

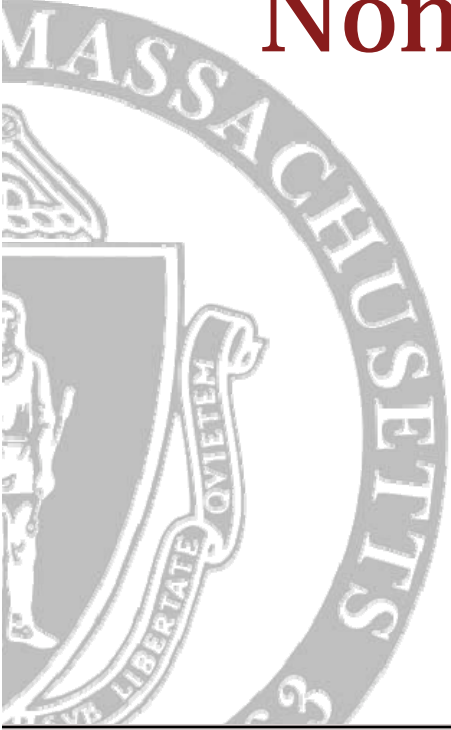


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## Bioretention Systems for Control of Non-Point Sources of Nitrogen

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# Bioretention Systems for Control of Non-Point Sources of Nitrogen



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Ryan Siegel, Yifu Yao and Arka Pandit

## Eutrophication assessment (NOAA, 1999)

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- Moderate to high eutrophication in 65% of estuary surface area studied.
- Most prevalent - Gulf of Mexico and Mid-Atlantic.
- Human influence
  - fertilizers
  - animal wastes
  - wastewater effluent
  - stormwater runoff
  - CSOs
  - atmospheric deposition



## Consequences of high nitrogen discharges

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- Undesirable growth of plants and algae.
- Nuisance and toxicity of algal mats and blooms
- Submerged aquatic vegetation decline.
- Turbidity, dissolved oxygen (DO) depletion and hypoxia,
- Decimation of commercial finfish and shellfish harvests
- Drinking water contamination – blue baby syndrome.

## Stormwater structural Best Management Practices\*

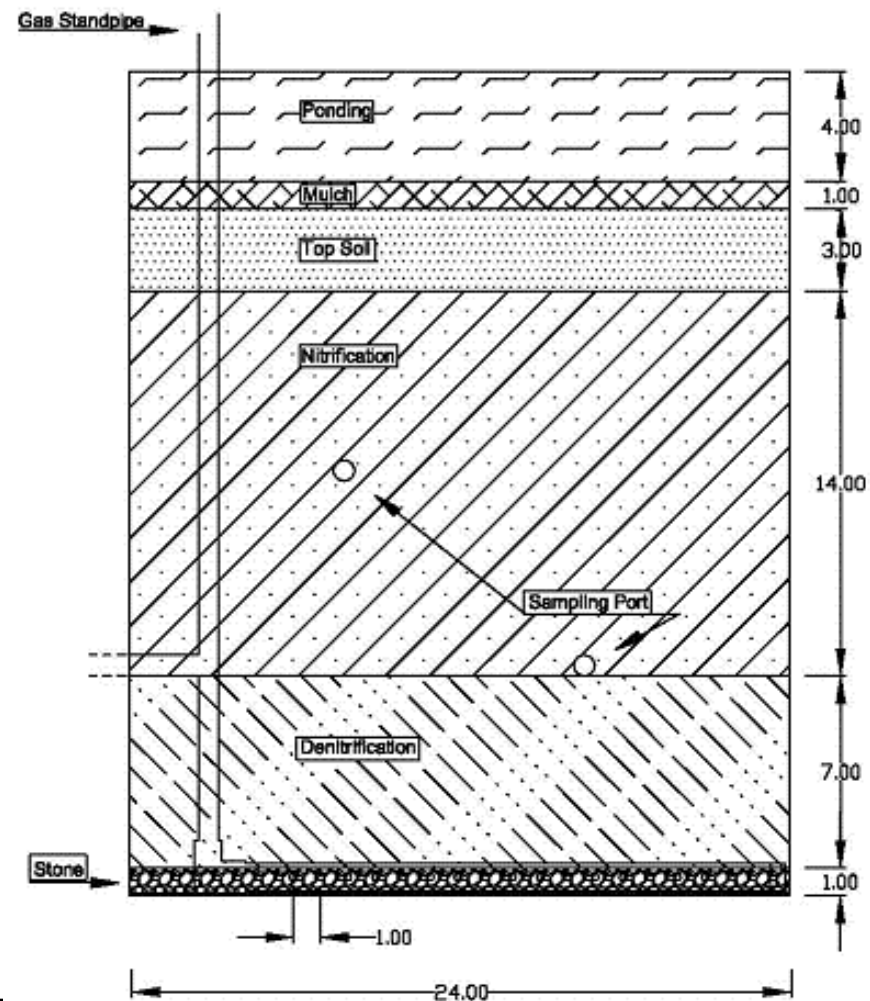
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- Swales
  - Wetlands
  - Infiltration basins
  - Media filters
  - Porous pavement
  - Bioretention systems
- Data available on flow reduction, travel time delays, solids and organics removal
  - Little data on nutrient removal
  - Conventional bioretention systems:
    - 70-85% P, 55-65% TKN, < 20%  $\text{NO}_3^-$  / $\text{NO}_2^-$

