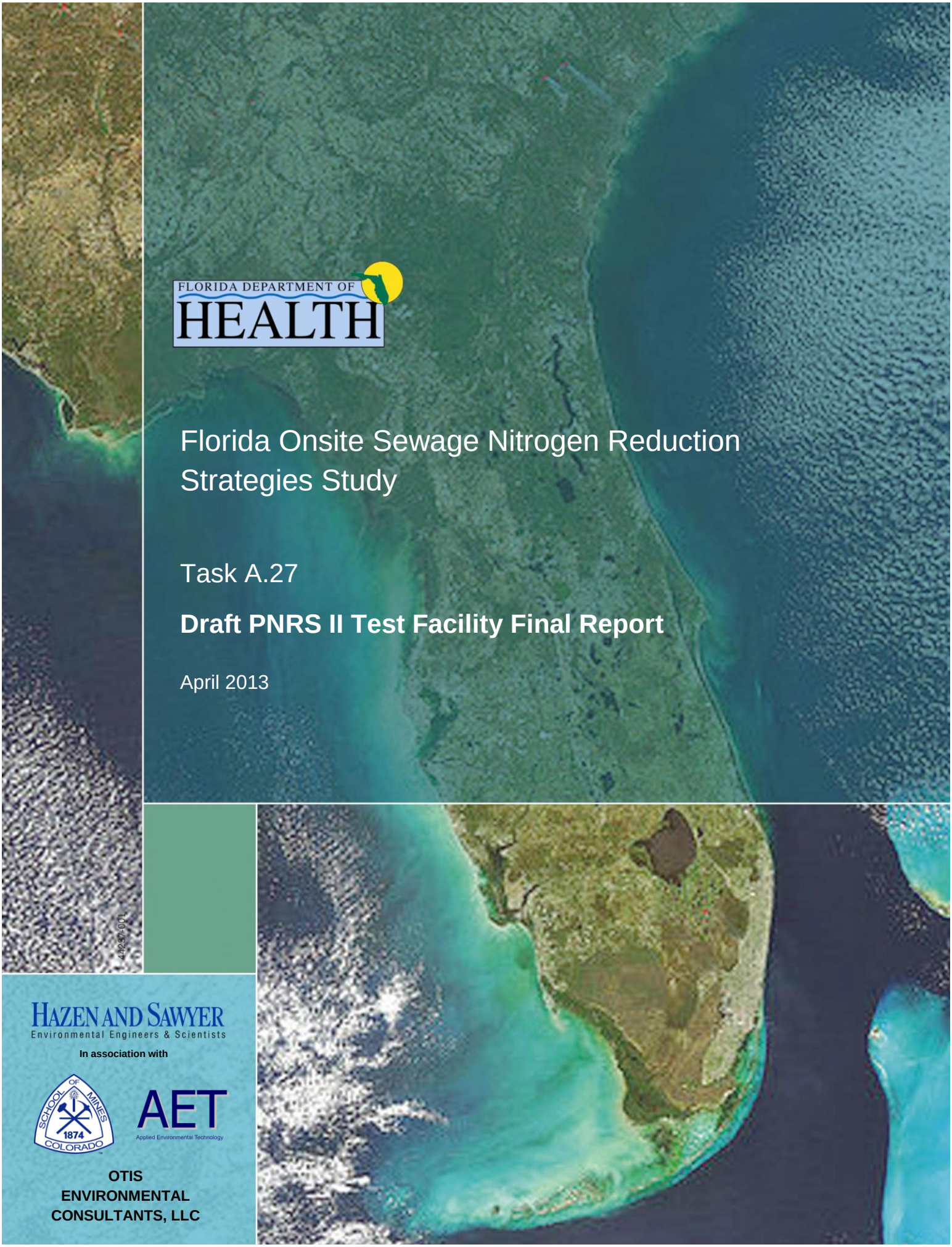

FLORIDA DEPARTMENT OF HEALTH

Florida Onsite Sewage Nitrogen Reduction Strategies Study

Task A.27

Draft PNRS II Test Facility Final Report

April 2013

4423-001

HAZEN AND SAWYER
Environmental Engineers & Scientists

In association with

SCHOOL OF MINES 1874 COLORADO

AET
Applied Environmental Technology

OTIS ENVIRONMENTAL CONSULTANTS, LLC

Florida Onsite Sewage Nitrogen Reduction Strategies Study

Task A.27
DRAFT REPORT

PNRS II Test Facility Final Report

Prepared for:

Florida Department of Health
Division of Environmental Health
Bureau of Onsite Sewage Programs
4042 Bald Cypress Way Bin #A-08
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FDOH Contract CORCL

April 2013

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Section 1.0
Study Background

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 adsorption systems commonly referred to as drainfields. These typical systems provide limited nitrogen removal prior to the renovated effluent reaching groundwater. FDOH commissioned an earlier bench-scale Passive Nitrogen Removal Study I (PNRS I) to investigate alternative methods to reduce nitrogen from onsite systems. A primary objective was to evaluate systems which operate relatively passively, with limited reliance on pumping, controls and forced aeration (Smith et al., 2008). The PNRS guidelines for passive nitrogen removing systems are OSTDS that contain at most only a single liquid pump, no mechanical aerators, and that use a reactive media for denitrification.

In the two-stage biofilter process, a first stage unsaturated biofilter is followed in series by a second stage biofilter operated in a water saturated mode. Septic tank effluent will be applied to the top of the first stage media, resulting in a downward percolation of wastewater over and through the porous media biofilter bed. The unsaturated pore spaces in the first stage media will allow air to reach microorganisms attached to the media surfaces, enabling aerobic biochemical reactions to occur. The significant target reactions are aerobic heterotrophic oxidation (by microorganisms that oxidize organic material and reduce biochemical oxygen demand), hydrolysis and ammonification (releasing ammonia), and nitrification (biochemical conversion of ammonia to nitrite and nitrate). Of particular interest are the organic and ammonia nitrogen concentrations in first stage effluent, and removal of oxidized nitrogen (nitrate and nitrite) by saturated Stage 2 biofilters. PNRS I provided a proof-of concept field demonstration of high nitrogen removal in two-stage biofiltration systems that met the FDOH passive criteria definition (Smith, 2009).

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FDOH initiated the Florida Onsite Sewage Nitrogen Reduction Strategies Study (FOSNRS) to further evaluate nitrogen management and treatment. FOSNRS Task A included a literature review and classification of nitrogen removal technologies (Hazen and Sawyer, 2009a), ranking of nitrogen removal systems and prioritization of technologies (Hazen and Sawyer, 2009b). Two stage biofiltration received a high ranking and recommendation. The Passive Nitrogen Removal Study II (PNRS II) was undertaken to evaluate nitrogen removal in numerous embodiments of two-stage biofiltration at a larger scale with a broader range of filtration media and process configurations.

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Section 2.0
Objectives

The objective of the PNRS II study was to establish pilot passive nitrogen removal systems to evaluate the effectiveness of various media and two-stage biofilter designs in removing total nitrogen from septic tank effluent. The pilot test systems consisted of various configurations of in-tank biofilters and passive in-situ systems.

The PNRS II objectives were:

- establish pilot facility to evaluate nitrogen removal by scalable two-stage biofiltration systems;
- perform experiments using actual onsite wastewater;
- evaluate various unsaturated and saturated media and process configurations;
- monitor individual performance of unsaturated, saturated, and vertically stacked unsaturated/saturated biofilters under defined operation;
- develop data sets to support design of full-scale nitrogen reduction systems at individual home sites.

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Section 3.0
Materials and Methods

The PNRS II study was previously described in the Quality Assurance Project Plan (Hazen and Sawyer, 2010a). PNRS II followed the QAPP closely in most aspects, with modifications of specific biofilter media and process sequencing which are included in this section and in the sample event and monitoring reports submitted during the study.

3.1 Pilot Systems Test Facility

3.1.1 Pilot Systems Layout

PNRS II was conducted at the Gulf Coast Research and Education Center in Wimauma, Florida. A schematic of the PNRS II test facility set-up is shown in Figure 3-1. Figure 3-2 provides a photo of the completed test facility, details of its design and construction can be found in the PNRS II Specification Report I (Hazen and Sawyer, 2010b) and PNRS II As-built documents (Hazen and Sawyer 2010c). Twenty-two biofilters were operated and evaluated, consisting of nine unsaturated Stage 1 biofilters, nine saturated Stage 2 biofilters, and four vertically stacked biofilter designs. The biofilters were categorized in four groups as listed in Table 3.1. Group A consisted of five two-stage systems which received primary effluent. The Group A systems were single pass Stage 1 biofilters directly connected to upflow Stage 2 denitrification biofilters. Figure 3-3 shows a schematic and photo of the Group A systems. Group B consisted of four Stage 1 biofilters with recirculation, which received primary effluent. Figure 3-4 illustrates these systems. Group C consisted of four Stage 2 biofilters which received composited Stage 1 effluents from Group B systems. Figure 3-5 provides a schematic and photo of these systems in place. Group D consisted of four biofilters with vertically stacked media which was unsaturated in the upper level and saturated at the lower level. Figure 3-6 shows a schematic of these systems. Three Group D systems received primary effluent, while one (UNSAT-IS4) received nitrified effluent from UNSAT-CL3.

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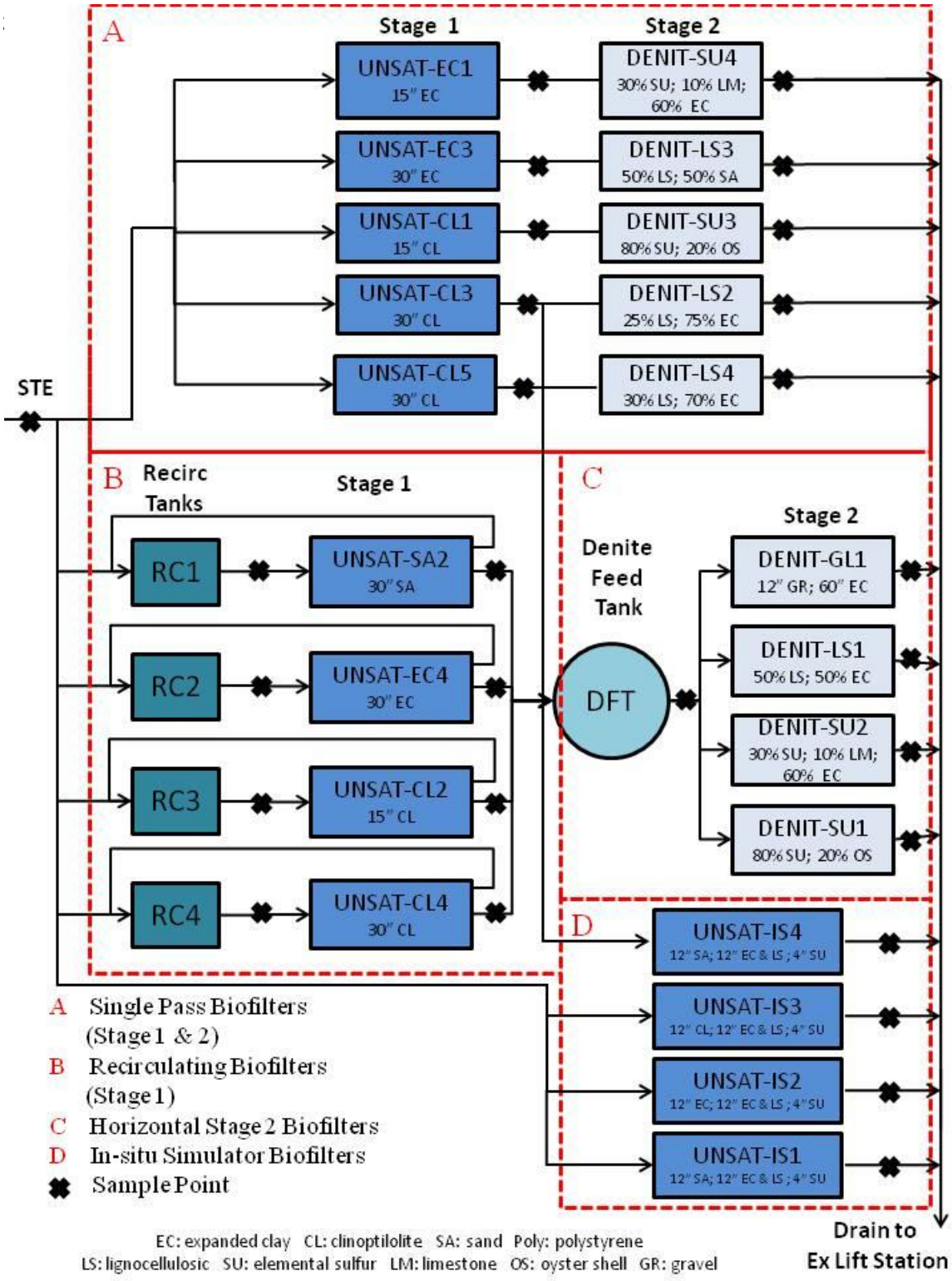

Figure 3-1: PNRS II Final Test Facility System Schematic

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Table 3.1
PNRS II Final Biofilters

Biofilter Group	Description	Influent	Biofilter & Process Designations			
A	Two Stage Biofilters Single Pass Stage 1 directly connected to Upflow Stage 2	Primary Effluent (septic tank effluent)	Stage 1 single pass / Stage 2 upflow			
			ID #	Biofilter ID	ID #	Biofilter ID
			1	UNSAT-EC1	10	DENIT-SU4
			2	UNSAT-EC3	11	DENIT-LS3
			3	UNSAT-CL1	12	DENIT-SU3
			4	UNSAT-CL3	13	DENIT-LS2
			5	UNSAT-CL5	14	DENIT-LS4
B	Two Stage Biofilters Stage 1 with effluent recycle to recirculation tank	Primary Effluent (septic tank effluent)	Recirculation Tank / Stage 1			
			ID #	Tank ID	ID #	Biofilter ID
			NA	RC1	6	UNSAT-SA2
			NA	RC2	7	UNSAT-EC4
			NA	RC3	8	UNSAT-CL2
			NA	RC4	9	UNSAT-CL4
C	Stage 2 Horizontal Saturated Biofilters	Composite nitrified effluent from Group B biofilters	15	DENIT-SU1		
			16	DENIT-SU2		
			17	DENIT-LS1		
			18	DENIT-GL1		
D	Stacked Saturated/ Unsaturated (In situ) Biofilters	Primary Effluent (septic tank effluent)	19	UNSAT-IS1		
		Primary Effluent (septic tank effluent)	20	UNSAT-IS2		
		Primary Effluent (septic tank effluent)	21	UNSAT-IS3		
		Nitrified Effluent, from UNSAT-CL3	22	UNSAT-IS4		

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Figure 3-2: Photos of PNRS II Test Facility

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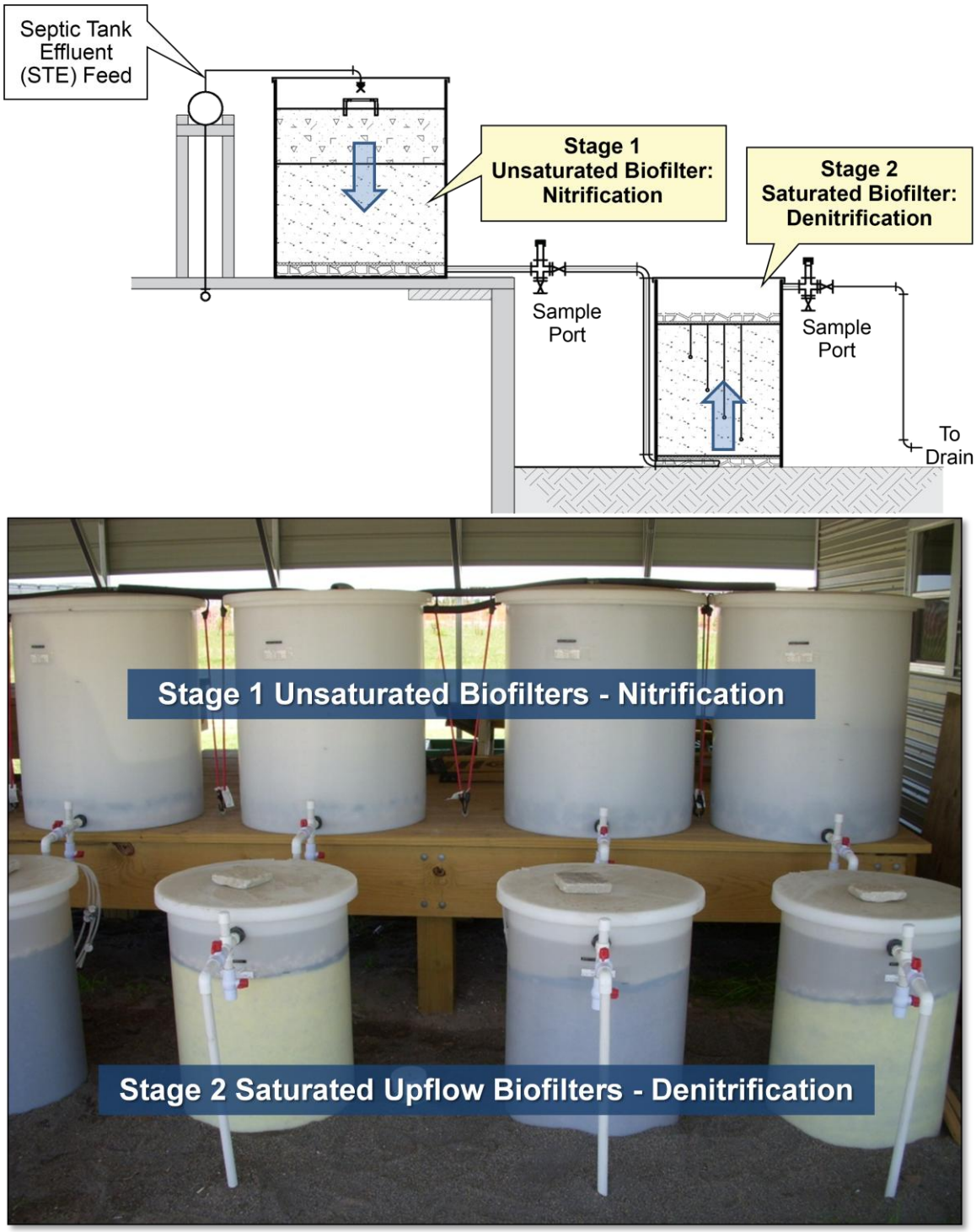

Figure 3-3: Schematic and Photo of Group A Systems

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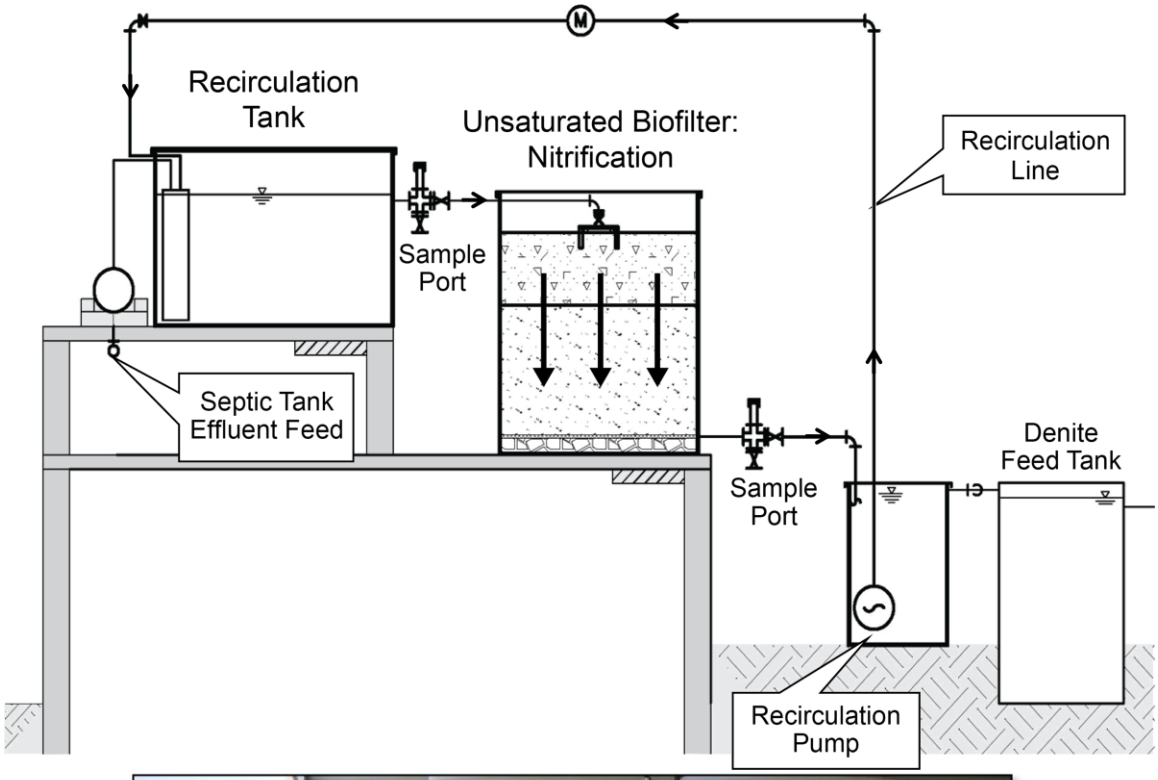

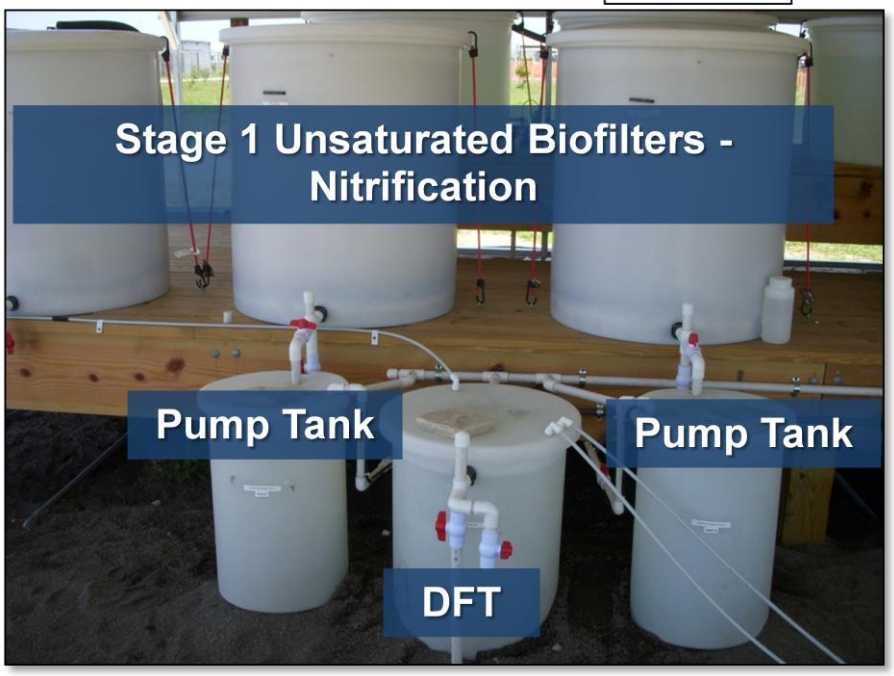

Figure 3-4: Schematic and Photo of Group B Systems

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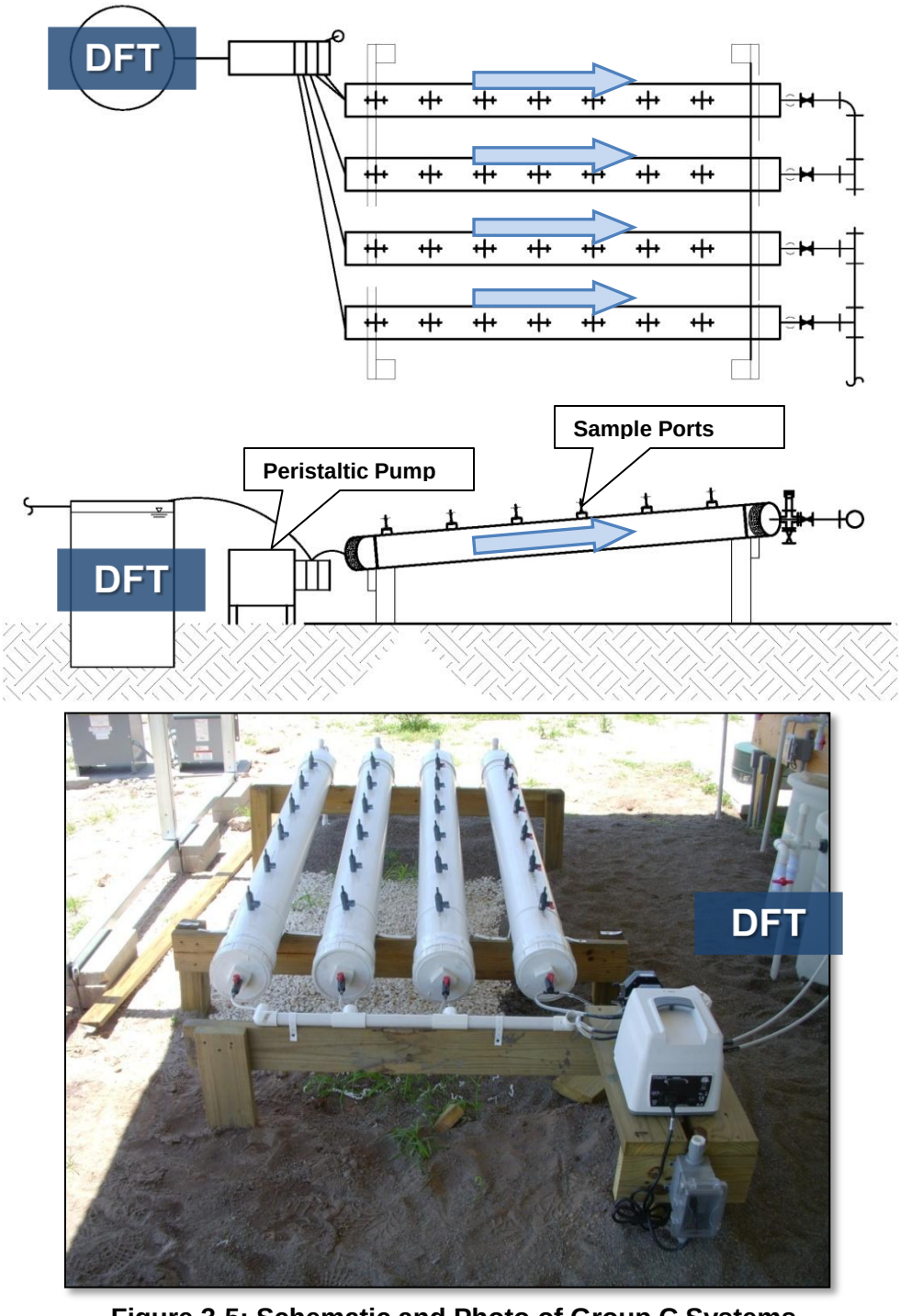

Figure 3-5: Schematic and Photo of Group C Systems

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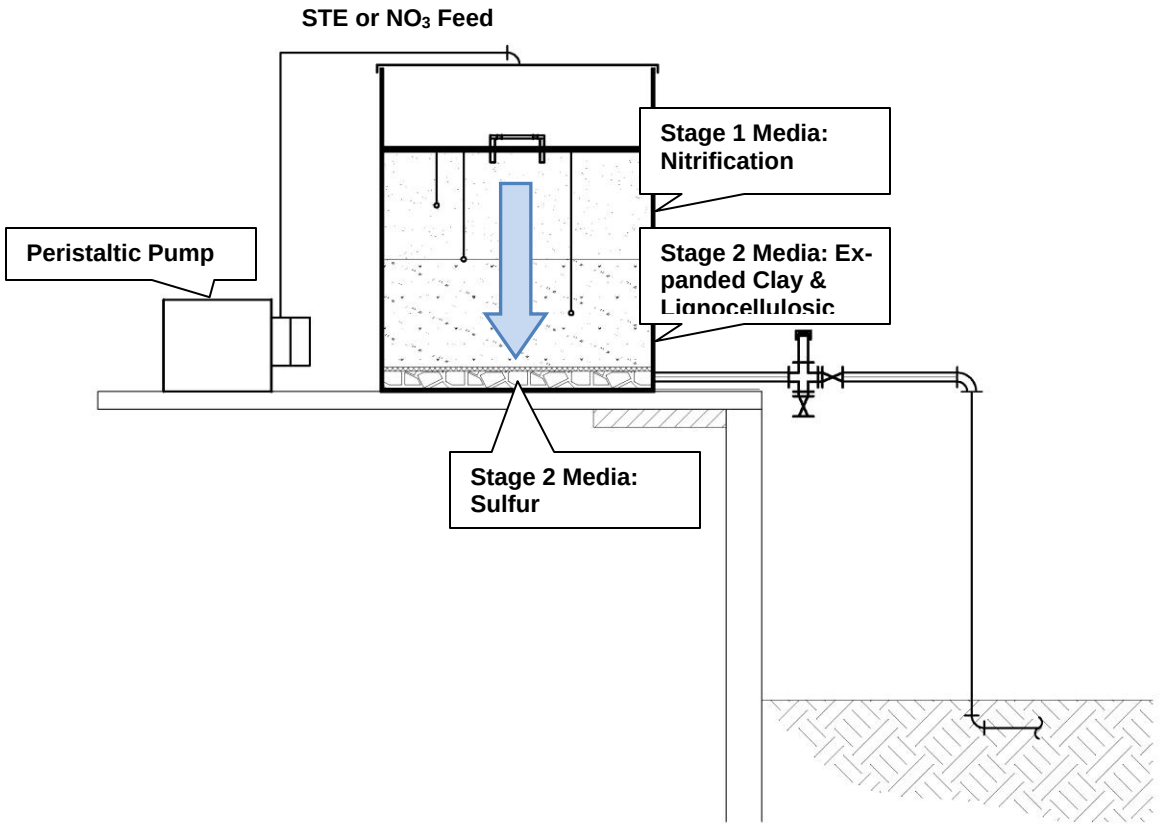

Figure 3-6: Schematic of Group D Systems

3.1.2 Design of Pilot Biofilters

The media employed in PNRS II biofilters are listed in Table 3.2 along with the sources. Stage 1 media included sand, expanded clay, clinoptilolite and expanded polystyrene. Stage 2 reactive media included elemental sulfur and lignocellulosic material (Southern yellow pine). Oyster shell, sodium sesquicarbonate or limestone were included as alkalinity sources in the Stage 2 biofilters. The details of biofilter designs employed in PNRS II are listed in Tables 3.3 through 3.6. Group A biofilter designs are shown in Table 3.3. Stage 1 and 2 biofilters are listed in their order of coupling, such that DENIT-SU4 receives effluent from UNSAT-EC1, for example. Group A Stage 1 biofilters consisted of size stratified expanded clay and clinoptilolite media, with two total media depths, larger media in the upper one third and smaller media in the bottom one third. Group A Stage 2 biofilters contained unstratified mixed media of 24 in depth, with elemental sulfur and Southern yellow pine as electron donors for denitrification. Group B systems consisted of 15 and 30 inch biofilters with sand, expanded clay and clinoptilolite media, each preceded by a recirculation

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tank (Table 3.4). Group C systems consisted of horizontal biofilters with elemental sulfur, Southern yellow pine, and dosed glycerol as electron donors (Table 3.5). Vertically stacked biofilter designs are shown in Table 3.6. Each consisted of an upper 12 inch unsaturated layer (with media of either sand, clinoptilolite, or expanded clay), a middle mixed media layer of Southern yellow pine and expanded clay, and a saturated lower layer with elemental sulfur media.

Table 3.2
PNRS II Biofilter Media

Material	Bulk density, lb/ft^3	Typical Particle Size Range as Supplied	Specifications	Supplier
Clinoptilolite ZS403H	55	1.4 – 2.38 mm	8X14 US Mesh Sieve Size	Zeox Mineral Materials Corp, Cortaro, AZ
		0.3 – 1.2 mm	16X50 US Mesh Sieve Size	
Elemental sulfur (granular)	77	2 – 4 mm	<0.5% fines	Georgia Sulfur, Valdosta, GA
Elemental sulfur (pastille)		2.0 - 3.36 mm	<0.5% fines	Southern Ag, Palmetto, FL
Glycerol	79	-	Synthetic 99%	Cole Parmer, Vernon Hills, IL
Lignocellulosic material (Southern yellow pine, sawdust)	20 – 28	3 to 30 mm		Robbins Products, Tarrytown, FL
				Suwannee Lumber Company, Cross City, FL
Livlite (expanded clay)	41	0.3 to 3.1 mm		Big River, Alpharetta, GA
Oyster shell	82	3 – 15 mm		Misc. Locations, FL
Polystyrene (expanded)	0.34 - 1.5	2.2 – 3.6 mm		JSP, Haymarket, Virginia
Sand	100	0.8 – 1.2 mm	d10 = 0.93, d50 = 1.23, U.C.= 1.4	National Suncoast Media, Gulfport, FL
		0.45 – 0.55 mm	d10 = 0.52, d50 = 0.67, U.C.= 1.4	
		0.3 - 1.2 mm	U.C. = 1.4	Standard Sand & Silica Co, Davenport, FL
Sodium Sesquicarbonate T-50	69	1 - 3 mm		Solvay, Houston, TX

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Table 3.3
Group A Biofilter Design

Process Component	Biofilter	Tank diameter, in	Media type	Media design				
				Layering	Total depth, in	Layer	Layer Thickness, in	Particle size, mm
Stage 1 Biofilter (unsaturated)	UNSAT-EC1	30	Expanded clay	Stratified	15	Upper	5	1.53-3
						Lower	10	0.3-1.53
	UNSAT-EC3	30	Expanded clay	Stratified	30	Upper	10	1.53-3
						Lower	20	0.3-1.53
	UNSAT-CL1	30	Clinoptilolite	Stratified	15	Upper	5	1.4-2.38
						Lower	10	0.30-1.2
	UNSAT-CL3	30	Clinoptilolite	Stratified	30	Upper	10	1.4-2.38
						Lower	20	0.30-1.2
	UNSAT-CL5	30	Clinoptilolite	Stratified	30	Upper	10	1.4-2.38
						Lower	20	0.30-1.2
	UNSAT-PS1[1]	30	Expanded polystyrene	Unstratified	30	-	-	2.2 - 3.6
Stage 2 Biofilter (saturated upflow)	DENIT-SU4	22	30% elemental sulfur 10% limestone 60% expanded clay	Unstratified	24	-	-	0.5-3
	DENIT-SU4[2]	22	80% elemental sulfur 20% sodium sesquicarbonate	Unstratified	24	-	-	0.5-3
	DENIT-LS3	22	50% Southern yellow pine 50% sand	Unstratified	24	-	-	1.13-30
	DENIT-LS3[3]	22	50% Southern yellow pine 50% sand	Unstratified	24	-	-	1.13-30
	DENIT-SU3	22	80% elemental sulfur 20% oyster shell	Unstratified	24	-	-	0.5-3
	DENIT-LS2	22	25% Southern yellow pine 75% expanded clay	Unstratified	24	-	-	1.13-30
	DENIT-LS2[3]	22	50% Southern yellow pine 50% expanded clay	Unstratified	24	-	-	1.13-30
	DENIT-LS4	22	30% Southern yellow pine 70% expanded clay	Unstratified	24	-	-	1.13-30
	DENIT-LS4[3]	22	30% Southern yellow pine 70% expanded clay	Unstratified	24	-	-	1.13-30

[1]Started-up as UNSAT-PS1 and was converted to UNSAT-CL5 April 14, 2011
[2]Sodium sesquicarbonate (alkalinity) media was replaced with limestone on October 25, 2010
[3]Robbins southern yellow pine media was replaced with Suwannee southern yellow pine January 28, 2011

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Table 3.4
Group B Biofilter Design

Process Component	Biofilter & Process	Tank diameter, in	Media type	Media design				
				Layering	Total depth, in	Layer	Layer Thickness, in	Particle size, mm
Recirculation Tank	RC1	30	No media	-	18	-	-	-
	RC2	30	No media	-	18	-	-	-
	RC3	30	No media	-	18	-	-	-
	RC4	30	No media	-	18	-	-	-
Stage 1 Biofilter (unsaturated)	UNSAT-SA2	30	Sand	Stratified	30	Upper	10	0.8-1.2
						Lower	20	0.45-0.55
	UNSAT-EC4	30	Expanded clay	Stratified	30	Upper	10	1.53-3
						Lower	20	0.3-1.53
	UNSAT-CL2	30	Clinoptilolite	Stratified	15	Upper	5	1.4-2.38
						Lower	10	0.30-1.2
	UNSAT-CL4	30	Clinoptilolite	Stratified	30	Upper	10	1.4-2.38
						Lower	20	0.30-1.2

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Table 3.5
Group C Biofilter Design

Process Component	Biofilter	Column diameter, in	Media design			
			Layering	Total length, in	Media type	Particle size, mm
Stage 2 Biofilter (unsaturated horizontal)	DENIT-SU1	6.0	Unstratified	72	80% elemental sulfur 20% oyster shell	1.13-3
	DENIT-SU2	6.0	Unstratified	72	30% elemental sulfur 10% limestone 60% expanded clay	1.13-3
	DENIT-SU2[1]	6.0	Unstratified	72	30% elemental sulfur 10% limestone 60% expanded clay	1.13-3
	DENIT-LS1	6.0	Unstratified	72	50% Southern yellow pine 50% expanded clay	1.13-30
	DENIT-LS1[2]	6.0	Unstratified	72	50% Southern yellow pine 50% expanded clay	1.13-30
	DENIT-GL1	6.0	Stratified	72	12 in. gravel	6-12
					60 in. expanded clay	1.13-3

[1]Sodium sesquicarbonate (alkalinity) media was replaced with limestone on October 25, 2010
[2]Robbins southern yellow pine media was replaced with Suwannee southern yellow pine January 28, 2011

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Table 3.6
Group D Biofilter Design

Process Component	Biofilter	Tank diameter, in	Media design (stratified layering)				
			Total depth, in	Layer	Layer Thickness, in	Media type	Particle size, mm
Vertically Stacked Media (In situ simulator)	UNSAT-IS1	30	30	Upper	12	100% sand	0.3-1.2
				Middle	12	40% Southern yellow pine	1.13-30
						60% expanded clay	
				Lower	4	100% elemental sulfur	1.13-3
	UNSAT-IS1[1]	30	30	Upper	15	100% sand	0.3-1.2
				Lower	12	45% expanded clay	1.13-30
						35% Southern yellow pine	
						20% elemental sulfur	
	UNSAT-IS2	30	30	Upper	12	100% expanded clay	1.53-3
				Middle	12	40% Southern yellow pine	1.13-30
						60% expanded clay	
				Lower	4	100% elemental sulfur	1.13-3
	UNSAT-IS2[1]	30	30	Upper	12	100% sand	0.3-1.2
				Lower	12	45% expanded clay	1.13-30
						35% Southern yellow pine	
						20% elemental sulfur	
	UNSAT-IS3	6	30	Upper	12	100% clinoptilolite	0.5-2.38
				Middle	12	40% Southern yellow pine	1.13-30
						60% expanded clay	
				Lower	4	100% elemental sulfur	1.13-3
	UNSAT-IS3[1,2]	6	30	Upper	12	100% sand	0.3-1.2
				Middle	10	40% Southern yellow pine	1.13-30
						60% expanded clay	
				Lower	3	100% elemental sulfur	1.13-3

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Table 3.6 (continued)
Group D Biofilter Design

Process Component	Biofilter	Tank diameter, in	Media design (stratified layering)				
			Total depth, in	Layer	Layer Thickness,	Media type	Particle size, mm
Vertically Stacked Media (In situ simulator)	UNSAT-IS4	6	30	Upper	12	100% sand	0.3-1.2
				Middle	12	40% Southern yellow pine	1.13-30
						60% expanded clay	
				Lower	4	100% elemental sulfur	1.13-3
	UNSAT-IS4[1,2]	6	30	Upper	12	100% sand	0.3-1.2
				Middle	10	40% Southern yellow pine	1.13-30
						60% expanded clay	
				Lower	3	100% elemental sulfur	1.13-3

[1]Robbins southern yellow pine media was replaced with Suwannee southern yellow pine January 28, 2011
[2]UNSAT-IS3 and IS4 columns initially started-up October 18, 2010

3.1.3 Influent Wastewater

The source of wastewater supplied to PNRS II was primary effluent collected as a sidestream from the wastewater facility at the Gulf Coast Research and Education Center (GCREC). The wastewater supply system for PNRS II is shown in Figure 3-7. Wastewater was withdrawn from the first septic tank in the GCREC system and directed to the second chamber of PNRS II Tank 1, which contained the pumps that supplied primary effluent to biofilters in Groups A, B and D. A pipe from PNRS II Tank 1 to the second septic tank in the GCREC system returned excess diverted wastewater to the GCREC system (Figure 3-7).

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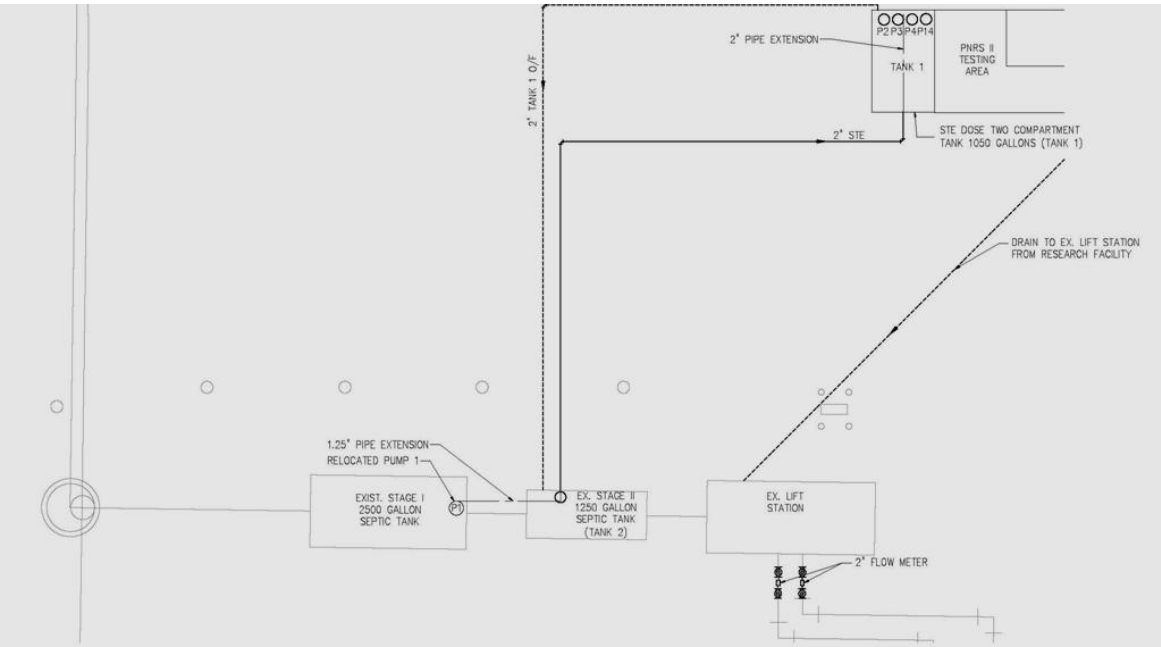

Figure 3-7: Primary Effluent Source

3.1.4 Target Operation

Operation of the PNRS II biofilter systems is summarized in Tables 3.7 through 3.11. Target loading to Group A Stage 1 biofilters was a surface loading of 3 gal/ft2-day, which provided a 5.7 gal/ft2-day surface loading to Group A Stage 2 biofilters (Table 3.7). Estimated water residence times were 5 to 11 hours in Stage 1 and approximately 26 hours in Stage 2. Target loading to Group B biofilters was a surface loading of 3 gal/ft2-day forward flow and a recycle ratio of 3:1 of biofilter effluent to wastewater forward flow. This provided a 12 gal/ft2-day total flow surface loading to the Group B biofilters and water residence times 1.9 to 3.7 hours in the biofilters and 22 hours in the recirculation tanks (Table 3.8). Target loading to Group C biofilters was a surface loading of 10 gal/ft2-day which provided an estimated water residence time of 43 hours (Table 3.9). Target loadings to Group D biofilters were surface loadings of 1.1 to 1.2 gal/ft2-day which provided an estimated water residence time of 38 to 41 hours (Table 3.10). The system to dose glycerol to DENIT-GL1 consisted of a peristaltic pump, a glycerol dosing solution kept in a cooler, and a connection of dosing flow tube to the wastewater influent line of DENIT-GL1. The dosing pump was connected to the same timer as the influent wastewater pump. Glycerol dosing was established to provide sufficient electron donor to reduce both dissolved oxygen and oxidized nitrogen (nitrate and nitrite) in

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influent wastewater (Table 3.11). The dosing flowrate and glycerol concentration in the dosing solution were adjusted to provide the target glycerol dose (Table 3.11).

