Low Cost Biofilters for Onsite Wastewater Nitrogen Removal

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UNIVERSITY of SOUTH FLORIDA

Hazen

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PRESENTATION OVERVIEW

- Nitrogen impacts to water quality
- Nitrogen reducing biofilters (NRBs): Florida DOH studies & lessons learned
- Groundwater quality improvements
- Hybrid Adsorption Biological Treatment Systems (HABiTS) Research at USF
- University-Utility Partnerships
- Q & A

NITROGEN IMPACTS TO WATER QUALITY

ADVERSE EFFECTS OF NITROGEN

- **Public Health:**
  - SDWA Limit 10 mg/L NO_3 – N, HABs
- **Ecosystem Health:**
  - N limiting nutrient in many water bodies
  - Algal blooms, loss of habitat, hypoxia

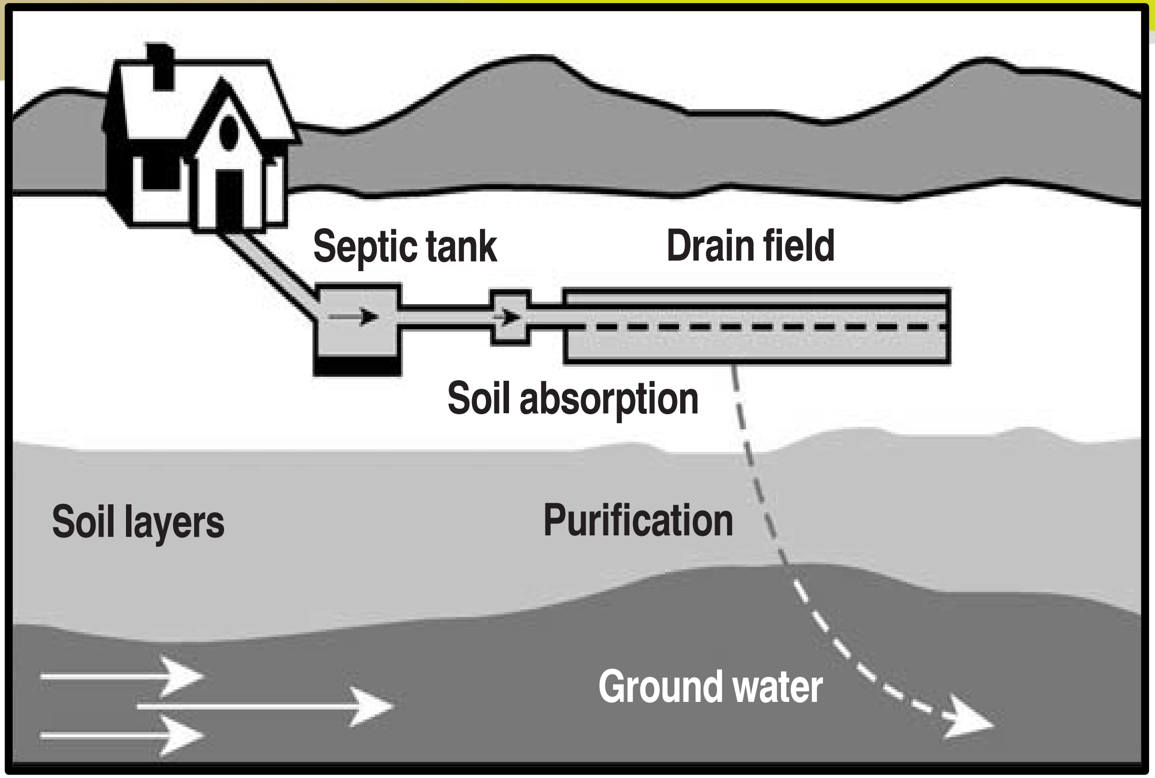
- **Impacts of excess nitrogen on water quality have been documented in many areas:**
  - Cape Cod, Long Island Sound
  - Chesapeake Bay
  - Puget Sound
  - Tampa Bay, Sarasota Bay
  - Florida Keys
  - Florida's Freshwater Springs
  - Many other places

WATER QUALITY PROBLEMS FOR FLORIDA'S FRESHWATER SPRINGS…

Photos courtesy of John Moran - SpringsEternalProject.org

N LOADING IS A WATER QUALITY CRISIS IN SOME AREAS

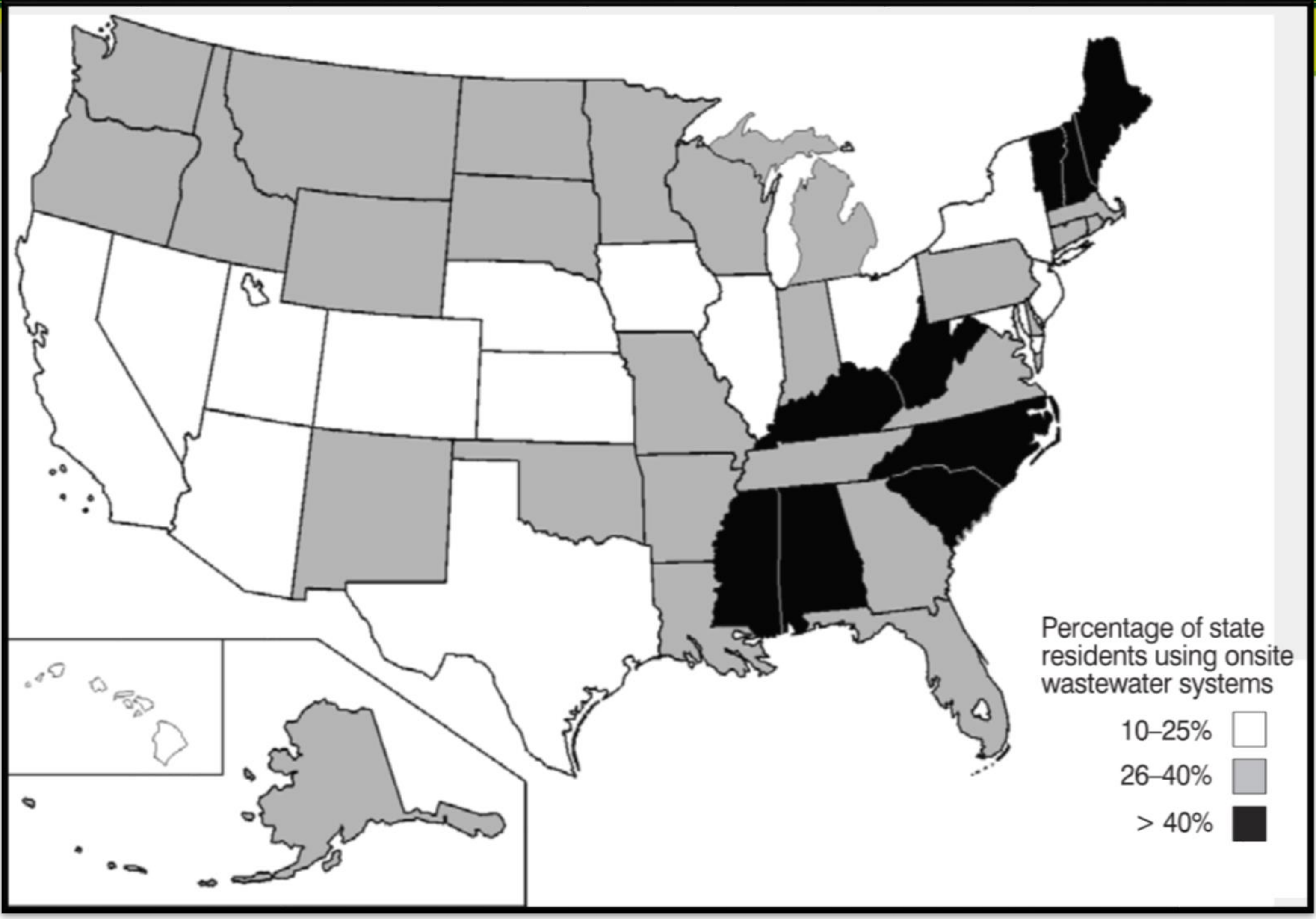
CONVENTIONAL ONSITE WASTEWATER TREATMENT SYSTEMS (OWTS)



Conventional OWT (USEPA, 2002)

- Advantages:
  - Low cost for suburban & rural areas
  - Low chemical & energy use
  - Good treatment performance (BOD, TSS, fecal indicator bacteria)
  - Groundwater recharge, onsite reuse
- Problems:
  - Limited nitrogen reduction
  - Lack of O & M
  - Variable loads, long idle periods.

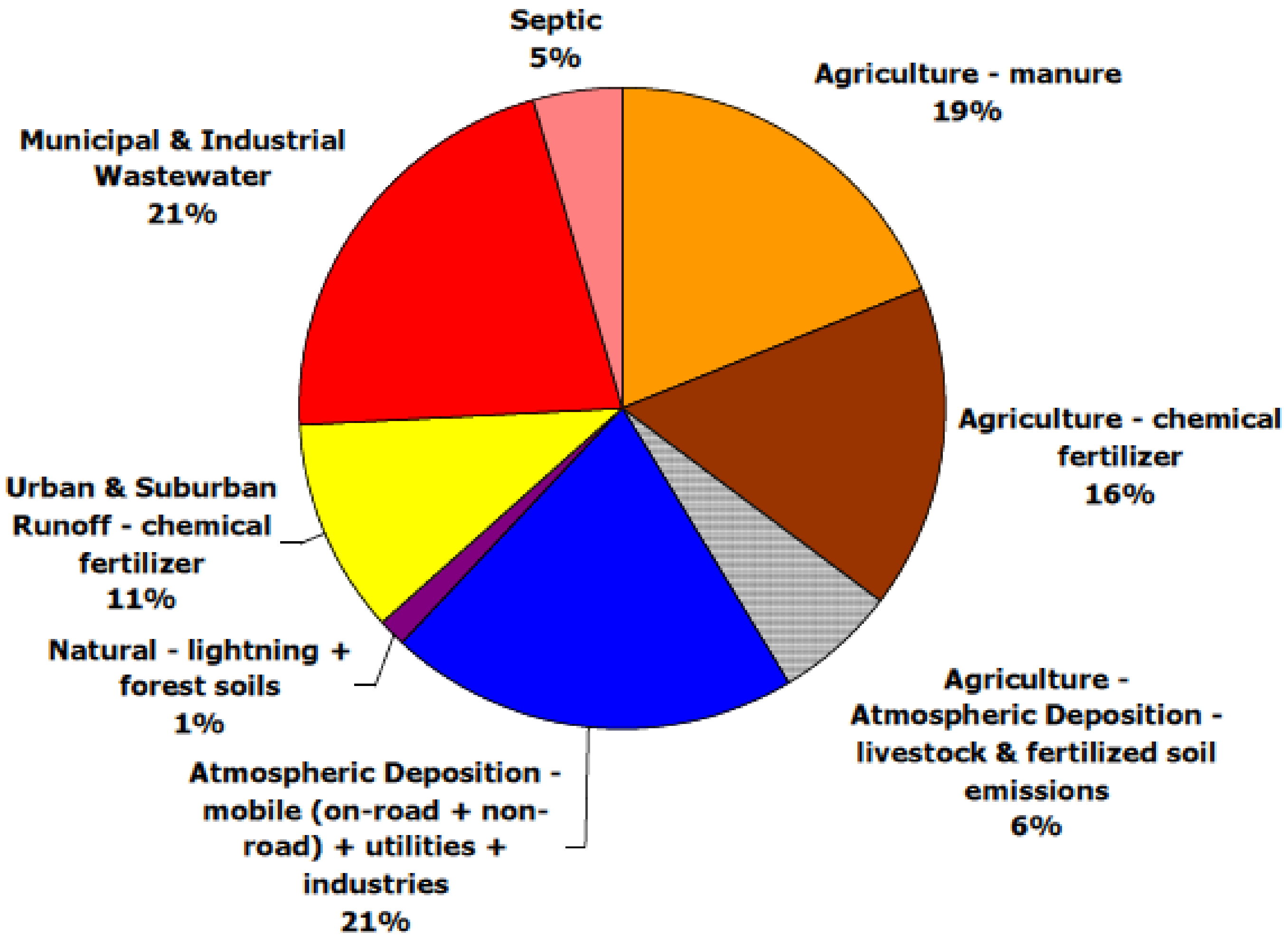
PERCENTAGE OF HOMES WITH OWTS



Percentage of state residents using onsite wastewater systems ~23% nationwide (USEPA, 2002)

