single pass
LP = low pressure distribution

Table 5-3: Hydraulic Loading Rate

System	Mean Forward Flowrate (gpd)	Stage 1 Biofilter		Stage 2A (Lignocellulosic) Biofilter		Stage 2b (Sulfur) Biofilter	
		Surface Area (ft^2)	HLR (gal/ft^2-d)	Surface Area (ft^2)	HLR (gal/ft^2-d)	Surface Area (ft^2)	HLR (gal/ft^2-d)
BHS-2	110.7	37	3.0	36	3.1	18	6.1
BHS-3	145.0	728	0.2	728	0.2	39	3.8
BHS-4	297.0	113	2.6	36	8.2	18	16.5
BHS-5	116.5	78	1.5	36	3.2	18	6.5
BHS-6	152.6	67	2.3	67	2.3	20	7.6
BHS-7	125.4	362	0.3	362	0.3		

5.2 Wastewater Temperature

Each system process component was monitored for field parameters including temperature. A cumulative frequency diagram showing all the influent wastewater (STE) and in-tank treated effluent, prior to subsurface dispersal, measurements taken during the study are provided in Figure 5-1. The influent STE temperature ranged from 16.1 to 29.4 degrees Celsius, and the treated effluent temperature ranged from 13.6 to 30.4 degrees Celsius. The 50th percentile influent and effluent temperatures were ca. 20.5 and 21.9˚C. respectively.

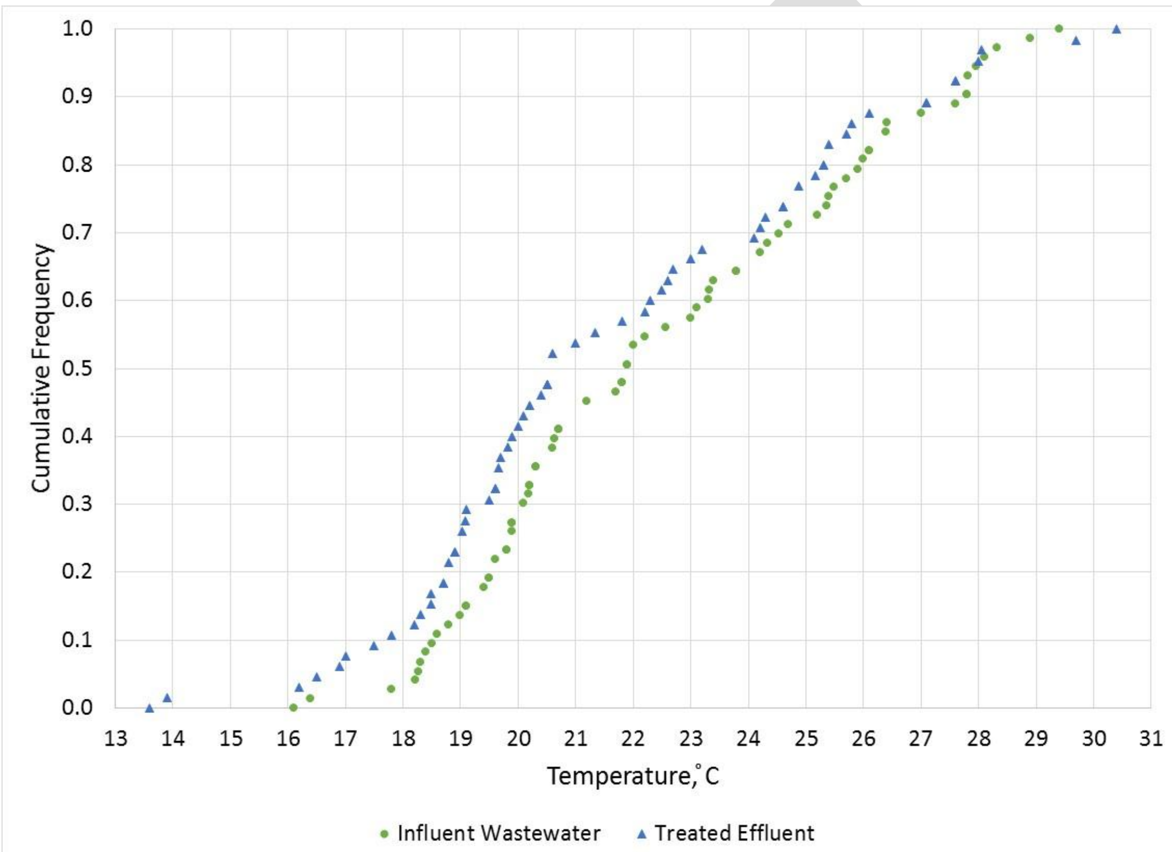


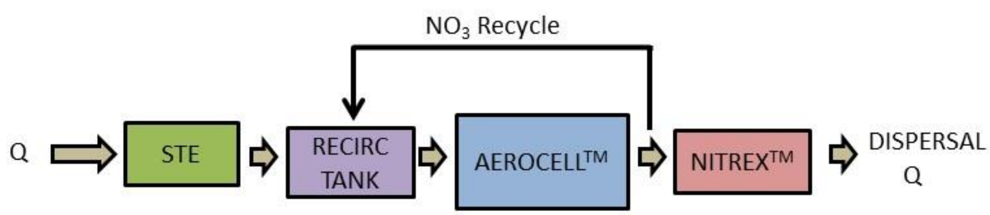
Figure 5-1: Temperature Cumulative Frequency Diagram

5.3 Water Quality

Mean effluent values and standard deviation (mean ± SD) for key water quality results and a time series of influent and effluent total nitrogen over the study period for each test system are graphically displayed in Figures 5-2 through 5-17. The performance of various system components can be compared by considering the changes through treatment of nitrogen species (TKN, NH_3-N, and NO_x-N) as well as

supporting water quality parameters. The System Monitoring Summary reports for each PNRS provide more detailed water quality monitoring summaries over the study period, and can be found in Appendix B.

The BHS-1 influent wastewater water quality parameters were in the upper range of values typically reported for Florida single family residences (Figure 5-2). The pump chamber effluent average NO_x-N was 28.1 mg/L, and Aerocell™ effluent average NO_x-N was 32.4 mg/L. These results indicate denitrification was occurring as the effluent was recirculated back into the pump chamber. The Aerocell™ unit provided significant nitrification with average effluent NH_3-N concentration of 8.3 mg/L and average effluent TKN of 12.1 mg/L. The Nitrex™ system was effective in producing a reducing environment and achieving the NO_x-N reduction goals (average NO_x-N concentration of 0.1 mg/L). The average final total nitrogen in the treatment system effluent was 7.1 mg/L (Figure 5-3), primarily as TKN (average TKN concentration of 7.0 mg/L). The Nitrex™ unit effluent average TSS and fecal coliform concentrations were effectively reduced to below 10.



Water quality parameter	Statistical parameter	Septic tank effluent	Recirculation tank effluent	Stage 1 effluent	Stage 2 effluent
	n	8	8	8	8
$CBOD_5$ mg/L	mean	108.0 ± 52.0	12.9 ±7.1	26.5 ±47.0	27.3±35.1
TSS mg/L	mean	48.6 ±13.0	7.3 ±4.6	4.8 ±5.7	3.5±2.1
TKN mg N/L	mean	82.6 ±11.0	18.1 ±12.9	11.5±9.4	7.0±5.8
NH_3 mg N/L	mean	64.1 ±9.7	14.2 ±12.8	8.3±9.1	4.5±4.6
NO_x mg N/L	mean	0.1 ±0.1	28.1 ±14.2	32.3±14.8	0.1±0.1
TN mg N/L	mean	82.7 ±11.0	46.2 ±11.9	43.8±11.8	7.1±5.7
Fecal Coliform (Ct/100 Ml)	geomean	151,088	2,703	436	5.9
TP mg/L	mean	8.7 ±1.5	8.2 ±1.3	8.1±1.3	7.6±1.7

Figure 5-2: BHS-1 Graphical Representation of Water Quality Results (mean ± SD)

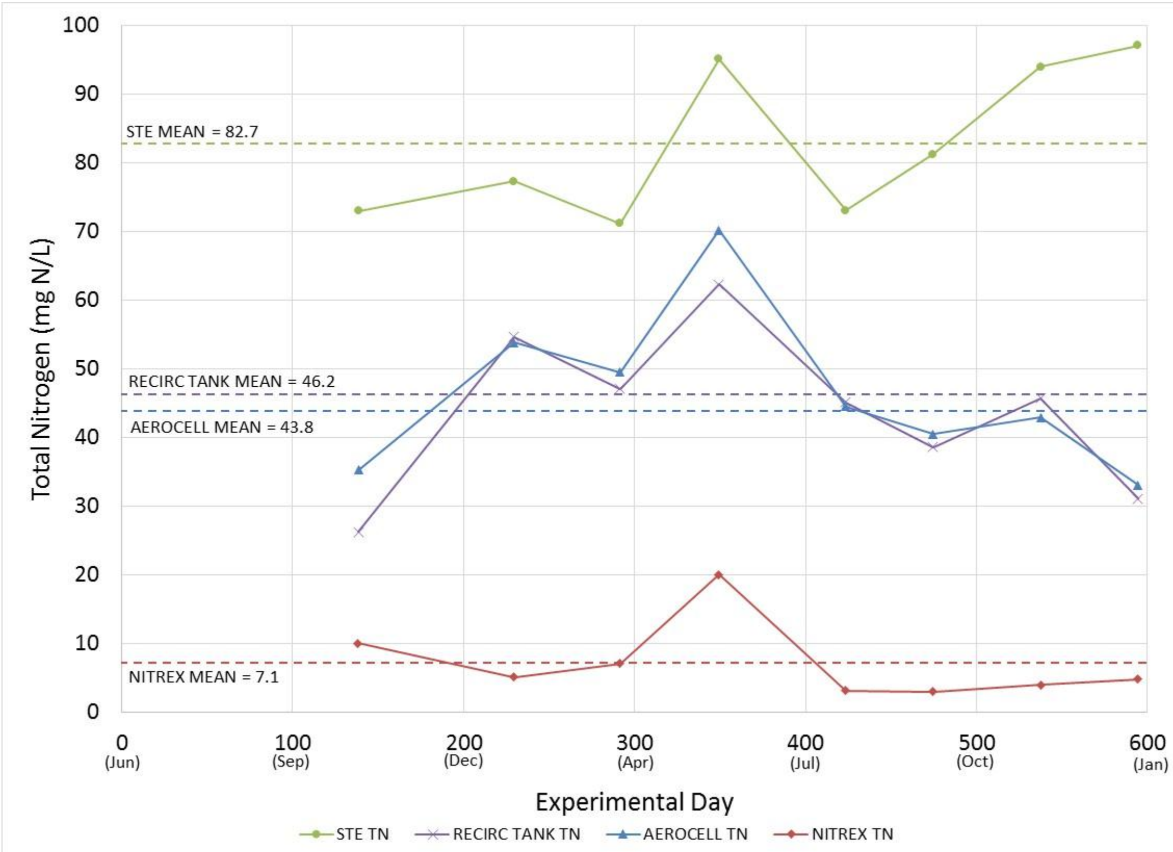
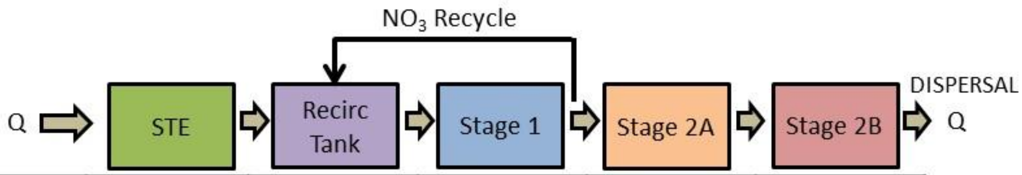


Figure 5-3: BHS-1 Total Nitrogen Time Series Graph

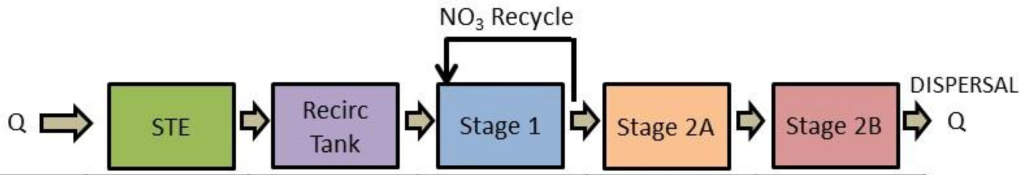
The BHS-2 prototype system was tested with two modes of recycle operation: Stage 1 recirculation to the recirculation tank (R tank) and Stage 1 internal recirculation (R internal) to spray nozzles located above the surface of the Stage 1 media**.** The initial mode of operation (R tank) was tested for 316 days of operation; the mode of operation was revised to R internal for the remainder of the study period. Figure 5-4 summarizes the overall water quality results for the R tank mode of operation throughout the study period. The influent wastewater average total nitrogen concentration was 50.5 mg/L. The Stage 1 biofilter with recirculation to tank provided significant nitrification with an average NH_3-N concentration of 0.9 mg/L and average TKN of 3.1 mg/L. The Stage 1 biofilter effluent average NO_x-N was 16.7 mg/L. These results indicate significant denitrification (approximately 60% total nitrogen reduction) was occurring. Stage 2 biofilter was effective in producing a reducing environment and achieving the NO_x-N reduction goals (average NO_x-N concentration of 0.02 mg/L). The average final total nitrogen in the treatment system effluent was 3.5 mg/L (Figure 5-4), primarily as TKN (average TKN concentration of 3.4 mg/L).



Water quality parameter	Statistical parameter	Septic tank effluent	Recirculation Tank effluent	Stage 1 effluent	Stage 2A lignocellulosic effluent	Stage 2B sulfur effluent
	n	5	5	5	5	5
$CBOD_5$ mg/L	mean	105.6±25.5	25.2±31.9	15.2±18.6	47.6±30.1	67.6±32.3
TSS, mg/L	mean	28.2±9.4	20.6±11.2	27.2±28.4	9.2±11.8	6.8±5.2
TKN mg N/L	mean	50.4±5.4	12.8±2.8	3.1±1.9	2.8±1.6	3.4±2.4
NH_3 mg N/L	mean	41.6±5.3	9.0±1.9	0.9±1.5	1.5±1.4	2.2±2.2
NO_x mg N/L	mean	0.05±0.04	6.5±7.0	16.7±7.2	0.02±0.00	0.02±0.00
TN mg N/L	mean	50.5±5.4	19.3±6.0	19.8±5.7	2.8±1.6	3.5±2.4
Sulfate mg/L	mean	83.4±44.7	na	na	159.2±53.8	192.0±27.8
Fecal Coliform (Ct/100 Ml)	geomean	115,416	38,350	166	38	53
TP mg/L	mean	8.2±5.5	6.0±4.0	5.6±3.6	5.0±4.0	4.9±3.5

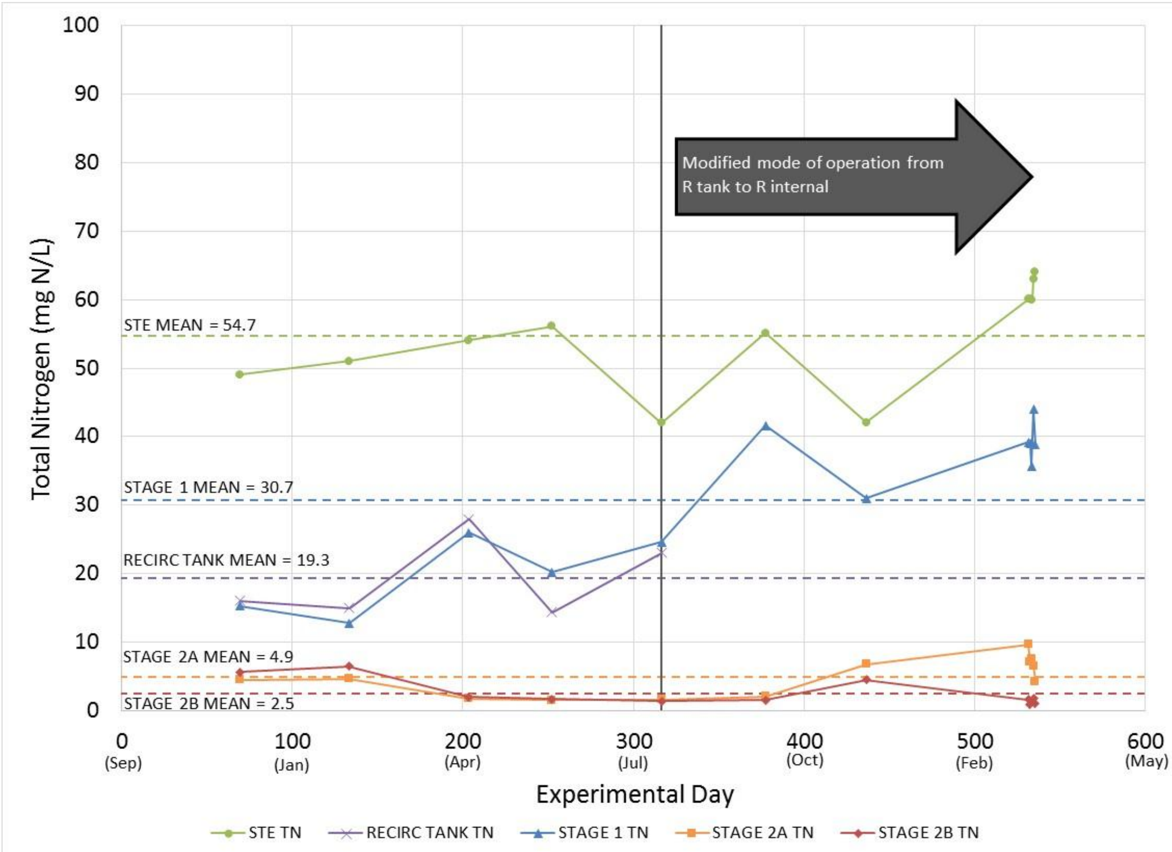
Figure 5-4: BHS-2 (R Tank) Graphical Representation of Water Quality Overall Results (mean ± SD)

The mode of operation was revised to R internal for the remainder of the study period. Figure 5-5 summarizes the overall water quality results for the R internal mode of operation throughout the study period. The influent wastewater average total nitrogen concentration was 57.8 mg/L. The Stage 1 biofilter with internal recirculation provided nitrification with an average NH_3-N concentration of 0.9 mg/L and average TKN of 4.5 mg/L. The Stage 1 biofilter effluent average NO_x-N was 34.0 mg/L. These results indicate denitrification (approximately 33% total nitrogen reduction) was occurring. Stage 2 biofilter was effective in producing a reducing environment and achieving the NO_x-N reduction goals (average NO_x-N concentration of 0.02 mg/L). The average final total nitrogen in the treatment system effluent was 1.8 mg/L (Figure 5-5), primarily as TKN (average TKN concentration of 1.8 mg/L). Figure 5-6 provides an overall study period total nitrogen time series graph which depicts the change in performance following the change in Stage 1 mode of operation.



Water quality parameter	Statistical parameter	Septic tank effluent	Recirculation Tank effluent	Stage 1 effluent	Stage 2A lignocellulosic effluent	Stage 2B sulfur effluent
	n	7	6	7	7	7
$CBOD_5$ mg/L	mean	254.3±112.7	171.7±29.3	8.4±6.6	13.1±11.8	54.9±25.4
TSS, mg/L	mean	16.3±7.3	13.5±6.4	1.9±1.1	7.3±7.7	2.4±1.7
TKN mg N/L	mean	57.7±7.5	58.5±5.8	4.5±2.7	2.4±1.1	1.8±1.2
NH_3 mg N/L	mean	41.1±7.6	41.3±4.9	0.9±0.9	0.7±0.9	0.7±0.9
NO_x mg N/L	mean	0.05±0.03	0.06±0.03	34.0±3.9	4.0±2.5	0.02±0.01
TN mg N/L	mean	57.8±7.5	58.6±5.8	38.5±4.2	6.3±2.5	1.8±1.2
Sulfate mg/L	mean	32.4±41.5	8.1±5.3	154.0±5.5	152.9±4.9	208.6±54.0
Fecal Coliform (Ct/100 Ml)	geomean	75,579	92,508	4,997	11	21
TP mg/L	mean	8.7±3.8	6.0±0.7	5.4±1.8	4.6±2.0	4.3±1.5

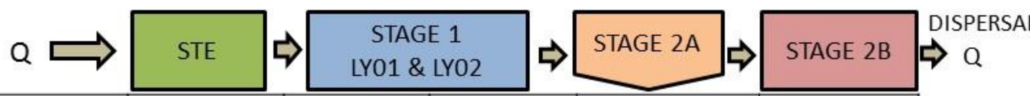
Figure 5-5: BHS-2 (R Internal) Graphical Representation of Water Quality Overall Results (mean ± SD)



[1]Daily samples were collected on experimental days 531 through 535

Figure 5-6: BHS-2 Total Nitrogen Time Series Graph

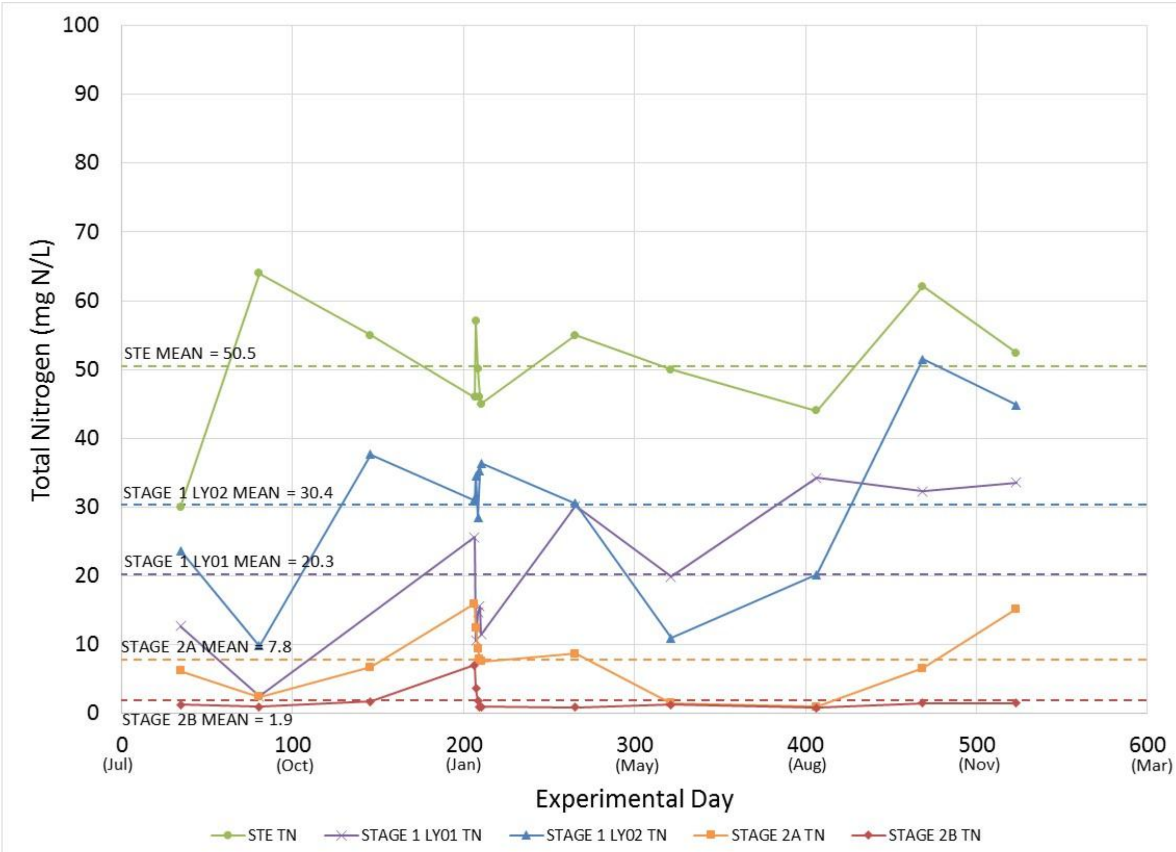
The BHS-3 influent wastewater average total nitrogen concentration was 50.5 mg/L (Figure 5-7). The Stage 1 suction lysimeters showed slightly variable results; however overall the Stage 1 biofilter provided significant ammonia, fecal coliform and total phosphorus removal. The combined Stage 1 and Stage 2a lined drip zone with lignocellulosic media effluent indicated significant ammonia removal with an average NH_3-N concentration of 0.2 mg/L and average TKN of 2.1 mg/L. The average Stage 1&2a biofilter effluent NO_x-N was 5.8 mg/L. These results indicate significant NO_x-N removal and approximately 84% total nitrogen reduction through the Stage 1 and Stage 2a process. The Stage 2b biofilter with sulfur media was effective in producing a reducing environment and achieving significant NO_x-N removal (average NO_x-N concentration of 0.6 mg/L). The average final total nitrogen in the treatment system effluent was 1.9 mg/L (Figure 5-8), primarily as TKN (average TKN concentration of 1.3 mg/L). This represents a 96 percent average reduction in total nitrogen from STE for this PNRS system over the study period.



Water quality parameter	Statistical parameter	Septic tank effluent	Stage 1 effluent LY01	Stage 1 effluent LY02	Stage 2A lignocellulosic effluent	Stage 2B sulfur effluent
	n	13	12	13	13	13
$CBOD_5$ mg/L	mean	72.2±46.1	9.5±9.1	6.0±6.9	3.8±3.7	14.3±21.6
TSS mg/L	mean	23.1±13.2	1.5±0.8	2.0±1.5	16.3±34.5	4.3±3.2
TKN mg N/L	mean	50.5±8.8	1.9±0.7	2.3±1.3	2.1±0.8	1.3±0.4
NH_3 mg N/L	mean	43.5±6.6	0.06±0.08	0.2±0.4	0.2±0.2	0.3±0.2
NO_x mg N/L	mean	0.1±0.1	18.4±10.3	28.1±11.7	5.8±4.4	0.6±1.5
TN mg N/L	mean	50.5±8.8	20.3±10.6	30.4±12.0	7.8±4.7	1.9±1.7
Sulfate mg/L	mean	21.9±12.3	40.6±14.6	45.0±14.3	31.0±18.1	113.8±56.5
Fecal Coliform (Ct/100mL)	geomean	65,033	NA	1,000	32	5
TP mg/L	mean	5.1±1.2	0.3±0.3	2.1±1.0	0.5±0.8	0.2±0.2

NA = not analyzed

Figure 5-7: BHS-3 Graphical Representation of Water Quality Results (mean ± SD)



[1]Daily samples were collected on experimental days 206 through 210

Figure 5-8: BHS-3 Total Nitrogen Time Series Graph

The BHS-4 influent wastewater average total nitrogen concentration was 70.1 mg/L (Figure 5-9). The Stage 1 biofilter provided ammonia removal with an average NH_3-N concentration of 8.1 mg/L and average TKN of 12.0 mg/L. The Stage 1 biofilter effluent average NO_x-N was 33.6 mg/L. These results indicate denitrification was likely occurring in the Stage 1 biofilter, with a total nitrogen reduction of approximately 35%. The Stage 2 biofilter was effective in producing a reducing environment and achieving significant NO_x-N removal (average NO_x-N concentration of 0.8 mg/L). The average final total nitrogen in the treatment system effluent was 7.4 mg/L (Figure 5-10), primarily as TKN (average TKN concentration of 6.6 mg/L). Average total nitrogen reduction from this PNRS was approximately 89 percent.

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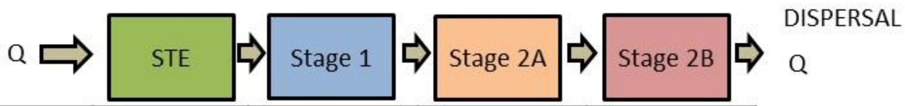
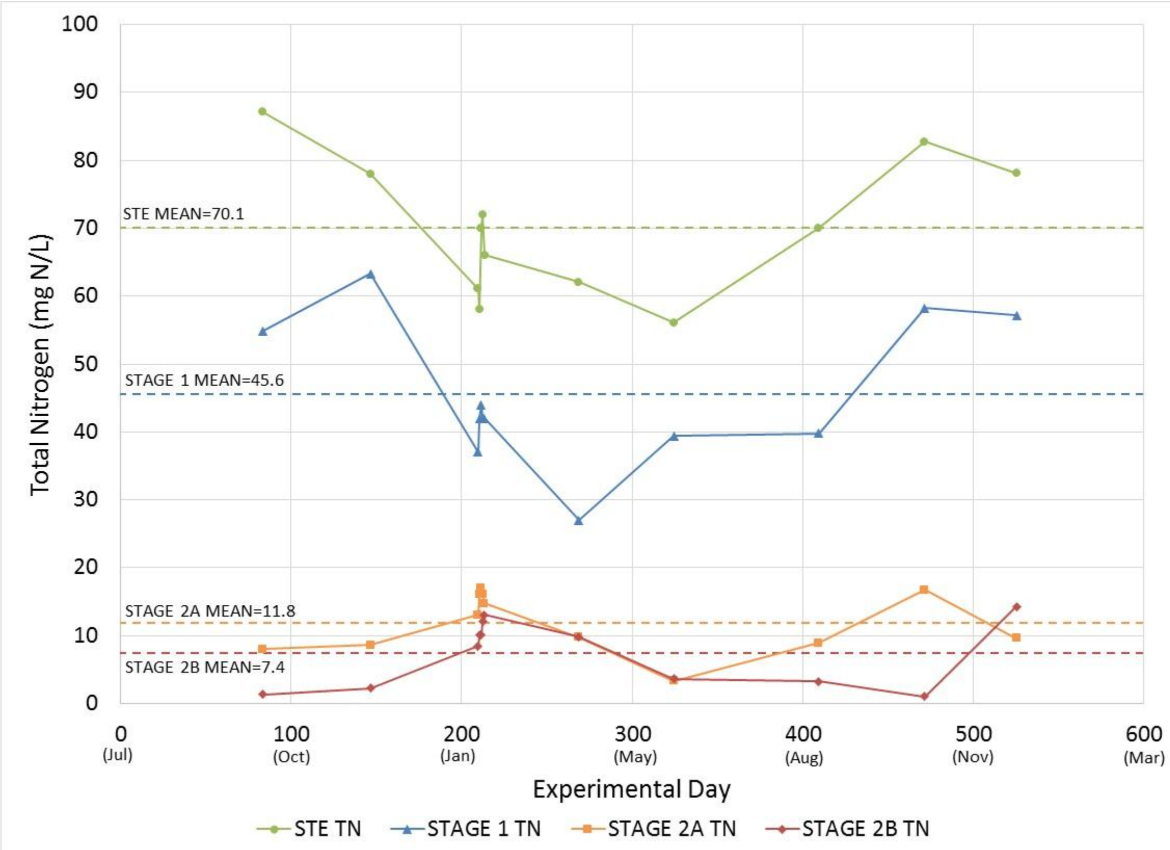


Water quality parameter	Statistical parameter	Septic tank effluent	Stage 1 effluent	Stage 2A lignocellulosic effluent	Stage 2B sulfur effluent
	n	12	12	12	12
$CBOD_5$ mg/L	mean	136.9±53.0	8.8±6.2	12.7±6.6	12.3±8.2
TSS, mg/L	mean	61.1±21.0	9.4±6.1	5.3±3.7	4.1±2.3
TKN mg N/L	mean	70.0±9.8	12.0±7.5	8.7±6.2	6.6±4.4
NH_3 mg N/L	mean	62.3±7.3	8.1±8.2	5.6±6.2	4.4±4.0
NO_x mg N/L	mean	0.1±0.2	33.6±15.5	3.2±4.1	0.8±2.7
TN mg N/L	mean	70.1±10.0	45.6±10.6	11.8±4.4	7.4±4.9
Sulfate mg/L	mean	1.7±1.5	19.7±3.1	14.7±7.5	37.2±17.6
Fecal Coliform (Ct/100 Ml)	geomean	48,499	2,764	1,150	409
TP mg/L	mean	9.4±2.1	3.3±1.5	2.7±1.4	2.6±1.1

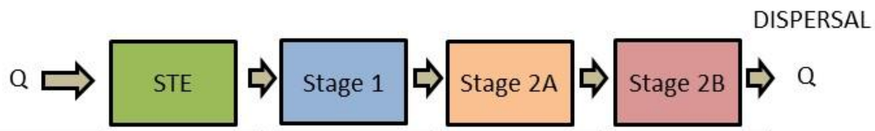
Figure 5-9: BHS-4 Graphical Representation of Water Quality Results (mean ± SD)



[1]Daily samples were collected on experimental days 209 through 213

Figure 5-10: BHS-4 Total Nitrogen Time Series Graph

The BHS-5 system was tested with two modes operation: Stage 1 single pass (SP) and Stage 1 with internal recirculation (R internal) to spray nozzles located above the surface of the Stage 1 media. The initial mode of operation (SP) was tested for 290 days of operation; the mode of operation was revised to R internal for the remainder of the study period. Figure 5-11 summarizes the overall water quality results for the Stage 1 single pass mode of operation throughout the study period. The influent wastewater average total nitrogen concentration was 70.8 mg/L. The Stage 1 biofilter provided significant nitrification with an average NH_3-N concentration of 3.3 mg/L and average TKN of 6.4 mg/L. The Stage 1 biofilter effluent average NO_x-N was 43.4 mg/L. These results indicate denitrification (approximately 30% total nitrogen reduction) was occurring. Stage 2 biofilter was effective in producing a reducing environment and achieving the NO_x-N reduction goals (average NO_x-N concentration of 0.04 mg/L). The average final total nitrogen in the treatment system effluent was 2.3 mg/L (Figure 5-11), primarily as TKN (average TKN concentration of 2.2 mg/L), representing a 96.7 percent average reduction in total nitrogen.

