Passive Wastewater Nitrogen Removal
Layer Cake / NRB / PNR
vs
2 Stage Biofiltration

6th Northeast
Onsite Wastewater Treatment Short Course
and Equipment Exhibition

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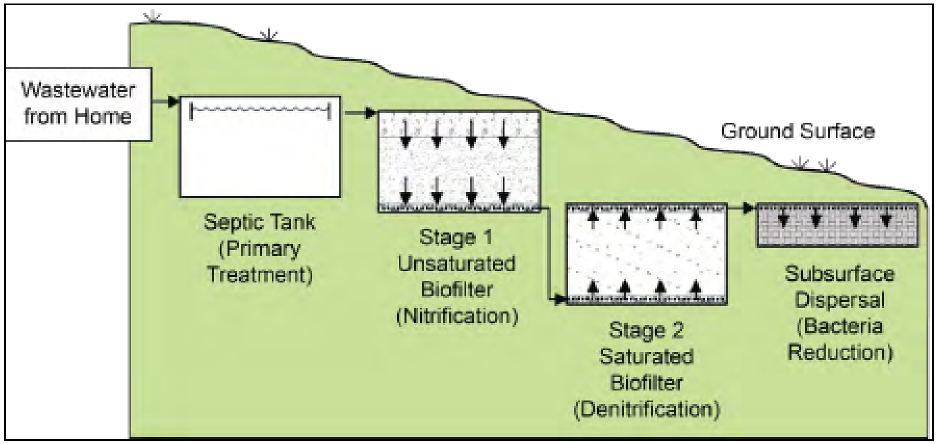


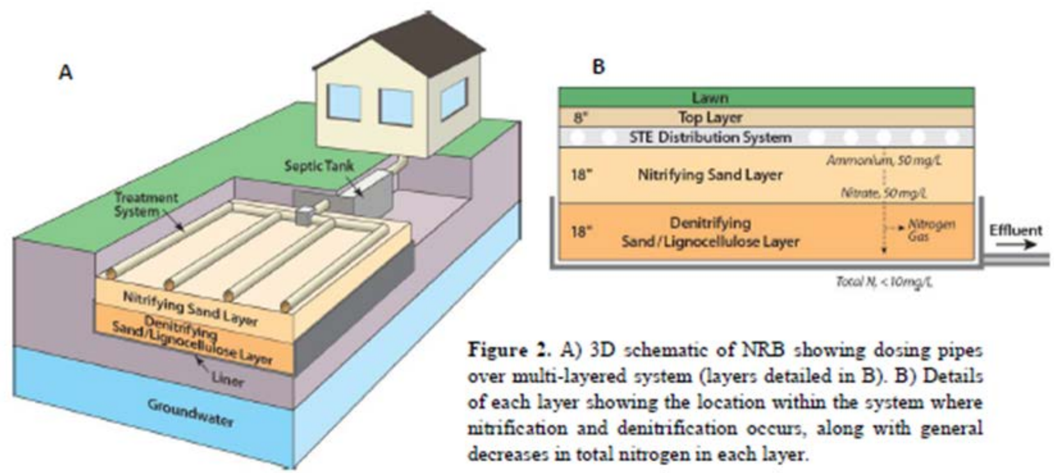


Figure 2. A) 3D schematic of NRB showing dosing pipes over multi-layered system (layers detailed in B). B) Details of each layer showing the location within the system where nitrification and denitrification occurs, along with general decreases in total nitrogen in each layer.