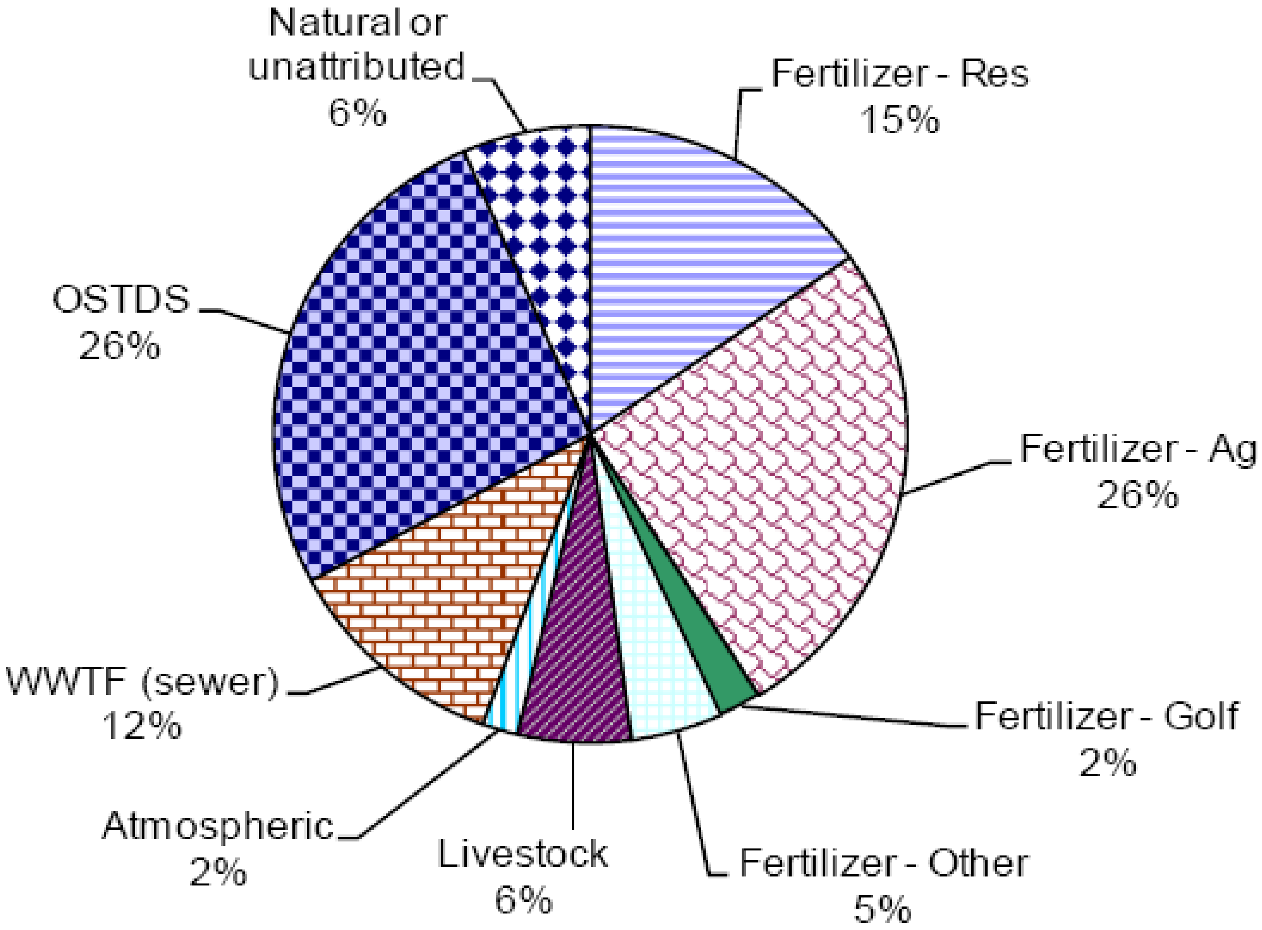
IN SOME WATERSHEDS OWTS N LOADS ARE RELATIVELY LOW

Chesapeake Bay
Nitrogen Loading Model



IN OTHER WATERSHEDS OWTS N LOADS ARE RELATIVELY HIGH

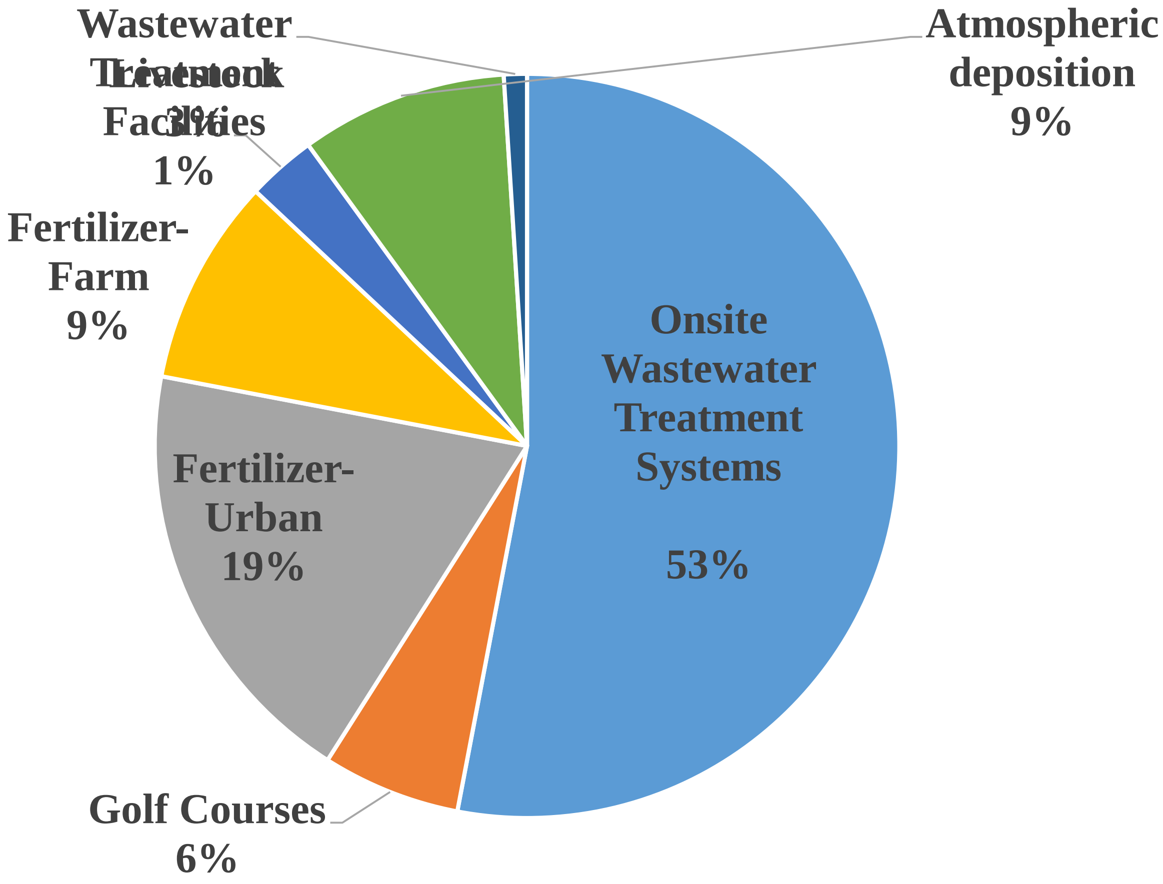
Wekiva Study Area



Source: MACTEC
Created by: SAR   Checked by: WAT

IN A FEW WATERSHEDS, OWTS N LOADS CAN BE VERY HIGH

Kings Bay FL Springshed



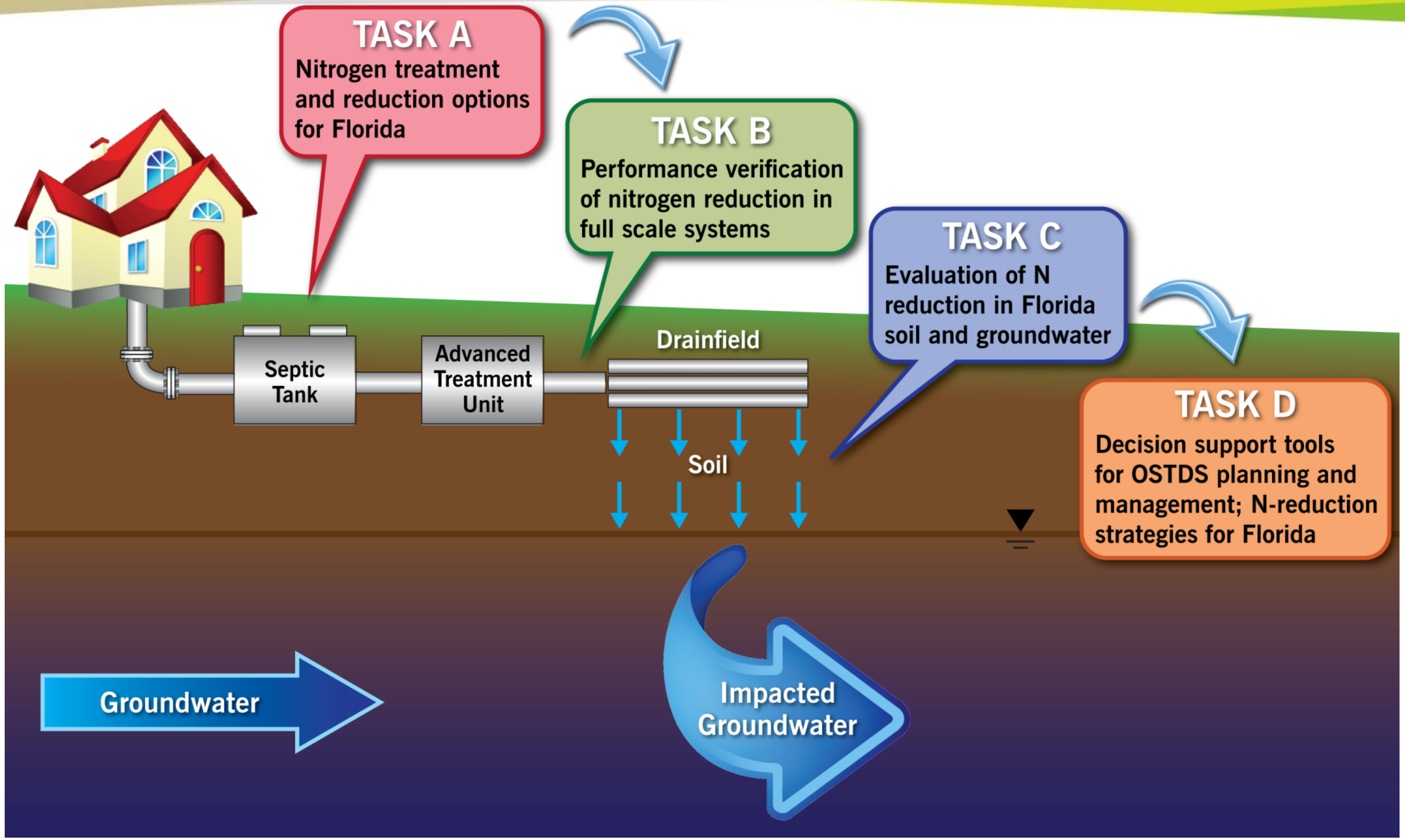
Source Florida Dept. Environmental Protection (2015)

NITROGEN REDUCING BIOFILTERS (NRBs): FLORIDA DOH STUDIES & LESSONS LEARNED

FLORIDA OWTS NITROGEN REDUCTION STUDIES

- Florida Legislature directed FDOH to conduct a study to further develop more cost-effective nitrogen reduction strategies for OWTS.
- Nitrogen reducing OWTS should be similar to conventional OWTS in their operation and maintenance, relatively passive in operation.
- Initiated the Florida Onsite Sewage Nitrogen Reduction Strategies (FOSNRS) Project in 2009.