\*UNH stormwater center 2007 annual report

## Denitrifying bioretention system

- Water slowly infiltrates through soil/mulch layer
- Nitrification in aerobic sand layer
- Denitrification in submerged layer supplied with solid substrate



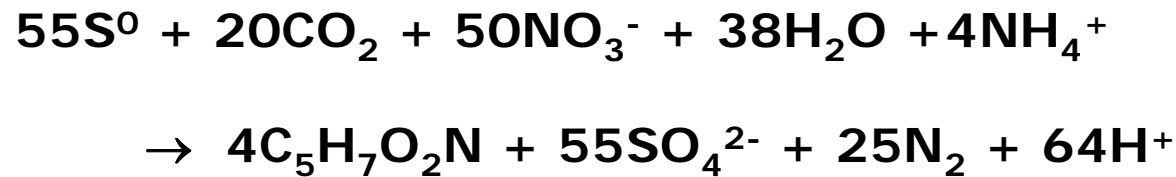
## Heterotrophic denitrifying bioreactor

**Organic carbon + NO<sub>3</sub><sup>-</sup> + H<sup>+</sup> ⇒ N<sub>2</sub> + CO<sub>2</sub> + H<sub>2</sub>O + new cells**

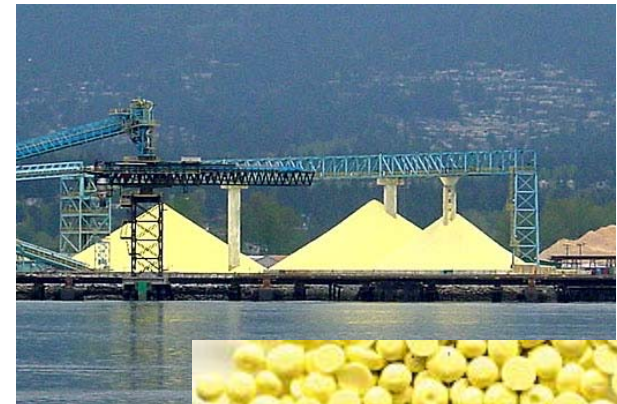
- Organic electron donor
- Wood chip/sand mixture
- Presby Environmental - De-Nyte™
- NO<sub>3</sub><sup>-</sup> electron acceptor
- Process generates alkalinity
- High growth and denitrification rates