Septic Tank Effluent Quality

Organic Nitrogen ~ 5 mg/L
Ammonia Nitrogen ~ 60 mg/L

Nitrogen Removal Mechanisms

Organic Nitrogen $\rightarrow$ Ammonia - NH_4^+

Ammonia NH_4^+ $\rightarrow$ Nitrite -NO_2^- $\rightarrow$ Nitrate NO_3^-

The reactions for ***Nitrification*** are:

Organic Nitrogen $\rightarrow$ NH_4^+ by ammonifying bacteria

$$NH_4^+ + 1.5\ O_2 + 0.05\ CO_2 \rightarrow 2\ H^+ + H_2O + NO_2^-$$

by Nitrosomonas bacteria

$$NO_2^- + 0.5\ O_2 + 0.03\ CO_2 \rightarrow NO_3^-$$

by Nitrobacter bacteria

Heterotrophic (organism requiring organic compounds for its principal source of food) ***Denitrification*** (using labile carbon for electron transfer) reaction is:

$$6NO_3^- + 5CH_3OH + H_2CO_3 \rightarrow 3N_2 + 8H_2O + 6HCO_3^-$$

Sulfur is used for autotrophic (organism capable of synthesizing its own food from inorganic substances) denitrification

Context - Why OWTS Nitrogen Management

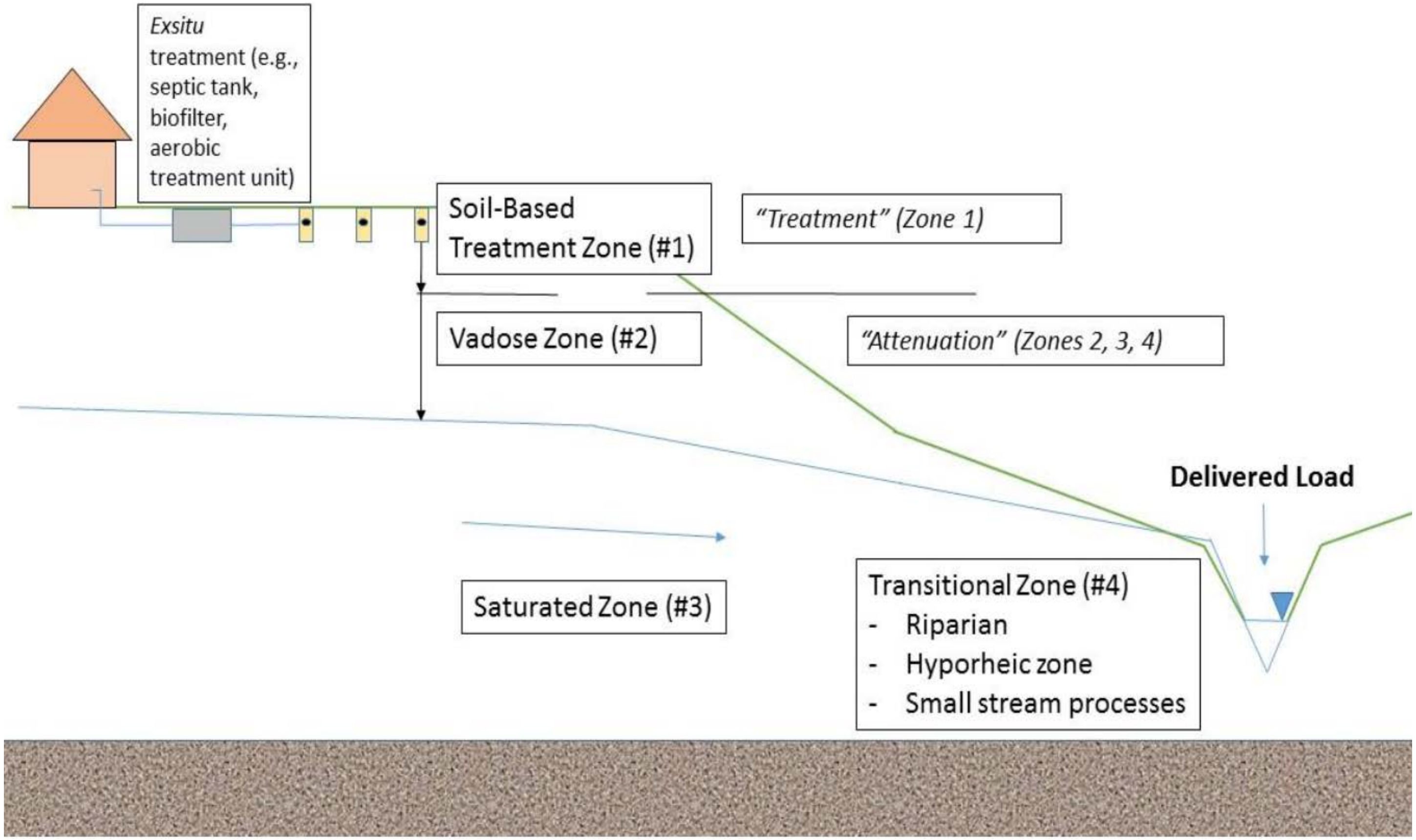
- ✓ TMDL Requirements in Estuarine Waters to Prevent Seriously Damaging Eutrophication
  - Water Quality conc. 0.035 mg/L TN max
  - < 50-kg-N/ha/yr for critical seagrasses to thrive
    > 100-kg-N/ha/yr Typically do not support stable eelgrass