FOUR PRIMARY STUDY AREAS



See FDOH Website: www.floridahealth.gov/environmental-health/onsite-sewage/research/nitrogenstudydeliverables.html

WHAT ARE “PASSIVE” NITROGEN REDUCTION SYSTEMS (PNRS)?

- Passive nitrogen reduction systems (PNRS) are generally defined as N-removing OWTS that are similar to conventional OWTS in their operation and maintenance requirements
- Florida: OWTS that reduce effluent N using reactive media for denitrification and a single liquid pump, if necessary.

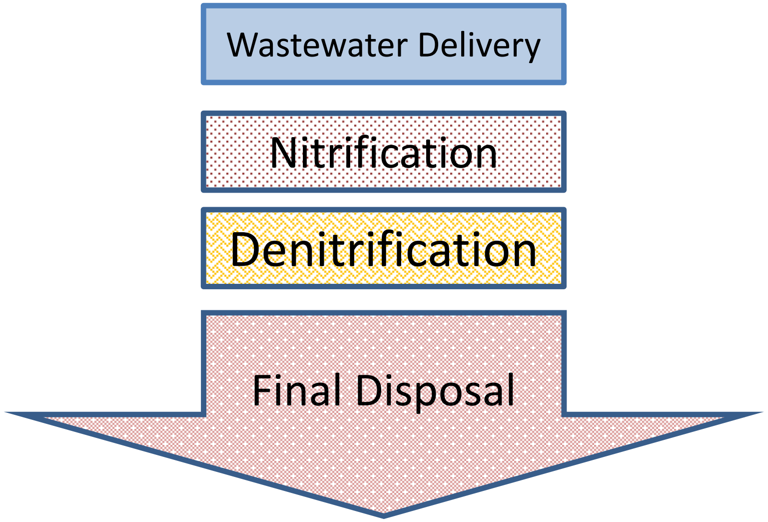
nitrification media:
Sand, expanded clay

denitrification media:
lignocellulosics

denitrification media:
elemental sulfur

WHAT ARE NITROGEN REDUCING BIOFILTERS?

- NRBs are in-ground, layered OWTS that reduce effluent N using reactive media for denitrification in a relatively passive process.
- Two stage biofiltration process:
  - Stage 1: “nitrify” nitrogen compounds to NO_3 (nitrification)
  - Stage 2: “denitrify” NO_3 to nitrogen gas (denitrification)

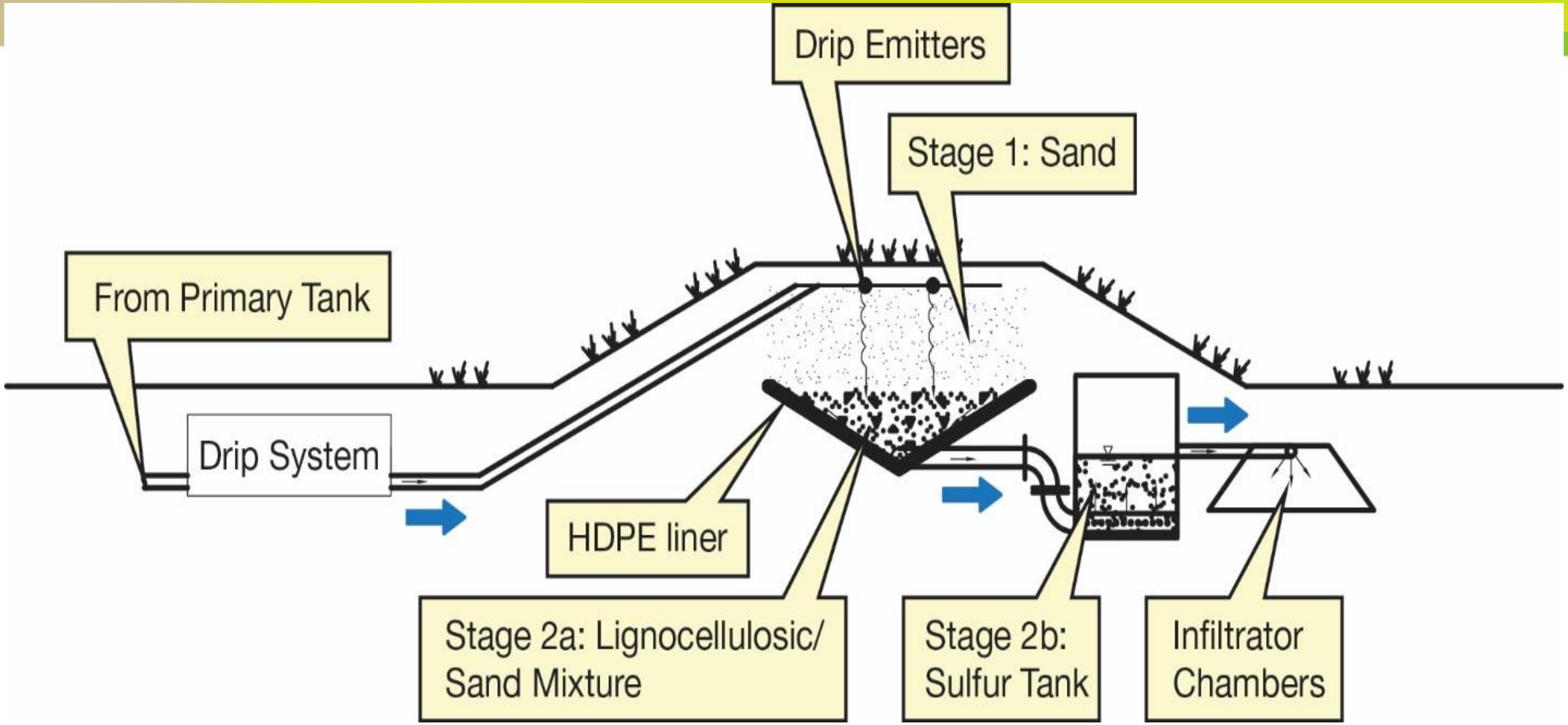


REACTIVE MEDIA STUDIED

denitrification media: lignocellulosics

denitrification media: elemental sulfur

SUCCESSFUL CONCEPT DEVELOPED INTO PROTOTYPE IN-GROUND NRB

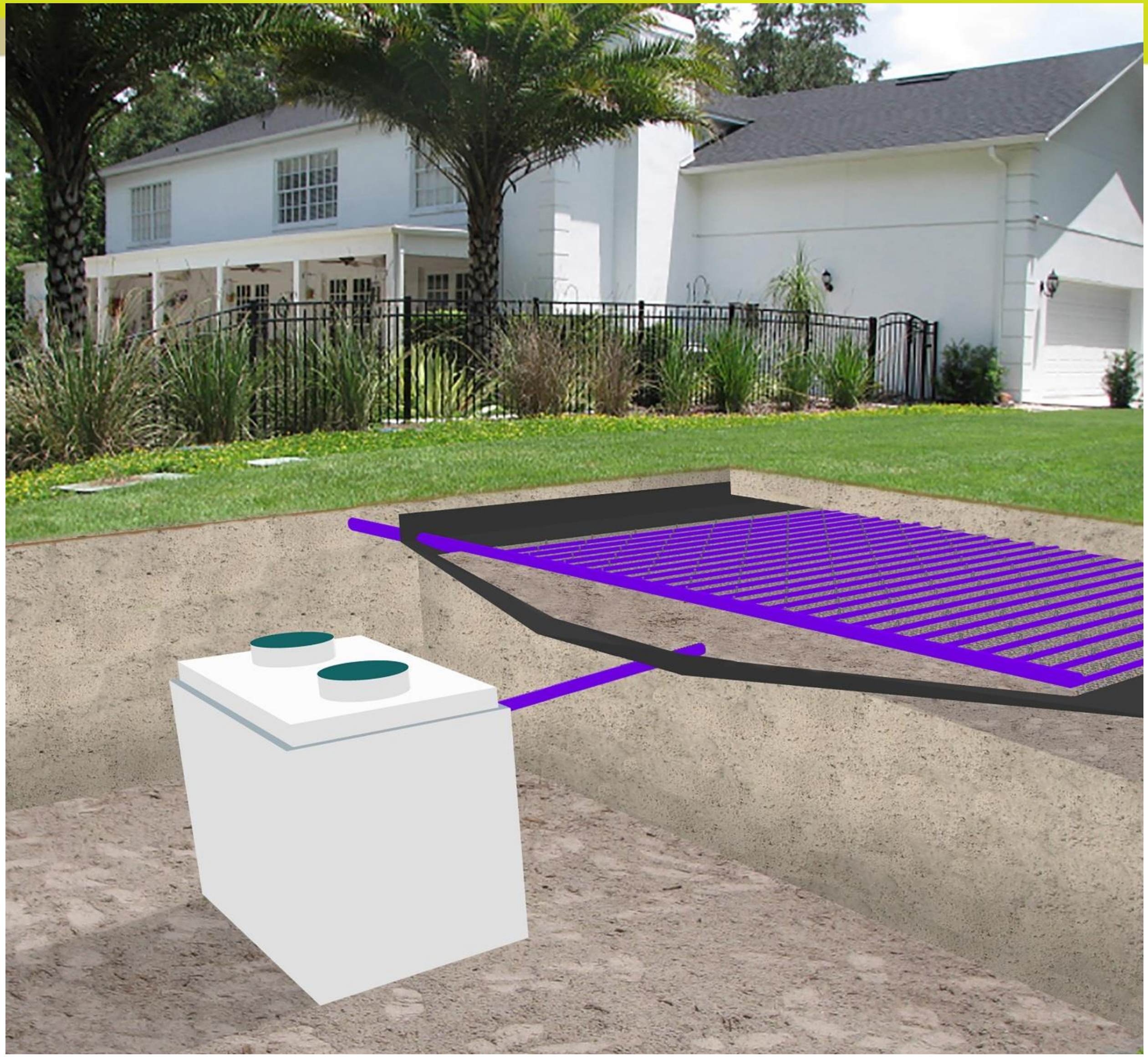


- **90% TN Reduction through ligno/sand**
- **95% TN reduction total**

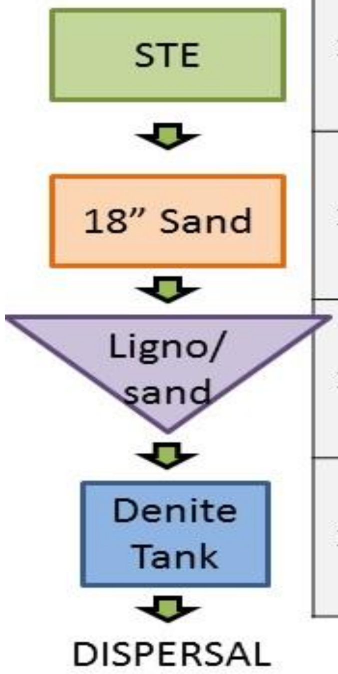
FULL-SCALE IMPLEMENTATION OF IN-GROUND NRB WITH ONSITE REUSE

- Single family home, Seminole County, FL
- 5 bedroom (2 residents)
- Flow of ~141 gpd
- Drainfield raised in fill
- Soils: Myakka and EauGallie fine sands
- Desired reuse of effluent for irrigation