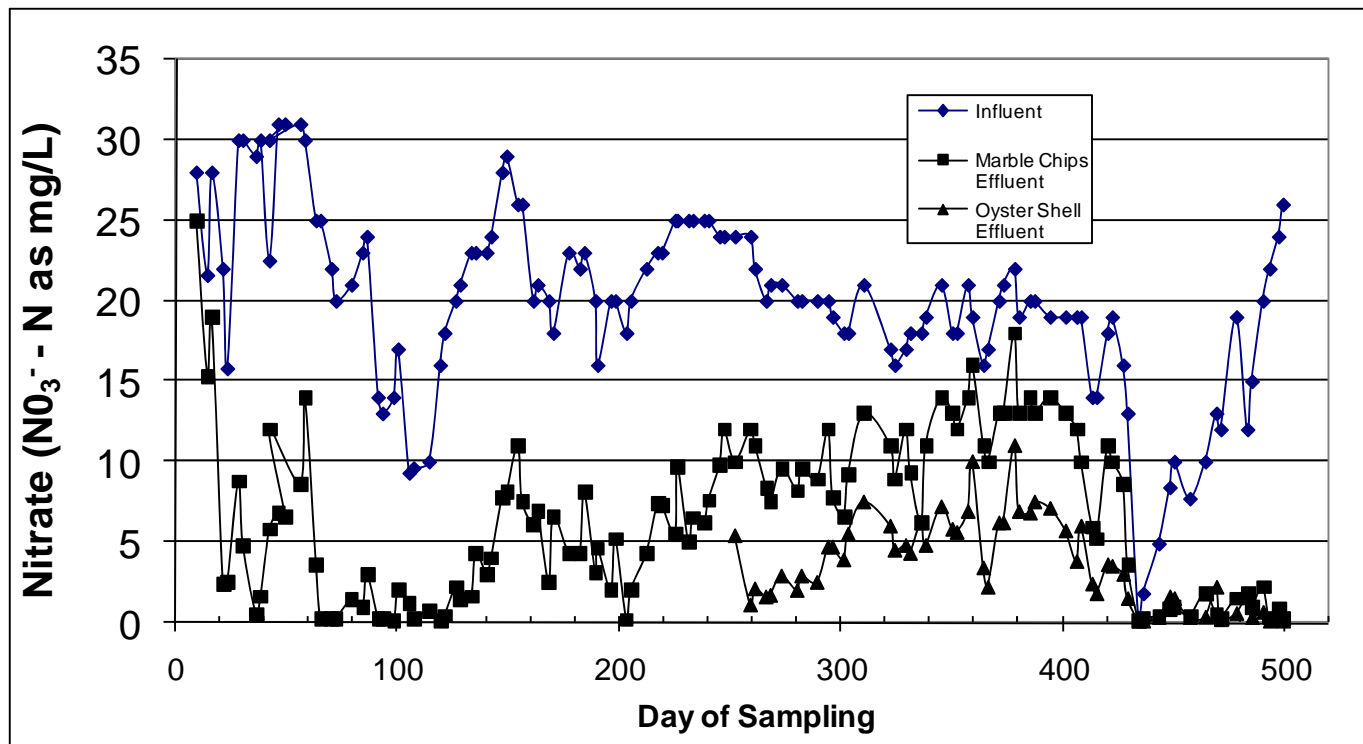
## Novel denitrifying process utilizing sulfur



- Readily available
- Autotrophic metabolism
- Low biomass generation
- Excellent packing material
- Process consumes alkalinity