Table 3.7
Group A Biofilter Operation

Process Component	Biofilter	Target Flowrate, L/day	Design Surface Loading Rate, gal/ft2-day	Estimated Mean Pore Residence Time @ Design, hour
Stage 1 Biofilter (unsaturated)	UNSAT-EC1	55.7	3.0	5.0
	UNSAT-EC3	55.7	3.0	10.1
	UNSAT-CL1	55.7	3.0	5.6
	UNSAT-CL3	55.7	3.0	11.2
	UNSAT-CL5	55.7	3.0	11.2
Stage 2 Biofilter (saturated upflow)	DENIT-SU4	55.7	5.6	26
	DENIT-LS3	55.7	5.6	26
	DENIT-SU3	55.7	5.6	26
	DENIT-LS2	55.7	5.6	26
	DENIT-LS4	55.7	5.6	26

Table 3.8
Group B Biofilter Operation

Process Component	Biofilter & Process	Target Flowrate, L/day[1]	Design Surface Loading Rate, gal/ft2-day[1]	Estimated Mean Pore Residence Time @ Design, hour
Recirculation Tank	RC1	222.8	8.3	22.4
	RC2	222.8	8.3	22.4
	RC3	222.8	8.3	22.4
	RC4	222.8	8.3	22.4
Stage 1 Biofilter (unsaturated)	UNSAT-SA2	222.8	12.0	3.0
	UNSAT-EC4	222.8	12.0	3.4
	UNSAT-CL2	222.8	12.0	1.9
	UNSAT-CL4	222.8	12.0	3.7

[1]includes recirculation flowrate @ recirculation ratio = 3

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Table 3.9
Group C Biofilter Operation

Process Component	Biofilter	Target Flowrate, L/day[1]	Design Surface Loading Rate, gal/ft2-day[1]	Estimated Mean Pore Residence Time @ Design, hour
Stage 2 Biofilter (unsaturated horizontal)	DENIT-SU1	7.41	10.0	43.1
	DENIT-SU2	7.41	10.0	43.1
	DENIT-LS1	7.41	10.0	43.1
	DENIT-GL1	7.41	10.0	43.1

Table 3.10
Group D Biofilter Operation

Process Component	Biofilter	Target Flowrate, L/day[1]	Design Surface Loading Rate, gal/ft2-day[1]	Estimated Total Mean Residence Time @ Design, hour
Vertically Stacked Media (In situ simulator)	UNSAT-IS1	14.8	1.10	41.3
	UNSAT-IS2	14.8	1.10	41.3
	UNSAT-IS3	0.893	1.20	37.9
	UNSAT-IS4	0.893	1.20	37.9

Table 3.11
Glycerol Dosing to DENIT-GL1

surface loading rate	gal/ft2-day	10
target wastewater flowrate	L/day	7.409
influent DO	mg/L	8.0
influent NO3-N	mg/L	75.0
$Y_{glycerol/O2}$	g/g	2.74
$Y_{glycerol/NO3-N}$	g/g	7.80
glycerol dose	gram/day	4.50
dose frequency	dose/day	24
wastewater dose volume	ml	309
glycerol dosing solution concentration	gram/L	50.4
glycerol solution dose volume	ml	3.72

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3.2 Performance Monitoring

The pilot facility was operated continuously for 962 days. Operation was initiated on May 17, 2010 (Experimental Day 0) and continued through January 3, 2013 (Experimental Day 962). The monitoring plan followed the procedures detailed in the Quality Assurance Project Plan (Hazen and Sawyer, 2010a).

3.2.1 Baseline Monitoring

3.2.1.1 Monitoring Events

The monitoring history for PNRS II is shown in Table 3.12. Six full monitoring events (1 through 6) were conducted with an average separation time of 63 days, and two partial monitoring events were conducted on Days 402 and 407. Monitoring events 1 through 7 comprise the main basis for performance evaluation of unsaturated and saturated biofilters in Groups A, B, and C. Data from Monitoring Events 5, 6, 8, 9 and 10 were used for performance assessment of the in situ biofilters Group D.

Table 3.12
PNRS II Monitoring

Sample Event	Date	Experimental Day
Start-up	May 17, 2010	0
Sample Event 1	July 1, 2010	45
Sample Event 2	August 31, 2010	106
Sample Event 3	November 10, 2010	177
Sample Event 4	January 13, 2011	241
Sample Event 5	March 17, 2011	304
Sample Event 6	May 19, 2011	367
Sample Event 7	June 23, 2011	402
Sample Event 8	June 28, 2011	407
Sample Event 9	September 15, 2011	486
Sample Event 10	March 20, 2013	1,038

3.2.1.2 Monitoring Locations

Thirty-two specific monitoring locations and their designations are listed in Table 3.13. They include primary effluent (i.e. septic tank effluent), 22 biofilter final effluents (10 Group A, 4 each in Groups B, C, D), 4 intermediate biofilter points (Group D), 4 recirculation tank effluents (Group B), and one composite effluent (Group C).

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Table 3.13
PNRS II Sample Identification

Group (Figure 3-1)	Sample Location	Sample Identification
	STE PNRS II Storage Tank 1	PNRS II-STE-T1
A	Stage 1 Single Pass Biofilters	UNSAT-EC1
		UNSAT-EC3
		UNSAT-CL1
		UNSAT-CL3
		UNSAT-CL5
	Stage 2 Single Pass Upflow Biofilters	DENIT-SU4
		DENIT-LS3
		DENIT-SU3
		DENIT-LS2
		DENIT-LS4
B	Recirculation Tanks	RC1
		RC2
		RC3
		RC4
	Stage 1 Recirculating Biofilters	UNSAT-SA2
		UNSAT-EC4
		UNSAT-CL2
		UNSAT-CL4
C	Denite Feed Collection Tank	DFT
	Stage 2 Horizontal Biofilters	UNSAT-SU1
		UNSAT-SU2
		UNSAT-LS1
		UNSAT-GL1
D	In Situ In-Tank Simulator Single Pass Biofilter	UNSAT-IS1
		UNSAT-IS2
		UNSAT-IS3
		UNSAT-IS4
	In Situ In-Tank Simulator Single Pass Biofilter Intermediate Sample Ports (below EC & LS mixture and above SU layer)	UNSAT-IS1-SP
		UNSAT-IS2-SP
		UNSAT-IS3-SP
		UNSAT-IS4-SP

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3.2.1.3 Monitoring Procedures

Flow rates for all PNRS II systems were calibrated at initial start-up. The flow rates were then measured and recorded at each sampling event and adjusted as necessary to maintain flow rates consistent with the experimental design following the sampling event. Flow volumes were measured just after sampling and field analyses and represent the flow rates in effect during the water quality monitoring.

Influent wastewater (GCREC septic tank effluent) was collected from the feed line connecting STE Storage Tank 1 (PNRS II-STE-T1) to the Group A Stage 1 biofilters. Sampling was performed by initiating a manual dose event on the process control panel until sufficient sample volume was collected in a clean sample container. Biofilter and recirculation tank effluents were sampled by directing the entire effluent flow into a large, clean sample container over a period of time sufficient to obtain the desired sample volume (approximately 3.5 liters). Sample containers were immediately placed in coolers on ice prior to subdivision of the composited sample.

The composite samples in the 3.5 liter sample containers were then subdivided into analysis-specific sample containers. The analysis-specific containers 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.

Equipment blank, field blank, and field sample duplicates were taken. The equipment blank was collected using a previously cleaned sample collection bottle. The bottle was filled with distilled water provided by the laboratory and allowed to sit for eight minutes. The sample containers were then analyzed for the same parameters as the samples. The field blank was collected by filling sample containers with distilled water that had been transported from the laboratory into the field along with the other sample containers. The field sample duplicate was collected immediately subsequent to the regular sample.

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 3.14). Temperature (Temp), dissolved oxygen (DO), and oxidation-reduction potential (ORP) were measured with probe tips placed in flow through samplers located directly in the outlet pipe at each sample location. Specific conductance and pH were measured using external sample collection reservoirs. The influent and effluent samples were analyzed by the laboratory for: total alkalinity, total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH_3-N), nitrate/nitrite nitrogen (NO_3+NO_2)-N, carbonaceous biochemical oxygen demand ($CBOD_5$), total dissolved solids (TDS), total

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suspended solids (TSS), and chemical oxygen demand (COD). Selected sample events included anlaysis for total phosphorus (TP) and fecal coliform (fc). For the denitrification biofilters containing elemental sulfur media, influent and effluent sample analyses were also conducted for sulfate (SO_4) and hydrogen sulfide (H_2S). Analytical parameters, analytical methods, and detection limits for these analyses are listed in Table 3.15.

Table 3.14
Field Analyses Methods

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

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Table 3.15
Laboratory Analyses Methods

Analytical Parameter	Method of Analysis	Laboratory Detection Limit (mg/L)
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_3+NO_2)-N	EPA353.2	0.01 mg/L
Carbonaceous BOD ($CBOD_5$)	SM 5210B	2 mg/L
Total Dissolved Solids (TDS)	SM 2540C	10 mg/L
Total Suspended Solids (TSS)	SM 2540D	1 mg/L
Chemical Oxygen Demand (COD)	EPA 410.4	10 mg/L
Total Phosphorus (TP)	SM 4500PE	0.01 mg/L
Fecal Coliform (fecal)	SM9222D	1 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

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3.2.2 Solute Profiling in Saturated Biofilters

Solute profiles of denitrification biofilters were collected four times in the study (Experimental Day 107, 242, 305 and 487). All samples were analyzed for (NO_3+NO_2)-N, and sulfate was included for samples collected from sulfur containing biofilters. For a single biofilter, the order of sample collection started in the farthest downstream collection point and proceeded upstream. For the Group A upflow biofilters, samples were collected by connecting a peristaltic pump to the stainless steel drivepoint samplers which were installed within the biofilter media at various depths (see Figure 3-3). For the Group C horizontal biofilters, samples were collected from sample ports that were installed along the length of the biofilter (see Figure 3-5).

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Section 4.0
Results and Discussion

4.1 Monitoring Events

As discussed in Section 3.2.1.1, ten monitoring events were conducted over 1,038 days by the schedule shown in Table 4.1. Each sampling event consisted of monitoring of field parameters, collection of water samples for laboratory analyses, and measurement of flow volumes and adjustment of flow rates if warranted. The first seven sampling events provided the datasets used for the performance assessment of the majority of the PNRS II systems while Sample Event 8, 9 and 10 provided additional monitoring data for the In Situ biofilters as described below.

A comprehensive summary of the operating periods for each biofilter and their associated sample events is presented in Table 4.2. Operating periods for individual biofilters were distinguished if significant modifications were made to their configuration or operation during the pilot study. This was necessary in order to delineate the specific sample events that comprise the basis for performance evaluation of each biofilter. For eleven biofilters, no modification was made and their performance assessment was based on data from six to seven sample events in Operating Period 1 (Table 4.2). Data from operating period 1b was used for performance assessment of five denitrification biofilters (Table 4.2). The original media in three lignocellulosic biofilters was replaced with a new lignocellulosic media after Sample Event 4 in a trial to improve performance. Two sulfur denitrification biofilters were modified after Sample Event 2 by replacing the original alkalinity releasing portion of the media mix. Therefore, data from Periods 1b represent steady operation under the modified condition for these five denitrification biofilters.

Unsaturated biofilter UNSAT-CL5 was established after Sample Event 5, and was monitored in only two sample events. Prior to the establishment of UNSAT-CL5, the bioreactor tank contained a polystyrene media unsaturated biofilter. The polystyrene biofilter exhibited operational issues and poor performance, and required high recycle rates to achieve less than optimal performance. It was determined that this biofilter would not meet the goals of the study, and its operation and monitoring was discontinued.

For the glycerol fed denitrification biofilter (DENIT-GL1), period 1b corresponds to the monitoring period after which a successful glycerol dosing system was established. The In Situ Biofilters underwent several modifications prior to Operating Period 4, which is

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the basis for their performance evaluation. Modifications included media configuration, applied flowrate, and the establishment of a monitoring location above the sulfur layer in three of the units. The number of sample event values used in the performance assessment of each biofilter ranged from a maximum of seven to two for UNSAT-CL5 (Table 4.2).

Table 4.1
PNRS II Monitoring Events

Sample Event	Date	Experimental Day
Start-up	May 17, 2010	0
Sample Event 1	July 1, 2010	45
Sample Event 2	August 31, 2010	106
Sample Event 3	November 10, 2010	177
Sample Event 4	January 13, 2011	241
Sample Event 5	March 17, 2011	304
Sample Event 6	May 19, 2011	367
Sample Event 7	June 23, 2011	402
Sample Event 8	June 28, 2011	407
Sample Event 9	September 15, 2011	486
Sample Event 10	March 20, 2013	1,038

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Table 4.2
PNRS II Monitoring Events by Operating Periods

Biofilter ID	SE 1	SE 2	SE 3	SE 4	SE 5	SE 6	SE 7	SE 8	SE 9	SE 10	OP 1	OP 2	OP 3
Stage 1 (Unsaturated) Single Pass											Stage 1 Single Pass (n)		
UNSAT-EC1	1	1	1	1	1	1			2	3	6	1	1
UNSAT-EC3	1	1	1	1	1	1	1		2	3	7	1	1
UNSAT-CL1	1	1	1	1	1	1			2	3	6	1	1
UNSAT-CL3	1	1	1	1	1	1	1		2	3	7	1	1
UNSAT-PS1	X	X	X	X	X								
UNSAT-CL5						1	1		2	3	2	1	1
Stage 1 (Unsaturated) Recirculating											Stage 1 Recirculating (n)		
UNSAT-SA2	1	1	1	1	1	1			2	3	6	1	1
UNSAT-EC4	1	1	1	1	1	1			2	3	6	1	1
UNSAT-CL2	1	1	1	1	1	1			2	3	6	1	1
UNSAT-CL4	1	1	1	1	1	1			2	3	6	1	1

Operating period 1
Operating period 2, increased hydraulic loading rate
Operating period 3, post mortem

Biofilter ID	SE 1	SE 2	SE 3	SE 4	SE 5	SE 6	SE 7	SE 8	SE 9	SE 10	OP 1	OP 1a	OP 1b	OP 2	OP 3
Stage 2 (Saturated) Upflow											Stage 2 (Saturated) Upflow (n)				
DENIT-SU4	1a	1a	1b	1b	1b	1b			2	3		2	4	1	1
DENIT-LS3	1a	1a	1a	1a	1b	1b	1b		2	3		4	3	1	1
DENIT-SU3	1	1	1	1	1	1			2	3	6			1	1
DENIT-LS2	1a	1a	1a	1a	1b	1b	1b		2	3		4	3	1	1
DENIT-LS4	1a	1a	1a	1a	1b	1b	1b		2	3		4	3	1	1
Stage 2 (Saturated) Horizontal											Stage 2 (Saturated) Horizontal (n)				
DENIT-SU1	1	1	1	1	1	1			2	2	6			2	
DENIT-SU2	1a	1a	1b	1b	1b	1b			2	2		2	4	2	
DENIT-LS1	1a	1a	1a	1a	1b	1b	1b		2	2		4	3	2	
DENIT-GL1	1a	1a	1b	1b	1b	1b			2			2	4	1	

Opearing period 1
Operating period 1a
Operating period 1b, media modification
Operating period 2, increased hydraulic loading rate
Operating period 3, post mortem

Biofilter ID	SE 1	SE 2	SE 3	SE 4	SE 5	SE 6	SE 7	SE 8	SE 9	SE 10	OP 1	OP 2	OP 3	OP 4
Stacked Unsaturated/Saturated (In situ) Biofilters											Stacked In situ Biofilters (n)			
UNSAT-IS1	1	2	3	3	4	4		4	4	4	1	1	2	5
UNSAT-IS2	1	2	2	2	4	4		4	4	4	1	3		5
UNSAT-IS3			3	3	4	4		4	4				2	4
UNSAT-IS4			3	3	4	4		4	4				2	4

Operating period 1, unsaturated operation
Operating period 2, saturated the bottom denitrification media layer
Operating period 3, media modification
Operating period 4, media modification

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4.2 Applied Flowrate

Monitored flowrates are summarized in Table 4.3. The mean relative error is the average percent difference of the monitored flowrate from the target flowrate. Mean biofilter flowrates were within 10% of the target wastewater application rates using data for the core performance evaluation period (Table 4.2, Operating Period 1, 1b or 4). Standard deviations of flowrates were generally less than 15%.

Table 4.3
PNRS II Monitored Flowrates

Biofilter Group	Process Component	Biofilter	Flowrate, L/day					Mean Relative Error, %
			Target	Mean	Standard Deviation	Maximum	Minimum	
A	Stage 1 Biofilter (unsaturated)	UNSAT-EC1	55.7	56.9	5.2	64.3	50.8	2.3
		UNSAT-EC3		55.9	6.2	65.3	47.3	0.5
		UNSAT-CL1		57.8	2.1	60.5	55.7	3.9
		UNSAT-CL3		53.7	6.2	63.6	45.1	-3.4
		UNSAT-CL5		57.5	4.0	60.4	54.7	3.4
	Stage 2 Biofilter (saturated upflow)	DENIT-SU4	55.7	51.0	2.2	53.9	48.5	-8.3
		DENIT-LS3		57.2	3.6	61.2	54.2	2.8
		DENIT-SU3		52.6	7.5	58.2	37.9	-5.5
		DENIT-LS2		56.0	8.3	61.9	50.2	0.7
		DENIT-LS4		59.8	4.6	64.8	55.9	7.4
B	Stage 1 Biofilter (unsaturated)	UNSAT-SA2	222.6	214.6	5.2	221.7	208.6	-3.6
		UNSAT-EC4		224.5	10.5	242.2	216.5	0.9
		UNSAT-CL2		220.2	3.8	224.4	216.6	-1.1
		UNSAT-CL4		182.5	73.2	223.7	51.8	-18.0
C	Stage 2 Biofilter (unsaturated horizontal)	DENIT-SU1	7.41	7.3	0.2	7.6	7.2	-1.0
		DENIT-SU2		7.4	0.2	7.6	7.1	-0.7
		DENIT-LS1		7.2	0.0	7.2	7.2	-2.5
		DENIT-GL1		7.1	0.2	7.2	6.8	-4.7
D	Vertically Stacked Media (In situ simulator)	UNSAT-IS1	14.8	17.9	2.2	19.4	16.3	20.7
		UNSAT-IS2		19.2	2.2	20.8	17.6	29.6
		UNSAT-IS3	0.893	0.8	0.1	0.8	0.7	-14.0
		UNSAT-IS4		0.8	0.1	0.9	0.8	-7.3

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4.3 Primary Effluent Quality

Primary effluent (PE) quality over the course of the study is summarized in Table 4.4 and Figure 4-1. Five day carbonaceous oxygen demand ($CBOD_5$) was generally in the 50 to 90 mg/L range, which is on the lower side of typical single family home values but not atypical. Mean total suspended solids (TSS) was 91 mg/L which is in a typical single family home range. Total nitrogen (TN) was generally 35 to 75 mg/L, which is a typical range. Other water quality parameters in the primary effluent were within typical ranges for single family residential wastewater.

Table 4.4
PNRS II Primary Effluent Quality

Parameter, mg/L	n	Mean	SD	Min	Max
Temp, C	10	24.76	4.39	13.7	28.3
pH, pH units	10	7.1	0.35	6.4	7.6
Dissolved Oxygen	8	1.41	1.21	0.040	2.8
Specific Conductivity, uS	10	1,014	196	649	1,250
Total Alkalinity	9	332	87	210	430
C-BOD_5	10	66.8	27.0	22	94
COD	6	251.7	69.7	180	380
TSS	10	90.9	136.1	15	467
TDS	7	390	80.4	240	470
TN	9	55.5	19.9	30	80
TKN	10	55.8	18.8	30	80
Org N	9	9.1	3.7	5	15
NH_3-N	9	46.3	19.1	20	67
(NO_3+NO_2)-N	9	0.035	0.019	0.010	0.06
Total Phosphorus	3	9.0	3.5	6.6	13.0
Fecal coliform, cfu/100 ml	5	19,236	32,585	80	77,000

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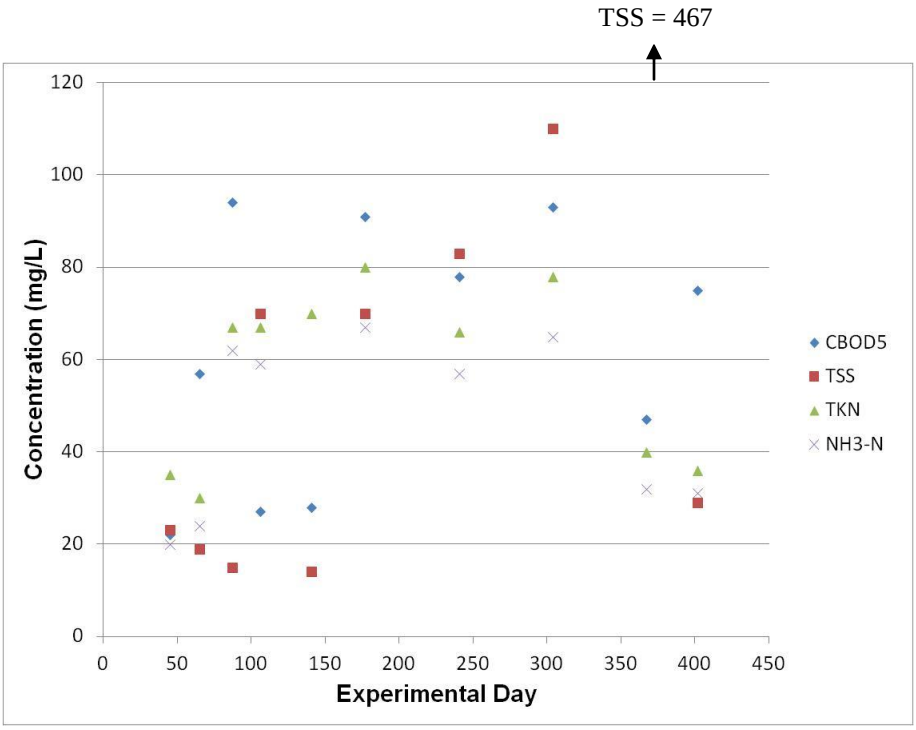

Figure 4-1:
PNRS II Primary Effluent Quality

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4.4 Biofilter Performance

4.4.1 Stage 1 (Unsaturated) Biofilters

Unsaturated biofilters include Group A Stage 1 single pass biofilters and Group B biofilters with recycle (Table 3.1).

4.4.1.1 Stage 1 (Unsaturated) Biofilters Modifications

In Sample Event 1, the unsaturated single pass biofilter with polystyrene media (UNSAT-PS1) exhibited limited reduction of organic nitrogen and ammonia as well as a lower effluent dissolved oxygen than the other single pass Stage 1 unsaturated biofilters. Visual observations of the media surface suggested that the STE application system resulted in a majority of dosing in the central area of the horizontal cross section of the media surface. Flow monitoring confirmed that water transported rapidly through the polystyrene media following an applied STE dose, unlike the other single pass Stage 1 biofilters. This not unexpected result can be attributed to the much larger media size of polystyrene media and its limited water retention characteristics versus other Stage 1 media. The results of Sample Event 2 also showed unacceptable performance of the polystyrene biofilter as currently configured. Devices to more uniformly distribute the flow were investigated. Upon further evaluation and analyses, however, it was concluded that the properties of polystyrene media would not be compatible with a practical, passive single pass or recycle unsaturated biofilter. Therefore, the polystyrene biofilter was replaced with clinoptilolite media (UNSAT-CL5) on April 14, 2011.

4.4.1.2 Stage 1 (Unsaturated) Biofilters Performance

Unsaturated biofilter effluent nitrogen concentrations are presented in Figures 4-2 through 4-10, which contain time series plots for influent (STE) TN, effluent TN, effluent (NO_3+NO_2)-N, and effluent NH_3-N. It is noted that in all unsaturated biofilters, effluent TN values are less than STE influent values. In the recycle biofilters, TN removal occurs in all sample events and is more pronounced. This result is expected and is due ostensibly to pre-denitrification. In all unsaturated biofilters, (NO_3+NO_2)-N profiles follow closely under the TN profiles, indicating that (NO_3+NO_2)-N comprises the majority of effluent nitrogen. The difference between effluent TN and effluent (NO_3+NO_2)-N represents the sum of organic and ammonia nitrogen and for all unsaturated effluents is generally between 2 to 4 mg/L. Ammonia levels are quite low in the effluents of all of the unsaturated biofilters, and consistently for every sample event.

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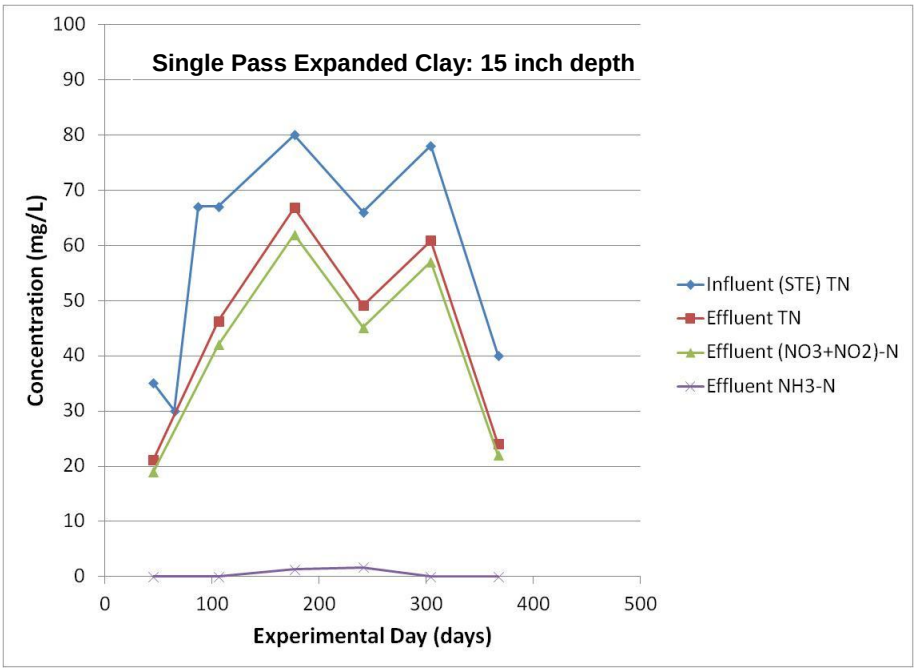

Figure 4-2:
UNSAT-EC1 Nitrogen Time Series

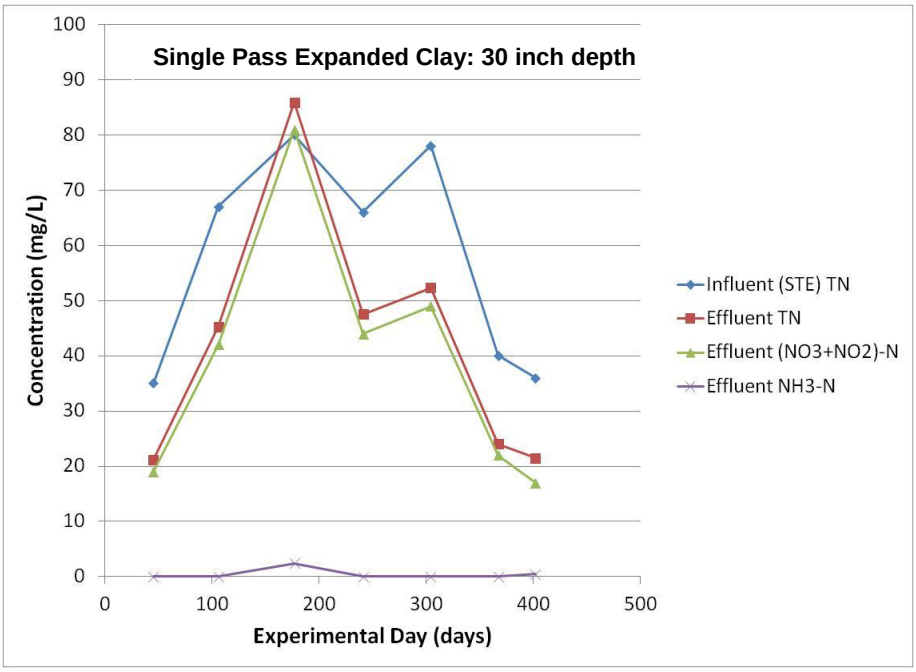

Figure 4-3:
UNSAT-EC3 Nitrogen Time Series

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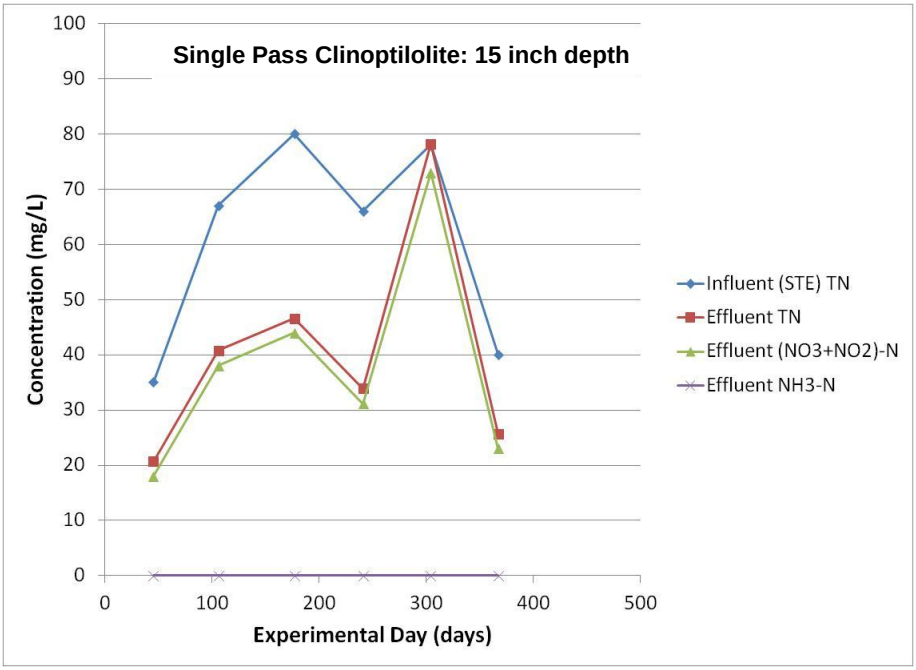

Figure 4-4:
UNSAT-CL1 Nitrogen Time Series

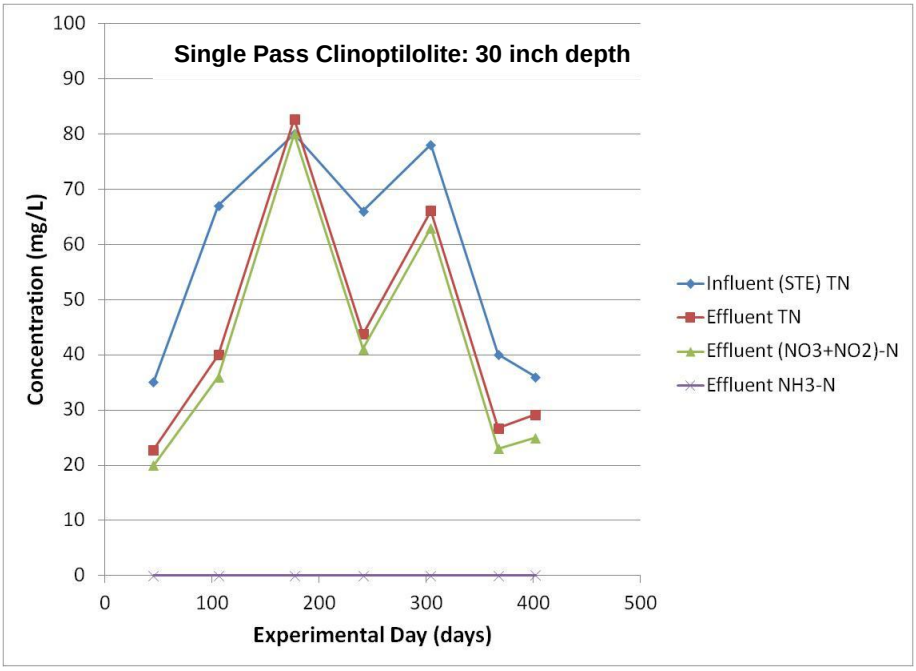

Figure 4-5:
UNSAT-CL3 Nitrogen Time Series

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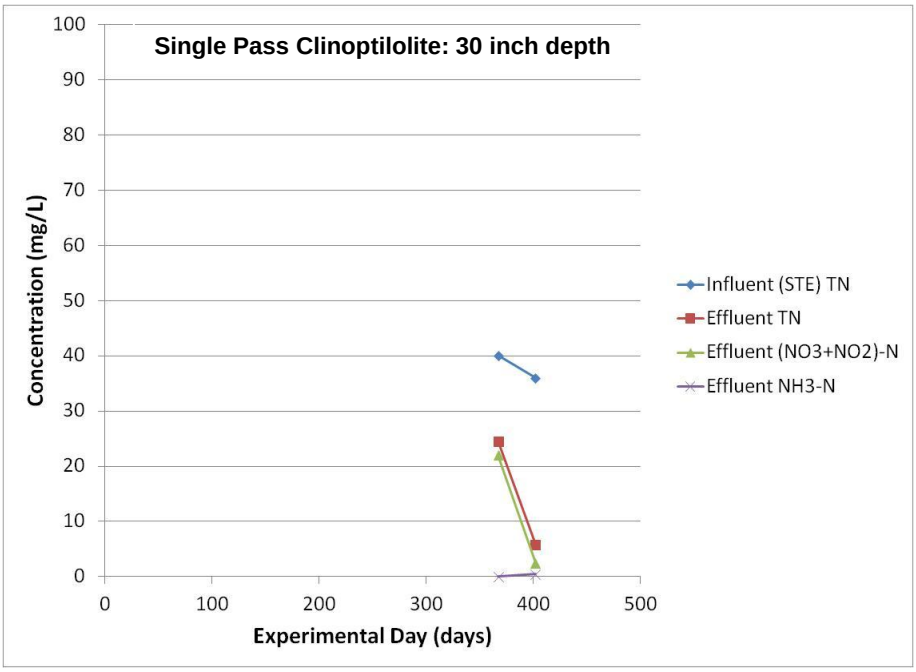

Figure 4-6:
UNSAT-CL5 Nitrogen Time Series

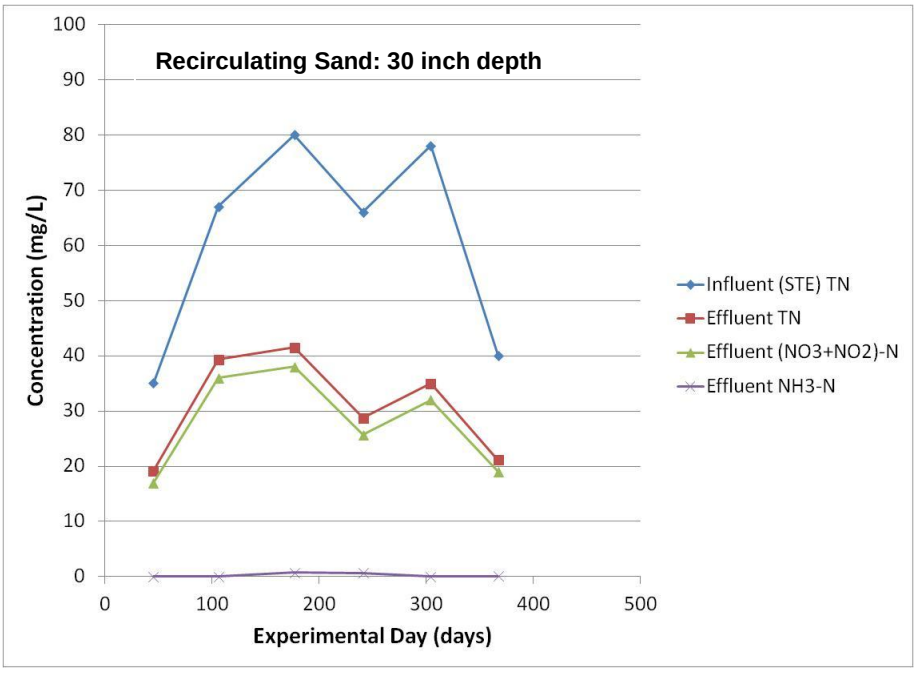

Figure 4-7:
UNSAT-SA2 Nitrogen Time Series

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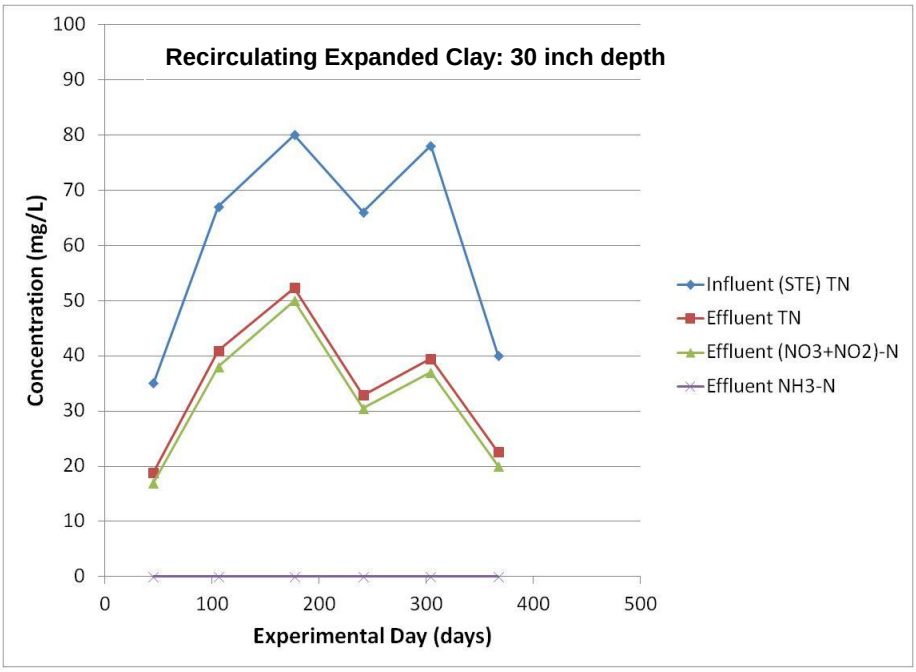

Figure 4-8:
UNSAT-EC4 Nitrogen Time Series

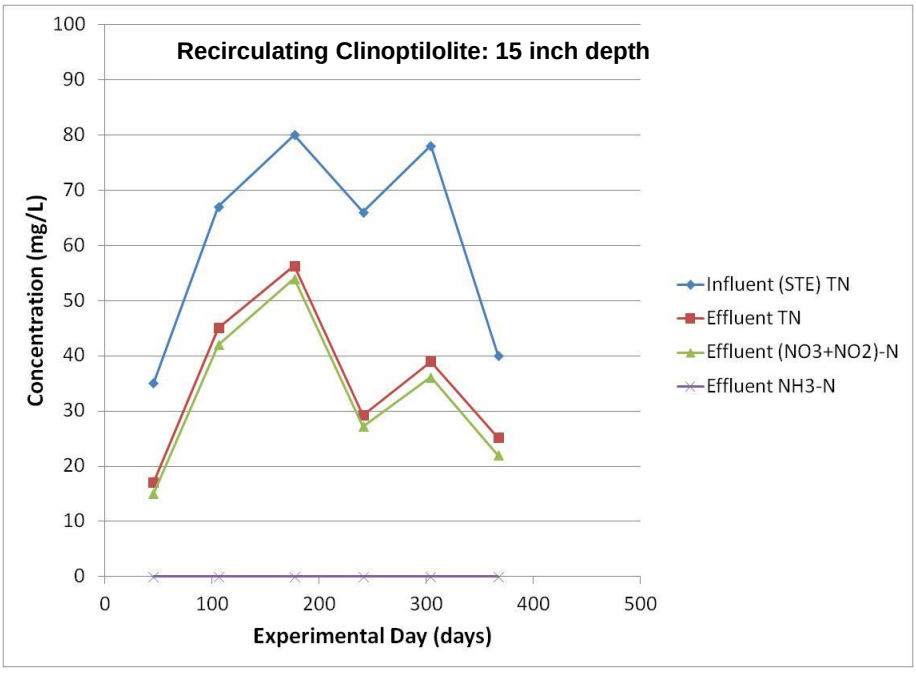

Figure 4-9:
UNSAT-CL2 Nitrogen Time Series

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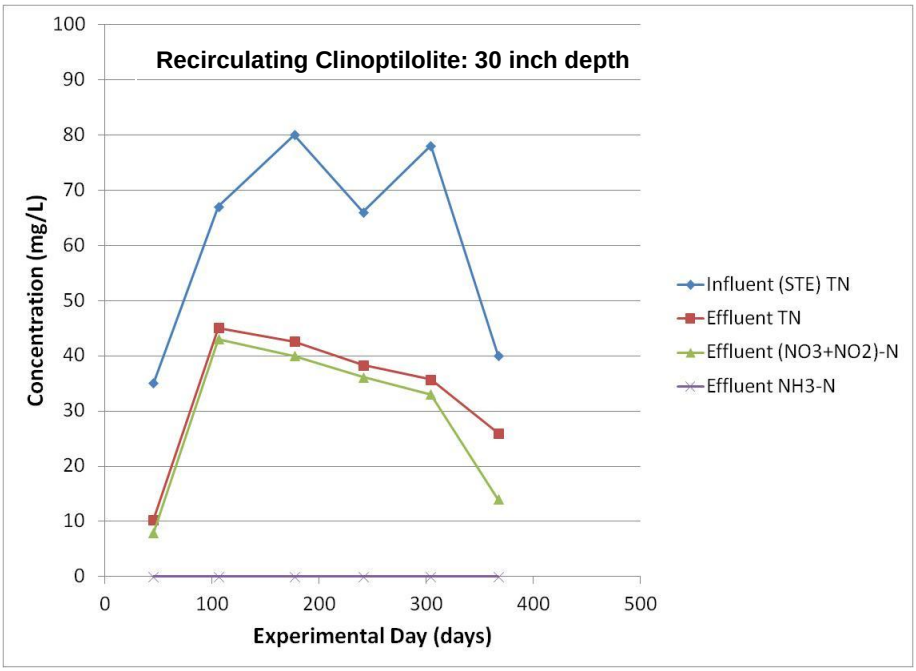

Figure 4-10:
UNSAT-CL4 Nitrogen Time Series

4.4.1.3 Stage 1 (Unsaturated) Biofilters Performance Summary and Statistics

Mean effluent values for water quality parameters are listed in Table 4.5 for the core performance evaluation period (Table 4.2, Sample Events 1 through 7). For each unsaturated biofilter, detailed nitrogen concentration data are listed for TN, TKN, Org N, NH_3-N and (NO_3+NO_2)-N in Tables 4.6 through 4.10. Unsaturated biofilters were highly effective in treating primary effluent, with mean effluent $CBOD_5$ of 2.2 mg/L or less, mean TSS and Org N of 4 mg/L or less, and mean NH_3-N of 0.5 mg/L or less (Table 4.5). All unsaturated biofilters produced mean effluent DO of 6.3 to 8.1 mg/L and near neutral pH. Removal efficiencies are summarized in Table 4.11.

Removal efficiency for TSS, C-BOD5 and Total Nitrogen, Total Kjeldahl Nitrogen, and Organic Nitrogen were calculated as:

$$\%\,RE = \frac{C_{inf} - C_{eff}}{C_{inf}}\ x\ 100$$

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

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Mean removal efficiencies of $CBOD_5$ and TSS exceeded 95%. Mean TKN removal efficiencies were 90 to 95%, while Org N mean removals were 57 to 76%.

Ammonia removal efficiencies were calculated using an effective influent ammonia concentration which was the sum of the analytical influent NH_3-N and the difference in Org N between influent and effluent. An alternative formula was used which accounted for ammonification of organic nitrogen within the biofilter:

$$\%\ NH_3\ RE \quad = \quad \frac{TKN_{inf} - TKN_{eff}}{TKN_{inf} - OrgN_{eff}} \ x\ 100$$

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

Mean ammonia removal efficiencies for all unsaturated biofilters were greater than 99%. The change in chemical parameters that occurs across unsaturated biofilters is an important metric of biofilter function and of the interaction of biochemical reactions with the wastewater matrix. Mean chemical parameter changes are listed in Table 4.12. All unsaturated biofilters provided effective DO increase (4.4 to 6.4 mg/L) as is needed to effect the desired aerobic reactions. Although all biofilters experienced significant alkalinity declines, the changes in pH were all less than one half pH unit, thus maintaining suitable conditions for nitrification.