COMPLETED FULL-SCALE IN-GROUND NRB CONCEPT WITH ONSITE REUSE



FULL-SCALE IN-GROUND NRB PERFORMANCE >500 DAYS OPERATION



n	TKN mg N/L		NH_3 mg N/L		NO_x mg N/L		TN mg N/L		Fecal Coliform (Ct/100 mL)		% TN Reduction
	mean	range	mean	range	mean	range	mean	range	mean	range	mean
13	50.5	30-64	43.5	27-54	0.07	0.02-0.4	50.5	30-64	65,033	20,000-420,000	
13	2.1	1.0-4.9	0.1	0.01-1.6	23.3	1.3-47	25.4	2.5-51.6	1,000 (n=1)	1,000 (n=1)	50%
13	2.1	0.9-4.2	0.2	0.04-0.7	5.8	0.02-14	7.9	1.0-16	32	Non-detect-6,800	84%
13	1.3	0.8-1.8	0.3	0.02-0.9	0.6	0.02-5.3	1.9	0.84-7.1	5	Non-detect-300	96%

Effluent Sulfate = 114 mg/L

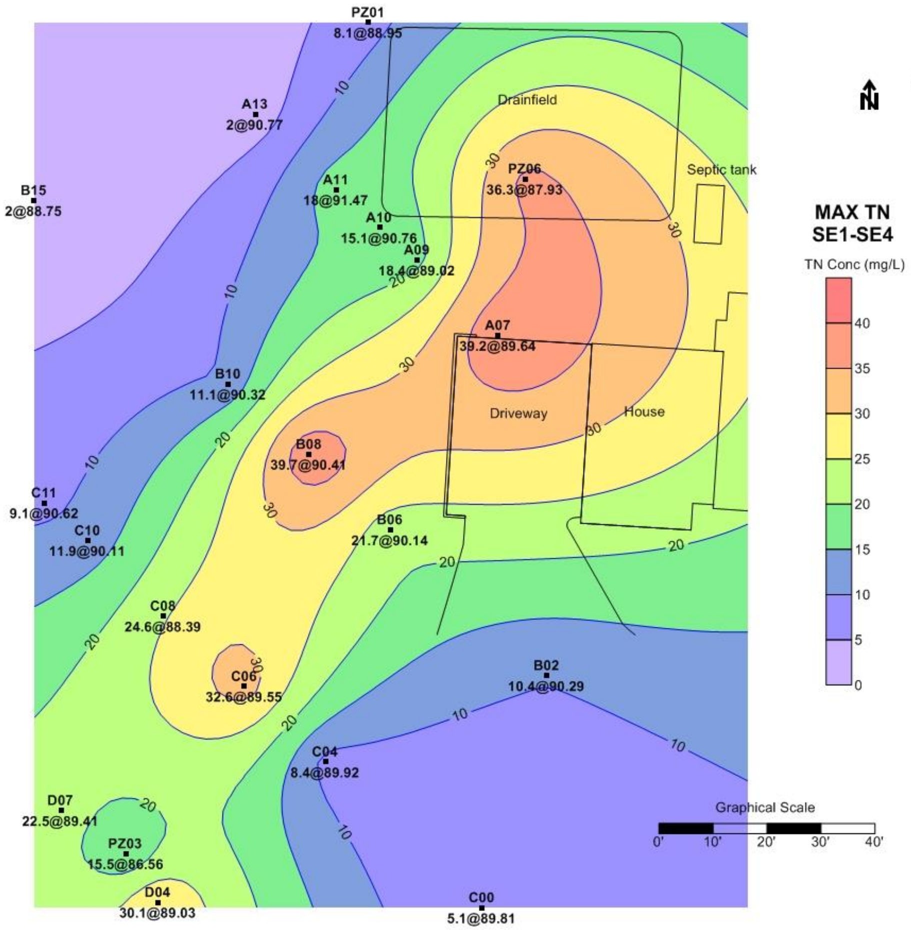
OPERATION & MAINTENANCE

- Average energy consumption of ~1 kWh/day or 7.8 kWh/1000 gal treated
- Stage 1 biofilter – no surficial biomat or clogging present
- Stage 2 biofilter – reactive media shows immeasurable reduction in volume