- ✓ NE Locations where Septic N Primary Contributor to Significant Water Quality – Aquatic Ecosystem Impairments
  - Long Island Sound
  - Cape Cod & Buzzards Bay – in particular southern coastal watersheds
  - Martha's Vineyard & Nantucket
  - Long Island Embayments

- ✓ Why occurring
  - More people than ecosystem can support with reliance on conventional septic systems
  - Devasting impacts – loss of aquatic resources and toxic algae production

Septic Nitrogen Delivery to Surface Waters – Four Transformation Zones

Methodology developed and used by the US EPA Chesapeake Bay Program



Septic Nitrogen Delivery to Surface Waters

- ✓ Conventional Septic System
  - ✓ STE TN 60 – 65 mg/L
    - increase from historical 40 mg/L due to use of water conserving devices
    - 10 - 12 +/- lbs/person-year
- ➢ Soils Attenuation – Zone 1

					Chesapeake Bay Study				
Soil Textural Class No.	Soil Textural Class	Loading Rate			TN reduction for specified depth to groundwater (DGW) and actual hydraulic loading rate (HLR) applied				
		(cm/day)	(in/day)	gpd/sf	DGW	30 cm		60 cm	
					HLR	100%	50%	100%	50%
1	Sand	4	1.6	1.0		7%	16%	16%	31%
2	Loamy Sand	4	1.6	1.0					
3	Sandy Loam	3	1.2	0.7					
4	Loam	3	1.2	0.7					
5	Silt Loam	1.8	0.71	0.44		11%	30%	34%	59%
6	Clay loam	1.8	0.71	0.44					
7	Sandy clay loam	1.8	0.71	0.44					
8	Silty clay loam	1.8	0.71	0.44					
9	Silt	1.8	0.71	0.44					
10	Silty clay	1	0.39	0.25		29%	54%	54%	80%
11	Clay	1	0.39	0.25					

Septic Nitrogen Delivery to Surface Waters

- Vadose Attenuation – Zone 2
  - Considered insignificant by CBP Experts

- Hydrogeomorphic Attenuation – Zone 3

Hydrogeomorphic Region[1]	Relative TN Transmission Classification	Recommended Zone 3 Attenuation Factor (Transmission Factor)
Fine Coastal Plain - Coastal Lowlands	Low	75% (25%)
Fine Coastal Plain - Alluvial and Estuarine Valleys	Low	75% (25%)
Fine Coastal Plain - Inner Coastal Plain - Upland Sands and Gravels	Medium	60% (40%)
Fine Coastal Plain - Middle Coastal Plain – mixed sediment texture	Medium	60% (40%)
Fine Coastal Plain - Middle Coastal Plain – fine sediment texture	Low	75% (25%)
Coarse Coastal Plain - Middle Coastal Plain – Sands with Overlying Gravels (also dissected)	High	45% (55%)
Coarse Coastal Plain - Inner Coastal Plain - Dissected Outcrop Belt	High	45% (55%)
Crystalline Piedmont	High	45% (55%)
Crystalline Blue Ridge	High	45% (55%)
Carbonate Piedmont	Very High	35% (65%)
Carbonate Valley and Ridge	Very High	35% (65%)
Carbonate Appalachian Plateau	Very High	35% (65%)
Siliciclastic Mesozoic Lowland	High	45% (55%)
Siliciclastic Valley and Ridge	Medium	60% (40%)
Siliciclastic Appalachian Plateau	Low	75% (25%)