Table 4.5
Stage 1 (Unsaturated) Biofilters Mean Effluent Values

	Biofilter	C-BOD_5	COD	TSS	TN	TKN	Organic N	NH_3-N	(NO_3+NO_2) - N	Dissolved Oxygen	pH	Total Alkalinity	Fecal coliform, cfu/100 ml
Single Pass	UNSAT-EC1	2.0	10.0	1.2	44.7	3.5	3.0	0.510	41.2	6.6	7.0	152	1,307
	UNSAT-EC3	2.0	13.3	1.5	42.5	3.4	3.0	0.417	39.1	6.9	6.8	177	2
	UNSAT-CL1	2.0	17.0	2.2	41.0	3.1	3.1	0.012	37.9	6.3	7.4	207	44
	UNSAT-CL3	2.0	20.0	1.3	44.5	3.3	3.3	0.020	41.2	7.6	7.7	282	38
	UNSAT-CL5	2.0	-	1.0	15.2	2.9	2.7	0.228	12.3	6.8	7.8	280	24
Recirculating	UNSAT-SA2	2.2	17.3	4.0	30.8	2.9	2.6	0.255	28.0	6.9	6.8	128	21
	UNSAT-EC4	2.0	14.3	2.2	34.5	2.4	2.4	0.015	32.1	7.9	7.1	137	8
	UNSAT-CL2	2.2	21.0	2.3	35.3	2.6	2.6	0.010	32.7	6.0	7.3	163	251
	UNSAT-CL4	2.0	13.3	2.5	33.0	4.0	4.0	0.010	29.0	8.1	7.4	192	7

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Table 4.6
Stage 1 (Unsaturated) Biofilters Total N Data

	Biofilter	Mean	Standard Deviation	Minimum	Maximum	n
Single Pass	UNSAT-EC1	44.7	18.7	21.2	66.8	6
	UNSAT-EC3	42.5	23.3	21.2	85.9	7
	UNSAT-CL1	41.0	20.6	20.7	78.2	6
	UNSAT-CL3	44.5	22.2	22.8	82.7	7
	UNSAT-CL5	15.2	13.2	5.8	24.5	2
Recirculating	UNSAT-SA2	30.8	9.4	19.2	41.5	6
	UNSAT-EC4	34.5	12.4	18.9	52.3	6
	UNSAT-CL2	35.3	14.3	17.1	56.3	6
	UNSAT-CL4	33.0	13.0	10.3	45.1	6

Table 4.7
Stage 1 (Unsaturated) Biofilters TKN Data

	Biofilter	Mean	Standard Deviation	Minimum	Maximum	n
Single Pass	UNSAT-EC1	3.5	1.2	2.0	4.8	6
	UNSAT-EC3	3.4	1.1	2.0	4.9	7
	UNSAT-CL1	3.1	1.0	2.6	5.2	6
	UNSAT-CL3	3.3	0.6	2.7	4.2	7
	UNSAT-CL5	2.9	0.6	2.5	3.3	2
Recirculating	UNSAT-SA2	2.9	0.6	2.1	3.5	6
	UNSAT-EC4	2.4	0.3	1.9	2.9	6
	UNSAT-CL2	2.6	0.5	2.0	3.2	6
	UNSAT-CL4	4.0	3.9	2.1	12.0	6

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Table 4.8
Stage 1 (Unsaturated) Biofilters Org N Data

	Biofilter	Mean	Standard Deviation	Minimum	Maximum	n
Single Pass	UNSAT-EC1	3.0	1.0	2.0	4.3	6
	UNSAT-EC3	3.4	1.1	2.0	4.9	7
	UNSAT-CL1	3.1	1.0	2.6	5.2	6
	UNSAT-CL3	3.3	0.6	2.7	4.1	7
	UNSAT-CL5	2.7	0.3	2.5	2.9	2
Recirculating	UNSAT-SA2	2.6	0.5	2.0	3.3	6
	UNSAT-EC4	2.4	0.3	1.9	2.9	6
	UNSAT-CL2	2.6	0.5	2.0	3.2	6
	UNSAT-CL4	4.0	3.9	2.1	12.0	6

Table 4.9
Stage 1 (Unsaturated) Biofilters NH3-N Data

	Biofilter	Mean	Standard Deviation	Minimum	Maximum	n
Single Pass	UNSAT-EC1	0.51	0.78	0.01	1.70	6
	UNSAT-EC3	2.97	0.75	2.00	4.02	7
	UNSAT-CL1	0.01	0.01	0.01	0.02	6
	UNSAT-CL3	0.02	0.02	0.01	0.06	7
	UNSAT-CL5	0.23	0.31	0.01	0.45	2
Recirculating	UNSAT-SA2	0.26	0.35	0.01	0.74	6
	UNSAT-EC4	0.01	0.01	0.01	0.04	6
	UNSAT-CL2	0.01	0.01	0.01	0.02	6
	UNSAT-CL4	0.01	0.01	0.01	0.02	6

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Table 4.10
Stage 1 (Unsaturated) Biofilters (NO3+NO2)-N Data

	Biofilter	Mean	Standard Deviation	Minimum	Maximum	n
Single Pass	UNSAT-EC1	41.2	17.7	19.0	62.0	6
	UNSAT-EC3	39.1	22.6	17.0	81	7
	UNSAT-CL1	37.9	19.7	18.0	73.01	6
	UNSAT-CL3	41.2	22.5	20.0	80.0	7
	UNSAT-CL5	12.3	13.8	2.5	22.0	2
Recirculating	UNSAT-SA2	28.0	8.8	17.0	38.0	6
	UNSAT-EC4	32.1	12.3	17.0	50.0	6
	UNSAT-CL2	32.7	14.2	15.0	54.0	6
	UNSAT-CL4	29.0	14.5	7.9	43.0	6

Table 4.11
Stage 1 (Unsaturated) Biofilters Mean Removal Efficiencies (%)

	Biofilter	C-BOD_5	TSS	TN	TKN	Organic N	NH_3-N
Single Pass	UNSAT-EC1	95.4	98.3	29.1	94.2	70.8	99.25
	UNSAT-EC3	95.4	97.5	29.4	93.7	65.1	99.33
	UNSAT-CL1	95.4	93.9	34.4	94.6	70.7	99.98
	UNSAT-CL3	95.4	98.0	24.7	93.4	61.2	99.95
	UNSAT-CL5	95.7	99.8	61.3	92.3	55.9	99.31
Recirculating	UNSAT-SA2	95.2	95.3	48.9	95.1	74.8	99.62
	UNSAT-EC4	95.4	98.0	43.8	95.7	76.0	99.97
	UNSAT-CL2	95.2	96.5	42.7	95.3	74.4	99.98
	UNSAT-CL4	95.4	93.3	46.9	91.7	57.2	99.98

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Table 4.12
Stage 1 (Unsaturated) Biofilters Mean Chemical Change across Biofilter

	Biofilter	Dissolved Oxygen	pH	Total Alkalinity	Specific Conductivity
Single Pass	UNSAT-EC1	5.20	-0.14	-210	-65
	UNSAT-EC3	5.02	-0.23	-184	-8
	UNSAT-CL1	4.71	0.22	-155	60
	UNSAT-CL3	6.05	0.48	-80	156
	UNSAT-CL5	5.20	0.55	-100	160
Recirculating	UNSAT-SA2	5.19	-0.46	-233	-211
	UNSAT-EC4	6.24	-0.19	-225	-182
	UNSAT-CL2	4.35	0.04	-198	-135
	UNSAT-CL4	6.40	0.19	-170	-103

Unsaturated biofilter effluent nitrogen concentrations are compared in Figures 4-11 through 4-15, which are box and whisker plots of TN, TKN, Org N, NH_3-N, and (NO_3+NO_2)-N, respectively. The box and whiskers plots provide immediate comparative visualization of biofilter effluent nitrogen levels, including the center and spread of the distribution. The box and whisker plots provide a summary of data values (median, upper and lower quartiles). They are non-parametric and make no assumptions of the underlying statistical distribution of data. Recirculating biofilter TN concentrations were generally lower than single pass TN (Figure 4-11), as influenced by effluent Organic N levels (Figure 4-13). Effluent ammonia levels were consistently less than 1 mg/L as N in all unsaturated effluents with the lowest levels in clinoptilolite effluents (Figure 4-14). Recirculating biofilters (NO_3+NO_2)-N was generally lower in effluent than in single pass (Figure 4-15). This result was likely due to pre-denitrification in the recirculation basin prior to the biofilters.

Following the core performance evaluation period (Table 4.2, Sample Events 1 through 7), loading rates to the unsaturated biofilters were increased to 5 and 6 gpd/ft^2 for the single pass and recycle biofilters, respectively. Sample Event 9 was conducted on Day 486 (Table 4.2) under the higher loading condition. Nitrogen removal was maintained at the higher loading rates and substantial performance deterioration was not observed, TKN in all the unsaturated biofilters ranged from 1.5 to 4 mg/L in Sample Event 9 (Appendix A). Several biofilters subsequently experienced surface clogging and ponding under the higher loading regime and loading was discontinued at Day 962. The biofilters

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were allowed to drain, the surface media was raked and allowed to dry out. In February 2013 (Day 1000), the systems were restarted at the initial lower surface loading rates. Limited additional monitoring was conducted on Day 1038.

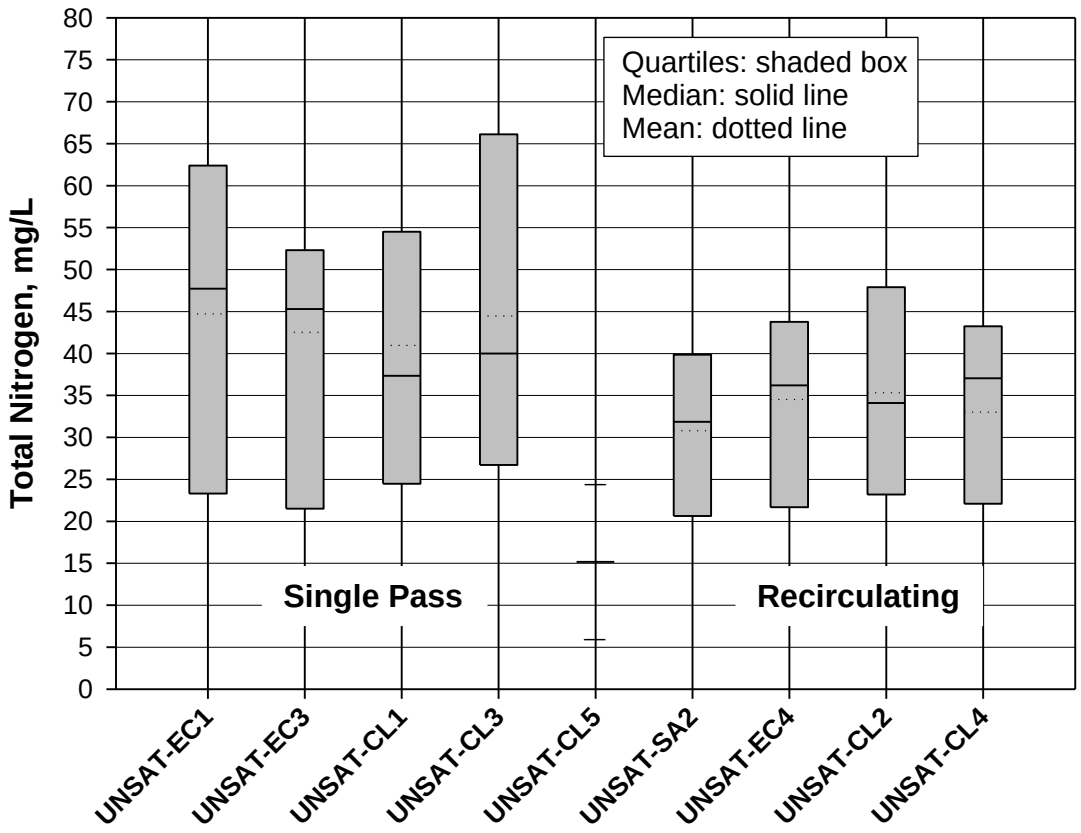

Figure 4-11: Stage 1 (Unsaturated) Biofilters
Total N Box and Whisker Plot

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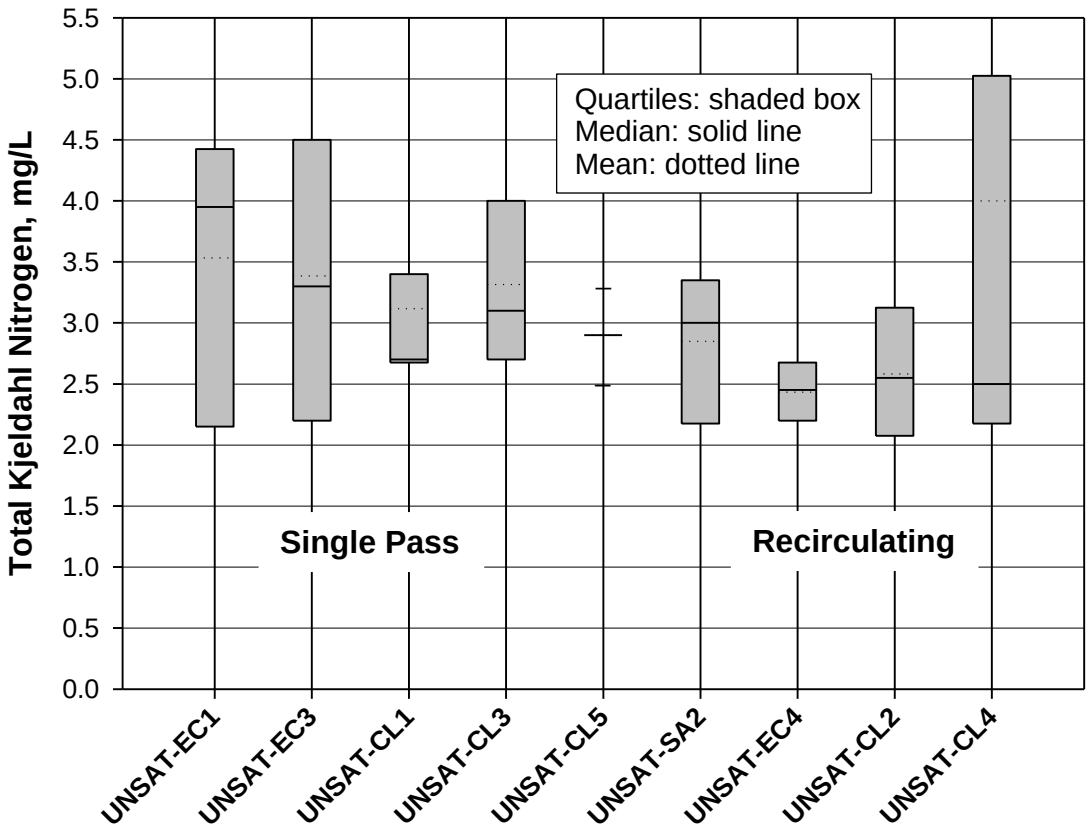

Figure 4-12: Stage 1 (Unsaturated) Biofilters
TKN Box and Whisker Plot

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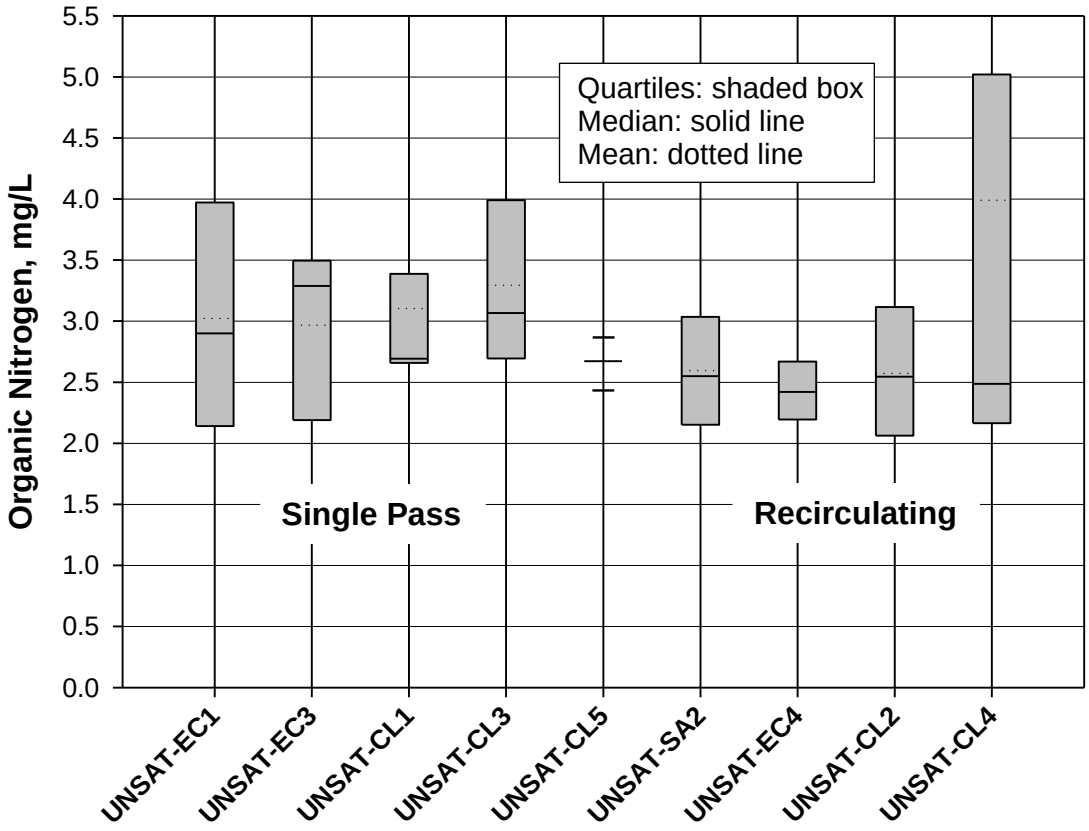

Figure 4-13: Stage 1 (Unsaturated) Biofilters
Org N Box and Whisker Plot

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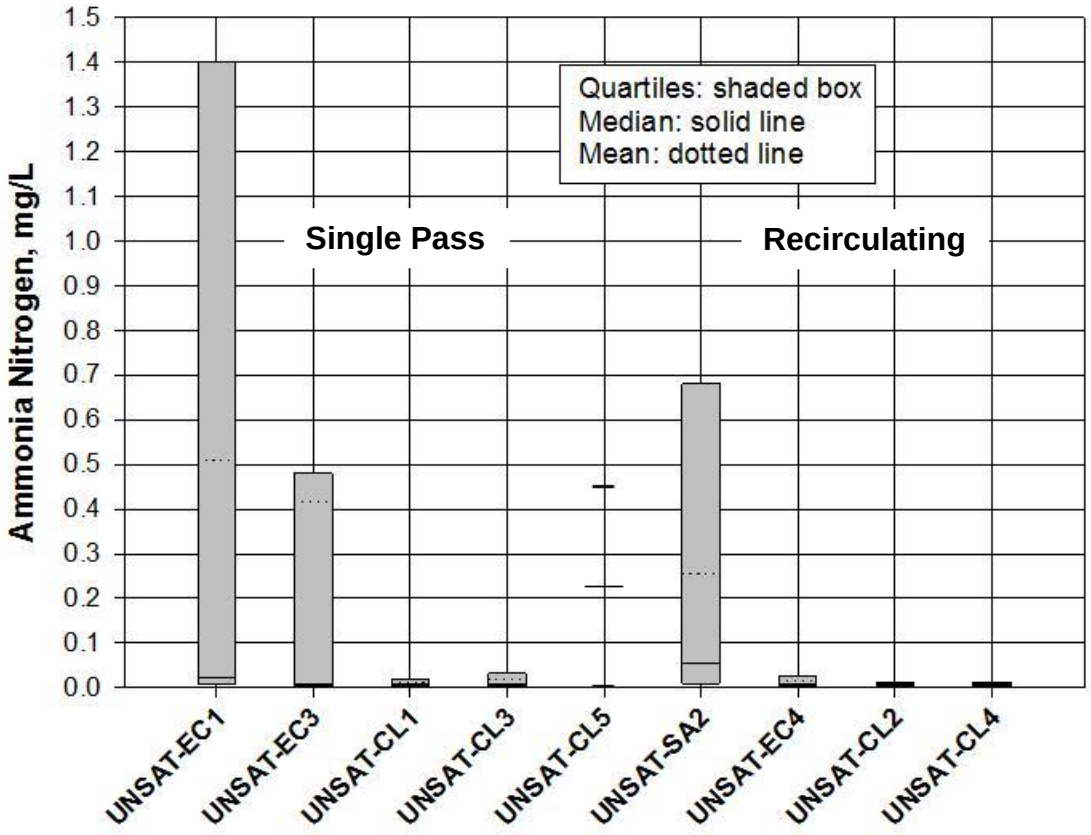

Figure 4-14: Stage 1 (Unsaturated) Biofilters
NH_3-N Box and Whisker Plot

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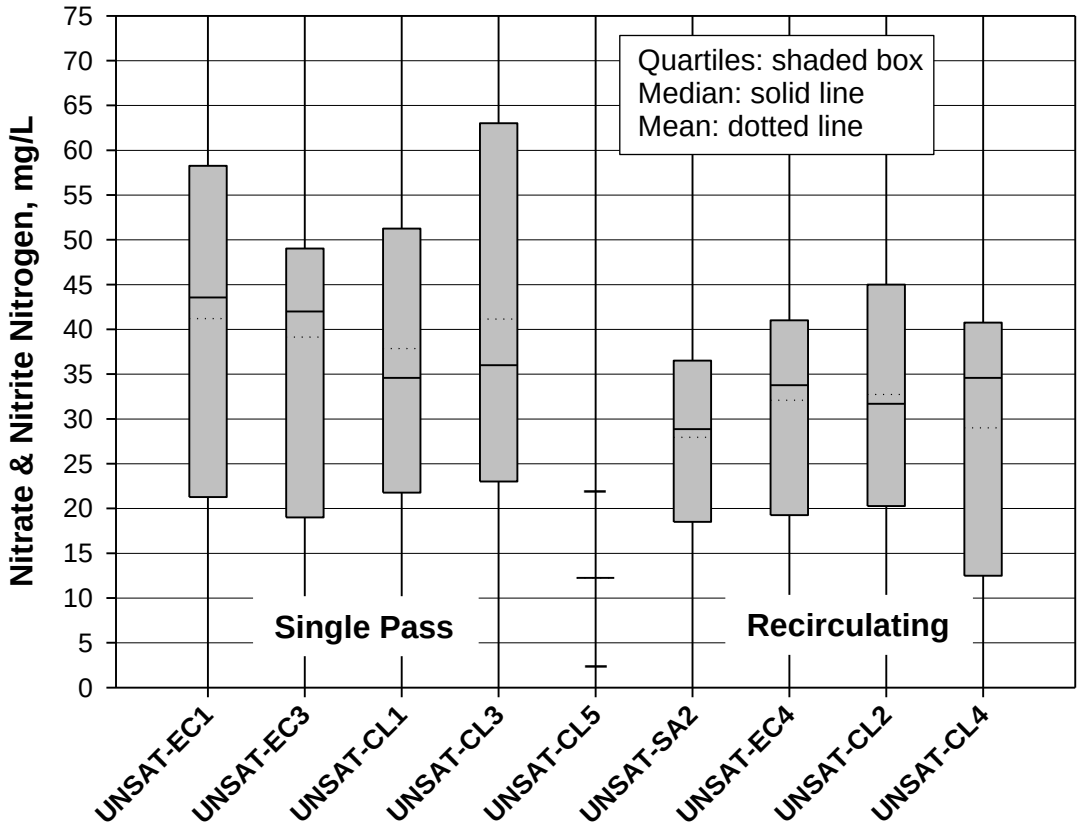

Figure 4-15: Stage 1 (Unsaturated) Biofilters
(NO_3+NO_2)-N Box and Whisker Plot

The nitrogen performance of unsaturated biofilters was compared using a number of statistical procedures (Table 4.13). Effluent concentrations (raw data) of five nitrogen species were evaluated to test if the differences in the mean effluent concentrations were great enough that they were statistically significant and could not be attributed to random sampling variability. Statistical tests were also performed for removal efficiency of nitrogen species including TN, TKN, Org N and NH_3-N. A parametric Analysis of Variance (One Way ANOVA) procedure was employed for datasets that passed the Shapiro-Walk test for normality ($p< 0.05$) and equal variance test ($p<0.05$). For non-normal or unequal variance datasets, a Kreskas-Wallis One Way Analysis of Variance on ranks was performed. Similar values were employed for t test analyses for comparison of two data groups, where a Mann-Whitney Rank Sum test was employed for non-normally distributed data. The limited number of data points may have limited the ability of statistical tests to elucidate significant differences in some cases. Differences between recirculating and

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single pass unsaturated biofilters were statistically significant for effluent Org N and TKN and for TN and TKN removal efficiency. The effect of unsaturated media type (sand, expanded clay, clinoptilolite) on effluent TN concentration was not significant (One Way Analysis of Variance). TN effluent concentration was compared with a Two Way ANOVA to compare three media types and two media depths (Table 4.13). Effluent TN differences were not significant for either media or depth factors. A Two Way ANOVA was performed to compare the effects of three media types and two flow modes (single pass and recycle) on TN effluent concentrations (Table 4.13). Effluent TN differences were not significant for either media or flow mode factors.

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Table 4.13
Stage 1 (Unsaturated) Biofilters Statistical Analyses

Nitrogen Species	Biofilters	Statistical Test	Statistically significant difference of means
Total Nitrogen	1-9	One Way ANOVA	No
Total Nitrogen	1-5 vs. 6-9	Mann-Whitney Rank Sum Test	No
Total Kjeldahl Nitrogen	1-9	Kruskall-Wallis	No
Total Kjeldahl Nitrogen	1-5 vs. 6-9	Mann-Whitney Rank Sum Test	Yes, lower TKN in recycle vs. single pass
Organic Nitrogen	1-9	Kruskall-Wallis	No
Organic Nitrogen	1-5 vs. 6-9	Mann-Whitney Rank Sum Test	Yes, lower OrgN in recycle vs. single pass
Ammonia Nitrogen	1-9	Kruskall-Wallis	No
Ammonia Nitrogen	1-5 vs. 6-9	Mann-Whitney Rank Sum Test	No
Nitrate + Nitrite Nitrogen	1-9	Kruskall-Wallis	No
Nitrate + Nitrite Nitrogen	1-5 vs. 6-9	Kruskall-Wallis	No
Total Nitrogen Removal Efficiency	1-9	Kruskall-Wallis	Yes
Total Nitrogen Removal Efficiency	1-5	Kruskall-Wallis	No
Total Nitrogen Removal Efficiency	6-9	One Way ANOVA	No
Total Nitrogen Removal Efficiency	1-5 vs. 6-9	Mann-Whitney Rank Sum Test	Yes, TN removal efficiency higher in recycle vs. single pass
Total Kjeldahl Nitrogen Removal Efficiency	1-5 vs. 6-9	Mann-Whitney Rank Sum Test	Yes, TKN removal efficiency higher in recycle vs. single pass
Organic Nitrogen Removal Efficiency	1-5 vs. 6-9	Mann-Whitney Rank Sum Test	No
Ammonia Removal Efficiency[1]	1-5 vs. 6-9	Mann-Whitney Rank Sum Test	No
Total Nitrogen	Sand (6) vs. Exp Clay (1,2,7) vs. Clino (3,4,5,8,9)	Kruskall-Wallis	No

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Table 4.13 (continued)
Stage 1 (Unsaturated) Biofilters Statistical Analyses

Total Nitrogen	Media (3) vs. Media Depth (2)	2 Way ANOVA, General Linear Model	Media factor, No
	15 inch depth	30 inch depth	Depth factor, No
Sand		6	
Expanded Clay	1	2,7	
Clinoptilolite	3,8	4,9	
Total Nitrogen	Media (3) vs.Flow mode (2)	2 Way ANOVA, General Linear Model	Media factor, No
	Single Pass	Recycle	Flow Mode factor, No
Sand		6	
Expanded Clay	1,2	7	
Clinoptilolite	3,4,5	8,9	

1= UNSAT-EC1; 2= UNSAT-EC3; 3=UNSAT-CL1; 4= UNSAT-CL3; 5= UNSAT-CL5; 6= UNSAT-SA2; 7= UNSAT-EC4
8= UNSAT-CL2; 9= UNSAT-CL5

4.4.2 Stage 2 (Saturated) Biofilters

Saturated biofilters include Group A Stage 2 upflow biofilters and Group C horizontal biofilters (Table 3.1).

4.4.2.1 Stage 2 (Saturated) Biofilters Modifications

The three upflow and one horizontal denitrification biofilters with lignocellulosic media showed limited (NO_3+NO_2)-N reduction in Sample Events 1 through 4. Possible reasons are lack of reactivity of lignocellulosic material, toxicity (release of toxic material from lignocellulosic material itself), or short circuiting as witnessed in a dye test performed. To investigate this potential problem, the media within all the biofilters containing lignocellulosic media was replaced with new lignocellulosic material from a different source on Day 256. The new lignocellulosic material was composed of sawdust and woodchip material (1-30 mm) originating from interior sections of Southern Yellow Pine and did not include bark; it was produced by sawing operations at a Florida sawmill. The one horizontal and three upflow denitrification biofilters containing lignocellulosic media were rebuilt using the same configurations and media percentages.

4.4.2.2 Stage 2 (Saturated) Biofilters Performance

Saturated biofilter effluent nitrogen concentrations are presented in Figures 4-16 through 4-21, which contain time series plots for influent and effluent (NO_3+NO_2)-N. The influent

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(NO_3+NO_2)-N to single pass saturated biofilters (Figures 4-16 to 4-20) is the effluent (NO_3+NO_2)-N from the directly connected single pass unsaturated biofilter (Figure 3-1). Influent (NO_3+NO_2)-N to the horizontal saturated biofilters is a combined effluent from the recycle unsaturated biofilters (Figure 4-21). Vertical lines demarcate the bioreactor operating periods that correspond to the sample event matrix presented in Table 4.2. All nitrogen in denitrification biofilter influent was dominated by (NO_3+NO_2)-N (Figures 4-16 to 4-21). Effluent TN was also dominated by (NO_3+NO_2)-N and effluent TN profiles consequently follow the (NO_3+NO_2)-N profiles. Upflow and horizontal sulfur-containing biofilters consistently achieved effluent (NO_3+NO_2)-N less than 0.5 mg/L. For lignocellulosic-containing biofilters, (NO_3+NO_2)-N removal performance improved following the change of media, but never reached the same performance as the sulfur based biofilters.

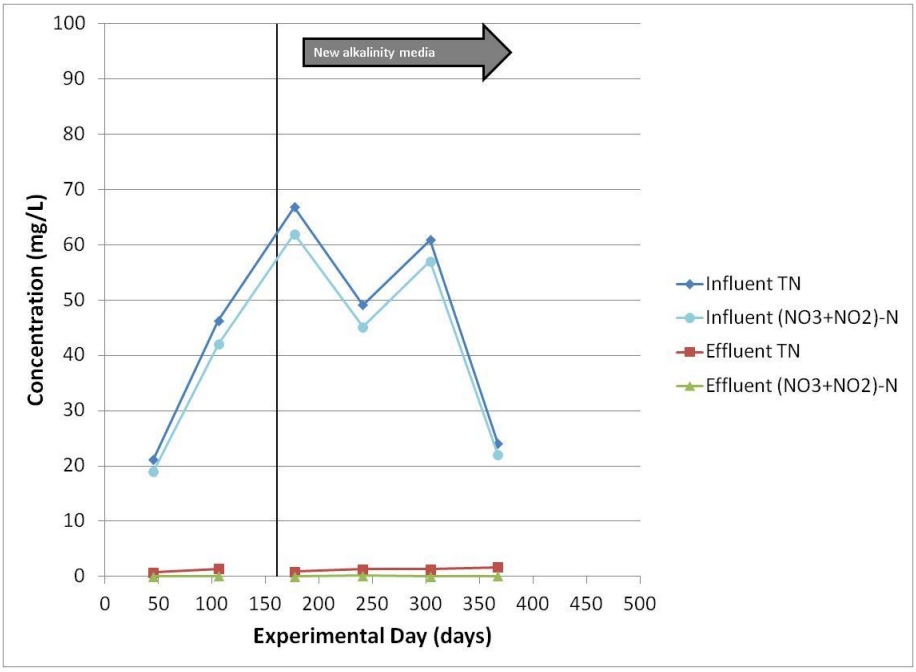

Figure 4-16:
DENIT-SU4 Nitrogen Time Series

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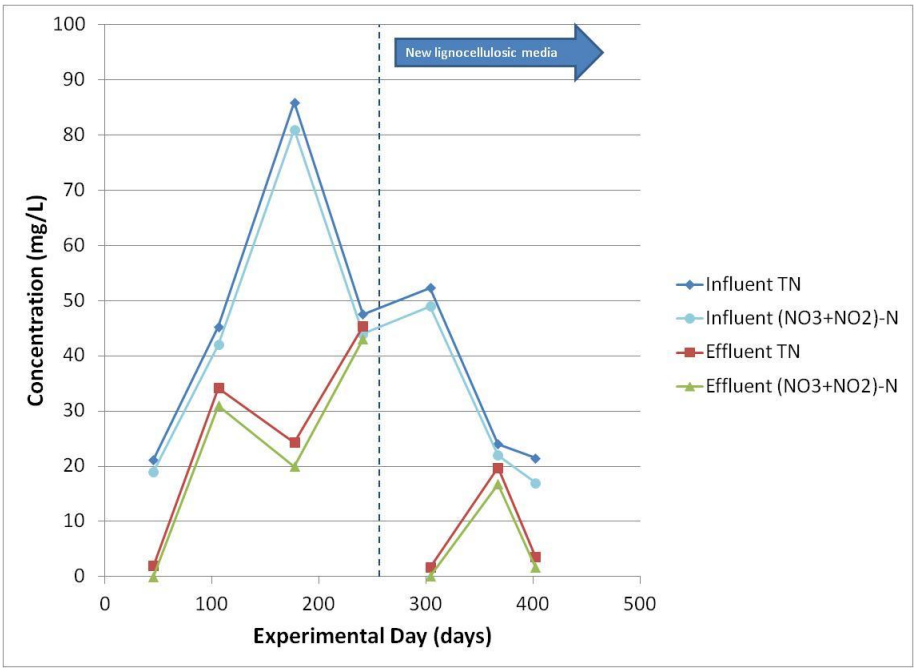

Figure 4-17:
DENIT-LS3 Nitrogen Time Series

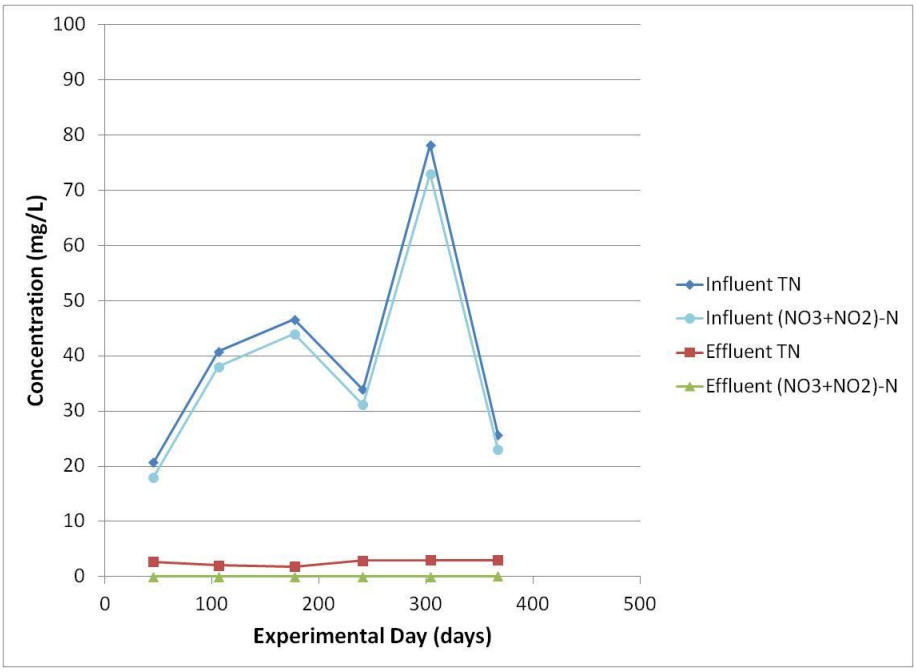

Figure 4-18:
DENIT-SU3 Nitrogen Time Series

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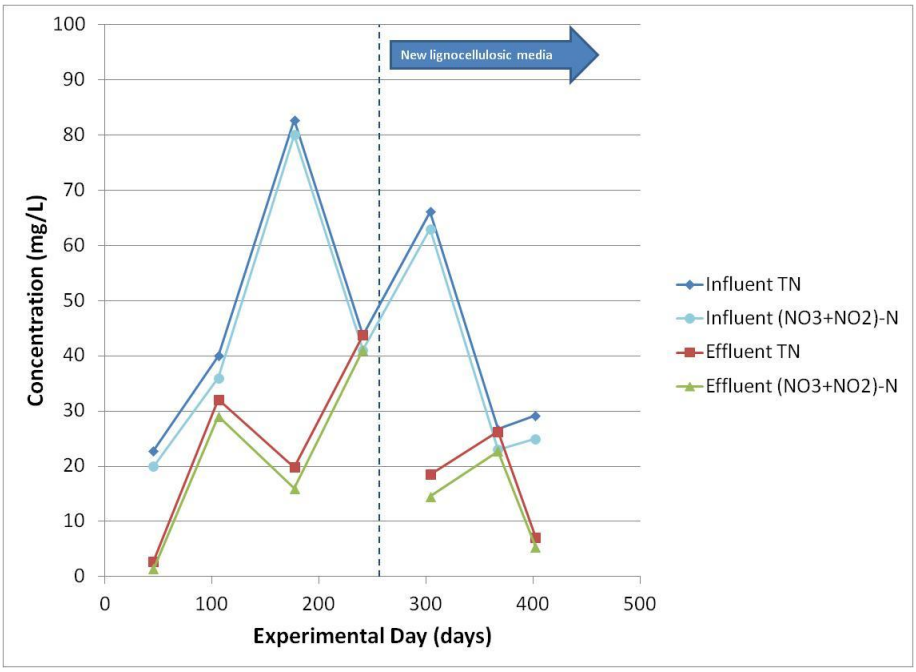

Figure 4-19:
DENIT-LS2 Nitrogen Time Series

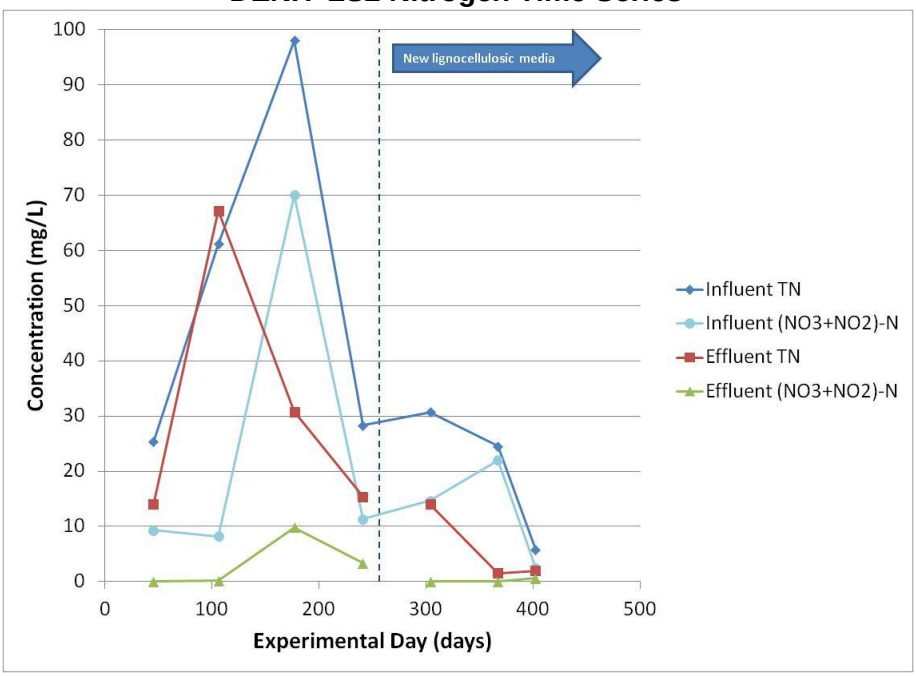

Figure 4-20:
DENIT-LS4 Nitrogen Time Series

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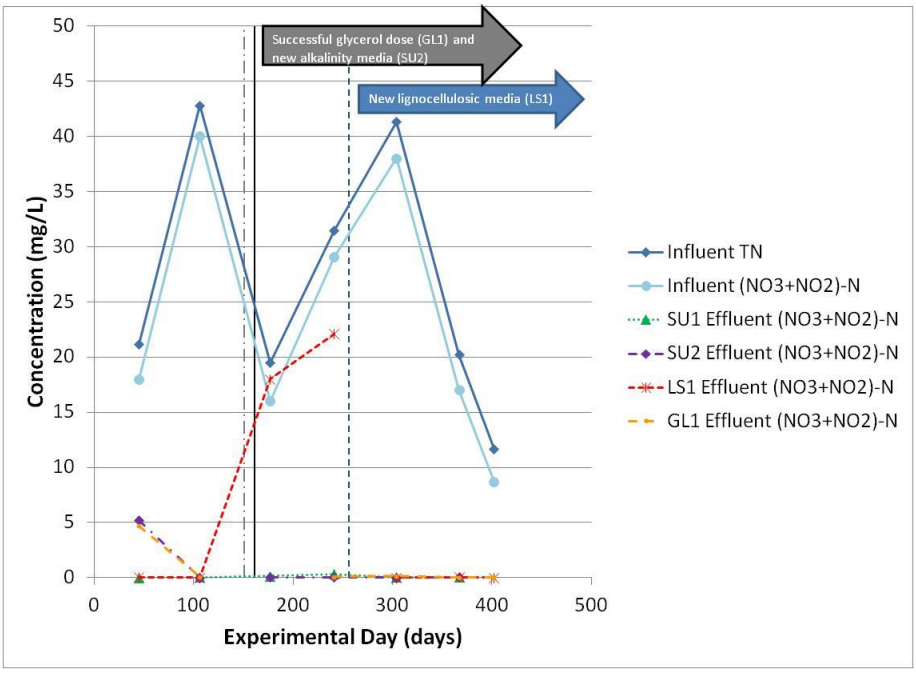

Figure 4-21:
Stage 2 Horizontal Nitrogen Time Series

4.4.2.3 Stage 2 (Saturated) Biofilters Performance Summary and Statistics

Mean effluent values for water quality parameters are listed in Table 4.14 for the core performance evaluation period (Table 4.2, Operating Period 1 or 1b). For each saturated biofilter, detailed nitrogen concentration data are listed for TN, TKN, Org N, NH_3-N and (NO_3+NO_2)-N in Tables 4.15 through 4.19. Saturated biofilters with sulfur media were uniformly highly effective in removing oxidized nitrogen (NO_3+NO_2)-N, with mean effluent (NO_3+NO_2)-N of 0.22 mg/L and less. Saturated biofilters with lignocellulosic media were not uniformly effective in removing oxidized nitrogen (NO_3+NO_2)-N, with mean effluent (NO_3+NO_2)-N ranging from 0.02 to 6 mg/L (Table 4.14). Lignocellulosic biofilter removal performance for (NO_3+NO_2)-N appeared to be affected by the specific batch of lignocellulosic media supplied, and improved when biofilters received replacement Southern Yellow Pine (SYP) from Suwannee Lumber Company. For example, DENIT-LS1 was operated on the replacement SYP and mean effluent (NO_3+NO_2)-N in three monitoring events was 0.02 mg/L (Table 4.19). Thus, SYP appears to be a potential media for saturated anoxic denitrification biofilters. It is also noted that the DENIT-LS1 horizontal saturated biofilter had a longer hydraulic retention time as compared to the saturated upflow lignocellulosic denitrification biofilters. Therefore, the DENIT-LS1 results could indicate that a longer retention time is needed for the lignocellulosic media biofilters. The DENIT-LS1 results also suggest that potentially the longer hydraulic reten-

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tion time is associated with a higher concentration of organic nitrogen (TKN) which may be attributed to bleed off from the lignocellulosic media itself.

The influent to the DENIT-LS4 biofilter was effluent from the directly connected unsaturated polystyrene biofilter (UNSAT-PS1) which was converted to a clinoptilolite biofilter (UNSAT-CL5) as previously discussed. The performance results for DENIT-LS4 include one sample event prior to the conversion. The UNSAT-PS1 biofilter did not successfully nitrify; therefore, the influent to DENIT-LS4 contained NH_3-N. The DENIT-LS4 biofilter successfully denitrified the relatively low influent (NO_3+NO_2)-N; however, the DENIT-LS4 effluent contained NH_3-N (TKN). This result confirms that NH_3-N will be readily transported through anoxic denitrification biofilters which are at the same time capable of achieving significant (NO_3+NO_2)-N reduction.

The glycerol fed horizontal biofilter (DENIT-GL1) performed well, with a mean effluent (NO_3+NO_2)-N (0.84 mg/L) that was higher than sulfur-containing biofilters. The higher mean (NO_3+NO_2)-N in DENIT-GL1 effluent was due to a high (NO_3+NO_2)-N in the first monitoring event, for which glycerol dosing was found to be inadequate. (NO_3+NO_2)-N was 0.15 mg/l or less in DENIT-GL1 effluent for the five subsequent monitoring events when glycerol dosing was adequate. Thus, the glycerol fed anoxic biofilter appears to provide highly effective denitrification provided that glycerol dosing is effectively maintained.

