

Florida Department of Health Passive Nitrogen Removal Study

Literature Review and Database

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Quality Assurance Project Plan

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Passive Nitrogen Removal Study

- Goal: Evaluate passive treatment media for on-site wastewater treatment
- Influent: septic tank effluent
- Treatment goal: reduce total N

Nitrogen Removal Study Tasks

- Task 1 Literature review and database
- Task 2 Laboratory experiments
- Task 3 Feasibility
- Task 4 Economic analysis
- Task 5 Final report

Literature review sources

- Peer reviewed: CSA Illumina, Science Direct, Applied Science and Technology,...
- Conference: ASAE, National Onsite Wastewater Recycling Ass.
- Test Centers: Massachusetts Alternative Septic System Test Center, LaPine Oregon national test center
- National experts
- Vendors

Literature review results

- Searchable Endnote database
- 224 entries
- URLs and abstracts provided
- Separate citation file with PDFs
- Summary performance synopsis (Excel)

Citation organization tree (compiled files)

General On-Site Nitrogen Removal (10)

Nitrification Unit Processes

Recirculating Sand Filters (6)

Waterloo Biofilter (1)

Peat Filters (9)

Textile Filters (2)

Coir Filters (3)

Zeolite Filters (2)

Eliminite

Denitrification Unit Processes

Heterotrophic Processes

Cellulosics (7)

Rich (5)

Hagerty (4)

Nitrex (5)

Black Gold (1)

Loomis (4)

Other Carbon Donors (6)

Autotrophic Processes

Sulfur (38)

Sulfide (1)

Iron (1)

Heterotrophic/autotrophic (3)

Drainfield Modifications (10)

Aerobic (unsaturated) filters

System Type	Description	Features	Treatment Performance
Intermittent sand filters	Sand filter Single pass	0.3 to 0.7 mm media 18 to 36 in. depth 0.7 to 1.5 gal/ft ² -day 12 to 48 dose/day	TN Removal: 20 to 50% Effluent: 20 to 20 mg/L NH ₃ -N Effluent: 1.9 to 9 mg/L
Recirculating sand filters	Sand filter Recirculation	1.5 to 3 mm media 18 to 36 in. depth 3 to 5 gal/ft ² -day 40 to 120 dose/day	TN Removal: 40 to 75% Effluent: 15 to 30 mg/L NH ₃ -N Effluent: 1 to 5 mg/L
Textile filters	Textile filter Recirculation	2 to 3 in. cubes 36 to 72 in. depth 8 to 17 gal/ft ² -day 80 to 140 dose/day	TN Removal: 20 to 60% Effluent: 10 to 60 mg/L NH ₃ -N Effluent: 1.7 to 5.9 NO ₃ -N Effluent: 11 mg/L
Peat filters	Peat media filter Single pass or recirculation	246 to 36 in. depth 3 to 6 gal/ft ² -day 12 to 120 dose/day	TN Removal: 10 to 75% Effluent: 10 to 60 mg/L TKN Removal: 90 to 95% NH ₃ -N Effluent: 1 mg/L NO ₃ -N Effluent: 20 to 50

Aerobic (unsaturated) filters

System Type	Description	Features	Treatment Performance
Waterloo biofilter	Open cell foam media, single pass or recirculation	3 to 4 in. cube media 48 in. depth 11 gal/ft ² -day	TN Removal: 62% Effluent: 14 mg/L NH ₃ -N Effluent: 2.4 mg/L NO ₃ -N Effluent: 10 mg/L
Zeolite filters	Zeolite media filter	20 to 30 in. depth 6.1 gal/ft ² -day	NH ₃ -N Removal: 98.6% Influent: 70 mg/L Effluent: 1 mg/L NO ₃ -N Effluent: 57 mg/L
Coir filters	Coir filter bed, with recirculation	Coconut coir media 30 in. depth 5 to 10 gal/ft ² -day	-

Anoxic (saturated) filters

System Type	Description	Features	Treatment Performance
Sulfur/oyster shell filter (bench scale)	1 liter bench column synthetic wastewater upflow single pass	Sulphur/oyster shell media (75/25% by volume) Sulphur: 4.7 mm	anoxic only NO ₃ -N Removal: 80% Influent: 50 mg/L Effluent: 10 mg/L
Sulfur/oyster shell filter	185 gal. column aerobic effluent upflow single pass	Sulphur/oyster shell media (75/25% by volume) 47 gal/ft ² -day	anoxic only TN Removal: 82% Effluent: 4.2 mg/L NO ₃ -N Removal: 88% Influent: 20 mg/L Effluent: 2.4 mg/L
Sulfur/limestone column	237 gal. column groundwater upflow single pass Residence time: 13 hr.	Sulphur/limestone media (67/33% by volume) 63 gal/ft ² -day Sulfur: 2.5 to 3.0 mm Limestone: 2.38 to 4.76 mm	anoxic only NO ₃ -N Removal: 96% Influent: 64 mg/L Effluent: 2.4 mg/L NO ₂ -N Effluent: 0.2 mg/L