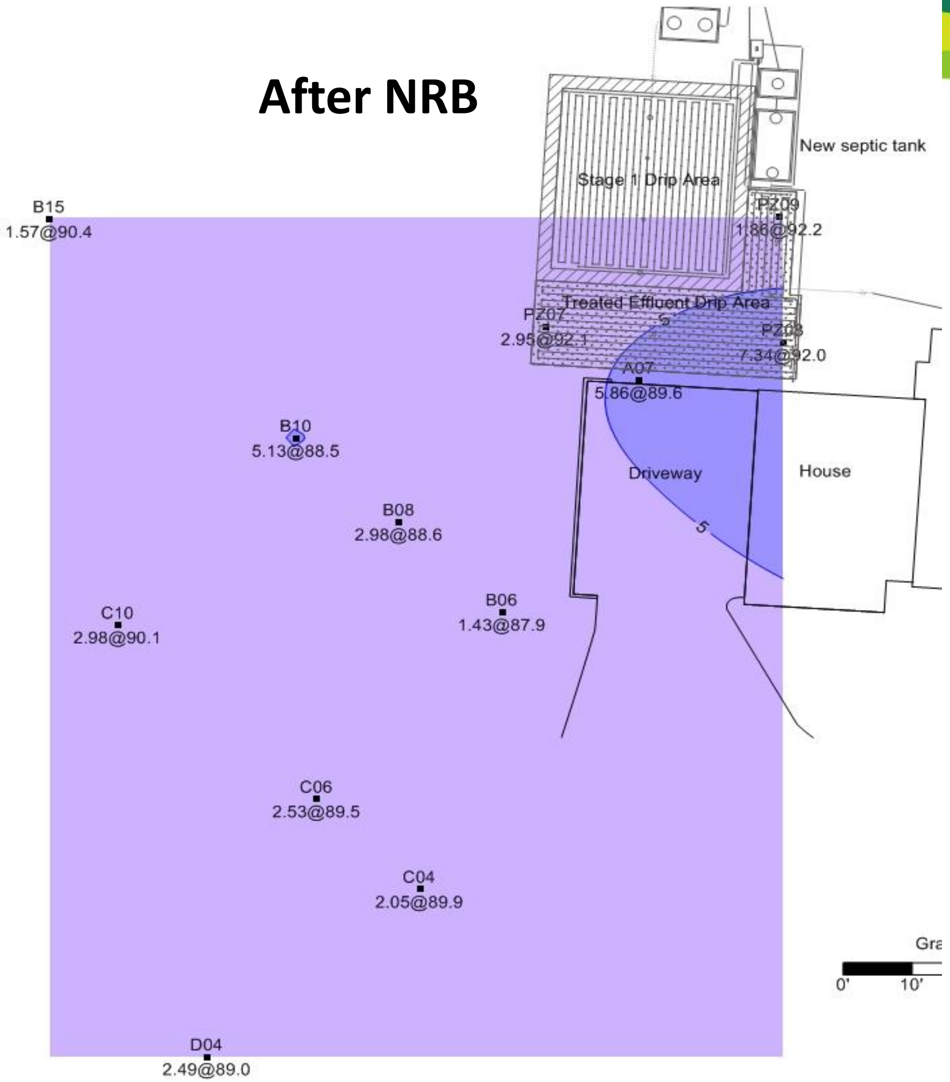
GROUNDWATER QUALITY IMPROVEMENTS

GROUNDWATER MONITORING BEFORE AND AFTER NRB INSTALLATION

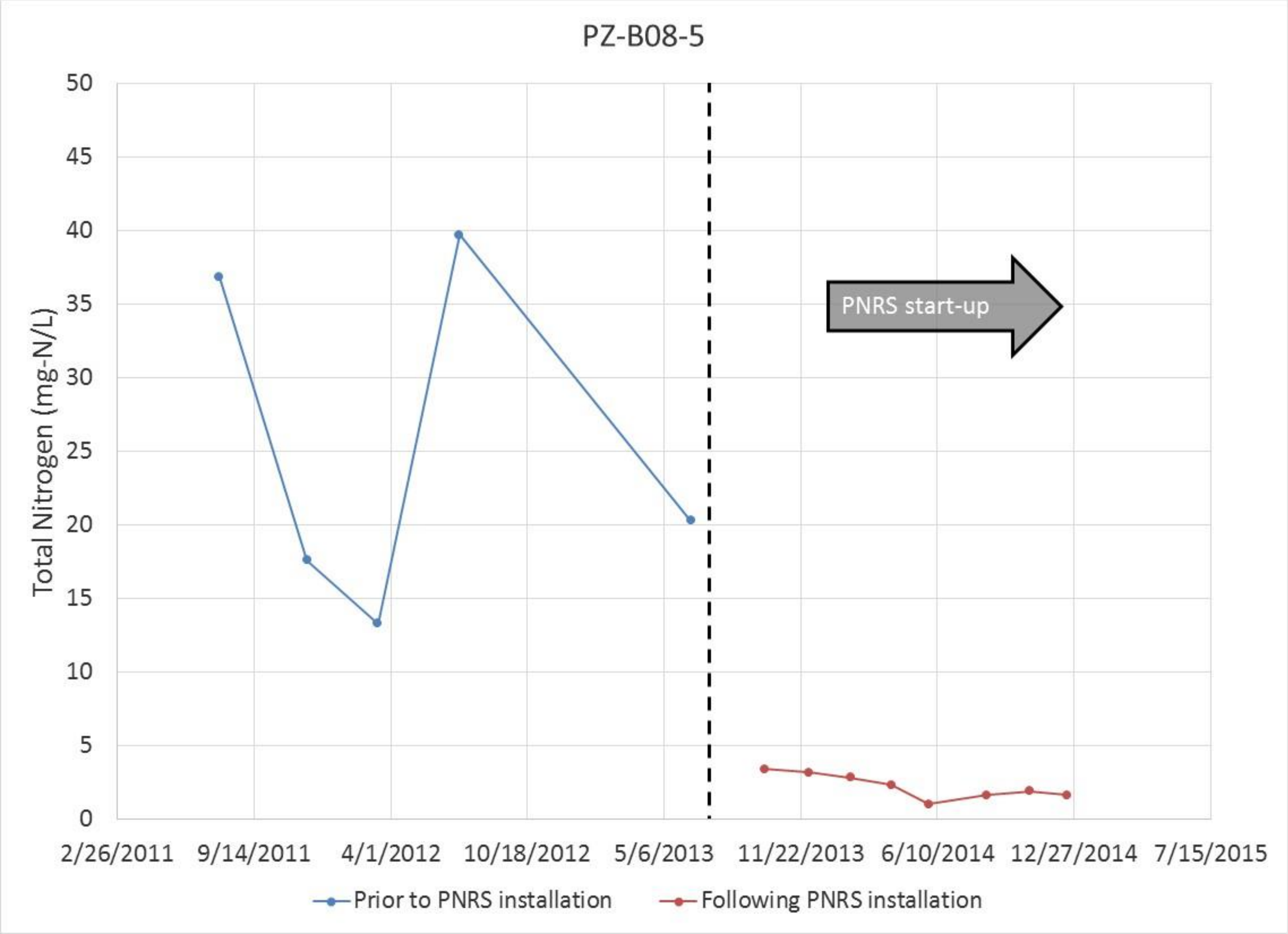
Before NRB



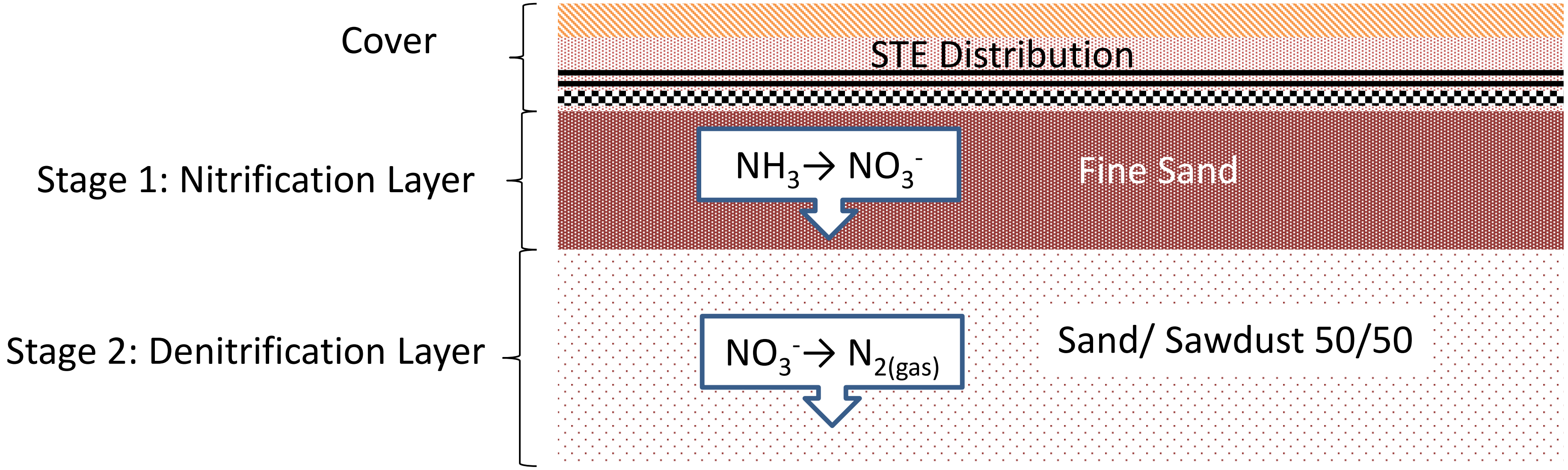
After NRB



MOST IMPACTED GROUNDWATER WELL TN TIME SERIES

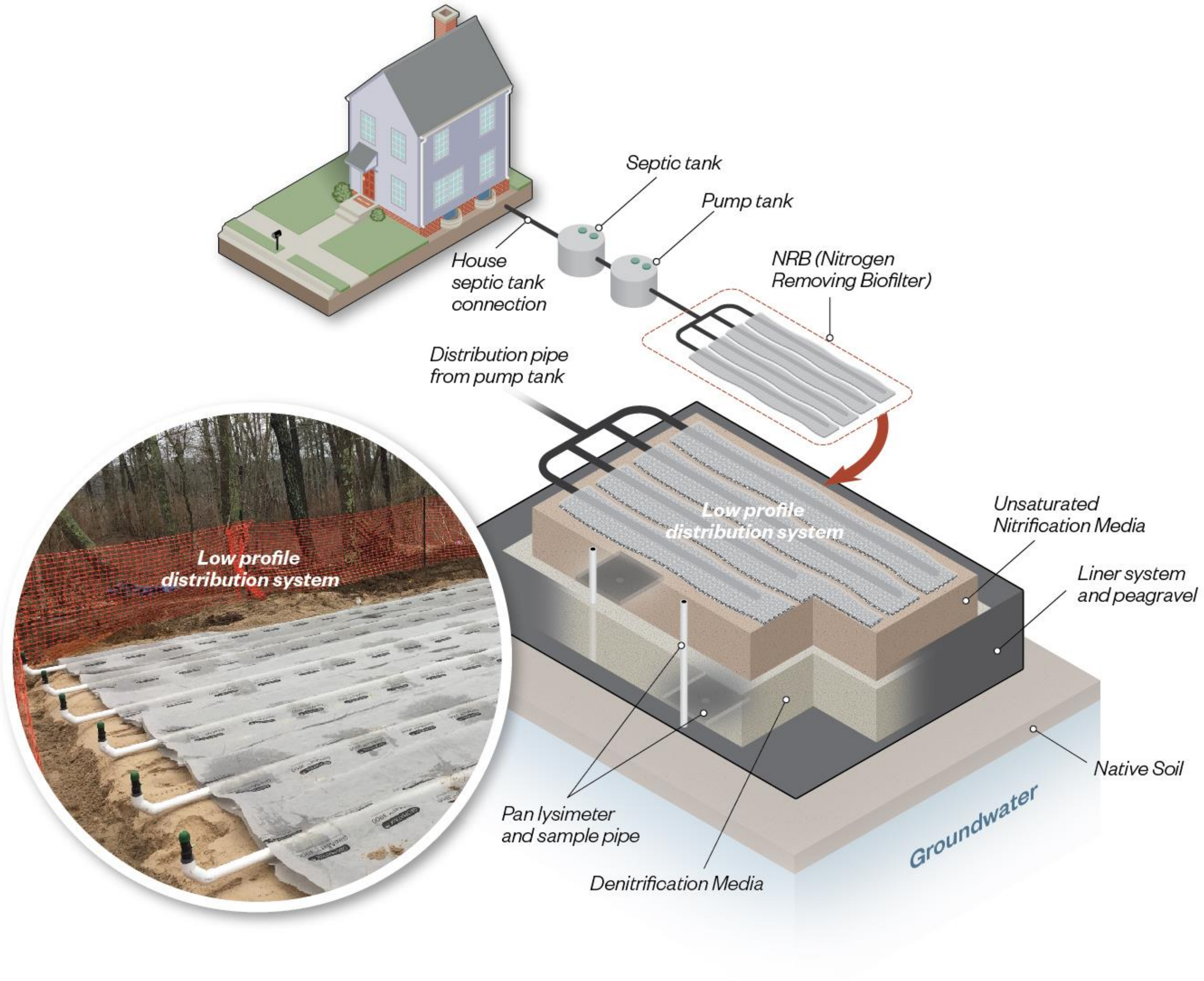


SIMPLE SYSTEM CONSTRUCTED LIKE A LAYERED DRAINFIELD DEVELOPED



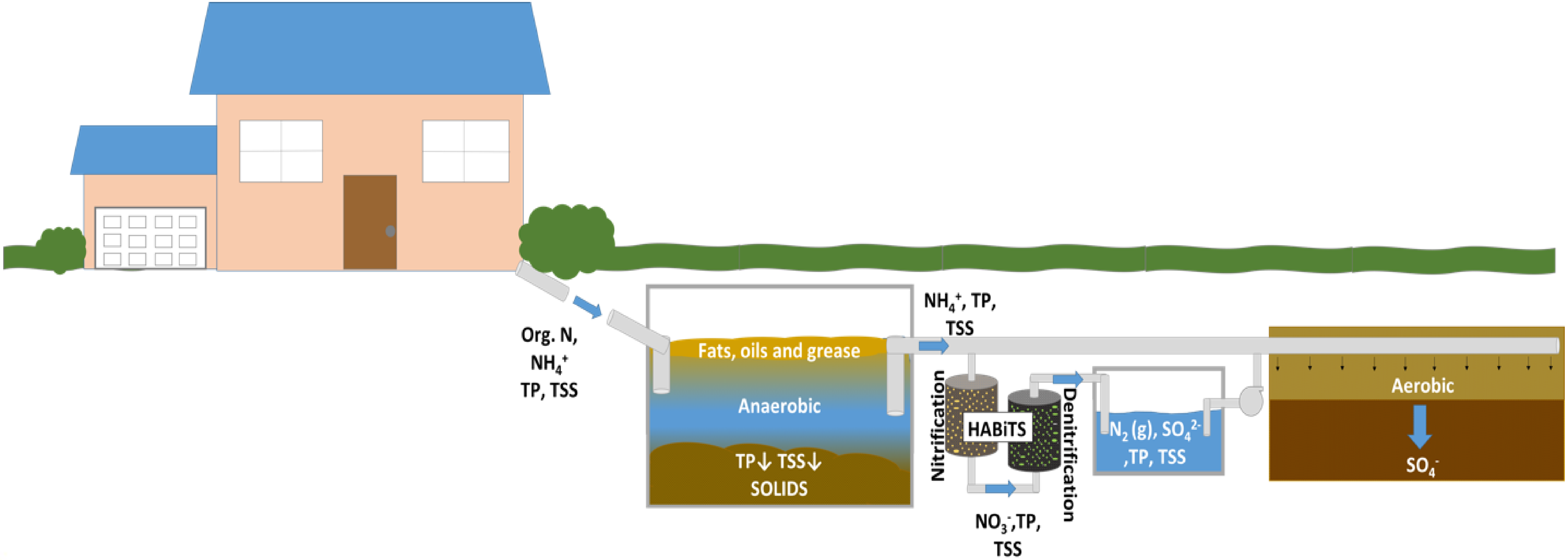
Underlain by impermeable liner for effluent collection or media with high water retention capacity (permeable layer)