Table 4.14
Stage 2 (Saturated) Biofilters Mean Effluent Values

Biofilter	C-BOD_5	COD	TSS	TN	TKN	Organic N	NH_3-N	(NO_3+NO_2) - N	Dissolved Oxygen	pH	Total Alkalinity	Fecal coliform, cfu/100 ml
DENIT-SU4	2.0	21.7	2.8	1.3	1.2	0.9	0.32	0.075	2.3	7.1	220	89
DENIT-LS3	61.0	320	1.5	8.3	2.2	1.3	0.87	6.18	2.2	7.1	355	1
DENIT-SU3	6.0	38.5	6.2	2.6	2.6	1.4	1.14	0.047	1.4	7.1	235	3
DENIT-LS2	2.0	39.0	3.0	17.3	3.1	2.4	0.62	14.2	3.6	7.9	197	0
DENIT-LS4	4.5	90.0	7.5	5.9	5.6	0.9	4.71	0.22	1.3	7.8	315	1
DENIT-SU1	13.3	45.0	1.5	2.5	2.4	1.1	1.35	0.11	0.6	7.0	223	3
DENIT-SU2	8.5	29.7	3.5	1.6	1.6	1.0	0.58	0.035	0.6	7.0	215	2
DENIT-LS1	89.5	320	13.0	10.0	10.0	9.7	0.27	0.020	0.1	7.2	270	1
DENIT-GL1	148	257	18.5	3.8	3.8	0.63	3.12	0.07	0.59	6.94	402	600

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Table 4.15
Stage 2 (Saturated) Biofilters Total N Data

Biofilter	Mean	Standard Deviation	Minimum	Maximum	n
DENIT-SU4	1.3	0.3	0.9	1.7	4
DENIT-LS3	8.3	9.9	1.7	19.8	3
DENIT-SU3	2.6	0.5	1.9	3.0	6
DENIT-LS2	17.3	9.6	7.1	26.3	3
DENIT-LS4	5.9	7.1	1.5	14.0	3
DENIT-SU1	2.5	0.4	2.0	3.0	6
DENIT-SU2	1.6	1.3	0.8	3.5	4
DENIT-LS1	10.0	14.8	1.1	27.0	3
DENIT-GL1	3.8	2.2	1.9	6.5	4

Table 4.16
Stage 2 (Saturated) Biofilters TKN Data

Biofilter	Mean	Standard Deviation	Minimum	Maximum	n
DENIT-SU4	1.2	0.3	0.9	1.6	4
DENIT-LS3	2.2	0.7	1.6	3.0	3
DENIT-SU3	2.6	0.5	1.8	3.0	6
DENIT-LS2	3.1	1.2	1.7	4.0	3
DENIT-LS4	5.6	7.2	1.4	14.0	3
DENIT-SU1	2.4	0.4	1.9	2.9	6
DENIT-SU2	1.6	1.3	0.7	3.5	4
DENIT-LS1	10.0	14.8	1.1	27.0	3
DENIT-GL1	3.8	2.2	1.9	6.3	4

Table 4.17
Stage 2 (Saturated) Biofilters Org N Data

Biofilter	Mean	Standard Deviation	Minimum	Maximum	n
DENIT-SU4	0.9	0.1	0.8	1.1	4
DENIT-LS3	1.3	0.4	0.9	1.6	3
DENIT-SU3	1.4	0.7	0.2	2.2	6
DENIT-LS2	2.4	0.9	1.7	3.5	3
DENIT-LS4	0.9	0.8	0.0	1.5	3
DENIT-SU1	1.1	0.7	0.3	2.1	6
DENIT-SU2	1.0	0.6	0.5	1.9	4
DENIT-LS1	9.7	15.0	0.9	27.0	3
DENIT-GL1	0.6	0.4	0.2	1.0	4

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Table 4.18
Stage 2 (Saturated) Biofilters NH_3-N Data

Biofilter	Mean	Standard Deviation	Minimum	Maximum	n
DENIT-SU4	0.32	0.30	0.10	0.77	4
DENIT-LS3	0.87	0.48	0.46	1.40	3
DENIT-SU3	1.14	0.85	0.46	2.70	6
DENIT-LS2	0.62	1.02	0.02	1.80	3
DENIT-LS4	4.70	8.0	0.01	14.0	3
DENIT-SU1	1.35	0.69	0.46	2.40	6
DENIT-SU2	0.58	0.70	0.03	1.60	4
DENIT-LS1	0.27	0.31	0.01	0.61	3
DENIT-GL1	3.10	2.2	0.9	5.8	4

Table 4.19
Stage 2 (Saturated) Biofilters (NO_3+NO_2)-N Data

Biofilter	Mean	Standard Deviation	Minimum	Maximum	n
DENIT-SU4	0.08	0.06	0.02	0.13	4
DENIT-LS3	6.18	9.20	0.07	16.76	3
DENIT-SU3	0.05	0.04	0.01	0.11	6
DENIT-LS2	14.2	8.7	5.4	22.8	3
DENIT-LS4	0.22	0.33	0.02	0.60	3
DENIT-SU1	0.11	0.13	0.01	0.35	6
DENIT-SU2	0.04	0.02	0.02	0.06	4
DENIT-LS1	0.02	0.01	0.01	0.03	3
DENIT-GL1	0.07	0.06	0.02	0.15	4

(NO_3+NO_2)-N removal efficiencies for saturated biofilters are summarized in Table 4.20. Mean (NO_3+NO_2)-N removal efficiencies of sulfur-containing biofilters were greater than 95%. Mean (NO_3+NO_2)-N removal efficiencies of SYP-containing biofilters were 62 to 92%. Mean (NO_3+NO_2)-N removal efficiency of the glycerol fed biofilter was 95%. The change in chemical parameters that occurs across saturated biofilters is an important metric of biofilter function and of the interaction of biochemical reactions with the wastewater matrix. Mean chemical parameter changes are listed in Table 4.21. All saturated biofilters provided a decrease in DO as is needed to effect the desired anoxic reactions. The pH change across the saturated biofilters was limited and ranged (-0.31 to +0.26), thus maintaining suitable conditions for denitrification.

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Table 4.20
Stage 2 (Saturated) Biofilters (NO_3+NO_2)-N Removal Efficiencies

Biofilter	(NO_3+NO_2)–N Removal Efficiency, %
DENIT-SU4	99.8
DENIT-LS3	71.2
DENIT-SU3	99.8
DENIT-LS2	52.2
DENIT-LS4	91.9
DENIT-SU1	99.5
DENIT-SU2	99.8
DENIT-LS1	99.9
DENIT-GL1	99.7

Table 4.21
Stage 2 (Saturated) Biofilters Mean Chemical Change across Biofilter

Biofilter	Dissolved Oxygen	pH	Total Alkalinity	Specific Conductivity
DENIT-SU4	-4.88	0.11	7	306
DENIT-LS3	-3.93	0.27	88	-20
DENIT-SU3	-4.56	-0.31	28	352
DENIT-LS2	-4.24	0.09	52	-11
DENIT-LS4	-0.76	3.28	147	363
DENIT-SU1	-7.36	-0.42	63	316
DENIT-SU2	-7.28	-0.10	62	372
DENIT-LS1	-7.39	-0.12	80	-8
DENIT-GL1	-7.40	-0.48	242	134

Following the core performance evaluation period (Table 4.2, Sample Events 1 through 7), loading rates to saturated biofilters were increased to 9.6 and 20 gpd/ft^2 to upflow and horizontal denitrification biofilters, respectively. Sample Event 9 was conducted on Day 486 (Table 4.2) under the higher loading condition. In all four sulfur-containing biofilters, effluent (NO_3+NO_2)-N remained below 0.5 mg/L in Sample Event 9, indicating that denitrification performance was not impaired at the higher loading rate. The effluent (NO_3+NO_2)-N of all three upflow lignocellulosic biofilters was substantially higher at the higher loading rate conditions of Sample Event 8, while that in the horizontal lignocellulosic-containing biofilter effluent remained below 0.5 mg/L. Several of the Stage 1 unsaturated biofilters subsequently experienced surface clogging under the higher loading regime and loading to all biofilters was discontinued for a limited time period. In February 2013 the systems were restarted at the initial lower surface loading rates. Limited additional monitoring was conducted on Day 1038.

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Saturated biofilter effluent nitrogen concentrations are compared in Figures 4-22 through 4-26, which are box plots of TN, TKN, Org N, NH3-N, and (NO_3+NO_2)-N, respectively. The box and whiskers plots provide immediate comparative visualization of biofilter effluent nitrogen levels, including the center and spread of the distribution. The box and whisker plots provide a summary of data values (median, upper and lower quartiles). They are non-parametric and make no assumptions of the underlying statistical distribution of data. TN, TKN, Org N and (NO_3+NO_2)-N appear to be higher in lignocellulosic-containing biofilter effluents than those in sulfur-containing and glycerol fed biofilter effluents (Figures 4-22, 4-23, 4-24 and 4-26) although some lignocellulosic-containing biofilters exhibit TN levels consistently less than 10 mg/L and have (NO_3+NO_2)-N of less than 5 mg/L. As previously discussed, the results also suggest that potentially organic nitrogen (TKN) may be attributed to bleed off from the lignocellulosic media itself.

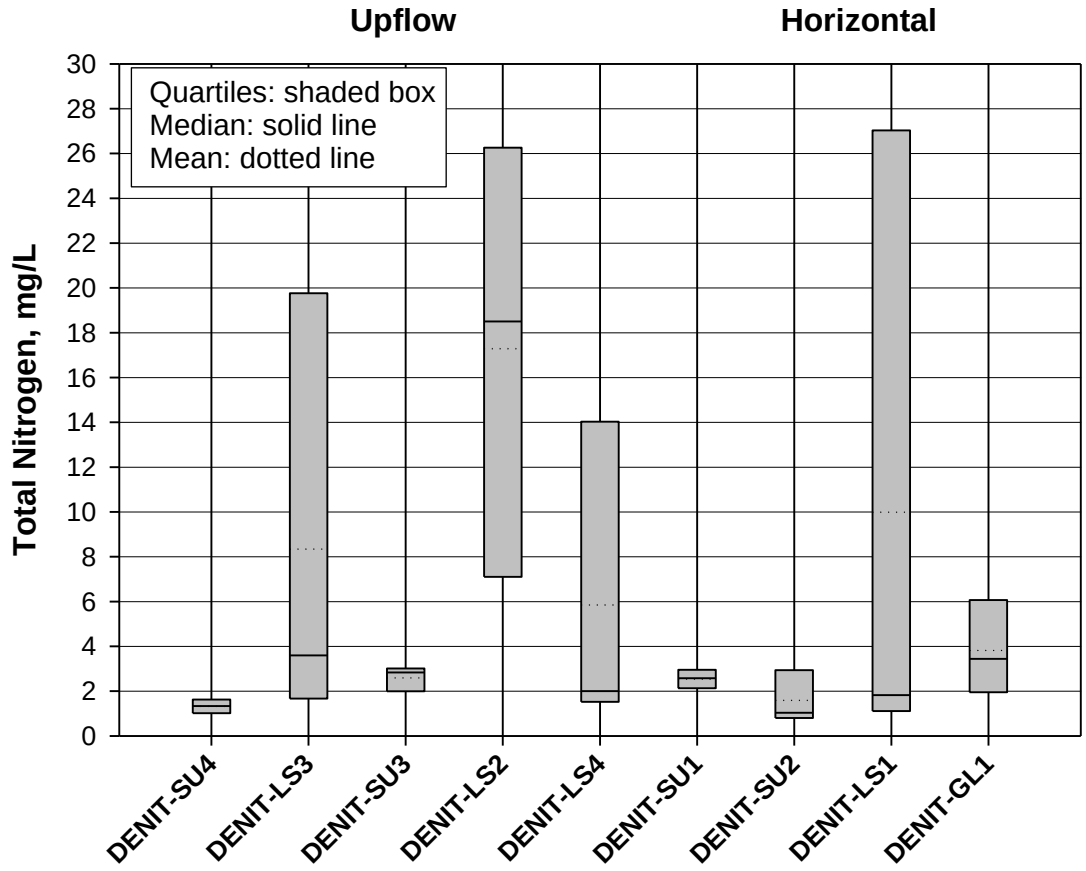

Figure 4-22: Stage 2 (Saturated) Biofilters
Total N Box and Whisker Plot

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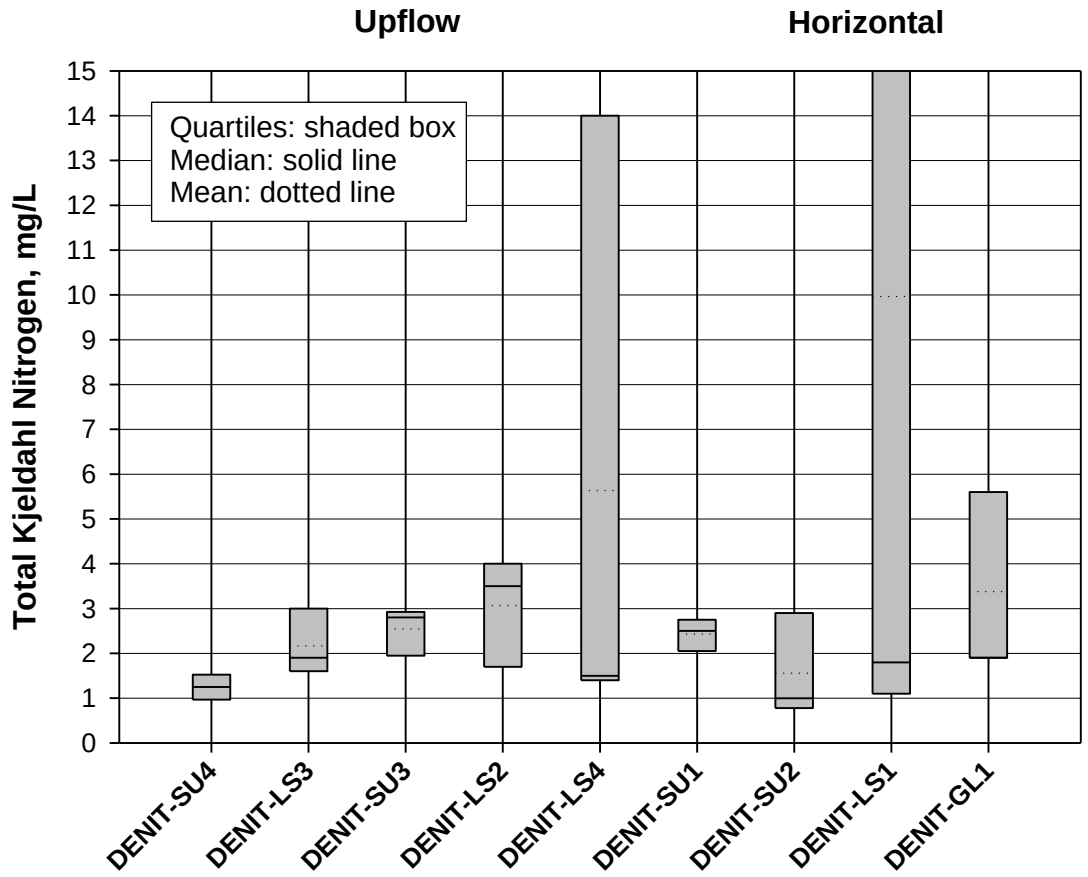

Figure 4-23: Stage 2 (Saturated) Biofilters
TKN Box and Whisker Plot

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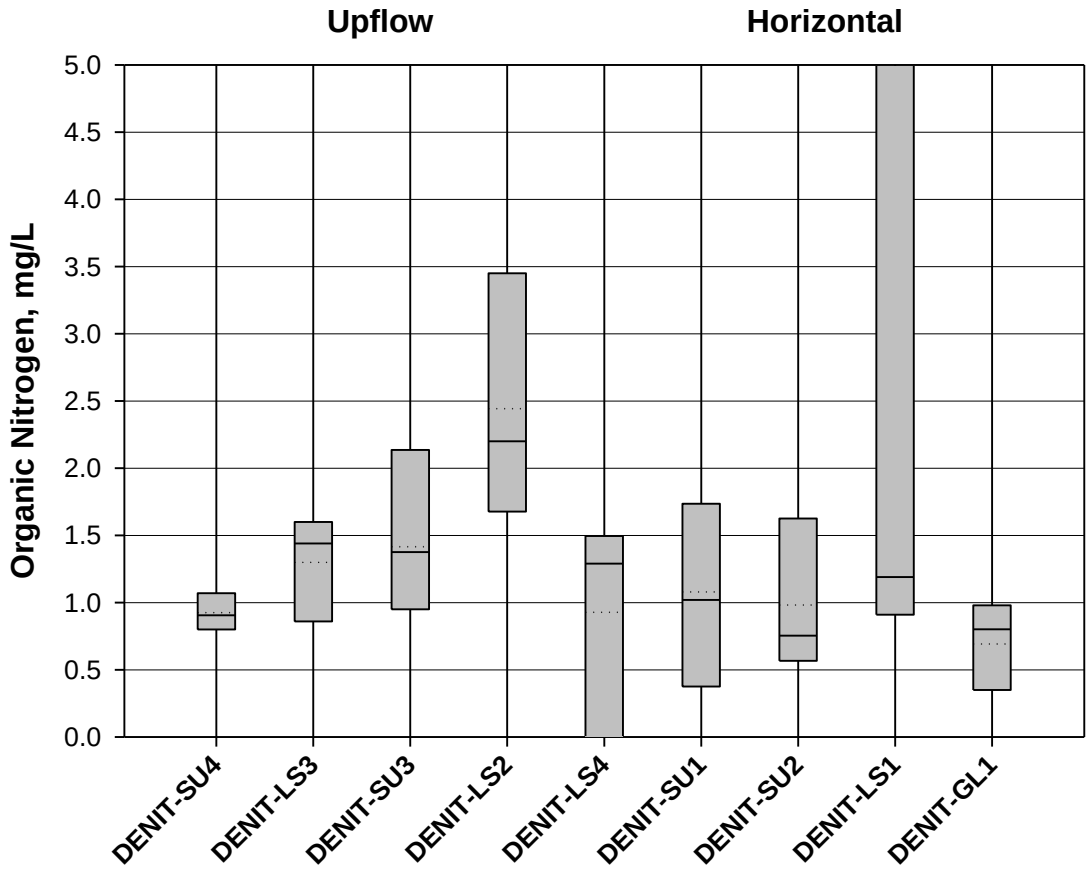

Figure 4-24: Stage 2 (Saturated) Biofilters
Org N Box and Whisker Plot

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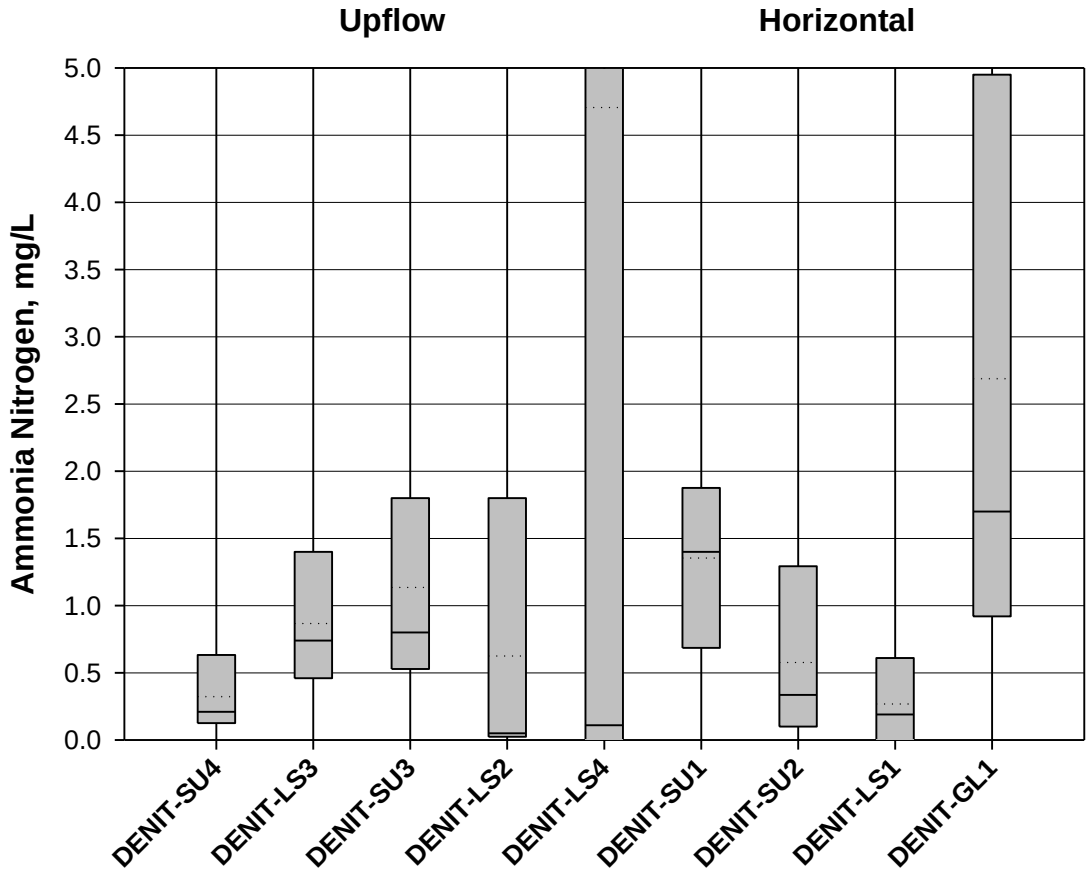

Figure 4-25: Stage 2 (Saturated) Biofilters
NH3-N Box and Whisker Plot

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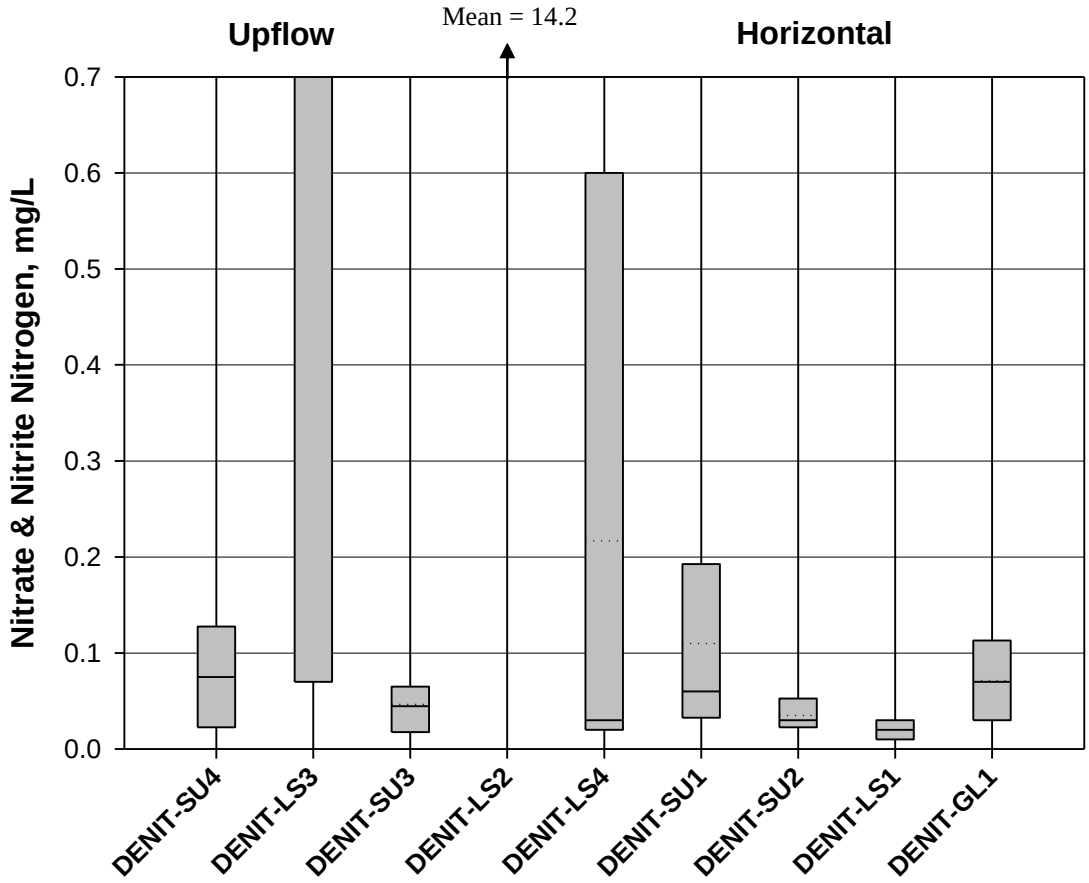

Figure 4-26: Stage 2 (Saturated) Biofilters
(NO_3+NO_2)-N Box and Whisker Plot

The nitrogen performance of saturated biofilters was compared using a number of statistical procedures (Table 4.22). Effluent concentrations (raw data) of five nitrogen species were evaluated to test if the differences in the mean effluent concentrations were great enough that they were statistically significant and could not be attributed to random sampling variability. Statistical tests were also performed for removal efficiency of nitrogen species including TN, TKN, Org N and NH_3-N. A parametric Analysis of Variance (One Way ANOVA) procedure was employed for datasets that passed the Shapiro-Walk test for normality ($p< 0.05$) and equal variance test ($p<0.05$). For non-normal or unequal variance datasets, a Kreskas-Wallis One Way Analysis of Variance on ranks was performed. Similar values were employed for t test analyses for comparison of two data groups, where a Mann-Whitney Rank Sum test was employed for non-normally distributed data.

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Table 4.22
Stage 2 (Saturated) Biofilters Statistical Analyses

Nitrogen Species	Biofilter Numbers	Test	Statistically significant difference of means
Total Nitrogen	10 - 18	Kruskall-Wallis	Yes, TN lower for sulfur vs. SYP
Total Kjeldahl Nitrogen	10 - 18	Kruskall-Wallis	No
Organic Nitrogen	10 - 18	Kruskall-Wallis	No
Ammonia Nitrogen	10 - 18	Kruskall-Wallis	Yes
Nitrate + Nitrite Nitrogen	10 - 18	Kruskall-Wallis	Yes
Nitrate + Nitrite Nitrogen Removal Efficiency	10 - 18	Kruskall-Wallis	No
Total Nitrogen	Sulfur (10,12,15,16) vs. Ligno (11,13,14,17) vs. Glycerol (18)	Kruskall-Wallis	Yes
Total Kjeldahl Nitrogen	Sulfur (10,12,15,16) vs. Ligno (11,13,14,17) vs. Glycerol (18)	Kruskall-Wallis	No
Organic Nitrogen	Sulfur (10,12,15,16) vs. Ligno (11,13,14,17) vs. Glycerol (18)	Kruskall-Wallis	No
Ammonia Nitrogen	Sulfur (10,12,15,16) vs. Ligno (11,13,14,17) vs. Glycerol (18)	Kruskall-Wallis	Yes
Nitrate + Nitrite Nitrogen	Sulfur (10,12,15,16) vs. Ligno (11,13,14,17) vs. Glycerol (18)	Kruskall-Wallis	Yes, NO_x is higher in ligno than sulfur or glycerol
Nitrate + Nitrite Nitrogen Removal Efficiency	Sulfur (10,12,15,16) vs. Ligno (11,13,14,17) vs. Glycerol (18)	Kruskall-Wallis	No
Total Nitrogen	Media (3) vs. MPRT (2)	2 Way ANOVA, General Linear Model	Media factor, Yes, TN lower in sulfur vs. ligno
			MPRT factor, No
	25.7 MPRT	43.1 MPRT	
Sulfur	10,12	15,16	
Southern yellow pine	11,13,14	17	
Glycerol		18	

10= DENIT-SU4; 11= DENIT-LS3; 12= DENIT-SU3; 13= DENIT-LS2; 14= DENIT-LS4; 15= DENIT-SU1; 16= DENIT-SU2

17= DENIT-LS1; 18= DENIT-GL1

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In overall comparisons of the nine saturated biofilters, differences between sulfur-and lignocellulosic-containing biofilter effluents were statistically significant for effluent TN, NH_3, and (NO_3+NO_2)-N. For One Way ANOVA comparison of three media (sulfur, SYP, glycerol), (NO_3+NO_2)-N removal efficiency was significantly higher for sulfur as compared to SYP. TN effluent concentration was compared with a Two Way ANOVA to compare three media types and two Mean Pore Residence Times (MPRT), where 25.7 hour MPRT pertains to upflow saturated biofilters and 43.1 hour MPRT pertains to horizontal saturated biofilters (Table 4.22). The media factor was significant. Effluent TN was significantly lower in biofilters containing sulfur media than SYP.

4.4.3 Stacked Unsaturated/Saturated Biofilters

Stacked unsaturated /saturated (In Situ) biofilters include Group D single pass biofilters with different configurations of media in the upper twelve inches but the same media configuration in the lower eighteen inches (Table 4.23).

Table 4.23
Stacked Unsaturated/Saturated (In Situ) Biofilters Media

Biofilter		UNSAT-IS1	UNSAT-IS2	UNSAT-IS3	UNSAT-IS4
Influent		Primary Effluent	Primary Effluent	Primary Effluent	Nitrified Effluent (UNSAT-CL3)
Media (in.)	0 - 4	Coarse Sand	Expanded Clay > 1.53 mm	Clinoptilolite 8 x14	Coarse Sand
	4 - 12	Fine Sand	Expanded Clay	Clinoptilolite 16 x50	Fine Sand
	12 - 24	60% Expanded clay 40% Southern Yellow Pine			
	24 - 26	Gravel			
	26 - 30	Elemental Sulfur			

4.4.3.1 Stacked Unsaturated/Saturated Biofilters Modifications

The biofilters with lignocellulosic media showed limited (NO_3+NO_2)-N reduction in Sample Events 1 through 4. All In Situ simulator biofilters were rebuilt with revised media configurations and the new lignocellulosic media discussed in Section 4.4.2.1.

4.4.3.2 Stacked Unsaturated/Saturated Biofilters Performance

Performance was assessed using data from Operating Period 4 (Table 4.2). Three of the biofilters contained a monitoring point in the gravel layer above the sulfur layer, which provided performance data for the biofilter media above the gravel layer (i.e. without sulfur media).

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Unsaturated/saturated biofilter effluent nitrogen concentrations are presented in Figures 4-27 through 4-30, which contain time series plots for influent (STE) TN, effluent TN, effluent NH_3-N, effluent (NO_3+NO_2)-N, and (NO_3+NO_2)-N above the sulfur layer (where applicable). The performance of the unsaturated/saturated biofilters was variable. Ammonia removal was limited in UNSAT-IS1, which did not produce effluent NH_3-N below 5 mg./L. UNSAT-IS2 appeared to provide good performance in two sample events, and had elevated effluent (NO_3+NO_2)-N in the last sample event. It is noted that (NO_3+NO_2)-N was not elevated in the overlying sulfur layer, suggesting that the sample may have been compromised. UNSAT-IS3 and UNSAT-IS4 produced low effluent TN, NH3, and (NO_3+NO_2)-N in the last three sampling events.

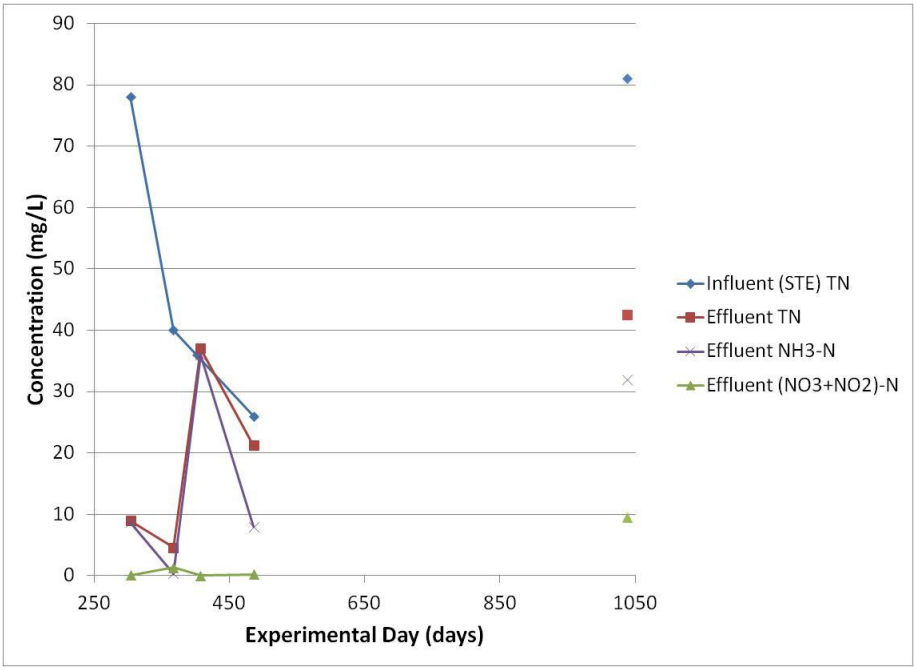

Figure 4-27:
UNSAT-IS1 Nitrogen Time Series

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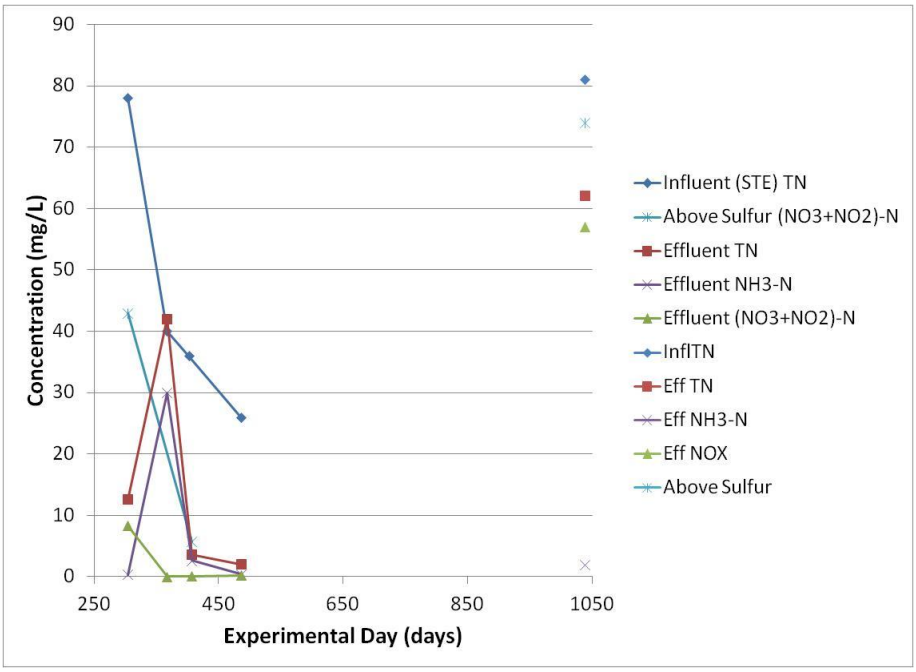

Figure 4-28:
UNSAT-IS2 Nitrogen Time Series

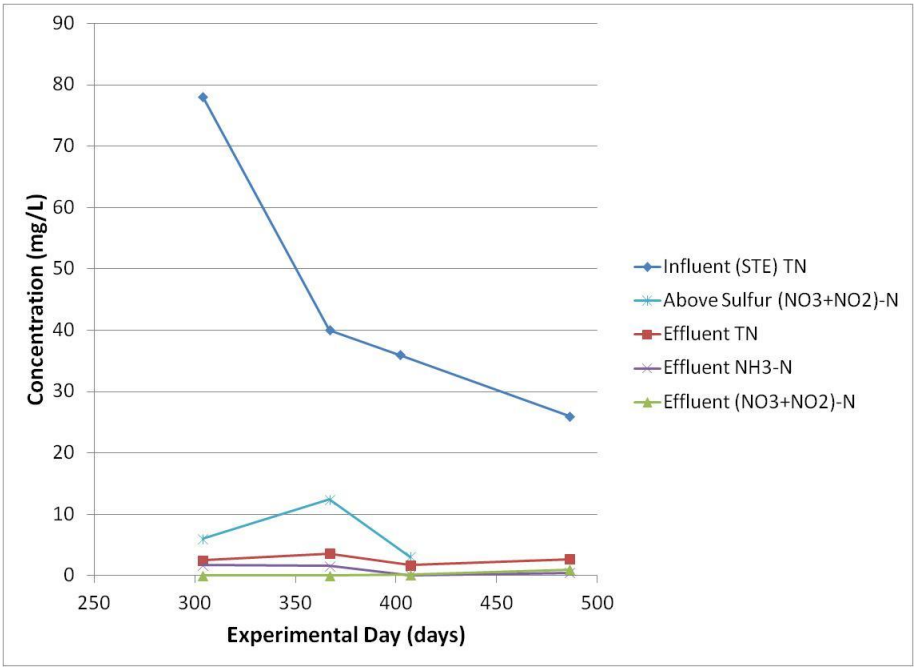

Figure 4-29:
UNSAT-IS3 Nitrogen Time Series

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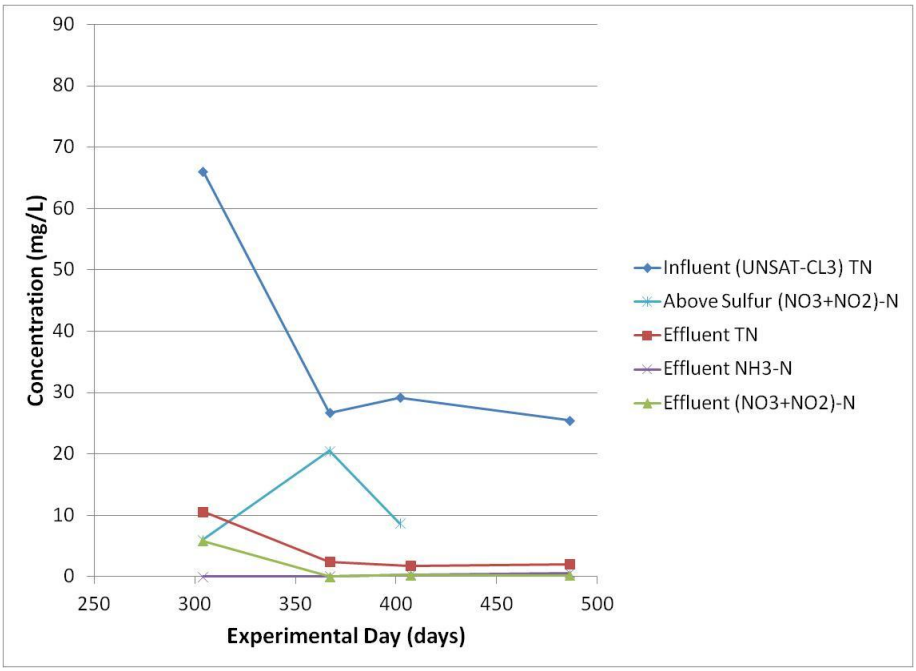

Figure 4-30:
UNSAT-IS4 Nitrogen Time Series

4.4.3.3 Stacked Unsaturated/Saturated Biofilters Performance Summary and Statistics

Mean effluent values for water quality parameters are listed in Table 4.24 for the core performance evaluation period (Table 4.2, Operating Period 4). For each biofilter, detailed nitrogen concentration data are listed for TN, TKN, Org N, NH_3-N and (NO_3+NO_2)-N in Tables 4.25 through 4.29.

Table 4.24
Stacked Unsaturated/Saturated (In Situ) Biofilters Mean Effluent Values

Biofilter	Influent	Sample Location	C-BOD_5	COD	TSS	TN	TKN	Organic N	NH_3-N	(NO_3+NO_2) - N	Dissolved Oxygen	pH	Total Alkalinity	Fecal coliform, cfu/100 ml
UNSAT-IS1	Primary Effluent	Final Effluent	62	240	5.0	22.9	20.6	3.6	17.0	2.2	4.1	7.1	320	1
UNSAT-IS2	Primary Effluent	Before Sulfur	13	63	2.0	35.4	4.7	1.6	3.10	30.7	1.0	6.4	69	-
		Final Effluent	11	82	8.5	24.5	11.4	4.3	7.05	13.1	5.0	7.2	255	19
UNSAT-IS3	Primary Effluent	Before Sulfur	2.5	120	3.0	13.3	3.4	3.1	0.23	9.9	3.3	7.1	455	1
		Final Effluent	4.5	96	4.5	2.6	2.4	1.4	0.98	1.1	5.0	7.3	385	9
UNSAT-IS4	Nitrified Effluent	Before Sulfur	6.0	80	12	12.0	2.9	2.5	0.37	9.1	2.1	7.0	325	1
		Final Effluent	24	88	39	2.6	2.4	1.4	0.98	1.1	1.2	6.8	495	7

Table 4.25
Stacked Unsaturated/Saturated (In Situ) Biofilters Total N Data

Biofilter	Mean	Standard Deviation	Minimum	Maximum	n
UNSAT-IS1	22.9	16.7	4.6	42.5	5
UNSAT-IS2	24.5	26.5	2.0	62.2	5
UNSAT-IS3	2.6	0.8	1.7	3.6	4
UNSAT-IS4	2.6	0.8	1.7	3.6	4
UNSAT-IS2 above Sulfur	35.4	38.7	1.8	85.0	4
UNSAT-IS3 above Sulfur	13.3	6.4	7.2	21.4	4
UNSAT-IS4 above Sulfur	12.0	8.3	3.3	23.1	4

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Table 4.26
Stacked Unsaturated/Saturated (In Situ) Biofilters TKN Data

Biofilter	Mean	Standard Deviation	Minimum	Maximum	n
UNSAT-IS1	20.6	14.7	3.3	37.0	5
UNSAT-IS2	11.4	17.2	1.8	42.0	5
UNSAT-IS3	2.4	0.9	1.6	3.6	4
UNSAT-IS4	2.4	0.9	1.6	3.6	4
UNSAT-IS2 above Sulfur	4.7	4.3	1.8	11.0	4
UNSAT-IS3 above Sulfur	3.4	0.5	2.8	4.1	4
UNSAT-IS4 above Sulfur	2.9	0.7	2.1	3.5	4

Table 4.27
Stacked Unsaturated/Saturated (In Situ) Biofilters Org N Data

Biofilter	Mean	Standard Deviation	Minimum	Maximum	n
UNSAT-IS1	3.6	5.3	0.2	13.0	5
UNSAT-IS2	4.3	4.5	0.9	12.0	5
UNSAT-IS3	1.4	0.5	0.8	2.0	4
UNSAT-IS4	1.4	0.5	0.8	2.0	4
UNSAT-IS2 above Sulfur	1.6	1.4	0.0	3.3	4
UNSAT-IS3 above Sulfur	3.1	0.6	2.4	3.9	4
UNSAT-IS4 above Sulfur	2.5	1.0	1.2	3.3	4

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Table 4.28
Stacked Unsaturated/Saturated (In Situ) Biofilters NH3-N Data

Biofilter	Mean	Standard Deviation	Minimum	Maximum	n
UNSAT-IS1	17.0	15.9	0.4	36.0	5
UNSAT-IS2	7.1	12.9	0.4	30.0	5
UNSAT-IS3	0.98	0.80	0.11	1.70	4
UNSAT-IS4	0.98	0.80	0.11	1.70	4
UNSAT-IS2 above Sulfur	3.10	5.27	0.28	11.00	4
UNSAT-IS3 above Sulfur	0.23	0.16	0.06	0.45	4
UNSAT-IS4 above Sulfur	0.37	0.34	0.07	0.86	4

Table 4.29
Stacked Unsaturated/Saturated (In Situ) Biofilters (NO_3+NO_2)-N Data

Biofilter	Mean	Standard Deviation	Minimum	Maximum	n
UNSAT-IS1	2.22	4.10	0.010	9.50	5
UNSAT-IS2	13.14	24.78	0.040	57.00	5
UNSAT-IS3	1.15	0.69	0.230	1.72	4
UNSAT-IS4	1.1	0.7	0.230	1.7	4
UNSAT-IS2 above Sulfur	30.7	34.6	0.0	74.0	4
UNSAT-IS3 above Sulfur	9.9	6.7	3.1	18.0	4
UNSAT-IS4 above Sulfur	9.1	8.2	1.2	20.5	4

Three In Situ biofilters treated primary effluent: UNSAT-IS1, UNSAT-IS2 and UNSAT-IS-3 (Table 4.23). In Situ 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 In Situ biofilters treating primary effluent (Tables 4.25 to 4.28). Mean (NO_3+NO_2)-N was 7 to 24 mg/l before the sulfur layer and 0.1 to 2.8 mg/L in final efflu-

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ent. The sulfur layer was highly significant to (NO_3+NO_2)-N reduction in the In Situ biofilters testing both primary effluent and nitrified effluent (Tables 4.24, 4.29).

Removal efficiencies are summarized in Table 4.30. Mean removal efficiencies from primary effluent ranged from 31 to 99% for $CBOD_5$ and were 94% and greater for TSS. For systems treating primary effluent, mean removal efficiencies were 48 to 93% for TN and 51 to 94% for Org-N. The change in chemical parameters that occurs across the unsaturated/saturated biofilters is an important metric of biofilter function and of the interaction of biochemical reactions with the wastewater matrix. Mean chemical parameter changes are listed in Table 4.31. Change in DO across the In Situ biofilters was variable, and while pH declined across all biofilters with a maximum decline on 0.67 pH units (Table 4.31).

Table 4.30
Stacked Unsaturated/Saturated (In Situ) Biofilters Mean Removal Efficiencies %

Biofilter	Sample Location	C-BOD_5	TSS	TN	TKN	Organic N
UNSAT-IS1	Final Effluent	31.2	98.2	48.0	51.2	20.0
UNSAT-IS2	Above Sulfur	43.0	49.1	40.3	72.8	51.4
	Final Effluent	78.2	94.7	56.9	73.3	43.0
UNSAT-IS3	Above Sulfur	95.7	98.7	62.0	91.1	46.5
	Final Effluent	92.0	98.7	93.1	94.2	77.2
UNSAT-IS4	Above Sulfur			61.2	-4.7	12.8
	Final Effluent			90.2	11.3	23.5

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Table 4.31
Stacked Unsaturated/Saturated (In Situ) Biofilters Mean Chemical Parameter Changes

Biofilter	Sample Location	Dissolved Oxygen	pH	Total Alkalinity	Specific Conductivity
UNSAT-IS1	Final Effluent	1.75	-0.27	-78	-8
UNSAT-IS2	Above Sulfur	0.1	-0.54	-200	-159
	Final Effluent	1.1	-0.20	-98	27
UNSAT-IS3	Above Sulfur	0.1	-0.22	-132	138
	Final Effluent	1.0	-0.13	-83	193
UNSAT-IS4	Above Sulfur	-6.1	-0.32	170	313
	Final Effluent	-3.6	-0.47	84	-78

Unsaturated/saturated biofilter nitrogen concentrations are compared in Figures 4-31 through 4-35, which are box plots of TN, TKN, Org N, NH3-N, and (NO_3+NO_2)-N, respectively. The above sulfur (AS) data are for the monitoring locations above the sulfur media and reflect nitrogen performance at that location, and correspond to a biofilter without a sulfur media layer. The box and whiskers plots provide immediate comparative visualization of biofilter effluent nitrogen levels, including the center and spread of the distribution. The box and whisker plots provide a summary of data values (median, upper and lower quartiles). They are non-parametric and make no assumptions of the underlying statistical distribution of data. UNSAT-IS3 and UNSAT-IS4 appear to have lower effluent concentrations of TN, TKN, Org N and NH_3-N (Figures 4-31 through 4-35). For UNSAT-IS3 and UNSAT-IS4, effluent TN, Org N and (NO_3+NO_2)-N appear to be lower in final effluent than above the sulfur layer (Figures 4-31, 4-33 and 4-35).