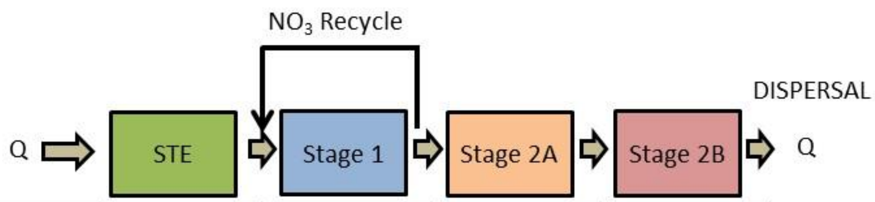


Water quality parameter	Statistical parameter	Septic tank effluent	Stage 1 effluent	Stage 2A lignocellulosic effluent	Stage 2B sulfur effluent
	n	9	9	9	9
$CBOD_5$ mg/L	mean	72.4±21.0	10.3±5.1	12.0±5.0	9.4±6.1
TSS, mg/L	mean	40.4±15.0	2.3±1.0	3.9±2.4	2.3±1.4
TKN mg N/L	mean	70.8±7.8	6.4±2.7	2.7±1.8	2.2±1.9
NH_3 mg N/L	mean	63.9±6.4	3.3±2.3	0.6±0.9	1.0±1.4
NO_x mg N/L	mean	0.03±0.02	43.4±5.9	4.1±3.6	0.04±0.05
TN mg N/L	mean	70.8±7.8	49.9±7.3	6.8±3.6	2.3±1.8
Sulfate mg/L	mean	3.8±4.0	29.3±6.5	24.1±3.3	68.1±19.5
Fecal Coliform (Ct/100 Ml)	geomean	42,035	2,406	416	23
TP mg/L	mean	7.5±2.0	2.5±0.5	1.1±0.4	1.1±0.3

Figure 5-11: BHS-5 (Single Pass) Graphical Representation of Water Quality Overall Results (mean ± SD)

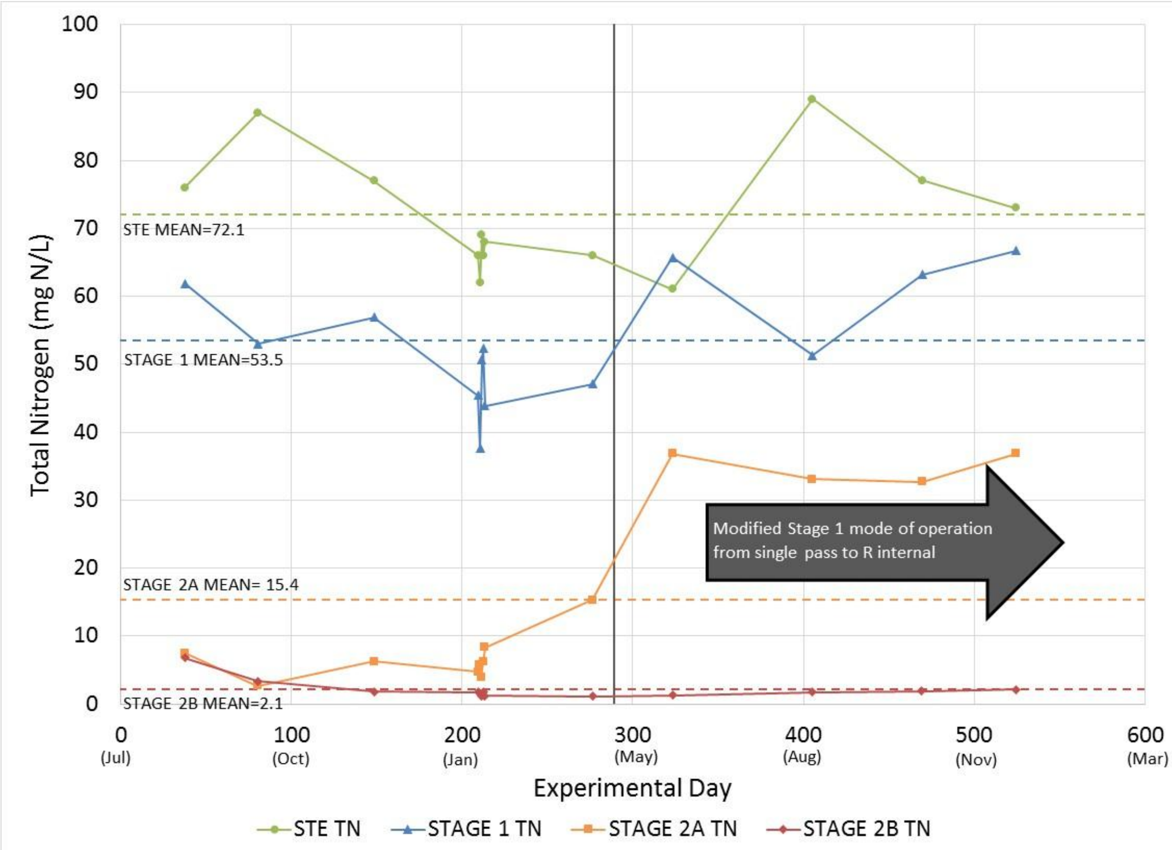
The mode of operation was revised to R internal for the remainder of the study period. Figure 5-12 summarizes the overall water quality results for the Stage 1 R internal mode of operation throughout the study period. The influent wastewater average total nitrogen concentration was 75.0 mg/L. Stage 1 recirculation mode of operation resulted in generally overall similar treatment performance as single pass mode. The Stage 1 biofilter provided significant nitrification with an average NH_3-N concentration of 0.1 mg/L and average TKN of 4.5 mg/L. The Stage 1 biofilter effluent average NO_x-N was 57.3 mg/L. These results indicate denitrification (approximately 17% total nitrogen reduction) was occurring. The time series plot (Figure 5-13) shows a trend in increasing total nitrogen in the Stage 2a lignocellulosic effluent with time which indicates less NO_x-N removal. The cause for the reduction in NO_x-N removal effectiveness in the lignocellulosic chamber is unclear; it could be related to the change in operation to recirculation, loss in reactivity of the media, higher dissolved oxygen in Stage 1 effluent, or other factors. However, the Stage 2b biofilter sulfur media was effective in producing a reducing environment and achieving the NO_x-N reduction goals (average NO_x-N concentration of 0.03 mg/L). The average final total nitrogen in the

treatment system effluent was 1.8 mg/L, primarily TKN (average TKN concentration of 1.8 mg/L), representing a 97.6 percent average reduction in total nitrogen. Figure 5-13 provides an overall study period total nitrogen time series graph which depicts the change in performance following the change in Stage 1 mode of operation.



Water quality parameter	Statistical parameter	Septic tank effluent	Stage 1 effluent	Stage 2A lignocellulosic effluent	Stage 2B sulfur effluent
	n	4	4	4	4
$CBOD_5$ mg/L	mean	108.5±42.4	4.0±2.2	4.0±2.2	15.5±12.9
TSS, mg/L	mean	33.8±6.8	1.0±0.0	2.3±2.5	3.3±1.5
TKN mg N/L	mean	75.0±11.6	4.5±0.3	2.6±0.6	1.8±0.3
NH_3 mg N/L	mean	71.0±11.4	0.1±0.0	0.02±0.03	0.9±0.5
NO_x mg N/L	mean	0.03±0.01	57.3±7.0	32.3±2.6	0.03±0.01
TN mg N/L	mean	75.0±11.6	61.7±7.1	34.9±2.3	1.8±0.4
Sulfate mg/L	mean	12.5±7.4	29.3±2.6	27.5±2.1	247.5±71.4
Fecal Coliform (Ct/100 Ml)	geomean	76,681	174	55	35
TP mg/L	mean	7.3±1.7	2.4±0.2	1.9±0.3	1.3±0.4

Figure 5-12: BHS-5 (R Internal) Graphical Representation of Water Quality Overall Results (mean ± SD)

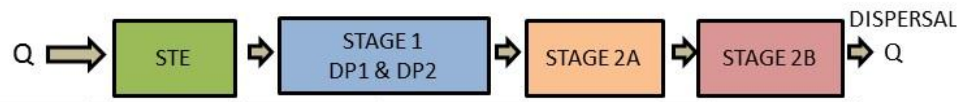


[1]Daily samples were collected on experimental days 209 through 213

Figure 5-13: BHS-5 Total Nitrogen Time Series Graph

The BHS-6 influent wastewater average total nitrogen concentration was 66.3 mg/L (Figure 5-14). During the study period the water level in the combined Stage 1 and Stage 2a tank was found to significantly fluctuate. The periods of high water level suggested hydraulic blockages in the system which could adversely affect nitrogen removal performance. The water level was significantly elevated during the sampling on Day 148. As a result of several system investigations, partial clogging of the Stage 2b inlet pipe and Stage 1&2a outlet pipe were found and fixed by Day 329. The low Stage 1 total nitrogen measured on Day 221 is likely a result of the elevated water level (Figure 5-15). The Stage 1 drivepoint samplers showed slightly variable results; however overall the Stage 1 biofilter provided significant ammonia removal. The combined Stage 1 and Stage 2a effluent indicated ammonia removal with an average NH_3-N concentration of 5.9 mg/L and average TKN of 8.0 mg/L. The average Stage 1&2a biofilter effluent NO_x-N was 24.8 mg/L. The Stage 2b biofilter with sulfur media was effective in producing a reducing environment and achieving NO_x-N removal (average NO_x-N concentration of 4.4 mg/L). The average final total nitrogen in the treatment system effluent was 12.4 mg/L (Figure 5-14), primarily as TKN

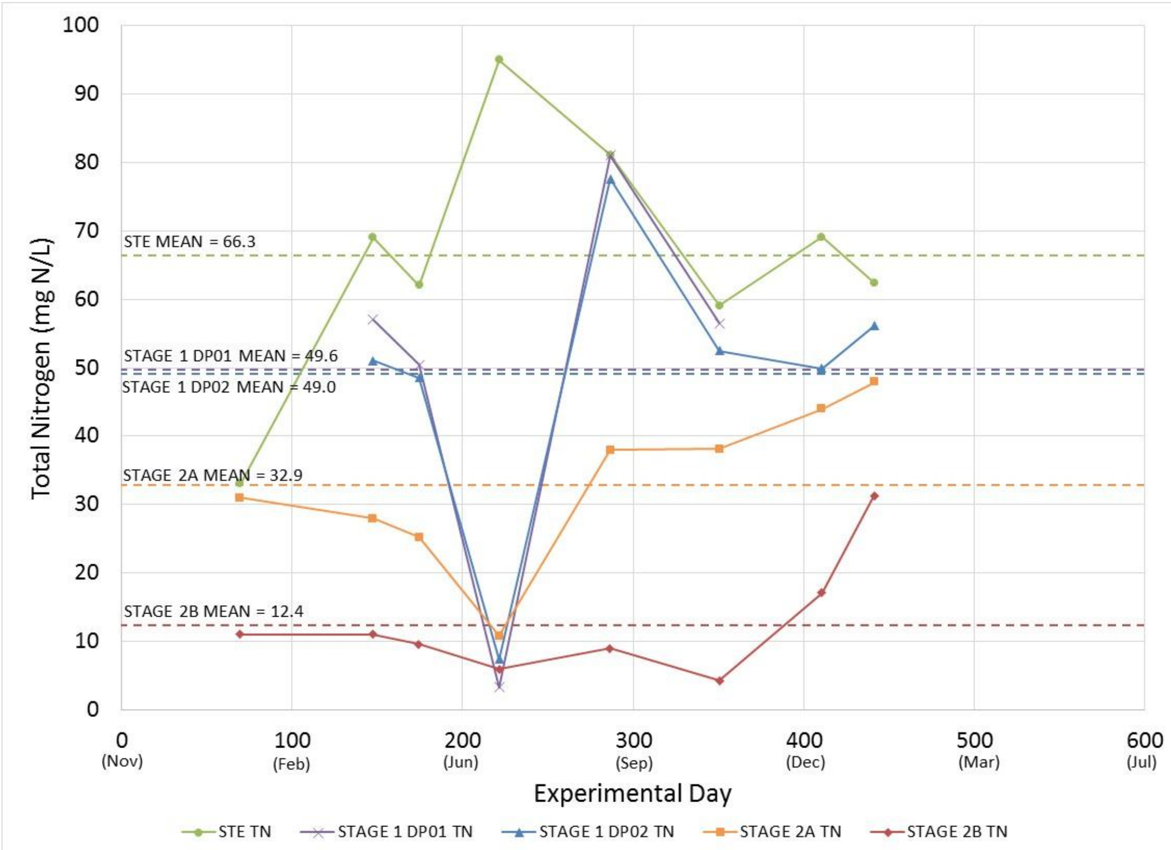
(average TKN concentration of 8.0 mg/L). This PNRS system reduced STE total nitrogen by an average of 81% over the study period.



Water quality parameter	Statistical parameter	Septic tank effluent	Stage 1 effluent DP1	Stage 1 effluent DP2	Stage 2A lignocellulosic effluent	Stage 2B sulfur effluent
	n	8	6	7	8	8
$CBOD_5$ mg/L	mean	80.0±26.8	55.8±96.2	5.5±3.0	24.5±24.1	8.3±9.5
TSS mg/L	mean	27.8±9.4	41.0±46.7	112.0±55.6	4.9±3.6	3.6±1.3
TKN mg N/L	mean	62.1±14.8	6.0±5.9	8.2±4.2	8.0±4.9	8.0±2.6
NH_3 mg N/L	mean	58.1±20.7	3.2±4.5	5.0±3.5	5.9±4.0	5.8±2.8
NO_x mg N/L	mean	0.1±0.1	42.9±25.0	41.0±19.5	24.9±14.4	4.4±8.6
TN mg N/L	mean	66.3±17.9	49.6±28.4	49.0±20.9	32.9±11.8	12.4±8.5
Sulfate mg/L	mean	5.3±3.9	NA	NA	18.0±5.3	135.5±37.1
Fecal Coliform (Ct/100mL)	geomean	338,145	NA	NA	8,945	1,838
TP mg/L	mean	8.1±1.9	NA	NA	4.1±1.0	4.1±0.8

NA = not analyzed

Figure 5-14: BHS-6 Graphical Representation of Water Quality Results (mean ± SD)

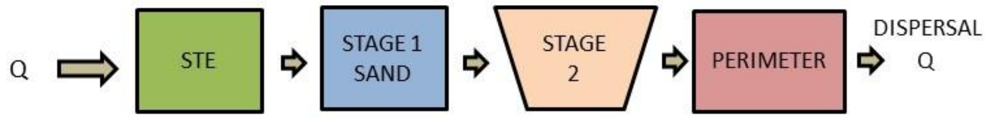


[1]Fluctuating water level in Stage 1&2a tank days 148 through 329

Figure 5-15: BHS-6 Total Nitrogen Time Series Graph

The BHS-7 influent wastewater average total nitrogen concentration was 54.9 mg/L (Figure 5-16). The four Stage 1 suction lysimeters showed variable results; however the overall average indicates that the Stage 1 biofilter provided significant ammonia, fecal coliform and total phosphorus removal. The Stage 1 results indicated significant ammonia removal with an average NH_3-N concentration of 0.6 mg/L and average TKN of 3.4 mg/L. The average Stage 1 effluent NO_x-N was 25.5 mg/L. The Stage 2 biofilter with lignocellulosic media was effective in producing a reducing environment and achieving significant NO_x-N removal (average NO_x-N concentration of 0.1 mg/L). However, the average perimeter soil water results (average NO_x-N concentration of 18.7 mg/L) indicated that the liner was not large enough to capture the unsaturated plume from the Stage 1 biofilter, and some of the nitrified effluent bypassed the liner. This is thought to be one reason for the high nitrate concentrations measured in the liner perimeter monitoring points. Therefore, it appears that the liner for this type of system needs to be designed much larger to capture all percolating effluent. Additionally, it appears that the fine sand media holds considerable water at the sand/lignocellulosic interface, and this also may contribute to nitrified effluent moisture transfer away from the liner into the surrounding soil. A better transitional interface between the

sand/lignocellulosic media is needed in order to direct the effluent flow into the liner. Also, using a 50/50 mixture of sand and lignocellulosic within the liner would better maintain the moisture profile into the liner. The average total nitrogen in the perimeter soil water was 19.1 mg/L (Figure 5-17), primarily NO_x-N (average TKN concentration of 2.2 mg/L). Based on the perimeter sample results, this PNRS system reduced STE total nitrogen by an average of 65% over the study period.



Water quality parameter	Statistical parameter	Septic tank effluent	Stage 1 native sand soil water	Stage 2 lignocellulosic effluent	Perimeter soil water
			4 suction lysimeters	5 drivepoints on liner	3 drivepoints in pans & 4 suction lysimeters
	n	8	32	38	49
$CBOD_5$ mg/L	mean	98.8±34.2	9.1±18.6	28.3±28.9	12.4±19.3
TSS mg/L	mean	35.5±12.4	3.7±2.8	10.5±4.3	4.4±3.7
TKN mg N/L	mean	54.9±9.8	3.4±1.6	3.2±1.2	2.2±0.5
NH_3 mg N/L	mean	43.9±16.0	0.6±0.9	0.1±0.04	0.2±0.2
NO_x mg N/L	mean	0.04±0.02	25.5±14.0	0.1±0.05	17.2±10.9
TN mg N/L	mean	54.9±9.8	28.9±15.2	3.3±1.2	19.1±10.9
Fecal Coliform (Ct/100mL)	geomean	31,754	2	4	1
TP mg/L	mean	6.9±1.2	0.2±0.3	9.1±16.5	0.7±0.9

NA = not analyzed

Figure 5-16: BHS-7 Graphical Representation of Water Quality Results (mean ± SD)

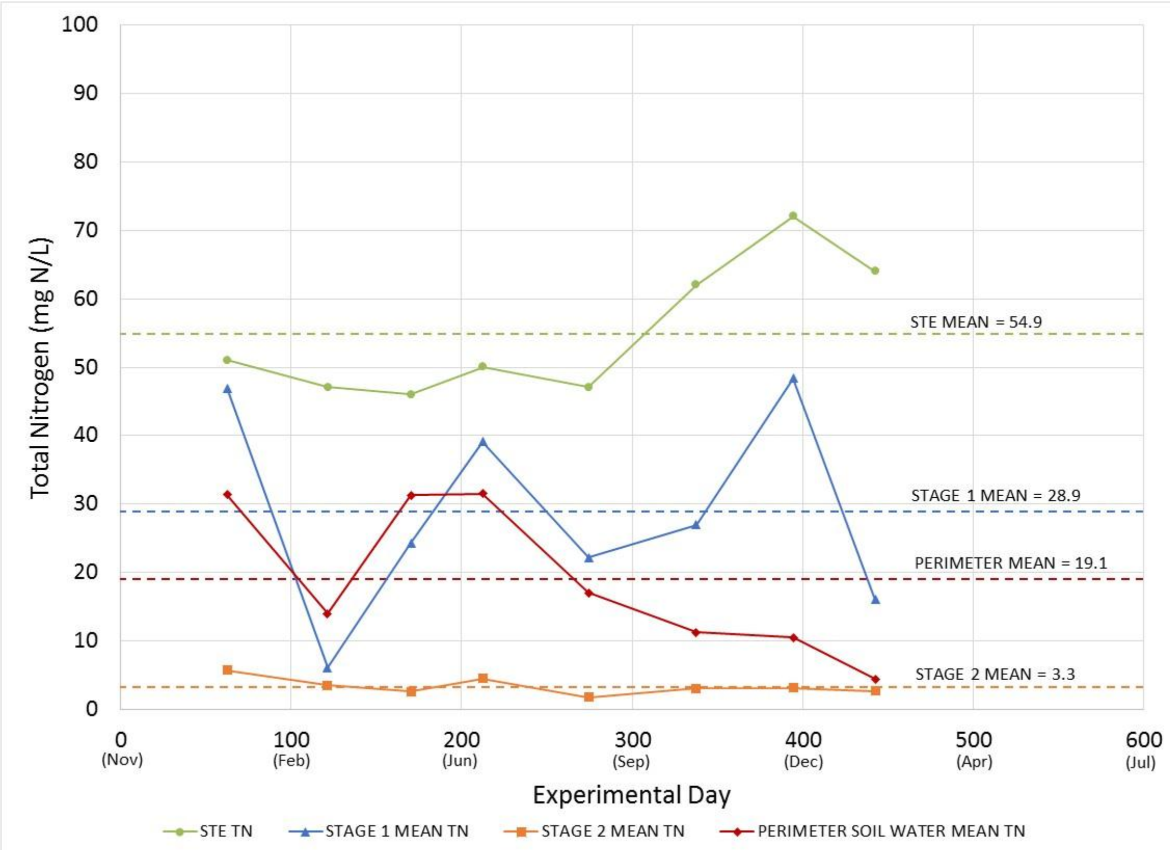


Figure 5-17: BHS-7 Total Nitrogen Time Series Graph

The mean effluent Total Nitrogen (TN) concentration for the seven prototype PNRS ranged from 1.8 to 19.1 mg/L (Table 5-4).

Table 5-4: Summary of Effluent Total Nitrogen (mean ± SD)

System	System Description	Mean Influent TN, mg/L	Mean Effluent TN, mg/L
BHS-1	Proprietary: Stage 1 Aerocell™ Stage 2 Nitrex™	82.7 ± 11.0	7.1 ± 5.7
BHS-2	In-tank Stage 1 with R tank, dual-media Stage 2	50.5 ± 5.4	3.5 ± 2.4
BHS-2	In-tank Stage 1 with R internal, dual-media Stage 2	57.8 ± 7.5	1.8 ± 1.2
BHS-3	In-ground stacked Stage 1 over Stage 2a ligno with supplemental Stage 2b sulfur	50.5 ± 8.8	1.9 ± 1.7
BHS-4	In-tank SP Stage 1, dual-media Stage 2	70.1 ± 10.0	7.4 ± 4.9
BHS-5	In-tank SP Stage 1, dual-media Stage 2	70.8 ± 7.8	2.3 ± 1.8
BHS-5	In-tank Stage 1 with R internal, dual-media Stage 2	75.0 ± 11.6	1.8 ± 0.4
BHS-6	In-tank stacked Stage 1 over Stage 2a ligno with supplemental Stage 2b sulfur	66.3 ± 17.9	12.4 ± 8.5
BHS-7	In-ground stacked SP Stage 1 over Stage 2 ligno	54.9 ± 9.8	19.1 ± 10.9

5.4 Operation and Maintenance

Overall the prototype PNRS operated continually following start-up as summarized in Table 5-5, with very limited or no downtime. A field technician visited the sites on a monthly basis. In general, very little maintenance was required. Most of the operational issues were resolved during start-up of the treatment systems as summarized in Table 5-6. A summary log of repairs, maintenance actions, inspection results and system observations are included in the System Monitoring Summary reports in Appendix B.

Table 5-5: System Operation

System	Total # of days operated during study period	Total # days offline during study period	Total # of monitoring site visits during study period
BHS-1	593	0	27
BHS-2	535	0	34
BHS-3	523	8[1]	46
BHS-4	525	21[2]	36
BHS-5	524	0	30
BHS-6	441	0	32
BHS-7	442	9[3]	30

[1]The PNRS system was not operating experimental days 59 through 67; a replacement part for the hydraulic unit was required.
[2]The PNRS system was bypassed experimental days 37 through 58; a smaller pump in the lift station was required.
[3]The PNRS system was bypassed experimental days 7 through 13 and 17 through 20 because the homeowners hosted two large holiday parties during the system start-up period.

Table 5-6: System Operation and Maintenance

System	Major Issues encountered	General O&M requirements	Other O&M
BHS-1	During start-up: • Flow splitter device flow split • Control panel wiring • Float placement within pump vault During study period: • Leaks detected in flow splitter device (was replaced)	• Recirculation ratio adjustment to meet target of 10:1	• Recirculation ratio was increased to target of 10:1 for better performance
BHS-2	During start-up: • Float placement	• Cleaning of septic tank effluent screen	• Recirculation mode of operation was revised from recirc tank to sprayers installed above Stage 1 biofilter media
BHS-3	During start-up: • Solenoid valve malfunction due to construction debris	• Cleaning of septic tank and STE dose tank effluent screens • Air release valve replacement	• The drip system controller includes automated cleaning sequences which leads to system complexity (9 solenoid valves) which requires additional oversight for system operation
BHS-4	During start-up: • Oversized STE transfer pump caused significant mixing in primary tank (was replaced) During study period: • Additional centerline distribution pipe was installed above Stage 1 media to improve coverage of effluent over entire surface of biofilter	• Cleaning of septic tank effluent screen • Raking of Stage 1 biofilter media surface	• High cleaning frequency of septic tank effluent screen attributed to flow transfer pump flow into single chamber septic tank • Solids carryover from the septic tank led to biomat formation and some ponding near Stage 1 distribution box
BHS-5	During start-up: • Float placement During study period: • During recirculation mode of operation sprayers required adjustment	• Cleaning of septic tank effluent screen	• Stage 1 mode of operation was revised from single pass to recirculating using sprayers installed above Stage 1 biofilter media.

Table 5-6 (cont.): System Operation and Maintenance

System	Major Issues encountered	General O&M requirements	Other O&M
BHS-6	During start-up: • Loose wiring During study period: • Stage 1 spray nozzle clogging and inadequate distribution • Stage 1&2a effluent collection pipe clogged • Stage 2 inlet pipe clogged	• Cleaning of Stage 1 spray nozzles • Clearing blockages in Stage 1&2a effluent collection pipe and Stage 2 inlet pipe • Cleaning of process flowmeter	• Operational issues are associated with design and construction problems. A better dosing system for the Stage 1 biofilter, a better underdrain design for the Stage 1&2a tank and improved inlet to the Stage 2 tank without bends between the tanks would likely eliminate most of the operational problems.
BHS-7	During start-up: • Float placement During study period: • Pump had erroneously been installed with a connection to a GFI breaker (replaced with regular 30-amp breaker)	• Cleaning of septic tank effluent screen • Flushing of low pressure distribution pipe	• It appears that the liner is was not large enough to capture the unsaturated plume from the Stage 1 biofilter, and some of the nitrified effluent missed the liner. Also a better transitional interface between the sand and the lignocellulosic media is needed, to direct the effluent into the liner. • However, this system type would provide the simplest operation and maintenance of all the systems tested.

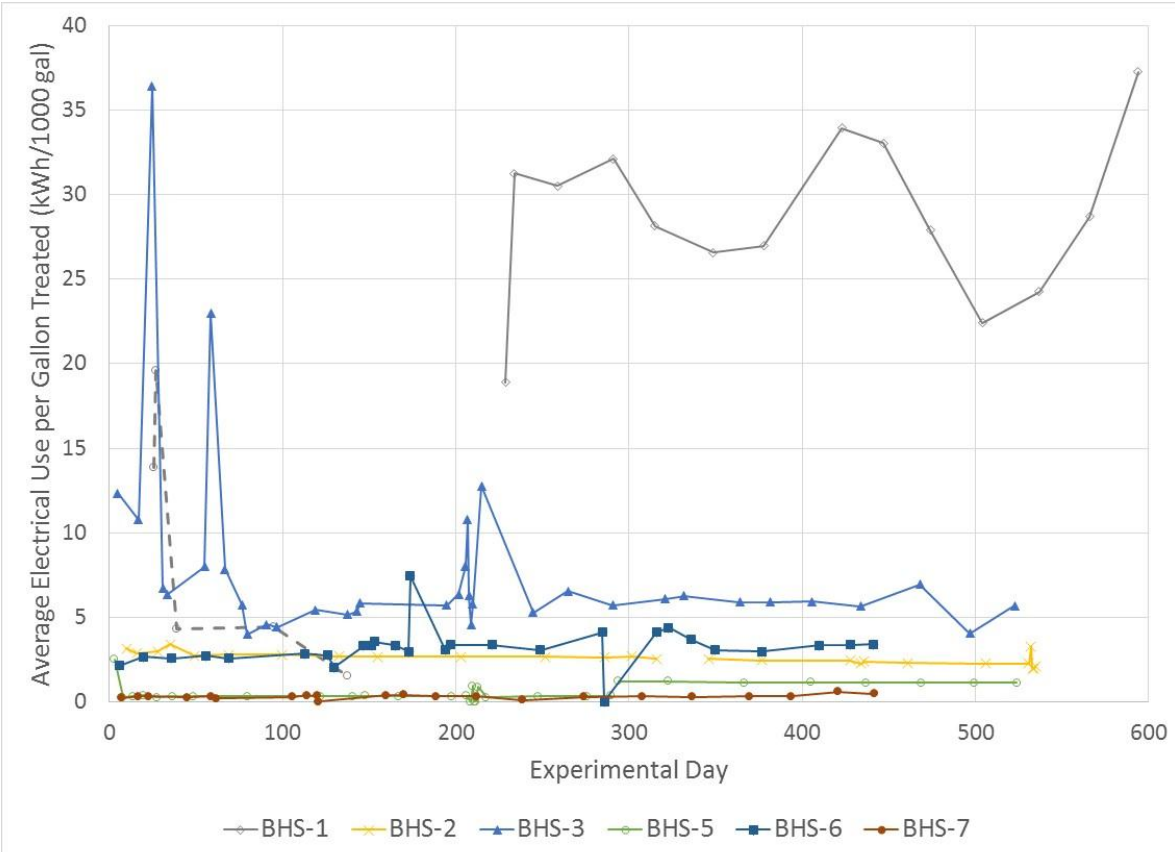
5.5 Energy and Media Consumption

Energy consumption was monitored using an electrical meter installed on the electrical line dedicated to the PNRS. The electrical meter records the cumulative power usage of the system in kilowatt-hours. The power usage of the system is primarily associated with the single pump; therefore the energy use is indicative of the size of the pump motor, the number of pump starts (doses per day), pump runtime (dose volume), and system hydraulic design. Table 5-7 provides the average power usage in kWh per day and the average power usage per 1000 gallons treated as graphically displayed in Figure 5-18.

Table 5-7: Energy Consumption

System	Mode of Operation[3]	Power Use		Electrical Use vs Treated Flow	
		Mean (kWh/day)	Standard Deviation (kWh/day)	Mean (kWh/1000 gallon)	Standard Deviation (kWh/1000 gallon)
BHS-1[1]	R tank	3.21	0.57	28.72	4.85
BHS-2	R tank	0.31	0.07	2.80	0.23
	R internal	0.26	0.13	2.36	0.34
	mean	0.28	0.1	2.59	0.36
BHS-3	Drip SP	0.98	0.56	7.83	5.99
BHS-4[2]	Gravity SP	0	0	0	0
BHS-5	SP	0.04	0.02	0.42	0.5
	R internal	0.14	0.02	1.15	0.04
	mean	0.07	0.05	0.61	0.54
BHS-6	SP	0.48	0.17	3.20[4]	1.16
BHS-7	In-ground LP	0.04	0.02	0.31	0.12

[1] After replacement of split flow recirculation device
[2] For system BHS-4 to test the total household wastewater volume, 0.14 kWh/day was used by a small transfer pump to get flow from the second OSTDS to the PNRS.
[3] R tank = recirculation to tank
R internal = recirculation to top of Stage 1 media
SP = single pass
LP = low pressure distribution
[4] Higher energy use at BHS-6 due to use of the pump from BHS-1, which was designed for high recirculation rate and higher head for sprayers.



[1] BHS-1 split recirculation device was replaced on experimental day 181; recirculation ratio was increased to a target of 10:1 from 5:1

[2] BHS-2 Stage 1 mode of operation was revised from tank recirculation to internal recirculation on experimental day 316

[3] BHS-4 is not included because energy was used by a small transfer pump to get flow from the second OSTDS to the PNRS

[4] BHS-5 Stage 1 mode of operation was revised from single pass to internal recirculation on experimental day 290

Figure 5-18: Time Series of Energy Use per 1000 Gallons Treated

There are no chemicals added to the systems. However, the Stage 2 media (lignocellulosic and sulfur) are reactive media which will be consumed during operation. The level of the top of the media surfaces were monitored throughout the study period, and the estimated change, which would represent media consumption, was negligible.

6 Data Analyses and Discussion

Based on the data collected during the prototype PNRS evaluations, several analyses have been conducted to assist with evaluation of PNRS performance. This section presents these analyses and performance metrics.

6.1 Stage 1 Performance

The prototype unsaturated biofilters (Stage 1) were highly effective in treating primary effluent. The performance of the various Stage 1 biofilters are compared by evaluating the removal efficiencies as summarized in Table 6-1 for single pass operation and recirculating operation. Removal efficiency for TSS, $CBOD_5$, and Total Nitrogen, Total Kjeldahl Nitrogen, and Organic Nitrogen were calculated as:

$$\%RE = \frac{C_{inf} - C_{eff}}{C_{inf}} \times 100 \qquad \text{(Eq. 6-1)}$$

where

% RE	=	percent removal efficiency
C_{inf}	=	influent concentration
C_{eff}	=	effluent concentration

Ammonia removal efficiencies were calculated using an effective influent ammonia concentration, which was defined as the sum of the analytical influent NH_3-N and the difference in organic N between influent and effluent. The effective influent NH_3 concept assumes that the release of ammonium due to ammonification of influent organic nitrogen is equal to the difference between influent organic N and effluent organic N. The effective influent ammonium nitrogen then equals the analytical influent NH_3-N plus the NH_3-N release from ammonification. The effective ammonia removal efficiency for the biofilter is:

$$\%NH_3\,RE = \frac{TKN_{inf} - TKN_{eff}}{TKN_{inf} - OrgN_{eff}} \times 100 \qquad \text{(Eq. 6-2)}$$

where

% NH_3 RE	=	percent ammonia removal efficiency
TKN_{inf}	=	influent Total Kjeldahl Nitrogen
TKN_{eff}	=	effluent Total Kjeldahl Nitrogen
$OrgN_{eff}$	=	effluent Organic Nitrogen

Table 6-1: Stage 1 Biofilters Mean Removal Efficiencies (%)

	System	TSS	$CBOD_5$	TN	TKN	Organic N	NH_3-N
Single Pass	BHS-3 (in-ground)	91%	90%	48%	96%	72%	100%
	BHS-4 (in-tank)	85%	94%	35%	83%	49%	88%
	BHS-5 (in-tank)	94%	86%	30%	91%	60%	95%
	BHS-6 (in-tank)	-207%[1]	72%	25%	88%	69%	92%
	BHS-7 (in-ground)	90%	91%	47%	94%	74%	99%
Recirculating	BHS-1 (R tank)	90%	75%	47%	86%	83%	90%
	BHS-2 (R tank)	4%	86%	61%	94%	76%	98%
	BHS-2 (R internal)	98%	97%	33%	92%	79%	98%
	BHS-5 (R internal)	97%	96%	18%	94%	50%	100%

[1] The Stage 1 samples from this vertically stacked system were taken from pan lysimeters placed at the expanded clay/lignocellulosic interface. It is suspected that pumping samples up from these pans included some fines from the expanded clay media, thus the increase in TSS over the influent value.

The aerobic biofilters (Stage 1) convert organic nitrogen to ammonia through ammonification and oxidize ammonia through nitrification. The mean ammonia removal efficiency is a good measure of Stage 1 performance. Mean ammonia removal efficiencies for the Stage 1 biofilters were greater than or equal to 88% for all seven systems, with many systems exceeding 95%. In addition to ammonia removal, the Stage 1 biofilters also ostensibly removed varying quantities of NO_x. PNRS systems with the greatest total nitrogen mean removal efficiency were the recirculating Stage 1 biofilters and the single pass in-ground systems (see Table 6-1 and Figure 6-1). The recirculating Stage 1 biofilters that include a separate recirculation tank show some pre-denitrification by recycling nitrified effluent back to a recirculation tank or to the Stage 1 biofilter itself. The higher total nitrogen removal efficiency shown in the single pass in-ground Stage 1 systems is most likely attributed to denitrification at anoxic microsites within the soil profile, resulting from lower applied hydraulic loading rates and finer textured sand, and agrees with previous studies of nitrogen reduction by soil treatment units (Anderson et. al, 1994; Anderson et. al., 1998; Anderson and Otis, 2000; Long, 1995; Siegrist and Jenssen, 1989). The Figure 6-1 box and whiskers plot provides an immediate comparative visualization of the total nitrogen removal efficiency of Stage 1 biofilter, including the center and spread of the distribution. The box plot provides a “six point” summary of data values, including the mean, median, minimum and maximum values, and upper and lower quartiles interval. The box plots show the third and first quartile (75^{th} and 25^{th} percentile) interval as bounded by the shaded area. The median is shown as the line between the shaded areas, the mean is shown as a black diamond, and maximum and minimum are horizontal “whisker” lines.

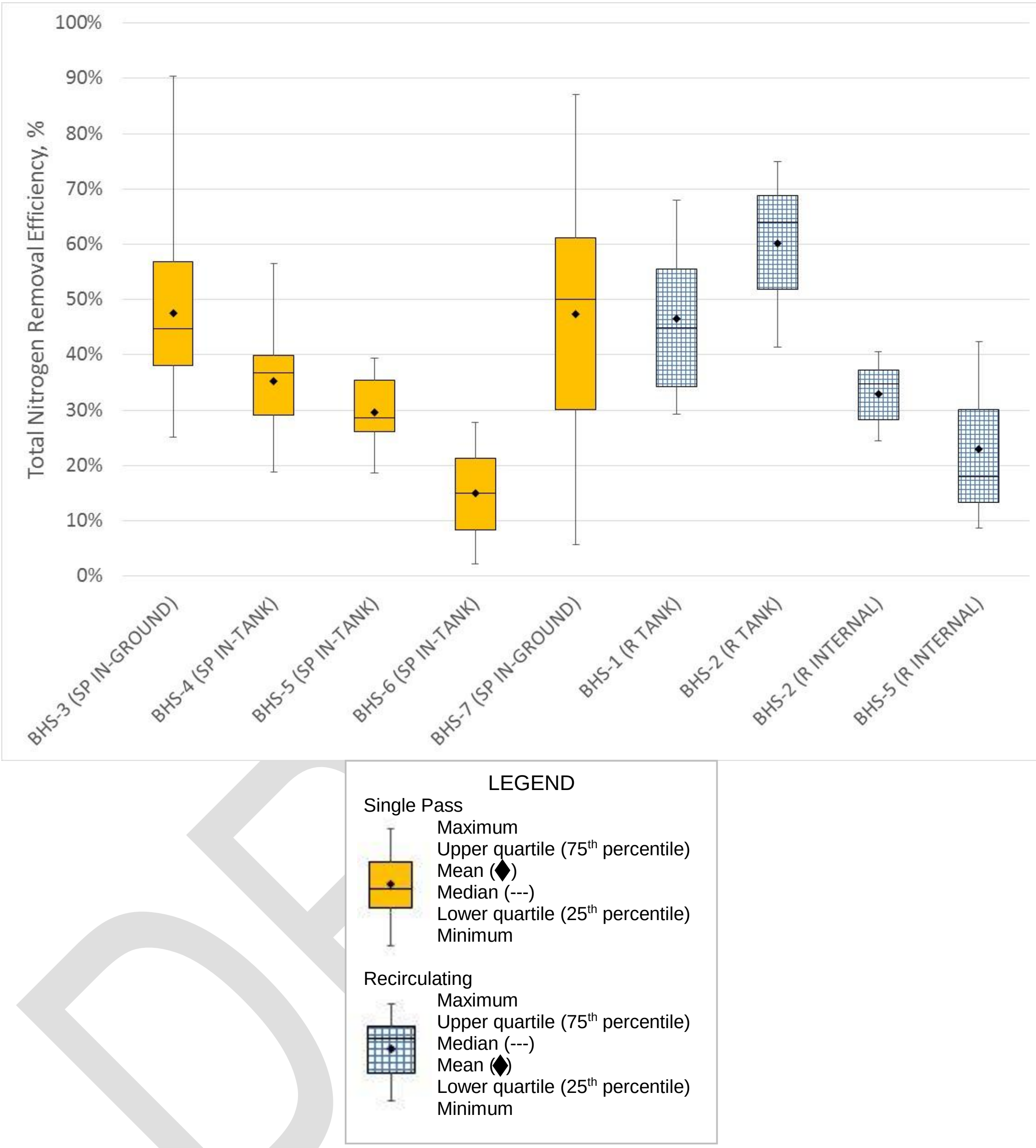


Figure 6-1: Stage 1 Biofilters Total Nitrogen Removal Efficiencies

6.2 Stage 2 Performance

The saturated biofilters (Stage 2) were highly effective in treating the Stage 1 nitrified effluent. The performance of the various prototype Stage 2 biofilters were compared by evaluating the oxidized nitrogen (NOx-N) removal efficiencies.