NRB DESIGNS CURRENTLY BEING IMPLEMENTED

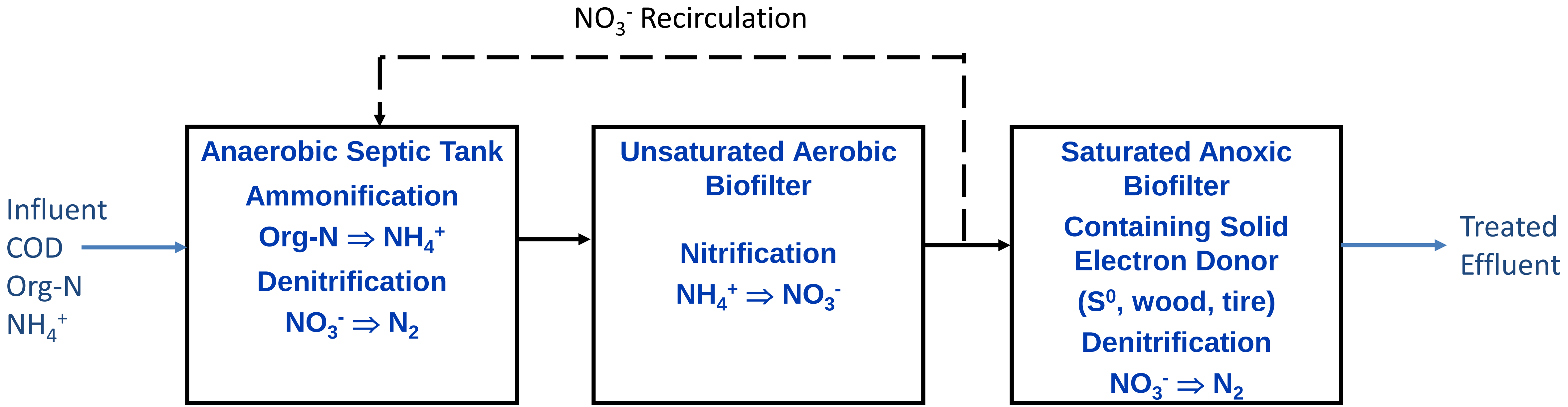


HYBRID ADSORPTION BIOLOGICAL TREATMENT SYSTEMS (HABITS) RESEARCH AT USF

PASSIVE ONSITE N REDUCTION SYSTEMS



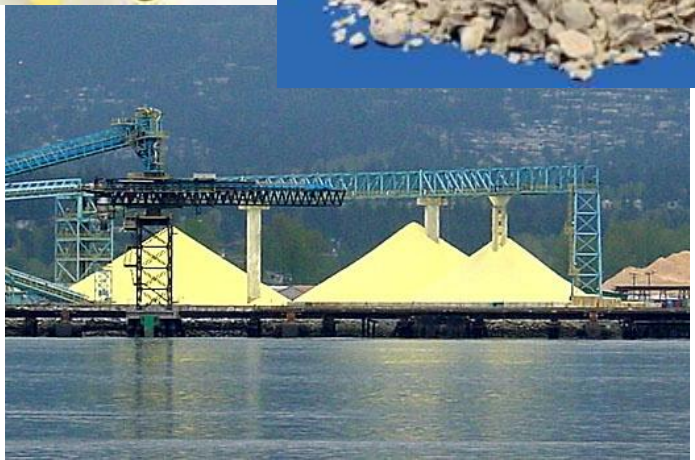
NITRIFICATION-DENITRIFICATION REVIEW



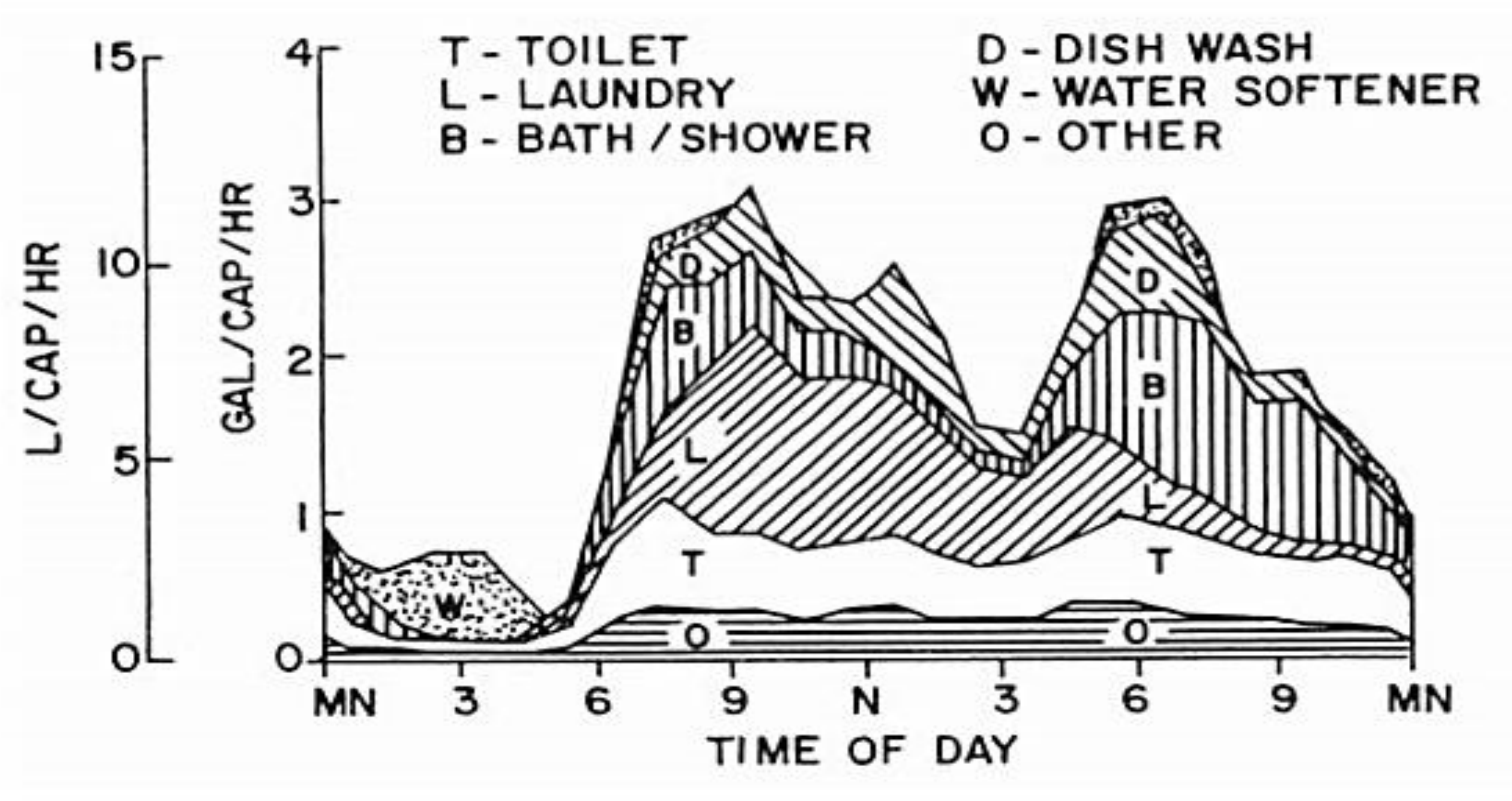
S^0 OXIDIZING DENITRIFICATION

$$55S^0 + 20CO_2 + 50NO_3^- + 38H_2O + 4NH_4^+ \rightarrow 4C_5H_7O_2N + 55SO_4^{2-} + 25N_2 + 64H^+$$

- Facultative, chemolithotrophic bacteria.
- Low biomass generation – reduced maintenance.
- Waste materials in simple packed bed reactors.
- Sulfur by-product of petroleum refining.
- Oyster shell used as solid phase buffer material.

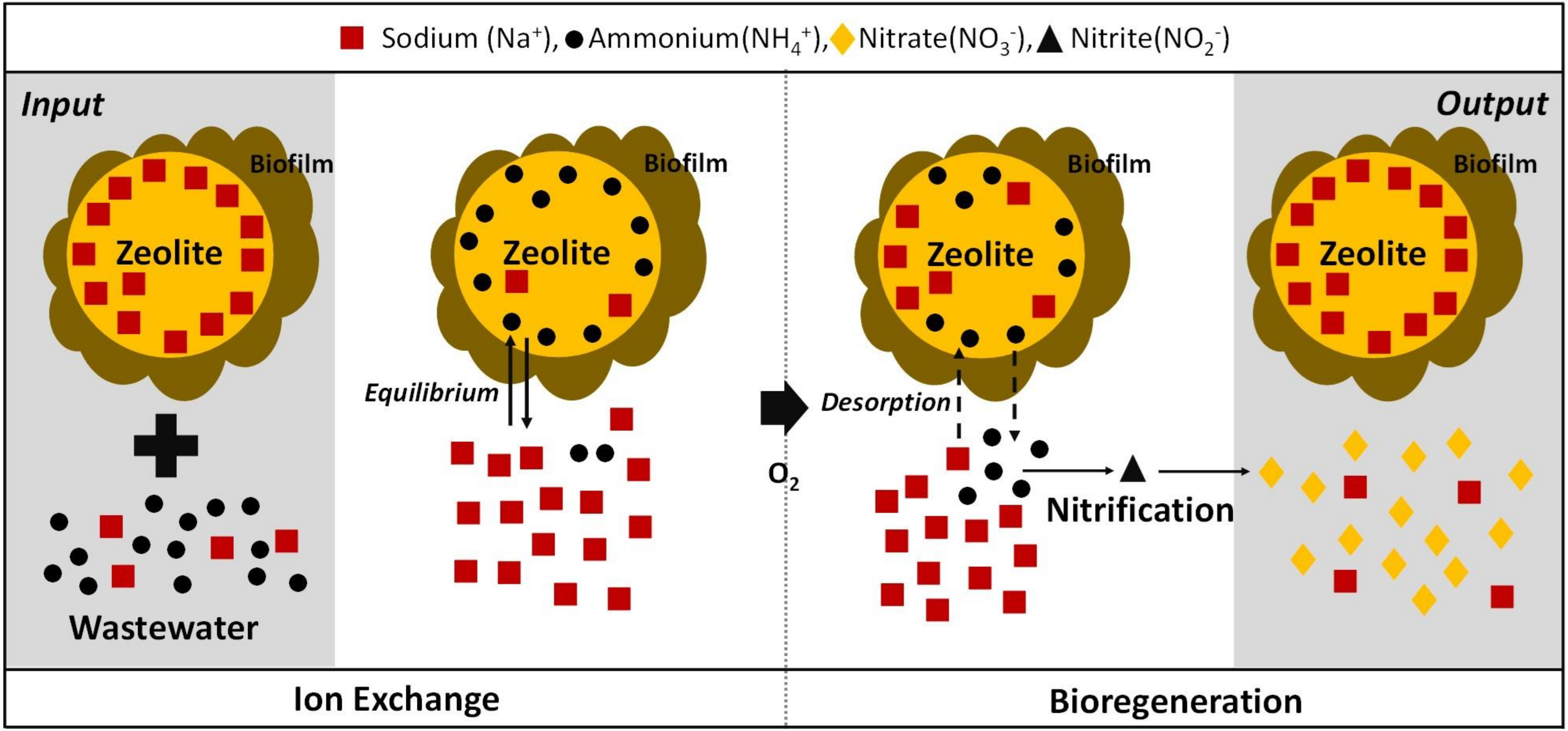


DIURNAL FLOW VARIATIONS IN THE HOME

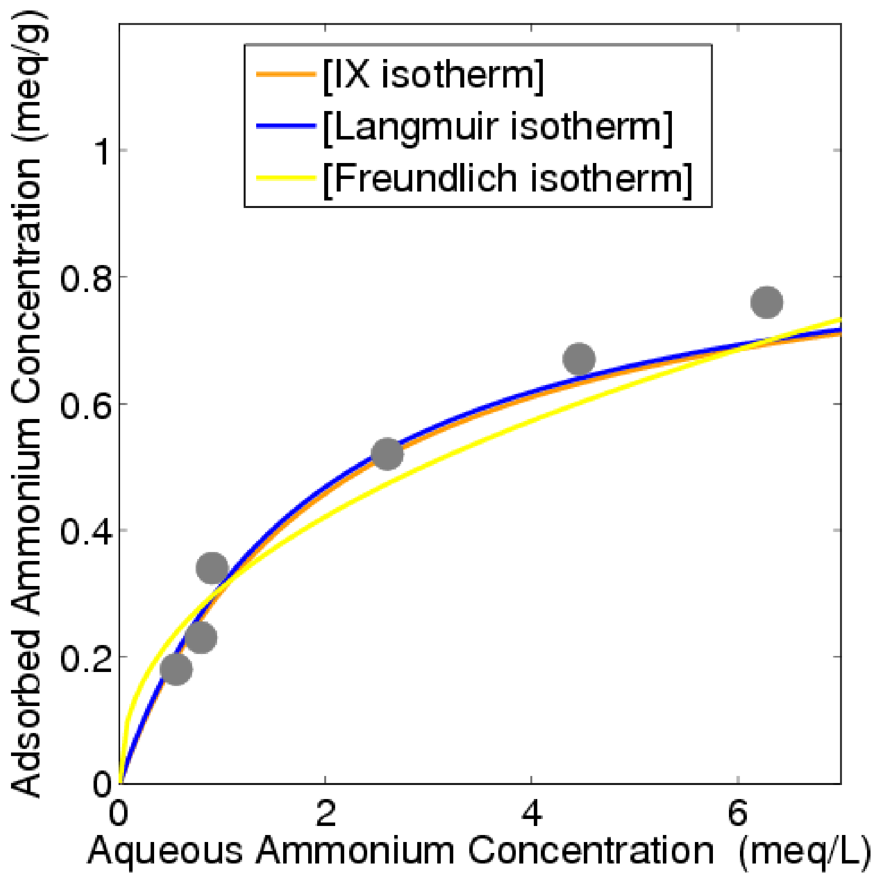


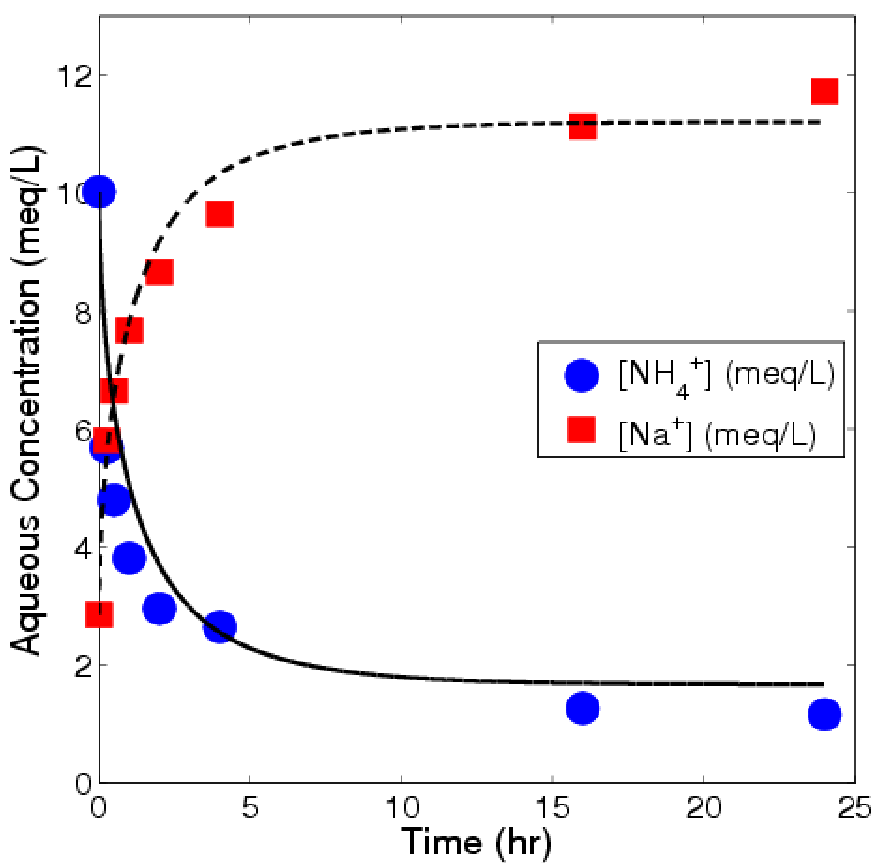
Source: University of Wisconsin, 1978.