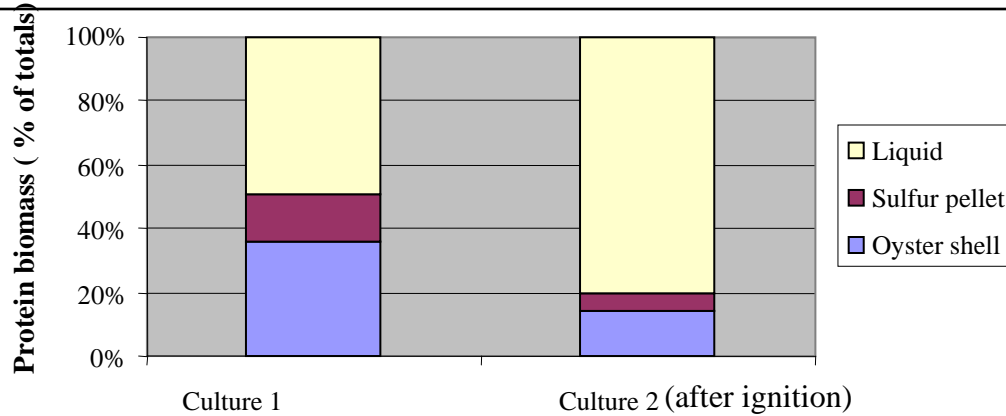


## Prior results: Alternative septic system test center

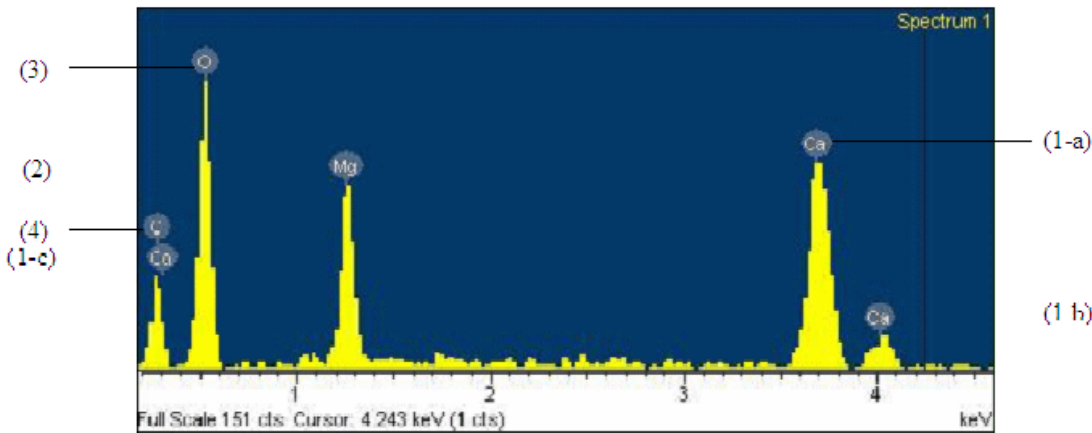
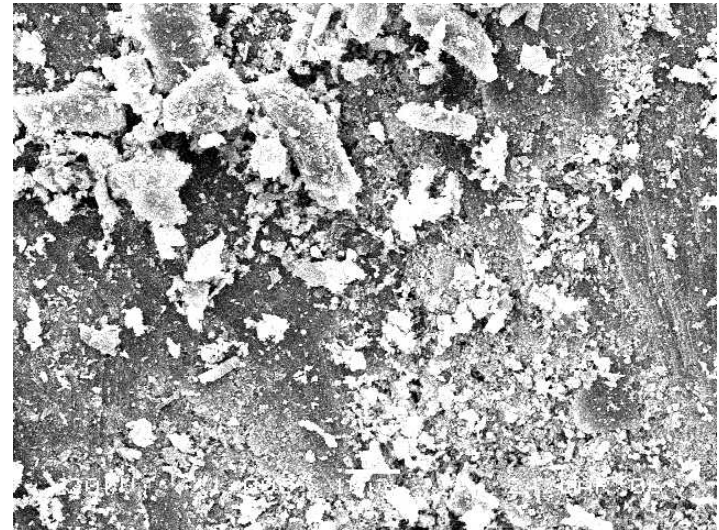


- High denitrification rates
- Stable performance – little maintenance required
- Oyster shells improved performance

# Oyster shells?



Biomass: pore water > oyster shells > sulfur



- μm sized CaCO<sub>3</sub> particles in scleroprotein matrix.
- High rate of alkalinity release seen in S<sup>0</sup> oxidizing denitrification studies

## Methods: Laboratory storm events

### Feed Composition

$\text{NO}_3^-$ -N	2 mg/L as N
$\text{NH}_4^+$ -N	2 mg/L as N
Organic N	4 mg/L as N
$\text{HPO}_4^{2-}$	0.6 mg/L as P