  - Use surficial geology as a surrogate when not in Chesapeake Bay watershed

Septic Nitrogen Delivery to Surface Waters

- Transitional Zone Attenuation – Zone 4
  - Site Specific not addressed by CBP Expert Panel
  - MEP uses attenuation
    - Ponds – up to 50%
    - Streams – up to 30%

OWTS Treatment Technologies
Total Treatment / Disposal Nitrogen Removal Capabilities

System Type	Onsite System Category	Flow	Eff. TN Conc. Prior to Disposal	% Disposal System Attenuation	Effluent TN Conc. to GW	Total % N Removal
		(gpd)	*(mg/L)*	*(%)*	*(mg/L)*	%
Standard Leaching Pool System						
1	Standard Septic Tank / Leaching Pool System	225	65	25%	48.75	25%
1	Suspended Growth	225	25	15%	21.25	67%
2	IFAS	225	25	15%	21.25	67%
3	Fixed Film	225	19	15%	16.15	75%
Secondary System with Nutrient Removal						
4	Carbon Feed & PreTreat	225	3	5%	2.85	96%

What is appropriate requirement for OWTS Nitrogen Discharge Quality?

- ✓ Watershed Specific
- ✓ Cost effectiveness needs to be integrated
- ✓ Not unusual for requirement to be 90+% Septic N Removal
  - Used to justify sewer projects

- Most Watersheds on LI, Cape Cod/ SE MA/Islands have sandy soils that provide little attenuation– cumulative to surface water<15 % - 25%

What is appropriate requirement for OWTS Nitrogen Discharge Quality?

Historical Practice per 1972 Water Pollution Control Act and subsequent Amendments and Updates

- ✓ Water Quality Impaired Water Bodies
  - Best Available Technology (BAT) required to be used
    - In other words, can't make pollution worse
  - Currently in some locations for larger projects, No Net Nitrogen Contribution strongly suggested

- Regulation of OWTS Nitrogen Requirements in NE in particular has been based predominately, if not exclusively, on technological capability of multiple technologies (with a low bar, i.e. effluent TN < 19 mg/L) – not water quality – public health protection

Technology Focus

- Watersheds requiring / needing 90+% Septic TN Removal
- Sewer Equivalency for TN Removal
  - Limits of Technology considered to be 3 mg/L
- Passive
- Low O&M

Technology History

- Scientific Basis Discovered by world class University of Waterloo hydrogeologists as part of research on septic systems funded by P&G
- Identified mechanisms for nitrogen removal in subsurface environment
  - Drainfields achieve complete nitrification
  - Septic plumes encountering groundwater with labile carbon achieve complete denitrification
- Published in peer review journals in 1995
- Patented System
  - Layered technique
  - Two stage technique