HYBRID ADSORPTION BIOLOGICAL TREATMENT (HABiTS)



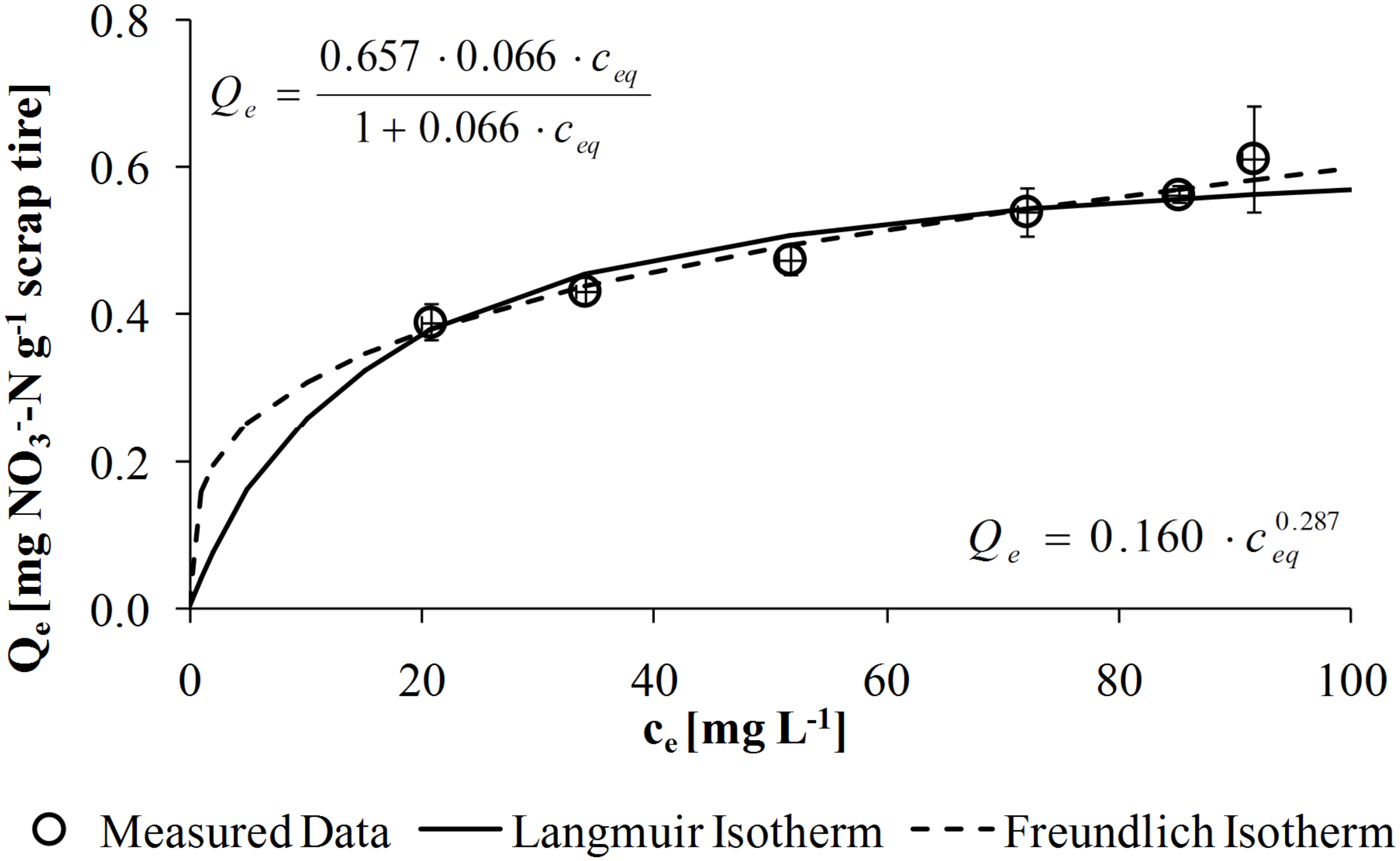
NH_4^+ ADSORPTION TO CLINOPTILOLITE





- Clinoptilolite - Low cost natural mineral with high capacity and selectivity for NH_4^+.

NO_3^- ADSORPTION TO TIRE CHIPS



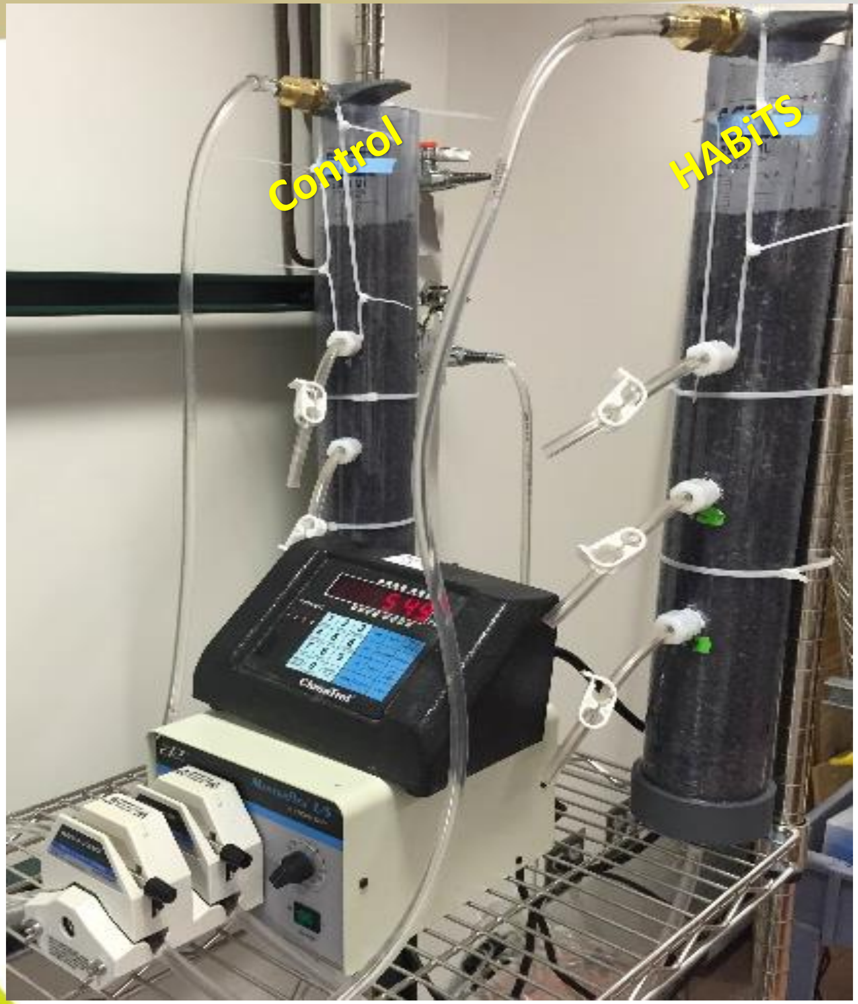
LOW COST BIOREACTOR MATERIALS

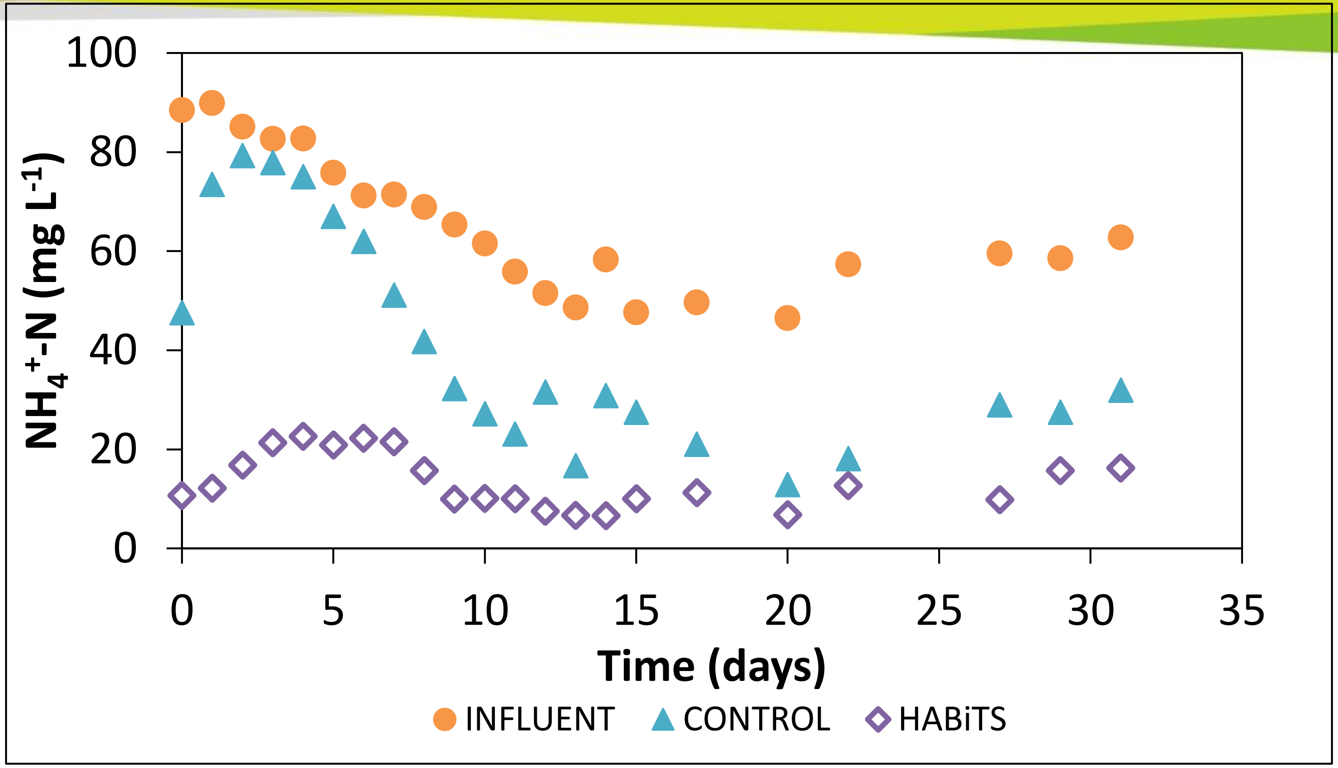
- Stage 1 - unsaturated - nitrification:
  – Expanded clay - biofilm carrier
  – Clinoptilolite - IX
  – Oyster shells - alkalinity
- Stage 2 - saturated - denitrification:
  – Elemental sulfur - e- donor SOD
  – Tire chips - biofilm carrier and e-donor for heterotrophs
  – Oyster Shells - alkalinity

Expanded Clay Tire chips Sulfur

Clinoptilolite Oyster Shell

BENCH-SCALE HABiTS - NITRIFICATION





- Faster start-up with HABiTS than control due to IX by clinoptilolite.
- NH_4^+ removal in HABiTS significantly greater than control.