### Application

**Rate**                      **4 ml/sec**

### Application

**Duration**                      **6 hrs**

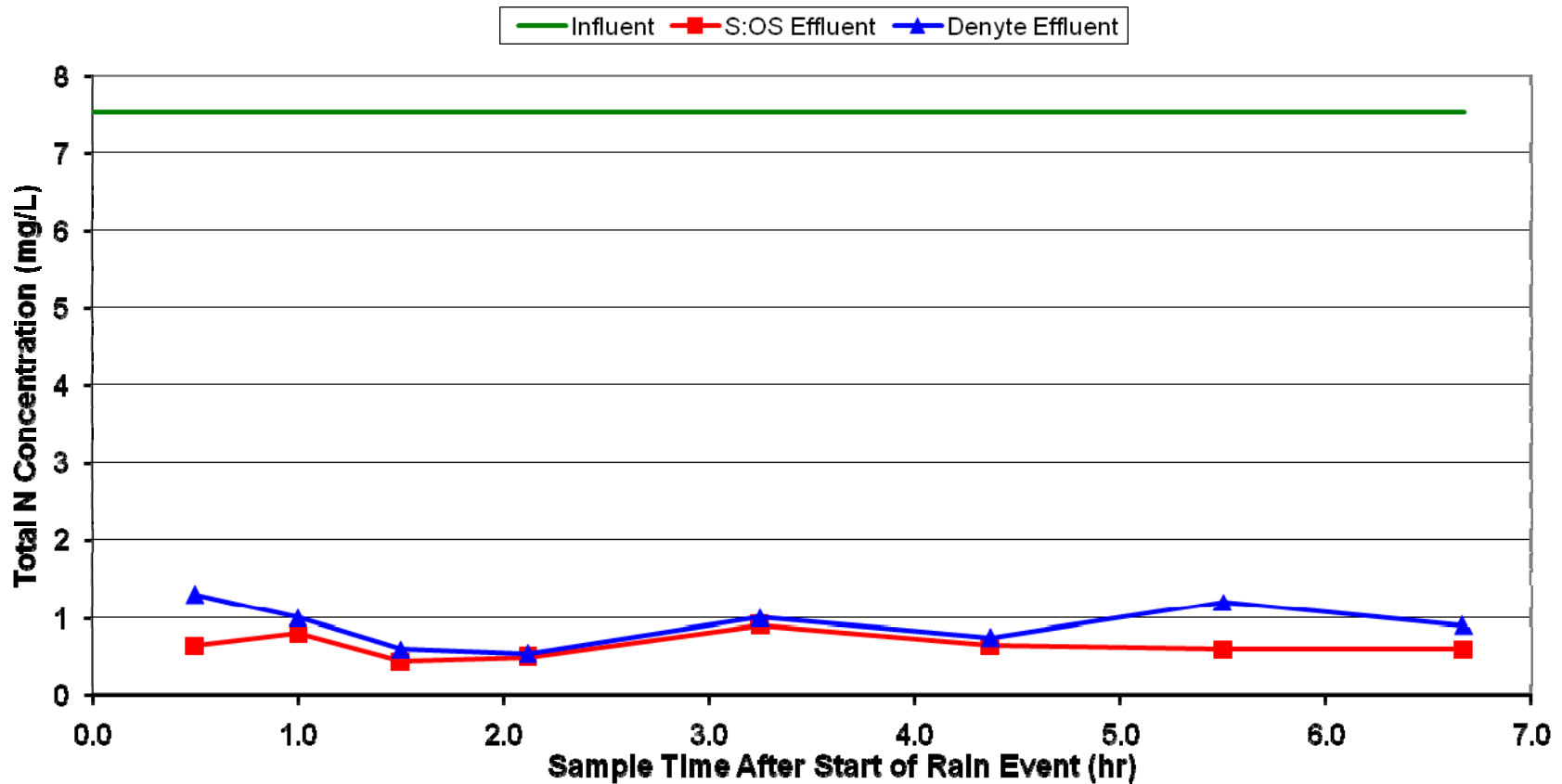
### Total Applied

**Volume**                      **86.4 L**

- Feed – literature values based on urban runoff (Davis *et al.*, 2001; Hsieh and Davis, 2005)
- Application – average W Mass storm event & 5% bioretention surface area
- Influent & effluent: pH, TALK, BOD, COD, TSS, VSS, TN,  $\text{NH}_4^+$ ,  $\text{NO}_3^-$ ,  $\text{NO}_2^-$

# Total N removal in simulated storm event

Simulated Rain Event #3: Total Nitrogen Concentration vs. Sample Time



## Nutrients: Simulated storm event

Analyte	Influent	Denyte	Sulfur/OS	Units
pH	7.08	6.7	7.60	
Alkalinity	10.5	280	163.3	mg/L as CaCO <sub>3</sub>
NO <sub>3</sub> <sup>-</sup> -N	1.93	ND	ND	mg/L as N
NH <sub>4</sub> <sup>+</sup> -N	3.52	0.3	0.5	mg/L as N
PO <sub>4</sub> <sup>3-</sup> -P	2.4	0.1	0.2	mg/L as P
SO <sub>4</sub> <sup>2-</sup>	1.4	2	48.9	mg/L SO <sub>4</sub> <sup>2-</sup>

- Excellent N and P removal similar to those observed in other studies.