Applications / Commercialization History - Two stage system

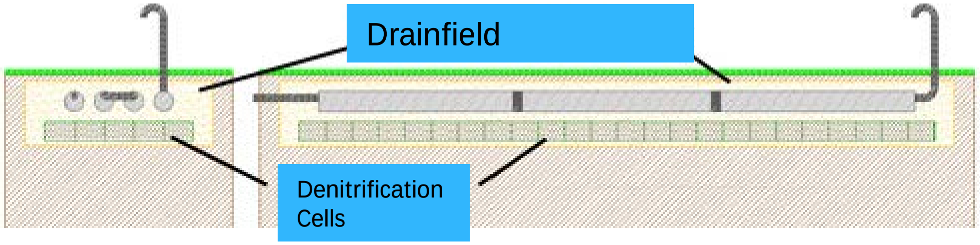
- Two stage system (completely passive – no pumps) installed and monthly monitoring by State for 2 sites at LaPine OR – effluent average TN 2.2 mg/L - 2000
- Two stage system (completely passive – no pumps) installed and monthly monitoring by State for 2 sites at Montana – effluent average TN 2.2 mg/L - 2001
- Two stage system (completely passive – no pumps) tested at MASSTC 2001 – 2004 – effluent average TN 4.1 mg/L
- US Residential and Commerical Installations starting in 2004
- FL DoH Residential Instal Testing 2012 effluent average TN 4 mg/L
- Suffolk County NY Testing 2013 effluent average TN 1.58 mg/L
- Permitted for < 10 mg/L in Oregon, AZ, CA, FL, VA, NY, RI, MA

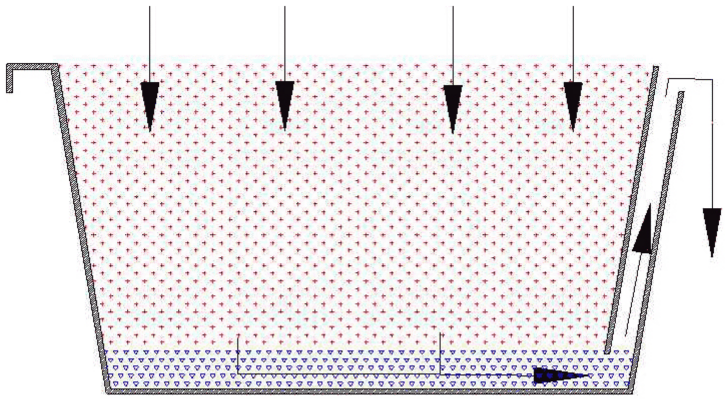
2 stage System Passive Nitrogen Removal System - Performance			
Site #	Location	Nitrex™ Effluent Total	Total Nitrogen
1	2950 Beacon Court, Lusby, MD	1.97	96.7%
2	6500 Long Beach Drive, St. Leonard, MD	2.80	95.3%
3	6586 Long Beach Drive, St. Leonard, MD	2.95	95.1%
4	18040 Barnesville Road, Barnesville, MD	4.20	93.0%
5	1933 Clifton Road, Virginia Beach, VA	3.26	94.6%
6	Dana Drive, Crawfordville, FL	5.30	91.2%
7	Mashpee, MA Main St Villages	3.00	94.6%
8	Eastham, MA Bracket Landing	2.03	95.5%
9	Suffolk County NY Environmental Center	3.39	96.6%
10	Bogue Sound Elementary & Croatan High School, Newport NC	2.57	97.6%
11	Malibu Village Plaza Malibu, CA	2.04	96.9%
12	Stone Residence LaPine, OR	2.20	96.1%
13	Fleming Residence LaPine, OR	2.65	96.1%
14	St. Ignatius, MT for MT Dept of Natural Resources	3.40	92.6%
15	Massachusetts Alternative Septic System Test Center, Cape Cod MA	4.50	88.5%
16	Harvard MA - 2 SFR	2.60	97.4%
	AVERAGE OF ALL SYSTEMS	3.05	94.9%

Applications/Commercialization History–Single stage system

- Testing on Cape Cod – 1999. System failure due to contractor installation problems

- MADEP Permitted in 2007 – no requests for use as no regulations requiring high N removal levels


Drainfield
Denitrification Cells



MASSTC Recent Investigations of Passive Nitrogen Removal Strategies

MASSTC tested versions of the FLDOH & NRB technique

MASSTC (2017) tested five full scale (220 gallon/day) systems using four concepts:

Design 1 - A saturated system -loamy sand as a nitrifying layer;

Design 2 - Operation of the above following replacement of the loamy sand with ASTM C33 Sand

Design 3 - A saturated system as directly above installed with support from Stony Brook University and substituting "Long Island Sand" for the sand in both layers and "Long Island mulch" as a substitute for sawdust (MASSTC Report figure 4 on Figure 3-6 modified as described);

Design 4 -A nitrification layer underdrained and diverted to a box of woodchips

Design 5 - An unsaturated system similar in dimensions to the silty-sand – sawdust system reported in Project 14-01 319

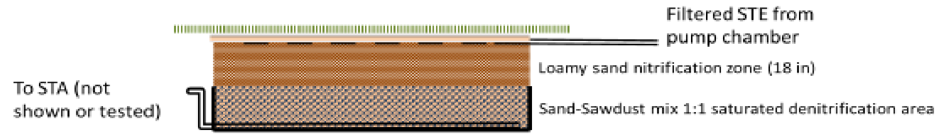


Figure 3. Saturated denitrification system design using a containment liner. Note the nitrifying layer is a loamy sand (60-440 Sand/soil, New England Specialty Soils, 435R Lancaster St Leominster, MA 01453). STA = Soil Treatment Area or leaching facility, STE = Septic tank effluent. DESIGN 1

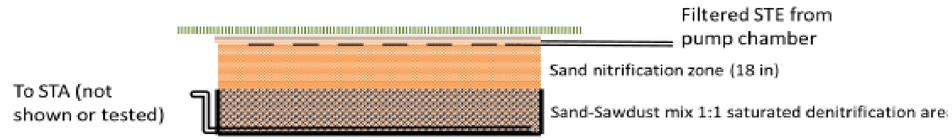


Figure 4. Saturated denitrification system design using containment liner. Note that nitrifying layer uses ASTM C-33 Sand (design 2) or sand provided by Stony Brook University and originating from Long Island, New York. STA = Soil Treatment Area or leaching facility, STE = Septic tank effluent. DESIGN 2 and DESIGN 3

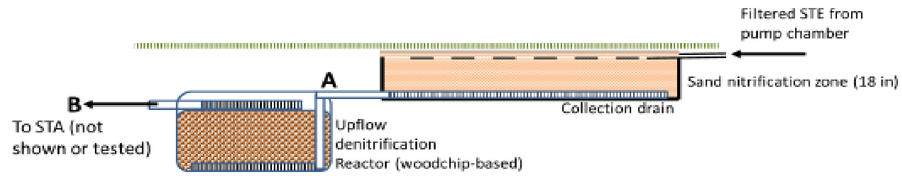


Figure 5. Denitrifying configuration with nitrifying STA percolate diverted through a container of lignocellulose. STA = Soil Treatment Area or leaching facility, STE = Septic tank effluent. A and B denote sampling locations. DESIGN 4

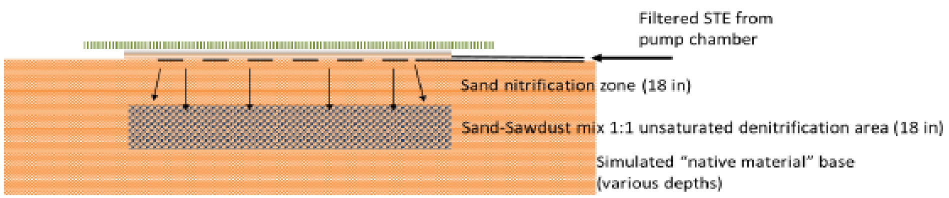


Figure 6. Unsaturated system design constructed in sand provided by Stony Brook University and originating from Long Island, New York. STE = Septic tank effluent. DESIGN 5

N Removal Performance Comparison

Cost Comparison

Risk Issues

Questions / Discussion

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