Anoxic (saturated) filters

System Type	Description	Features	Treatment Performance
Nitrex™	aerobic effluent gravity flow upflow single pass	Nitrex wood-based media 24 to 30 inch media depth (est.) 4.6 gal/ft ² -day (est.)	aerobic+anoxic TN Removal: 79 to 96% Effluent: 3 to 18 mg/L NO ₃ -N Effluent: 0.3 to 8 mg/L
Black& Gold™	wood-based media single pass downflow gravity	Influent: STE 280 gal. column Sand/tire crumb/woodchip (85/11/5% by volume) 8.3 gal/ft ² -day	aerobic+anoxic TN Removal: 98% Influent: 414 mg/L Effluent: 7.1 mg/L NH ₃ -N Effluent: 4.4 mg/L NO ₃ -N Effluent: 0.05 mg/L

Approach to Passive Treatment

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

Biochemical Requirement

- Biochemical requirement: require initial aerobic filter followed by anoxic filter
- Aerobic: Organic N \rightarrow NH_4
 $\text{NH}_4 \rightarrow \text{NO}_3$
- Anoxic: $\text{NO}_3 \rightarrow \text{N}_2$

Passive constraints: require two filters in series

- No aerator
- First stage: unsaturated media filter
ammonification, nitrification
- Second stage: saturated media filter
electron donor media
anoxic
denitrification

Treatment Goal: Total N < 3 mg/L

- $TN = \text{Organic N} + \text{NH}_3\text{-N} + \text{NO}_3\text{-N}$

- $TN_{\text{allowable}} < 3.0$

- First stage filter:

$$\text{Organic N} + \text{NH}_3\text{-N} < 1.5$$

- Second stage filter

$$\text{NO}_3\text{-N} < 1.5$$

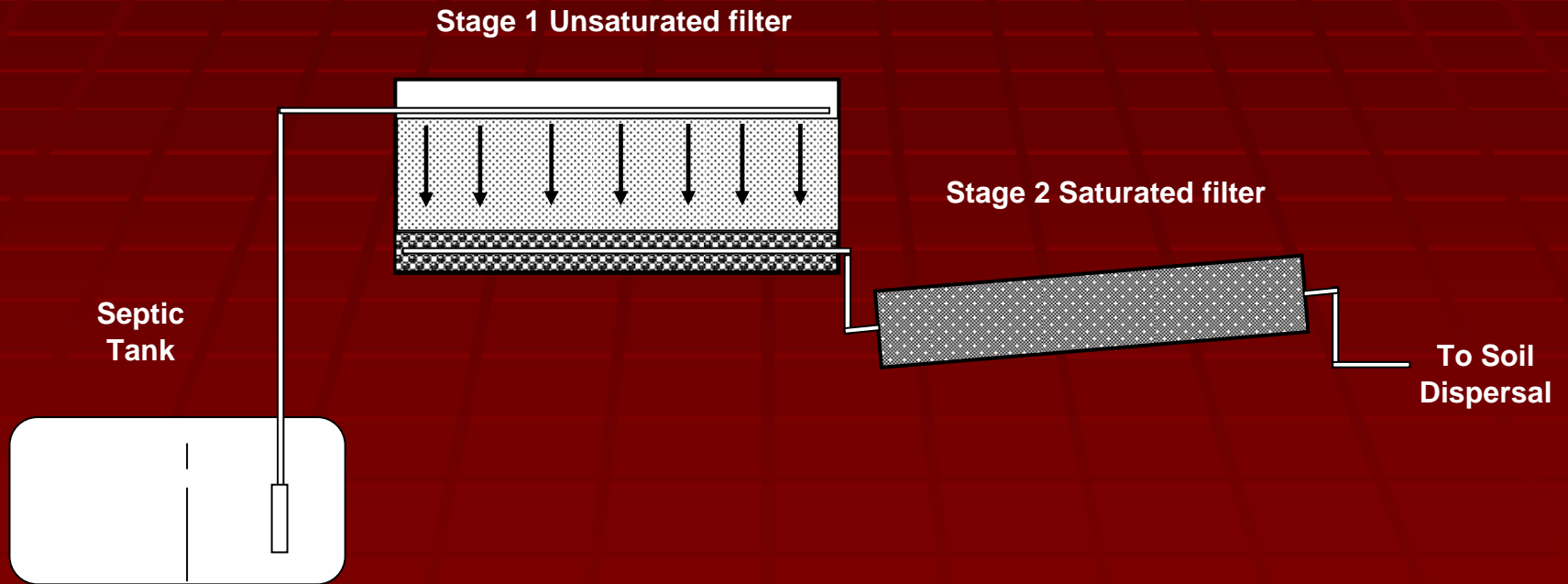
Passive constraints: one pump

- Where to place?
- Hydraulics require gravity flow before and after
- Options:
 - before first stage filter, gravity flow through second stage filter to dispersal field
 - after first stage filter, gravity flow to first stage filter and from second stage filter to dispersal field

Preferred alternative: pump from septic tank or separate chamber

- Allows pressure dosing of first stage filter
- Superior flow distribution over filter surface area
- Timed dosing provides frequent low doses of STE and superior treatment
- 24/day or more
- Potential to recirculate around first stage filter for pre-denitrification

Illustration of One Configuration



Unsaturated Filter Performance Factors

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

Filter Media Characteristics

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

Saturated Filter Performance Factors

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

Candidate Media

Material	Bulk density, lb/ft ³	Particle Size Range	Supplier
ZK406H Clinoptilolite	59	0.8 - 1.7mm	GSA Resources, Tuscon, AZ
AMZ 4/8 Clinoptilolite	55	2.3 - 4.8 mm	Ash Meadows, Armagosa, NV
AMZ 8/20 Clinoptilolite	55	0.8 - 2.3 mm	Ash Meadows, Armagosa, NV
AMZ 16/50 Clinoptilolite	55	0.3 - 1.1 mm	Ash Meadows, Armagosa, NV
Livlite Expanded Clay	41	3 to 5 mm	Big River, Alpharetta, GA
Coir fiber	8.7	0.5 - 9 cm L 0.1 - 0.3 mm D	RoLanka International, Stockbridge, GA
Elemental sulfur	77	2 - 4 mm	Georgia Sulfur, Valdosta, GA
Oyster shell	82	3 - 15 mm	Harold's Farm Supply, Dover, FL
ACT-MX ESF-580 Utelite	54	4 -20 mm	ES Filter, Ogden, UT
ACT-MX ESF-416 Utelite	54	2 - 10 mm	ES Filter, Ogden, UT
ACT-MX ESF-450 Utelite	54	0.4 - 4.5 mm	ES Filter, Ogden, UT

Granular Zeolite



- Anion exchanger for NH_4^+
- Surface for growth of nitrifiers
- 55% internal porosity
- Retains 18% of its weight as water at 10% relative humidity