Lignocellulosic Performance

Saturated biofilters with lignocellulosic media, as characterized in Table 6-2, were not uniformly effective in removing oxidized nitrogen (NO_x-N) as summarized in Table 6-3. The box and whiskers plot (Figure 6-2 provides an immediate comparative visualization of Stage 2 biofilters with lignocellulosic media influent and effluent NOx-N, including the center and spread of the distribution. As shown in the cumulative frequency diagram of influent and effluent NO_x-N for all lignocellulosic biofilters (Figure 6-3), approximately 80 percent of the lignocellosic effluent NO_x-N sample concentrations were below 10 mg-N/L. As noted during the pilot work, hydraulic retention time should be considered when evaluating lignocellulosic performance. To further evaluate the effect of retention time, NO_x-N removal rate as a function of empty bed hydraulic retention time for the various in-tank saturated lignocellulosic-containing biofilters was plotted to examine any trends (Figure 6-4). It appears from the limited data that NO_x removal rate decreases with retention time. Others have shown that these systems are nitrate limited at higher retention times, resulting in lower NO_x removal rates as NO_x concentrations decrease to low levels (Schipper et al., 2010).

The nitrate removal rate in denitrification biofilters incorporating lignocellulosic media are commonly reported as g N m^{-3} media day^{-1}. Cameron and Schipper (2012) tested nine different carbon substrates including softwood and hardwood which showed no statistical difference. Mean nitrate removal rates tested at two temperatures 14˚C and 23.5˚C were 3.0 and 4.9 g N m^{-3} day^{-1} for softwood and 3.3 and 4.4 g N m^{-3} day^{-1} for hardwood, respectively. Schmidt and Clark (2013) found similar results of 3.0 and 3.61 g N m^{-3} day^{-1} for softwood and hardwood, respectively. Both studies determined that temperature and carbon availability of the media are more important for controlling nitrate removal rate than hydraulic efficiency. Schipper (2010) summarized that nitrate removal rates supported by denitrification beds incorporating wood generally range from 2 to 10 g N m^{-3} day^{-1}. Table 6-3 summarizes the mean nitrate removal rates (g N m^{-3} day^{-1}) for the seven test systems which ranged from 1.18 to 9.59 g N m^{-3} day^{-1}. These values are within the range reported by other investigators as summarized in Table 6-4. In Florida, temperature should not be a controlling factor for denitrification with lignocellulosic media (see Figure 5-1).

Table 6-2: Stage 2 Lignocellulosic Biofilter Characteristics

System	Media (% Reactive)	Media placement	Stage 1 Operation	Mean Influent Flow (m^3/day)	Media Volume (m^3)	Hydraulic Retention Time[1] (days)
BHS-1	Nitrex™	In-tank	Aerocell™	0.424	5.52	13.0
BHS-2	Sawdust (100%)	In-tank	R tank	0.413	3.57	8.6
			R internal	0.426	3.57	8.4
BHS-3	Urban Waste Wood (50%)	Underlying Stage 1 above liner in-ground	Drip application	0.547	7.73	NA
BHS-4	Urban Waste Wood (100%)	In-tank	Single Pass	1.124	3.57	3.2
BHS-5	Urban Waste Wood (100%)	In-tank	Single pass	0.432	3.57	8.3
			R internal	0.468	3.57	7.6
BHS-6	Urban Waste Wood (100%)	Underlying Stage 1 in-tank	Single Pass	0.578	1.90[2]	2.2[2]
BHS-7	Urban Waste Wood (100%)	Underlying Stage 1 above liner in-ground	In-ground LP	0.475	10.25[3]	10.8[3]

[1] Calculated for in-tank systems as empty bed residence time

[2] Calculated for the saturated portion of the lignocellulosic media.

[3] Calculated for the saturated portion of the lignocellulosic/liner volume. However, as discussed, much effluent from this system likely did not reach the liner.

The BHS-7 prototype in-ground system is not included further in the Stage 2 performance analysis due to the unknown hydraulic conditions surrounding the lignocellulosic Stage 2 liner. As discussed previously, it appeared that the flow from the Stage 1 soil media at this system did not routinely flow through the liner system, thus the Stage 2 performance of the system is not well represented by the liner samples.

Table 6-3: Stage 2 Lignocellulosic Biofilter NO_x-N Removal

System	Stage 1 Operation	Influent Mean NO_x-N, mg N/L	Effluent Mean NO_x-N, mg N/L	Mean NO_x-N Removal Efficiency (%)	Mean NO_x-N removal rate (g N $m^{-3}d^{-1}$)
BHS-1	R tank	32.33	0.09	100%	2.48
BHS-2	R tank	16.72	0.02	100%	1.93
	R internal	34.00	3.96	88%	3.58
BHS-3	Drip SP	23.92	5.77	76%	1.28[1]
BHS-4	SP	33.58	3.15	91%	9.59
BHS-5	Single pass	43.44	4.10	91%	4.76
	R internal	57.25	32.25	44%	3.28
BHS-6	SP	42.26	24.87	41%	5.30

[1]The BHS-3 lignocellulosic media mixture was 50% reactive media, the mean NO_X-N removal rate is calculated using the total mixed media volume.

Table 6-4: Summary of Literature Values for Lignocellulosic Denitrification

No.	Reference	System Type	Field site location	Influent NO_3-N (mg N/L)	Temperature (^oC)	N removal rate (g N/m3 media*day)
1	Robertson and Cherry, 1995	Wall	Canada	57-62	NR	1.0 - 1.9
2	Schipper and Vojvodic-Vokuvic, 1998	Wall	New Zealand	5-16	13-21	3.6
3	Robertson et al., 2000	Wall	Canada	28-57	NR	0.7-0.8 for reactive barriers
		Bioreactor		4.8		1.3-10.2 for mulch reactor
4	Robertson et al., 2008	Wall	Canada	2-100	6-10	0.07-0.35
		Wall			20-22	1.1-1.9
5	Schipper et al., 2010	Lined Bed	New Zealand	2-20	NR	0.1-11
6	Cameron and Schipper, 2010	Bed	New Zealand	159	14	3.0
				141	23.5	4.9
		Bed	New Zealand	159	14	3.3
				141	23.5	4.4
7	Robertson, 2010	Columns	Lab Column Study	3.1-48.8	21-23	10.8-16.1 (fresh wood)
				3.1-48.8	21-23	8.5 (2 yr old bioreactor)
				3.1-48.8	21-23	6.4 (7 yr old bioreactor)
8	Moorman et al., 2010	Bioreactor	Iowa	20-25	NR	5.4-22.7
9	Long et al., 2011	Wall	New Zealand	2-15	11-14	NR
10	Schmidt and Clark, 2012	Wall	Florida	3-10	15-22	4.9-5.5
11	Schmidt and Clark, 2013	Columns	Florida, Lab study	7.5	7.9-24.1	2-6

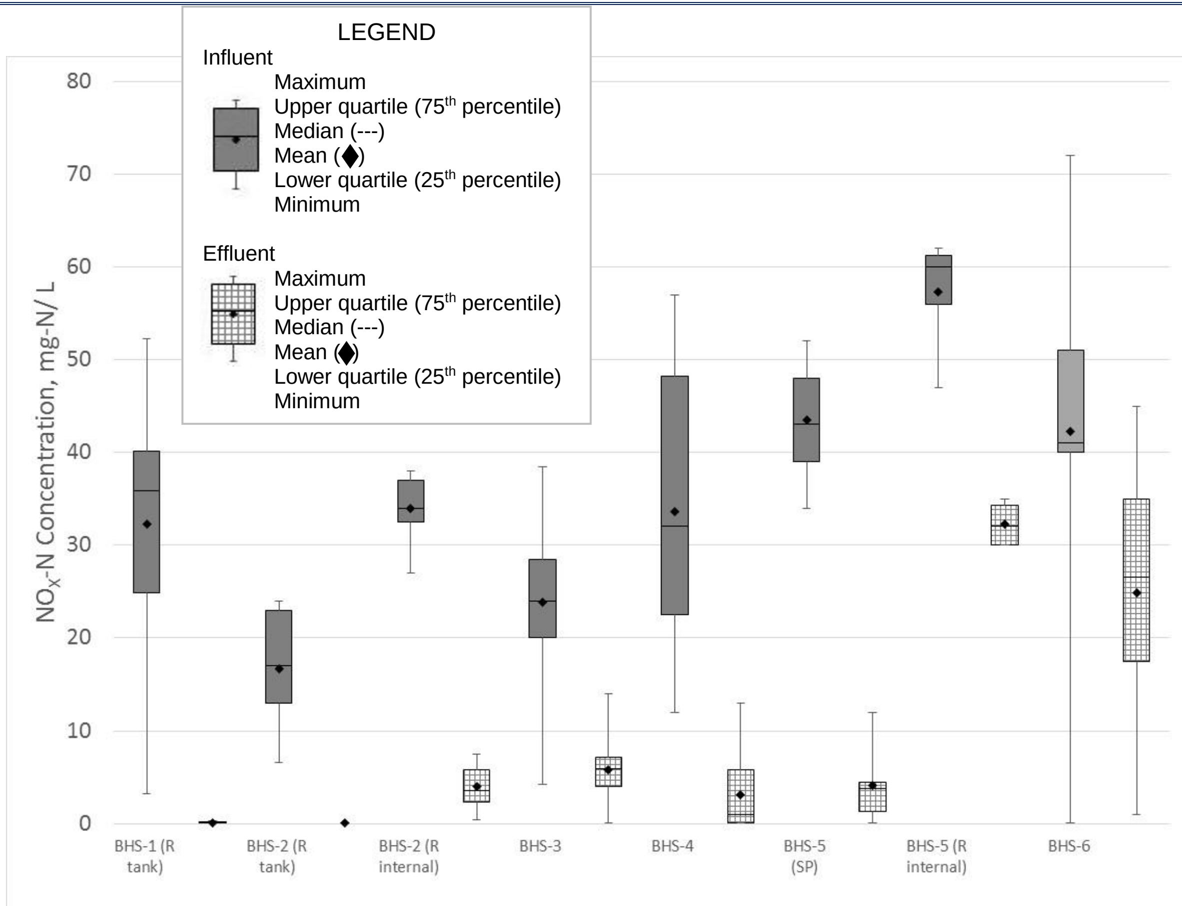


Figure 6-2: Stage 2 Lignocellulosic Biofilter Effluent NO_x-N

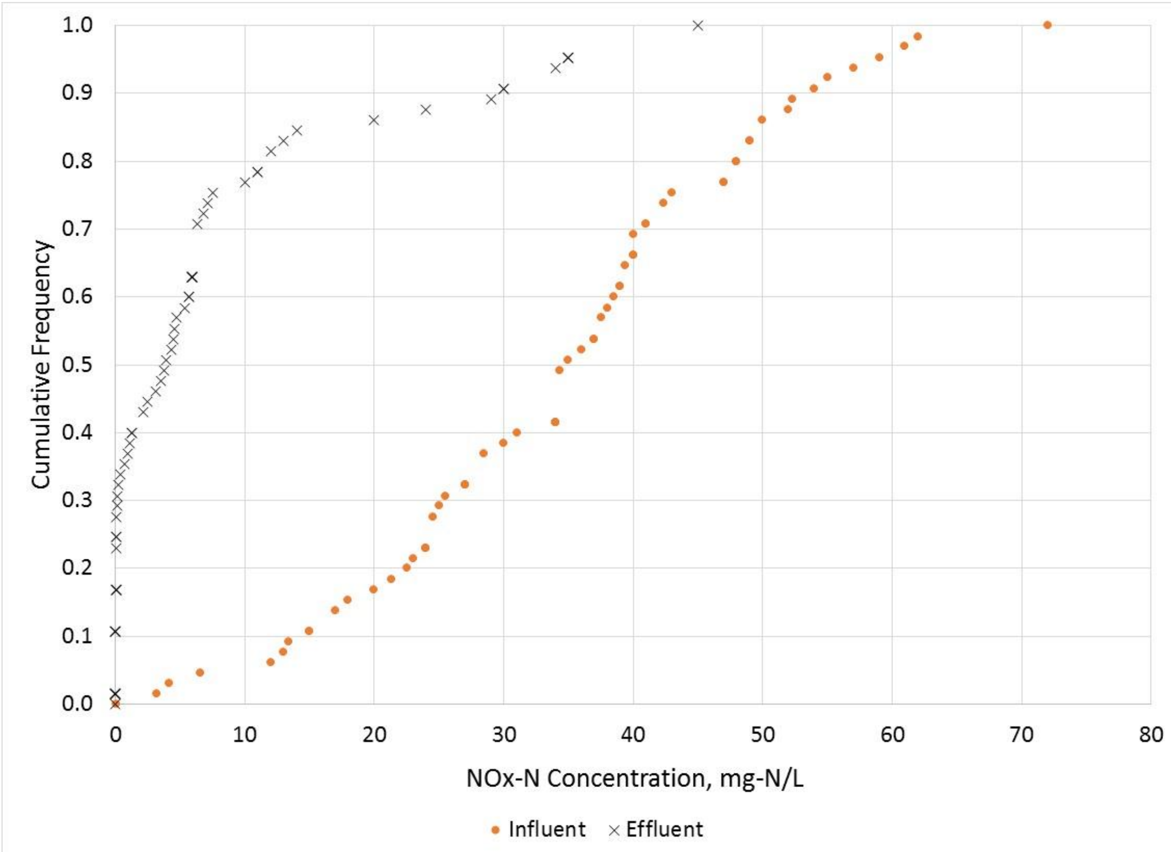


Figure 6-3: Stage 2 Lignocellulosic Biofilter NO_x-N, Cumulative Frequency Diagram

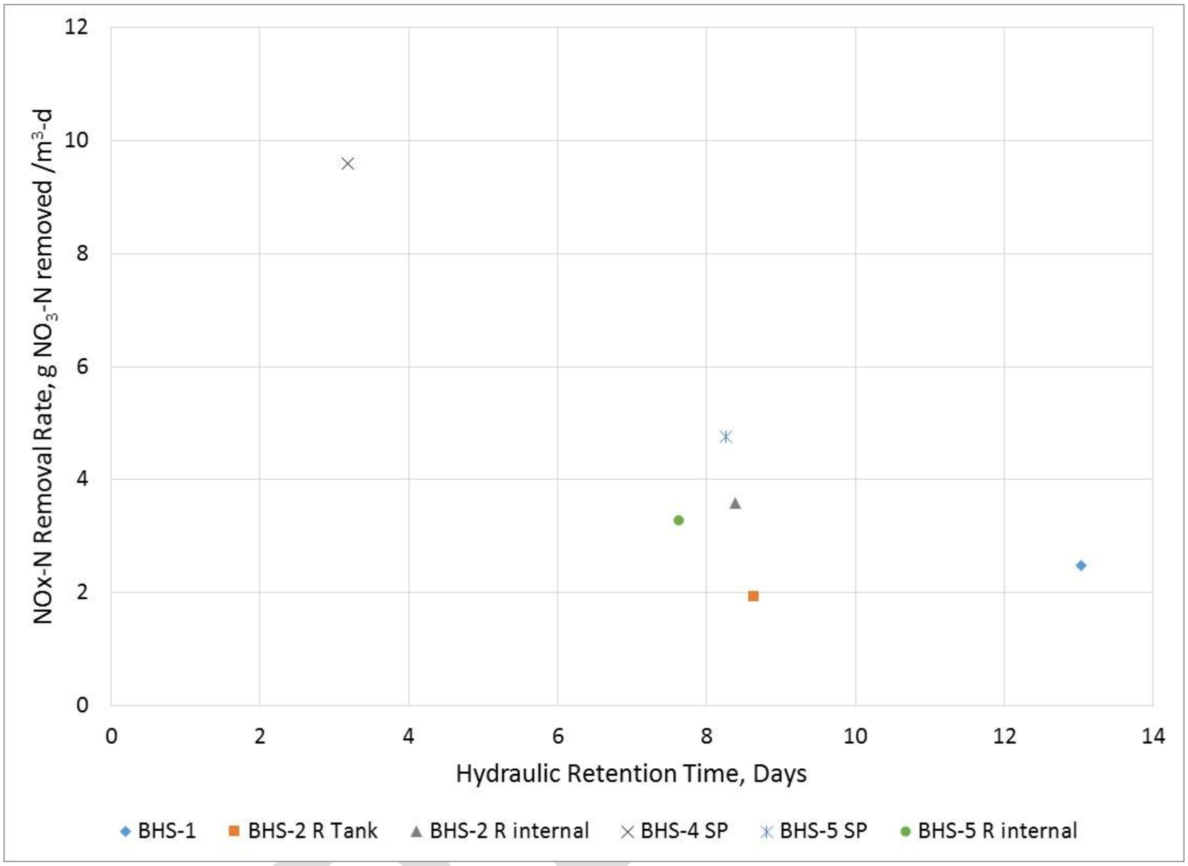


Figure 6-4: In-tank Lignocellulosic Biofilter NO_x-N Removal Rate vs HRT

6.2.1 Sulfur Performance

The Figure 6-5 box and whisker plot provides an immediate comparative visualization of influent and effluent NO_x concentrations of Stage 2 biofilters with sulfur media. Saturated biofilters with sulfur media were generally but not uniformly effective in removing oxidized nitrogen (NO_x-N) as summarized in Table 6-5. However in all prototype PNRS that employed sulfur, the sulfur media biofilters followed treatment by preceding lignocellulosic media biofilters. In some individual sample events for some systems, NO_x removal was highly complete in sulfur biofilter influent and little NO_x reduction occurred. As shown in Figure 6-6, a cumulative frequency diagram for all the sulfur biofilter influent and effluent NO_x-N sample concentrations, greater than 90 percent of the sulfur effluent NO_x-N concentrations were below 0.2 mg-N/L. These values are within the range reported by other investigators as summarized in Table 6-6.

Table 6-5: Stage 2 Sulfur Biofilter NO_x-N Removal

System	Percent Reactive Media	Stage 1 Operation	Mean Influent Flow (m^3/day)	Media Volume (m^3)	Hydraulic Retention Time[1] (days)	Influent Mean NO_x-N, mg N/L	Effluent Mean NO_x-N, mg N/L	Mean NO_x-N Removal Efficiency (%)
BHS-2	90%	R tank	0.413	1.02	2.5	0.02	0.02	NA
		R internal	0.426	1.02	2.4	3.96	0.02	99%
BHS-3	90%	Drip SP	0.548	1.09	2.0	5.77	0.61	89%
BHS-4	90%	SP	1.124	0.76	0.7	3.15	0.82	74%
BHS-5	90%	Single pass	0.432	0.76	1.8	4.10	0.04	99%
		R internal	0.468	0.76	1.6	32.25	0.03	100%
BHS-6	90%	SP	0.578	0.57	1.0	24.87	4.41	82%

[1]Calculated as empty bed residence time

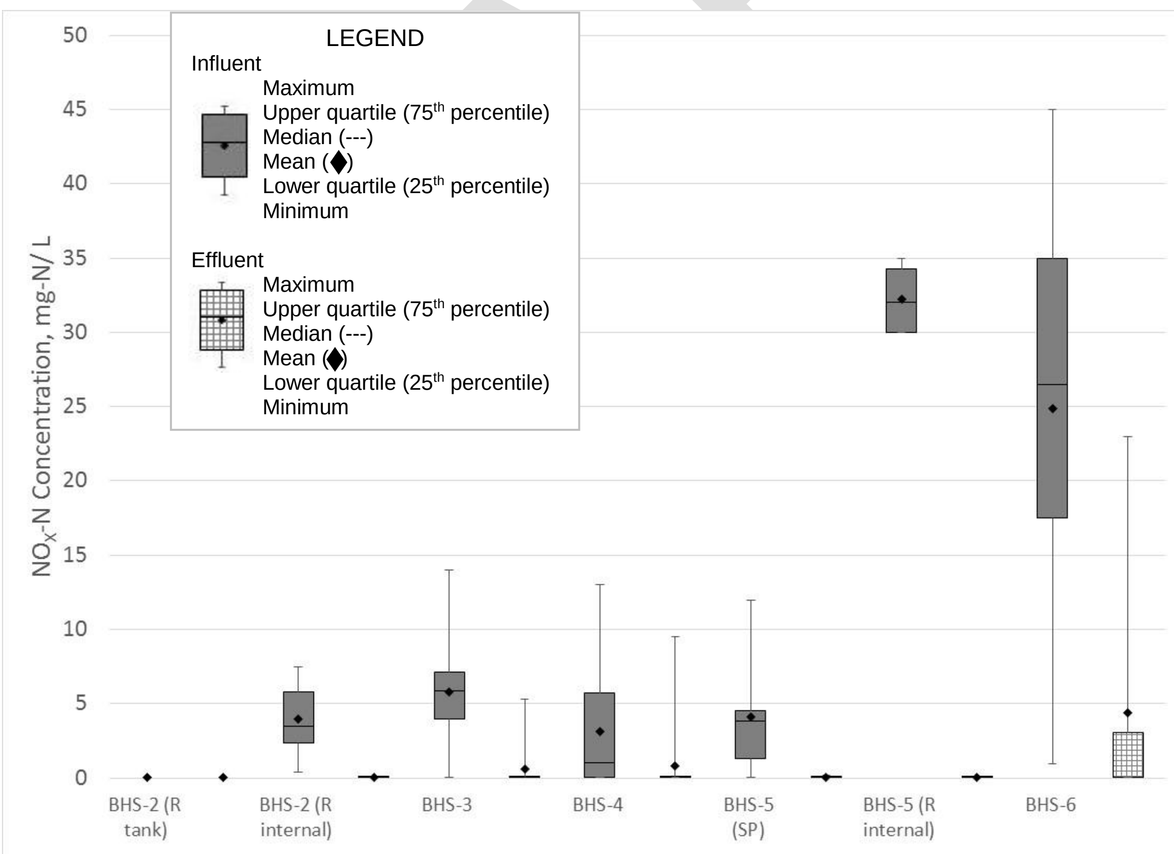


Figure 6-5: Sulfur Biofilter Effluent NO_x-N Box

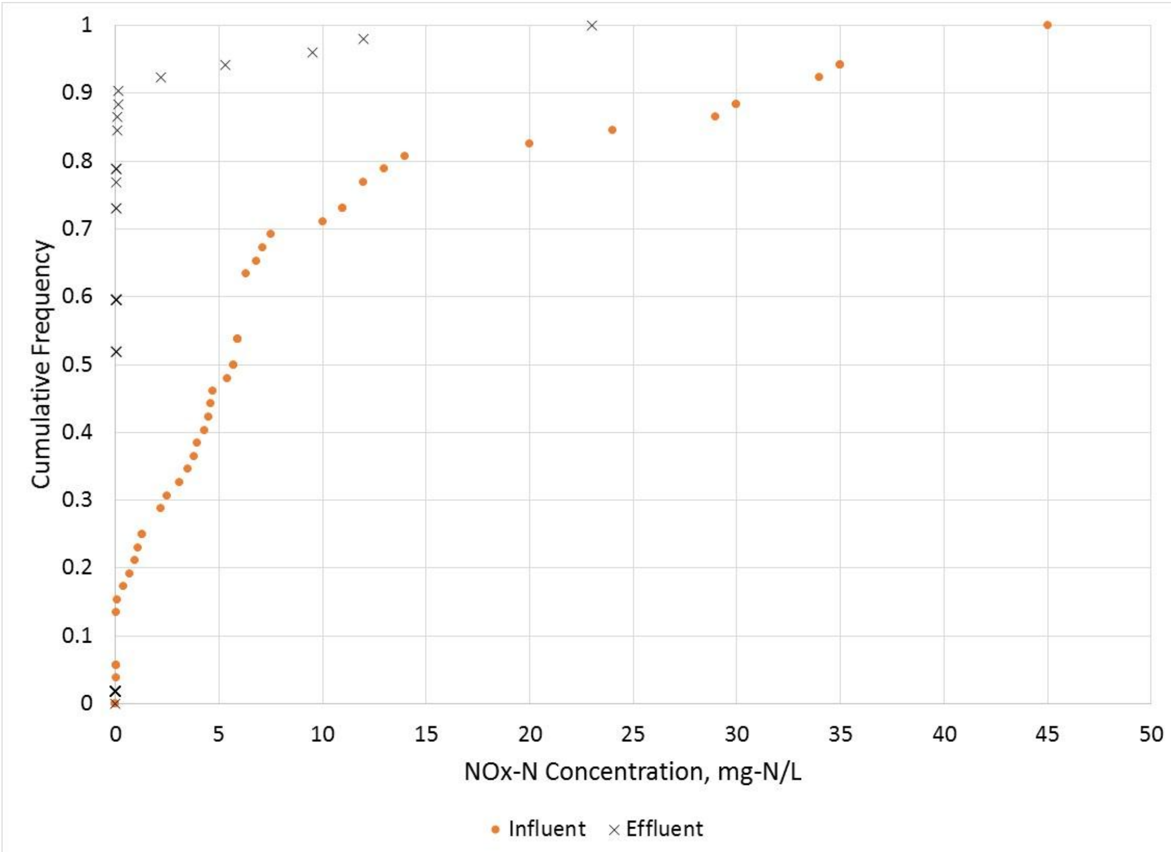


Figure 6-6: Sulfur Biofilter Effluent NO_x-N Cumulative Frequency Diagram

[1]BHS-2 R tank operation is not included because the influent NO_x-N was never above the method detection limit

Table 6-6: Summary of Literature Values for Sulfur Denitrification

Reference No.	Reference	Systems Studied	Field site location	Influent NO_3-N (mg N/L)	Temperature (°C)	N removal rate (g N/m3 media*day)	Media life
1	Batchelor and Lawrence, 1978	Denitrification of nitrate using elemental sulfur in a mixed liquor slurry reactor system	New York, Lab study	30 mg N/L	12-30	0.97-3.92 mg NO^3-N/mg biomass (as org N) /day	2.5 - 5.6 mg S/mg NO_3 removed
2	Kanter et al., 1998	mound with liner Sulfur/dolomite	University of Wisconsin, Madison	25.7 mg-N/L and 51.7 mg/L	NR	66-98% TN reduction	NR
3	Sengupta et al., 2006	Lab-scale and pilot-scale upflow packed bioreactors. Media was Sulfur mixed with 3 different alkalinity sources: marble chips, crushed limestone and crushed oyster shell at 3:1 ratio	Massachusetts, at the MASSTC	2-32 mg-N/L	NR	80% NO_3-N reduction	NR
4	Smith, 2012	Lab-scale study of two stage biofiltration for N removal. Stage 2 sulfur based denitrification system (PNRS I). Media was sulfur and oyster shell at 3:1 ratio		59 mg NOx-N/L	NR	exceeded 99.8% NO_x-N reduction	NR
5	Smith, 2009	Lab-scale study of two stage biofiltration for N removal. Stage 2 sulfur based denitrification system (PNRS I). Media was sulfur and oyster shell at 3:1 ratio	Florida, PNRS I study	59 mg NOx-N/L	10-30	14.4 (based on total media volume, a mixture of 60% sulfur, 20% oyster shell, and 20% expanded shale)	NR - based on media volume and should approximately follow stoichiometry
6	Shao et al., 2010	Literature review of sulfur based denitrification, packed bed reactor (PBR) results reported.	Literature review	Varied	NR	48-2688	NR

A potential concern associated with the use of sulfur media biofilters is the effluent sulfate concentration, which was previously discussed in Section 3.2. Effluent sulfate concentrations for sulfur biofilters are summarized in Table 6-7. Mean effluent sulfate levels were below the secondary drinking water standard of 250 mg/L for all systems utilizing sulfur media.

Table 6-7: Effluent Sulfate

System	Stage 1 Operation[1]	Effluent Sulfate, mg/L			
		Mean	Standard Deviation	Min	Max
BHS-2	R tank	192	28	170	240
	R internal	209	54	160	320
BHS-3	Drip SP	114	57	27	250
BHS-4	SP	37	18	21	71
BHS-5	SP	68	20	29	98
	R internal	248	71	160	330
BHS-6	SP	136	37	64	190

[1] R tank = recirculation to tank
R internal = recirculation to top of Stage 1 media
SP = single pass

6.2.2 Estimates of Media Life

Studies in the literature suggest very long life spans for lignocellulosic denitrification biofilters (Schipper et. al., 2010). Robertson et al. (2008) reported on a lignocellulosic reactive barrier wall that had been removing nitrate from groundwater for 15 years, and samples taken from the wall in year 15 indicated the wall was still functional with a 4 g N/m^3/day denitrification rate, approximately 50% less than the rate in year 1. Several studies have shown leaching of carbon content during the first few months of operation of lignocellulosic bioreactors; however, the denitrification rates were still sufficient to account for nitrate removal for five years and greater following initial startup (Schipper et. al., 2001).

Moorman et al. (2010) studied an in situ wood chip bioreactor receiving influent nitrate levels of 20-25 mg NO_3-N/L for 8 years, and measured the loss of wood. The half-life of the reactive media was estimated to be over 36 years in the saturated zone under anaerobic conditions. Based on these and other literature sources, it appears that lignocellulosic denitrifying systems could be designed for many years of life.

The lifespan of the lignocellulosic biofilters is difficult to calculate. However, if an assumption that the lignocellulosic organic carbon material is consumed only by the heterotrophic denitrification equation (Schmidt and Clark, 2012) a theoretical calculation of media life can be made.

$$5C_6H_{12}O_6 + 24NO_3^- + 24H^+ \rightarrow 12N_2 + 42H_2O + 30CO_2 \quad \text{(Eq. 6-3)}$$

The longevity of the mass of lignocellulosic media to denitrify the mean NO_X-N supplied to each treatment system was estimated using the total wastewater volume applied, mean NO_X-N concentration applied and

stoichiometric relationships for lignocellulosic based heterotrophic denitrification (Eq. 6-3). Results of these calculations are presented in Table 6-8. From the calculations indicates, it appears that Stage 2 denitrification biofilters using lignocellulosic media can be designed to last many years. Additionally, the media for in-tank Stage 2 biofilters is easily replenished via manholes above the biofilter if needed to maintain performance goals.

Table 6-8: Lignocellulosic Media Life

System	Mode of Operation	Percent reactive media	Volume of Lignocellulosic Media, ft^3	Calculated Longevity[1], years	Longevity with factor of safety[2], years
BHS-1	upflow	100%	194.8	83.8	64.5
BHS-2	Dual media tank	100%	126.0	107.5	82.7
BHS-3	in-ground liner	50%	136.5	80.8	62.2
BHS-4	Dual media tank	100%	126.0	21.6	16.6
BHS-5	Dual media tank	100%	126.0	43.6	33.5
BHS-6	Stacked Stage1/Stage 2	100%	67.0	39.1	30.1
BHS-7 (ligno/liner water)	in-ground liner	100%	362.0	176.2[3]	135.5[3]
PNRS II 17-LS-50	horizontal	50%	0.6	20.2	15.5
PNRS II 9-LS-25	upflow	25%	1.3	5.4	4.1
PNRS II 7-LS-50	upflow	50%	2.6	8.4	6.5
PNRS II 10-LS-30	upflow	30%	1.6	13.4	10.3

[1] Assumptions regarding lignocellulosic media included: dry bulk density of 20 lb./ft^3; 50% carbon content by weight with available carbon being approximately 50% of carbon content

[2] Factor of safety used was 1.3

[3] The longevity calculation is based on the liner water samples (essentially complete NO_x-N reduction). Our opinion is that for this system the majority of the effluent did not go through the lignocellulosic liner media; however the design could be modified to direct all effluent to the liner media, and the calculated longevity presented would be the result.

As discussed in Section 3, autotrophic denitrification with elemental sulfur can be represented with the following biochemical reaction (Batchelor and Lawrence, 1978; Smith, 2009a):

$$50\ S^0 + 49.9\ NO_3^- + 11\ CO_2 + 32.8\ H_2O \rightarrow 2.2\ C_5H_7O_2N + 50\ SO_4^- + 23.8\ N_2 + 50.1H^+ \quad \text{(Eq. 6-4)}$$

Based on this equation, for each gram of NO_3-N removed approximately 2.29 grams of sulfur are utilized and 6.87 grams of sulfate are generated. Sample ports were installed along the depth of the Stage 2 biofilters to enable longitudinal profiling of nitrogen species and other water quality parameters. Solute profiles of the Stage 2 sulfur-containing denitrification biofilters showed significant decline in NO_x-N concentration and increase in sulfate concentration at the entrance region (see Figure 6-7, 6 inches from inlet). During PNRS pilot work, the sulfate concentration in the biofilter did not increase substantially after NO_x-N (and presumably DO) were depleted. However, Figure 6-7 shows an increase in sulfate after NOx-N depletion which may be attributed to air entering the Stage 2 biofilter and increasing DO near the sulfur media for some of the systems (BHS-2 Day 436; BHS-3 Day 523 and BHS-5 Day 524).

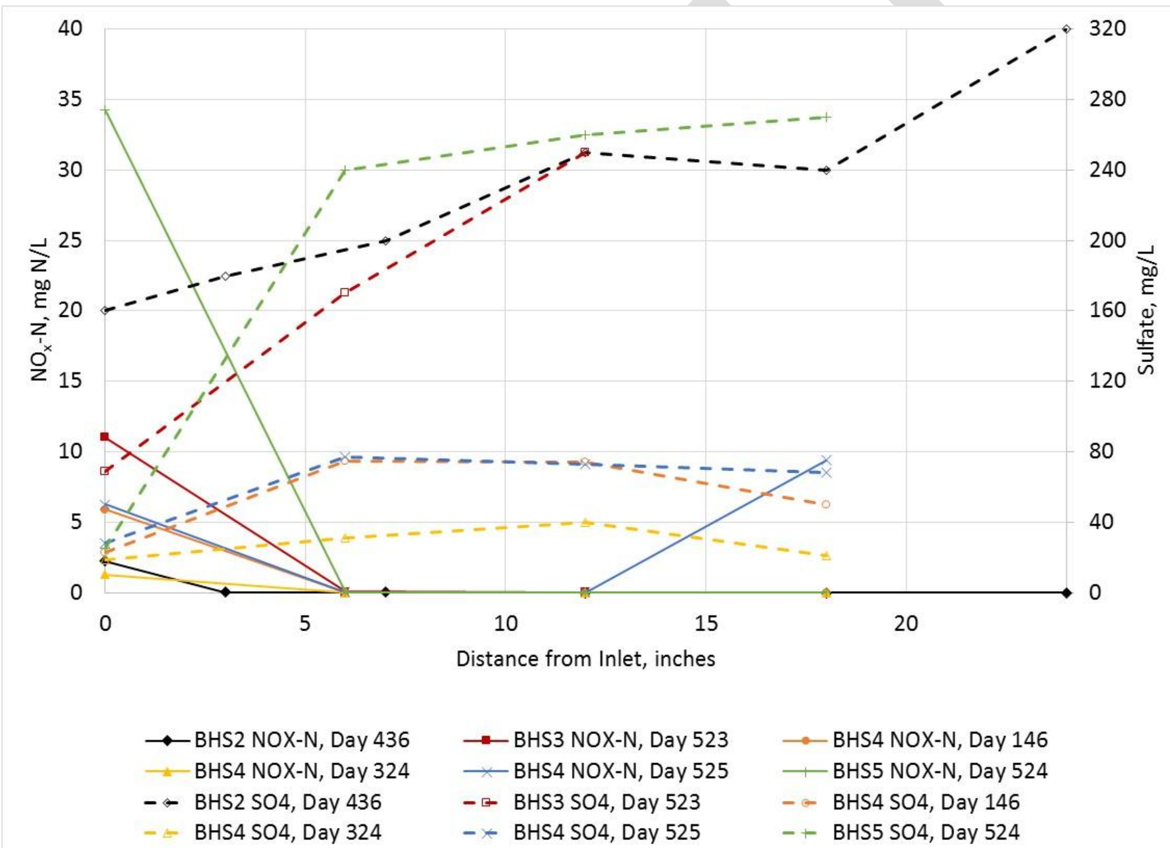


Figure 6-7: Solute Profiles for Stage 2 Sulfur Biofilters

The theoretical longevity of the sulfur media for each Stage 2 sulfur-containing biofilter was estimated using the total wastewater volume and mean NO_x-N concentrations applied, and stoichiometric relationships for sulfur based autotrophic denitrification (Eq. 6-4). The theoretical longevity of sulfur media are summarized in Table 6-9. Based on equation 6-4, the moles of sulfate produced is equivalent to the moles of NO_3-N reduced. Therefore, the solute profile results were used to determine a ratio of

mole sulfate produced to mole NO_3-N reduced for each of the treatment systems which includes the effect of dissolved oxygen. The mean 12-inch profile results indicate that the sulfate produced through the biofilter was 1.2 times greater than the mole of NO_3-N removed. Therefore, a factor of safety of 1.3 was applied to estimates of the longevity of the sulfur media. The estimated sulfur media longevity for the home systems under the study conditions is generally high (ranged from 44 to 400 years) which was determined using the lignocellulosic biofilter mean effluent NO_x-N as the applied concentration. As expected, the sulfur media longevity using the higher effluent NO_x-N in Stage 1 as the applied concentration to the sulfur biofilter decreases theoretical sulfur longevity to a range from 20 to 149 years.