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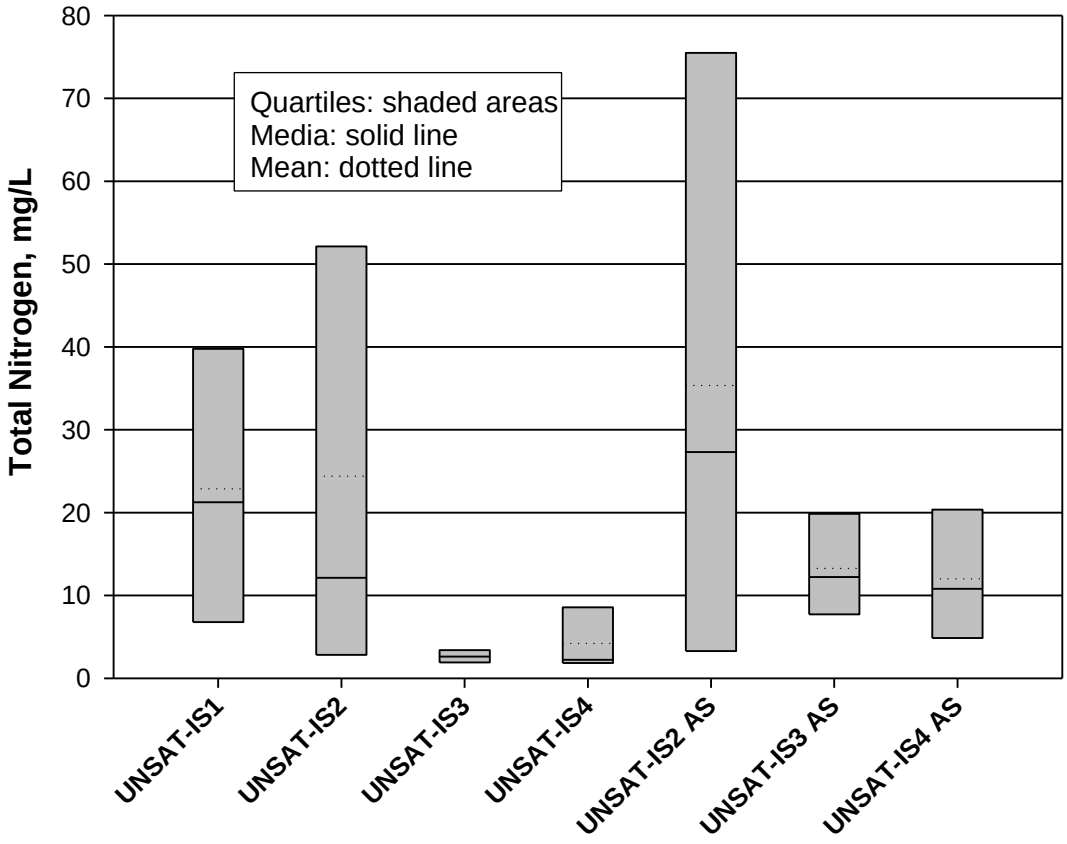

Figure 4-31: Stacked Unsaturated/Saturated (In Situ) Biofilters
Total N Box and Whisker Plot

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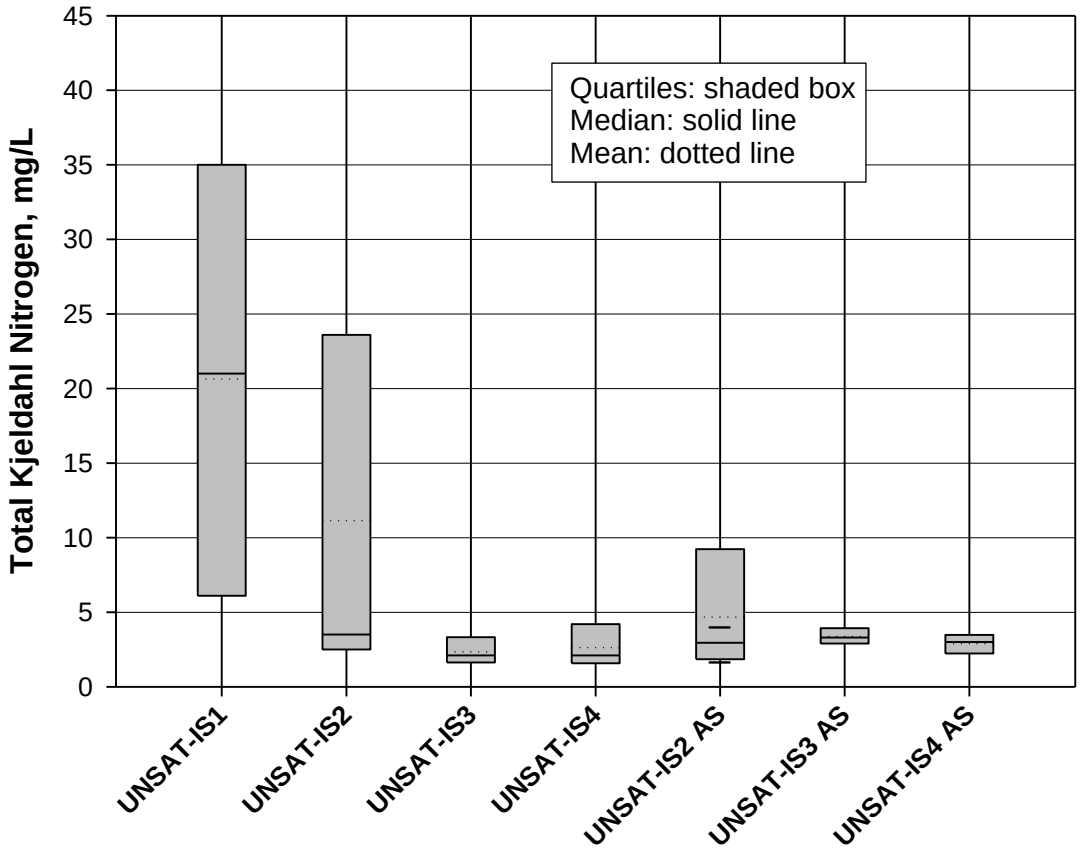

Figure 4-32: Stacked Unsaturated/Saturated (In Situ) Biofilters TKN Box and Whisker Plot

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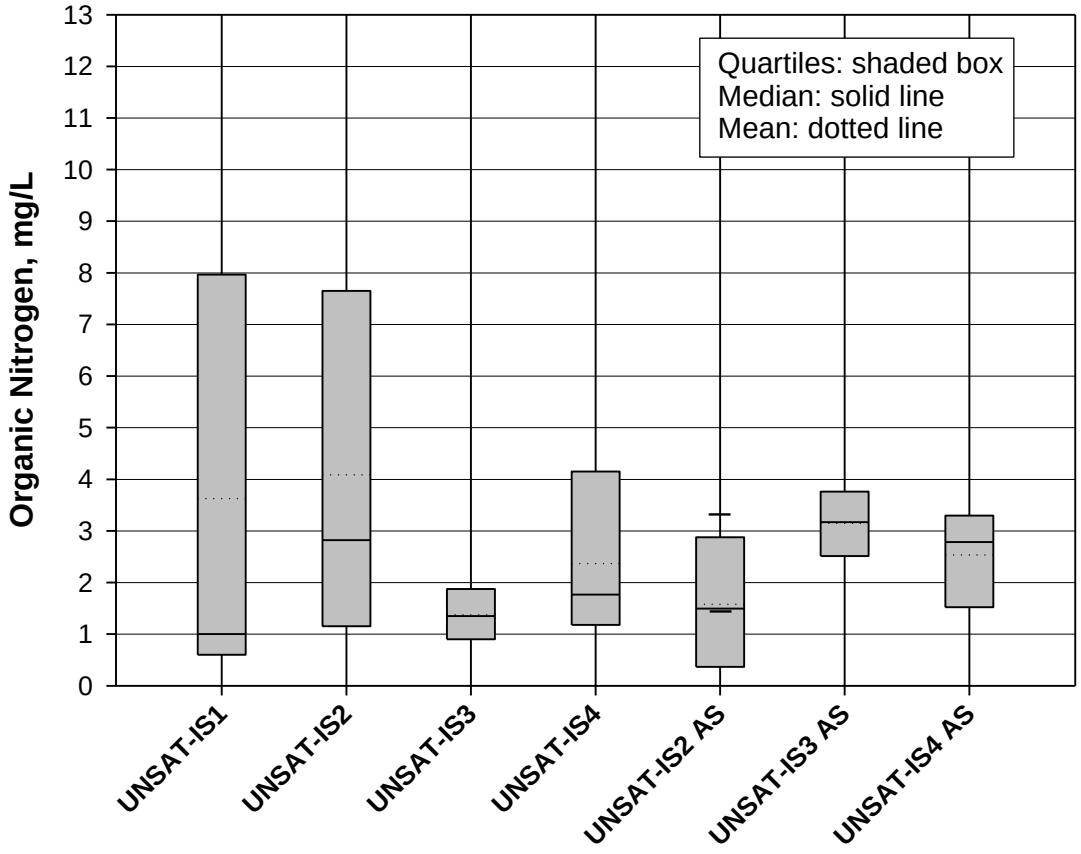

Figure 4-33: Stacked Unsaturated/Saturated (In Situ) Biofilters Organic Nitrogen Box and Whisker Plot

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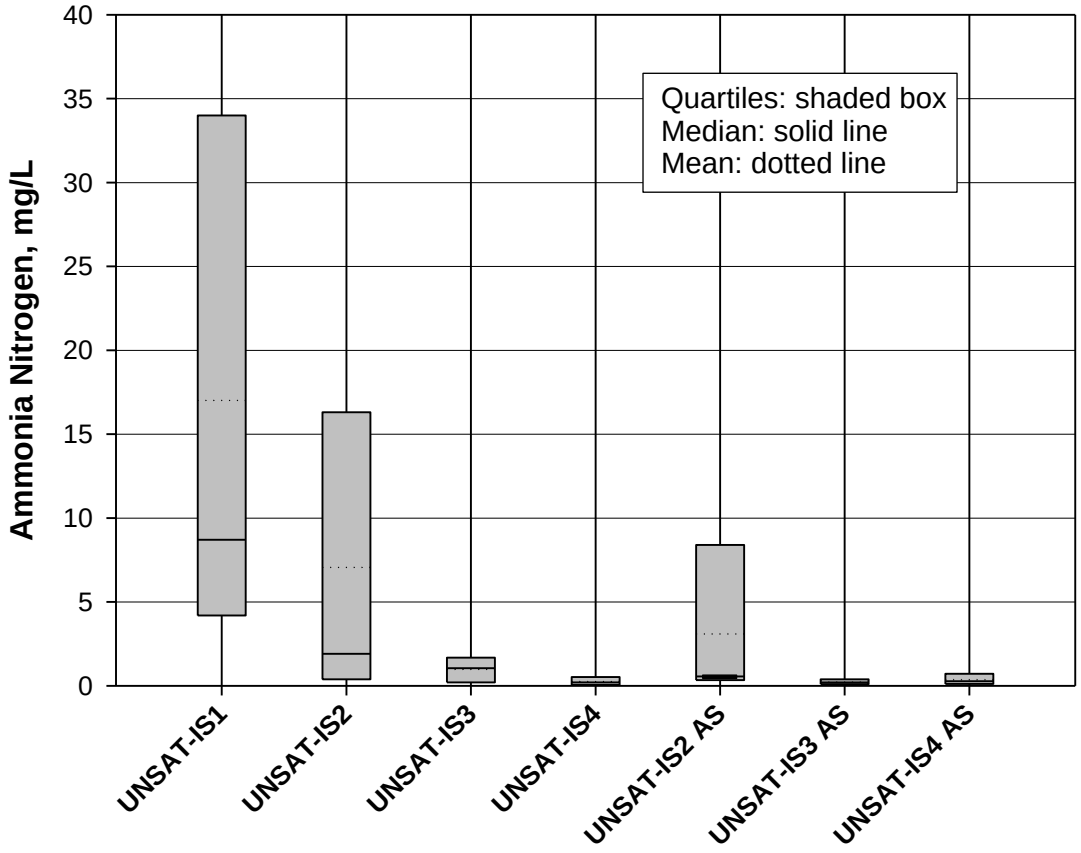

Figure 4-34: Stacked Unsaturated/Saturated (In Situ) Biofilters
NH_3-N Box and Whisker Plot

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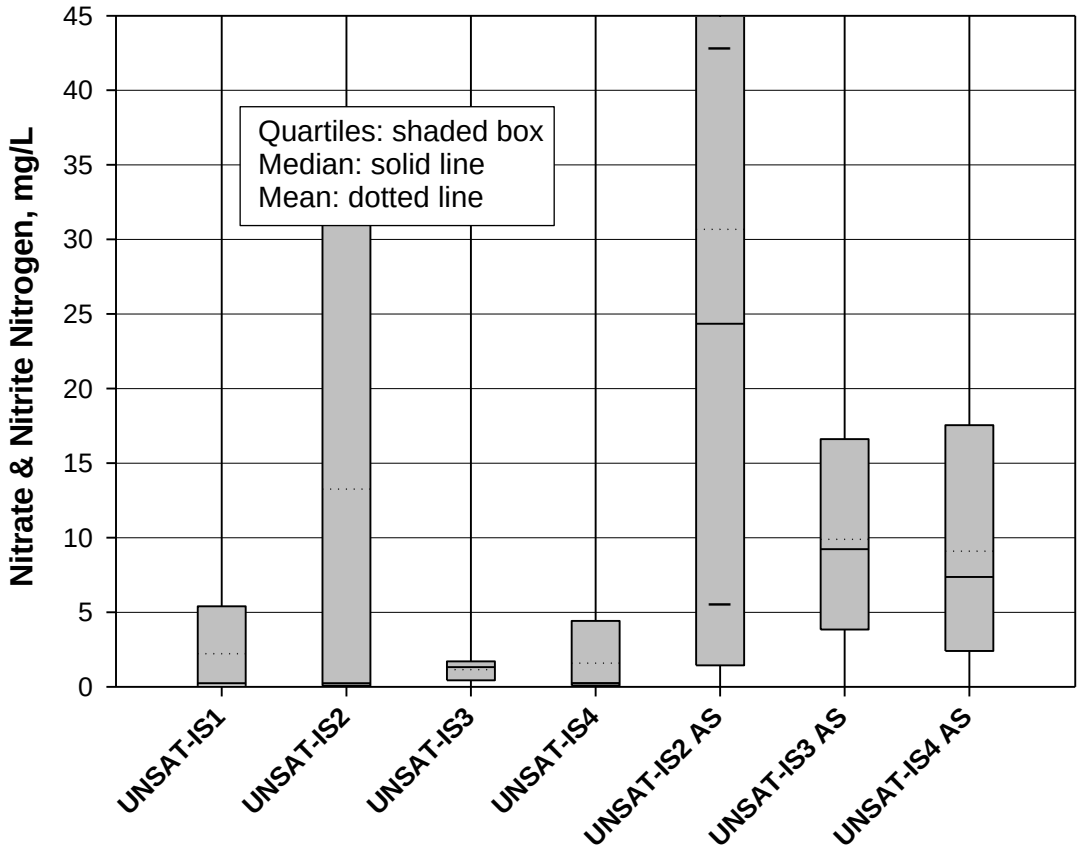

Figure 4-35: Stacked Unsaturated/Saturated (In Situ) Biofilters (NO_3+NO_2)-N Box and Whisker Plot

The nitrogen performance of the unsaturated/saturated biofilters was compared using a number of statistical procedures (Table 4.32). Effluent concentrations (raw data) of five nitrogen species were evaluated to test if the differences in the mean effluent concentrations were great enough that they were statistically significant and could not be attributed to random sampling variability. Statistical tests were also performed for removal efficiency of nitrogen species including TN, TKN, and Org N. A parametric Analysis of Variance (One Way ANOVA) procedure was employed for datasets that passed the Shapiro-Wilk test for normality ($p< 0.05$) and equal variance test ($p<0.05$). For non-normal or unequal variance datasets, a Kruskal-Wallis One Way Analysis of Variance on ranks was performed. Similar values were employed for t test analyses for comparison of effluent TN and effluent (NO_3+NO_2)-N for In Situ biofilters with and without sulfur me-

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dia. One Way ANOVA and Kruskall-Wallis tests did not show statistically significant differences in mean effluent concentrations of the five nitrogen species and for mean removal efficiencies of TN, TKN and Org N (Table 4.32). T tests for In Situ biofilters with and without sulfur media did not show a statistically significant difference in mean effluent TN concentrations, but effluent (NO_3+NO_2)-N were significantly lower in systems with sulfur as compared to without sulfur.

Table 4.32
Stacked Unsaturated/Saturated (In Situ) Biofilters Statistical Analyses

Nitrogen Species	Biofilter Numbers	Test	Statistically significant difference of means
Total Nitrogen	19 - 22	One Way ANOVA	No
Total Kjeldahl Nitrogen	19 - 22	Kruskall-Wallis	Yes
Organic Nitrogen	19 - 22	Kruskall-Wallis	No
Ammonia Nitrogen	19 - 22	Kruskall-Wallis	Yes, NH_3 lower in IS-4 than IS-1
Nitrate + Nitrite Nitrogen	19 - 22	Kruskall-Wallis	No
Total Nitrogen Removal Efficiency	19 - 22	Kruskall-Wallis	Yes
Total Kjeldahl Nitrogen Removal Efficiency	19 - 22	Kruskall-Wallis	No
Organic Nitrogen Removal Efficiency	19 - 22	Kruskall-Wallis	No
Total Nitrogen	With Sulfur (20,21,22) vs. Without Sulfur (20AS,21AS,22AS)	Mann-Whitney Rank Sum Test	No
NO_x	With Sulfur (20,21,22) vs. Without Sulfur (20AS,21AS,22AS)	Mann-Whitney Rank Sum Test	Yes, effluent NO_x significantly lower with sulfur vs. without sulfur

19= UNSAT-IS1; 20= UNSAT-IS2; 21= UNSAT-IS3; 22= UNSAT-IS4; 20AS = UNSAT-IS2 AS
21AS = UNSAT-IS3 AS; 22AS= UNSAT-IS4 AS

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4.4.4 Total Nitrogen Removal Efficiency

The total nitrogen concentrations are compared with time (experimental days) in Figures 4-36 through 4-38 for the single pass systems, recirculating systems and stacked unsaturated/saturated (In Situ) biofilter systems respectively. The single pass system TN is higher for biofilters containing lignocellulosic media than sulfur (Figure 4-36) under the conditions studied. Lignocellulosic-containing recycle biofilters also exhibit elevated effluent TN (Figure 4-36), as do vertically stacked configurations (Figure 4-37), when compared to sulfur as the reactive media, under the conditions studied.

Overall Total Nitrogen (TN) removal efficiency from primary effluent was statistically compared for biofilter systems representing complete treatment trains (Table 4.33). These included five Group A systems (single pass Stage 1/upflow Stage 2), four Group C systems (composite Group B Stage 1/horizontal Stage 2), and three Group D systems (vertically stacked unsaturated/ saturated). TN removal efficiency (raw data) was evaluated to test if the differences in the mean removals were great enough that they were statistically significant and could not be attributed to random sampling variability. A parametric Analysis of Variance (One Way ANOVA) procedure was employed for datasets that passed the Shapiro-Wilk test for normality ($p < 0.05$) and equal variance test ($p<0.05$). For non-normal or unequal variance datasets, a Kruskal-Wallis One Way Analysis of Variance on ranks was performed. Similar values were employed for t test analyses for comparison of two data groups, where a Mann-Whitney Rank Sum test was employed for non-normally distributed data. For comparative analysis of all eleven systems (One Way ANOVA), Mean TN removal efficiencies were statistically significant with higher TN removal efficiency for systems containing sulfur vs. SYP. Mean TN removal efficiencies were statistically greater for single pass and recycle systems than for vertically stacked media systems (One Way ANOVA). T test comparison (Mann-Whitney Rank Sum) of sulfur vs. SYP showed significantly higher mean TN removal efficiency for sulfur vs. SYP systems (Table 4.33), under the conditions studied.

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Table 4.33
Overall Total N Removal Efficiency Statistical Tests

Biofilter Systems	Data Periods	Test	Result
1 - 12	Period 1: systems 1 - 9 Period 4:systems 10 - 12	Kruskall-Wallis One Way Analysis of Variance	There is a statistically significant difference in means
		Pairwise Multiple Comparison Procedures (Dunn's Method)	Higher TN Removal efficiency with sulfur than with ligno
1 - 12	Period 1: systems 3,6,9 Period 1b: systems 1,2,4,5,7,8 Period 4:systems 10 - 12	Kruskall-Wallis One Way Analysis of Variance	There is a statistically significant difference in means
Single Pass (1,2,3,4,5) vs. Recycle/Horiz. Denit (6,7,8,9) vs. In Situ (10,11,12)	Period 1: systems 3,6,9 Period 1b: systems 1,2,4,5,7,8 Period 4:systems 10 - 12	Kruskall-Wallis One Way Analysis of Variance	There is a statistically significant difference in means
		Pairwise Multiple Comparison Procedures (Dunn's Method)	Higher TN Removal efficiency with single pass and recycle versus in-situ; no significant difference between single pass and recycle
Ligno (2,4,5,8) vs. Sulfur (1,3,6,7)	Period 1: systems 3,6,9 Period 1b: systems 1,2,4,5,7,8	Mann-Whitney Rank Sum Test	Higher TN Removal efficiency with sulfur than with ligno

1= UNSAT-EC1 / DENIT-SU4; 2= UNSAT-EC3 / DENIT-LS3; 3= UNSAT-CL1 / DENIT-SU3; 4= UNSAT-CL3 / DENIT-LS2
5= UNSAT-CL5 / DENIT-LS4; 6= DFT / DENIT-SU1; 7= DFT / DENIT-SU2; 8= DFT / DENIT-LS1; 9= DFT / DENIT-GL1
10= UNSAT-IS1; 11= UNSAT-IS2; 12= UNSAT-IS3

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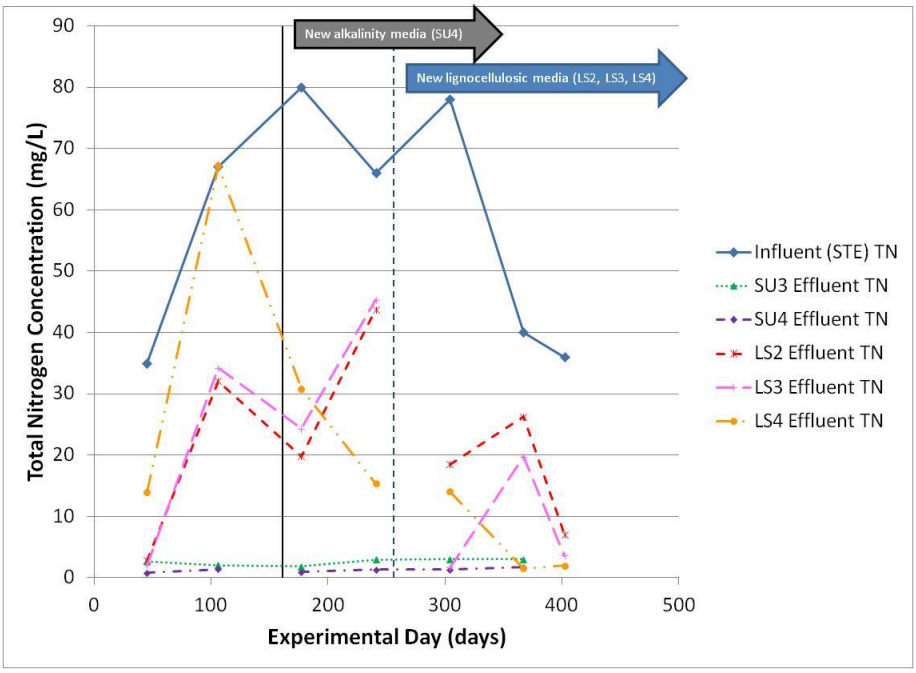

Figure 4-36:
Total Nitrogen Removal of Single Pass Systems

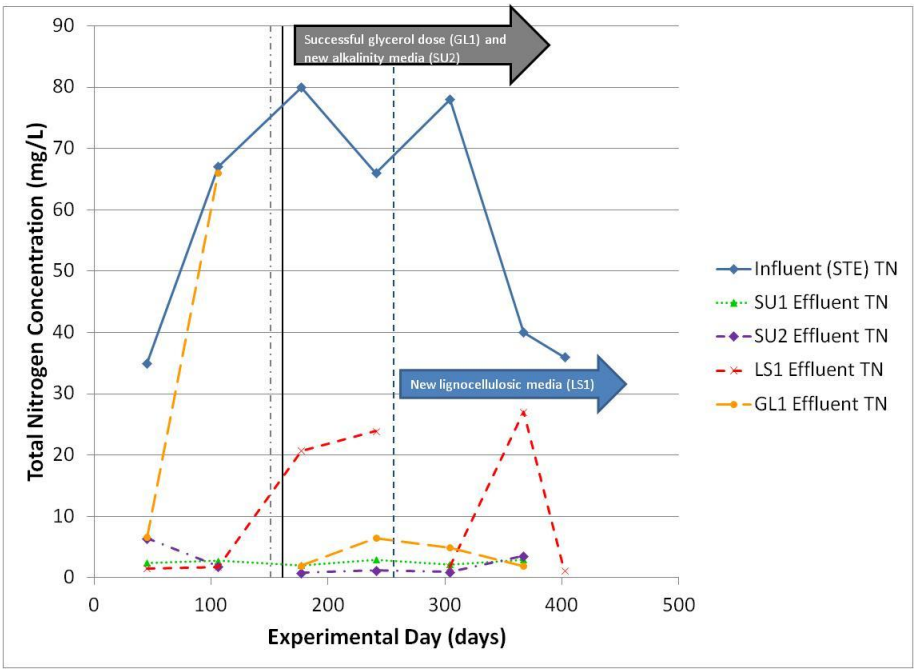

Figure 4-37:
Total Nitrogen Removal of Recirculating Systems

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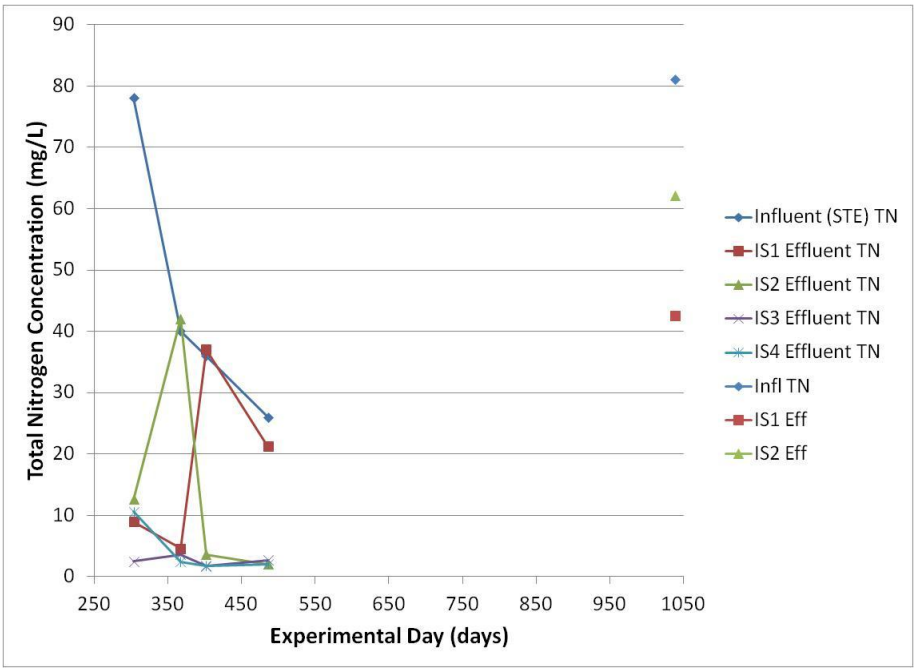

Figure 4-38: Total Nitrogen Removal of Stacked Unsaturated/Saturated (In Situ) Biofilter Systems

4.4.5 Sulfur Biofilter Solute Profiles and Effluent Sulfate

Solute profiles for horizontal and upflow biofilters containing sulfur are shown respectively in Figures 4-39 and 4-40. The horizontal biofilter profile shows significant decline in (NO_3+NO_2)-N concentration and increase in sulfate concentration at the entrance region. (NO_3+NO_2)-N is essentially depleted at the 24 inch distance. The vertical biofilter profile (Figure 4-40) shows significant decline in (NO_3+NO_2)-N concentration and increase in sulfate concentration at the entrance region (upflow biofilter, depth = 0 inch). (NO_3+NO_2)-N is essentially depleted by the 10 inch depth and sulfate increase is limited above that point. It is significant that the sulfate concentration in the biofilter does not increase substantially after (NO_3+NO_2)-N (and ostensibly DO) are depleted. Also shown is the prediction of sulfate concentration based on a stoichiometric model that accounts for sulfur utilization for processes that consume both oxygen and nitrate as electron acceptors.

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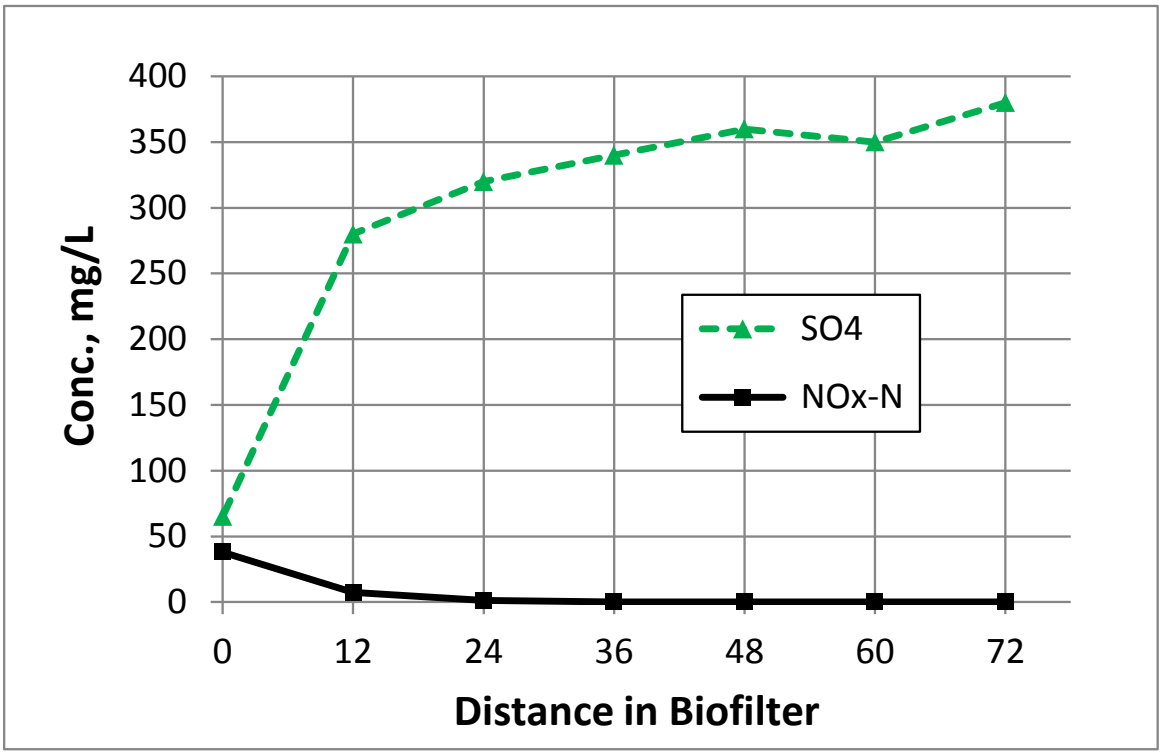

Figure 4-39: Solute Profile in DENIT-SU2 on Day 305, 10 gal/ft^2-day

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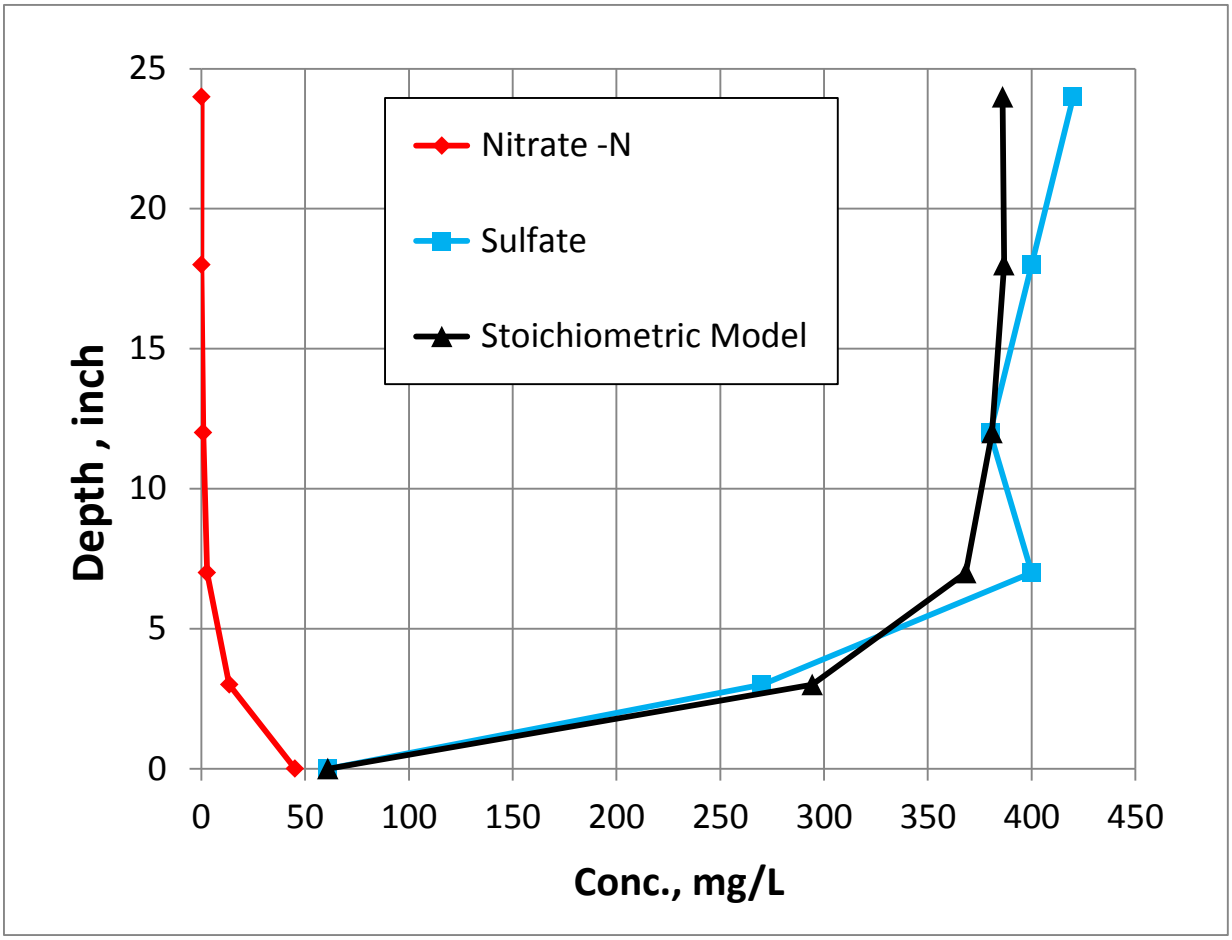

Figure 4-40: Solute Profile in DENIT-SU4 on Day 242, 5.6 gal/ft^2-day

$$\text{Effluent } SO_4 = \text{Influent } SO_4 + Y_{SO4/O2}\,(\text{Influent } O_2 - O_2) + Y_{SO4/NO3\text{-}N}\,(\text{Influent } NO_3\text{-}N - NO_3\text{-}N)$$

The stoichiometric model appears to provide a reasonable prediction of measured sulfate levels in the biofilter (Figure 4-40).

Effluent sulfate levels in four sulfur-containing biofilters are summarized in Table 4.34. Mean effluent sulfate levels are 325 to 482 mg/L, and increases in sulfate range from 266 to 396 mg/L. The stoichiometric model was applied to sulfur biofilter data for individual monitoring events in which all data inputs were available: influent DO, influent (NO_3+NO_2)-N, effluent DO, and effluent (NO_3+NO_2)-N. Comparison of measured with predicted effluent sulfate is shown in Figure 4-41. The dashed line indicated perfect

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agreement between measurement and model prediction. Some effluent sulfate levels lie close to the model prediction line while many measured sulfate levels are greater than the model prediction. Ingress of oxygen into the biofilter and contact of DO with sulfur media is one possible explanation for higher than predicted sulfate levels.

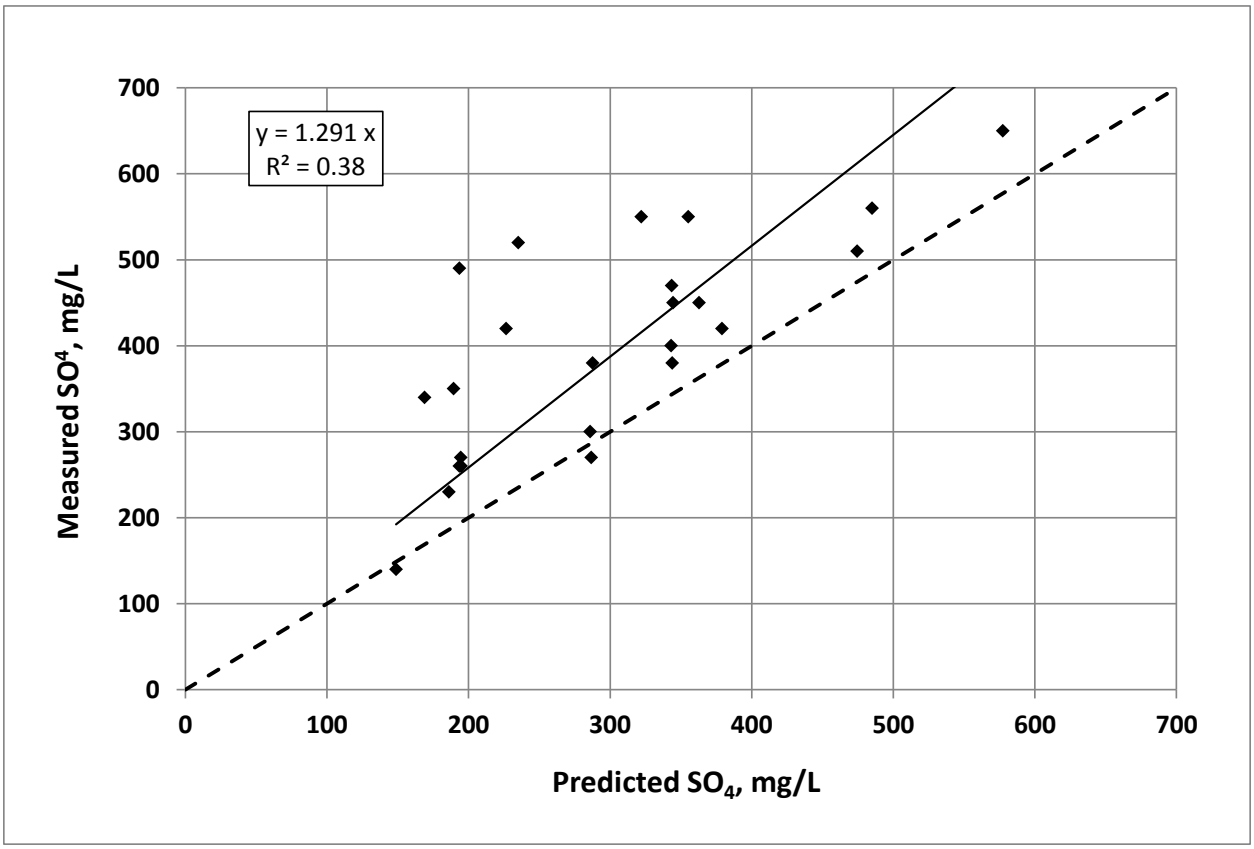

Figure 4-41: Model Prediction of Effluent Sulfate Levels

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Table 4.34
Effluent Sulfate

Biofilter	Effluent Sulfate, mg/L				Change in Sulfate Across Biofilter, mg/L			
	Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max
DENIT-SU1	325	33.8	230	450	266	33.7	184	398
DENIT-SU2	343	55.1	140	490	284	53.7	94	426
DENIT-SU3	482	46.9	340	650	427	45.1	303	589
DENIT-SU4	453	46.0	260	560	396	44.5	214	499

4.4.6 Increased Hydraulic Loading Rate

Following Sample Event No. 8, a track record of acceptable performance had been established for many PNRS II systems and increasing the flowrates was recommended. The following modifications were made:

Unsaturated Stage 1 Biofilters

- Increased loading rates:
  - Single pass: from 3 gal/ft^2-day to 5 gal/ft^2-day STE on June 28, 2011 (Day 407)
  - Recycle: from 3 gal/ft^2-day to 6 gal/ft^2-day STE on May 31, 2011 (Day 379)

Saturated Stage 2 Biofilters

- Increase loading rates:
  - Single pass coupled: single pass Stage 1 effluent from 5.6 to 9.3 gal/ft^2-day; 25.7 to 15.4 hour mean pore water residence time (MPWRT) on June 28, 2011 (Day 407)
  - Horizontal: Stage 1 w/recycle combined effluent from 10 to 20 gal/ft^2-day; 43 to 21.5 hour MPWRT on June 28, 2011 (Day 407)

4.4.6.1 Stage 1 (Unsaturated) Biofilters

Sample event 9 showed effluent NH_3-N levels were below 0.5 mg/L for all five Stage 1 single pass biofilters and all DO levels were greater than 3.9 mg/L. TSS and $CBOD_5$ were 3 mg/L or below in all effluents. Organic N ranged from 1.5 to 3.3 mg/L in these same five systems. (NO_3+NO_2)-N increased significantly in all Stage 1 biofilter effluents corresponding to the decrease in TKN from nitrification. The five single pass biofilters performed exceptionally well in removing suspended solids and $CBOD_5$ and in converting ammonium to oxidized nitrogen. Effluent TN of all biofilters was only slightly less than the influent TN, indicating that denitrification was limited.

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NH_3-N levels were at or below 0.04 mg/L for all four recirculating Stage 1 biofilters, and effluent DO was 6.2 to 7.2 mg/L. Effluent (NO_3+NO_2)-N ranged from 14 to 18 mg/L and organic N from 1.5 to 1.6 mg/L. The nitrification performance of these biofilters was quite acceptable and TN reduction from recirculation (pre-denitrification) averaged 31%. TSS and $CBOD_5$ were 10 mg/L or below in all effluents.

4.4.6.2 Stage 2 (Saturated) Biofilters

Sample event 9 showed (NO_3+NO_2)-N was less than 0.5 mg/L in the two single pass upflow denitrification biofilters that contained sulfur media., Effluent SO_4 was higher in the biofilter containing 80% sulfur than in the biofilter with 30% sulfur. (NO_3+NO_2)-N removal was incomplete in all upflow biofilters containing lignocellulosic media, with effluent (NO_3+NO_2)-N of 8 to 20 mg/L. A higher percent of lignocellulosic media in the biofilter media appeared to be accompanied by higher (NO_3+NO_2)-N reductions.

Influent (NO_3+NO_2)-N to the four Stage 2 horizontal biofilters (from the denite feed tank (DFT)) was 16 mg/L. Effluent (NO_3+NO_2)-N was 0.25 mg/L and less in all four horizontal biofilters. The low (NO_3+NO_2)-N were accompanied by < 0.3 mg/L DO and ORP of -284 to –366 mV. All horizontal biofilters were highly effective in producing a reducing environment and achieving their (NO_3+NO_2)-N reduction goals. DENIT-LS1 with the new lignocellulosic media exhibited complete denitrification, with effluent (NO_3+NO_2)-N of 0.24 mg/L.

4.4.6.3 Long-term Performance

Ponding developed (attributed to a thick biomat formation) within the following Stage 1 unsaturated biofilters: UNSAT-SA2, UNSAT-EC4, UNSAT-EC1, UNSAT-EC3 and UNSAT-CL1. On November 5, 2012 (Day 903), the loading rate to the Stage 1 unsaturated biofilters with recycle was decreased back to 3 gal/ft^2-day, however the recycle ratio remained at 5:1. However, ponding of effluent at the surface of several biofilters continued; therefore, on December 13, 2012 (Day 941), the loading rate to all the Stage 1 unsaturated biofilters was decreased back to 3 gal/ft^2-day. However, several unsaturated biofilters subsequently experienced ponding; therefore, on January 3, 2013 (Day 962) the unsaturated biofilters were allowed to drain by stopping the flow to the systems, the surface media was raked and allowed to dry out. On February 10, 2013 (Day 1000), the systems were re-started at the initial lower surface loading rates. Limited additional monitoring was conducted on Day 1038.