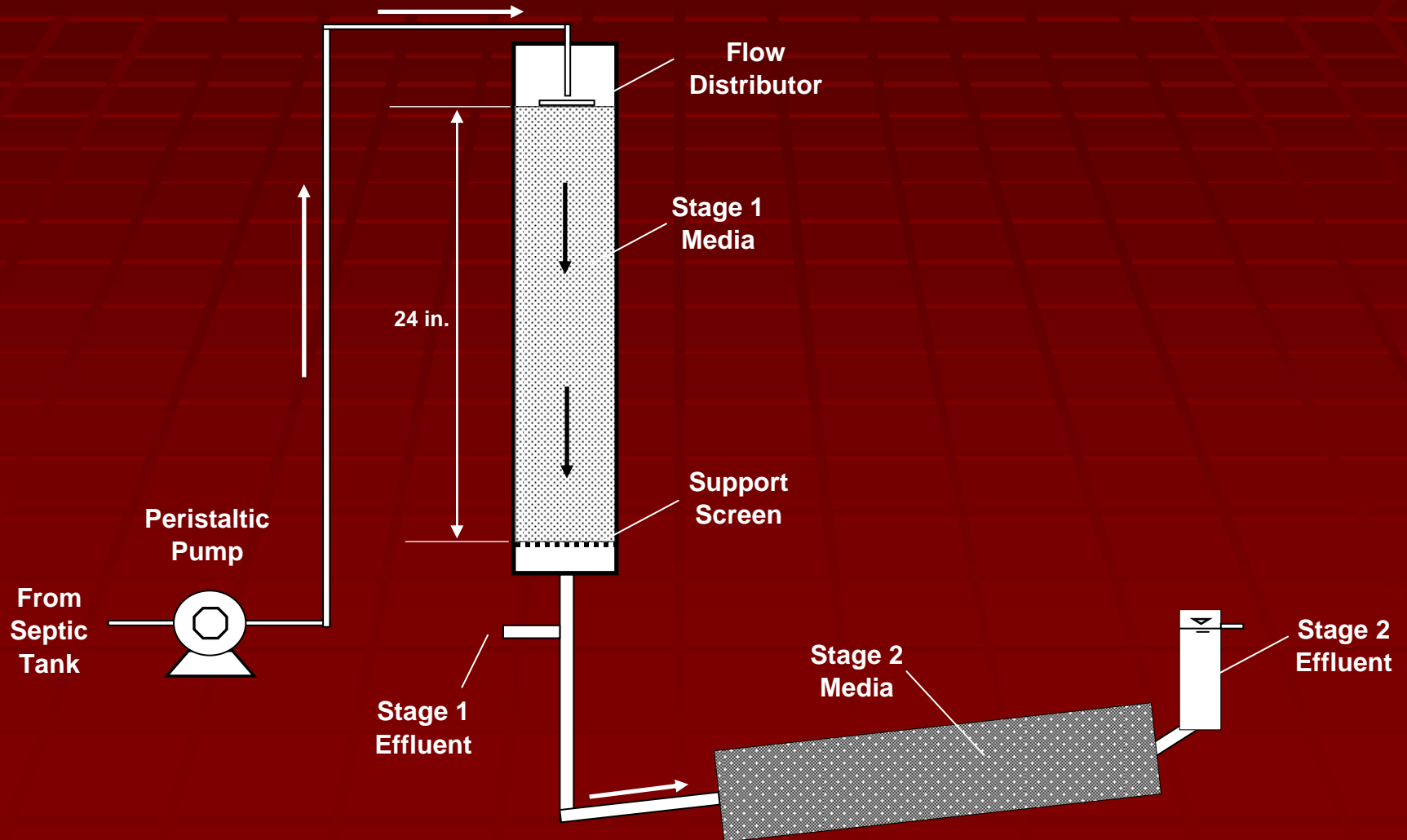
Laboratory Experiments

- Two stage filters systems:
unsaturated/saturated
- Influent: septic tank effluent
- Four sites in Hillsborough County
 - 3 at parks, 1 private
 - 3 single family, 1 visitor center

Media Configuration

Stage	Filter	Column ID, inch.	Total depth, inch	Media placement	Media
Stage 1	1A	3.0	24.0	Stratified	8 in. clinoptilolite (2.3-4.8 mm) 8 in. clinoptilolite (0.8-2.3 mm) 8 in. clinoptilolite (0.5-1.1 mm)
	1B	3.0	24.0	Stratified	8 in. expanded clay (3-5 mm) 8 in. clinoptilolite (0.8-2.3 mm) 8 in. clinoptilolite (0.5-1.1 mm)
	1C	3.0	24.0	Nonstratified	100% coir fiber
Stage 2	2A	1.5	24.0	Nonstratified	75% elemental sulfur 25% oyster shell
	2B	1.5	24.0	Nonstratified	60% elemental sulfur 20% oyster shell 20% expanded shale
	2C	1.5	24.0	Nonstratified	45 % elemental sulfur 15% oyster shell 40% expanded shale

Laboratory Two Stage Filter



Laboratory Experiments

- Stage 1 Aerobic: dose 24 times per day for 2 to 3 min.
- Initial hydraulic loading at 2 gal./ft²-day
- Stage 2 Anoxic: receives gravity flow
- Operate and monitor over 60 days
- Temperature, pH, alkalinity, DO, TKN, (NO₃+NO₂)-N, SO₄ (Stage 2)

Lab Column Configuration

Unsaturated filter

Flow, gpd/ft ²	2.00
Diameter, inch	4.00
Media depth, inch	24.0
Flow, gal/day	0.174
Flow, ml/hour	27.5
Time for 250 ml sample, hour	9.1
Doses/day	24
Flow, ml/dose	27.5
Empty bed volume, liter	4.9
Resident water volume, liter ¹	0.37
Single dose vol. / resident water vol.	0.07
Average water residence time, hour	13.5

¹Assumes 50% pore space, 15% of pore space filled with water

Saturated filter

Diameter, inch	1.50
Media depth, inch	24.0
Flow, gal/day	0.174
Flow, gpd/ft ²	14.22
Flow, ml/hour	27.5
Time for 250 ml sample, hour	9.1
Empty bed volume, liter	0.7
Pore volume, liter ¹	0.28
Average residence time, hour	10.1
¹ Assumes 40% pore space	

Comments/questions

- Literature review and database
- Laboratory studies

Biochemical Transformations