Table 6-9: Sulfur Media Life

System	Percent reactive media	Volume of sulfur media, ft^3	Study Conditions			If lignocellulosic media is depleted		
			Mean influent NO_x-N, mg-N/L	Longevity[1], years	Longevity with factor of safety[2], years	Stage 1 mean effluent NO_x-N, mg-N/L	Longevity[1], years	Longevity with factor of safety[2], years
BHS-2	90%	32.4	0.02	N/A	N/A	16.7	194.0	149.2
BHS-3	90%	34.7	5.8	461.2	354.8	23.9	112.2	86.3
BHS-4	90%	24.3	3.2	348.5	268.0	33.6	27.2	20.9
BHS-5	90%	24.3	4.1	520.5	400.4	43.4	53.5	41.1
BHS-6	90%	18.0	24.9	57.2	44.0	42.3	34.0	26.1
PNRS II 15-SU-80	80%	0.9	23.8	204.7	157.5	N/A	N/A	N/A
PNRS II 16-SU-30	30%	0.4	23.8	75.5	58.1	N/A	N/A	N/A
PNRS II 8-SU-80	80%	4.2	37.9	72.5	55.8	N/A	N/A	N/A
PNRS II 6-SU-30	30%	1.6	41.2	25.4	19.6	N/A	N/A	N/A

[1]Assumptions regarding sulfur media included: dry bulk density of 76 lb./ft^3 and influent NOx concentrations from the preceding process. In systems where lignocellulosic denitrification preceded the sulfur, low influent NO_x concentrations resulted in very long estimates of longevity.

[2] Factor of safety used was 1.3

6.3 Overall System Performance

The objective of the FOSNRS Task B was to perform field demonstrations under actual operating conditions of prototype full scale PNRS to critically assess these nitrogen reduction technologies.

Therefore the primary water quality constituent for assessing overall system performance is total nitrogen (TN) removal efficiency. The overall system TN removal efficiencies and other water quality constituents of interest are summarized in Table 6-10. Other water quality constituents of interest include carbonaceous biochemical oxygen demand ($cBOD_5$), total suspended solids (TSS), and total phosphorus (TP). An overall analysis of PNRS performance is presented here for the first six prototype PNRS (BHS-1 through BHS-6).

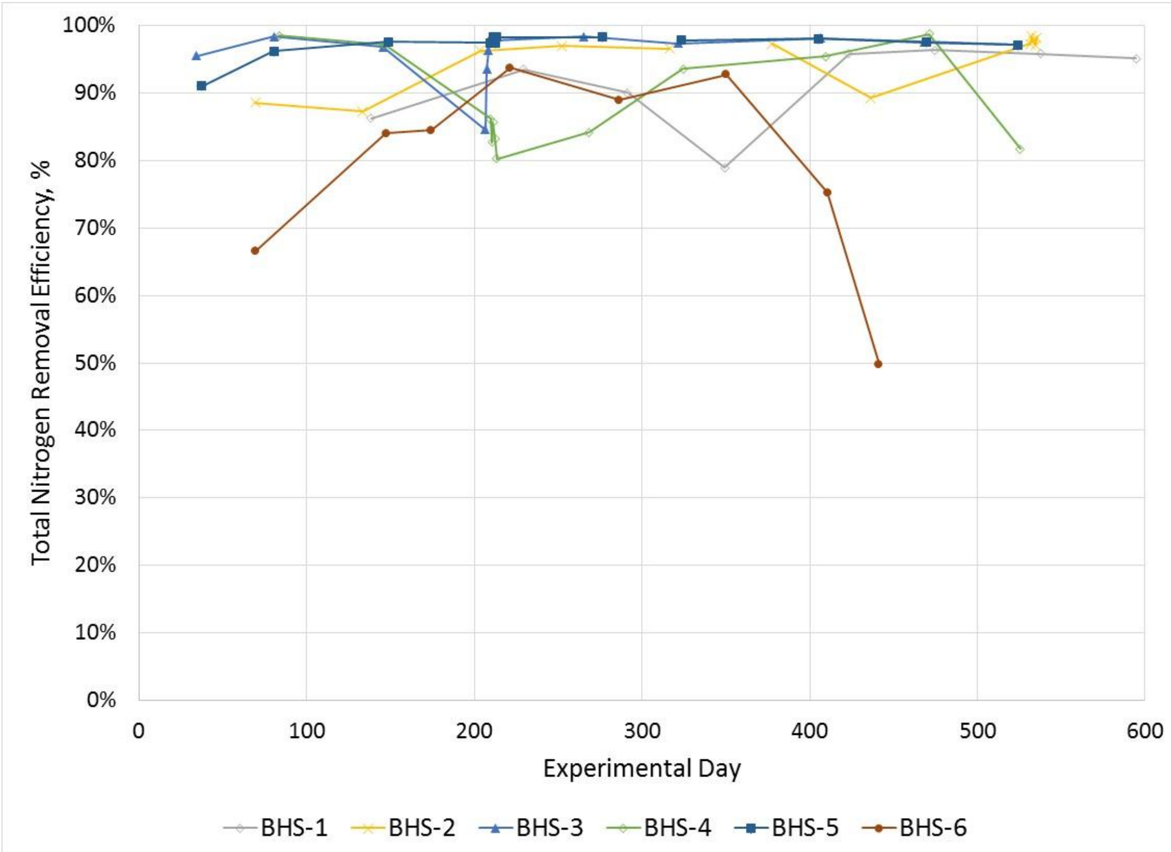
The prototype BHS-7 in-ground system was excluded from the overall performance analysis for reasons discussed previously. The total nitrogen removal efficiency time series for each system is presented in Figure 6-8 and mean total concentrations are presented in Figure 6-9.

Table 6-10: Overall Performance of Prototype PNRS Systems

System	Stage 1 Operation	Mean TN Removal Efficiency, %	Mean $cBOD_5$ Removal Efficiency, %	Mean TSS Removal Efficiency, %	Mean TP Removal Efficiency, %
BHS-1	R tank	91%	75%	93%	12%
BHS-2	R tank	93%	36%	76%	40%
	R internal	97%	78%	97%	51%
BHS-3	Drip SP	96%	80%	81%	96%
BHS-4	SP	89%	91%	93%	72%
BHS-5	Single pass	97%	87%	94%	85%
	R internal	98%	86%	90%	83%
BHS-6[1]	SP	81%	90%	87%	49%
BHS-7[2]	In-ground LP	65%[2]	87%[2]	88%[2]	90%[2]

[1] Clogging of internal drainage and distribution pipes within this system caused flooding of the Stage 1 media on several occasions, which hampered performance. Different construction materials for drains and a revised design would eliminate these problems.

[2] The reported values are calculated using the mean perimeter monitoring samples. Since it is believed that the hydraulics of the system as designed did not allow most flow to pass through the liner media, this reduction is most likely not attributed to lignocellulosic media, but to reductions in the Stage 1 media. A revised liner design could solve this problem.



[1] BHS-1 Stage 1 mode of operation was revised from R tank to R internal on experimental day 316
[2] BHS-5 Stage 1 mode of operation was revised from single pass to R internal on experimental day 290

Figure 6-8: Overall PNRS Total Nitrogen Removal Efficiency Time Series

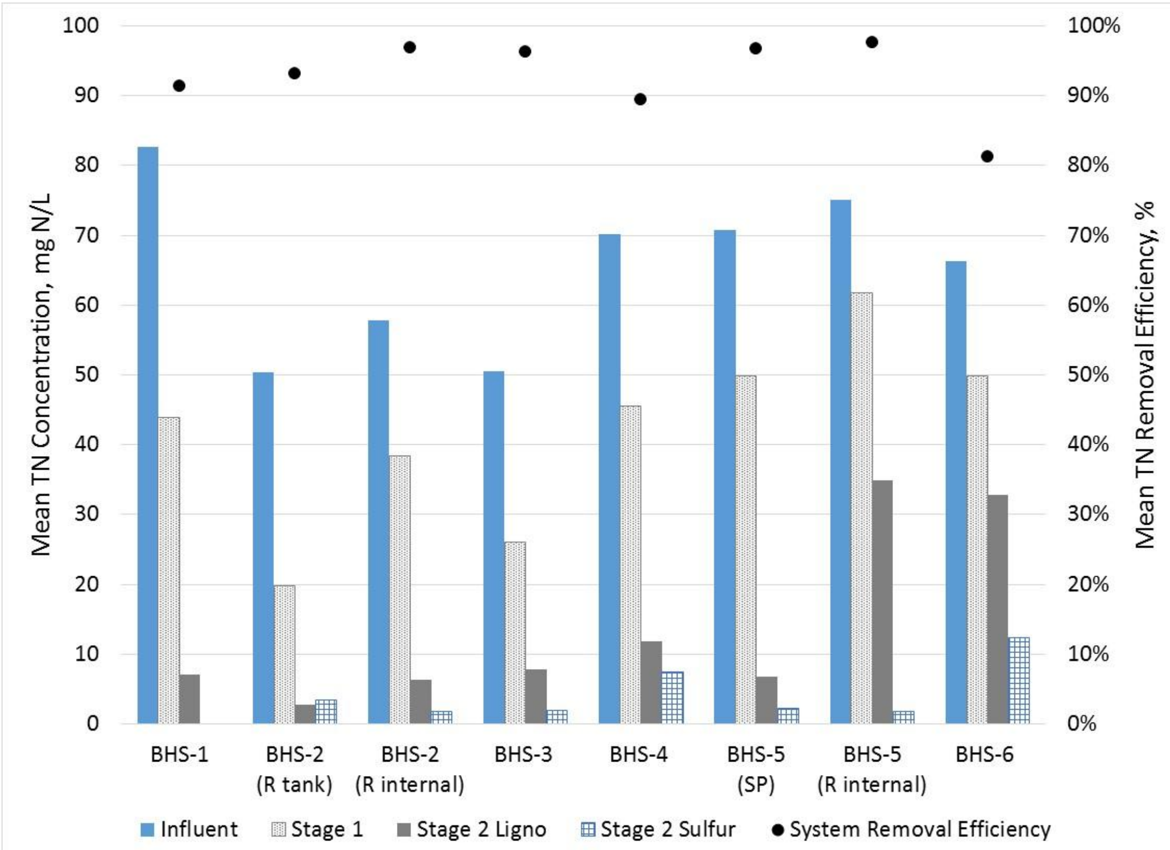


Figure 6-9: Overall PNRS Mean Total Nitrogen Removal Performance

A summary of the total nitrogen mass balance through each process of the treatment trains is summarized in Table 6-11. The BHS-2 mass balances for the two recirculation modes of operation tested illustrate greater Stage 1 biofilter total nitrogen reduction utilizing recirculation to a recirculation tank as compared to internal recirculation (60% as compared to 33%).

Table 6-11: Total Nitrogen Mass Balance for Prototype PNRS

System	Parameter, units	Influent (STE)	Stage 1 biofilter effluent	Stage 2 lignocellulosic effluent	Stage 2 sulfur effluent
BHS-1 (R tank)	g TN/day	35.03	18.85	3.01	NA
	g TN/day reduction from previous unit process	NA	16.18	15.84	NA
	% reduction from STE	NA	46.19	91.41	NA
BHS-2 (R tank)	g TN/day	20.86	8.18	1.16	1.45
	g TN/day reduction from previous unit process	NA	12.68	7.02	-0.29
	% reduction from STE	NA	60.79	94.46	93.07
BHS-2 (R internal)	g TN/day	24.59	16.38	2.68	0.77
	g TN/day reduction from previous unit process	NA	8.21	13.70	1.91
	% reduction from STE	NA	33.39	89.10	96.89
BHS-3 (in-ground)	g TN/day	27.66	14.24	4.29	1.05
	g TN/day reduction from previous unit process	NA	13.42	9.95	3.25
	% reduction from STE	NA	48.51	84.48	96.22
BHS-4 (SP)	g TN/day	78.82	51.23	13.28	8.35
	g TN/day reduction from previous unit process	NA	27.59	37.96	4.92
	% reduction from STE	NA	35.00	83.16	89.40
BHS-5 (SP)	g TN/day	30.58	21.54	2.92	0.98
	g TN/day reduction from previous unit process	NA	9.04	18.62	1.94
	% reduction from STE	NA	29.58	90.45	96.79

Table 6-11 (cont.): Total Nitrogen Mass Balance for Prototype PNRS

System	Parameter, units	Influent (STE)	Stage 1 biofilter effluent	Stage 2 lignocellulosic effluent	Stage 2 sulfur effluent
BHS-5 (R internal)	g TN/day	35.08	28.86	16.29	0.83
	g TN/day reduction from previous unit process	NA	6.22	12.57	15.46
	% reduction from STE	NA	17.73	53.55	97.63
BHS-6 (SP vertically stacked)	g TN/day	78.82	51.23	13.28	8.35
	g TN/day reduction from previous unit process	NA	27.59	37.96	4.92
	% reduction from STE	NA	35.00	83.16	89.40
BHS-7 (in-ground)	g TN/day	26.07	13.72	9.06[1]	NA
	g TN/day reduction from previous unit process	NA	12.35	4.66[1]	NA
	% reduction from STE	NA	47.37	65.25[1]	NA

[1]The reported value is the mean of the perimeter monitoring locations. Since it is believed that the hydraulics of the system did not allow flow into the through the liner media, this reduction is most likely not attributed to lignocellulosic media, but to TN reductions in the stage 1 media.

Other water quality constituents of interest include carbonaceous biochemical oxygen demand ($cBOD_5$), total suspended solids (TSS), and total phosphorus (TP). Figures 6-10 through 6-12 summarize respectively the mean $cBOD_5$, TSS, and TP concentrations for influent and effluents of each PNRS process. Figures 6-13 through 6-15 depict the mean fecal coliforms**,** sulfate and total alkalinity concentration for each process, respectively.

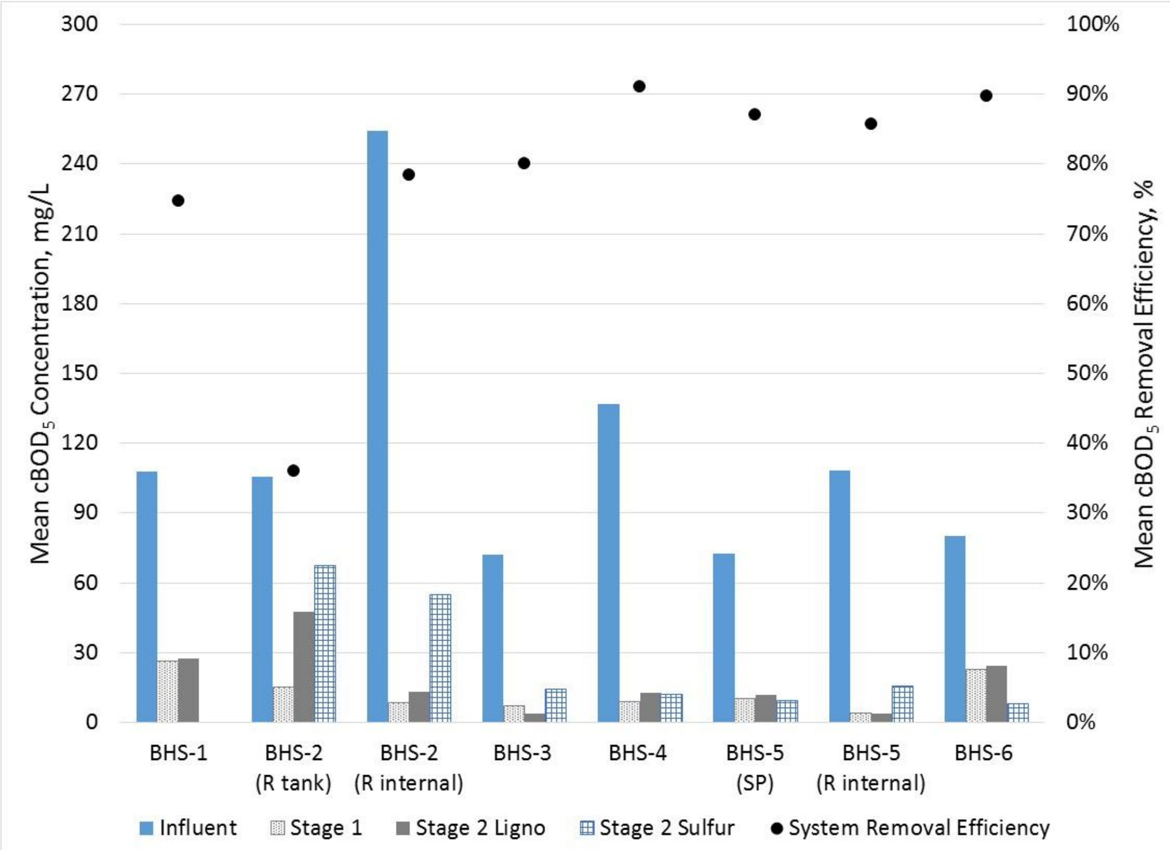
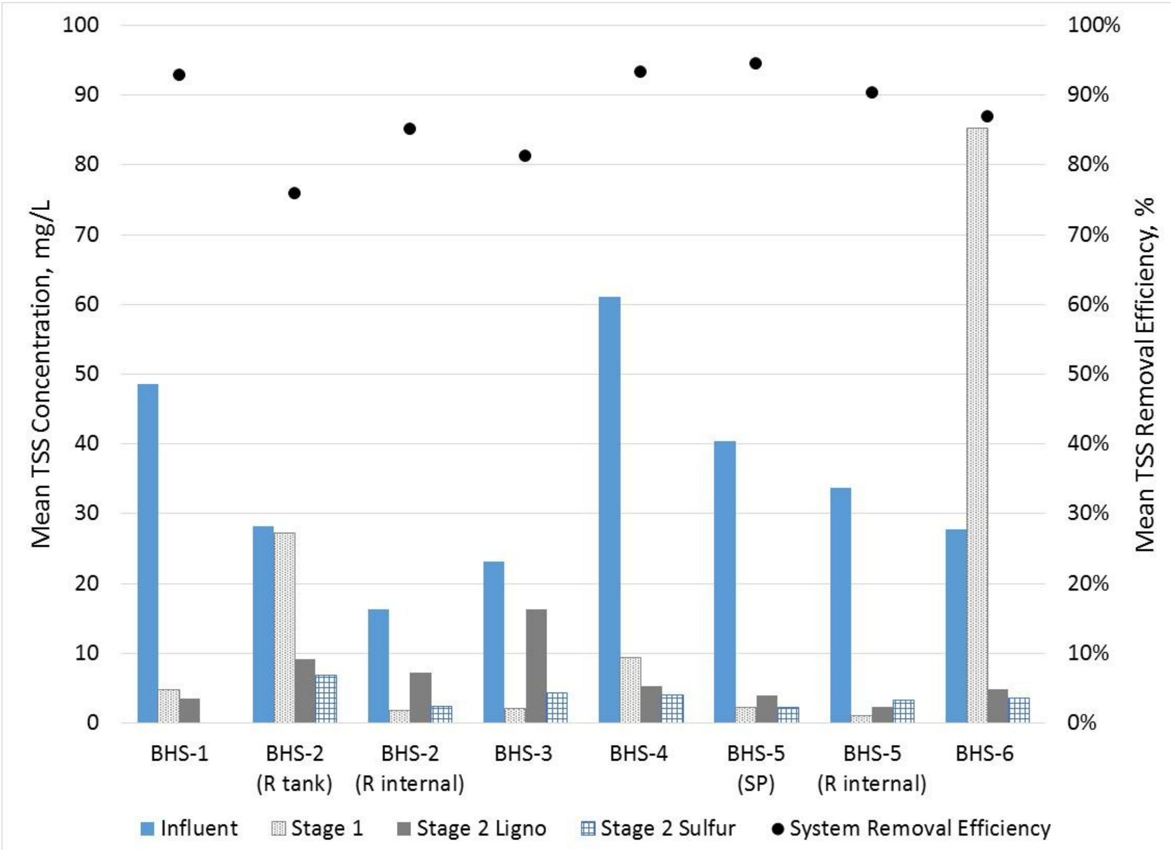


Figure 6-10: Overall Prototype Systems Mean $cBOD_5$ Removal Performance



[1] The BHS-6 Stage 1 samples from this vertically stacked system were taken from pan lysimeters placed at the expanded clay/lignocellulosic interface. It is suspected that pumping samples up from these pans included some fines from the expanded clay media, thus the increase in TSS over the influent value.

Figure 6-11: Overall Prototype Systems Mean TSS Removal Performance

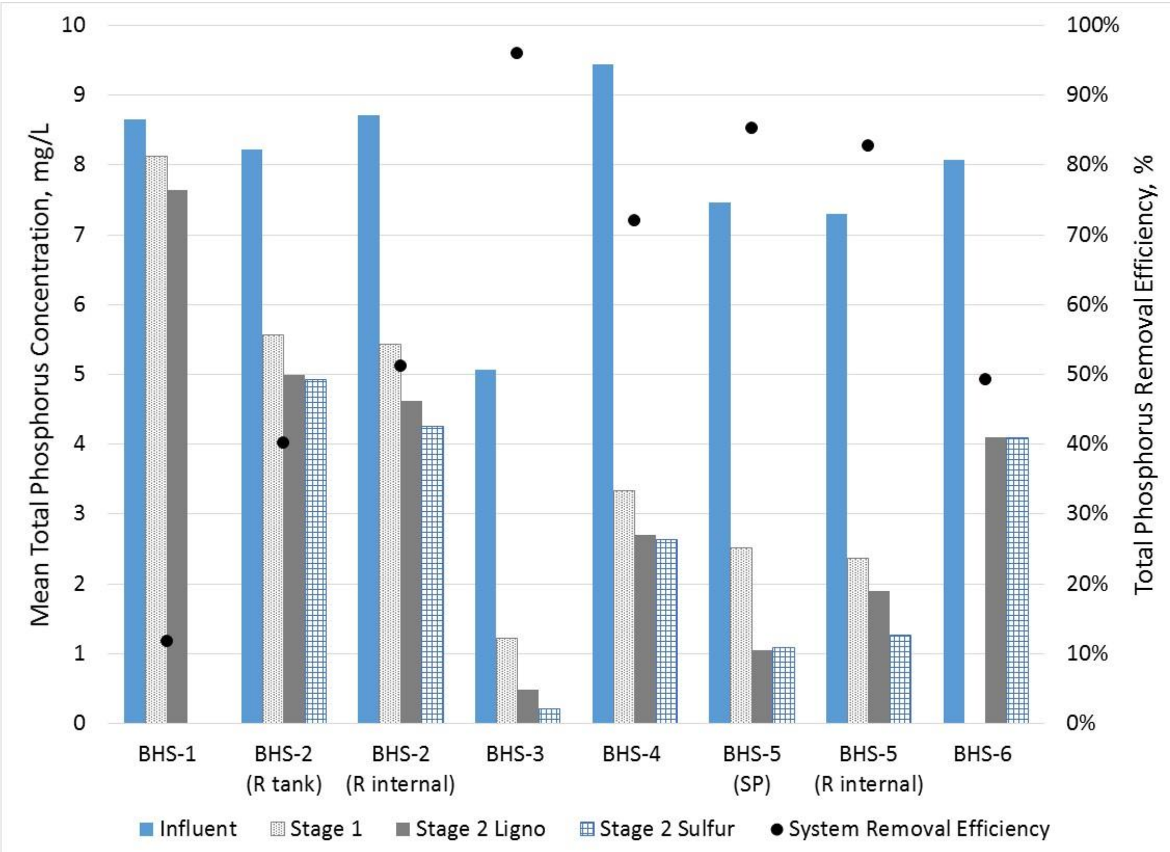


Figure 6-12: Overall Prototype Systems Mean Total Phosphorus Removal Performance

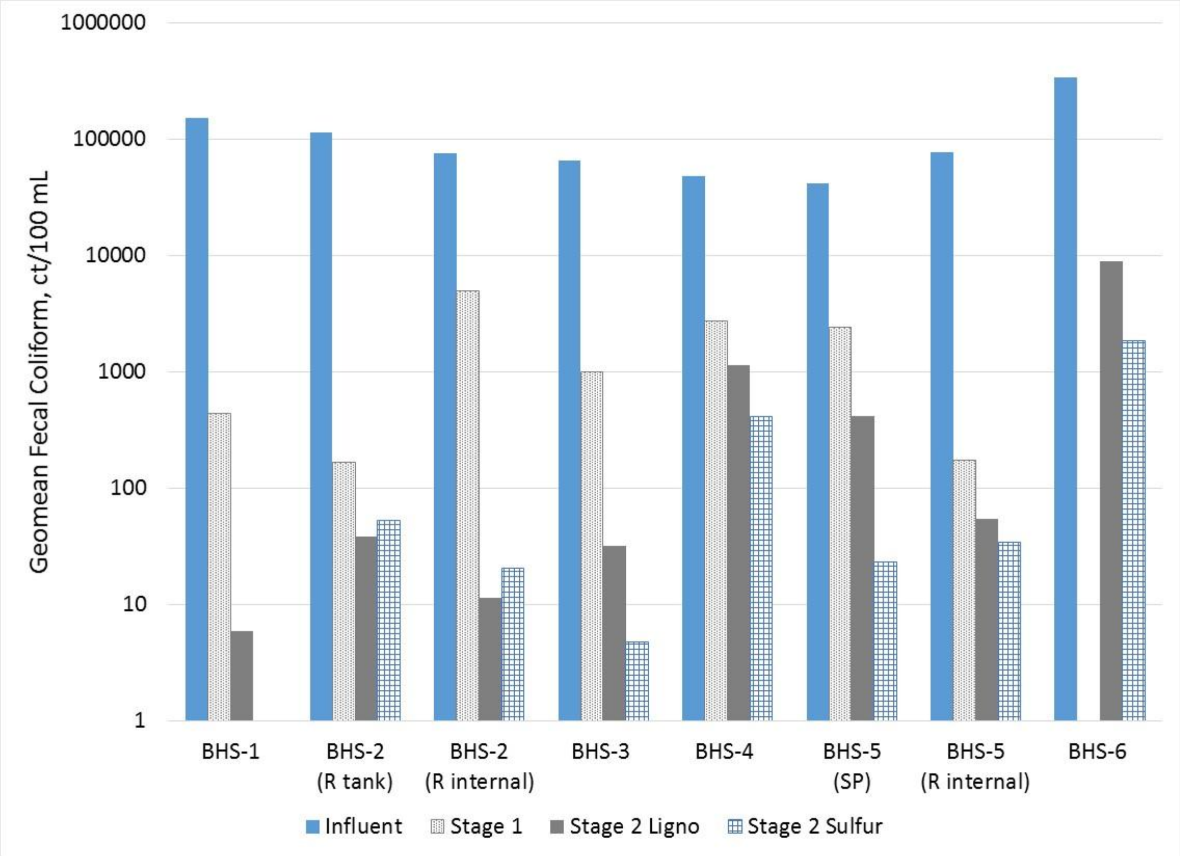


Figure 6-13: Overall Prototype Systems Geomean Fecal Coliform

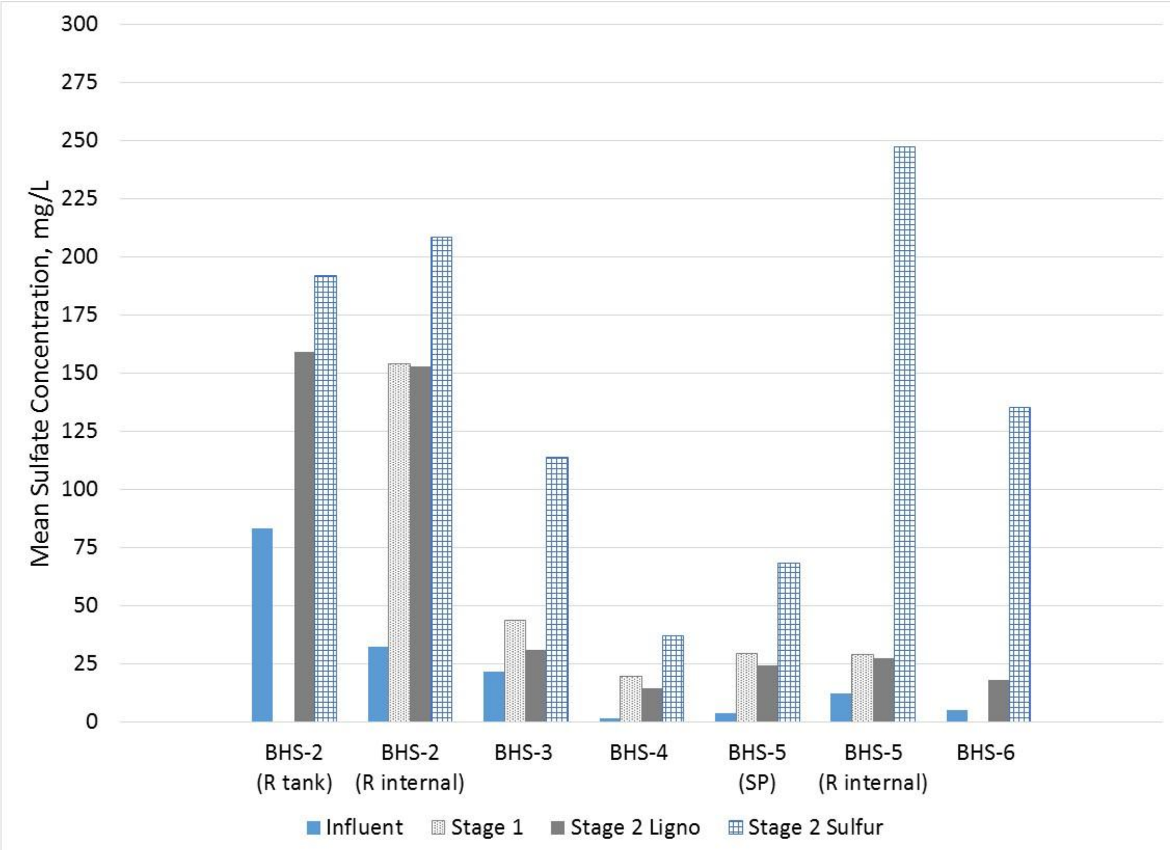


Figure 6-14: Overall Prototype Systems Mean Sulfate for Systems using Sulfur in Stage 2

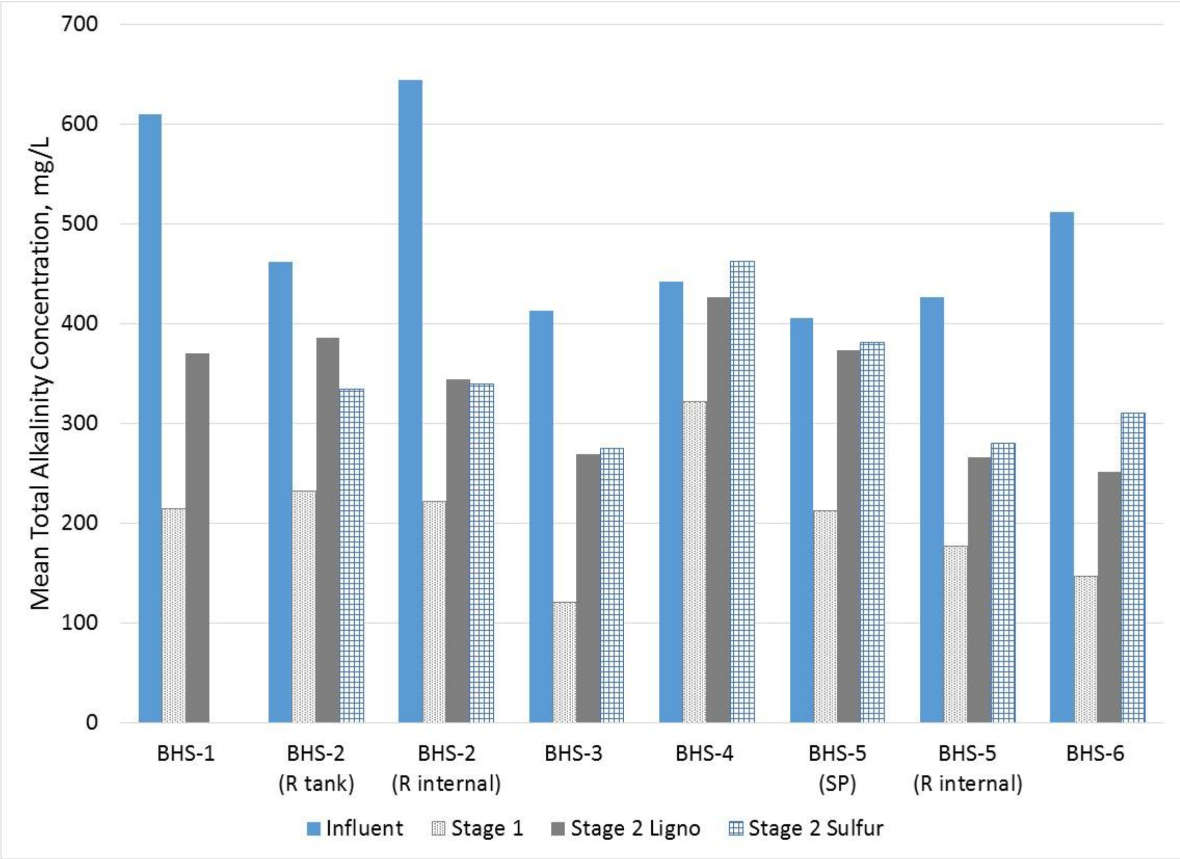


Figure 6-15: Overall Prototype Systems Mean Total Alkalinity

7 Life Cycle Cost Analysis

The LCCA tool developed by the project team to provide life cycle costs for the PNRS systems was applied to the seven prototype PNRS evaluated in FOSNRS Task B. This section summarizes the LCCA result for each PNRS installed and provides a comparison to the actual reported as-built installation costs.

7.1 Life Cycle Cost Analysis Tool (PNRS LCCA)

The PNRS LCCA (Life Cycle Cost Analysis Tool for Passive Nitrogen Removal Systems) is a computer spreadsheet tool developed by the FOSNRS Project Team to estimate life cycle costs for PNRS systems. The user specifies a desired nitrogen removal efficiency range, and PNRS LCCA provides selections for treatment processes that achieve the selected nitrogen removal range and estimates the costs to meet the selected nitrogen removal efficiency. PNRS LCCA incorporates all system costs over the entire project life, including construction, engineering fees, state and county permitting, system maintenance, media and pump replacement, water quality monitoring, and energy, as well as primary treatment solids removal (Hazen and Sawyer, 2015). PNRS LCCA applies discounting to future costs at a specified net interest rate to derive the Present Worth (PW) of a PNRS system, also termed Net Present Value (NPV). PNRS LCCA estimates Present Worth (PW) for both the entire treatment system (conventional OSTDS components + PNRS) and for the conventional OSTDS components alone (primary tank and STU). Although the default system sizing and cost data in PNRS LCCA are based on the OSTDS code and costs in Florida, the tool allows user specific inputs which allow its use elsewhere, with some limitations.