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Section 5.0
Summary and Recommendations

Twenty-two pilot scale biofilters were operated over a period of over 18 months to evaluate passive two-stage nitrogen removal from wastewater primary effluent. Two-stage biofiltration showed capability to continuously achieve total nitrogen removals of over 95% from primary effluent over eighteen months. Expanded clay, clinoptilolite and sand appear to provide suitable media for aerobic biofilters and consistently reduced ammonia nitrogen to less than 1 mg/L. 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 denitrifying biofilters. Anoxic biofilters containing lignocellulosic media (Southern yellow pine) were also capable of achieving high NO3+NO2 reductions in the conditions of this study but performance was highly variable and not equal to the sulfur biofilter performance. The pilot studies have also demonstrated that biofilters with vertically stacked media configurations are capable of achieving high Total Nitrogen reductions from septic tank effluent, under certain conditions.

The results of the Passive Nitrogen Removal Study II provide a basis for the design of full-scale biofiltration systems at individual homesites. Design recommendations for single family home biofiltration systems follow closely the media types, media particle sizes, media size and depth configurations, and applied loading rates used in the pilot study. Full-scale designs that follow the pilot-based design recommendations can be deployed with a reasonable degree of confidence. Deviations from the design and operating conditions employed in the pilot study, and presented in Table 5.1, should be considered with a high degree of caution.

Design recommendations are summarized in Table 5.1. The recommendations are process based and focus on factors and parameters that provide effective biological treatment in varied biofilter configurations. Designs are organized into unsaturated biofilters (single pass and recycle), saturated biofilters, and unsaturated/saturated biofilter configurations. The PNRS II pilot facility was configured to provide separate design guidance for unsaturated (Stage 1) biofilters and saturated (Stage 2) biofilters. This approach was intended to enable the modular coupling of Stage 1 and Stage 2 systems. Consequently, the structure of the recommendations is for discreet designs of Stage 1 and Stage 2 systems. The recommendations for vertically stacked unsaturated/saturated biofilters follow the configurations of four PNRS II pilot systems which had important commonalities and defined differences.

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Table 5.1
Preliminary Guidance Recommendations for Design of Single Family Home Systems

Unsaturated Recycle (Stage 1)

Media	Hydraulic Loading Rate, gal/ft^2-day	Total Media Depth, inch	Media Stratification and Particle Size Distribution		
			Layer	Depth, inch	Particle Size Spec, mm
Expanded Clay	≤ 3.0	≥ 24	Upper	≥ 8	≥1.53
			Lower	≥ 16	<1.53
Clinoptilolite	≤ 3.0	≥ 24	Upper	≥ 8	≥ 1.4 - 2.3
			Lower	≥ 16	0.5 - 1.5
Sand	≤ 3.0	≥ 24	Upper	≥ 8	E.S. ≥ 0.8-1.2 U.C.≤4
			Lower	≥ 16	E.S. 0.45 - 0.55 U.C.≤4

Unsaturated Single Pass (Stage 1)

Media	Forward Flow Hydraulic Loading Rate, gal/ft^2-day	Total Media Depth, inch	Media Stratification and Particle Size Distribution		
			Layer	Depth, inch	Particle Size Spec, mm
Expanded Clay	≤ 3.0	≥ 24	Upper	≥ 8	≥1.53
			Lower	≥ 16	<1.53
Clinoptilolite	≤ 3.0	≥ 24	Upper	≥ 8	≥ 1.4 - 2.3
			Lower	≥ 16	0.5 - 1.5

Saturated (Stage 2)

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 (SYP)	80-100	≥ 24	≥ 120	1 - 30

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Table 5.1 (Continued)
Preliminary Guidance Recommendations for Design of Single Family Home Systems

Vertically Stacked Biofilters

Influent	Hydraulic Loading Rate, gal/ft^2-day	Media Layer	Media Layer Depth, inch	Media	Media Stratification and Particle Size Particle Size Spec, mm
Septic Tank Effluent	0.8 - 2.0	Upper	≥ 18	Sand	E.S. ≥ 0.8-1.2 U.C.≤4
					E.S. 0.45-0.55 U.C.≤4
		Middle	≥ 12	50% Ligno 50% Expanded Clay	Ligno = 1 - 30 EC = >1.13
		Lower	≥ 4	Elemental Sulfur	2.0 - 3.36
		Upper	≥ 18	Expanded Clay	>1.53
					<1.53
		Middle	≥ 12	50% Ligno 50% Expanded Clay	Ligno = 1 - 30 EC = >1.13
		Lower	≥ 4	Elemental Sulfur	2.0 - 3.36
		Upper	≥ 18	Clinoptilolite	≥ 1.4 - 2.3
					0.3 - 1.2
		Middle	≥ 12	50% Ligno 50% Expanded Clay	Ligno = 1 - 30 EC = >1.13
		Lower	≥ 4	Elemental Sulfur	2.0 - 3.36
Nitrified Effluent	≤ 1.2	Upper	≥ 12	Sand	E.S. ≥ 0.8-1.2 U.C.≤4
					E.S. 0.45-0.55 U.C.≤4
		Middle	≥ 12	50% Ligno 50% Expanded Clay	Ligno = 1 - 30 EC = >1.13
		Lower	≥ 4	Elemental Sulfur	2.0 - 3.36

[1]As needed for alkalinity adjustment

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

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Preliminary two-stage biofilter recommendations are based on PNRS II pilot testing of nine unsaturated biofilters and nine saturated denitrification biofilters. Stage 1 design recommendations for single pass systems are based on overall consistent nitrogen performance achieved by five single pass PNRS II systems. Similarly, design recommendations for Stage 1 recycle systems are based on overall consistent nitrogen performance of four PNRS II systems. The recommended Stage 1 designs (single pass or recycle) can be coupled with any recommended Stage 2 design for an effective two-stage biofilter design for Total Nitrogen Reduction.

The design recommendations presented in Table 5.1 can be used to derive hybrid designs that couple biofilters in a manner not tested in the PNRS II pilot study. One example is the use of a vertically stacked biofilter design (unsaturated/saturated) followed by direct hydraulic connection to a saturated upflow denitrification biofilter. In this case and for many other potential combinations, the design of individual biofilters should adhere to the design recommendations presented in Table 5.1.

These preliminary guidance criteria are recommended to be used for sizing full-scale biofilter systems for installation in Task B of the FOSNRS project. Following full-scale testing of these systems over a greater than 12 month period, the design criteria should be re-visited and revised as necessary to provide design guidance for full-scale use of these systems in Florida.

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Section 6.0
References

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Appendix A: PNRS II Database

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Biofilter ID	SE 1	SE 2	SE 3	SE 4	SE 5	SE 6	SE 7	SE 8	SE 9	SE 10	OP 1	OP 2	OP 3
Stage 1 (Unsaturated) Single Pass											Stage 1 Single Pass (n)		
UNSAT-EC1	1	1	1	1	1	1			2	3	6	1	1
UNSAT-EC3	1	1	1	1	1	1	1		2	3	7	1	1
UNSAT-CL1	1	1	1	1	1	1			2	3	6	1	1
UNSAT-CL3	1	1	1	1	1	1	1		2	3	7	1	1
UNSAT-PS1	X	X	X	X	X								
UNSAT-CL5						1	1		2	3	2	1	1
Stage 1 (Unsaturated) Recirculating											Stage 1 Recirculating (n)		
UNSAT-SA2	1	1	1	1	1	1			2	3	6	1	1
UNSAT-EC4	1	1	1	1	1	1			2	3	6	1	1
UNSAT-CL2	1	1	1	1	1	1			2	3	6	1	1
UNSAT-CL4	1	1	1	1	1	1			2	3	6	1	1

Operating period 1

Operating period 2, increased hydraulic loading rate

Operating period 3, post mortem

Biofilter ID	SE 1	SE 2	SE 3	SE 4	SE 5	SE 6	SE 7	SE 8	SE 9	SE 10	OP 1	OP 1a	OP 1b	OP 2	OP 3
Stage 2 (Saturated) Upflow											Stage 2 (Saturated) Upflow (n)				
DENIT-SU4	1a	1a	1b	1b	1b	1b			2	3		2	4	1	1
DENIT-LS3	1a	1a	1a	1a	1b	1b	1b		2	3		4	3	1	1
DENIT-SU3	1	1	1	1	1	1			2	3	6			1	1
DENIT-LS2	1a	1a	1a	1a	1b	1b	1b		2	3		4	3	1	1
DENIT-LS4	1a	1a	1a	1a	1b	1b	1b		2	3		4	3	1	1
Stage 2 (Saturated) Horizontal											Stage 2 (Saturated) Horizontal (n)				
DENIT-SU1	1	1	1	1	1	1			2	2	6			2	
DENIT-SU2	1a	1a	1b	1b	1b	1b			2	2		2	4	2	
DENIT-LS1	1a	1a	1a	1a	1b	1b	1b		2	2		4	3	2	
DENIT-GL1	1a	1a	1b	1b	1b	1b			2			2	4	1	

Opearing period 1

Operating period 1a

Operating period 1b, media modification

Operating period 2, increased hydraulic loading rate

Operating period 3, post mortem

Biofilter ID	SE 1	SE 2	SE 3	SE 4	SE 5	SE 6	SE 7	SE 8	SE 9	SE 10	OP 1	OP 2	OP 3	OP 4
Stacked Unsaturated/Saturated (In situ) Biofilters											Stacked In situ Biofilters (n)			
UNSAT-IS1	1	2	3	3	4	4		4	4	4	1	1	2	5
UNSAT-IS2	1	2	2	2	4	4		4	4	4	1	3		5
UNSAT-IS3			3	3	4	4		4	4				2	4
UNSAT-IS4			3	3	4	4		4	4				2	4

Operating period 1, unsaturated operation

Operating period 2, saturated the bottom denitrification media layer

Operating period 3, media modification

Operating period 4, media modification

PNRS II TEST FACILITY
SAMPLE EVENT NO. 1
EXPERIMENTAL DAY 45

Sample ID	Media Composition	Sample Date/Time	Sample Type	Temp (°C)	pH	Total Alkalinity (mg/L)	DO (mg/L)	Specific Conductance (µS)	TDS (mg/L)	TSS (mg/L)	$CBOD_5$ (mg/L)	TN (mg/L N)	TKN (mg/L N)	Organic N (mg/L N)	NH3-N (mg/L N)	NOx (mg/L N)	TIN (mg/L N)	Sulfide (mg/L)	H_2S (mg/L)	SO_4 (mg/L)
STE Sample																				
PNRS II STE-Tank 1		7/1/10 14:00	G	26.00	6.91	210	0.1	649	240	23	22.0	35.02	35.00	15.00	20.00	0.02	20.02			
Stage 1 Single Pass Biofilters Effluent																				
UNSAT-EC1	15" Expanded Clay	7/1/10 13:45	G	27.20	7.25	110	7.08	617	350	1	2.0	21.20	2.20	2.19	0.01	19.00	19.01	0.17	0.06	46
UNSAT-EC3	30" Expanded Clay	7/1/10 13:40	G	27.60	7.34	84	6.94	712	410	2	2.0	21.20	2.20	2.19	0.01	19.00	19.01			
UNSAT-CL1	15" Clinoptilolite	7/1/10 13:30	G	27.20	8.30	230	3.53	857	470	7	2.0	20.70	2.70	2.69	0.01	18.00	18.01	0.10	0.01	37
UNSAT-CL3	30" Clinoptilolite	7/1/10 13:20	G	26.60	8.64	270	6.85	974	550	1	2.0	22.80	2.80	2.79	0.01	20.00	20.01			
UNSAT-PS1	30" Polystyrene	7/1/10 13:15	G	27.00	7.28	160	2.70	599	270	4	3.0	25.30	16.00	9.60	6.40	9.30	15.70			
Stage 2 Single Pass Upflow Biofilters Effluent																				
DENIT-SU4	80% Sulfur; 20% Sodium Sesqui.	7/1/10 10:40	G	27.10	7.30	140	0.1	929	560	1	3.9	0.78	0.77	0.67	0.10	0.01	0.11	1.80	0.6	260
DENIT-LS3	50% Lignocellulosic; 50% Sand	7/1/10 10:30	G	28.10	7.70	200	0.1	695	370	2	12.0	2.01	2.00	1.05	0.95	0.01	0.96			
DENIT-SU3	80% Sulfur; 20% Oyster Shell	7/1/10 10:10	G	27.60	7.17	170	0.1	1,257	710	16	13.0	2.71	2.70	2.24	0.46	0.01	0.47	4.70	1.8	340
DENIT-LS2	50% Lignocellulosic; 50% Expanded Clay	7/1/10 10:00	G	27.20	8.14	370	0.1	998	510	9	5.5	2.80	1.40	1.17	0.23	1.40	1.63			
DENIT-LS4	30% Lignocellulosic; 70% Expanded Clay	7/1/10 9:45	G	28.10	7.62	180	0.46	618	270	1	9.1	14.01	14.00	8.20	5.80	0.01	5.81			
Recirculation Tanks Effluent																				
RC1		7/1/10 14:10	G	30.80	7.28	160		637	330	5	2.8	27.00	15.00	9.30	5.70	12.00	17.70			
RC2		7/1/10 13:45	G	30.50	7.27	140		679	340	3	2.0	27.00	15.00	9.70	5.30	12.00	17.30			
RC3		7/1/10 12:50	G	29.20	7.61	200		760	360	6	2.0	27.00	16.00	10.50	5.50	11.00	16.50			
RC4		7/1/10 12:40	G	28.80	7.61	220		811	400	21	2.7	27.00	16.00	10.50	5.50	11.00	16.50			
Stage 1 Recirculating Biofilters Effluent																				
UNSAT-CL4	30" Clinoptilolite	7/1/10 11:15	G	27.60	6.72	220	7.28	860	480	8	2.0	10.30	2.40	2.38	0.02	7.90	7.92			
UNSAT-CL2	15" Clinoptilolite	7/1/10 11:20	G	27.10	7.85	200	6.69	781	440	3	2.0	17.10	2.10	2.09	0.01	15.00	15.01			
UNSAT-EC4	30" Expanded Clay	7/1/10 11:50	G	27.40	7.28	160	7.21	661	350	1	2.0	18.90	1.90	1.89	0.01	17.00	17.01			
UNSAT-SA2	30" Sand	7/1/10 12:25	G	26.70	6.04	110	6.96	604	330	1	2.0	19.20	2.20	2.19	0.01	17.00	17.01			
Denite Feed Tank (Tank 3)																				
DFT		7/1/10 12:15	G	26.90	8.06	160	7.31	744	390	1	2.0	21.20	3.20	3.19	0.01	18.00	18.01	0.10	0.01	46
Stage 2 Horizontal Biofilters Effluent																				
DENIT-SU1	80% Sulfur; 20% Oyster Shell	7/1/10 14:20	G	27.50	7.15	200	0.53	1,192	660	1	26.0	2.41	2.40	0.90	1.50	0.01	1.51	29.00	11	230
DENIT-SU2	80% Sulfur; 20% Sodium Sesqui.	7/1/10 14:25	G	27.90	9.08	260	1.23	1,398	690	1	4.9	6.40	1.20	1.19	0.01	5.20	5.21	0.10	0.01	140
DENIT-LS1	50% Lignocellulosic; 50% Expanded Clay	7/1/10 13:05	G	27.30	7.51	250	0.45	738	370	1	56.0	1.54	1.50	0.74	0.76	0.04	0.80			
DENIT-GL1	12" Gravel; 60" Expanded Clay	7/1/10 12:08	G	27.80	7.96	220	1.54	794	380	1	39.0	6.60	1.90	0.94	0.96	4.70	5.66			
In-situ Simulator Biofilters Effluent																				
UNSAT-IS1 (STE)	12" Sand; 12" Mix (45% EC, 35% Ligno, 20% Sulfur)	7/1/10 14:35	G	26.70	6.39	130	0.1	2,438	1,600	113	7.8	0.43	0.41	0.37	0.05	0.02	0.07	0.10	0.01	1,100
UNSAT-IS2 (NO_3)	12" Sand; 12" Mix (45% EC, 35% Ligno, 20% Sulfur)	7/1/10 14:35	G	26.60	6.14	210	0.41	3,506	3,000	108	13.0	0.63	0.62	0.51	0.11	0.01	0.12	0.10	0.01	1,800

Notes

[1]Total Nitrogen (TN) is a calculated value equal to the sum of TKN and NO_x

[2]Organic Nitrogen (ON) is a calculated value equal to the difference of TKN and NH_3

[3]Total Inorganic Nitrogen (TIN) is a calculated value equal to the sum of NH_3 and NO_x

EC: expanded clay, CL: clinoptilolite, PS: polystyrene, SU: elemental sulfur, LS: lignocellulosic, GL: glycerol, OS: oyster shell, NS: sodium sesquicarbonate, GR: gravel

DO - Dissolved oxygen

G - Grab sample

Gray - Shaded data points indicate values below method detection level (mdl), mdl value used for statistical analyses.

Yellow shaded data points indicate the reported value is between the laboratory method detection limit and the laboratory practical quantitation limit.

PNRS II TEST FACILITY
SAMPLE EVENT NO. 2
EXPERIMENTAL DAY 106

Sample ID	Media Composition	Sample Date/Time	Sample Type	Temp (°C)	pH	Total Alkalinity (mg/L)	DO (mg/L)	ORP (mV)	Specific Conductance (µS)	TDS (mg/L)	TSS (mg/L)	$CBOD_5$ (mg/L)	COD (mg/L)	TN (mg/L N)[1]	TKN (mg/L N)	Organic N (mg/L N)[2]	NH_3-N (mg/L N)	NOx (mg/L N)	TIN (mg/L N)[3]	TP (mg/L)	Sulfide (mg/L)	H_2S (mg/L)	SO_4 (mg/L)	Fecal (Ct/100 mL)
STE Sample																								
PNRS II STE-Tank 1		8/31/10 13:35	G	27.9	7.2	370	0.0	-263.9	1,092	380	70	27	210	67.05	67	8.00	59	0.053	59.05	7.4				800
Stage 1 Single Pass Biofilters Effluent																								
UNSAT-EC1	15" Expanded Clay	8/31/10 12:40	G	28.6	7.0	130	6.8	137.5	1,055	670	1	2	13	46.30	4.3	4.29	0.01	42	42.01	3.9	0.1	0.05	51	1
UNSAT-EC1-D	15" Expanded Clay	8/31/10 12:40	G																					1
UNSAT-EC3	30" Expanded Clay	8/31/10 12:50	G	29.2	7.0	150	6.7	117.0	1,133	740	1	2	16	45.30	3.3	3.29	0.01	42	42.01	3.9				1
UNSAT-CL1	15" Clinoptilolite	8/31/10 12:30	G	29.5	7.4	250	5.5	116.2	1,271	750	1	2	20	40.80	2.8	2.79	0.01	38	38.01	8.0	0.3	0.08	48	12
UNSAT-CL1-D	15" Clinoptilolite	8/31/10 12:30	G																					10
UNSAT-CL3	30" Clinoptilolite	8/31/10 12:00	G	28.7	7.8	340	7.1	83.8	1,388	850	1	2	20	40.00	4.0	3.99	0.01	36	36.01	6.8				3
UNSAT-PS1	30" Polystyrene	8/31/10 11:40	G	28.6	7.6	280	2.5	60.0	1,010	420	2	5.7	48	61.20	53	7.00	46	8.2	54.20	5.9				930
Stage 2 Single Pass Upflow Biofilters Effluent																								
DENIT-SU4	80% Sulfur; 20% Sodium Sesqui.	8/31/10 10:25	G	28.1	6.6	150	0.2	-106.6	1,395	950	1	2	22	1.39	1.3	0.99	0.31	0.091	0.40	3.2	0.1	0.01	550	1
DENIT-LS3	50% Lignocellulosic; 50% Sand	8/31/10 10:15	G	27.8	7.3	220	1.3	-21.0	1,114	680	1	2	29	34.20	3.2	3.05	0.15	31	31.15	3.3				1
DENIT-SU3	80% Sulfur; 20% Oyster Shell	8/31/10 10:00	G	28.4	6.7	270	0.1	-279.6	1,655	1,100	1	2	39	2.04	2.0	1.20	0.80	0.039	0.84	6.2	7.0	4.5	550	1
DENIT-LS2	50% Lignocellulosic; 50% Expanded Clay	8/31/10 9:50	G	27.3	7.8	380	4.1	-11.5	1,448	850	1	2	24	32.10	3.1	2.80	0.30	29	29.30	5.7				1
DENIT-LS4	30% Lignocellulosic; 70% Expanded Clay	8/31/10 9:40	G	27.1	7.6	360	0.4	-43.7	1,120	430	1	2	35	67.17	67	34.00	33	0.17	33.17	6.9				12
DENIT-LS4-D	30% Lignocellulosic; 70% Expanded Clay	8/31/10 9:40	G			350				420	1	2												
Recirculation Tanks Effluent																								
RC1		8/31/10 13:00	G	30.0	7.3	210	0.03	-128.3	1,011	550	1	6	22	53.00	17	4.00	13	36	49.00	5.8				114
RC2		8/31/10 13:10	G	30.2	7.3	180	0.1	-108.2	1,031	560	1	2	24	40.00	17	2.00	15	23	38.00	4.2				99
RC3		8/31/10 13:20	G	30.2	7.6	160	0.1	89.0	1,128	590	1	3.3	61	45.00	12	3.30	8.7	33	41.70	6.4				109
RC4		8/31/10 13:30	G	30.4	7.8	180	0.0	73.0	1,112	620	12	3.0	29	38.00	11	2.60	8.4	27	35.40	6.7				112
Stage 1 Recirculating Biofilters Effluent																								
UNSAT-CL4	30" Clinoptilolite	8/31/10 10:55	G	29.3	7.8	170	7.1	35.5	1,174	680	1	2	13	45.10	2.1	2.09	0.01	43	43.01	7.6				1
UNSAT-CL4-D	30" Clinoptilolite	8/31/10 10:55	G										18	45.20	2.2	2.19	0.01	43	43.01	7.4				
UNSAT-CL2	15" Clinoptilolite	8/31/10 11:05	G	26.8	7.4	120	6.4	30.2	1,050	650	1	2	22	45.10	3.1	3.09	0.01	42	42.01	7.1				4
UNSAT-EC4	30" Expanded Clay	8/31/10 11:20	G	28.5	7.0	130	6.9	78.8	1,000	640	1	2	13	40.90	2.9	2.89	0.01	38	38.01	3.8				1
UNSAT-SA2	30" Sand	8/31/10 11:30	G	28.2	6.9	110	6.3	89.2	953	638	1	2	13	39.30	3.3	3.29	0.01	36	36.01	6.3				1
Denite Feed Tank (Tank 3)																								
DFT		8/31/10 14:30	G	28.1	7.6	130	7.4	25.5	1,020	660	1	2	18	42.80	2.8	2.79	0.01	40	40.01	6.5	0.1	0.01	52	1
Stage 2 Horizontal Biofilters Effluent																								
DENIT-SU1	80% Sulfur; 20% Oyster Shell	8/31/10 8:55	G	25.1	7.0	240	0.1	-317.2	1,473	1,000	1	24	63	2.74	2.7	0.30	2.4	0.04	2.44	5.0	25	12	450	3
DENIT-SU2	80% Sulfur; 20% Sodium Sesqui.	8/31/10 9:05	G	24.8	7.0	210	0.5	-279.0	1,402	930	2	20	50	1.83	1.8	0.88	0.92	0.025	0.95	4.8	14	6.7	470	1
DENIT-LS1	50% Lignocellulosic; 50% Expanded Clay	8/31/10 9:20	G	25.2	7.7	250	0.2	-199.7	962	530	1	3.9	44	1.81	1.8	1.10	0.70	0.01	0.71	0.46				1
DENIT-GL1	12" Gravel; 60" Expanded Clay	8/31/10 9:30	G	25.2	6.4	660	0.00	-174.9	1,686	1,200	100	810	1,100	66.08	66	37.00	29	0.076	29.08	2.9				800
In-situ Simulator Biofilters Effluent																								
UNSAT-IS1 (STE)	12" Sand; 12" Mix (45% EC, 35% Ligno, 20% Sulfur)	8/31/10 13:35	G	29.5	6.5	270	0.1	-42.5	1,206	780	3	8.4	57	20.09	20	0.00	20	0.086	20.09	1.2	0.9	0.7	300	1
UNSAT-IS2 (NO_3)	12" Sand; 12" Mix (45% EC, 35% Ligno, 20% Sulfur)	9/1/10 10:20	G	29.0	6.29	200	0.09	-174.5	1,543	950	60	2	50	0.65	0.64	0.43	0.21	0.01	0.22	1.5	0.1	0.01	470	1
Field Blank	Reagent Water	8/31/10 8:30				2				10	1	2	10	0.06	0.05	0.04	0.01	0.01	0.02	0.01	0.1		0.2	
Equipment Blank	Reagent Water	8/31/10 8:40				2				10	1	2	10	0.06	0.05	0.04	0.01	0.01	0.02	0.01	0.1		0.2	

Notes:

[1]Total Nitrogen (TN) is a calculated value equal to the sum of TKN and NO_X.

[2]Organic Nitrogen (ON) is a calculated value equal to the difference of TKN and NH_3.

[3]Total Inorganic Nitrogen (TIN) is a calculated value equal to the sum of NH_3 and NO_X

EC: expanded clay, CL: clinoptilolite, PS: polystyrene, SU: elemental sulfur, LS: lignocellulosic, GL: glycerol, OS: oyster shell, NS: sodium sesquicarbonate, GR: gravel

D.O. - Dissolved oxygen

G - Grab sample

Gray-shaded data points indicate values below method detection level (mdl), mdl value used for statistical analyses.

Yellow-shaded data points indicate the reported value is between the laboratory method detection limit and the laboratory practical quantitation limit, value used for statistical analysis.

Orange - shaded data points indicate too many colonies were present. The numberic value represents the dilution factor times the maximum reportable number of colonies.

Purple-shaded data points indicate results based upon colony counts outside the method indicated ideal range.

PNRS II TEST FACILITY
PROFILES
EXPERIMENTAL DAY 107

Sample ID	Sample Location within Biofilter	Media Composition	Sample Date/Time	Sample Type	NOx (mg/L N)	SO_4 (mg/L)
Stage 2 Single Pass Upflow Biofilters Effluent						
DENIT-SU4 - Effluent	24" from Inlet (Bottom)	80% Sulfur; 20% Sodium Sesqui.	8/31/10 10:25	G	0.091	550
DENIT-SU4-1	18" from Inlet (Bottom)		9/1/10 11:50	G	0.034	510
DENIT-SU4-2	12" from Inlet (Bottom)		9/1/10 11:52	G	14	370
DENIT-SU4-3	7" from Inlet (Bottom)		9/1/10 11:54	G	11	310
DENIT-SU4-4	3" from Inlet (Bottom)		9/1/10 11:56	G	8.4	300
DENIT-SU4-5	Influent (EC1 Effluent)		8/31/10 12:40	G	42.0	51
DENIT-LS3 - Effluent	24" from Inlet (Bottom)	50% Lignocellulosic; 50% Sand	8/31/10 10:15	G	31	
DENIT-LS3-1	18" from Inlet (Bottom)		9/1/10 11:42	G	37	
DENIT-LS3-2	12" from Inlet (Bottom)		9/1/10 11:43	G	42	
DENIT-LS3-3	7" from Inlet (Bottom)		9/1/10 11:44	G	53	
DENIT-LS3-4	3" from Inlet (Bottom)		9/1/10 11:46	G	40	
DENIT-LS3-5	Influent (EC3 Effluent)		8/31/10 12:50	G	42	
DENIT-SU3 - Effluent	24" from Inlet (Bottom)	80% Sulfur; 20% Oyster Shell	8/31/10 10:00	G	0.039	550
DENIT-SU3-1	18" from Inlet (Bottom)		9/1/10 11:33	G	0.01	480
DENIT-SU3-2	12" from Inlet (Bottom)		9/1/10 11:35	G	0.01	490
DENIT-SU3-3	7" from Inlet (Bottom)		9/1/10 11:37	G	0.01	510
DENIT-SU3-4	3" from Inlet (Bottom)		9/1/10 11:39	G	0.01	510
DENIT-SU3-5	Influent (CL1 Effluent)		8/31/10 12:30	G	38.00	48
DENIT-LS2 - Effluent	24" from Inlet (Bottom)	50% Lignocellulosic; 50% Expanded Clay	8/31/10 9:50	G	29	
DENIT-LS2-1	18" from Inlet (Bottom)		9/1/10 11:26	G	26	
DENIT-LS2-2	12" from Inlet (Bottom)		9/1/10 11:27	G	32	
DENIT-LS2-3	7" from Inlet (Bottom)		9/1/10 11:28	G	46	
DENIT-LS2-4	3" from Inlet (Bottom)		9/1/10 11:30	G	53	
DENIT-LS2-5	Influent (CL3 Effluent)		8/31/10 12:00	G	36	
DENIT-LS4 - Effluent	24" from Inlet (Bottom)	30% Lignocellulosic; 70% Expanded Clay	8/31/10 9:40	G	0.17	
DENIT-LS4-1	18" from Inlet (Bottom)		9/1/10 11:15	G	0.11	
DENIT-LS4-2	12" from Inlet (Bottom)		9/1/10 11:18	G	0.026	
DENIT-LS4-3	7" from Inlet (Bottom)		9/1/10 11:20	G	0.028	
DENIT-LS4-4	3" from Inlet (Bottom)		9/1/10 11:21	G	0.74	
DENIT-LS4-5	Influent (PS1 Effluent)		8/31/10 11:40	G	8.20	
Stage 2 Horizontal Biofilters Effluent						
DENIT-SU1-Effluent	72" from Inlet	80% Sulfur; 20% Oyster Shell	8/31/10 8:55	G	0.04	450
DENIT-SU1-36	36" from Inlet		9/1/10 9:00	G	17	270
DENIT-SU1-24	24" from Inlet		9/1/10 10:05	G	22	170
DENIT-SU1-12	12" from Inlet		9/1/10 11:05	G	21	200
DENIT-SU1-0	Influent (DFT Effluent)		8/31/10 14:30	G	40	52
DENIT-SU2-Effluent	72" from Inlet	80% Sulfur; 20% Sodium Sesqui.	8/31/10 9:05	G	0.025	470
DENIT-SU2-36	36" from Inlet		9/1/10 9:00	G	0.01	420
DENIT-SU2-24	24" from Inlet		9/1/10 10:05	G	0.01	400
DENIT-SU2-12	12" from Inlet		9/1/10 11:05	G	42	76
DENIT-SU2-0	Influent (DFT Effluent)		8/31/10 14:30	G	40	52
DENIT-LS1-Effluent	72" from Inlet	50% Lignocellulosic; 50% Expanded Clay	8/31/10 9:20	G	0.01	
DENIT-LS1-36	36" from Inlet		9/1/10 9:00	G	11	
DENIT-LS1-24	24" from Inlet		9/1/10 10:05	G	49	
DENIT-LS1-12	12" from Inlet		9/1/10 11:05	G	56	
DENIT-LS1-0	Influent (DFT Effluent)		8/31/10 14:30	G	40	
DENIT-GL1-Effluent	72" from Inlet	12" Gravel; 60" Expanded Clay	8/31/10 9:30	G	0.076	
DENIT-GL1-36	36" from Inlet		9/1/10 9:00	G	0.043	
DENIT-GL1-24	24" from Inlet		9/1/10 10:05	G	0.061	
DENIT-GL1-12	12" from Inlet		9/1/10 11:05	G	1.8	
DENIT-GL1-0	Influent (DFT Effluent)		8/31/10 14:30	G	40	

Notes
G - Grab sample
Gray - Shaded data points indicate values below method detection level (mdl), mdl value used for statistical analyses.
Yellow shaded data points indicate the reported value is between the laboratory method detection limit and the laboratory practical quantitation limit.

PNRS II TEST FACILITY
SAMPLE EVENT NO. 3
EXPERIMENTAL DAY 177

Sample ID	Media Composition	Sample Date/Time	Sample Type	Temp (°C)	pH	Total Alkalinity (mg/L)	DO (mg/L)	ORP (mV)	Specific Conductance (µS)	TDS (mg/L)	TSS (mg/L)	$CBOD_5$ (mg/L)	COD (mg/L)	TN (mg/L N)[1]	TKN (mg/L N)	Organic N (mg/L N)[2]	NH_3-N (mg/L N)	NOx (mg/L N)	TIN (mg/L N)[3]	TP (mg/L)	Sulfide (mg/L)	H_2S (mg/L)	SO_4 (mg/L)
STE Sample																							
PNRS II STE-Tank 1		11/10/10 13:50	G	25.1	7.2	430	2.4	-235.0	1,250	450	70	91	240	80.0	80	13.0	67	0.01	67.0		15	5.4	33
PNRS II STE-Tank 1-D		11/10/10 14:00	G	25.3	7.3	410	2.2	-230.0	1,250	470	64	100	240	85.1	85	11.0	74	0.11	74.1				
Stage 1 Single Pass Biofilters Effluent																							
UNSAT-EC1	15" Expanded Clay	11/10/10 16:00	G	20.6	6.9	180	7.1	108.0	1,150	770	1	2	10	66.8	4.8	3.5	1.3	62	63.3		1.0	0.01	61
UNSAT-EC3	30" Expanded Clay	11/10/10 15:30	G	21.5	6.8	220	6.8	105.0	1,250	850	1	2	10	85.9	4.9	2.5	2.4	81	83.4				
UNSAT-CL1	15" Clinoptilolite	11/10/10 15:40	G	22.0	7.1	230	7.3	105.5	1,130	800	1	2	10	46.6	2.6	2.6	0.005	44	44.0		1.0	0.01	62
UNSAT-CL3	30" Clinoptilolite	11/10/10 15:50	G	22.0	7.4	290	7.6	100.5	1,280	820	2	2	29	82.7	2.7	2.7	0.005	80	80.0				
Stage 2 Single Pass Upflow Biofilters Effluent																							
DENIT-SU4	10% Limestone; 30% Sulfur; 60% Expanded Clay	11/10/10 13:40	G	21.0	7.3	210	7.8	-118.0	1,510	1,100	6	2	13	0.9	0.89	0.8	0.10	0.02	0.1		1.0	0.09	560
DENIT-LS3	50% Lignocellulosic; 50% Sand	11/10/10 12:30	G	20.0	6.9	220	4.7	67.5	1,200	840	1	2	11	24.3	4.3	3.8	0.52	20	20.5				
DENIT-SU3	80% Sulfur; 20% Oyster Shell	11/10/10 13:30	G	21.4	7.2	260	7.7	-180.0	1,480	1,000	2	3	26	1.9	1.8	1.3	0.55	0.05	0.6		2.4	0.85	450
DENIT-LS2	25% Lignocellulosic; 75% Expanded Clay	11/10/10 12:15	G	21.5	7.4	320	4.1	71.0	1,200	780	2	2	26	19.8	3.8	3.7	0.10	16	16.1				
DENIT-LS4	30% Lignocellulosic; 70% Expanded Clay	11/10/10 12:05	G	20.0	7.3	200	3.8	81.0	900	480	2	2	20	30.8	21	6.0	15	9.8	24.8				
Recirculation Tanks Effluent																							
RC1		11/10/10 12:50	G	20.6	7.3	180	2.1	57.0	1,000	580	3	2	29	41.0	17	5.0	12	24	36.0				
RC2		11/10/10 13:00	G	19.5	7.2	210	1.6	58.5	1,020	590	2	8	35	43.0	19	6.0	13	24	37.0				
RC3		11/10/10 13:10	G	19.2	7.2	260	2.3	57.5	1,040	550	6	9	39	36.0	19	7.0	12	17	29.0				
RC4		11/10/10 13:20	G	19.7	7.4	260	1.9	49.3	1,090	590	2	4	26	35.0	17	5.0	12	18	30.0				
RC5		11/10/10 16:10	G	22.0	7.3	260	3.3	96.0	1,050	480	8	8	61	45.0	31	3.0	28	14	42.0				
Stage 1 Recirculating Biofilters Effluent																							
UNSAT-CL4	30" Clinoptilolite	11/10/10 11:40	G	23.5	7.2	270	8.0	52.8	1,040	660	1	2	11	42.6	2.6	2.6	0.005	40	40.0				63
UNSAT-CL2	15" Clinoptilolite	11/10/10 11:30	G	23.1	7.0	200	5.4	50.2	1,000	630	2	2	24	56.3	2.3	2.3	0.005	54	54.0				
UNSAT-EC4	30" Expanded Clay	11/10/10 11:20	G	22.2	6.9	140	7.3	46.5	980	660	2	2	10	52.3	2.3	2.3	0.005	50	50.0				
UNSAT-SA2	30" Sand	11/10/10 11:10	G	22.5	6.9	120	7.7	47.5	930	610	13	2	22	41.5	3.5	2.8	0.74	38	38.7				
UNSAT-PS1	30" Polystyrene	11/10/10 13:50	G	23.8	7.2	200	7.8	90.0	950	550	5	4	39	98.0	28	7.0	21	70	91.0				
Pump 15 Tank (DENIT-LS4 Influent)		11/10/10 13:45	G	20.7	7.4	200	7.1	18.8	970	550	6	3	33	42.0	21	4.0	17	21	38.0				
Denite Feed Tank (Tank 3)																							
DFT		11/10/10 11:50	G	18.5	7.2	200	8.3	62.2	980	630	1	2	22	19.5	3.5	3.3	0.17	16	16.2		1.0	0.1	64
Stage 2 Horizontal Biofilters Effluent																							
DENIT-SU1	80% Sulfur; 20% Oyster Shell	11/10/10 10:15	G	28.0	6.9	230	1.6	-270.0	1,250	900	1	18	50	2.0	1.9	1.1	0.76	0.14	0.9		17	9.2	350
DENIT-SU2	10% Limestone; 30% Sulfur; 60% Expanded Clay	11/10/10 10:25	G	25.5	7.0	210	0.2	-90.0	1,350	1,000	8	2	18	0.8	0.74	0.7	0.033	0.03	0.1		1.0	0.01	490
DENIT-LS1	50% Lignocellulosic; 50% Expanded Clay	11/10/10 10:40	G	21.4	7.4	210	1.1	-120.0	970	540	1	2	18	20.7	2.7	2.7	0.005	18	18.0				
DENIT-GL1	12" Gravel; 60" Expanded Clay	11/10/10 10:55	G	21.0	6.9	390	0.8	-180.0	900	540	4	3	22	2.0	1.9	1.0	0.88	0.07	1.0				
In-situ Simulator Biofilters Effluent																							
UNSAT-IS1 (STE)	12" Sand; 12" Mix (45% EC, 35% Ligno, 20% Sulfur)	11/10/10 10:00	G	20.5	6.8	390	1.9	-161.0	1,120	540	6	2	76	53.2	53	3.0	50	0.18	50.2		4.7	2.8	79
UNSAT-IS1 (STE)	12" Sand; 12" Mix (45% EC, 35% Ligno, 20% Sulfur)	11/12/10 6:45	G	17.0	7.1	370	2.0	221.6	1,168	530	2	2	76	75.0	75	6.0	69	0.04	69.0		4.3	1.8	83
UNSAT-IS2 (NO_3)	12" Sand; 12" Mix (45% EC, 35% Ligno, 20% Sulfur)	11/10/10 9:45	G	19.2	6.8	180	0.8	-130.0	1,300	820	19	2	20	1.3	1.2	0.4	0.80	0.05	0.9		1.0	0.01	380
UNSAT-IS2 (NO_3)	12" Sand; 12" Mix (45% EC, 35% Ligno, 20% Sulfur)	11/12/10 6:45	G	17.1	6.5	170	0.8	-213.6	365	890	10	2	13	1.2	1.2	0.5	0.71	0.04	0.8		1.0	0.01	400
UNSAT-IS3 (STE)	12" Sand; 10" Mix (60% EC, 40% Ligno); 3" Sulfur)	11/15/10 8:30	G	18.7	6.7	280	0.4	158.3	1,505	2,300	4	3	46	34.4	6.4	0.2	6.2	28	34.2		1.0	0.01	290
UNSAT-IS4 (NO_3)	12" Sand; 10" Mix (60% EC, 40% Ligno); 3" Sulfur)	11/10/10 15:15	G											43.1	2.1	2.1	0.036	41	41.0				490
UNSAT-IS4 (NO_3)	12" Sand; 10" Mix (60% EC, 40% Ligno); 3" Sulfur)	11/15/10 8:45	G	18.3	7.48	280	9.0	152.8	0.01				35	12.8	1.8	1.7	0.086	11	11.1				440
Field Blank	Reagent Water	11/10/10 15:00		24.5	6.5	2	8.0	12.5	25	10	1	2	10	0.1	0.07	0.1	0.005	0.01	0.02				
Equipment Blank	Reagent Water - Cleaned STE Bottle #2	11/10/10 14:10		23.0	6.7	2	8.5	-80.0	28	10	1	2	10	0.1	0.06	0.1	0.005	0.01	0.02				

Notes:

[1]Total Nitrogen (TN) is a calculated value equal to the sum of TKN and NO_x

[2]Organic Nitrogen (ON) is a calculated value equal to the difference of TKN and NH_3.

[3]Total Inorganic Nitrogen (TIN) is a calculated value equal to the sum of NH_3 and NO_x.

EC: expanded clay, CL: clinoptilolite, PS: polystyrene, SU: elemental sulfur, LS: lignocellulosic, GL: glycerol, OS: oyster shell, NS: sodium sesquicarbonate, GR: gravel

D.O. - Dissolved oxygen

G - Grab sample

Gray-shaded data points indicate values below method detection level (mdl), mdl value used for statistical analyses.

Yellow-shaded data points indicate the reported value is between the laboratory method detection limit and the laboratory practical quantitation limit, value used for statistical analysis.

Orange - shaded data points indicate too many colonies were present. The numberic value represents the dilution factor times the maximum reportable number of colonies.

Purple-shaded data points indicate results based upon colony counts outside the method indicated ideal range.

Blue-shaded data points indicate matrix spike was outside typical range. All other QC criteria were acceptable.

Green-shaded data points indicate that sample was re-run by Southern Analytical Laboratories, Inc. The sample was held beyond the accepted holding time.