## Organics, solids: simulated storm event

Analyte	Influent	Denyite	Sulfur/OS	Units
COD	13	88	61	mg/L
BOD <sub>5</sub>	7	29	13	mg/L
TSS	<1	8	2	mg/L
VSS	<1	8	2	mg/L

- Some generation of organics and solids due to leaching from organic material, production of soluble microbial products.

## Impaired water bodies in Little River watershed

Segment Name	Location	Impaired Use	Cause	Potential Source
Roseland Lake	Southeast Woodstock	Primary & Secondary Contact Recreation	Exotic species, Noxious plants	Source unknown
Little River	Mouth to diversion	Primary Contact Recreation	Indicator bacteria	Source unknown
Muddy Brook	Between Rte 197 & Rte 169	Aquatic Life Support	Cause unknown	Agriculture, Source unknown
North Running Brook	0.3 miles upstream from mouth at Muddy Brook	Aquatic Life Support	Cause unknown (possible organic enrichment/low DO, nutrients)	Agriculture, Crop-related sources

### CT DEP: Quinebaug watershed data

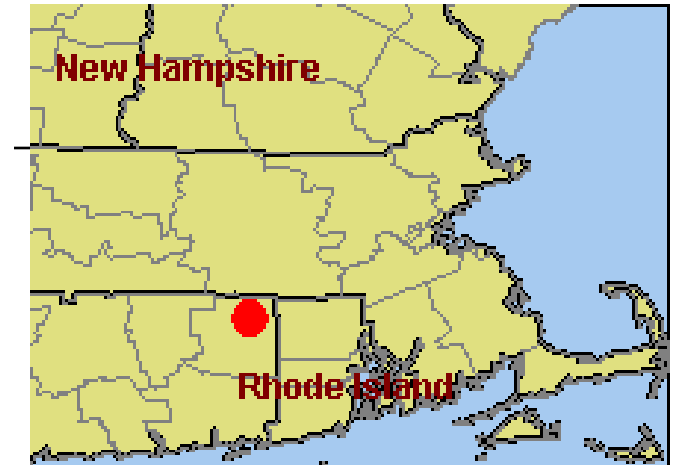
## North central CT agricultural basin (Broad Brook)

Land Use	N load to water table lbs (2002)
Developed	14,200
Turf and Grass	470
<b>Other grasses and agriculture</b>	<b>137,000</b>
Forest and wetland	1,450
Utility right of way and barren land	970

USGS data from Mullaney, 2007

## Field Site: Putnam CT

- Dairy farm in Putnam, CT
- Runoff from barn conveyed to detention pond
- Reactors used to treat detention pond water