Three levels of nitrogen removal efficiency are available to choose from. Conventional treatment (primary + soil treatment and dispersal) can reduce total nitrogen by 25 to 35%, and is assigned a total nitrogen removal of 30% (Low Level) in PNRS LCCA. Stage 1 systems alone will nitrify wastewater and if recirculation is provided can provide 50 to 70% total nitrogen removal via pre-denitrification (Medium Level). Also, several of the simple in-ground system designs can achieve similar reductions in total nitrogen. A 60% TN removal rate is thus assigned for Medium Level systems. Adding Stage 2 biofilter systems will denitrify wastewater further and can increase total nitrogen removal to a High Level (95%) provided that they are preceded by highly effective nitrification and include a soil treatment unit (STU) for effluent dispersal. Additional details on the PNRS LCCA tool can be found in the LCCA Report and User Guidelines (Hazen and Sawyer, 2015).

PNRS LCCA provides detailed cost breakouts for each life cycle analysis in both tabular and graphical format. Estimates are provided for the mass of nitrogen removed by each system and the unit cost of nitrogen removed ($PW/lb. nitrogen).

7.2 Application of PNRS LCCA

PNRS LCCA was applied to the seven prototype PNRS studied in Task B, and listed in Table 7-1. These PNRS each included Stage 1 and Stage 2 biofiltration processes. All systems were designed for high level nitrogen removal (ca. 95% including STU), however not all systems met that level of treatment during the study. As discussed in previous sections, the BHS-6 and BHS-7 PNRS had hydraulic issues and/or construction material flaws. . The BHS-6 in-tank vertically stacked Stage 1 and Stage 2a tank water level fluctuated throughout the study period due to hydraulic blockages in the effluent collection and Stage 2 influent pipe. During monitoring events at the intended water level, the system performed at a high level of treatment. Therefore, this type of PNRS system was classified as High Level of treatment. The BHS-7 in-ground vertically stacked system hydraulics did not appear to allow much of the Stage 1 effluent flow into the liner media. With consideration to uncertainty in performance, this type of PNRS system was classified as Medium Level of treatment, although it is thought that an improved liner module design could correct the problem.

Table 7-1: Seven PNRS Evaluated

System ID	County	First Stage			Second Stage	
		Media	Enclosure	Hydraulics	Media	Enclosure
BHS-1	Wakulla	Aerocell™	tank	recirculation	Nitrex™	tank
BHS-2	Hillsborough	ex clay	tank	recirculation	dual media ligno-sulfur	tank
BHS-3	Seminole	stacked sand/ligno	in-ground liner	single pass	sulfur	tank
BHS-4	Seminole	ex clay	tank	single pass	dual media ligno-sulfur	tank
BHS-5	Seminole	ex clay	tank	single pass & recirculation	dual media ligno-sulfur	tank
BHS-6	Wakulla	stacked ex clay/ligno	tank	single pass	sulfur	tank
BHS-7	Marion	stacked sand/ligno	in-ground liner	single pass	ligno	liner

The sources of input data to the LCCA analysis included:

- Cost data from installation reports for each prototype PNRS
- Cost estimates of onsite contractors familiar with onsite system installation procedures and costs
- Florida Department of Health and counties permitting fee structures
- Electrical rates from Florida utilities
- Service Provider costs for inspection and maintenance visits and water quality monitoring

To provide a uniform basis for comparison of results, several inputs to PNRS LCCA were kept the same for all systems. These included:

- Project life of 30 years
- Net interest rate of 2.0%
- Two inspection and maintenance visits per year
- One water quality monitoring event per year of equal cost
- Primary treatment system solids removal every five years
- Stage 2 media replacement every 15 years
- Pump replacement every ten years

A brief summary of PNRS LCCA application for each prototype PNRS evaluated is included here. The default costs imbedded within PNRS LCCA were used without adjustment for four systems, while user override cost adjustments were applied for BHS-1, BHS-4 and BHS-6 as noted below.

- **BHS-1** Stage 1 was a commercial proprietary Stage 1 system (Aerocell™) followed by a commercial proprietary Stage 2 system (Nitrex™). Although individual components were proprietary, the packaged system was considered prototype as it was the first such system installed under a "passive nitrogen reduction" definition. Installed cost of the Stage 1 system is taken directly from cost documentation supplied by the vendor. An engineer design cost of $700 was entered into PNRS LCCA, which when added to the imbedded engineer design cost of $1,000 for PNRS systems equaled the vendor cost of $1,700 for engineer design plus as-built engineering design. Electricity use was the average daily electricity use measured for the home system scaled up to 300 gpd from measured mean flowrate. Cost estimates for Stage 2 were based on those for lignocellulosic Stage 2 biofilters embedded in the PNRS LCCA. User override costs were entered for conventional system pump and conventional system energy cost.

- **BHS-2** Stage 1 and 2 were prototype PNRS systems designed for the site. Costs included a new primary tank. All costs were PNRS LCCA imbedded costs.

- **BHS-3** Stage 1 and 2 were prototype PNRS systems designed for the site. Costs included a new primary tank and new drip dispersal system. All costs were PNRS LCCA imbedded costs.

- **BHS-4** Stage 1 and 2 were prototype PNRS systems designed for the site. Costs included a new STU. User override costs were specified for STU, PNRS tankage and media.

- **BHS-5** Stage 1 and 2 were prototype PNRS systems designed for the site. An existing primary tank and STU was present, so no conventional system costs were incurred. All costs were PNRS LCCA imbedded costs.

- **BHS-6** Stage 1 and 2 were prototype PNRS systems designed for the site. No conventional system costs incurred. User override costs were specified for PNRS tankage, media, pump and control panel, and contractor fee.

- **BHS-7** Stage 1 and 2 were prototype PNRS systems designed for the site. No conventional system costs were incurred. All costs were PNRS LCCA imbedded costs.

7.3 PNRS LCCA Results

Detailed life cycle cost output reports generated by PNRS LCCA for each of the evaluated prototype PNRS are presented in Tables 7-2 through 7-8. PNRS LCCA cost estimates for the total systems (including PNRS and conventional treatment components) are summarized in Table 7-9. Also shown are as-built construction costs estimated from the Task B full scale system installation reports. Adjustments were made to the full scale costs to reflect treatment system construction costs only, e.g. costs for permitting, experimental monitoring equipment, and other non-construction costs were removed. PNRS LCCA construction cost estimates for PNRS treatment components only are listed in Table 7-10.

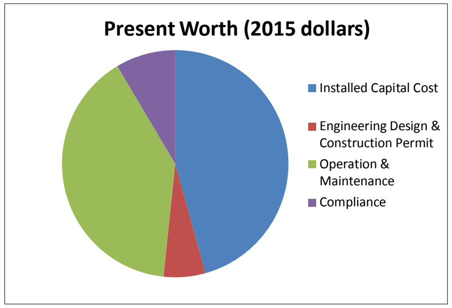
.

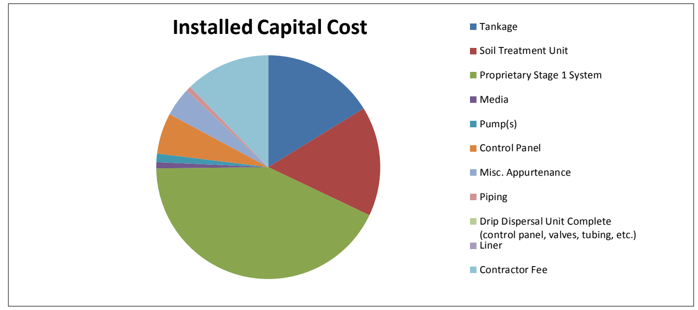
Table 7-2: PNRS LCCA results output for BHS-1 PNRS

PNRS LCCA: Life Cycle Cost Analysis Tool for Passive Nitrogen Reduction Systems
LCCA Identification: BHS-1

Worksheet
1. LCCA Structure
2. Table of LCCA Worksheets
3. WW Quantity & System Parameters
4. PNRS Process Selection
5. Baseline Design & Cost
6. Baseline Design Cost Summary
7. User Override Costs
8. LCCA Conventional
9. LCCA Total System
10. Design Data
11. Example LCCAs

9. LCCA Total System





Conventional System Summary

No. of Bedrooms	3
Building area, square feet	2200
Depth to seasonal high water table (inches)	32
New OSTDS installation or retrofit of existing system	retrofit
Design wastewater flow, gallon/day	300

No user override Conventional costs have been specified

PNRS System Summary

PNRS System	26
Stage 1: PNRS or proprietary	proprietary
PNRS Stage(s)	Stage 2 only
Stage 1 in-tank or in-ground	0
Stage 1 single pass or recirculation	0
Stage 1 media type	0
Ligno disposition	Tank
Stage 2 media type	Ligno only
Construction Complexity	Moderate
Level of nitrogen removal efficiency provided by system	High

No user override PNRS costs have been specified

Life Cycle Cost Calculations

Project Life (PL), years	30
Interest Rate (IR), %	2.000
Primary tank pump out interval (TI), years	5.0
Pump out analysis life (PL), years	25.0
Stage 2 media replacement interval (MI), years	15.0
Stage 2 media cost analysis life (ML), years	15.0
Equipment replacement interval (EI), years	10.0
Equipment replacement analysis life (EL), years	20.0
Compound Interest Factors	
P/A PL/IR	22.396
A/P PL/IR	0.04465
A/F TI	0.19216
P/A PL	19.523
A/F MI	0.05783
P/A ML	12.849
A/F EI	0.09133
P/A EL	16.351
Nitrogen Removal	
Mass loading/year, lbs.	27.0
Removal efficiency, %	95.0
Mass removal/year, lbs.	25.66

Life Cycle Cost

Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Total Life Cycle Cost
Conventional System Installation			
Primary treatment tank	1,400.00	62.51	3.1
Pump tank	600.00	26.79	1.3
Conventional system pump	0.00	0.00	0.0
Soil treatment unit	3,225.00	144.00	7.2
Subtotal Conventional	5,225.00	233.30	11.7
Proprietary Stage 1 system	8,700.00	388.45	19.5
PNRS Installation			
Tankage	1,300.00	58.04	2.9
Media	182.54	8.15	0.4
PNRS Pump	250.00	11.16	0.6
Control Panel	1,200.00	53.58	2.7
Piping	144.80	6.47	0.3
Misc. Appurtenance	846.50	37.80	1.9
Stage 1 Drip Dispersal System Complete (control panel, valves, tubing, etc.)	0.00	0.00	0.0
Liner	0.00	0.00	0.0
Contractor Fee	2,500.00	111.62	5.6
Subtotal	6,423.84	286.82	14.4
Total System Installation	20,348.84	908.57	45.7
Engineering Design & Construction Permit			
Construction permit	955.00	42.64	2.1
Engineering design fees	1,700.00	75.90	3.8
Operation and Maintenance			
Annual energy cost	8,063.12	360.02	18.1
Annual inspection & maintenance	7,838.76	350.00	17.6
Primary tank pump out	937.90	41.88	2.1
Stage 2 media replacement	135.63	6.06	0.3
Equipment replacement	746.66	33.34	1.7
Subtotal	17,722.07	791.29	39.8
Compliance			
Operating permit fee	1,119.82	50.00	2.5
Water quality monitoring	2,687.57	120.00	6.0
Subtotal	3,807.40	170.00	8.5
Total	44,533.30	1,988.41	100.00

Installed Capital Cost

Installation Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Installation Cost
Tankage	3,300.00	147.34	16.2
Soil Treatment Unit	3,225.00	144.00	15.8
Proprietary Stage 1 System	8,700.00	388.45	42.8
Media	182.54	8.15	0.9
Pump(s)	250.00	11.16	1.2
Control Panel	1,200.00	53.58	5.9
Misc. Appurtenance	846.50	37.80	4.2
Piping	144.80	6.47	0.7
Drip Dispersal Unit Complete (control panel, valves, tubing, etc.)	0.00	0.00	0.0
Liner	0.00	0.00	0.0
Contractor Fee	2,500.00	111.62	12.3
Total System	20,348.84	908.57	100.0

Life Cycle Cost

Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Total Life Cycle Cost
Installed Capital Cost	20,348.84	908.57	45.7
Engineering Design & Construction Permit	2,655.00	118.55	6.0
Operation & Maintenance	17,722.07	791.29	39.8
Compliance	3,807.40	170.00	8.5
Total	44,533.30	1,988.41	100.0
$/lb nitrogen removed	57.84	77.48	

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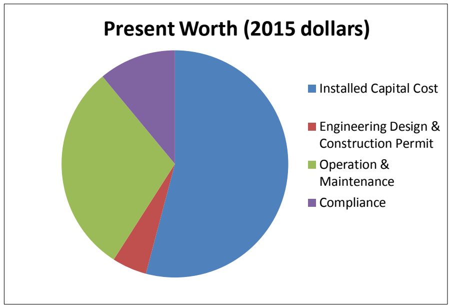
Table 7-3: PNRS LCCA results output for BHS-2 PNRS

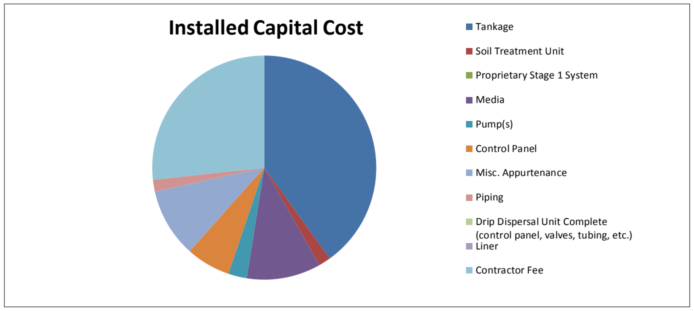
PNRS LCCA: Life Cycle Cost Analysis Tool for Passive Nitrogen Reduction Systems
LCCA Identification: BHS-2

Worksheet

1. LCCA Structure
2. Table of LCCA Worksheets
3. WW Quantity & System Parameters
4. PNRS Process Selection
5. Baseline Design & Cost
6. Baseline Design Cost Summary
7. User Override Costs
8. LCCA Conventional
9. LCCA Total System
10. Design Data
11. Example LCCAs

9. LCCA Total System





Conventional System Summary

No. of Bedrooms	3
Building area, square feet	2542
Depth to seasonal high water table (inches)	12
New OSTDS installation or retrofit of existing system	retrofit
Design wastewater flow, gallon/day	360

No user override Conventional costs have been specified

PNRS System Summary

PNRS System	9
Stage 1: PNRS or proprietary	PNRS
PNRS Stage(s)	Stage 1&2
Stage 1 in-tank or in-ground	Tank
Stage 1 single pass or recirculation	Recirculation
Stage 1 media type	Expanded Clay
Ligno disposition	Tank
Stage 2 media type	Dual: Ligno & sulfur
Construction Complexity	Moderate
Level of nitrogen removal efficiency provided by system	High

No user override PNRS costs have been specified

Life Cycle Cost Calculations

Project Life (PL), years	30
Interest Rate (IR), %	2.000
Primary tank pump out interval (TI), years	4.0
Pump out analysis life (PL), years	28.0
Stage 2 media replacement interval (MI), years	15.0
Stage 2 media cost analysis life (ML), years	15.0
Equipment replacement interval (EI), years	10.0
Equipment replacement analysis life (EL), years	20.0
Compound Interest Factors	
P/A PL/IR	22.396
A/P PL/IR	0.04465
A/F TI	0.24262
P/A PL	21.281
A/F MI	0.05783
P/A ML	12.849
A/F EI	0.09133
P/A EL	16.351
Nitrogen Removal	
Mass loading/year, lbs.	27.0
Removal efficiency, %	95.0
Mass removal/year, lbs.	25.66

Life Cycle Cost

Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Total Life Cycle Cost
Conventional System Installation			
Primary treatment tank	1,400.00	62.51	4.1
Pump tank	600.00	26.79	1.7
Conventional system pump	250.00	11.16	0.7
Soil treatment unit	326.00	14.56	0.9
Subtotal Conventional	2,576.00	115.02	7.5
Proprietary Stage 1 system	0.00	0.00	0.0
PNRS Installation			
Tankage	5,489.90	245.12	15.9
Media	2,000.07	89.30	5.8
PNRS Pump	250.00	11.16	0.7
Control Panel	1,200.00	53.58	3.5
Piping	318.56	14.22	0.9
Misc. Appurtenance	1,862.30	83.15	5.4
Stage 1 Drip Dispersal System Complete (control panel, valves, tubing, etc.)	0.00	0.00	0.0
Liner	0.00	0.00	0.0
Contractor Fee	5,000.00	223.25	14.5
Subtotal	16,120.83	719.79	46.7
Total System Installation	18,696.83	834.81	54.1
Engineering Design & Construction Permit			
Construction permit	710.00	31.70	2.1
Engineering design fees	1,000.00	44.65	2.9
Operation and Maintenance			
Annual energy cost	1,004.95	44.87	2.9
Annual inspection & maintenance	6,718.94	300.00	19.4
Primary tank pump out	1,290.84	57.64	3.7
Stage 2 media replacement	569.13	25.41	1.6
Equipment replacement	746.66	33.34	2.2
Subtotal	10,330.51	461.26	29.9
Compliance			
Operating permit fee	1,119.82	50.00	3.2
Water quality monitoring	2,687.57	120.00	7.8
Subtotal	3,807.40	170.00	11.0
Total	34,544.74	1,542.42	100.00

Installed Capital Cost

Installation Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Installation Cost
Tankage	7,489.90	334.42	40.1
Soil Treatment Unit	326.00	14.56	1.7
Proprietary Stage 1 System	0.00	0.00	0.0
Media	2,000.07	89.30	10.7
Pump(s)	500.00	22.32	2.7
Control Panel	1,200.00	53.58	6.4
Misc. Appurtenance	1,862.30	83.15	10.0
Piping	318.56	14.22	1.7
Drip Dispersal Unit Complete (control panel, valves, tubing, etc.)	0.00	0.00	0.0
Liner	0.00	0.00	0.0
Contractor Fee	5,000.00	223.25	26.7
Total System	18,696.83	834.81	100.0

Life Cycle Cost

Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Total Life Cycle Cost
Installed Capital Cost	18,696.83	834.81	54.1
Engineering Design & Construction Permit	1,710.00	76.35	5.0
Operation & Maintenance	10,330.51	461.26	29.9
Compliance	3,807.40	170.00	11.0
Total	34,544.74	1,542.42	100.0
$/lb nitrogen removed	44.87	60.10	

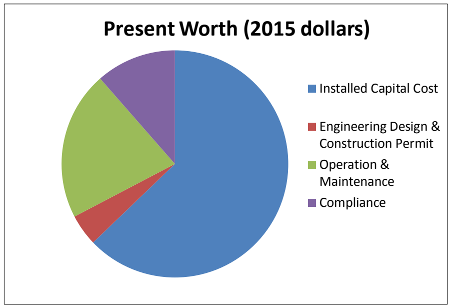
Developed by: HAZEN AND SAWYER Environmental Engineers & Scientists and AET Applied Environmental Technology

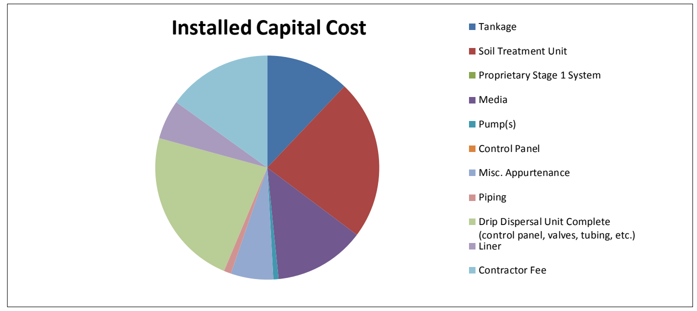
Table 7-4: PNRS LCCA results output for BHS-3 PNRS

PNRS LCCA: Life Cycle Cost Analysis Tool for Passive Nitrogen Reduction Systems
LCCA Identification: BHS-3

Worksheet
1. LCCA Structure
2. Table of LCCA Worksheets
3. WW Quantity & System Parameters
4. PNRS Process Selection
5. Baseline Design & Cost
6. Baseline Design Cost Summary
7. User Override Costs
8. LCCA Conventional
9. LCCA Total System
10. Design Data
11. Example LCCAs

9. LCCA Total System





Conventional System Summary	
No. of Bedrooms	5
Building area, square feet	4940
Depth to seasonal high water table (inches)	12
New OSTDS installation or retrofit of existing system	retrofit
Design wastewater flow, gallon/day	580

No user override Conventional costs have been specified

PNRS System Summary	
PNRS System	18
Stage 1: PNRS or proprietary	PNRS
PNRS Stage(s)	Stage 1&2
Stage 1 in-tank or in-ground	In-ground
Stage 1 single pass or recirculation	Single pass
Stage 1 media type	Native Sand
Ligno disposition	Underlying Stage 1 in-ground liner
Stage 2 media type	Dual: Ligno & sulfur
Construction Complexity	Moderate
Level of nitrogen removal efficiency provided by system	High

No user override PNRS costs have been specified

Life Cycle Cost Calculations	
Project Life (PL), years	30
Interest Rate (IR), %	2.000
Primary tank pump out interval (TI), years	5.0
Pump out analysis life (PL), years	25.0
Stage 2 media replacement interval (MI), years	15.0
Stage 2 media cost analysis life (ML), years	15.0
Equipment replacement interval (EI), years	10.0
Equipment replacement analysis life (EL), years	20.0
Compound Interest Factors	
P/A PL/IR	22.396
A/P PL/IR	0.04465
A/F TI	0.19216
P/A PL	19.523
A/F MI	0.05783
P/A ML	12.849
A/F EI	0.09133
P/A EL	16.351
Nitrogen Removal	
Mass loading/year, lbs.	45.0
Removal efficiency, %	95.0
Mass removal/year, lbs.	42.77

Life Cycle Cost

Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Total Life Cycle Cost
Conventional System Installation			
Primary treatment tank	2,108.97	94.17	4.0
Pump tank	700.00	31.25	1.3
Conventional system pump	250.00	11.16	0.5
Soil treatment unit	7,675.00	342.69	14.5
Subtotal Conventional	10,733.97	479.27	20.3
Proprietary Stage 1 system	0.00	0.00	0.0
PNRS Installation			
Tankage	1,200.00	53.58	2.3
Media	4,357.03	194.54	8.3
PNRS Pump	0.00	0.00	0.0
Control Panel	0.00	0.00	0.0
Piping	347.52	15.52	0.7
Misc. Appurtenance	2,031.60	90.71	3.9
Stage 1 Drip Dispersal System Complete (control panel, valves, tubing, etc.)	7,600.00	339.34	14.4
Liner	1,884.53	84.14	3.6
Contractor Fee	5,000.00	223.25	9.5
Subtotal	22,420.68	1,001.08	42.5
Total System Installation	33,154.65	1,480.35	62.8
Engineering Design & Construction Permit			
Construction permit	870.00	38.85	1.6
Engineering design fees	1,500.00	66.97	2.8
Operation and Maintenance			
Annual energy cost	391.43	17.48	0.7
Annual inspection & maintenance	7,838.76	350.00	14.9
Primary tank pump out	937.90	41.88	1.8
Stage 2 media replacement	1,276.99	57.02	2.4
Equipment replacement	746.66	33.34	1.4
Subtotal	11,191.73	499.71	21.2
Compliance			
Operating permit fee	3,359.47	150.00	6.4
Water quality monitoring	2,687.57	120.00	5.1
Subtotal	6,047.04	270.00	11.5
Total	52,763.43	2,355.88	100.00

Installed Capital Cost

Installation Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Installation Cost
Tankage	4,008.97	179.00	12.1
Soil Treatment Unit	7,675.00	342.69	23.1
Proprietary Stage 1 System	0.00	0.00	0.0
Media	4,357.03	194.54	13.1
Pump(s)	250.00	11.16	0.8
Control Panel	0.00	0.00	0.0
Misc. Appurtenance	2,031.60	90.71	6.1
Piping	347.52	15.52	1.0
Drip Dispersal Unit Complete (control panel, valves, tubing, etc.)	7,600.00	339.34	22.9
Liner	1,884.53	84.14	5.7
Contractor Fee	5,000.00	223.25	15.1
Total System	33,154.65	1,480.35	100.0

Life Cycle Cost

Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Total Life Cycle Cost
Installed Capital Cost	33,154.65	1,480.35	62.8
Engineering Design & Construction Permit	2,370.00	105.82	4.5
Operation & Maintenance	11,191.73	499.71	21.2
Compliance	6,047.04	270.00	11.5
Total	52,763.43	2,355.88	100.0
$/lb nitrogen removed	41.12	55.08	

Developed by: HAZEN AND SAWYER Environmental Engineers & Scientists and AET

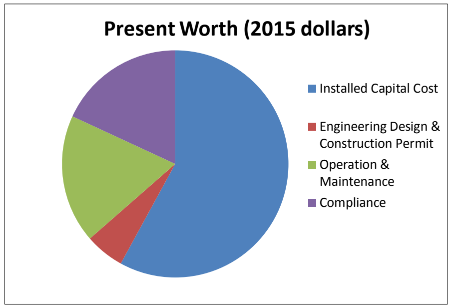
Table 7-5: PNRS LCCA results output for BHS-4 PNRS

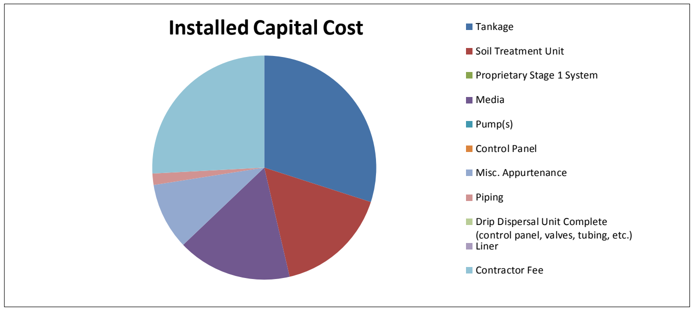
PNRS LCCA: Life Cycle Cost Analysis Tool for Passive Nitrogen Reduction Systems
LCCA Identification: BHS-4

Worksheet

1. LCCA Structure
2. Table of LCCA Worksheets
3. WW Quantity & System Parameters
4. PNRS Process Selection
5. Baseline Design & Cost
6. Baseline Design Cost Summary
7. User Override Costs
8. LCCA Conventional
9. LCCA Total System
10. Design Data
11. Example LCCAs

9. LCCA Total System





Conventional System Summary

No. of Bedrooms	4
Building area, square feet	2517
Depth to seasonal high water table (inches)	60
New OSTDS installation or retrofit of existing system	retrofit
Design wastewater flow, gallon/day	400

User override Conventional costs have been specified

PNRS System Summary

PNRS System	3
Stage 1: PNRS or proprietary	PNRS
PNRS Stage(s)	Stage 1&2
Stage 1 in-tank or in-ground	Tank
Stage 1 single pass or recirculation	Single pass
Stage 1 media type	Expanded Clay
Ligno disposition	Tank
Stage 2 media type	Dual: Ligno & sulfur
Construction Complexity	Moderate
Level of nitrogen removal efficiency provided by system	High

User override PNRS costs have been specified

Life Cycle Cost Calculations

Project Life (PL), years	30
Interest Rate (IR), %	2.000
Primary tank pump out interval (TI), years	5.0
Pump out analysis life (PL), years	25.0
Stage 2 media replacement interval (MI), years	15.0
Stage 2 media cost analysis life (ML), years	15.0
Equipment replacement interval (EI), years	10.0
Equipment replacement analysis life (EL), years	20.0
Compound Interest Factors	
P/A PL/IR	22.396
A/P PL/IR	0.04465
A/F TI	0.19216
P/A PL	19.523
A/F MI	0.05783
P/A ML	12.849
A/F EI	0.09133
P/A EL	16.351
Nitrogen Removal	
Mass loading/year, lbs.	36.0
Removal efficiency, %	95.0
Mass removal/year, lbs.	34.22

Life Cycle Cost

Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Total Life Cycle Cost
Conventional System Installation			
Primary treatment tank	0.00	0.00	0.0
Pump tank	0.00	0.00	0.0
Conventional system pump	0.00	0.00	0.0
Soil treatment unit	3,170.75	141.57	9.5
Subtotal Conventional	3,170.75	141.57	9.5
Proprietary Stage 1 system	0.00	0.00	0.0
PNRS Installation			
Tankage	5,800.15	258.98	17.4
Media	3,198.73	142.82	9.6
PNRS Pump	0.00	0.00	0.0
Control Panel	0.00	0.00	0.0
Piping	318.56	14.22	1.0
Misc. Appurtenance	1,862.30	83.15	5.6
Stage 1 Drip Dispersal System Complete (control panel, valves, tubing, etc.)	0.00	0.00	0.0
Liner	0.00	0.00	0.0
Contractor Fee	5,000.00	223.25	15.0
Subtotal	16,179.74	722.42	48.5
Total System Installation	19,350.49	864.00	58.0
Engineering Design & Construction Permit			
Construction permit	870.00	38.85	2.6
Engineering design fees	1,000.00	44.65	3.0
Operation and Maintenance			
Annual energy cost	0.00	0.00	0.0
Annual inspection & maintenance	4,479.29	200.00	13.4
Primary tank pump out	937.90	41.88	2.8
Stage 2 media replacement	688.99	30.76	2.1
Equipment replacement	0.00	0.00	0.0
Subtotal	6,106.18	272.64	18.3
Compliance			
Operating permit fee	3,359.47	150.00	10.1
Water quality monitoring	2,687.57	120.00	8.1
Subtotal	6,047.04	270.00	18.1
Total	33,373.71	1,490.13	100.00

Installed Capital Cost

Installation Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Installation Cost
Tankage	5,800.15	258.98	30.0
Soil Treatment Unit	3,170.75	141.57	16.4
Proprietary Stage 1 System	0.00	0.00	0.0
Media	3,198.73	142.82	16.5
Pump(s)	0.00	0.00	0.0
Control Panel	0.00	0.00	0.0
Misc. Appurtenance	1,862.30	83.15	9.6
Piping	318.56	14.22	1.6
Drip Dispersal Unit Complete (control panel, valves, tubing, etc.)	0.00	0.00	0.0
Liner	0.00	0.00	0.0
Contractor Fee	5,000.00	223.25	25.8
Total System	19,350.49	864.00	100.0

Life Cycle Cost

Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Total Life Cycle Cost
Installed Capital Cost	19,350.49	864.00	58.0
Engineering Design & Construction Permit	1,870.00	83.50	5.6
Operation & Maintenance	6,106.18	272.64	18.3
Compliance	6,047.04	270.00	18.1
Total	33,373.71	1,490.13	100.0
$/lb nitrogen removed	32.51	43.55	

Developed by: HAZEN AND SAWYER Environmental Engineers & Scientists **and** AET

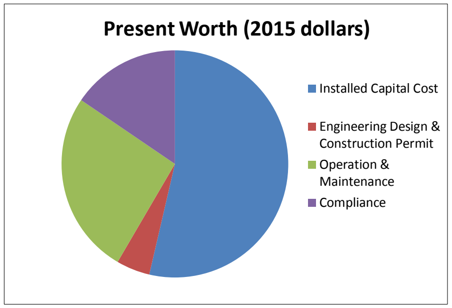
Table 7-6: PNRS LCCA results output for BHS-5 PNRS

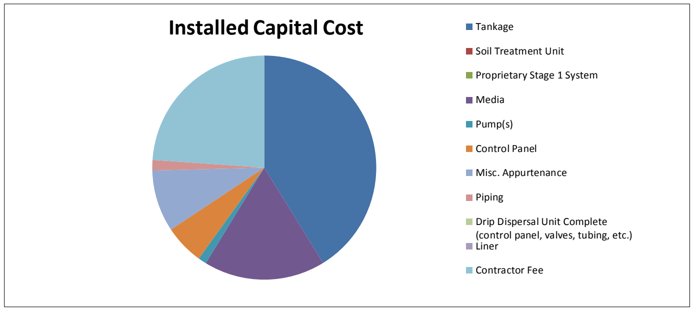
PNRS LCCA: Life Cycle Cost Analysis Tool for Passive Nitrogen Reduction Systems
LCCA Identification: BHS-5

Worksheet

1. LCCA Structure
2. Table of LCCA Worksheets
3. WW Quantity & System Parameters
4. PNRS Process Selection
5. Baseline Design & Cost
6. Baseline Design Cost Summary
7. User Override Costs
8. LCCA Conventional
9. LCCA Total System
10. Design Data
11. Example LCCAs

9. LCCA Total System





Conventional System Summary

No. of Bedrooms	5
Building area, square feet	3315
Depth to seasonal high water table (inches)	72
New OSTDS installation or retrofit of existing system	retrofit
Design wastewater flow, gallon/day	460

No user override Conventional costs have been specified

PNRS System Summary

PNRS System	9
Stage 1: PNRS or proprietary	PNRS
PNRS Stage(s)	Stage 1&2
Stage 1 in-tank or in-ground	Tank
Stage 1 single pass or recirculation	Recirculation
Stage 1 media type	Expanded Clay
Ligno disposition	Tank
Stage 2 media type	Dual: Ligno & sulfur
Construction Complexity	Moderate
Level of nitrogen removal efficiency provided by system	High

No user override PNRS costs have been specified

Life Cycle Cost Calculations

Project Life (PL), years	30
Interest Rate (IR), %	2.000
Primary tank pump out interval (TI), years	5.0
Pump out analysis life (PL), years	25.0
Stage 2 media replacement interval (MI), years	15.0
Stage 2 media cost analysis life (ML), years	15.0
Equipment replacement interval (EI), years	10.0
Equipment replacement analysis life (EL), years	20.0
Compound Interest Factors	
P/A PL/IR	22.396
A/P PL/IR	0.04465
A/F TI	0.19216
P/A PL	19.523
A/F MI	0.05783
P/A ML	12.849
A/F EI	0.09133
P/A EL	16.351
Nitrogen Removal	
Mass loading/year, lbs.	45.0
Removal efficiency, %	95.0
Mass removal/year, lbs.	42.77

Life Cycle Cost

Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Total Life Cycle Cost
Conventional System Installation			
Primary treatment tank	0.00	0.00	0.0
Pump tank	0.00	0.00	0.0
Conventional system pump	0.00	0.00	0.0
Soil treatment unit	0.00	0.00	0.0
Subtotal Conventional	0.00	0.00	0.0
Proprietary Stage 1 system	0.00	0.00	0.0
PNRS Installation			
Tankage	8,618.58	384.82	22.1
Media	3,670.69	163.90	9.4
PNRS Pump	250.00	11.16	0.6
Control Panel	1,200.00	53.58	3.1
Piping	318.56	14.22	0.8
Misc. Appurtenance	1,862.30	83.15	4.8
Stage 1 Drip Dispersal System Complete (control panel, valves, tubing, etc.)	0.00	0.00	0.0
Liner	0.00	0.00	0.0
Contractor Fee	5,000.00	223.25	12.8
Subtotal	20,920.13	934.08	53.6
Total System Installation	20,920.13	934.08	53.6
Engineering Design & Construction Permit			
Construction permit	870.00	38.85	2.2
Engineering design fees	1,000.00	44.65	2.6
Operation and Maintenance			
Annual energy cost	1,241.77	55.44	3.2
Annual inspection & maintenance	6,718.94	300.00	17.2
Primary tank pump out	937.90	41.88	2.4
Stage 2 media replacement	893.48	39.89	2.3
Equipment replacement	373.33	16.67	1.0
Subtotal	10,165.42	453.89	26.1
Compliance			
Operating permit fee	3,359.47	150.00	8.6
Water quality monitoring	2,687.57	120.00	6.9
Subtotal	6,047.04	270.00	15.5
Total	39,002.60	1,741.46	100.00

Installed Capital Cost

Installation Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Installation Cost
Tankage	8,618.58	384.82	41.2
Soil Treatment Unit	0.00	0.00	0.0
Proprietary Stage 1 System	0.00	0.00	0.0
Media	3,670.69	163.90	17.5
Pump(s)	250.00	11.16	1.2
Control Panel	1,200.00	53.58	5.7
Misc. Appurtenance	1,862.30	83.15	8.9
Piping	318.56	14.22	1.5
Drip Dispersal Unit Complete (control panel, valves, tubing, etc.)	0.00	0.00	0.0
Liner	0.00	0.00	0.0
Contractor Fee	5,000.00	223.25	23.9
Total System	20,920.13	934.08	100.0