PNRS II TEST FACILITY
SAMPLE EVENT NO. 4
EXPERIMENTAL DAY 241

Sample ID	Media Composition	Analytical Laboratory	Sample Date/Time	Sample Type	Temp (°C)	pH	Total Alkalinity (mg/L)	DO (mg/L)	ORP (mV)	Specific Conductance (µS)	TDS (mg/L)	TSS (mg/L)	$CBOD_5$ (mg/L)	COD (mg/L)	TN (mg/L N)[1]	TKN (mg/L N)	Organic N (mg/L N)[2]	NH_3-N (mg/L N)	NO_3-N (mg/L N)	NO_2-N (mg/L N)	NOx (mg/L N)	TIN (mg/L N)[3]	TP (mg/L)		Sulfide (mg/L)	H_2S (mg/L)	SO_4 (mg/L)	Fecal (Ct/100 mL)
STE Sample																												
PNRS II STE-Tank 1		Southern	1/13/11 13:15	G	13.7	7.1	380	2.7	-236.5	1,220	470	83	78	230	66.0	66	9.0	57	0.02	0.01	0.03	57.03			16	6.9	13	8,900
PNRS II STE-Tank 1-D		Southern	1/13/11 13:15	G	13.7	7.1	340	2.7	-236.5	1,220	470	64	85	280	62.1	62	4.0	58	0.05	0.01	0.06	58.06						11,100
PNRS II STE-Tank 1-D2		Pace	1/13/11 13:15	G	13.7	7.1	351	2.7	-236.5	1,220	570	15.5	87.9	290	61.3	61.1	9.8	51.3	0.12	0.12	0.24	51.54	14.1				17.6	100
Stage 1 Single Pass Biofilters Effluent																												
UNSAT-EC1	15" Expanded Clay	Southern	1/13/11 12:05	G	7.8	6.7	160	7.9	36.5	1,110	730	1	2	16	49.1	4.0	2.3	1.7	45	0.11	45.11	46.81					61	3,900
UNSAT-EC1-D	15" Expanded Clay	Southern	1/13/11 12:05	G	7.8	6.7	180	7.9	36.5	1,110	720	1	2	24	48.2	4.1	2.5	1.6	44	0.11	44.11	45.71						3,000
UNSAT-EC3	30" Expanded Clay	Southern	1/13/11 12:05	G	6.3	6.8	210	7.9	38.7	1,150	740	1	2	11	47.5	3.5	3.5	0.005	44	0.01	44.01	44.02						4
UNSAT-EC3-D	30" Expanded Clay	Pace	1/13/11 12:05	G	6.3	6.8	222	7.9	38.7	1,150	914	5	3	16.2	35.8	0.42	0.4	0.020	35.1	0.25	35.35	35.37	5.6				64.4	12
UNSAT-CL1	15" Clinoptilolite	Southern	1/13/11 11:45	G	8.2	7.2	180	8.8	32.3	1,200	710	1	2	16	33.9	2.7	2.7	0.020	31	0.16	31.16	31.18					59	100
UNSAT-CL1-D	15" Clinoptilolite	Southern	1/13/11 11:45	G	8.2	7.2	280	8.8	32.3	1,200	700	3	2	20	24.1	2.9	2.9	0.020	21	0.18	21.18	21.20						40
UNSAT-CL3	30" Clinoptilolite	Southern	1/13/11 12:05	G	8.3	7.3	300	9.9	20.2	1,300	810	1	2	13	43.8	2.7	2.7	0.016	41	0.07	41.07	41.09						110
UNSAT-CL3-D	30" Clinoptilolite	Southern	1/13/11 12:05	G	8.3	7.3	280	9.9	20.2	1,300	840	2	2	16	42.9	2.8	2.8	0.018	40	0.06	40.06	40.08						25
Stage 2 Single Pass Upflow Biofilters Effluent																												
DENIT-SU4	10% Limestone; 30% Sulfur; 60% Expanded Clay	Southern	1/13/11 9:00	G	7.0	6.8	240	4.2	-99.6	1,350	1,000	2	2	20	1.3	1.2	1.0	0.22	0.10	0.03	0.13	0.35			0.14	0.08	420	3
DENIT-LS3	50% Lignocellulosic; 50% Sand	Southern	1/13/11 9:00	G	6.6	6.7	240	5.4	-79	1,150	790	1	2	16	45.4	2.3	2.3	0.012	43	0.05	43.05	43.06						1
DENIT-SU3	80% Sulfur; 20% Oyster Shell	Southern	1/13/11 9:00	G	6.9	6.9	280	2.8	-208.7	1,420	1,000	11	9	50	3.0	2.9	2.1	0.80	0.01	0.04	0.05	0.85					380	6
DENIT-LS2	25% Lignocellulosic; 75% Expanded Clay	Southern	1/13/11 9:00	G	6.8	7.3	340	5.0	-135	1,300	860	1	2	16	43.8	2.7	2.6	0.085	41	0.07	41.07	41.16						1
DENIT-LS4	30% Lignocellulosic; 70% Expanded Clay	Southern	1/13/11 9:00	G	7.4	7.3	230	5.2	-98.6	810	460	118	4	22	15.4	12	2.5	9.5	3.1	0.29	3.39	12.89						1
Recirculation Tanks Effluent																												
RC1		Southern	1/13/11 11:45	G	7.2	7.2	190	1.6	-0.9	950	520	7	11	37	26.5	12	1.0	11	14	0.53	14.53	25.53						8,200
RC2		Southern	1/13/11 11:40	G	7.4	7.1	200	2.5	-5	1,000	570	4	9	41	29.2	13	0.0	13	16	0.22	16.22	29.22						9,100
RC3		Southern	1/13/11 11:40	G	7.4	6.9	220	2.0	-21.7	990	560	13	12	46	28.4	12	1.0	11	14	2.4	16.40	27.40						13,000
RC4		Southern	1/13/11 12:30	G	8.3	7.3	280	0.4	-121.9	1,050	600	12	9	57	31.5	18	2.0	16	10	3.5	13.50	29.50						8,700
RC5		Southern	1/13/11 11:10	G	7.9	7.1	220	1.5	-120.7	930	500	17	16	57	36.9	29	6.0	23	6.3	1.6	7.90	30.90						12,700
Stage 1 Recirculating Biofilters Effluent																												
UNSAT-CL4	30" Clinoptilolite	Southern	1/13/11 11:15	G	7.9	7.3	170	11.0	55.5	970	660	1	2	13	38.4	2.2	2.2	0.011	36	0.15	36.15	36.16						1
UNSAT-CL2	15" Clinoptilolite	Southern	1/13/11 9:50	G	6.0	7.0	180	7.9	-88.9	990	600	1	3	16	29.2	2.0	2.0	0.019	27	0.23	27.23	27.25						730
UNSAT-EC4	30" Expanded Clay	Southern	1/13/11 10:10	G	7.0	6.9	150	10.0	-88.8	960	600	1	2	16	32.9	2.4	2.4	0.038	30	0.50	30.50	30.54						21
UNSAT-SA2	30" Sand	Southern	1/13/11 10:10	G	6.2	6.8	150	9.6	-70.8	900	550	1	3	16	28.7	3.0	2.3	0.66	25	0.71	25.71	26.37						41
UNSAT-PS1	30" Polystyrene	Southern	1/13/11 10:15	G	5.8	7.3	200	5.2	-28.5	930	490	9	12	52	28.3	17	1.0	16	10	1.3	11.30	27.30						9,500
Pump 15 Tank (DENIT-LS4 Influent)		Southern	1/13/11 9:20	G	5.0	7.0	200	6.4	-26.9	900	510	4	10	41	33.2	21	4.0	17	11	1.2	12.20	29.20						3,900
Denite Feed Tank (Tank 3)																												
DFT		Southern	1/13/11 10:35	G	6.4	7.0	160	9.8	-40.9	950	590	1	2	46	31.5	2.4	2.3	0.054	29	0.06	29.06	29.11					67	22
Stage 2 Horizontal Biofilters Effluent																												
DENIT-SU1	80% Sulfur; 20% Oyster Shell	Southern	1/13/11 8:00	G	0.2	6.8	220	1.2	-231.2	1,080	760	1	8	22	3.0	2.6	2.1	0.46	0.11	0.24	0.35	0.81					270	5
DENIT-SU2	10% Limestone; 30% Sulfur; 60% Expanded Clay	Southern	1/13/11 8:00	G	0.3	6.8	200	1.6	-212.2	1,130	740	1	6	24	1.2	1.1	0.8	0.30	0.01	0.05	0.06	0.36			4.3	2.6	300	3
DENIT-LS1	50% Lignocellulosic; 50% Expanded Clay	Southern	1/13/11 8:00	G	0.3	7.0	190	0.6	-173.1	910	590	1	2	16	23.9	1.8	1.8	0.007	22	0.1	22.10	22.11						1
DENIT-LS1-D	50% Lignocellulosic; 50% Expanded Clay	Pace	1/13/11 8:00	G	0.3	7.0	219	0.6	-173.1	910	640	5	3	20.5	22.3	0.63	0.6	0.020	21.5	0.12	21.62	21.64	5.2				55.5	
DENIT-GL1	12" Gravel; 60" Expanded Clay	Southern	1/13/11 8:00	G	0.3	6.6	400	0.9	-208.7	1,000	540	3	17	48	6.5	6.3	0.5	5.8	0.11	0.04	0.15	5.95						1
In-situ Simulator Biofilters Effluent																												
UNSAT-IS1 (receives STE)	15" Sand; 12" Mix (45% EC, 35% Ligno, 20% Sulfur)	Southern	1/13/11 10:00	G	1.2	6.7	430	0.4	-141.2	1,200	480	7	65	120	64.4	64	6.0	58	0.08	0.29	0.37	58.37					7	10
UNSAT-IS2 (receives NO_3)	12" Sand; 12" Mix (45% EC, 35% Ligno, 20% Sulfur)	Southern	1/13/11 8:15	G	6.2	6.8	200	3.9	-234.5	680	710	1	6	18	1.3	1.1	0.6	0.53	0.01	0.21	0.22	0.75					250	1
UNSAT-IS3-SP (receives STE)	12" Sand; 10" Mix (60% EC, 40% Ligno)	Southern	1/13/11 14:10	G	4.0	7.5	210	12	39.2	980	600	3	2	26	7.7	1.8	1.8	0.036	3.70	2.20	5.90	5.94					130	
UNSAT-IS3 (receives STE)	12" Sand; 10" Mix (60% EC, 40% Ligno); 3" Sulfur	Southern	1/11/11 8:20	G	11.6	6.97	300	0.4	136.5	1,331	850	10	2	31	36.4	4.1	2.9	1.2	24.0	8.3	32.30	33.50					120	
UNSAT-IS3 (receives STE)	12" Sand; 10" Mix (60% EC, 40% Ligno); 3" Sulfur	Pace	1/11/11 8:20	G	11.6	6.97	280	0.4	136.5	1,331	868	10		24.2	41.8	1.9	0.8	1.1	31.3	8.6	39.90	41.00	0.50				116	1
UNSAT-IS4-SP (receives NO_3)	12" Sand; 10" Mix (60% EC, 40% Ligno)	Southern	1/13/11 14:00	G	5.1	6.60	100	12.0	35.1	1,050	710	1	2	22	52.4	3.5	3.4	0.1	46.0	2.9	48.90	49.00					92	1
UNSAT-IS4 (receives NO_3)	12" Sand; 10" Mix (60% EC, 40% Ligno); 3" Sulfur	Southern	1/11/11 8:30	G	11.6	7.08	260	1.0	150.4	993	620	7	2	29	1.0	0.87	0.8	0.092	0.11	0.01	0.12	0.21					110	
UNSAT-IS4 (receives NO_3)	12" Sand; 10" Mix (60% EC, 40% Ligno); 3" Sulfur	Pace	1/11/11 8:30	G	11.6	7.08	264	1.0	150.4	993	637	5.0		29.5	1.1	1.0	0.9	0.052	0.050	0.050	0.10	0.15	3.9				119	1
Field Blank	Reagent Water	Southern	1/13/11 8:45		5.0	7.0	2	9.8	-54.6	40	10	1	2	10	0.1	0.05	0.05	0.005	0.01	0.01	0.02	0.03						1
Equipment Blank	Reagent Water - Cleaned STE Bottle #2	Southern	1/13/11 11:30		5.3	7.0	2	9.8	-54.6	40	10	1	2	10	0.1	0.05	0.04	0.008	0.01	0.01	0.02	0.03						1

Notes:

[1]Total Nitrogen (TN) is a calculated value equal to the sum of TKN and NO_x

[2]Organic Nitrogen (ON) is a calculated value equal to the difference of TKN and NH_3

[3]Total Inorganic Nitrogen (TIN) is a calculated value equal to the sum of NH_3 and NO_x

EC: expanded clay, CL: clinoptilolite, PS: polystyrene, SU: elemental sulfur, LS: lignocellulosic, GL: glycerol, OS: oyster shell, NS: sodium sesquicarbonate, GR: gravel

D.O. - Dissolved oxygen

G - Grab sample

Gray-shaded data points indicate values below method detection level (mdl), mdl value used for statistical analyses.

Yellow-shaded data points indicate the reported value is between the laboratory method detection limit and the laboratory practical quantitation limit, value used for statistical analysis.

Orange - shaded data points indicate too many colonies were present. The numberic value represents the dilution factor times the maximum reportable number of colonies.

Purple-shaded data points indicate results based upon colony counts outside the method indicated ideal range.

Blue-shaded data points indicate matrix spike was outside typical range. All other QC criteria were acceptable.

PNRS II TEST FACILITY
PROFILES
EXPERIMENTAL DAY 242

Sample ID	Sample Location within Biofilter	Media Composition	Sample Date/Time	Sample Type	COD (mg/L)	NO_3-N (mg/L N)	NO_2-N (mg/L N)	NOx (mg/L N)	SO_4 (mg/L)
Stage 2 Single Pass Upflow Biofilters Effluent									
DENIT-SU4 - Effluent	24" from Inlet (Bottom)	10% Limestone; 30% Sulfur; 60% Expanded Clay	1/13/11 9:00	G	20	0.1	0.030	0.13	420
DENIT-SU4-18	18" from Inlet (Bottom)		1/14/11 12:30	G	26	0.01	0.010	0.02	400
DENIT-SU4-12	12" from Inlet (Bottom)		1/14/11 12:20	G	18	0.85	0.010	0.86	380
DENIT-SU4-7	7" from Inlet (Bottom)		1/14/11 12:25	G	13	2.7	0.010	2.71	400
DENIT-SU4-3	3" from Inlet (Bottom)		1/14/11 12:30	G	22	13	0.480	13.48	270
UNSAT-EC1	Influent (EC1 Effluent)		1/13/11 12:05	G	16	45	0.110	45.11	61
DENIT-LS3 - Effluent	24" from Inlet (Bottom)	50% Lignocellulosic; 50% Sand	1/13/11 9:00	G	16	43	0.050	43.05	
DENIT-LS3-18	18" from Inlet (Bottom)		1/14/11 11:55	G	26	42	0.01	42.01	
DENIT-LS3-12	12" from Inlet (Bottom)		1/14/11 11:50	G	11	45	0.01	45.01	
DENIT-LS3-7	7" from Inlet (Bottom)		1/14/11 11:45	G	18	43	0.01	43.01	
DENIT-LS3-3	3" from Inlet (Bottom)		1/14/11 11:40	G	13	46	0.01	46.01	
UNSAT-EC3	Influent (EC3 Effluent)		1/13/11 12:05	G	11	44	0.01	44.01	
DENIT-SU3 - Effluent	24" from Inlet (Bottom)	80% Sulfur; 20% Oyster Shell	1/13/11 9:00	G	50	0.01	0.04	0.05	380
DENIT-SU3-18	18" from Inlet (Bottom)		1/14/11 10:55	G	37	0.01	0.01	0.02	290
DENIT-SU3-12	12" from Inlet (Bottom)		1/14/11 11:00	G	44	0.01	0.01	0.02	300
DENIT-SU3-7	7" from Inlet (Bottom)		1/14/11 11:05	G	44	0.19	0.01	0.20	260
DENIT-SU3-3	3" from Inlet (Bottom)		1/14/11 11:10	G	26	3.3	2.2	5.50	270
UNSAT-CL1	Influent (CL1 Effluent)		1/13/11 11:45	G	16	31	0.160	31.16	59
DENIT-LS2 - Effluent	24" from Inlet (Bottom)	50% Lignocellulosic; 50% Expanded Clay	1/13/11 9:00	G	16	41	0.070	41.07	
DENIT-LS2-18	18" from Inlet (Bottom)		1/14/11 9:50	G	46	39	0.01	39.01	
DENIT-LS2-12	12" from Inlet (Bottom)		1/14/11 9:55	G	52	43	0.01	43.01	
DENIT-LS2-7	7" from Inlet (Bottom)		1/14/11 10:00	G	59	41	0.01	41.01	
DENIT-LS2-3	3" from Inlet (Bottom)		1/14/11 10:05	G	70	36	0.01	36.01	
UNSAT-CL3	Influent (CL3 Effluent)		1/13/11 12:05	G	13	41	0.070	41.07	
DENIT-LS4 - Effluent	24" from Inlet (Bottom)	30% Lignocellulosic; 70% Expanded Clay	1/13/11 9:00	G	22	3.1	0.290	3.39	
DENIT-LS4-18	18" from Inlet (Bottom)		1/14/11 11:10	G	24	0.02	0.01	0.03	
DENIT-LS4-12	12" from Inlet (Bottom)		1/14/11 11:10	G	20	0.36	0.01	0.37	
DENIT-LS4-7	7" from Inlet (Bottom)		1/14/11 11:10	G	22	2.8	0.01	2.81	
DENIT-LS4-3	3" from Inlet (Bottom)		1/14/11 11:10	G	22	3.3	0.01	3.31	
UNSAT-P15-T	Influent (PS1 Effluent)		1/13/11 9:20	G	41	11	1.2	12.20	
Stage 2 Horizontal Biofilters Effluent									
DENIT-SU1-Effluent	72" from Inlet	80% Sulfur; 20% Oyster Shell	1/13/11 8:00	G	22	0.11	0.24	0.35	270
DENIT-SU1-60	60" from Inlet		1/14/11 10:20	G	31	22	1.2	23.20	110
DENIT-SU1-48	48" from Inlet		1/14/11 9:20	G	13	25	1.7	26.70	95
DENIT-SU1-36	36" from Inlet		1/14/11 8:20	G	11	27	1.3	28.30	84
DFT	Influent (DFT Effluent)		1/13/11 10:35	G	46	29	0.06	29.06	67
DENIT-SU2-Effluent	72" from Inlet	80% Sulfur; 20% Sodium Sesqui.	1/13/11 8:00	G	24	0.01	0.05	0.06	300
DENIT-SU2-36	36" from Inlet		1/14/11 10:20	G	22	1.2	5.1	6.30	240
DENIT-SU2-24	24" from Inlet		1/14/11 9:20	G	13	7.8	5.1	12.90	190
DENIT-SU2-12	12" from Inlet		1/14/11 8:20	G	18	26	1.8	27.80	110
DFT	Influent (DFT Effluent)		1/13/11 10:35	G	46	29	0.06	29.06	67
DENIT-LS1-Effluent	72" from Inlet	50% Lignocellulosic; 50% Exp	1/13/11 8:00	G	16	22	0.1	22.10	
DENIT-LS1-60	60" from Inlet		1/14/11 10:20	G	13	27	0.01	27.01	
DENIT-LS1-48	48" from Inlet		1/14/11 9:20	G	13	26	0.01	26.01	
DENIT-LS1-36	36" from Inlet		1/14/11 8:20	G	10	29	0.01	29.01	
DFT	Influent (DFT Effluent)		1/13/11 10:35	G	46	29	0.06	29.06	67
DENIT-GL1-Effluent	72" from Inlet	12" Gravel; 60" Expanded Clay	1/13/11 8:00	G	48	0.11	0.040	0.15	
DENIT-GL1-36	36" from Inlet		1/14/11 10:20	G	87	0.03	0.47	0.50	
DENIT-GL1-24	24" from Inlet		1/14/11 9:20	G	160	0.01	0.01	0.02	
DENIT-GL1-12	12" from Inlet		1/14/11 8:20	G	260	0.98	0.44	1.42	
DFT	Influent (DFT Effluent)		1/13/11 10:35	G	46	29	0.06	29.06	67

Notes
G - Grab sample
Gray - Shaded data points indicate values below method detection level (mdl), mdl value used for statistical analyses.
Yellow shaded data points indicate the reported value is between the laboratory method detection limit and the laboratory practical quantitation limit.

PNRS II TEST FACILITY
SAMPLE EVENT NO. 5
EXPERIMENTAL DAY 304

Sample ID	Media Composition	Analytical Laboratory	Sample Date/Time	Sample Type	Temp (°C)	pH	Total Alkalinity (mg/L)	DO (mg/L)	ORP (mV)	Specific Conductance (µS)	TDS (mg/L)	TSS (mg/L)	$CBOD_5$ (mg/L)	COD (mg/L)	TN (mg/L N)[1]	TKN (mg/L N)	Organic N (mg/L N)[2]	NH_3-N (mg/L N)	NO_3-N (mg/L N)	NO_2-N (mg/L N)	NOx (mg/L N)	TIN (mg/L N)[3]	TP (mg/L)	Ortho P (mg/L P)	Sulfide (mg/L)	H_2S (mg/L)	SO_4 (mg/L)
STE Sample																											
PNRS II STE-Tank 1		Southern	3/17/11 12:15	G	21.4	7.5	400	2.8	-231.7	1,099	450	110	93	380	78.06	78	13	65	0.05	0.01	0.06	65.06	13		5.2	1.2	38
PNRS II STE-Tank 1-D		Southern	3/17/11 12:20	G	21.4	7.5	400	2.8	-231.7	1,099	430	130	61	430	78.15	78	64	14	0.14	0.01	0.15	14.15		5.4			
PNRS II STE-Tank 1-D2		Pace	3/17/11 12:20	G	21.4	7.5	387	2.8	-231.7	1,099	456	60.0	88.8	372	71.4	71.3	13.8	57.5	0.050	0.050	0.1	57.6	8.2	5.7		3.1	28.5
Stage 1 Single Pass Biofilters Effluent																											
UNSAT-EC1	15" Expanded Clay	Southern	3/17/11 11:30	G	9.6	7.1	160	6.6	25.7	1,048	720	2	2	22	60.91	3.9	3.865	0.035	57	0.01	57.01	57.045		1.0			67
UNSAT-EC3	30" Expanded Clay	Southern	3/17/11 11:25	G	10.8	7.1	210	6.1	22.2	1,059	740	2	2	16	52.31	3.3	3.289	0.011	49	0.01	49.01	49.021		1.5			
UNSAT-CL1	15" Clinoptilolite	Southern	3/17/11 11:20	G	5.8	7.4	190	6.2	10.7	1,193	850	2	2	22	78.21	5.2	5.179	0.021	73	0.01	73.01	73.031		1.8			61
UNSAT-CL3	30" Clinoptilolite	Southern	3/17/11 11:15	G	10.6	7.5	230	7.5	8.2	1,130	850	2	2	18	66.11	3.1	3.067	0.033	63	0.01	63.01	63.043		3.0			
Stage 2 Single Pass Upflow Biofilters Effluent																											
DENIT-SU4	10% Limestone; 30% Sulfur; 60% Expanded Clay	Southern	3/17/11 9:30	G	14.7	7.4	210	0.1	-231.6	1,311	1,100	1	2	32	1.33	1.3	1.1	0.2	0.02	0.01	0.03	0.23		1.3	1.0	0.29	510
DENIT-SU4-D	10% Limestone; 30% Sulfur; 60% Expanded Clay		3/17/11 9:35	G	14.7	7.4	220	0.1	-231.6	1,311	1,100	2	2	32	1.22	1.2	0.98	0.22	0.01	0.01	0.02	0.24		1.3			
DENIT-LS3	50% New Lignocellulosic; 50% Sand	Southern	3/17/11 9:25	G	17.3	7.4	410	0.8	-294.6	1,027	720	2	120	320	1.67	1.6	0.86	0.74	0.06	0.01	0.07	0.81		2.6			
DENIT-SU3	80% Sulfur; 20% Oyster Shell	Southern	3/17/11 9:20	G	13.1	7.6	230	0.1	-285.2	1,552	1,200	6	2	39	3.02	3.0	1.5	1.5	0.01	0.01	0.02	1.52		2.3			650
DENIT-LS2	25% New Lignocellulosic; 75% Expanded Clay	Southern	3/17/11 9:10	G	14.3	8.0	350	3.4	-99.1	1,077	710	4	2	39	18.5	4.0	2.2	1.8	12	2.5	14.5	16.3		2.8			
DENIT-LS2-D	25% New Lignocellulosic; 75% Expanded Clay	Southern	3/17/11 9:15	G	14.3	8.0	350	3.4	-99.1	1,077	740	6	2	41	19.5	4.0	2.3	1.7	13	2.5	15.5	17.2		2.4			
DENIT-LS4	30% New Lignocellulosic; 70% Expanded Clay	Southern	3/17/11 9:00	G	16.2	7.7	250	0.6	-195.5	835	450	10	2	90	14.03	14	0	14	0.02	0.01	0.03	14.03		2.2			
DENIT-LS4-D	30% New Lignocellulosic; 70% Expanded Clay	Southern	3/17/11 9:05	G	16.2	7.7	260	0.6	-195.5	835	420	10	2	76	15.03	15	1	14	0.02	0.01	0.03	14.03		2.1			
Recirculation Tanks Effluent																											
RC1		Southern	3/17/11 12:05	G	17.0	7.4	180	0.2	-69.7	894	530	1	2	32	36.4	14	2	12	21	1.4	22.4	34.4		3.2			
RC2		Southern	3/17/11 12:00	G	18.2	7.4	180	0.2	-67.3	904	550	2	2	34	37.2	13	1	12	23	1.2	24.2	36.2		3.4			
RC3		Southern	3/17/11 11:55	G	17.6	7.5	230	1.5	-47.2	925	510	8	8	51	34	16	0	16	13	5.0	18	34		6.6			
RC4		Southern	3/17/11 11:50	G	16.9	7.8	290	0.1	-68.6	901	460	2	3	47	25.84	24	11	13	0.14	1.7	1.84	14.84		6.1			
RC5		Southern	3/17/11 11:40	G	16.5	7.4	230	0.5	-52.7	888	440	8	2	57	32.6	24	1	23	5.2	3.4	8.6	31.6		5.7			
Stage 1 Recirculating Biofilters Effluent																											
UNSAT-CL4	30" Clinoptilolite	Southern	3/17/11 10:00	G	12.2	8.2	110	7.4	-98.2	860	600	1	2	16	35.71	2.7	2.694	0.006	33	0.01	33.01	33.016		4.9			
UNSAT-CL2	15" Clinoptilolite	Southern	3/17/11 10:05	G	11.7	7.2	150	2.9	-48.3	900	620	1	2	22	38.95	2.8	2.794	0.006	36	0.15	36.15	36.156		2.3			
UNSAT-EC4	30" Expanded Clay	Southern	3/17/11 10:10	G	14.9	7.0	110	8.1	-20.2	869	590	1	2	18	39.51	2.5	2.479	0.021	37	0.01	37.01	37.031		1.8			
UNSAT-SA2	30" Sand	Southern	3/17/11 10:25	G	14.1	7.0	140	6.1	-26.5	859	560	1	2	18	35.01	3.0	2.95	0.050	32	0.01	32.01	32.06		2.1			
UNSAT-PS1	30" Polystyrene	Southern	3/17/11 11:45	G	15.1	7.3	130	0.6	-49.9	845	490	2	2	51	30.7	16	1	15	13	1.7	14.7	29.7		2.2			
Pump 15 Tank (DENIT-LS4 Influent)		Southern	3/17/11 11:00	G	18.6	7.2	190	1.0	-3.5	834	480	1	4	45	37.98	24	2	22	13	0.98	13.98	35.98		3.8			
Denite Feed Tank (Tank 3)																											
DFT		Southern	3/17/11 11:05	G	18.8	7.2	140	7.5	5.6	891	610	1	2	22	41.31	3.3	3.235	0.065	38	0.01	38.01	38.075	9.10	1.9	1.4	0.53	65
Stage 2 Horizontal Biofilters Effluent																											
DENIT-SU1	80% Sulfur; 20% Oyster Shell	Southern	3/17/11 8:16	G	7.2	7.0	250	0.1	-281.9	1,254	890	2	2	45	2.16	2.1	0.4	1.7	0.05	0.01	0.06	1.76		2.9			380
DENIT-SU2	10% Limestone; 30% Sulfur; 60% Expanded Clay	Southern	3/17/11 8:20	G	5.3	7.0	190	0.5	-268.4	1,296	940	2	2	47	0.91	0.89	0.52	0.37	0.01	0.01	0.02	0.39		2.0	7.8	3.7	400
DENIT-LS1	50% New Lignocellulosic; 50% Expanded Clay	Southern	3/17/11 8:30	G	4.6	7.4	320	0.1	-271.5	886	630	20	150	320	1.82	1.8	1.19	0.61	0.01	0.01	0.02	0.63		2.0			
DENIT-GL1	12" Gravel; 60" Expanded Clay	Southern	3/17/11 8:40	G	3.9	7.0	340	0.1	-259.0	927	540	1	2	36	4.92	4.9	0.8	4.1	0.01	0.01	0.02	4.12		3.0			
In-situ Simulator Biofilters Effluent																											
UNSAT-IS1 (receives STE)	4" Coarse Sand; 8" Fine Sand; 12" Mix (60% EC, 40% New Ligno); 4" Sulfur	Southern	3/17/11 12:45	G	10.7	7.3	400	NR	NR	999	660	2	120	240	8.96	8.9	0.2	8.7	0.05	0.01	0.06	8.76		5.2			20
UNSAT-IS2-SP (receives STE)	Above 4" Sulfur layer	Southern	3/18/11 13:55	G	25.8	6.6	69	0.5	-57.9	970	510	2	13	63	46.9	3.9	3.33	0.57			43	43.57		5.2			58
UNSAT-IS2 (receives STE)	4" EC>1.53mm; 8" EC As-Is; 12" Mix (60% EC, 40% New Ligno); 4" Sulfur	Southern	3/17/11 12:40	G	11.8	7.4	190	NR	NR	977	670	10	3	82	12.62	4.3	3.93	0.37	0.72	7.6	8.32	8.69		0.68			210
UNSAT-IS2-D (receives STE)	4" EC>1.53mm; 8" EC As-Is; 12" Mix (60% EC, 40% New Ligno); 4" Sulfur	Pace	3/17/11 12:45	G	11.8	7.4	204	NR	NR	977	682	6.0	3.9		12.13	3.2	2.82	0.38	0.83	8.1	8.93	9.31	2.5	1.5		1.0	185
UNSAT-IS3-SP (receives STE)	Above 4" Sulfur layer	Southern	3/17/11 12:35	G	6.2	7.6	500	NR	NR	1269	910	2	2	120	9.23	3.2	3	0.20	5.8	0.23	6.03	6.23		3.5			98
UNSAT-IS3 (receives STE)	4" CL 8X14; 8" CL 16X50; 12" Mix (60% EC, 40% New Ligno); 4" Sulfur	Southern	3/15/11 7:50	G	13.4	7.74	380	NR	-79.6	1481	990	1	3	96	2.52	2.5	0.8	1.70	0.01	0.01	0.02	1.72		2.3			200
UNSAT-IS4-SP (receives NO_3)	Above 4" Sulfur layer	Southern	3/17/11 12:30	G	14.9	7.4	430	NR	NR	1087	800	20	10	80	9.51	3.5	3.2	0.30	6.0	0.01	6.01	6.31		0.46			120
UNSAT-IS4 (receives NO_3)	4" Coarse Sand; 8" Fine Sand; 12" Mix (60% EC, 40% New Ligno); 4" Sulfur	Southern	3/15/11 7:45	G	12.2	6.99	460	NR	19.1	1346	870	44	10	88	10.6	4.8	4.762	0.038	4.6	1.2	5.8	5.838		0.018			170
Field Blank	Reagent Water	Southern	3/17/11 10:30		17.3	7.9	2.0	9.3	-39.8	55	20	1	2	10	0.09	0.07	0.026	0.044	0.01	0.01	0.02	0.064		0.010			
Equipment Blank	Reagent Water - Cleaned STE Bottle #1	Southern	3/17/11 10:45		17.9	7.6	2.0	9.1	-26	52	16	1	2	10	0.07	0.05	0.034	0.016	0.01	0.01	0.02	0.036		0.010			

Notes:

[1]Total Nitrogen (TN) is a calculated value equal to the sum of TKN and NO_x

[2]Organic Nitrogen (ON) is a calculated value equal to the difference of TKN and NH_3

[3]Total Inorganic Nitrogen (TIN) is a calculated value equal to the sum of NH_3 and NO_x

EC: expanded clay, CL: clinoptilolite, PS: polystyrene, SU: elemental sulfur, LS: lignocellulosic, GL: glycerol, OS: oyster shell, NS: sodium sesquicarbonate, GR: gravel

D.O. - Dissolved oxygen

G - Grab sample

Gray-shaded data points indicate values below method detection level (mdl), mdl value used for statistical analyses.

Yellow-shaded data points indicate the reported value is between the laboratory method detection limit and the laboratory practical quantitation limit, value used for statistical analysis.

Orange - shaded data points indicate too many colonies were present. The numberic value represents the dilution factor times the maximum reportable number of colonies.

Purple-shaded data points indicate results based upon colony counts outside the method indicated ideal range.

Blue-shaded data points indicate matrix spike was outside typical range. All other QC criteria were acceptable.

PNRS II TEST FACILITY
PROFILES
EXPERIMENTAL DAY 305

Sample ID	Sample Location within Biofilter	Media Composition	Sample Date/Time	Sample Type	COD (mg/L)	NO_3-N (mg/L N)	NO_2-N (mg/L N)	NOx (mg/L N)	SO_4 (mg/L)
Stage 2 Single Pass Upflow Biofilters Effluent									
DENIT-SU4 - Effluent	24" from Inlet (Bottom)	10% Limestone; 30% Sulfur; 60% Expanded Clay	3/17/11 9:30	G	32	0.02	0.01	0.03	510
DENIT-SU4-18	18" from Inlet (Bottom)		3/18/11 13:15	G	55	0.01	0.01	0.02	490
DENIT-SU4-12	12" from Inlet (Bottom)		3/18/11 13:05	G	47	0.02	0.01	0.03	500
DENIT-SU4-7	7" from Inlet (Bottom)		3/18/11 12:50	G	34	0.01	0.01	0.02	490
DENIT-SU4-3	3" from Inlet (Bottom)		3/18/11 12:40	G	39	0.14	0.01	0.15	490
UNSAT-EC1	Influent (EC1 Effluent)		3/17/11 11:30	G	22	57	0.01	57.01	67
DENIT-LS3 - Effluent	24" from Inlet (Bottom)	50% Lignocellulosic; 50% Sand	3/17/11 9:25	G	320	0.06	0.01	0.07	
DENIT-LS3-18	18" from Inlet (Bottom)		3/18/11 12:25	G	200	0.02	0.01	0.03	
DENIT-LS3-12	12" from Inlet (Bottom)		3/18/11 12:15	G	100	0.2	0.01	0.21	
DENIT-LS3-7	7" from Inlet (Bottom)		3/18/11 12:05	G	51	14	1.2	15.2	
DENIT-LS3-3	3" from Inlet (Bottom)		3/18/11 11:55	G	43	36	0.68	36.68	
UNSAT-EC3	Influent (EC3 Effluent)		3/17/11 11:25	G	16	49	0.01	49.01	
DENIT-SU3 - Effluent	24" from Inlet (Bottom)	80% Sulfur; 20% Oyster Shell	3/17/11 9:20	G	39	0.01	0.01	0.02	650
DENIT-SU3-18	18" from Inlet (Bottom)		3/18/11 11:20	G	65	0.01	0.01	0.02	600
DENIT-SU3-12	12" from Inlet (Bottom)		3/18/11 11:10	G	51	0.01	0.01	0.02	550
DENIT-SU3-7	7" from Inlet (Bottom)		3/18/11 11:00	G	45	0.02	0.01	0.03	600
DENIT-SU3-3	3" from Inlet (Bottom)		3/18/11 10:50	G	28	4.9	0.01	4.91	560
UNSAT-CL1	Influent (CL1 Effluent)		3/17/11 11:20	G	22	73	0.01	73.01	61
DENIT-LS2 - Effluent	24" from Inlet (Bottom)	50% Lignocellulosic; 50% Expanded Clay	3/17/11 9:10	G	39	12	2.5	14.5	
DENIT-LS2-18	18" from Inlet (Bottom)		3/18/11 10:25	G	43	14	2.6	16.6	
DENIT-LS2-12	12" from Inlet (Bottom)		3/18/11 10:20	G	55	38	1.3	39.3	
DENIT-LS2-7	7" from Inlet (Bottom)		3/18/11 10:10	G	130	50	0.82	50.82	
DENIT-LS2-3	3" from Inlet (Bottom)		3/18/11 10:00	G	94	54	0.42	54.42	
UNSAT-CL3	Influent (CL3 Effluent)		3/17/11 11:15	G	18	63	0.01	63.01	
DENIT-LS4 - Effluent	24" from Inlet (Bottom)	30% Lignocellulosic; 70% Expanded Clay	3/17/11 9:00	G	90	0.02	0.01	0.03	
DENIT-LS4-18	18" from Inlet (Bottom)		3/18/11 9:25	G	140	0.01	0.01	0.02	
DENIT-LS4-12	12" from Inlet (Bottom)		3/18/11 9:15	G	92	0.01	0.01	0.02	
DENIT-LS4-7	7" from Inlet (Bottom)		3/18/11 9:05	G	120	0.01	0.01	0.02	
DENIT-LS4-3	3" from Inlet (Bottom)		3/18/11 8:45	G	57	0.41	0.21	0.62	
UNSAT-P15-T	Influent (PS1 Effluent)		3/17/11 11:00	G	45	13	0.98	13.98	
Stage 2 Horizontal Biofilters Effluent									
DENIT-SU1-Effluent	72" from Inlet	80% Sulfur; 20% Oyster Shell	3/17/11 8:16	G	45	0.05	0.01	0.06	380
DENIT-SU1-60	60" from Inlet		3/18/11 12:30	G	72	0.02	0.01	0.03	350
DENIT-SU1-48	48" from Inlet		3/18/11 11:30	G	45	0.02	0.01	0.03	360
DENIT-SU1-36	36" from Inlet		3/18/11 10:30	G	51	0.02	0.01	0.03	340
DENIT-SU1-24	24" from Inlet		3/18/11 9:30	G	30	1.2	0.01	1.21	320
DENIT-SU1-12	12" from Inlet		3/18/11 8:30	G	24	6.8	0.56	7.36	280
DFT	Influent (DFT Effluent)		3/17/11 11:05	G	22	38	0.01	38.01	65
DENIT-SU2-Effluent	72" from Inlet	80% Sulfur; 20% Sodium Sesqui.	3/17/11 8:20	G	47	0.01	0.01	0.02	400
DENIT-SU2-60	60" from Inlet		3/18/11 12:30	G	65	0.02	0.01	0.03	380
DENIT-SU2-48	48" from Inlet		3/18/11 11:30	G	57	0.03	0.01	0.04	360
DENIT-SU2-36	36" from Inlet		3/18/11 10:30	G	47	0.01	0.01	0.02	370
DENIT-SU2-24	24" from Inlet		3/18/11 9:30	G	32	0.03	0.01	0.04	340
DENIT-SU2-12	12" from Inlet		3/18/11 8:30	G	24	9.3	0.01	9.31	260
DFT	Influent (DFT Effluent)		3/17/11 11:05	G	22	38	0.01	38.01	65
DENIT-LS1-Effluent	Effluent	50% Lignocellulosic; 50% Exp	3/17/11 8:30	G	320	0.01	0.01	0.02	
DENIT-LS1-72	72" from Inlet		3/18/11 14:30	G	NR	0.01	0.01	0.02	
DENIT-LS1-60	60" from Inlet		3/18/11 12:30	G	280	0.03	0.01	0.04	
DENIT-LS1-48	48" from Inlet		3/18/11 11:30	G	240	0.09	0.01	0.1	
DENIT-LS1-36	36" from Inlet		3/18/11 10:30	G	120	0.02	0.01	0.03	
DENIT-LS1-24	24" from Inlet		3/18/11 9:30	G	39	15	0.96	15.96	
DENIT-LS1-12	12" from Inlet		3/18/11 8:30	G	18	33	0.26	33.26	
DFT	Influent (DFT Effluent)		3/17/11 11:05	G	22	38	0.01	38.01	65
DENIT-GL1-Effluent	72" from Inlet	12" Gravel; 60" Expanded Clay	3/17/11 8:40	G	36	0.01	0.01	0.02	
DENIT-GL1-60	60" from Inlet		3/18/11 12:30	G	69	0.01	0.01	0.02	
DENIT-GL1-48	48" from Inlet		3/18/11 11:30	G	65	0.01	0.01	0.02	
DENIT-GL1-36	36" from Inlet		3/18/11 10:30	G	59	0.03	0.01	0.04	
DENIT-GL1-24	24" from Inlet		3/18/11 9:30	G	76	0.01	0.01	0.02	
DENIT-GL1-12	12" from Inlet		3/18/11 8:30	G	240	0.03	0.01	0.04	
DFT	Influent (DFT Effluent)		3/17/11 11:05	G	22	38	0.01	38.01	65

Notes
G - Grab sample
Gray - Shaded data points indicate values below method detection level (mdl), mdl value used for statistical analyses.
Yellow shaded data points indicate the reported value is between the laboratory method detection limit and the laboratory practical quantitation limit.

PNRS II TEST FACILITY
SAMPLE EVENT NO. 6
EXPERIMENTAL DAY 367

Sample ID	Media Composition	Analytical Laboratory	Sample Date/Time	Sample Type	Temp (°C)	pH	Total Alkalinity (mg/L)	DO (mg/L)	ORP (mV)	Specific Conductance (µS)	TSS (mg/L)	$CBOD_5$ (mg/L)	TN (mg/L N)[1]	TKN (mg/L N)	Organic N (mg/L N)[2]	NH_3-N (mg/L N)	NO_3-N (mg/L N)	NO_2-N (mg/L N)	NOx (mg/L N)	TIN (mg/L N)[3]	TP (mg/L)	Sulfide (mg/L)	H_2S (mg/L)	SO_4 (mg/L)	Fecal (Ct/100 mL)
STE Sample																									
PNRS II STE-Tank 1		Southern	5/19/11 12:15	G	25.1	7.6	380	2	-243.5	960	467	47	40.04	40	8.00	32	0.03	0.01	0.04	32.04		9.1	1.7	24	9400
PNRS II STE-Tank 1-D		Southern	5/19/11 12:15	G	25.1	7.6	400	2	-243.5	960	473	59	41.04	41	8.00	33	0.03	0.01	0.04	33.04					9900
PNRS II STE-Tank 1-D2		Pace	5/19/11 12:15	G	25.1	7.6	347	2	-243.5	960	256	44.8	56.74	56.5	3.70	52.8	0.12	0.12	0.24	53.04	5.4		1.8	32.9	
Stage 1 Single Pass Biofilters Effluent																									
UNSAT-EC1	15" Expanded Clay	Southern	5/19/11 10:00	G	23.5	7.2	170	6.3	50.3	900	1	2	24.01	2	2.00	0.005	22	0.01	22.01	22.02				61	20
UNSAT-EC3	30" Expanded Clay	Southern	5/19/11 10:00	G	23.5	7.1	190	5.7	42.7	940	2	2	24.01	2	2.00	0.005	22	0.01	22.01	22.02					1
UNSAT-CL1	15" Clinoptilolite	Southern	5/19/11 10:00	G	23.5	7.4	160	6.9	35.2	980	1	2	25.71	2.7	2.70	0.005	23	0.01	23.01	23.02				61	20
UNSAT-CL3	30" Clinoptilolite	Southern	5/19/11 10:00	G	22.9	7.5	260	7.6	32.3	1120	1	2	26.71	3.7	3.70	0.005	23	0.01	23.01	23.02					1
UNSAT-CL5	30" Clinoptilolite	Southern	5/19/11 10:00	G	23.5	7.9	280	6.9	18.4	1130	1	2	24.51	2.5	2.50	0.005	22	0.01	22.01	22.02					24
Stage 2 Single Pass Upflow Biofilters Effluent																									
DENIT-SU4	10% Limestone; 30% Sulfur; 60% Expanded Clay	Southern	5/19/11 9:00	G	21.1	7.4		0.1	-239.9	1220	2	2	1.72	1.6	0.83	0.77	0.11	0.01	0.12	0.89		0.21	0.05	420	1
DENIT-LS3	50% New Lignocellulosic; 50% Sand	Southern	5/19/11 9:00	G	21.1	7.7	300	4.2	-72.5	940	1	2	19.76	3	1.60	1.4	16	0.76	16.76	18.16					1
DENIT-LS3-D	50% New Lignocellulosic; 50% Sand	Southern	5/19/11 9:00	G	21.1	7.7	300	4.2	-72.5	940	4	2	20.04	3.3	0.40	2.9	16	0.74	16.74	19.64					1
DENIT-SU3	80% Sulfur; 20% Oyster Shell	Southern	5/19/11 9:00	G	20.8	7.4	200	0.1	-248.9	1380	1	7	3.01	2.9	0.20	2.7	0.1	0.01	0.11	2.81				520	1
DENIT-SU3-D	80% Sulfur; 20% Oyster Shell	Southern	5/19/11 9:00	G	20.8	7.4	200	0.1	-248.9	1380	1	3	2.03	2	0.60	1.4	0.02	0.01	0.03	1.43					1
DENIT-LS2	25% New Lignocellulosic; 75% Expanded Clay	Southern	5/19/11 9:00	G	20.2	7.9	240	3.1	-54.9	1100	2	2	26.26	3.5	3.45	0.05	22	0.76	22.76	22.81					1
DENIT-LS2-D	25% New Lignocellulosic; 75% Expanded Clay	Southern	5/19/11 9:00	G	20.1	7.9	340	3.1	-54.9	1100	1	2	26.02	3.3	3.26	0.044	22	0.72	22.72	22.76					1
DENIT-LS4	30% New Lignocellulosic; 70% Expanded Clay	Southern	5/19/11 9:00	G	19.9	8.1	380	0.6	-106.5	1080	5	7	1.52	1.5	1.50	0.005	0.01	0.01	0.02	0.03					1
Recirculation Tanks Effluent																									
RC1		Southern	5/19/11 11:30	G	23.4	7.5	200	0.1	26.4	750	3	2	21.88	8.7	0.70	8	13	0.18	13.18	21.18					460
RC2		Southern	5/19/11 11:00	G	21.2	7.5	170	0.7	-7	770	5	2	27.34	10	4.60	5.4	17	0.34	17.34	22.74					370
RC3		Southern	5/19/11 10:30	G	21.9	7.4	190	0.1	3	780	7	4	33.13	16	7.20	8.8	17	0.13	17.13	25.93					560
RC4		Southern	5/19/11 10:45	G	21.7	7.5	270	0.1	-4.6	800	5	8	28.06	21	9.00	12	6.2	0.86	7.06	19.06					8600
Stage 1 Recirculating Biofilters Effluent																									
UNSAT-CL4	30" Clinoptilolite	Southern	5/19/11 9:50	G	22.2	7.4	210	7.6	7.8	750	3	2	26.01	12	12.00	0.005	14	0.01	14.01	14.02					18
UNSAT-CL2	15" Clinoptilolite	Southern	5/19/11 9:50	G	22.8	7.3	130	6.8	22.2	740	6	2	25.21	3.2	3.19	0.008	22	0.01	22.01	22.02					20
UNSAT-EC4	30" Expanded Clay	Southern	5/19/11 10:05	G	22.7	7.3	130	7.9	30.6	710	7	2	22.61	2.6	2.60	0.005	20	0.01	20.01	20.02					1
UNSAT-SA2	30" Sand	Southern	5/19/11 9:50	G	22.5	7.1	140	4.5	27.4	760	7	2	21.11	2.1	2.04	0.062	19	0.01	19.01	19.07					21
Denite Feed Tank (Tank 3)																									
DFT		Southern	5/19/11 12:00	G	21.2	7.5	170	7.5	35.1	770	3	2	20.21	3.2	3.20	0.005	17	0.01	17.01	17.02	11			60	11
DFT-D		Pace	5/19/11 12:05	G	21.2	7.5	167	7.5	35.1	770	5	2	22.38	0.55	0.53	0.02	21.8	0.025	21.825	21.85	4.9		1	68	
Stage 2 Horizontal Biofilters Effluent																									
DENIT-SU1	80% Sulfur; 20% Oyster Shell	Southern	5/19/11 8:00	G	16.9	7.2	200	0.1	-323.1	1000	3	2	2.96	2.9	1.60	1.3	0.05	0.01	0.06	1.36				270	1
DENIT-SU2	10% Limestone; 30% Sulfur; 60% Expanded Clay	Southern	5/19/11 8:00	G	16.7	7.1	260	0.1	-309.9	1010	3	24	3.53	3.5	1.90	1.6	0.02	0.01	0.03	1.63		17	7.4	260	1
DENIT-LS1	50% New Lignocellulosic; 50% Expanded Clay	Southern	5/19/11 8:00	G	16.1	7.3	220	0.1	-301.8	700	6	29	27.03	27	27.00	0.005	0.02	0.01	0.03	0.04					1
DENIT-GL1	12" Gravel; 60" Expanded Clay	Southern	5/19/11 8:00	G	16.4	6.8	400	0.1	-267.3	850	2	15	1.94	1.9	0.20	1.7	0.03	0.01	0.04	1.74					1000
In-situ Simulator Biofilters Effluent																									
UNSAT-IS1 (receives STE)	4" Coarse Sand; 8" Fine Sand; 12" Mix (60% EC, 40% New Ligno); 4" Sulfur	Southern	5/19/11 11:25	G	24.1	7.3	240	2.4	-51.7	810	8	4	4.60	3.3	2.93	0.37	0.48	0.82	1.3	1.67				200	1
UNSAT-IS2 (receives STE)	4" EC>1.53mm; 8" EC As-Is; 12" Mix (60% EC, 40% New Ligno); 4" Sulfur	Southern	5/19/11 11:25	G	24.4	7.3	320	4.7	-23.1	850	7	19	42.04	42	12.00	30	0.03	0.01	0.04	30.04				54	19
UNSAT-IS3-SP (receives STE)	Above 4" Sulfur layer	Southern	5/19/11 8:45	G	18.2	7.1	410		-100.3	1000	4	3	15.22	2.8	2.35	0.45	12	0.42	12.42	12.87				88	1
UNSAT-IS3 (receives STE)	4" CL 8X14; 8" CL 16X50; 12" Mix (60% EC, 40% New Ligno); 4" Sulfur	Southern	5/17/11 9:10	G	12	7.38	390		97.5	1395	8	6	3.63	3.6	2.00	1.6	0.02	0.01	0.03	1.63				300	9
UNSAT-IS4-SP (receives UNSAT-CL3 NO_3)	Above 4" Sulfur layer	Southern	5/19/11 8:45	G	17.5	7	220		-150.1	1140	4	2	23.10	2.6	2.37	0.23	20	0.5	20.5	20.73				100	1
UNSAT-IS4 (receives UNSAT-CL3 NO_3)	4" Coarse Sand; 8" Fine Sand; 12" Mix (60% EC, 40% New Ligno); 4" Sulfur	Southern	5/17/11 9:15	G	14.3	7.13	530		76.1	1379	34	38	2.43	2.4	2.32	0.076	0.02	0.01	0.03	0.11				190	1
Field Blank	Reagent Water	Southern	5/19/11 9:45		19.9	7	11	7.4	-54.2	5	1	2	0.07	0.05	0.04	0.008	0.01	0.01	0.02	0.03					1
Equipment Blank	Reagent Water - Cleaned STE Bottle #1	Southern	5/19/11 9:45		19.4	7.5	11	8.2	-14.4	5	1	2	0.07	0.05	0.05	0.005	0.01	0.01	0.02	0.03					

Notes:

[1]Total Nitrogen (TN) is a calculated value equal to the sum of TKN and NO_X

[2]Organic Nitrogen (ON) is a calculated value equal to the difference of TKN and NH_3

[3]Total Inorganic Nitrogen (TIN) is a calculated value equal to the sum of NH_3 and NO_x

EC: expanded clay, CL: clinoptilolite, PS: polystyrene, SU: elemental sulfur, LS: lignocellulosic, GL: glycerol, OS: oyster shell, NS: sodium sesquicarbonate, GR: gravel

D.O. - Dissolved oxygen

G - Grab sample

Gray-shaded data points indicate values below method detection level (mdl), mdl value used for statistical analyses.