## Lagoon characteristics

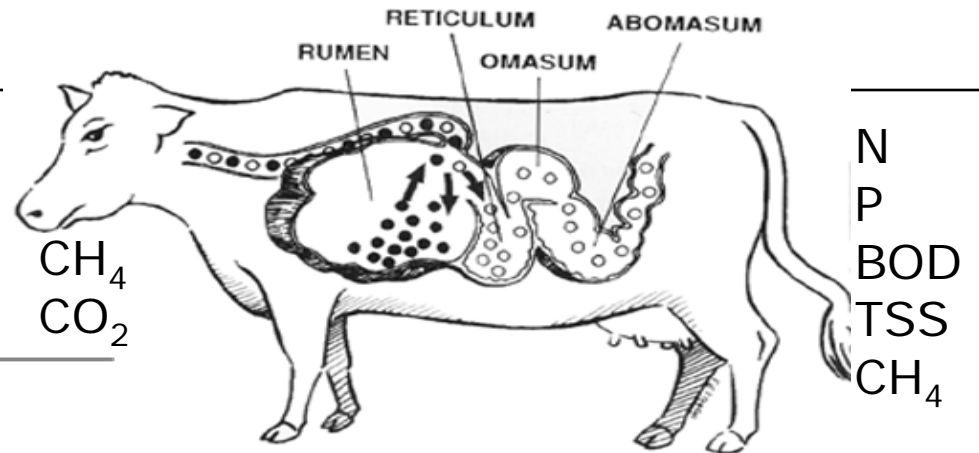
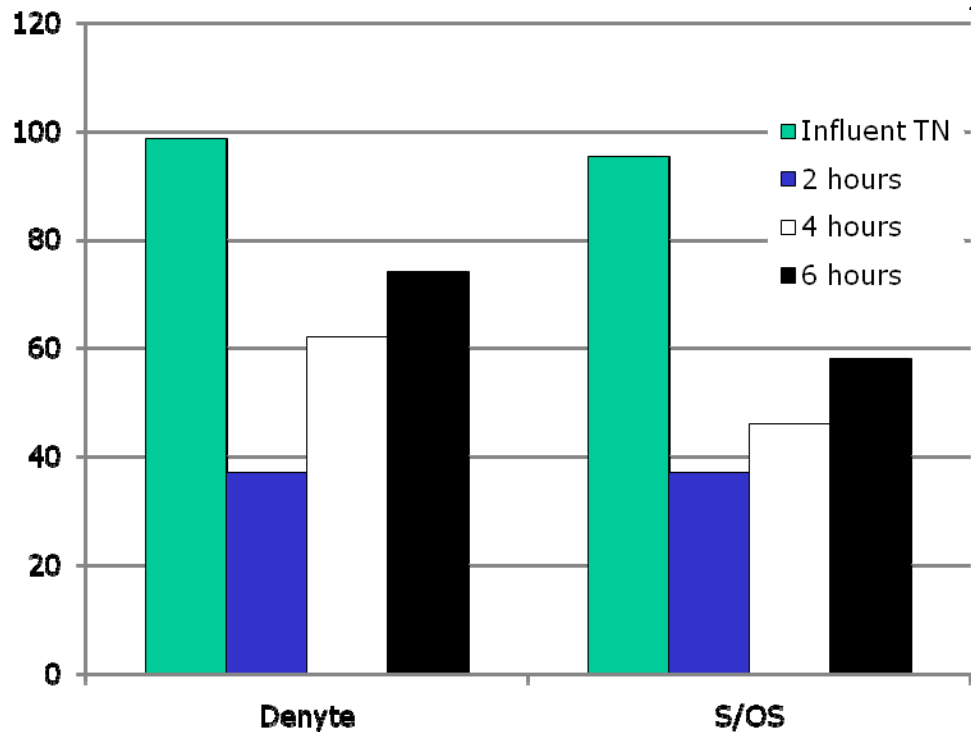
### Average Detention Pond Composition

pH	7.8
TN	90 mg/L
NO <sub>3</sub> <sup>-</sup> -N	ND
NH <sub>4</sub> <sup>+</sup> -N	22 mg/L
PO <sub>4</sub> <sup>-2</sup> -P	27 mg/L
BOD <sub>5</sub>	200 mg/L



# Total N removal

Concentration of TN over time during typical field test



[www.newtonsapple.t](http://www.newtonsapple.t)  
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## Field tests – nutrients

Analyte	Influent	Denyte	Sulfur/OS	Units
pH	7.9	6.5	7.0	
Alkalinity	890	615	470	mg/L as CaCO <sub>3</sub>
NO <sub>3</sub> <sup>-</sup> -N	ND	ND	ND	mg/L
NO <sub>2</sub> <sup>-</sup> -N	ND	ND	ND	mg/L
NH <sub>4</sub> <sup>+</sup> -N	22	9.3	8.4	mg/L
Total N	99	58	47	mg/L
PO <sub>4</sub> <sup>3-</sup> -P	28.8	ND	ND	mg/L
Total P	53	20	17	mg/L
SO <sub>4</sub> <sup>2-</sup>	27	22	440	mg/L

## Field results – organics, solids

Analyte	Influent	Denyite	Sulfur/OS	Units
COD	1216	790	695	mg/L
BOD <sub>5</sub>	144	95	50	mg/L
TSS	252	68	31	mg/L
VSS*	222	55	25	mg/L

\* Approximately 56% TN, 14% TP and 55% COD removal due to removal of solids

- Hydrolysis of dissolved and particulate organic N appears to be rate limiting.
- Current research focused on pretreatment to remove organic C, and hydrolyze organic N.

## Conclusions

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- Initial steps taken in developing a low cost, low maintenance, passive system for total N removal in stormwater.
- Laboratory results indicate >90% TN removal achievable for runoff from developed land, fertilized fields
- Treatment of runoff from livestock operations challenging – low rates of organic N hydrolysis
- Bench scale tests currently focused on increasing ammonification rates

## Acknowledgements

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