Life Cycle Cost

Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Total Life Cycle Cost
Installed Capital Cost	20,920.13	934.08	53.6
Engineering Design & Construction Permit	1,870.00	83.50	4.8
Operation & Maintenance	10,165.42	453.89	26.1
Compliance	6,047.04	270.00	15.5
Total	39,002.60	1,741.46	100.0
$/lb nitrogen removed	30.40	40.72	

Developed by: HAZEN AND SAWYER Environmental Engineers & Scientists **and** AET Applied Environmental Technology

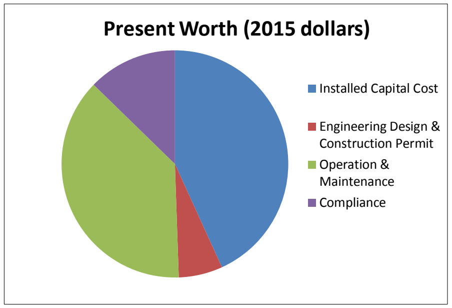
Table 7-7: PNRS LCCA results output for BHS-6 PNRS

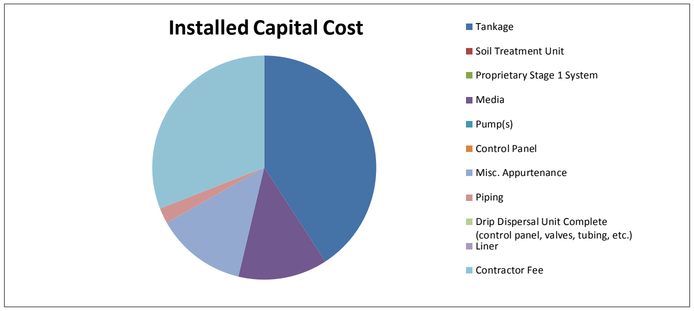
PNRS LCCA: Life Cycle Cost Analysis Tool for Passive Nitrogen Reduction Systems
LCCA Identification: BHS-6

Worksheet

1. LCCA Structure
2. Table of LCCA Worksheets
3. WW Quantity & System Parameters
4. PNRS Process Selection
5. Baseline Design & Cost
6. Baseline Design Cost Summary
7. User Override Costs
8. LCCA Conventional
9. LCCA Total System
10. Design Data
11. Example LCCAs

9. LCCA Total System





Conventional System Summary

No. of Bedrooms	3
Building area, square feet	1200
Depth to seasonal high water table (inches)	32
New OSTDS installation or retrofit of existing system	retrofit
Design wastewater flow, gallon/day	300

No user override Conventional costs have been specified

PNRS System Summary

PNRS System	13
Stage 1: PNRS or proprietary	PNRS
PNRS Stage(s)	Stage 1&2
Stage 1 in-tank or in-ground	Tank
Stage 1 single pass or recirculation	Single pass
Stage 1 media type	Expanded Clay
Ligno disposition	Underlying Stage 1 in Tank
Stage 2 media type	Dual: Ligno & sulfur
Construction Complexity	Moderate
Level of nitrogen removal efficiency provided by system	High

User override PNRS costs have been specified

Life Cycle Cost Calculations

Project Life (PL), years	30
Interest Rate (IR), %	2.000
Primary tank pump out interval (TI), years	5.0
Pump out analysis life (PL), years	25.0
Stage 2 media replacement interval (MI), years	15.0
Stage 2 media cost analysis life (ML), years	15.0
Equipment replacement interval (EI), years	10.0
Equipment replacement analysis life (EL), years	20.0
Compound Interest Factors	
P/A PL/IR	22.396
A/P PL/IR	0.04465
A/F TI	0.19216
P/A PL	19.523
A/F MI	0.05783
P/A ML	12.849
A/F EI	0.09133
P/A EL	16.351
Nitrogen Removal	
Mass loading/year, lbs.	27.0
Removal efficiency, %	95.0
Mass removal/year, lbs.	25.66

Life Cycle Cost

Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Total Life Cycle Cost
Conventional System Installation			
Primary treatment tank	0.00	0.00	0.0
Pump tank	0.00	0.00	0.0
Conventional system pump	0.00	0.00	0.0
Soil treatment unit	0.00	0.00	0.0
Subtotal Conventional	0.00	0.00	0.0
Proprietary Stage 1 system	0.00	0.00	0.0
PNRS Installation			
Tankage	5,276.68	235.60	17.6
Media	1,666.85	74.42	5.6
PNRS Pump	0.00	0.00	0.0
Control Panel	0.00	0.00	0.0
Piping	289.60	12.93	1.0
Misc. Appurtenance	1,693.00	75.59	5.7
Stage 1 Drip Dispersal System Complete (control panel, valves, tubing, etc.)	0.00	0.00	0.0
Liner	0.00	0.00	0.0
Contractor Fee	4,000.00	178.60	13.4
Subtotal	12,926.13	577.15	43.2
Total System Installation	12,926.13	577.15	43.2
Engineering Design & Construction Permit			
Construction permit	875.00	39.07	2.9
Engineering design fees	1,000.00	44.65	3.3
Operation and Maintenance			
Annual energy cost	202.46	9.04	0.7
Annual inspection & maintenance	6,718.94	300.00	22.5
Primary tank pump out	937.90	41.88	3.1
Stage 2 media replacement	3,084.91	137.74	10.3
Equipment replacement	373.33	16.67	1.2
Subtotal	11,317.54	505.33	37.8
Compliance			
Operating permit fee	1,119.82	50.00	3.7
Water quality monitoring	2,687.57	120.00	9.0
Subtotal	3,807.40	170.00	12.7
Total	29,926.07	1,336.20	100.00

Installed Capital Cost

Installation Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Installation Cost
Tankage	5,276.68	235.60	40.8
Soil Treatment Unit	0.00	0.00	0.0
Proprietary Stage 1 System	0.00	0.00	0.0
Media	1,666.85	74.42	12.9
Pump(s)	0.00	0.00	0.0
Control Panel	0.00	0.00	0.0
Misc. Appurtenance	1,693.00	75.59	13.1
Piping	289.60	12.93	2.2
Drip Dispersal Unit Complete (control panel, valves, tubing, etc.)	0.00	0.00	0.0
Liner	0.00	0.00	0.0
Contractor Fee	4,000.00	178.60	30.9
Total System	12,926.13	577.15	100.0

Life Cycle Cost

Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Total Life Cycle Cost
Installed Capital Cost	12,926.13	577.15	43.2
Engineering Design & Construction Permit	1,875.00	83.72	6.3
Operation & Maintenance	11,317.54	505.33	37.8
Compliance	3,807.40	170.00	12.7
Total	29,926.07	1,336.20	100.0
$/lb nitrogen removed	38.87	52.07	

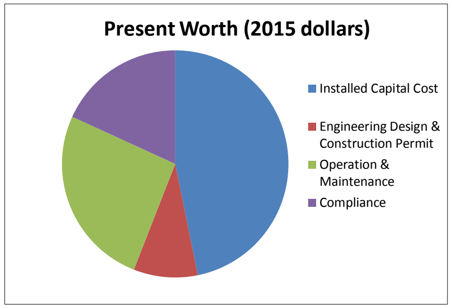
Developed by: HAZEN AND SAWYER Environmental Engineers & Scientists and AET

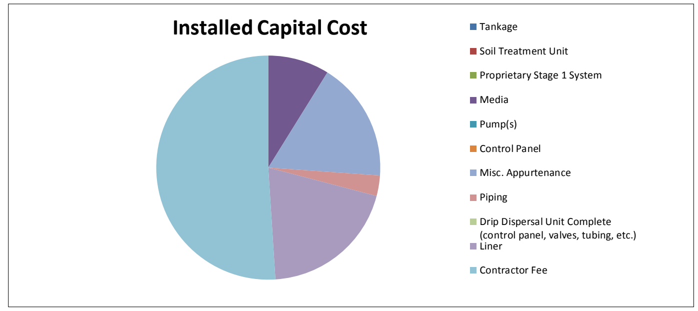
Table 7-8: PNRS LCCA results output for BHS-7PNRS

PNRS LCCA: Life Cycle Cost Analysis Tool for Passive Nitrogen Reduction Systems
LCCA Identification: BHS-7

Worksheet

1. LCCA Structure
2. Table of LCCA Worksheets
3. WW Quantity & System Parameters
4. PNRS Process Selection
5. Baseline Design & Cost
6. Baseline Design Cost Summary
7. User Override Costs
8. LCCA Conventional
9. LCCA Total System
10. Design Data
11. Example LCCAs





9. LCCA Total System

Conventional System Summary	
No. of Bedrooms	2
Building area, square feet	1112
Depth to seasonal high water table (inches)	72
New OSTDS installation or retrofit of existing system	retrofit
Design wastewater flow, gallon/day	200

No user override Conventional costs have been specified

PNRS System Summary	
PNRS System	17
Stage 1: PNRS or proprietary	PNRS
PNRS Stage(s)	Stage 1&2
Stage 1 in-tank or in-ground	In-ground
Stage 1 single pass or recirculation	Single pass
Stage 1 media type	Native Sand
Ligno disposition	Underlying Stage 1 in-ground liner
Stage 2 media type	Ligno only
Construction Complexity	Moderate
Level of nitrogen removal efficiency provided by system	Medium

No user override PNRS costs have been specified

Life Cycle Cost Calculations	
Project Life (PL), years	30
Interest Rate (IR), %	2.000
Primary tank pump out interval (TI), years	5.0
Pump out analysis life (PL), years	25.0
Stage 2 media replacement interval (MI), years	15.0
Stage 2 media cost analysis life (ML), years	15.0
Equipment replacement interval (EI), years	10.0
Equipment replacement analysis life (EL), years	20.0
Compound Interest Factors	
P/A PL/IR	22.396
A/P PL/IR	0.04465
A/F TI	0.19216
P/A PL	19.523
A/F MI	0.05783
P/A ML	12.849
A/F EI	0.09133
P/A EL	16.351
Nitrogen Removal	
Mass loading/year, lbs.	18.0
Removal efficiency, %	60.0
Mass removal/year, lbs.	10.81

Life Cycle Cost

Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Total Life Cycle Cost
Conventional System Installation			
Primary treatment tank	0.00	0.00	0.0
Pump tank	0.00	0.00	0.0
Conventional system pump	0.00	0.00	0.0
Soil treatment unit	0.00	0.00	0.0
Subtotal Conventional	0.00	0.00	0.0
Proprietary Stage 1 system	0.00	0.00	0.0
PNRS Installation			
Tankage	0.00	0.00	0.0
Media	867.50	38.73	4.1
PNRS Pump	0.00	0.00	0.0
Control Panel	0.00	0.00	0.0
Piping	289.60	12.93	1.4
Misc. Appurtenance	1,693.00	75.59	8.1
Stage 1 Drip Dispersal System Complete (control panel, valves, tubing, etc.)	0.00	0.00	0.0
Liner	1,950.00	87.07	9.3
Contractor Fee	5,000.00	223.25	23.9
Subtotal	9,800.10	437.57	46.8
Total System Installation	9,800.10	437.57	46.8
Engineering Design & Construction Permit			
Construction permit	915.00	40.85	4.4
Engineering design fees	1,000.00	44.65	4.8
Operation and Maintenance			
Annual energy cost	0.00	0.00	0.0
Annual inspection & maintenance	4,479.29	200.00	21.4
Primary tank pump out	937.90	41.88	4.5
Stage 2 media replacement	0.00	0.00	0.0
Equipment replacement	0.00	0.00	0.0
Subtotal	5,417.19	241.88	25.9
Compliance			
Operating permit fee	1,119.82	50.00	5.3
Water quality monitoring	2,687.57	120.00	12.8
Subtotal	3,807.40	170.00	18.2
Total	20,939.69	934.96	100.00

Installed Capital Cost

Installation Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Installation Cost
Tankage	0.00	0.00	0.0
Soil Treatment Unit	0.00	0.00	0.0
Proprietary Stage 1 System	0.00	0.00	0.0
Media	867.50	38.73	8.9
Pump(s)	0.00	0.00	0.0
Control Panel	0.00	0.00	0.0
Misc. Appurtenance	1,693.00	75.59	17.3
Piping	289.60	12.93	3.0
Drip Dispersal Unit Complete (control panel, valves, tubing, etc.)	0.00	0.00	0.0
Liner	1,950.00	87.07	19.9
Contractor Fee	5,000.00	223.25	51.0
Total System	9,800.10	437.57	100.0

Life Cycle Cost

Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Total Life Cycle Cost
Installed Capital Cost	9,800.10	437.57	46.8
Engineering Design & Construction Permit	1,915.00	85.50	9.1
Operation & Maintenance	5,417.19	241.88	25.9
Compliance	3,807.40	170.00	18.2
Total	20,939.69	934.96	100.0
$/lb nitrogen removed	64.60	86.53	

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Table 7-9: Summary of Construction Costs for Full Scale PNRS, LCCA Tool vs. As-built Cost

System ID	System Description	PNRS LCCA Estimated Total System Costs		Total System As-built Construction Cost for Task B Systems		
		Total PW, $	Total Construction Cost, $	Task B Total Cost, $	Adjustment for permitting, monitoring, and other costs, $	Task B Total Construction Cost, $
BHS-1	Proprietary: Stage 1 Aerocell™ Stage 2 Nitrex™	44,533.30	20,348.84	23,600.00	4,994.00	18,606.00
BHS-2	In-tank Stage 1 with R, dual-media Stage 2	34,544.74	18,696.83	19,142.18	1,085.84	18,056.34
BHS-3	In-ground stacked Stage 1 over Stage 2a ligno with supplemental Stage 2b sulfur	52,763.43	33,154.65	40,129.79	8,014.05	32,115.74
BHS-4	In-tank SP Stage 1, dual-media Stage 2	33,373.71	19,350.49	22,030.34	5,933.17	16,097.17
BHS-5	In-tank Stage 1 with R, dual-media Stage 2	39,002.60	20,920.13	22,361.55	4,066.24	18,295.31
BHS-6	In-tank stacked Stage 1 over Stage 2a ligno with supplemental Stage 2b sulfur	29,926.07	12,926.13	13,727.12	3,327.88	10,399.24
BHS-7	In-ground stacked SP Stage 1 over Stage 2 ligno	20,939.69	9,800.10	13,836.66	3,320.81	10,515.86

Table 7-10: Summary of Estimated Construction Costs by Treatment component

System ID	System Description	Total System Costs		Conv. Component Construction Cost, $	PNRS Component Construction Cost, $
		Total PW, $	Total Construction Cost, $		
BHS-1	Proprietary: Stage 1 Aerocell™ Stage 2 Nitrex™	44,533	20,349	5,225	15,124
BHS-2	In-tank Stage 1 with R, dual-media Stage 2	34,545	18,697	2,576	16,121
BHS-3	In-ground stacked Stage 1 over Stage 2a ligno with supplemental Stage 2b sulfur	52,763	33,155	10,734	22,421
BHS-4	In-tank SP Stage 1, dual-media Stage 2	33,373	19,350	3,171	16,180
BHS-5	In-tank Stage 1 with R, dual-media Stage 2	39,003	20,920	0	20,920
BHS-6	In-tank stacked Stage 1 over Stage 2a ligno with supplemental Stage 2b sulfur	29,926	12,926	0	12,926
BHS-7	In-ground stacked SP Stage 1 over Stage 2 ligno	20,940	9,800	0	9,800

Table 7-9 shows the reasonable comparison of PNRS LCCA estimated construction costs to actual as-built construction costs for the various PNRS evaluated. PNRS LCCA is to be used as a planning tool and contains many default values, while the actual construction costs are specific to details at each site, therefore some difference in costs are expected. Overall, PNRS LCCA should provide good planning level estimates of the various PNRS construction costs and life cycle costs of such a system.

The seven prototype systems required varying levels of new conventional OSTDS components, depending on site conditions. Some of the sites required a new primary tank and soil treatment unit, while others had conventional treatment components that could be reused within the new PNRS. Table 7-10 provides a comparison of the PNRS LCCA total estimated construction costs for the seven systems, the portion of that cost which was for required conventional treatment components, and the estimated construction cost of the PNRS components alone. This provides a more representative comparison of the cost of the PNRS installations, and narrows the range of PNRS costs relative to total system costs. Further analyses and comparisons of these cost results are discussed in the following sections.

7.4 Comparison of Life Cycle Costs of PNRS

The life cycle costs and unit nitrogen removal costs estimated by PNRS LCCA varied based on the size and complexity of the seven systems. Table 7-11 provides a statistical summary of these key life cycle cost metrics.

Table 7-11: Key Life Cycle Cost Statistics for Prototype PNRS

Metric	PNRS LCCA Statistics for the Seven PNRS Evaluated			
	Mean	Standard Deviation	Minimum	Maximum
Total PW, $	36,441	10,281	20,940	52,763
Total Construction Cost, $	19,314	7,381	9,800	33,155
lb. N removed per year	29.7	11.3	10.8	42.8
$ PW/ lb. N removed	44.32	12.70	30.40	64.60

7.4.1 PNRS System Total Present Worth and Construction Costs

The mean Total Present Worth (PW) of life cycle costs and total construction costs estimated by PNRS LCCA were $36,441 and $19,314, respectively. Total Present Worth of life cycle costs reflected system complexity and ranged from $20,940 to $52,763 (Figure 7-1). Total Present Worth was highest for the dual drip irrigation system at BHS-3 and lower for relatively simpler systems such as BHS-7.

Construction costs estimated by PNRS LCCA ranged from $9,800 to $33,155 (Figure 7-1). The construction cost estimate was also highest for the dual drip irrigation system (BHS-3) and lower for relatively simpler systems such as BHS-7.

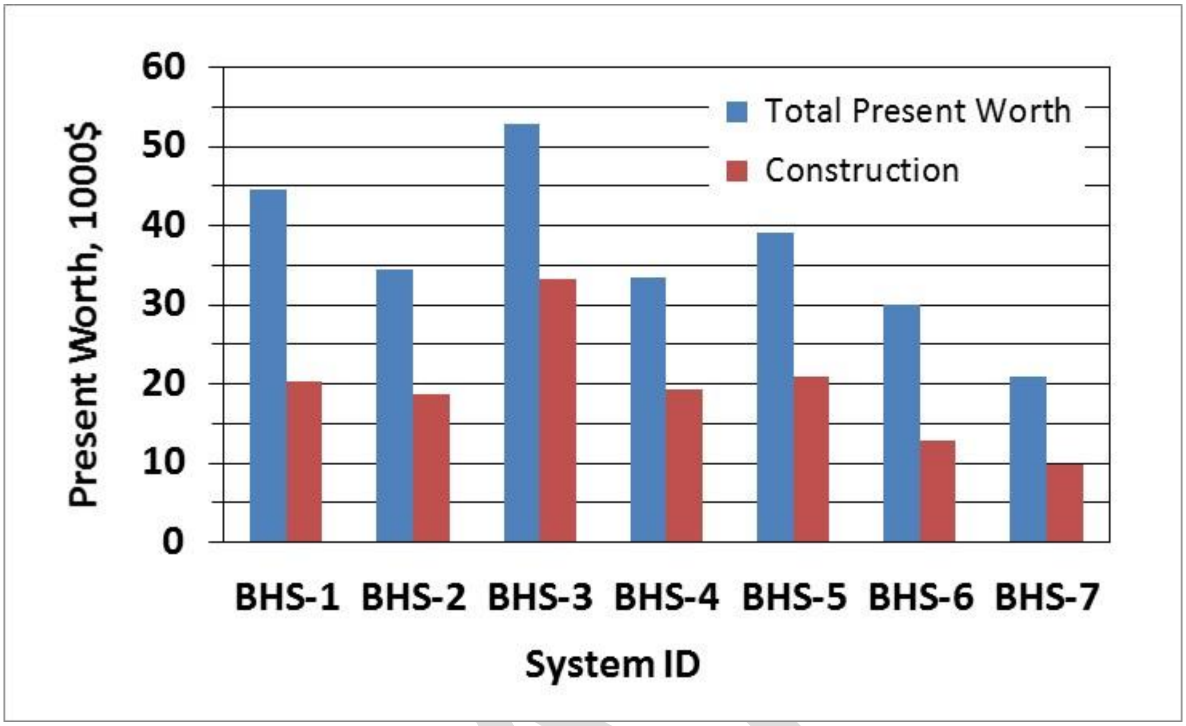


Figure 7-1: Total Present Worth of Life Cycle Costs and Estimated Construction Cost of PNRS Systems from PNRS LCCA

7.4.2 Task B System Construction Costs and PNRS LCCA Estimates

Task B as-built construction costs and PNRS LCCA construction cost estimates are shown in Figure 7-2. PNRS LCCA estimates provided somewhat higher costs than those derived from the Task B installation reports for six of the systems, with an average relative error for all systems of 10.2% versus the Task B cost. Task B as-built construction costs are plotted in Figure 7-3 versus the PNRS LCCA construction cost estimate. PNRS LCCA provides construction cost estimates that are quite acceptable for planning level analysis.

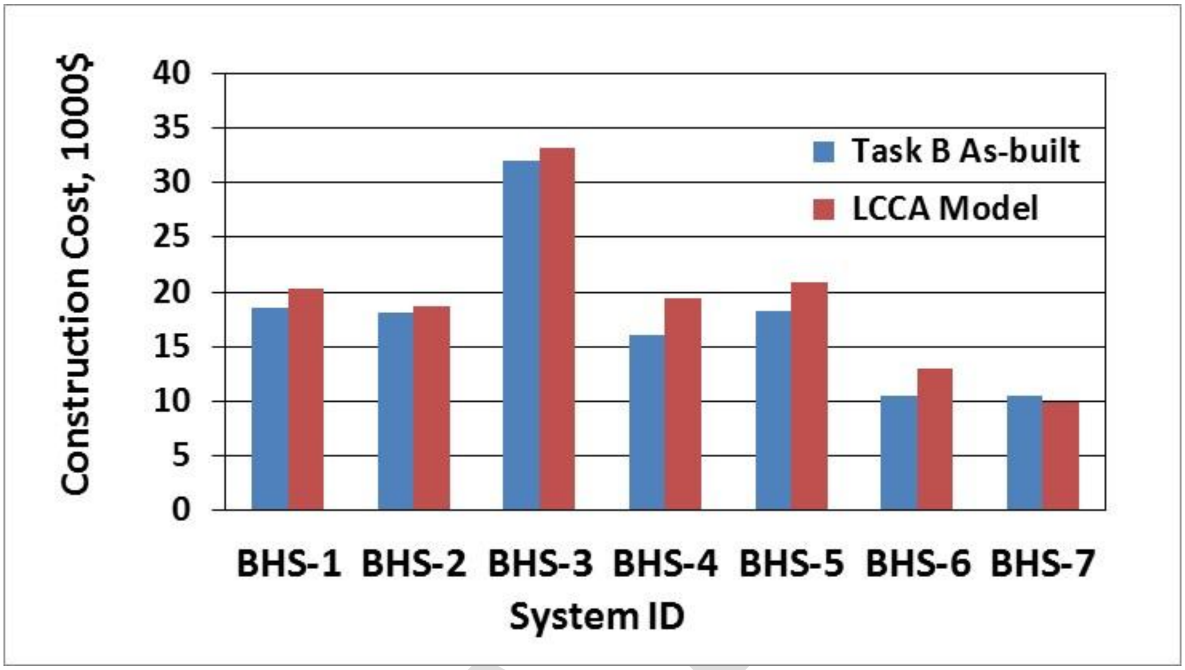


Figure 7-2: Comparison of PNRS As-built Construction Costs and PNRS LCCA Construction Cost Estimates

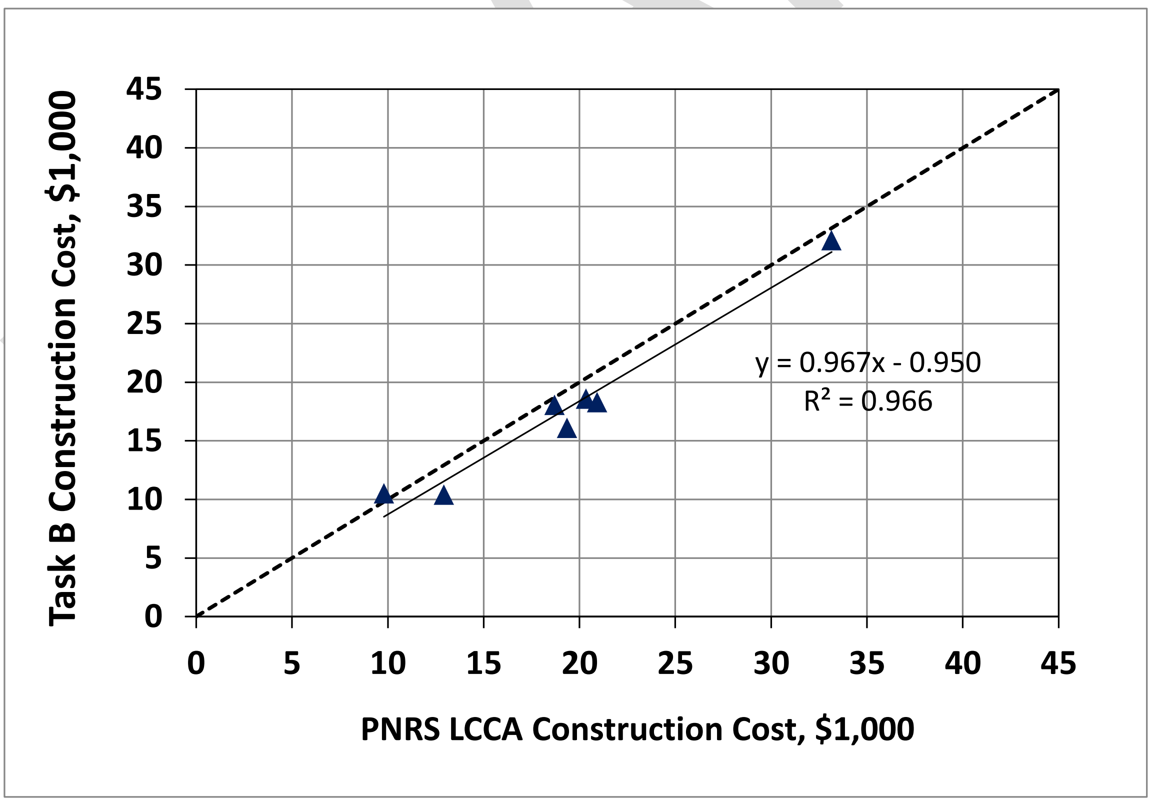


Figure 7-3: Trend Line for As-built Construction Costs and PNRS LCCA Estimates

7.4.3 PNRS LCCA Construction Cost Estimate as Percentage of Present Worth

Estimated construction costs of the seven PNRS systems averaged 52% of the Total Present Worth of Life Cycle Costs and ranged from 43 to 63% (Figure 7-4). The balance of the Total Present Worth, which ranged from 36 to 57% of the total life cycle cost, includes the non-construction costs such as: site design, inspection and maintenance visits, permits, monitoring, media and pump replacement, energy, and primary treatment solids removal. For all home systems evaluated, non-construction costs are a significant component of total life cycle costs.

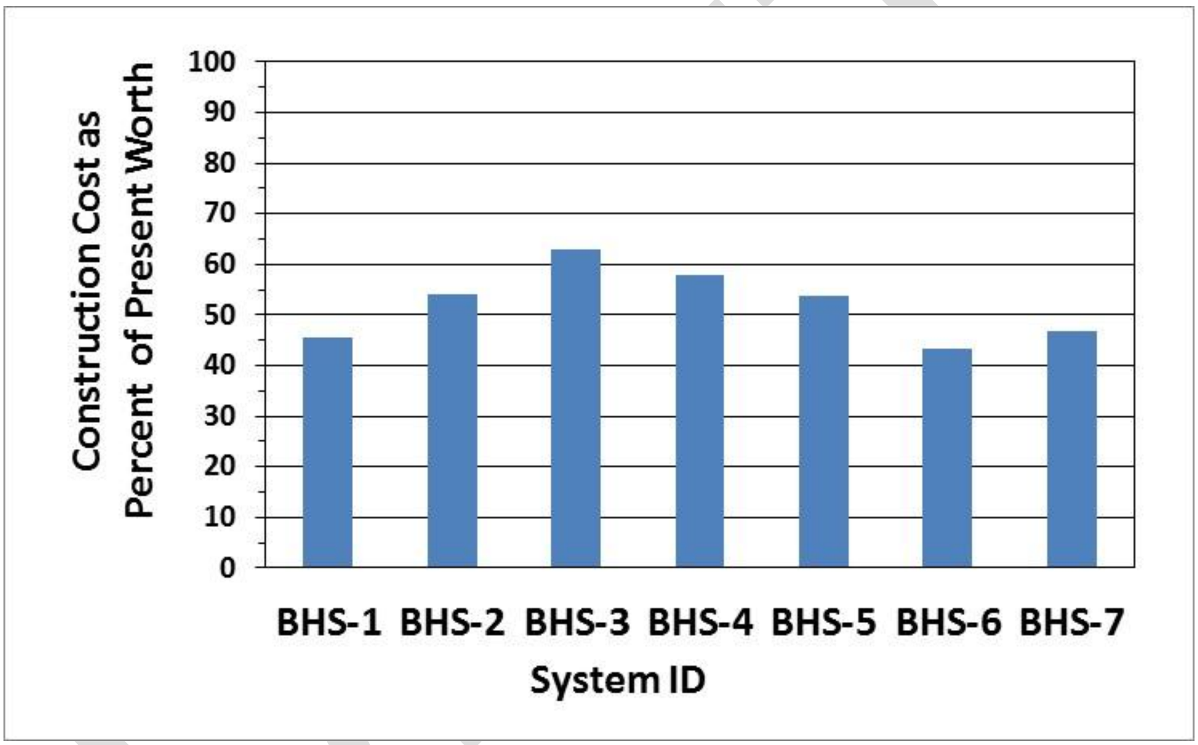


Figure 7-4: PNRS Construction Cost as Percentage of Present Worth

7.4.4 PNRS Present Worth per Mass Nitrogen Removed

The mean Total Present Worth per pound of nitrogen removed for all the prototype PNRS systems was estimated by PNRS LCCA as $44.32. Cost per nitrogen mass removed ranged from $31 to 65 (Figure 7-5). Present Worth per pound of nitrogen removed is affected by all system costs, the nitrogen generation rate of the home occupants, and the nitrogen reduction efficiency of the PNRS system.

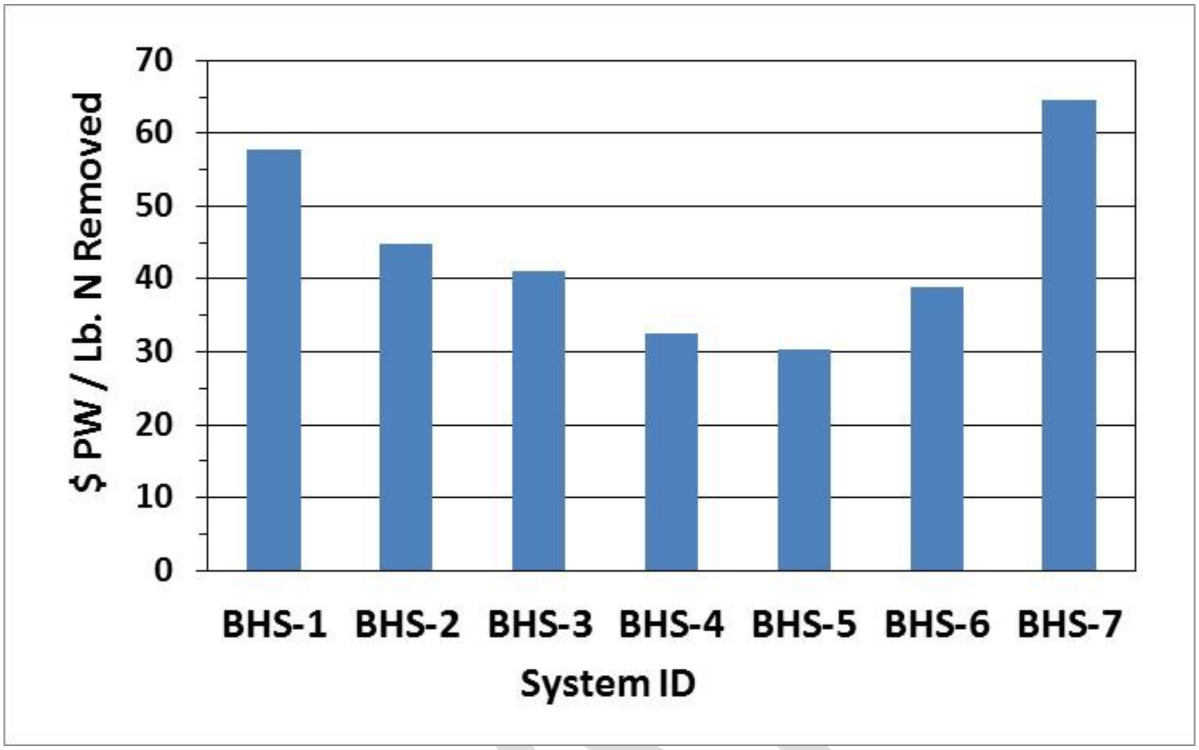


Figure 7-5: PNRS Present Worth per Mass of Nitrogen Removal

7.5 Comparison of Life Cycle Costs to Other Studies

The Maryland Department of the Environment initiated the Bay Restoration Fund (BRF) Program (2015) in an effort to reduce nitrogen loading to the Chesapeake Bay. The program evaluated several best available technologies for OSTDS nitrogen removal and determined a field verified mean percent TN reduction based on arithmetic mean of the effluent for each technology tested (Maryland DEP, 2015). Therefore, as a comparison to the FOSNRS prototype PNRS, LCCA were performed for BRF technologies. BRF LCCA incorporated the reported capital cost, percent TN reduction, and energy use to determine a present worth in $/lb. N removed and total present worth. Similar LCCA were also performed for six PNRS technologies incorporating the PNRS LCCA capital costs, PNRS percent TN reduction, and PNRS energy use. The standard inputs into the LCCA comparison for all systems included:

- 3 bedroom single family home of 2,200 ft^2 area
- Cost of 900 gallon septic tank
- Cost of 375 ft^2 soil treatment unit trench configuration designed for 0.8 gal/ft2-day loading rate
- 42 inch depth to seasonal high water table at soil treatment unit
- Cost of Florida PBTS construction and operating permit (State fees)

- Electrical rate of $0.1/kw-hour
- Two inspection and maintenance visits per year at a cost of $150 per visit except for PNRS in-tank Stage 1 single pass, Stage 2 dual media and PNRS in-ground Stage 1/2a (ligno) which were run at a cost of $100 per visit because of relative system simplicity
- One water quality monitoring event per year at a cost of $120 per sample event
- Cost of $300 for primary treatment tank pump out at a 5 year interval
- Project life of 30 years
- Net interest rate of 2 percent
- Stage 2 media replacement and equipment replacement were not included in this PNRS LCCA for comparison purposes because similar information was not available for BRF technologies

The Present Worth per pound of nitrogen removed for the technologies ranged from $23.78 to 65.07 (Figures 7-6 and 7-7). The total present worth for the technologies is compared in Figure 7-6, and the mean percent total nitrogen removed is compared in Figure 7-7. Overall, the present worth per pound of nitrogen removed for the prototype PNRS systems were less than the BRF technologies, and they achieved higher percent nitrogen removal. The conventional OSTDS had the lowest estimated cost per pound of nitrogen removed, however these systems can only achieve approximately 30% nitrogen reduction. It is noteworthy that several PNRS systems with very high % TN reductions have lower PW cost per pound of nitrogen removed than systems with lower TN removal efficiency (Figure 7-7). It also should be noted that the systems evaluated in the FOSNRS project were prototype systems, installed at existing residences, with customized components, which added to their cost. As PNRS are implemented on a wider scale, it is anticipated that considerable reductions in cost can be achieved.