Yellow-shaded data points indicate the reported value is between the laboratory method detection limit and the laboratory practical quantitation limit, value used for statistical analysis.

Orange - shaded data points indicate too many colonies were present. The numberic value represents the dilution factor times the maximum reportable number of colonies.

Purple-shaded data points indicate results based upon colony counts outside the method indicated ideal range.

Blue-shaded data points indicate matrix spike was outside typical range. All other QC criteria were acceptable.

PNRS II TEST FACILITY
SAMPLE EVENT NO. 7
EXPERIMENTAL DAY 402

Sample ID	Media Composition	Analytical Laboratory	Sample Date/Time	Sample Type	Temp (°C)	pH	Total Alkalinity (mg/L)	DO (mg/L)	ORP (mV)	Specific Conductance (µS)	TSS (mg/L)	$CBOD_5$ (mg/L)	COD	TN (mg/L N)[1]	TKN (mg/L N)	Organic N (mg/L N)[2]	NH_3-N (mg/L N)	NOx (mg/L N)	TIN (mg/L N)[3]	Sulfide (mg/L)	H_2S (mg/L)	SO_4 (mg/L)
STE Sample																						
PNRS II STE-Tank 1		Southern	6/23/11 9:45	G	27.7	6.8	210	1.1	-257.9	850	29	75	180	36.01	36	5	31	0.01	31.01			39
PNRS II STE-Tank 1-D		Southern	6/23/11 9:45	G	27.7	6.8	210	1.1	-257.9	850	31	93	180	33.01	33	3	30	0.01	30.01			34
Stage 1 Single Pass Biofilters Effluent																						
UNSAT-EC3	30" Expanded Clay	Southern	6/23/11 10:00	G	29	7.2		5.7	-15.3	820				21.5	4.5	4.02	0.48	17	17.48			
UNSAT-CL3	30" Clinoptilolite	Southern	6/23/11 10:00	G	28.3	7.5		6.9	-56	1020				29.2	4.2	4.139	0.061	25	25.061			
UNSAT-CL5	30" Clinoptilolite	Southern	6/23/11 10:00	G	28.3	7.6		6.6	-115.6	1000				5.8	3.3	2.85	0.45	2.5	2.95			
Stage 2 Single Pass Upflow Biofilters Effluent																			0			
DENIT-LS3	50% New Lignocellulosic; 50% Sand	Southern	6/23/11 8:45	G	28.2	7.5		1.8	39.2	800				3.6	1.9	1.44	0.46	1.7	2.16			
DENIT-LS2	25% New Lignocellulosic; 75% Expanded Clay	Southern	6/23/11 8:45	G	27.2	7.7		4	-32	1010				7.1	1.7	1.676	0.024	5.4	5.424			
DENIT-LS4	30% New Lignocellulosic; 70% Expanded Clay	Southern	6/23/11 8:45	G	27.6	7.7		2.3	-27.2	920				2	1.4	1.29	0.11	0.6	0.71			
Denite Feed Tank (Tank 3)																						
DFT		Southern	6/23/11 9:15	G	27.2	7.4		6.6	67.5	720				11.7	3	2.988	0.012	8.7	8.712	0.1	0.01	59
Stage 2 Horizontal Biofilters Effluent																						
DENIT-LS1-REV	50% New Lignocellulosic;	Southern	6/23/11 8:00	G	25.1	6.8		0.1	-249	850				1.11	1.1	0.91	0.19	0.01	0.2			
Field Blank	Reagent Water	Southern	6/23/11 9:25		29.5	8.2		7.6	48.6	5				0.06	0.05	0.04	0.01	0.01	0.02			
Equipment Blank	Reagent Water - Cleaned STE Bottle #1	Southern	6/23/11 9:30		29.4	8.1		7.6	42.8	5				0.06	0.05	0.029	0.021	0.01	0.031			

Notes:

[1]Total Nitrogen (TN) is a calculated value equal to the sum of TKN and NO_X

[2]Organic Nitrogen (ON) is a calculated value equal to the difference of TKN and NH_3.

[3]Total Inorganic Nitrogen (TIN) is a calculated value equal to the sum of NH_3 and NO_X

EC: expanded clay, CL: clinoptilolite, PS: polystyrene, SU: elemental sulfur, LS: lignocellulosic, GL: glycerol, OS: oyster shell, NS: sodium sesquicarbonate, GR: gravel

D.O. - Dissolved oxygen

G - Grab sample

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Orange - shaded data points indicate too many colonies were present. The numberic value represents the dilution factor times the maximum reportable number of colonies.

Purple-shaded data points indicate results based upon colony counts outside the method indicated ideal range.

Blue-shaded data points indicate matrix spike was outside typical range. All other QC criteria were acceptable.

PNRS II TEST FACILITY
SAMPLE EVENT NO. 8
EXPERIMENTAL DAY 486

Sample ID	Media Composition	Analytical Laboratory	Sample Date/Time	Sample Type	Temp (°C)	pH	Total Alkalinity (mg/L)	DO (mg/L)	ORP (mV)	Specific Conductance (µS)	TSS (mg/L)	$CBOD_5$ (mg/L)	COD	TN (mg/L N)[1]	TKN (mg/L N)	Organic N (mg/L N)[2]	NH_3-N (mg/L N)	NOx (mg/L N)	TIN (mg/L N)[3]	Sulfide (mg/L)	H_2S (mg/L)	SO_4 (mg/L)
In-situ Simulator Biofilters Effluent																						
UNSAT-IS1 (receives STE)	4" Coarse Sand; 8" Fine Sand; 12"	Southern	6/28/11 12:45	G	28.9	6.82		0.46	-158.5	1057				37.01	37	1	36	0.01	36.01			49
UNSAT-IS1-D (receives STE)	4" Coarse Sand; 8" Fine Sand; 12"	Southern	6/28/11 12:50	G	28.9	6.82		0.46	-158.5	1057				35.01	35	0	35	0.01	35.01			50
UNSAT-IS2-SP (receives STE)	Above 4" Sulfur layer	Southern	6/28/11 13:20	G	28.6	6.37		0.97	-65.7	612				7.7	2	1.47	0.53	5.7	6.23			54
UNSAT-IS2 (receives STE)	4" EC>1.53mm; 8" EC As-Is; 12" Mix	Southern	6/28/11 12:45	G	28.3	7.01		2.62	-208.8	996				3.59	3.5	0.9	2.6	0.09	2.69			160
UNSAT-IS3-SP (receives STE)	Above 4" Sulfur layer	Southern	6/28/11 12:40	G	28.1	6.45		3.33	-38	951				7.2	4.1	3.9	0.2	3.1	3.3			76
UNSAT-IS3 (receives STE)	4" CL 8X14; 8" CL 16X50; 12" Mix	Southern	6/27/11 8:00	G	26.5	6.71		1.76		1168				1.72	1.6	1.49	0.11	0.12	0.23			160
UNSAT-IS4-SP (receives UNSAT-CL3 NO_3)	Above 4" Sulfur layer	Southern	6/28/11 12:40	G	28.1	6.46		2.08	-109.5	1091				12.1	3.4	3.33	0.07	8.7	8.77			75
UNSAT-IS4 (receives UNSAT-CL3 NO_3)	4" Coarse Sand; 8" Fine Sand; 12"	Southern	6/27/11 0:00	G	25.4	6.59		0.35		1373				1.76	1.5	1.17	0.33	0.26	0.59			110

Notes:

[1]Total Nitrogen (TN) is a calculated value equal to the sum of TKN and NO_X

[2]Organic Nitrogen (ON) is a calculated value equal to the difference of TKN and NH_3.

[3]Total Inorganic Nitrogen (TIN) is a calculated value equal to the sum of NH_3 and NO_X.

EC: expanded clay, CL: clinoptilolite, PS: polystyrene, SU: elemental sulfur, LS: lignocellulosic, GL: glycerol, OS: oyster shell, NS: sodium sesquicarbonate, GR: gravel

D.O. - Dissolved oxygen

G - Grab sample

Gray-shaded data points indicate values below method detection level (mdl), mdl value used for statistical analyses.

Yellow-shaded data points indicate the reported value is between the laboratory method detection limit and the laboratory practical quantitation limit, value used for statistical analysis.

Orange - shaded data points indicate too many colonies were present. The numberic value represents the dilution factor times the maximum reportable number of colonies.

Purple-shaded data points indicate results based upon colony counts outside the method indicated ideal range.

Blue-shaded data points indicate matrix spike was outside typical range. All other QC criteria were acceptable.

PNRS II TEST FACILITY
SAMPLE EVENT NO. 9
EXPERIMENTAL DAY 486

Sample ID	Media Composition	Analytical Laboratory	Sample Date/Time	Sample Type	Temp (°C)	pH	Total Alkalinity (mg/L)	DO (mg/L)	ORP (mV)	Specific Conductance (µS)	TDS (mg/L)	TSS (mg/L)	$CBOD_5$ (mg/L)	COD	TN (mg/L N)[1]	TKN (mg/L N)	Organic N (mg/L N)[2]	NH_3-N (mg/L N)	NO_3-N (mg/L N)	NO_2-N (mg/L N)	NOx (mg/L N)	TIN (mg/L N)[3]	Sulfide (mg/L)	H_2S (mg/L)	SO_4 (mg/L)	Fecal (Ct/100 mL)
STE Sample																										
PNRS II STE-Tank 1		Southern	9/15/11 11:50	G	28.4	7.4	240	4	262.2	820		15	35	97	26.02	26	4	22	0.01	0.01	0.02	22.02	5.6	1.6	31	8400
PNRS II STE-Tank 1-D		Southern	9/15/11 11:55	G	28.4	7.4	250	4	262.2	820		20	30	93	25.02	25	2	23	0.01	0.01	0.02	23.02	5.5	1.5	32	8900
PNRS II STE-Tank 1-D2		Pace	9/15/11 11:50	G	28.4	7.4	258	4	262.2	820	327	7	37.4	132	27.55	27.5	1.8	25.7	0.025	0.025	0.05	25.75		1.3	34.5	
Stage 1 Single Pass Biofilters Effluent																										
UNSAT-EC1	15" Expanded Clay	Southern	9/15/11 11:45	G	28.8	7	140	3.9	57.6	810		2	2	10	25.9	3.8	3.26	0.54	22	0.1	22.1	22.64	0.1	0.01	55	690
UNSAT-EC3	30" Expanded Clay	Southern	9/15/11 11:40	G	28.7	7.1	160	5.6	25.3	826		1	2	10	23.91	1.9	1.88	0.023	22	0.01	22.01	22.033				3
UNSAT-CL1	15" Clinoptilolite	Southern	9/15/11 11:35	G	28.7	7.4	130	6.6	42.9	825		2	2	10	26.01	2	1.98	0.016	24	0.01	24.01	24.026	0.1	0.01	53	40
UNSAT-CL3	30" Clinoptilolite	Southern	9/15/11 11:30	G	28.2	7.3	190	6.4	24.8	903		3	2	10	25.51	1.5	1.48	0.02	24	0.01	24.01	24.03				120
UNSAT-CL5	30" Clinoptilolite	Southern	9/15/11 11:20	G	28.8	7.5	140	6.7	14.3	817		2	2	10	26.51	1.5	1.48	0.018	25	0.01	25.01	25.028				410
Stage 2 Single Pass Upflow Biofilters Effluent																										
DENIT-SU4	10% Limestone; 30% Sulfur; 60% Expanded Clay	Southern	9/15/11 10:00	G	26.8	7.2	140	0.1	-355.8	1004		3	8	10	3.13	2.9	1.40	1.5	0.22	0.01	0.23	1.73	1.4	0.49	260	740
DENIT-LS3	50% New Lignocellulosic; 50% Sand	Southern	9/15/11 9:50	G	27.2	7.4	220	2.3	-159.6	739		4	2	10	10.91	1.3	1.27	0.033	9.1	0.51	9.61	9.643				3
DENIT-LS3-D	50% New Lignocellulosic; 50% Sand	Southern	9/15/11 9:55	G	27.2	7.4	210	2.3	-159.6	739		3	2	10	9.96	1.3	1.27	0.03	8.2	0.46	8.66	8.69				2
DENIT-SU3	80% Sulfur; 20% Oyster Shell	Southern	9/15/11 9:40	G	27	7.4	150	0.1	-354.9	1126		2	6	10	1.53	1.3	0.75	0.55	0.22	0.01	0.23	0.78	0.98	0.26	320	30
DENIT-SU3-D	80% Sulfur; 20% Oyster Shell	Southern	9/15/11 9:45	G	27	7.4	140	0.1	-354.9	1126		6	6	10	1.75	1.5	0.99	0.51	0.24	0.01	0.25	0.76	0.78	0.21	330	20
DENIT-LS2	25% New Lignocellulosic; 75% Expanded Clay	Southern	9/15/11 9:35	G	26.8	7.5	220	3.1	19.1	862		2	2	10	22.37	1.9	1.86	0.039	20	0.47	20.47	20.509				4
DENIT-LS4	30% New Lignocellulosic; 70% Expanded Clay	Southern	9/15/11 9:25	G	26.3	7.7	200	3.3	21.5	809		1	2	10	17.99	1.6	1.58	0.023	16	0.39	16.39	16.413				16
DENIT-LS4-D	30% New Lignocellulosic; 70% Expanded Clay	Southern	9/15/11 9:30	G	26.3	7.7	200	3.3	21.5	809		1	2	10	17.91	1.4	1.38	0.021	16	0.51	16.51	16.531				14
Recirculation Tanks Effluent																										
RC1		Southern	9/15/11 10:05	G	26.8	7.3	150	0.3	-119.8	706		3	4	15	16.51	2.5	1.2	1.3	14	0.01	14.01	15.31				4300
RC2		Southern	9/15/11 10:10	G	26.3	7.2	140	0.7	-123.4	696		1	4	10	17.31	5.3	2.3	3	12	0.01	12.01	15.01				4600
RC3		Southern	9/15/11 10:15	G	25.8	7.3	140	0.1	-128.6	713		1	5	10	16.45	3.1	0.1	3	13	0.35	13.35	16.35				3600
RC4		Southern	9/15/11 10:20	G	26.6	7.4	180	0.1	-129.3	750		1	4	10	12.41	2.8	0.2	2.6	9.6	0.01	9.61	12.21				4900
Stage 1 Recirculating Biofilters Effluent																										
UNSAT-CL4	30" Clinoptilolite	Southern	9/15/11 8:55	G	26.3	7.4	170	7.2	28.7	767		5	2	10	15.61	1.6	1.56	0.037	14	0.01	14.01	14.047				5
UNSAT-CL2	15" Clinoptilolite	Southern	9/15/11 9:10	G	26.1	7.2	120	6.2	29.9	697		10	2	18	18.51	1.5	1.48	0.023	17	0.01	17.01	17.033				760
UNSAT-EC4	30" Expanded Clay	Southern	9/15/11 9:20	G	26	7	110	7.1	51.7	693		1	2	10	18.51	1.5	1.48	0.021	17	0.01	17.01	17.031				50
UNSAT-SA2	30" Sand	Southern	9/15/11 9:00	G	26	7	130	6.7	8	687		1	2	10	19.61	1.6	1.58	0.017	18	0.01	18.01	18.027				70
Denite Feed Tank (Tank 3)																										
DFT		Southern	9/15/11 8:20	G	25.8	7.4	130	6.8	6.2	711		1	2	10	17.71	1.7	1.68	0.016	16	0.01	16.01	16.026	0.1	0.01	58	66
DFT-D		Southern	9/15/11 8:25	G	25.8	7.4	120	6.8	6.2	711		2	2	10	17.81	1.8	1.77	0.034	16	0.01	16.01	16.044	0.2	0.06	58	71
Stage 2 Horizontal Biofilters Effluent																										
DENIT-SU1	80% Sulfur; 20% Oyster Shell	Southern	9/15/11 7:45	G	22	7	170	0.2	-365.9	1009		1	41	89	2.65	2.4	1.20	1.2	0.24	0.01	0.25	1.45	30	14	200	9
DENIT-SU2	10% Limestone; 30% Sulfur; 60% Expanded Clay	Southern	9/15/11 7:50	G	22.5	7	170	0.1	-343.5	961		1	27	40	8.24	8	5.80	2.2	0.23	0.01	0.24	2.44	24	11	210	10
DENIT-LS1	50% New Lignocellulosic; 50% Expanded Clay	Southern	9/15/11 7:55	G	22.2	7.2	210	0.3	-284.3	644		2	9	24	0.62	0.38	0.36	0.02	0.23	0.01	0.24	0.26				1
DENIT-GL1	12" Gravel; 60" Expanded Clay	Southern	9/15/11 8:00	G	22.5	6.6	330	0.1	-283.5	794		5	13	20	0.94	0.7	0.43	0.27	0.23	0.01	0.24	0.51				140
In-situ Simulator Biofilters Effluent																										
UNSAT-IS1 (receives STE)	4" Coarse Sand; 8" Fine Sand; 12" Mix (60% EC, 40% New Ligno); 4" Sulfur	Southern	9/16/11 12:05	G	13.4	6.8	280	9.5	-158.3	831		3	6	44	21.24	21	13.00	8	0.23	0.01	0.24	8.24	1.2	0.7	53	42
UNSAT-IS1-D (receives STE)	4" Coarse Sand; 8" Fine Sand; 12" Mix (60% EC, 40% New Ligno); 4" Sulfur	Pace		G	13.4	6.8	273	9.54	-158.3	831			6.4	53.7	10.55	10.5	1.10	9.4	0.025	0.025	0.05	9.45		1.1	89.2	
UNSAT-IS2-SP (receives STE)			9/16/11 11:55	G	29.3	6.3	130	1.4	-130.9	667		4	7	71	1.82	1.8	1.52	0.28	0.01	0.01	0.02	0.3	1.8	1.5	72	1
UNSAT-IS2 (receives STE)	4" EC>1.53mm; 8" EC As-Is; 12" Mix (60% EC, 40% New Ligno); 4" Sulfur	Southern	9/16/11 12:10	G	10.1	7	240	7.7	-59.6	865		4	9	130	2.04	1.8	1.41	0.39	0.23	0.01	0.24	0.63	1.8	0.86	120	1
UNSAT-IS3-SP (receives STE)	Above 4" Sulfur layer	Southern	9/16/11 16:00	G			59					2	7	44	21.4	3.4	3.34	0.061			18	18.061	0.1	0.01	75	1
UNSAT-IS3 (receives STE)	4" CL 8X14; 8" CL 16X50; 12" Mix (60% EC, 40% New Ligno); 4" Sulfur	Southern	9/16/11 12:10	G	22.9	7.49	180	8.23	-13.9	923		8	3	48	2.71	1.7	1.21	0.49	0.68	0.33	1.01	1.5	0.1	0.01	200	1
UNSAT-IS4-SP (receives UNSAT-CL3 NO_3)	Above 4" Sulfur layer	Southern	9/16/11 11:55	G			270					2	5	61	3.3	2.1	1.24	0.86			1.2	2.06	0.1	0.01	63	1
UNSAT-IS4 (receives UNSAT-CL3 NO_3)	4" Coarse Sand; 8" Fine Sand; 12" Mix (60% EC, 40% New Ligno); 4" Sulfur	Southern	9/16/11 12:10	G	22.4	6.75	400	2.11	-222.7	1136		6	2	69	2.04	1.8	1.21	0.59	0.23	0.01	0.24	0.83	0.1	0.01	110	1
Field Blank	Reagent Water	Southern	9/15/11 11:10		26	8.2	9.9	7.9	11.2	36		1	2	10	0.07	0.05	0.05	0.005	0.01	0.01	0.02	0.025				1
Equipment Blank	Reagent Water - Cleaned STE Bottle #1	Southern	9/15/11 11:00		25.9	7.8	9.9	7.9	7.7	32		1	2	10	0.07	0.05	0.05	0.005	0.01	0.01	0.02	0.025				1

Notes:

[1]Total Nitrogen (TN) is a calculated value equal to the sum of TKN and NO_X

[2]Organic Nitrogen (ON) is a calculated value equal to the difference of TKN and NH_3

[3]Total Inorganic Nitrogen (TIN) is a calculated value equal to the sum of NH_3 and NO_X

EC: expanded clay, CL: clinoptilolite, PS: polystyrene, SU: elemental sulfur, LS: lignocellulosic, GL: glycerol, OS: oyster shell, NS: sodium sesquicarbonate, GR: gravel

D.O. - Dissolved oxygen

G - Grab sample

Gray-shaded data points indicate values below method detection level (mdl), mdl value used for statistical analyses.

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Blue-shaded data points indicate matrix spike was outside typical range. All other QC criteria were acceptable.

PNRS II TEST FACILITY
PROFILES
EXPERIMENTAL DAY 487

Sample ID	Distance from Inlet, inches	Media Composition	Sample Date/Time	Sample Type	Water Temperature	pH	Specific conductance	Dissolved Oxygen	COD (mg/L)	NO_3-N (mg/L N)	NO_2-N (mg/L N)	NOx (mg/L N)	SO_4 (mg/L)
Stage 2 Single Pass Upflow Biofilters Effluent													
DENIT-SU4 - Effluent	24	10% Limestone; 30% Sulfur; 60% Expanded Clay	9/15/11 10:00	G	26.8	7.2	1004	0.1	10	0.22	0.01	0.23	260
DENIT-SU4-18	18		9/16/11 11:15	G	27.5	6.7	1008	1.2	46	0.22	0.01	0.23	220
DENIT-SU4-12	12		9/16/11 11:10	G	27.3	6.4	897	1.4	32	0.01	0.01	0.02	240
DENIT-SU4-7	7		9/16/11 11:05	G	27.1	6.4	860	1	34	0.24	0.01	0.25	230
DENIT-SU4-3	3		9/16/11 11:00	G	27	6.3	854	1.3	38	0.23	0.01	0.24	220
UNSAT-EC1	0		9/15/11 11:45	G	28.8	7	810	3.9	10	22	0.1	22.1	55
DENIT-LS3 - Effluent	24	50% Lignocellulosic; 50% Sand	9/15/11 9:50	G	27.2	7.4	739	2.3	10	9.1	0.51	9.61	
DENIT-LS3-18	18		9/16/11 10:55	G	26.8	6.9	737	0.8	26	0.57	0.26	0.83	
DENIT-LS3-12	12		9/16/11 10:50	G	27.1	6.8	772	0.8	32	2.4	0.29	2.69	
DENIT-LS3-7	7		9/16/11 10:45	G	27.1	7	775	1.6	18	4.6	0.37	4.97	
DENIT-LS3-3	3		9/16/11 10:40	G	26.9	6.8	804	1.1	20	20	0.33	20.33	
UNSAT-EC3	0		9/15/11 11:40	G	28.7	7.1	826	5.6	10	22	0.01	22.01	
DENIT-SU3 - Effluent	24	80% Sulfur; 20% Oyster Shell	9/15/11 9:40	G	27	7.4	1126	0.1	10	0.22	0.01	0.23	320
DENIT-SU3-18	18		9/16/11 10:10	G	27.2	7	1136	0.7	46	0.23	0.01	0.24	270
DENIT-SU3-12	12		9/16/11 10:05	G	26.6	6.9	1091	0.7	50	0.24	0.01	0.25	270
DENIT-SU3-7	7		9/16/11 10:00	G	26.8	6.8	1047	0.7	46	0.22	0.01	0.23	270
DENIT-SU3-3	3		9/16/11 9:55	G	26.7	6.7	1022	0.6	44	0.22	0.01	0.23	270
UNSAT-CL1	0		9/15/11 11:35	G	28.7	7.4	825	6.6	10	24	0.01	24.01	53
DENIT-LS2 - Effluent	24	50% Lignocellulosic; 50% Expanded Clay	9/15/11 9:35	G	26.8	7.5	862	3.1	10	20	0.47	20.47	
DENIT-LS2-18	18		9/16/11 9:50	G	26.3	7.1	859	1	15	12	1.6	13.6	
DENIT-LS2-12	12		9/16/11 9:45	G	26.3	7.2	892	1.1	<10	19	0.7	19.7	
DENIT-LS2-7	7		9/16/11 9:40	G	26.3	7.2	860	1.3	<10	22	0.45	22.45	
DENIT-LS2-3	3		9/16/11 9:35	G	26.3	7.2	887	1.8	13	25	0.3	25.3	
UNSAT-CL3	0		9/15/11 11:30	G	28.2	7.3	903	6.4	10	24	0.01	24.01	
DENIT-LS4 - Effluent	24	30% Lignocellulosic; 70% Expanded Clay	9/15/11 9:25	G	26.3	7.7	809	3.3	10	16	0.39	16.39	
DENIT-LS4-18	18		9/16/11 8:55	G	26.9	7.3	740	2	15	1.1	0.52	1.62	
DENIT-LS4-12	12		9/16/11 8:50	G	26.8	7.3	770	1.4	18	5.7	1.4	7.1	
DENIT-LS4-7	7		9/16/11 8:45	G	26.7	7.3	802	1.8	38	12	1.9	13.9	
DENIT-LS4-3	3		9/16/11 8:40	G	26	7.2	822	1.6	13	26	0.54	26.54	
UNSAT-CL5	0		9/15/11 11:20	G	28.8	7.5	817	6.7	10	25	0.01	25.01	
Stage 2 Horizontal Biofilters Effluent													
DENIT-SU1-Effluent	72	80% Sulfur; 20% Oyster Shell	9/15/11 7:45	G	22	7	1009	0.2	89	0.24	0.01	0.25	200
DENIT-SU1-72	72		9/16/11 7:20	G	24.8	6.9	910	1.2	46	0.44	0.01	0.45	180
DENIT-SU1-60	60		9/16/11 10:20	G	26.2	6.9	930	1.4	46	0.28	0.01	0.29	180
DENIT-SU1-48	48		9/16/11 11:20	G	28.2	6.9	961	0.6	50	0.24	0.01	0.25	190
DENIT-SU1-36	36		9/16/11 12:20	G	29.7	6.8	1022	1	53	0.23	0.01	0.24	190
DENIT-SU1-24	24		9/16/11 13:20	G	30.5	6.8	1012	1	57	0.23	0.01	0.24	200
DENIT-SU1-12	12		9/16/11 14:20	G	33.1	6.9	758	1.3	18	11	0.01	11.01	86
DFT	0		9/15/11 8:20	G	25.8	7.4	711	6.8	10	16	0.01	16.01	58
DENIT-SU2-Effluent	72	80% Sulfur; 20% Sodium Sesqui.	9/15/11 7:50	G	22.5	7	961	0.1	40	0.23	0.01	0.24	210
DENIT-SU2-72	72		9/16/11 9:20	G	23.4	6.8	948	1.3	59	0.23	0.01	0.24	210
DENIT-SU2-60	60		9/16/11 10:20	G	25.9	6.6	932	0.9	50	0.22	0.01	0.23	210
DENIT-SU2-48	48		9/16/11 11:20	G	27	6.7	922	1.4	40	0.22	0.01	0.23	190
DENIT-SU2-36	36		9/16/11 12:20	G	29.4	6.6	948	0.6	46	0.22	0.01	0.23	210
DENIT-SU2-24	24		9/16/11 13:20	G	30.6	6.6	886	1	34	0.32	0.01	0.33	200
DENIT-SU2-12	12		9/16/11 14:20	G	32.7	6.6	789	1.4	22	8.4	0.01	8.41	120
DFT	0		9/15/11 8:20	G	25.8	7.4	711	6.8	10	16	0.01	16.01	58
DENIT-LS1-Effluent	72	50% Lignocellulosic; 50% Exp	9/15/11 7:55	G	22.2	7.2	644	0.3	24	0.23	0.01	0.24	
DENIT-LS1-72	72		9/16/11 9:20	G	23.2	7	645	0.9	24	0.29	0.01	0.3	
DENIT-LS1-60	60		9/16/11 10:20	G	25.6	7	658	1.6	13	2.4	0.27	2.67	
DENIT-LS1-48	48		9/16/11 11:20	G	27.5	7	704	1.9	<10	6.5	0.46	6.96	
DENIT-LS1-36	36		9/16/11 12:20	G	29.5	7	775	0.5	<10	9.5	0.64	10.14	
DENIT-LS1-24	24		9/16/11 13:20	G	30.9	6.9	730	1	<10	12	0.69	12.69	
DENIT-LS1-12	12		9/16/11 14:20	G	32.1	6.9	723	1.1	30	14	0.39	14.39	
DFT	0		9/15/11 8:20	G	25.8	7.4	711	6.8	10	16	0.01	16.01	
DENIT-GL1-Effluent	72	12" Gravel; 60" Expanded Clay	9/15/11 8:00	G	22.5	6.6	794	0.1	20	0.23	0.01	0.24	
DENIT-GL1-72	72		9/16/11 9:20	G	24.7	6.4	661	1.4	50	0.26	0.01	0.27	
DENIT-GL1-60	60		9/16/11 10:20	G	26.3	6.3	693	1.3	44	0.24	0.01	0.25	
DENIT-GL1-48	48		9/16/11 11:20	G	27.4	6.3	726	0.8	59	0.23	0.01	0.24	
DENIT-GL1-36	36		9/16/11 12:20	G	29.2	6.3	751	0.5	55	0.22	0.01	0.23	
DENIT-GL1-24	24		9/16/11 13:20	G	30.6	6.3	740	0.7	61	0.22	0.01	0.23	
DENIT-GL1-12	12		9/16/11 14:20	G	31.7	6.2	726	0.5	160	0.26	0.01	0.27	
DFT	0		9/15/11 8:20	G	25.8	7.4	711	6.8	10	16	0.01	16.01	

Notes
G - Grab sample
Gray - Shaded data points indicate values below method detection level (mdl), mdl value used for statistical analyses.
Yellow shaded data points indicate the reported value is between the laboratory method detection limit and the laboratory practical quantitation limit.

PNRS II TEST FACILITY
SAMPLE EVENT NO. 10
EXPERIMENTAL DAY 1038

Sample ID	Media Composition	Analytical Laboratory	Sample Date/Time	Sample Type	Temp (°C)	pH	Total Alkalinity (mg/L)	DO (mg/L)	ORP (mV)	Specific Conductance (µS)	TDS (mg/L)	TSS (mg/L)	$CBOD_5$ (mg/L)	COD	TN (mg/L N)[1]	TKN (mg/L N)	Organic N (mg/L N)[2]	NH_3-N (mg/L N)	NO_3-N (mg/L N)	NO_2-N (mg/L N)	NOx (mg/L N)	TIN (mg/L N)[3]	Sulfide (mg/L)	H_2S (mg/L)	SO_4 (mg/L)	Fecal (Ct/100 mL)
STE Sample																										
PNRS II STE-Tank 1		Southern	3/20/13 14:05	G	21.1	7.13	240	0.07	-317.1	1373		15	35	97	26.02	26	4	22	0.01	0.01	0.02	22.02	5.6	1.6	31	8400
PNRS II STE-Tank 1-D		Southern	3/20/13 14:10	G	21.1	7.13	250	0.07	-317.1	1373		20	30	93	25.02	25	2	23	0.01	0.01	0.02	23.02	5.5	1.5	32	8900
Stage 1 Single Pass Biofilters Effluent																										
UNSAT-EC1	15" Expanded Clay	Southern	3/20/13 12:00	G	21.3	7.19	140	0.45	21.5	1300		2	2	10	25.9	3.8	3.26	0.54	22	0.1	22.1	22.64	0.1	0.01	55	690
UNSAT-EC3	30" Expanded Clay	Southern	3/20/13 12:05	G	20.6	7.03	160	0.32	65.4	1358		1	2	10	23.91	1.9	1.88	0.023	22	0.01	22.01	22.033				3
UNSAT-CL1	15" Clinoptilolite	Southern	3/20/13 11:28	G	21.5	7.01	130	0.43	70.5	1437		2	2	10	26.01	2	1.98	0.016	24	0.01	24.01	24.026	0.1	0.01	53	40
UNSAT-CL3	30" Clinoptilolite	Southern	3/20/13 12:05	G	21.8	6.92	190	6.13	69.7	1340		3	2	10	25.51	1.5	1.48	0.02	24	0.01	24.01	24.03				120
UNSAT-CL5	30" Clinoptilolite	Southern	3/20/13 12:00	G	21.1	6.52	140	3.96	79.1	1348		2	2	10	26.51	1.5	1.48	0.018	25	0.01	25.01	25.028				410
Stage 2 Single Pass Upflow Biofilters Effluent																										
DENIT-SU4	10% Limestone; 30% Sulfur; 60% Expanded Clay	Southern	3/20/13 11:05	G	20.1	7.18	140	0.1	-329.4	1427		3	8	10	3.13	2.9	1.40	1.5	0.22	0.01	0.23	1.73	1.4	0.49	260	740
DENIT-LS3	50% New Lignocellulosic; 50% Sand	Southern	3/20/13 11:10	G	20.2	7.18	220	1.81	-188.1	1406		4	2	10	10.91	1.3	1.27	0.033	9.1	0.51	9.61	9.643				3
DENIT-LS3-D	50% New Lignocellulosic; 50% Sand	Southern	3/20/13 11:15	G	20.2	7.18	210	1.81	-188.1	1406		3	2	10	9.96	1.3	1.27	0.03	8.2	0.46	8.66	8.69				2
DENIT-SU3	80% Sulfur; 20% Oyster Shell	Southern	3/20/13 11:20	G	20.4	6.99	150	0.09	-330	1567		2	6	10	1.53	1.3	0.75	0.55	0.22	0.01	0.23	0.78	0.98	0.26	320	30
DENIT-LS2	25% New Lignocellulosic; 75% Expanded Clay	Southern	3/20/13 11:05	G	20.1	7.18	220	3.06	148.2	227		2	2	10	22.37	1.9	1.86	0.039	20	0.47	20.47	20.509				4
DENIT-LS4	30% New Lignocellulosic; 70% Expanded Clay	Southern	3/20/13 11:05	G	19.9	6.87	200	2.67	148.1	1416		1	2	10	17.99	1.6	1.58	0.023	16	0.39	16.39	16.413				16
DENIT-LS4-D	30% New Lignocellulosic; 70% Expanded Clay	Southern	3/20/13 11:06	G	19.9	6.87	200	2.67	148.1	1416		1	2	10	17.91	1.4	1.38	0.021	16	0.51	16.51	16.531				14
Recirculation Tanks Effluent																										
RC1		Southern	3/20/13 9:30	G	19.9	6.66	150	2.15	166.4	1337		3	4	15	16.51	2.5	1.2	1.3	14	0.01	14.01	15.31				4300
RC2		Southern	3/20/13 9:30	G	26.3	7.2	140	0.7	-123.4	1354		1	4	10	17.31	5.3	2.3	3	12	0.01	12.01	15.01				4600
RC3		Southern	3/20/13 9:30	G	20	6.5	140	1.48	185.9	1273		1	5	10	16.45	3.1	0.1	3	13	0.35	13.35	16.35				3600
RC4		Southern	3/20/13 9:30	G	19.9	6.48	180	2.08	178.7	1457		1	4	10	12.41	2.8	0.2	2.6	9.6	0.01	9.61	12.21				4900
Stage 1 Recirculating Biofilters Effluent																										
UNSAT-CL4	30" Clinoptilolite	Southern	3/20/13 8:45	G	20.2	5.98	170	6.08	253.5	1267		5	2	10	15.61	1.6	1.56	0.037	14	0.01	14.01	14.047				5
UNSAT-CL2	15" Clinoptilolite	Southern	3/20/13 8:47	G	20.6	5.4	120	3.16	271.5	1300		10	2	18	18.51	1.5	1.48	0.023	17	0.01	17.01	17.033				760
UNSAT-EC4	30" Expanded Clay	Southern	3/20/13 8:50	G	20	6.28	110	6.58	198.5	1351		1	2	10	18.51	1.5	1.48	0.021	17	0.01	17.01	17.031				50
UNSAT-SA2	30" Sand	Southern	3/20/13 0:00	G	19.8	6.3	130	5.81	196.2	1334		1	2	10	19.61	1.6	1.58	0.017	18	0.01	18.01	18.027				70
Denite Feed Tank (Tank 3)																										
DFT		Southern	3/20/13 10:05	G	20.5	6.37	130	6.69	189.2	1381		1	2	10	17.71	1.7	1.68	0.016	16	0.01	16.01	16.026	0.1	0.01	58	66
Stage 2 Horizontal Biofilters Effluent																										
DENIT-SU1	80% Sulfur; 20% Oyster Shell	Southern	3/20/13 12:55	G	20.3	7.03	170	0.13	-312	1802		1	41	89	2.65	2.4	1.20	1.2	0.24	0.01	0.25	1.45	30	14	200	9
DENIT-SU2	10% Limestone; 30% Sulfur; 60% Expanded Clay	Southern	3/20/13 13:00	G	19.9	6.91	170	0.09	-285.9	1745		1	27	40	8.24	8	5.80	2.2	0.23	0.01	0.24	2.44	24	11	210	10
DENIT-LS1	50% New Lignocellulosic; 50% Expanded Clay	Southern	3/20/13 12:55	G	20.2	6.68	210	1.31	-161.2	1342		2	9	24	0.62	0.38	0.36	0.02	0.23	0.01	0.24	0.26				1
DENIT-GL1	12" Gravel; 60" Expanded Clay	Southern	9/15/11 8:00	G	22.5	6.6	330	0.1	-283.5	794		5	13	20	0.94	0.7	0.43	0.27	0.23	0.01	0.24	0.51				140
In-situ Simulator Biofilters Effluent																										
UNSAT-IS1 (receives STE)	4" Coarse Sand; 8" Fine Sand; 12" Mix (60% EC, 40% New Ligno); 4" Sulfur	Southern	3/20/13 13:10	G	16.8	7.38	280	7.89	39.1	1422		3	6	44	21.24	21	13.00	8	0.23	0.01	0.24	8.24	1.2	0.7	53	42
UNSAT-IS1-D (receives STE)	4" Coarse Sand; 8" Fine Sand; 12" Mix (60% EC, 40% New Ligno); 4" Sulfur	Pace		G	13.4	6.8	273	9.54	-158.3	831			6.4	53.7	10.55	10.5	1.10	9.4	0.025	0.025	0.05	9.45		1.1	89.2	
UNSAT-IS2-SP (receives STE)			3/20/13 13:35	G	20.9	3.93	130	1.96	-4.1	1357		4	7	71	1.82	1.8	1.52	0.28	0.01	0.01	0.02	0.3	1.8	1.5	72	1
UNSAT-IS2-SP-D(receives STE)			3/20/13 13:40		20.9	3.93		1.96	-4.1	1357																
UNSAT-IS2 (receives STE)	4" EC>1.53mm; 8" EC As-Is; 12" Mix (60% EC, 40% New Ligno); 4" Sulfur	Southern	3/20/13 13:15	G	16	7.3	240	9.11	48.2	1369		4	9	130	2.04	1.8	1.41	0.39	0.23	0.01	0.24	0.63	1.8	0.86	120	1
UNSAT-IS3-SP (receives STE)	Above 4" Sulfur layer	Southern	9/16/11 16:00	G			59					2	7	44	21.4	3.4	3.34	0.061			18	18.061	0.1	0.01	75	1
UNSAT-IS3 (receives STE)	4" CL 8X14; 8" CL 16X50; 12" Mix (60% EC, 40% New Ligno); 4" Sulfur	Southern	9/16/11 12:10	G	22.9	7.49	180	8.23	-13.9	923		8	3	48	2.71	1.7	1.21	0.49	0.68	0.33	1.01	1.5	0.1	0.01	200	1
UNSAT-IS4-SP (receives UNSAT-CL3 NO_3)	Above 4" Sulfur layer	Southern	9/16/11 11:55	G			270					2	5	61	3.3	2.1	1.24	0.86			1.2	2.06	0.1	0.01	63	1
UNSAT-IS4 (receives UNSAT-CL3 NO_3)	4" Coarse Sand; 8" Fine Sand; 12" Mix (60% EC, 40% New Ligno); 4" Sulfur	Southern	9/16/11 12:10	G	22.4	6.75	400	2.11	-222.7	1136		6	2	69	2.04	1.8	1.21	0.59	0.23	0.01	0.24	0.83	0.1	0.01	110	1
Field Blank	Reagent Water	Southern	3/20/13 14:20		21.1	7.18	9.9	8.62		1.16		1	2	10	0.07	0.05	0.05	0.005	0.01	0.01	0.02	0.025				1
Equipment Blank	Reagent Water - Cleaned STE Bottle #1	Southern	3/20/13 14:25		21.4	7.36	9.9	8.48		2.25		1	2	10	0.07	0.05	0.05	0.005	0.01	0.01	0.02	0.025				1

Notes:

[1]Total Nitrogen (TN) is a calculated value equal to the sum of TKN and NO_x

[2]Organic Nitrogen (ON) is a calculated value equal to the difference of TKN and NH_3

[3]Total Inorganic Nitrogen (TIN) is a calculated value equal to the sum of NH_3 and NO_x

EC: expanded clay, CL: clinoptilolite, PS: polystyrene, SU: elemental sulfur, LS: lignocellulosic, GL: glycerol, OS: oyster shell, NS: sodium sesquicarbonate, GR: gravel

D.O. - Dissolved oxygen

G - Grab sample

Gray-shaded data points indicate values below method detection level (mdl), mdl value used for statistical analyses.

Yellow-shaded data points indicate the reported value is between the laboratory method detection limit and the laboratory practical quantitation limit, value used for statistical analysis.

Orange - shaded data points indicate too many colonies were present. The numberic value represents the dilution factor times the maximum reportable number of colonies.

Purple-shaded data points indicate results based upon colony counts outside the method indicated ideal range.

Blue-shaded data points indicate matrix spike was outside typical range. All other QC criteria were acceptable.