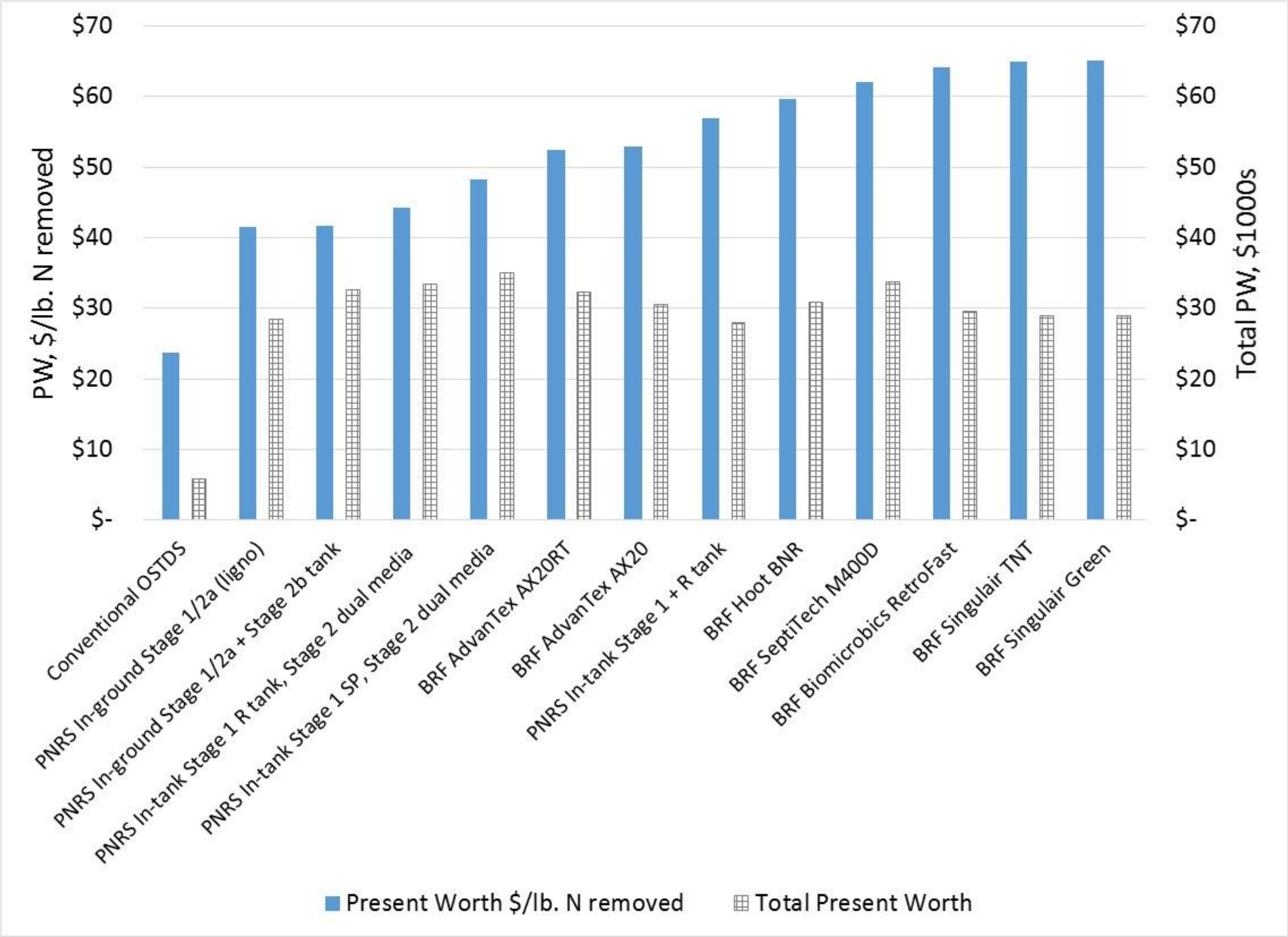
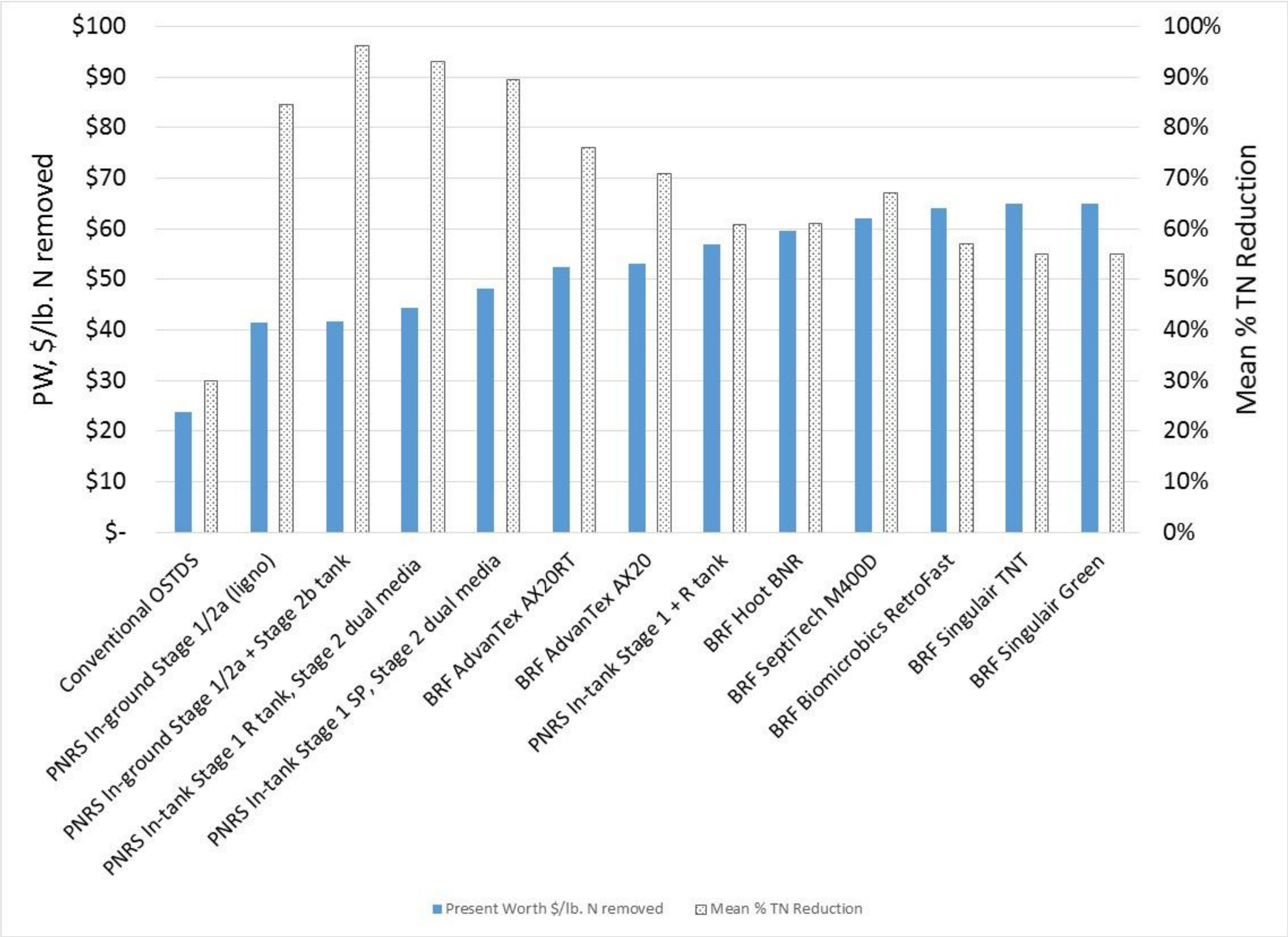


Figure 7-6: Comparison of Present Worth per Pound Nitrogen Removed and Total Present Worth



[1] The PNRS In-ground Stage 1/2a (ligno) % TN Reduction is the mean BHS-3 Stage 2 lignocellulosic effluent
[2] The PNRS In-ground Stage 1/2a + Stage 2b tank % TN Reduction is the mean BHS-3 Stage 2 sulfur effluent
[3] The PNRS In-tank Stage 1 R tank, Stage 2 dual media % TN Reduction is the mean BHS-2 Stage 2 sulfur effluent
[4] The PNRS In-tank Stage 1 SP, Stage 2 dual media % TN Reduction is the mean BHS-4 Stage 2 sulfur effluent
[5] The PNRS In-tank Stage 1 R tank % TN Reduction is the mean BHS-2 Stage 1 effluent

Figure 7-7: Comparison of Present Worth per Pound Nitrogen Removed and Percent TN Reduction

7.6 Summary

PNRS LCCA provides a useful planning level tool for Passive Nitrogen Removal Systems for nitrogen removal from onsite wastewater treatment systems. For the seven PNRS prototype systems, which varied significantly in design and operation, PNRS LCCA cost estimates were in reasonable agreement with actual Task B construction costs. For all seven prototype systems, PNRS LCCA results highlight that recurring costs are a significant component of the total life cycle costs of passive nitrogen removal systems for onsite wastewater treatment. Recurring costs must be included in any economic and planning analysis of Passive Nitrogen Removal Systems and alternative technologies as well.

A comparison of the PNRS systems to the Maryland Department of the Environment BRF best available technologies showed that the PNRS systems present worth per pound of nitrogen removed were less than the BRF technologies evaluated, and also achieved higher percent total nitrogen removals. The conventional OSTDS had the lowest cost per pound of nitrogen removed, but can only achieve approximately 30% nitrogen reduction.

8 Recommended Framework for Onsite Wastewater Nitrogen Reduction in Florida

Florida contains a wide variety of landscapes, soils, geology and water resources, each with different sensitivities to nitrogen loading. In some locations, such as Florida's unique springs and the watersheds/springsheds that feed them, significant nitrogen load reductions from all sources including OSTDS may be critical to rehabilitating or maintaining a pristine water quality. In other locations, such as those with deep soils and no direct linkage to surface waters or potable aquifers, nitrogen load reductions from OSTDS may be less critical. Many other locations may require nitrogen load reductions from onsite wastewater systems that lie in between these two options. As specific total maximum daily loads (TMDLs) and basin management action plans (BMAPs) are developed for Florida water bodies, it will become important to have a range of available options for nitrogen load reductions from OSTDS, since the cost of nitrogen reducing OSTDS is related to the level of treatment achieved. Therefore, it appears a strategy that includes a range of onsite wastewater nitrogen removal treatment alternatives should be recommended.

This section describes a framework for recommended treatment systems and processes at three expected performance levels in regards to onsite wastewater nitrogen removal (level of treatment). Effluent quality from onsite wastewater systems can be highly variable, and depends on many factors in the home and the treatment system itself. For this reason, a range of expected treatment is provided at each of the three recommended nitrogen removal levels, described below:

Low level onsite wastewater nitrogen removal: defined as achieving a 25 – 35 percent reduction in total nitrogen reaching the water table below the OSTDS. A 30% reduction is used as the basis for reduction calculations at this level.

Medium level onsite wastewater nitrogen removal: defined as achieving a 50 – 70 percent reduction in total nitrogen reaching the water table below the OSTDS. A 60% reduction is used as the basis for load reduction calculations at this level.

High level onsite wastewater nitrogen removal: defined as achieving greater than 95 percent reduction in total nitrogen reaching the water table below the OSTDS. A 95% reduction is used as the basis for load reduction calculations at this level.

The expected operation, maintenance and permitting requirements are provided for each level of treatment. Example systems are run in PNRS LCCA to obtain life cycle costs, assuming a 3 bedroom, 2200 ft^2 existing single family home and includes new conventional system components (primary tank and

STU) as required by the system type. Fine sand soils are assumed at the site with a water table greater than 42 inches below grade. Based on these assumptions, the associated PNRS LCCA output report is provided.

8.1 Low Level Onsite Wastewater Nitrogen Removal

The low level nitrogen removal option is defined as a current code compliant conventional onsite wastewater treatment system. This OSTDS typically would consist of a two chamber primary treatment tank (i.e. septic tank) followed by a soil treatment unit (STU or drainfield). Soil treatment units can be bed or trench configuration. The low level option may require a mounded soil treatment unit as determined by site topography, seasonal high groundwater levels and soil characteristics. Maintaining at least a 2 foot separation between the bottom of the STU and the water table is essential to achieving this level of nitrogen removal from effluent prior to reaching groundwater.

8.1.1 Expected Performance

The low level nitrogen removal option provides an expected percentage of total nitrogen removal in the range of 25 to 35% (ca. 30%). Table 8-1 summarizes multiple studies that help to document the nitrogen removal performance of low level options. Anderson and Otis (2000) and Hazen and Sawyer (2009) each provided a literature review that includes many other examples of field studies documenting this level of treatment performance for properly functioning STUs.

Table 8-1: Performance References for Low-Level Nitrogen Removal Option

	Mean % reduction from STE					
Reference	**TSS**	**$CBOD_5$**	**TN**	**TKN**	**NH_3**	**TP**
Anderson et al., 1994 (Candler FS at 2', USF Lysimeter Station)	na	99	**51**	98	na	90
Long, 1995 (medium sand)	na	na	**40**	na	na	na
Long, 1995 (fine sand)	na	na	**60**	na	na	na
Anderson et al., 1998 (Keys OWNRS Report, Sand SDI Bed)	53	96	**34**	95	99	40
Anderson and Otis, 2000 (Conventional OWTS)	95	95	**10-50**	na	na	80-95
Hazen & Sawyer and AET, 2009a (Task A Literature Review)	na	na	**0-86**[a]	na	na	na
Florida Onsite Sewage Nitrogen Reduction Strategies Study						
Task B Home Systems, Hazen & Sawyer and AET, 2015						
BHS-3 Stage 1 Fine Sand Fill (LY01, LY02)	91	90	**48**	96	100	73
BHS-7 Candler FS (SL 01, 02, 03, 04)	90	91	**47**	94	99	96
BHS-5 Single Pass Stage 1, Expanded clay	94	86	**30**	91	95	67
BHS-4 Single Pass Stage 1, Expanded clay	85	94	**35**	83	88	65
BHS-6 Stage 1, Expanded clay (DP2)	na[b]	72	**25**	88	92	na
PNRS Pilot, Hazen & Sawyer and AET, 2014						
S&GW Test Facility TA1 (Trench) LY24S	na	na	**29**	95	100	97
S&GW Test Facility TA3 (Drip) LY24S	na	na	**61**	96	100	98

[a] Range of nitrogen reduction results from a review of numerous onsite wastewater studies
[b] TSS samples higher than STE, suspect media fines in samples

8.1.2 Operation and Maintenance

The operation and maintenance requirement for low level nitrogen removal systems is minimal. Primary tank solids should be removed every three to five years. Conventional systems with a pump require periodic inspection and pump replacement if necessary, and a maintenance inspection of the pump and floats is recommended at the time of primary solids removal.

8.1.3 Permitting and Monitoring Requirements

A new OSTDS requires a new system conventional construction permit from the Florida Department of Health. A retrofit system requires an existing system conventional construction permit from the Florida Department of Health. Water quality monitoring is not required for conventional OSTDS.

8.1.4 Life Cycle Cost Analysis

The PNRS-LCCA low level treatment result for the example 3 bedroom single family house of 2,200 ft^2 area is shown in Table 8-2.

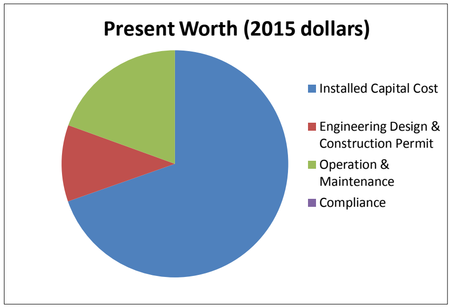
Table 8-2: PNRS LCCA Result for Low Level Nitrogen Removal Option (30%)

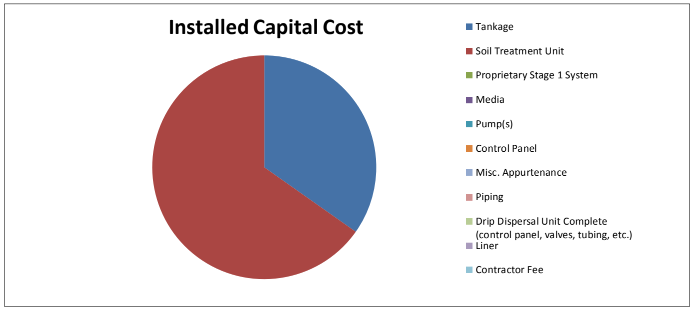
PNRS LCCA: Life Cycle Cost Analysis Tool for Passive Nitrogen Reduction Systems
LCCA Identification: Low Level

Worksheet

1. LCCA Structure
2. Table of LCCA Worksheets
3. WW Quantity & System Parameters
4. PNRS Process Selection
5. Baseline Design & Cost
6. Baseline Design Cost Summary
7. User Override Costs
8. LCCA Conventional
9. LCCA Total System
10. Design Data
11. Example LCCAs

9. LCCA Total System





Conventional System Summary

No. of Bedrooms	3
Building area, square feet	2200
Depth to seasonal high water table (inches)	42
New OSTDS installation or retrofit of existing system	retrofit
Design wastewater flow, gallon/day	300

No user override Conventional costs have been specified

PNRS System Summary

PNRS System	0
Stage 1: PNRS or proprietary	0
PNRS Stage(s)	0
Stage 1 in-tank or in-ground	0
Stage 1 single pass or recirculation	0
Stage 1 media type	0
Ligno disposition	0
Stage 2 media type	0
Construction Complexity	Complex
Level of nitrogen removal efficiency provided by system	Low

No user override PNRS costs have been specified

Life Cycle Cost Calculations

Project Life (PL), years	30
Interest Rate (IR), %	2.000
Primary tank pump out interval (TI), years	5.0
Pump out analysis life (PL), years	25.0
Stage 2 media replacement interval (MI), years	15.0
Stage 2 media cost analysis life (ML), years	15.0
Equipment replacement interval (EI), years	10.0
Equipment replacement analysis life (EL), years	20.0
Compound Interest Factors	
P/A PL/IR	22.396
A/P PL/IR	0.04465
A/F TI	0.19216
P/A PL	19.523
A/F MI	0.05783
P/A ML	12.849
A/F EI	0.09133
P/A EL	16.351
Nitrogen Removal	
Mass loading/year, lbs.	27.0
Removal efficiency, %	30.0
Mass removal/year, lbs.	8.10

Life Cycle Cost

Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Total Life Cycle Cost
Conventional System Installation			
Primary treatment tank	1,400.00	62.51	24.2
Pump tank	0.00	0.00	0.0
Conventional system pump	0.00	0.00	0.0
Soil treatment unit	2,625.00	117.21	45.4
Subtotal Conventional	4,025.00	179.72	69.6
Proprietary Stage 1 system	0.00	0.00	0.0
PNRS Installation			
Tankage	0.00	0.00	0.0
Media	0.00	0.00	0.0
PNRS Pump	0.00	0.00	0.0
Control Panel	0.00	0.00	0.0
Piping	0.00	0.00	0.0
Misc. Appurtenance	0.00	0.00	0.0
Stage 1 Drip Dispersal System Complete (control panel, valves, tubing, etc.)	0.00	0.00	0.0
Liner	0.00	0.00	0.0
Contractor Fee	0.00	0.00	0.0
Subtotal	0.00	0.00	0.0
Total System Installation	4,025.00	179.72	69.6
Engineering Design & Construction Permit			
Construction permit	630.00	28.13	10.9
Engineering design fees	0.00	0.00	0.0
Operation and Maintenance			
Annual energy cost	0.00	0.00	0.0
Annual inspection & maintenance	0.00	0.00	0.0
Primary tank pump out	1,125.48	50.25	19.5
Stage 2 media replacement	0.00	0.00	0.0
Equipment replacement	0.00	0.00	0.0
Subtotal	1,125.48	50.25	19.5
Compliance			
Operating permit fee	0.00	0.00	0.0
Water quality monitoring	0.00	0.00	0.0
Subtotal	0.00	0.00	0.0
Total	5,780.48	258.10	100.00

Installed Capital Cost

Installation Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Installation Cost
Tankage	1,400.00	62.51	34.8
Soil Treatment Unit	2,625.00	117.21	65.2
Proprietary Stage 1 System	0.00	0.00	0.0
Media	0.00	0.00	0.0
Pump(s)	0.00	0.00	0.0
Control Panel	0.00	0.00	0.0
Misc. Appurtenance	0.00	0.00	0.0
Piping	0.00	0.00	0.0
Drip Dispersal Unit Complete (control panel, valves, tubing, etc.)	0.00	0.00	0.0
Liner	0.00	0.00	0.0
Contractor Fee	0.00	0.00	0.0
Total System	4,025.00	179.72	100.0

Life Cycle Cost

Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Total Life Cycle Cost
Installed Capital Cost	4,025.00	179.72	69.6
Engineering Design & Construction Permit	630.00	28.13	10.9
Operation & Maintenance	1,125.48	50.25	19.5
Compliance	0.00	0.00	0.0
Total	5,780.48	258.10	100.0
$/lb nitrogen removed	23.78	31.85	

Developed by: HAZEN AND SAWYER Environmental Engineers & Scientists and AET Applied Environmental Technology

8.2 Medium Level Onsite Wastewater Nitrogen Removal

The recommended medium level nitrogen removal options consist of both an in-tank approach and an in-ground approach. The in-tank approach consists of a primary treatment tank (i.e. septic tank), a Stage 1 unsaturated biofilter with recirculation to a recirculation tank, and a soil treatment unit. Soil treatment units could be bed or trench configuration. This option is similar to the BHS-2 Stage 1 module, without the Stage 2 biofilter.

The in-ground approach consists of a primary treatment tank (i.e. septic tank) followed by an in-ground Stage 1 unsaturated biofilter in native soil underlain by a Stage 2 lignocellulosic biofilter in a liner, with the effluent overflowing the liner into surrounding soil. This option is similar to the BHS-7 system, with low pressure effluent dosing to the Stage 1 biofilter. However, based on the hydraulic problems suspected at BHS-7, a larger liner and a 50/50 lignocellulosic/fine sand mix was assumed.

8.2.1 Expected Performance

The medium level nitrogen removal option provides an expected percentage of total nitrogen removal in the range of 50 to 70% (ca. 60%). Table 8-3 summarizes multiple studies that document nitrogen removal performance of medium level options.

Table 8-3: Performance References for Medium-Level Nitrogen Removal Option (50-70%)

	Mean % reduction from STE			
Reference	**$CBOD_5$**	**TN**	**TKN**	**NH_3**
Venhuizen et al., 1998	94-98	**59-89**	na	na
Piluk & Peters, 1994	98	**59-70**	na	na
Osesek et al., 1994	95-98	**60-69**	73-89	71-89
Boyle et al., 1994	95-96	**57-59**	78-93	na
Florida Onsite Sewage Nitrogen Reduction Strategies Study				
Task B Home Systems, Hazen & Sawyer and AET, 2015				
BHS-2 In-tank Stage 1 Expanded Clay with Recirculation	86	**61**	94	98
BHS-3 In-ground Stage 1 underlain by Stage 2 Lignocellulosic	95	**84**	96	100
Florida Onsite Sewage Nitrogen Reduction Strategies Study				
PNRS Pilot, Hazen & Sawyer and AET, 2014				
S&GW Test Facility TA5 (PNRS In-ground biofilter 23)	94	**90**	95	99

8.2.2 Operation and Maintenance

The medium level option requires a twice per year maintenance inspection under Florida code. Inspection should include pump operation and electrical connections, general hydraulic inspection including flow distribution to the Stage 1 biofilter, flushing and cleaning of distribution lines, inspection of biofilter media surfaces, and measurement of recycle flowrate and adjustment if needed. The medium level option requires periodic inspection of the pump and replacement if necessary. Primary tank solids should be removed every three to five years.

8.2.3 Permitting and Monitoring Requirements

A Performance Based Treatment System Construction Permit and a Performance Based Treatment System Operating Permit are required by the Florida Department of Health. Once per year water quality monitoring is recommended for TKN, ammonia nitrogen, nitrite + nitrate nitrogen, carbonaceous biochemical oxygen demand, and alkalinity.

8.2.4 Life Cycle Cost Analysis

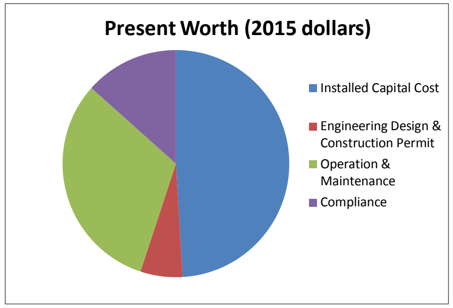
The PNRS-LCCA medium level results for the example 3 bedroom house of 2,200 ft^2 area are shown in Table 8-4 and 8-5. Table 8-4 provides the PNRS-LCCA for an in-tank PNRS system that includes a Stage 1 biofilter with recirculation to a recirculation tank. Table 8-5 provides the PNRS-LCCA for an in-ground PNRS system that includes a Stage 1 biofilter underlain by a Stage 2 lignocellulosic/fine sand mix biofilter in a liner.

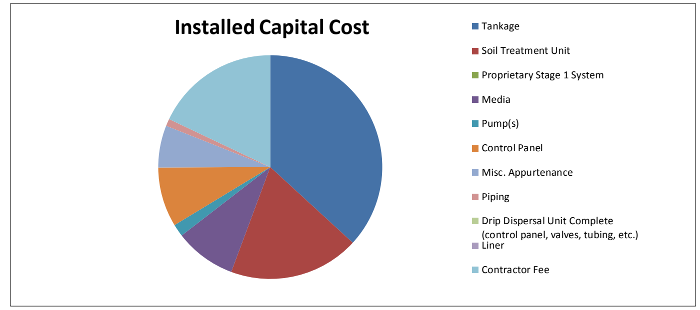
Table 8-4: PNRS LCCA Result for Medium Level In-Tank Nitrogen Removal Option (60%)

PNRS LCCA: Life Cycle Cost Analysis Tool for Passive Nitrogen Reduction Systems
LCCA Identification: Medium Level

Worksheet
1. LCCA Structure
2. Table of LCCA Worksheets
3. WW Quantity & System Parameters
4. PNRS Process Selection
5. Baseline Design & Cost
6. Baseline Design Cost Summary
7. User Override Costs
8. LCCA Conventional
9. LCCA Total System
10. Design Data
11. Example LCCAs

9. LCCA Total System





Conventional System Summary

No. of Bedrooms	3
Building area, square feet	2200
Depth to seasonal high water table (inches)	42
New OSTDS installation or retrofit of existing system	retrofit
Design wastewater flow, gallon/day	300

No user override Conventional costs have been specified

PNRS System Summary

PNRS System	24
Stage 1: PNRS or proprietary	PNRS
PNRS Stage(s)	Stage 1 only
Stage 1 in-tank or in-ground	Tank
Stage 1 single pass or recirculation	Recirculation
Stage 1 media type	EC
Ligno disposition	None
Stage 2 media type	None
Construction Complexity	Moderate
Level of nitrogen removal efficiency provided by system	Medium

No user override PNRS costs have been specified

Life Cycle Cost Calculations

Project Life (PL), years	30
Interest Rate (IR), %	2.000
Primary tank pump out interval (TI), years	5.0
Pump out analysis life (PL), years	25.0
Stage 2 media replacement interval (MI), years	15.0
Stage 2 media cost analysis life (ML), years	15.0
Equipment replacement interval (EI), years	10.0
Equipment replacement analysis life (EL), years	20.0
Compound Interest Factors	
P/A PL/IR	22.396
A/P PL/IR	0.04465
A/F TI	0.19216
P/A PL	19.523
A/F MI	0.05783
P/A ML	12.849
A/F EI	0.09133
P/A EL	16.351
Nitrogen Removal	
Mass loading/year, lbs.	27.0
Removal efficiency, %	60.0
Mass removal/year, lbs.	16.21

Life Cycle Cost

Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Total Life Cycle Cost
Conventional System Installation			
Primary treatment tank	1,400.00	62.51	4.9
Pump tank	0.00	0.00	0.0
Conventional system pump	0.00	0.00	0.0
Soil treatment unit	2,625.00	117.21	9.2
Subtotal Conventional	4,025.00	179.72	14.2
Proprietary Stage 1 system	0.00	0.00	0.0
PNRS Installation			
Tankage	3,728.68	166.49	13.1
Media	1,234.09	55.10	4.3
PNRS Pump	250.00	11.16	0.9
Control Panel	1,200.00	53.58	4.2
Piping	144.80	6.47	0.5
Misc. Appurtenance	846.50	37.80	3.0
Stage 1 Drip Dispersal System Complete (control panel, valves, tubing, etc.)	0.00	0.00	0.0
Liner	0.00	0.00	0.0
Contractor Fee	2,500.00	111.62	8.8
Subtotal	9,904.07	442.22	34.9
Total System Installation	13,929.07	621.93	49.0
Engineering Design & Construction Permit			
Construction permit	710.00	31.70	2.5
Engineering design fees	1,000.00	44.65	3.5
Operation and Maintenance			
Annual energy cost	736.23	32.87	2.6
Annual inspection & maintenance	6,718.94	300.00	23.7
Primary tank pump out	1,125.48	50.25	4.0
Stage 2 media replacement	0.00	0.00	0.0
Equipment replacement	373.33	16.67	1.3
Subtotal	8,953.97	399.79	31.5
Compliance			
Operating permit fee	1,119.82	50.00	3.9
Water quality monitoring	2,687.57	120.00	9.5
Subtotal	3,807.40	170.00	13.4
Total	28,400.44	1,268.08	100.00

Installed Capital Cost

Installation Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Installation Cost
Tankage	5,128.68	229.00	36.8
Soil Treatment Unit	2,625.00	117.21	18.8
Proprietary Stage 1 System	0.00	0.00	0.0
Media	1,234.09	55.10	8.9
Pump(s)	250.00	11.16	1.8
Control Panel	1,200.00	53.58	8.6
Misc. Appurtenance	846.50	37.80	6.1
Piping	144.80	6.47	1.0
Drip Dispersal Unit Complete (control panel, valves, tubing, etc.)	0.00	0.00	0.0
Liner	0.00	0.00	0.0
Contractor Fee	2,500.00	111.62	17.9
Total System	13,929.07	621.93	100.0

Life Cycle Cost

Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Total Life Cycle Cost
Installed Capital Cost	13,929.07	621.93	49.0
Engineering Design & Construction Permit	1,710.00	76.35	6.0
Operation & Maintenance	8,953.97	399.79	31.5
Compliance	3,807.40	170.00	13.4
Total	28,400.44	1,268.08	100.0
$/lb nitrogen removed	58.41	78.24	

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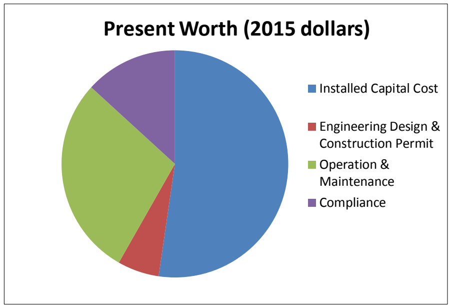
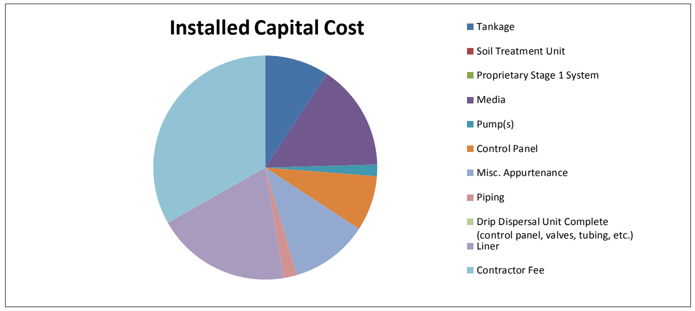
Table 8-5: PNRS LCCA Result for Medium Level In-Ground Nitrogen Removal Option (60%)

PNRS LCCA: Life Cycle Cost Analysis Tool for Passive Nitrogen Reduction Systems
LCCA Identification: Medium Level

Worksheet
1. LCCA Structure
2. Table of LCCA Worksheets
3. WW Quantity & System Parameters
4. PNRS Process Selection
5. Baseline Design & Cost
6. Baseline Design Cost Summary
7. User Override Costs
8. LCCA Conventional
9. LCCA Total System
10. Design Data
11. Example LCCAs

9. LCCA Total System





Conventional System Summary	
No. of Bedrooms	3
Building area, square feet	2200
Depth to seasonal high water table (inches)	42
New OSTDS installation or retrofit of existing system	retrofit
Design wastewater flow, gallon/day	300

No user override Conventional costs have been specified

PNRS System Summary	
PNRS System	17
Stage 1: PNRS or proprietary	PNRS
PNRS Stage(s)	Stage 1&2
Stage 1 in-tank or in-ground	In-ground
Stage 1 single pass or recirculation	Single pass
Stage 1 media type	Native Sand
Ligno disposition	Underlying Stage 1 in-ground liner
Stage 2 media type	Ligno only
Construction Complexity	Moderate
Level of nitrogen removal efficiency provided by system	Medium

No user override PNRS costs have been specified

Life Cycle Cost Calculations	
Project Life (PL), years	30
Interest Rate (IR), %	2.000
Primary tank pump out interval (TI), years	5.0
Pump out analysis life (PL), years	25.0
Stage 2 media replacement interval (MI), years	15.0
Stage 2 media cost analysis life (ML), years	15.0
Equipment replacement interval (EI), years	10.0
Equipment replacement analysis life (EL), years	20.0
Compound Interest Factors	
P/A PL/IR	22.396
A/P PL/IR	0.04465
A/F TI	0.19216
P/A PL	19.523
A/F MI	0.05783
P/A ML	12.849
A/F EI	0.09133
P/A EL	16.351
Nitrogen Removal	
Mass loading/year, lbs.	27.0
Removal efficiency, %	60.0
Mass removal/year, lbs.	16.21

Life Cycle Cost

Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Total Life Cycle Cost
Conventional System Installation			
Primary treatment tank	1,400.00	62.51	4.9
Pump tank	0.00	0.00	0.0
Conventional system pump	0.00	0.00	0.0
Soil treatment unit	0.00	0.00	0.0
Subtotal Conventional	1,400.00	62.51	4.9
Proprietary Stage 1 system	0.00	0.00	0.0
PNRS Installation			
Tankage	0.00	0.00	0.0
Media	2,301.25	102.75	8.0
PNRS Pump	250.00	11.16	0.9
Control Panel	1,200.00	53.58	4.2
Piping	289.60	12.93	1.0
Misc. Appurtenance	1,693.00	75.59	5.9
Stage 1 Drip Dispersal System Complete (control panel, valves, tubing, etc.)	0.00	0.00	0.0
Liner	2,925.00	130.60	10.2
Contractor Fee	5,000.00	223.25	17.4
Subtotal	13,658.85	609.87	47.4
Total System Installation	15,058.85	672.38	52.3
Engineering Design & Construction Permit			
Construction permit	710.00	31.70	2.5
Engineering design fees	1,000.00	44.65	3.5
Operation and Maintenance			
Annual energy cost	0.00	0.00	0.0
Annual inspection & maintenance	6,718.94	300.00	23.3
Primary tank pump out	1,125.48	50.25	3.9
Stage 2 media replacement	0.00	0.00	0.0
Equipment replacement	373.33	16.67	1.3
Subtotal	8,217.75	366.92	28.5
Compliance			
Operating permit fee	1,119.82	50.00	3.9
Water quality monitoring	2,687.57	120.00	9.3
Subtotal	3,807.40	170.00	13.2
Total	28,793.99	1,285.65	100.00

Installed Capital Cost

Installation Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Installation Cost
Tankage	1,400.00	62.51	9.3
Soil Treatment Unit	0.00	0.00	0.0
Proprietary Stage 1 System	0.00	0.00	0.0
Media	2,301.25	102.75	15.3
Pump(s)	250.00	11.16	1.7
Control Panel	1,200.00	53.58	8.0
Misc. Appurtenance	1,693.00	75.59	11.2
Piping	289.60	12.93	1.9
Drip Dispersal Unit Complete (control panel, valves, tubing, etc.)	0.00	0.00	0.0
Liner	2,925.00	130.60	19.4
Contractor Fee	5,000.00	223.25	33.2
Total System	15,058.85	672.38	100.0

Life Cycle Cost

Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Total Life Cycle Cost
Installed Capital Cost	15,058.85	672.38	52.3
Engineering Design & Construction Permit	1,710.00	76.35	5.9
Operation & Maintenance	8,217.75	366.92	28.5
Compliance	3,807.40	170.00	13.2
Total	28,793.99	1,285.65	100.0
$/lb nitrogen removed	59.22	79.32	

Developed by: HAZEN AND SAWYER Environmental Engineers & Scientists and AET Applied Environmental Technology

8.3 High Level Onsite Wastewater Nitrogen Removal

The recommended high level nitrogen removal options consist of both an in-tank approach and an in-ground approach. The high level option consists overall of a primary treatment tank (i.e. septic tank), a Stage 1 unsaturated biofilter, a Stage 2 saturated media biofilter, and a soil treatment unit. The in-tank Stage 1 biofilter hydraulics can be can be single pass or recirculation. In-tank Stage 2 biofilters can be single or dual media. The recommended in-tank system would be similar to BHS-2 or BHS-5. The in-ground system would contain the Stage 1/2a biofilter in a liner, with effluent collection to a saturated sulfur biofilter for further TN reduction, or directly to an STU. This system would be similar to BHS-3, but without drip distribution to the Stage 1 module. Soil treatment units can be bed or trench configuration. The high level option may require a mounded soil treatment unit as determined by site topography, seasonal high groundwater levels and soil characteristics.

8.3.1 Expected Performance

The high level nitrogen removal option provides an expected percentage of total nitrogen removal of 95% or greater when considering additional treatment provided by the soil treatment unit prior to effluent reaching the water table. Table 8-6 summarizes recent studies that document nitrogen removal performance of high level options.

Table 8-6: Performance References for High Level Nitrogen Removal Options (results prior to STU)

	Mean % reduction from STE			
Reference	**$CBOD_5$**	**TN**	**NH_3**	**TSS**
Smith, 2008 Passive Nitrogen Removal Study 1				
Two Stage Biofiltration				
Single Pass Stage 1 Expanded Clay/ Stage 2 Elemental Sulfur	>96	**95.2**	97.8	
Single Pass Stage 1 Clinoptilolite/ Stage 2 Elemental Sulfur	>96	**96.7**	99.1	
Florida Onsite Sewage Nitrogen Reduction Strategies Study				
PNRS Pilot, Hazen & Sawyer and AET, 2014				
Single Pass Stage 1 Expanded Clay/ Stage 2 Elemental Sulfur Biofilter 6-SU-30	97	**97.7**	99	97
Stage 1 with Recirculation Composite/ Stage 2 Elemental Sulfur Biofilter 15-SU-80	80	**95.3**	97	98
Stage 1 with Recirculation Composite/ Stage 2 Elemental Sulfur Biofilter 16-SU-30	87	**96.8**	99	96
S&GW Test Facility TA5 (PNRS In-ground biofilter 23)	64	**95**	98	19
Task B Home Systems, Hazen & Sawyer and AET, 2015				
BHS-2 Recirculating Stage 1 Expanded Clay/ Stage 2 Ligno & Elemental Sulfur	36	**93**	95	76
BHS-5 Recirculating Stage 1 Expanded Clay/ Stage 2 Ligno & Elemental Sulfur	86	**98**	98	90
BHS-4 Single Pass Stage 1 Expanded Clay/Stage 2 Ligno & Elemental Sulfur	91	**89**	93	93
BHS-3 In-ground Stage 1 Sand Underlain by Stage 2 Ligno & In-tank Elemental Sulfur	80	**96**	99	81

8.3.2 Operation and Maintenance

The high level nitrogen removal options require twice per year maintenance inspection under Florida code. Inspection should include pump operation and electrical connection, general hydraulic inspection including flow distribution to the Stage 1 biofilter, flushing and cleaning of distribution lines, inspection of biofilter media surfaces, and measurement of recycle flowrate and adjustment if needed. The high level option requires periodic inspection of the pump and replacement if necessary. Primary tank solids should be removed every three to five years.

8.3.3 Permitting and Monitoring Requirements

The Performance Based Treatment System Construction Permit and a Performance Based Treatment System Operating Permit are required by the Florida Department of Health. Once per year water quality monitoring is recommended for TKN, ammonia nitrogen, nitrite + nitrate nitrogen, carbonaceous biochemical oxygen demand, and alkalinity.

8.3.4 Life Cycle Cost Analysis

The PNRS-LCCA high level nitrogen removal system results for the example 3 bedroom house of 2,200 ft^2 area are shown in Table 8-7 and 8-8. Table 8-7 provides the PNRS-LCCA for an in-tank PNRS system that includes a Stage 1 biofilter with recirculation and Stage 2 dual media biofilter. Table 8-8 provides the PNRS-LCCA for an in-ground PNRS system that includes a Stage 1 biofilter underlain by a Stage 2a lignocellulosic biofilter in a liner and an additional Stage 2b sulfur biofilter tank prior to the STU.

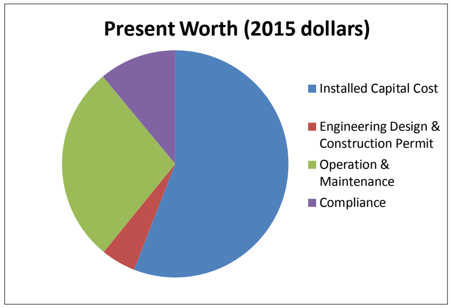
Table 8-7: PNRS LCCA Result for High Level In-tank Nitrogen Removal Option

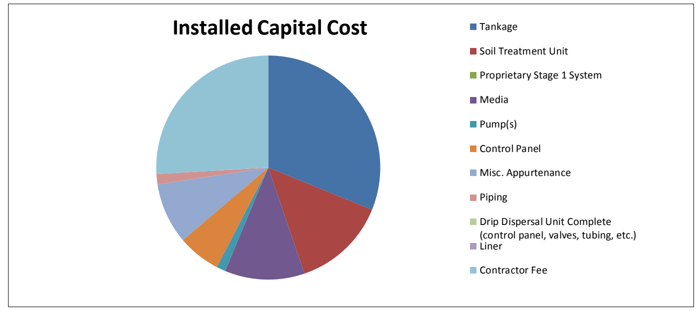
PNRS LCCA: Life Cycle Cost Analysis Tool for Passive Nitrogen Reduction Systems
LCCA Identification: High Level

Worksheet

1. LCCA Structure
2. Table of LCCA Worksheets
3. WW Quantity & System Parameters
4. PNRS Process Selection
5. Baseline Design & Cost
6. Baseline Design Cost Summary
7. User Override Costs
8. LCCA Conventional
9. LCCA Total System
10. Design Data
11. Example LCCAs

9. LCCA Total System





Conventional System Summary

No. of Bedrooms	3
Building area, square feet	2200
Depth to seasonal high water table (inches)	42
New OSTDS installation or retrofit of existing system	retrofit
Design wastewater flow, gallon/day	300

No user override Conventional costs have been specified

PNRS System Summary

PNRS System	9
Stage 1: PNRS or proprietary	PNRS
PNRS Stage(s)	Stage 1&2
Stage 1 in-tank or in-ground	Tank
Stage 1 single pass or recirculation	Recirculation
Stage 1 media type	Expanded Clay
Ligno disposition	Tank
Stage 2 media type	Dual: Ligno & sulfur
Construction Complexity	Moderate
Level of nitrogen removal efficiency provided by system	High

No user override PNRS costs have been specified

Life Cycle Cost Calculations

Project Life (PL), years	30
Interest Rate (IR), %	2.000
Primary tank pump out interval (TI), years	5.0
Pump out analysis life (PL), years	25.0
Stage 2 media replacement interval (MI), years	15.0
Stage 2 media cost analysis life (ML), years	15.0
Equipment replacement interval (EI), years	10.0
Equipment replacement analysis life (EL), years	20.0
Compound Interest Factors	
P/A PL/IR	22.396
A/P PL/IR	0.04465
A/F TI	0.19216
P/A PL	19.523
A/F MI	0.05783
P/A ML	12.849
A/F EI	0.09133
P/A EL	16.351
Nitrogen Removal	
Mass loading/year, lbs.	27.0
Removal efficiency, %	95.0
Mass removal/year, lbs.	25.66

Life Cycle Cost

Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Total Life Cycle Cost
Conventional System Installation			
Primary treatment tank	1,400.00	62.51	4.1
Pump tank	0.00	0.00	0.0
Conventional system pump	0.00	0.00	0.0
Soil treatment unit	2,625.00	117.21	7.6
Subtotal Conventional	4,025.00	179.72	11.7
Proprietary Stage 1 system	0.00	0.00	0.0
PNRS Installation			
Tankage	4,609.29	205.80	13.4
Media	2,226.78	99.43	6.5
PNRS Pump	250.00	11.16	0.7
Control Panel	1,200.00	53.58	3.5
Piping	289.60	12.93	0.8
Misc. Appurtenance	1,693.00	75.59	4.9
Stage 1 Drip Dispersal System Complete (control panel, valves, tubing, etc.)	0.00	0.00	0.0
Liner	0.00	0.00	0.0
Contractor Fee	5,000.00	223.25	14.5
Subtotal	15,268.67	681.75	44.3
Total System Installation	19,293.67	861.46	55.9
Engineering Design & Construction Permit			
Construction permit	710.00	31.70	2.1
Engineering design fees	1,000.00	44.65	2.9
Operation and Maintenance			
Annual energy cost	736.23	32.87	2.1
Annual inspection & maintenance	6,718.94	300.00	19.5
Primary tank pump out	1,125.48	50.25	3.3
Stage 2 media replacement	737.58	32.93	2.1
Equipment replacement	373.33	16.67	1.1
Subtotal	9,691.56	432.73	28.1
Compliance			
Operating permit fee	1,119.82	50.00	3.2
Water quality monitoring	2,687.57	120.00	7.8
Subtotal	3,807.40	170.00	11.0
Total	34,502.63	1,540.54	100.00

Installed Capital Cost

Installation Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Installation Cost
Tankage	6,009.29	268.31	31.1
Soil Treatment Unit	2,625.00	117.21	13.6
Proprietary Stage 1 System	0.00	0.00	0.0
Media	2,226.78	99.43	11.5
Pump(s)	250.00	11.16	1.3
Control Panel	1,200.00	53.58	6.2
Misc. Appurtenance	1,693.00	75.59	8.8
Piping	289.60	12.93	1.5
Drip Dispersal Unit Complete (control panel, valves, tubing, etc.)	0.00	0.00	0.0
Liner	0.00	0.00	0.0
Contractor Fee	5,000.00	223.25	25.9
Total System	19,293.67	861.46	100.0

Life Cycle Cost

Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Total Life Cycle Cost
Installed Capital Cost	19,293.67	861.46	55.9
Engineering Design & Construction Permit	1,710.00	76.35	5.0
Operation & Maintenance	9,691.56	432.73	28.1
Compliance	3,807.40	170.00	11.0
Total	34,502.63	1,540.54	100.0
$/lb nitrogen removed	44.82	60.03	

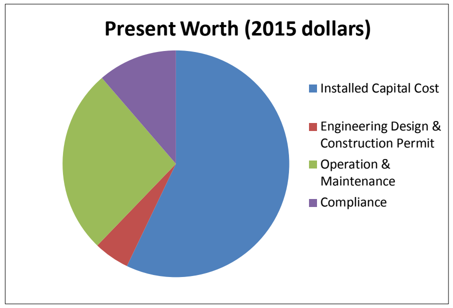
Developed by: HAZEN AND SAWYER Environmental Engineers & Scientists and AET Applied Environmental Technology

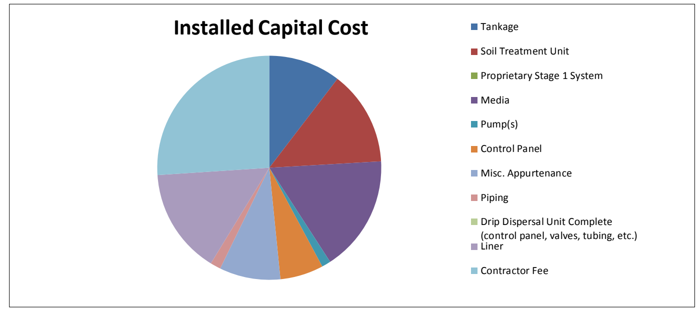
Table 8-8: PNRS LCCA Result for High Level In-ground Nitrogen Removal Option

PNRS LCCA: Life Cycle Cost Analysis Tool for Passive Nitrogen Reduction Systems
LCCA Identification: High Level

Worksheet
1. LCCA Structure
2. Table of LCCA Worksheets
3. WW Quantity & System Parameters
4. PNRS Process Selection
5. Baseline Design & Cost
6. Baseline Design Cost Summary
7. User Override Costs
8. LCCA Conventional
9. LCCA Total System
10. Design Data
11. Example LCCAs

9. LCCA Total System





Conventional System Summary	
No. of Bedrooms	3
Building area, square feet	2200
Depth to seasonal high water table (inches)	42
New OSTDS installation or retrofit of existing system	retrofit
Design wastewater flow, gallon/day	300

No user override Conventional costs have been specified

PNRS System Summary	
PNRS System	18
Stage 1: PNRS or proprietary	PNRS
PNRS Stage(s)	Stage 1&2
Stage 1 in-tank or in-ground	In-ground
Stage 1 single pass or recirculation	Single pass
Stage 1 media type	Native Sand
Ligno disposition	Underlying Stage 1 in-ground liner
Stage 2 media type	Dual: Ligno & sulfur
Construction Complexity	Moderate
Level of nitrogen removal efficiency provided by system	High

No user override PNRS costs have been specified

Life Cycle Cost Calculations	
Project Life (PL), years	30
Interest Rate (IR), %	2.000
Primary tank pump out interval (TI), years	5.0
Pump out analysis life (PL), years	25.0
Stage 2 media replacement interval (MI), years	15.0
Stage 2 media cost analysis life (ML), years	15.0
Equipment replacement interval (EI), years	10.0
Equipment replacement analysis life (EL), years	20.0
Compound Interest Factors	
P/A PL/IR	22.396
A/P PL/IR	0.04465
A/F TI	0.19216
P/A PL	19.523
A/F MI	0.05783
P/A ML	12.849
A/F EI	0.09133
P/A EL	16.351
Nitrogen Removal	
Mass loading/year, lbs.	27.0
Removal efficiency, %	95.0
Mass removal/year, lbs.	25.66

Life Cycle Cost

Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Total Life Cycle Cost
Conventional System Installation			
Primary treatment tank	1,400.00	62.51	4.2
Pump tank	0.00	0.00	0.0
Conventional system pump	0.00	0.00	0.0
Soil treatment unit	2,625.00	117.21	7.8
Subtotal Conventional	4,025.00	179.72	12.0
Proprietary Stage 1 system	0.00	0.00	0.0
PNRS Installation			
Tankage	600.00	26.79	1.8
Media	3,219.84	143.77	9.6
PNRS Pump	250.00	11.16	0.7
Control Panel	1,200.00	53.58	3.6
Piping	289.60	12.93	0.9
Misc. Appurtenance	1,693.00	75.59	5.0
Stage 1 Drip Dispersal System Complete (control panel, valves, tubing, etc.)	0.00	0.00	0.0
Liner	2,925.00	130.60	8.7
Contractor Fee	5,000.00	223.25	14.9
Subtotal	15,177.44	677.67	45.1
Total System Installation	19,202.44	857.39	57.1
Engineering Design & Construction Permit			
Construction permit	710.00	31.70	2.1
Engineering design fees	1,000.00	44.65	3.0
Operation and Maintenance			
Annual energy cost	0.00	0.00	0.0
Annual inspection & maintenance	6,718.94	300.00	20.0
Primary tank pump out	1,125.48	50.25	3.3
Stage 2 media replacement	682.53	30.47	2.0
Equipment replacement	373.33	16.67	1.1
Subtotal	8,900.27	397.40	26.5
Compliance			
Operating permit fee	1,119.82	50.00	3.3
Water quality monitoring	2,687.57	120.00	8.0
Subtotal	3,807.40	170.00	11.3
Total	33,620.11	1,501.14	100.00

Installed Capital Cost

Installation Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Installation Cost
Tankage	2,000.00	89.30	10.4
Soil Treatment Unit	2,625.00	117.21	13.7
Proprietary Stage 1 System	0.00	0.00	0.0
Media	3,219.84	143.77	16.8
Pump(s)	250.00	11.16	1.3
Control Panel	1,200.00	53.58	6.2
Misc. Appurtenance	1,693.00	75.59	8.8
Piping	289.60	12.93	1.5
Drip Dispersal Unit Complete (control panel, valves, tubing, etc.)	0.00	0.00	0.0
Liner	2,925.00	130.60	15.2
Contractor Fee	5,000.00	223.25	26.0
Total System	19,202.44	857.39	100.0

Life Cycle Cost

Cost Item	Present Worth, $	Uniform Annual Cost, $	% of Total Life Cycle Cost
Installed Capital Cost	19,202.44	857.39	57.1
Engineering Design & Construction Permit	1,710.00	76.35	5.1
Operation & Maintenance	8,900.27	397.40	26.5
Compliance	3,807.40	170.00	11.3
Total	33,620.11	1,501.14	100.0
$/lb nitrogen removed	43.67	58.50	

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8.4 Comparison of Recommended Nitrogen Removal System Costs

Comparison of the PNRS LCCA results for the three onsite wastewater nitrogen removal levels is shown in Table 8-9 and Figure 8-1. As the nitrogen removal level of the recommended systems proceeds from low to medium to high, construction costs, present worth of life cycle costs and lbs. per year of nitrogen removed increase. The present worth cost per pound of nitrogen removed is lowest for the low level options (conventional treatment), however they also remove much less nitrogen than the PNRS options. The high level treatment options have lower cost per pound of nitrogen removed than the medium level options. Construction costs, operation and maintenance costs, and compliance costs are all significantly higher for the medium and high nitrogen removal level options than for conventional OSTDS.

Table 8-9 Comparison of PNRS LCCA Results for Recommended Nitrogen Removal Systems

Nitrogen Removal Level	System	Present Worth, $					Lbs/year Nitrogen removed	$ PW/ lb. Nitrogen Removed
		Total	Construction	Engineering Design and Permit	Operation and Maintenance	Compliance		
Low (25-35%)	Conventional: primary treatment + soil treatment unit	5,780.48	4,025.00	630.00	1,125.48	0.00	8.1	23.78
Medium (50-70%)	Conventional + In-tank PNRS Stage 1 + R tank	28,400.44	13,929.07	1,710.00	8,953.97	3,807.40	16.2	58.41
	Conventional + PNRS In-ground Stage 1 underlain by Stage 2	28,793.99	15,058.85	1,710.00	8,217.75	3,807.40	16.2	59.22
High (>95%)	Conventional + PNRS In-tank Stage 1 + PNRS In-tank Stage 2	34,502.63	19,293.67	1,710.00	9,691.56	3,807.40	25.7	44.82
	Conventional + PNRS In-ground Stage 1&2a + PNRS In-tank Stage 2b	33,620.11	19,202.44	1,710.00	8,900.27	3,807.40	25.7	43.67

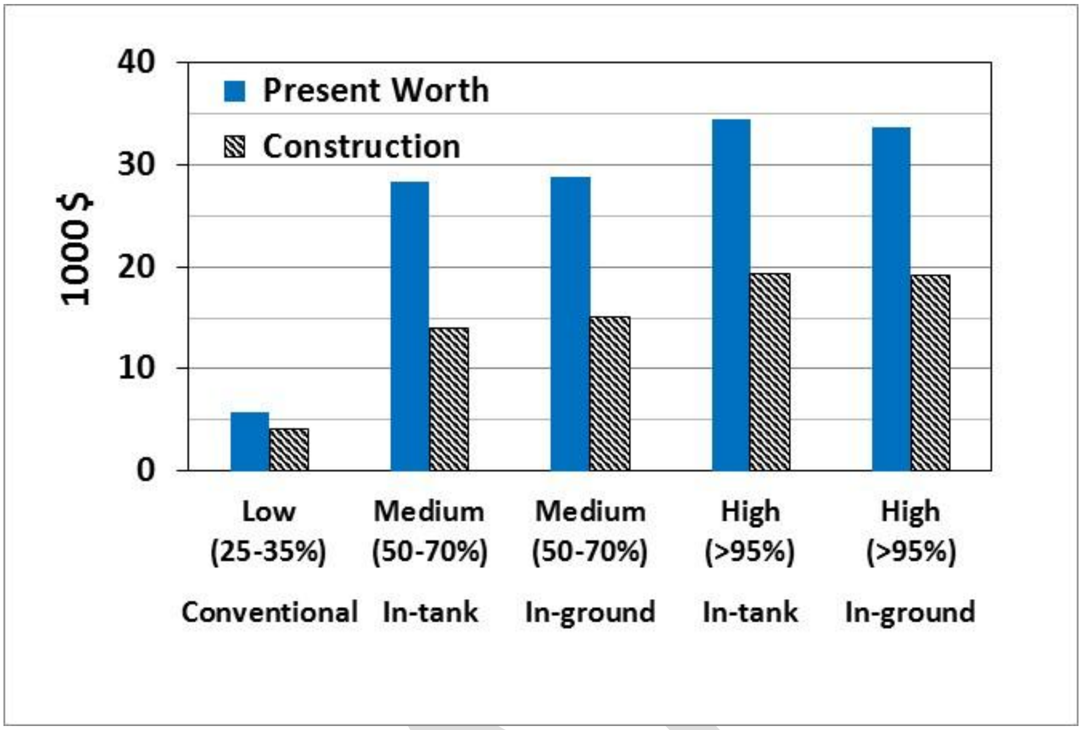

Figure 8-1 Total Present Worth of Life Cycle Costs and Construction Costs for Three Recommended Nitrogen Removal Systems

9 Conclusions and Recommendations

This report provides a summary of the full-scale passive nitrogen reduction system (PNRS) prototype development, design, installation, and testing under Task B of the Florida Onsite Sewage Nitrogen Reduction Strategies (FOSNRS) Project. It provides a summary background of the FOSNRS project and the goals and objectives of the full-scale prototype evaluations (Sections 1 & 2). Section 3 provides the background leading to the selection of the passive nitrogen reduction system treatment processes that were tested, and the basic design concepts that were used to design the prototype full scale systems. The prototype PNRS that were designed, constructed and tested are described in Section 4, along with the test sites chosen and monitoring methods used. Section 5 presents the results of the prototype full scale PNRS testing and evaluations based on the monitoring reports developed earlier in Task B. An analysis of the monitoring data collected and discussion of the results is provided in Section 6. Section 7 presents the Life Cycle Cost Analysis of full scale PNRS based on the PNRS LCCA tool developed earlier in Task B. Based on the results and experience gained from the full scale testing of prototype PNRS, recommended treatment processes for onsite wastewater nitrogen reduction in Florida are presented in Section 8. The recommended PNRS systems are organized by technologies that can provide low, medium or high levels of nitrogen removal from onsite wastewater, depending on the nitrogen sensitivity of the receiving waters. Finally, this section (Section 9) summarizes conclusions drawn from the prototype PNRS evaluations and provides recommendations for next steps in moving forward with PNRS in Florida.

9.1 PNRS Technologies and Performance

Based on a review, prioritization and ranking of available onsite wastewater nitrogen removal technologies in Task A of the FOSNRS project, nitrogen removal by two stage biofiltration was selected as the most operationally simple, effective, and applicable nitrogen removal process for development of Passive Nitrogen Reduction Systems (PNRS) for onsite wastewater treatment. A unique pilot scale test facility was therefore designed and constructed at the UF Gulf Coast Research and Education Center to test numerous design concepts for two stage biofiltration and to develop further design criteria for implementation of full scale PNRS for testing in FOSNRS Task B. Based on approximately two years of pilot study results, seven prototype full scale two stage biofilter based PNRS were designed and constructed for evaluation at existing homes in Florida.

The seven prototype single family home PNRS systems evaluated in FOSNRS Task B encompassed a variety of designs of passive two-stage biofiltration systems for onsite nitrogen removal. Construction of each PNRS was evaluated for cost and ease of construction, and the systems were subsequently monitored over an approximately 2 year period with water quality sampling conducted bi-monthly over 18

months. The prototype systems have performed very well over multiple years in real onsite conditions. Nitrogen removal performance of the full scale PNRS confirmed the results of previous PNRS pilot testing and established the two-stage biofiltration process as an effective and viable technology for onsite nitrogen removal. The prototype system demonstrations provide valuable guidance for future PNRS design for individual homesites and for planning level analysis to achieve nitrogen reduction goals in Florida. The prototype PNRS performance was such that, with relatively minor design refinements, several of the system designs could be configured for innovative systems permitting. Several other systems showed considerable potential as PNRS, but need further design refinements and testing. The results of individual home PNRS testing revealed:

- The PNRS Stage 1 biofilters were all very effective in nitrifying organic and ammonia nitrogen to nitrate+nitrite (NOx) nitrogen (Table 6-1). Mean ammonia removal efficiencies for the seven prototype PNRS Stage 1 biofilters ranged from 88 to 100%, which provided a Stage 1 effluent (Stage 2 influent) suitable for denitrification and high total nitrogen removal efficiency.

- All seven Stage 1 biofilters also achieved some level of denitrification and total nitrogen (TN) removal (Table 6-1). Mean TN removal efficiency by the Stage 1 biofilters ranged from 18 – 61%, with the highest efficiency achieved in BHS-2 by recycling a portion of the nitrified effluent to a recirculation tank for significant pre-denitrification.

- The PNRS Stage 2 biofilters were very effective in denitrifying NOx nitrogen to gaseous N forms, thus reducing Total Nitrogen in the system effluent. Mean NOx-N removal efficiency for the Stage 2 lignocellulosic biofilters ranged from 41 to 100%, with the lower performance from BHS-6 which malfunctioned on several occasions (Table 6-3). Mean NOx-N removal efficiency for the Stage 2 elemental sulfur biofilters ranged from 74 to 100% (Table 6-5). Since all Stage 2 sulfur biofilters were preceded by a lignocellulosic biofilter, there was often very little NOx reaching the sulfur media, which influenced the efficiency. Mean NOx-N concentrations in sulfur biofilter effluents ranged from below detection limits (0.02 mg N/L) to 4.4 mg NOx-N/L for the Stage 2 biofilters containing sulfur media. Excluding BHS-6 (malfunctions), mean Stage 2 effluent from sulfur biofilters was less than 1 mg NOx-N/L.

- The mean Total Nitrogen (TN) removal efficiency for seven prototype full-scale passive two-stage nitrogen removal systems ranged from 65 to 98% with an overall mean of 90% for all systems (Table 6-10). However, the nitrogen removal efficiency of the three most refined and best performing prototype systems (BHS-2, BHS-3, and BHS-5) averaged over 95% TN removal. The two lowest performing PNRS (BHS-6 and BHS-7) showed the potential to achieve similar TN

removal efficiencies, but their performance was hampered by less than optimal design or construction issues.

- The mean effluent Total Nitrogen (TN) concentration for the seven prototype PNRS ranged from 1.8 to 19.1 mg/L (Table 5-4). The highest mean TN effluent concentrations can be attributed to the BHS-7 design issues previously discussed. Once again, the most refined and best performing prototype systems (BHS-2, BHS-3, and BHS-5) produced a mean effluent TN concentration of 2.6 mg/L.

- Mean electrical consumption of the prototype PNRS was 4.5 kw-hour per 1000 gallons of wastewater flow from the home and ranged from 0 to 28.7 kw-hr/1000 gallon (Table 5-7). The highest energy usages were for BHS-1 due to a Stage 1 biofilter with a very high recirculation ratio and BHS-3 which included pumping to drip dispersal zones for both Stage 1 STE and final effluent irrigation. Operation of single pass in-tank systems ranged from 0 to 3.2 kw-hour per 1000 gallons, while operation of recirculating in-tank systems (with a 3:1 R ratio) ranged from 1.2 to 2.8 kw-hour per 1000 gallons. This electrical use would equate to a cost of less than $1.00 per month for a PNRS similar to the single pass or recirculating Stage 1 systems tested.

- Operation and maintenance (O&M) of the prototype PNRS systems reflected system complexity (Table 5-6). The simplest system O&M was the BHS-7 in-ground PNRS, which has O&M requirements similar to a conventional OSTDS with pressure dosed STU. Slightly more complex were the in-tank PNRS with single pass Stage 1 biofilters. O&M of these PNRS was also relatively simple, adding only Stage 1 STE distribution issues to the in-ground pressure dosed system. The O&M of the in-tank PNRS with Stage 1 recirculation is only slightly more complex than the single pass systems, in that timed dosing is added to the controls, and the recirculation ratio must be checked and adjusted occasionally. The most complex system was BHS-3, and this complexity was due to the use of drip dispersal for both STE application in Stage 1 and irrigation of final treated effluent to turf grass, all with one pump. This system had O&M requirements similar to more complex PBTS or STE drip systems. However, without the irrigation component, and with STE low pressure distribution instead of drip, this system would be similar to the single pass Stage 1 in-tank systems in O&M complexity.

- The longevity of the PNRS reactive media could not be determined directly in the seven prototype PNRS evaluations due to the very low use of media over the approximately 2 year observation period. Theoretical calculations and literature experience with both lignocellulosic and sulfur Stage 2 biofilters suggests that it would not be difficult to design systems for media life of 25

years or longer (Tables 6-8 and 6-9). It would also be relatively easy to add reactive media to the in-tank Stage 2 biofilters, and sizing of these systems could potentially be reduced if routine media additions were made during the life of the system.

9.2 PNRS Cost

A life cycle cost analysis (LCCA) tool for PNRS (PNRS LCCA) was developed as part of the FOSNRS project and was used to develop life cycle costs based on the seven prototype PNRS, other PNRS configurations, and for other advanced onsite wastewater treatment systems for comparison purposes (Section 7). The PNRS LCCA tool provides an output report summarizing the life cycle cost analysis.

- A comparison of estimated construction costs between PNRS LCCA and the actual construction costs for the seven prototype systems showed good agreement, with a relative percent error between the two costs of approximately 10%.

- The mean estimated as-built construction cost for seven PNRS home systems was $17,726 and ranged from $10,399 to $32,116. Lowest estimated construction cost was for the BHS-7 in-ground PNRS, which was also the simplest system. While this system's performance was less than optimal, design revisions to the Stage 2 liner module could potentially make it the most cost effective of all systems. Highest construction cost was for BHS-3, a dual drip dispersal PNRS system with turf grass irrigation. Construction costs of in-tank 2 stage biofilter PNRS were in the middle of the range with construction costs of $18,000 to $20,000. It should be noted that all seven prototype PNRS were installed at existing homes, which required additional construction time and restoration of property, increasing costs as compared to a new home installation. Additionally, these were prototype systems (with the exception of the proprietary BHS-1) that were unfamiliar to contractors and which had not been designed and constructed in Florida previously. Costs for PNRS would most likely come down with more standard designs and widespread implementation.

- The average total present worth of life cycle costs for the seven prototype PNRS was $36,441 and ranged from $20,940 to 52,763 (Table 7-9). Highest Present Worth was for the BHS-3 dual drip dispersal system, while the simpler designs had lower Present Worth.

- Of key importance is that non-construction costs accounted for 37 to 57% of the total present worth of the prototype PNRS (48% mean). In general order of higher to lower cost, these items included annual inspection and maintenance fees, water quality monitoring, primary tank solids removal, operating permit fees, energy costs, and media and equipment replacement.

- The average Present Worth cost per pound of nitrogen removal for the seven prototype PNRS systems was $44.32 /lb. N, and ranged from $31 to $65 /lb. N (Figure 7-5). A comparison with the Maryland Bay Restoration Fund (BRF) data indicated that the prototype PNRS operated at a lower present worth cost per pound of nitrogen removal than the PBTS evaluated by Maryland BRF, and at significantly greater effluent TN removal efficiencies (Figure 7-7).

9.3 Recommended Treatment Process and Level of Treatment Expectations

The nutrient sensitivity of Florida watersheds varies greatly, and includes areas of extremely high sensitivity to nitrogen loading and other areas where nitrogen loading from OSTDS may be less critical. To accommodate this variability, three operational levels of nitrogen removal efficiency were established as part of an onsite nutrient reduction strategy related to treatment technologies (Section 8):

- Low level onsite wastewater nitrogen removal was defined as achieving total nitrogen reductions from septic tank effluent of 25 to 35% prior to reaching the water table. The de facto technology for low level nitrogen removal is the conventional OSTDS, which consists of primary treatment followed by a soil treatment unit (STU) (Table 8-1).

- Medium level onsite wastewater nitrogen removal was defined as achieving total nitrogen reductions from STE of 50 to 70% prior to reaching the water table below the OSTDS. Technologies for medium level nitrogen removal include in-tank Stage 1 biofilters with recirculation for pre-denitrification followed by a STU or an in-ground single pass Stage 1 unsaturated biofilter over a Stage 2 lignocellulosic/fine sand media mix contained in a liner. Table 8-3 provides references for the performance of such systems.

- High level onsite wastewater nitrogen removal was defined as achieving total nitrogen reductions from STE of at least 95% prior to reaching the water table. Technologies for high level nitrogen removal include (all would be followed by a STU):

    - single pass unsaturated biofilters followed by denitrification biofilters with lignocellulosic media

    - single pass unsaturated biofilters followed by denitrification biofilters with sulfur media

    - single pass unsaturated biofilters followed by denitrification biofilters with lignocellulosic and sulfur media (dual media)

    - recirculating unsaturated biofilters followed by denitrification biofilters with sulfur media

- recirculating unsaturated biofilters followed by denitrification biofilters with lignocellulosic and sulfur media (dual media)

References for the performance of such systems are provided in Table 8-5. The STU following the high level nitrogen removal system would provide additional water quality treatment.

9.4 Technical Recommendations

The FOSNRS project has demonstrated that passive nitrogen removal systems (PNRS) can provide effective and resilient nitrogen removal from onsite wastewater. Prior to moving ahead with PNRS implementation however, further technical refinements will be required of the prototype systems developed and tested in this project. The following technical recommendations are made based on the experience and results obtained during the FOSNRS project.

- The prototype PNRS installed as part of this study have operated for approximately 2 years as of this writing. While this period was long enough to establish the treatment performance of the systems, long term performance and reliability of the systems is unknown. Therefore, it is recommended that FDOH establish long term monitoring of these home systems. This would provide invaluable knowledge of continued system performance, the longevity of media, further guidance for system designs, and the long term needs for maintenance and monitoring.

- The prototype systems installed were designed and constructed based on available equipment and materials, to establish the process and performance basis for PNRS designs. Some of the equipment, tanks and media required for the PNRS were not readily available and existing materials were customized to meet the needs of the project, adding difficulty and expense. Therefore, the systems as currently designed and constructed are not ready for widespread implementation.

- Prior to implementation at the State level, several standardized PNRS designs should be established with technical specifications for system sizing and for all system components. Innovative system permits (or other new type of permit) should be developed for these initial PNRS. Other designs would eventually evolve if widespread implementation of onsite nitrogen removal was required.

- Specifications should be established for biofilter tankage and other system tankage to be used in PNRS, including tanks spaced across a range of sizes pertinent to single home PNRS.

Specifications should include specific tank designations, source, materials, dimensions, strength requirements and pre-approved suppliers.

- Specifications should be established for tank lids and covers that provide full and easy access to media within PNRS biofilters, including pre-approved suppliers, specific tank designations, source, materials, dimensions and technical specifications.

- Specifications should be established for liners used for in-ground PNRS including pre-approved suppliers, specific liner designations, source and technical specifications.

- Specifications should be established for PNRS media including pre-approved suppliers, specific media size designations, media description, source and technical specifications.

9.5 Recommendations for PNRS Implementation

Passive nitrogen removal systems (PNRS) can provide effective nitrogen removal from onsite wastewater and are a practical and resilient technology. Substantial benefits can accrue to the State of Florida through proper and judicious application of PNRS systems where necessary. There are also challenges to PNRS implementation that must be addressed. If the benefits of PNRS are to be realized in practice, the State must prepare for the implementation of PNRS systems by addressing several issues:

- Watershed/water body sensitivity to nitrogen varies widely across the state. Determination of necessary nutrient reductions to protect or improve water quality by watershed and GIS mapping of nutrient sensitive zones would allow determination of which level of nitrogen reduction is required for implementation in a given location. Nitrogen load reductions from onsite wastewater should not be required everywhere, and in many locations upgrading existing OSTDS to current standards may be enough.

- Uniform guidance for regulation and permitting specific to PNRS need to be established, and should be streamlined. The existing permitting structure as applied to the new PNRS technology may become cumbersome, leading to lack of implementation, delay, and administrative burden. Generic permitting of the initial pre-approved designs for several PNRS system could streamline permitting of PNRS systems while insuring the effective performance of installed systems.

- Uniform requirements for inspecting and maintaining PNRS systems should be established and updated as necessary. FDOH should establish a uniform policy for inspection and maintenance of PNRS systems through private or public maintenance entities

- Uniform requirements for performance monitoring of PNRS systems should be established and updated as necessary. FDOH should establish a uniform policy for performance monitoring of PNRS systems.

- FDOH should implement technology transfer and training on PNRS implementation for state personnel, county regulators, environmental engineers and scientists.

- Sufficient staffing by FDOH is crucial for PNRS implementation. Review and permitting of PNRS systems should be conducted by engineers with education and experience in wastewater treatment and by or under the supervision of a licensed Professional Engineer.

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