BENCH SCALE HABiTS - DENITRIFICATION

Elemental Sufur Pellets

$S^0 \rightarrow SO_4^{2-}$

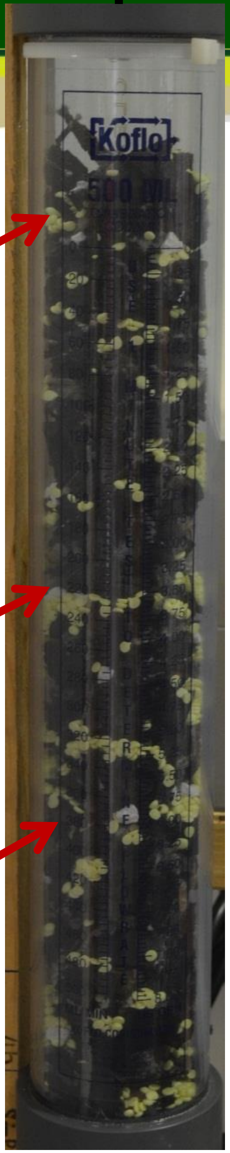
$NO_3^- \rightarrow N_2$

Crushed Oyster Shell

alkalinity source

Scrap Tire

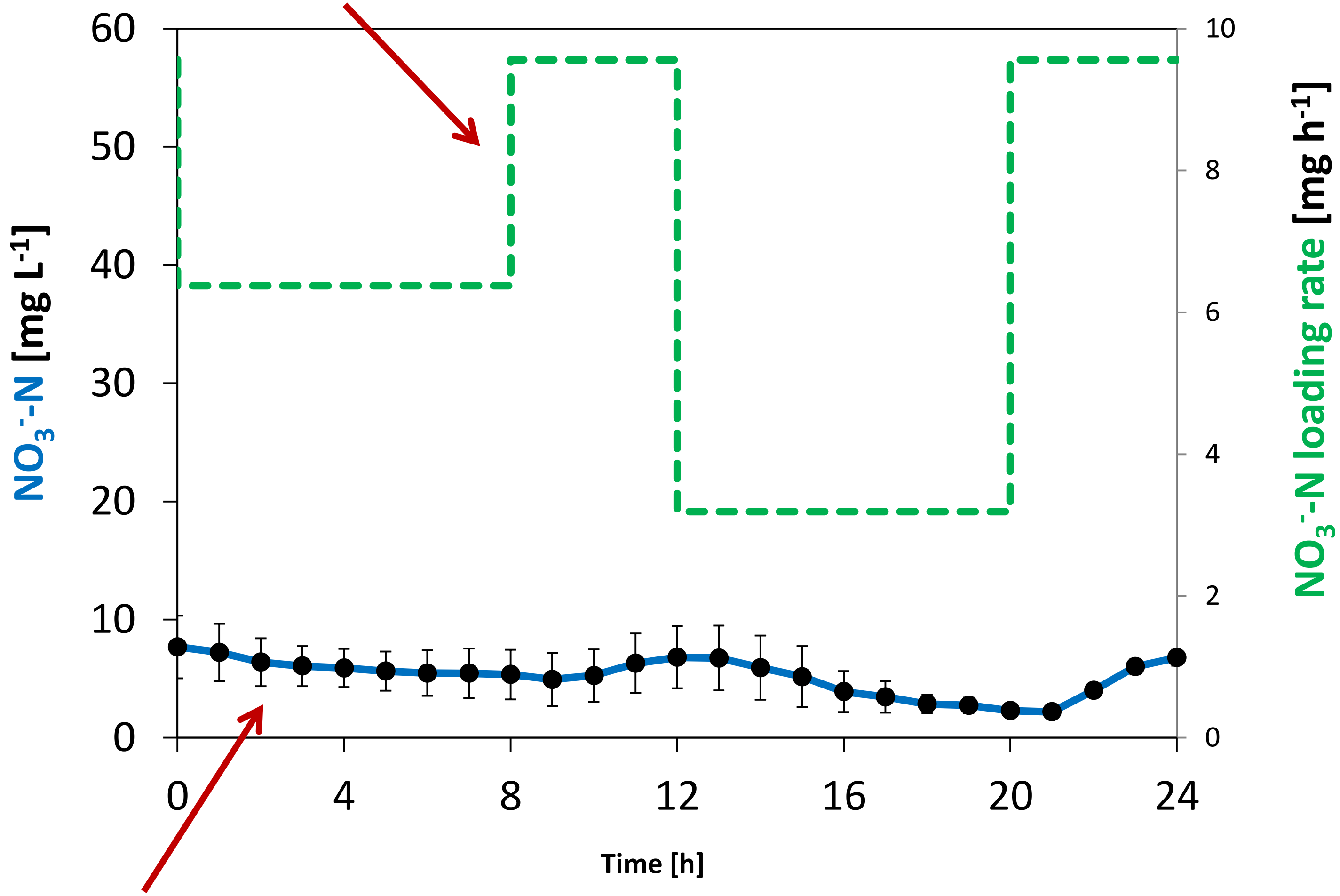
adsorbent



Denitrified Effluent

Nitrified onsite wastewater influent

Highly variable N loading rate



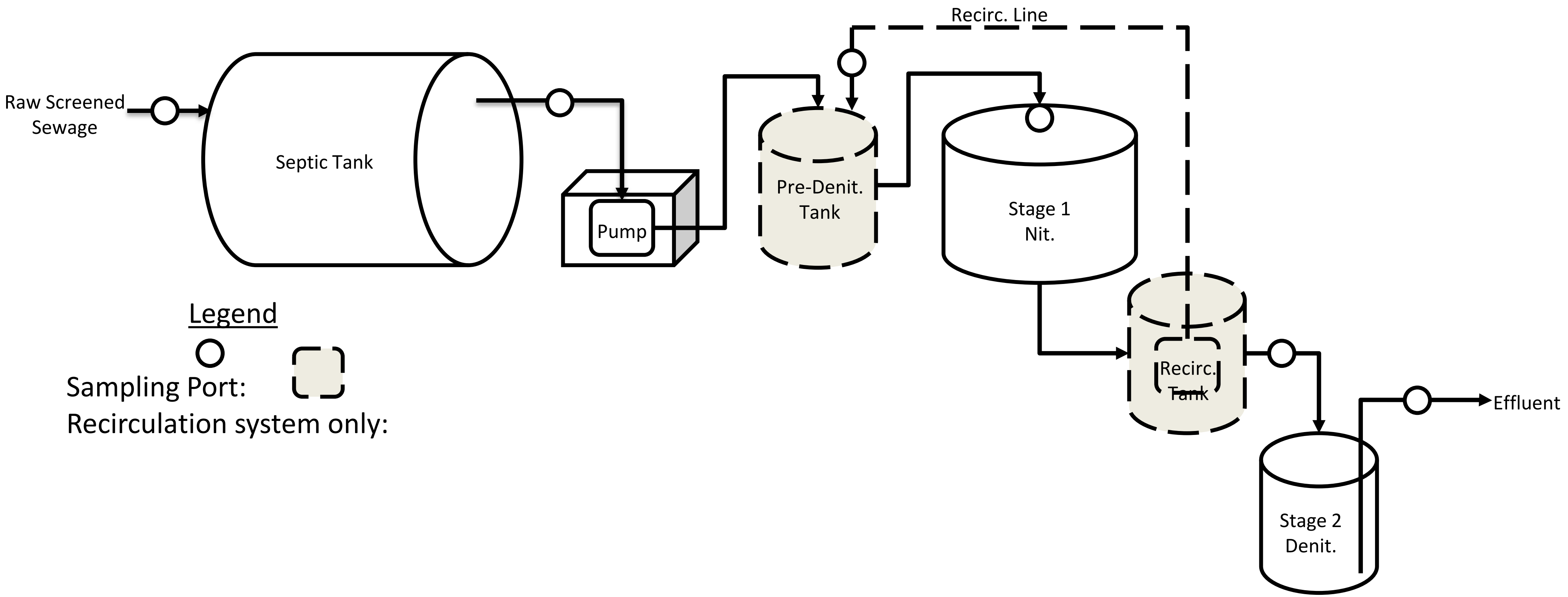
Low & stable effluent N concentration

HILLSBOROUGH COUNTY AWTP PILOT

- 2-Stage HABiTS tested with
  - R - Recirculation and pre-denitrification
  - FF - No recirculation (forward flow).
- Diurnal influent load:
  - 35% 6:00-8:00 am,
  - 25% 11:00 am-2:00 pm,
  - 45% 6:00-8:00 pm
  - Off 8:00 pm-6:00 am
- Part of the WEF Leadership Inovation Forum for Technology

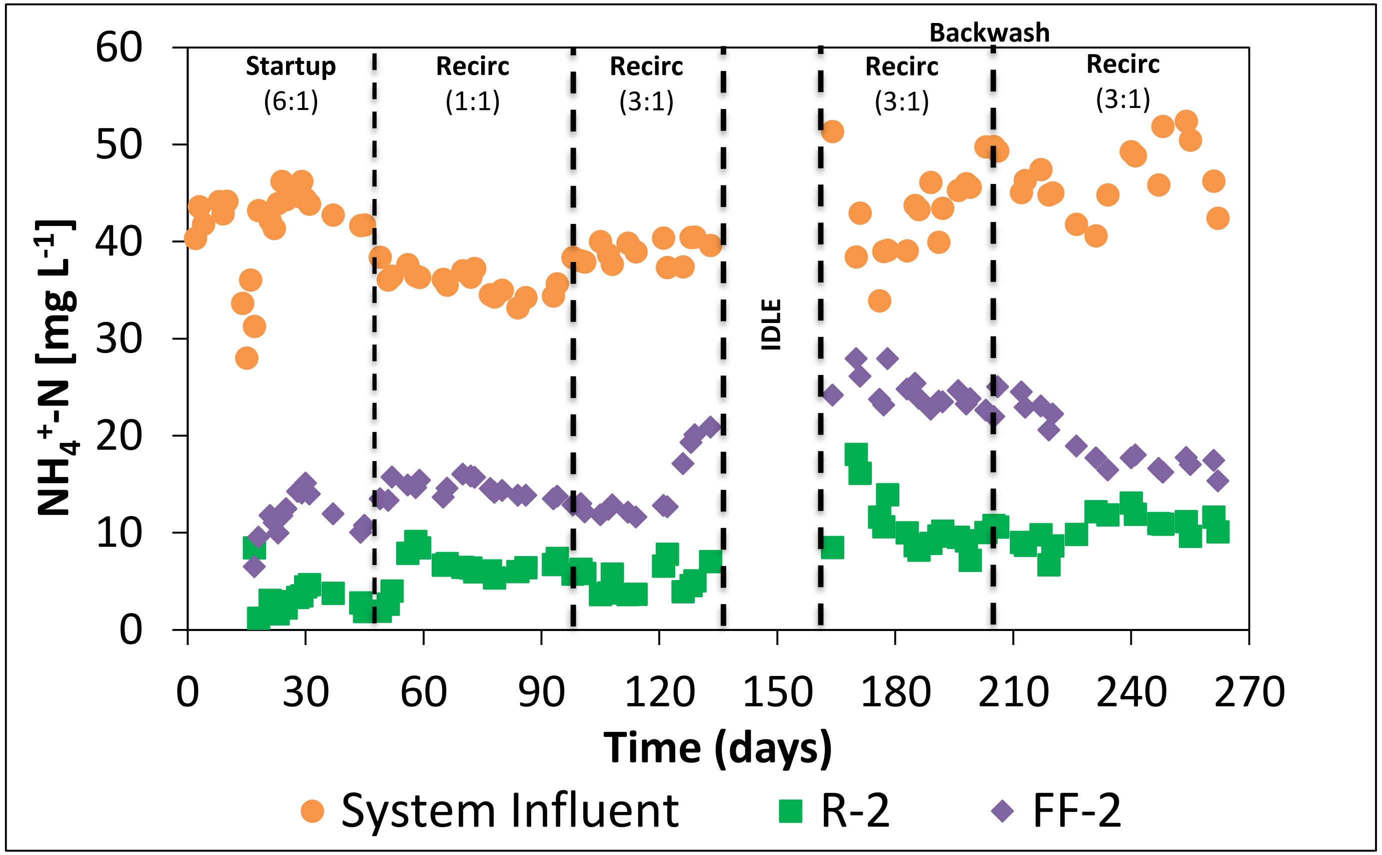
LIFT ©

HILLSBOROUGH COUNTY AWTP PILOT

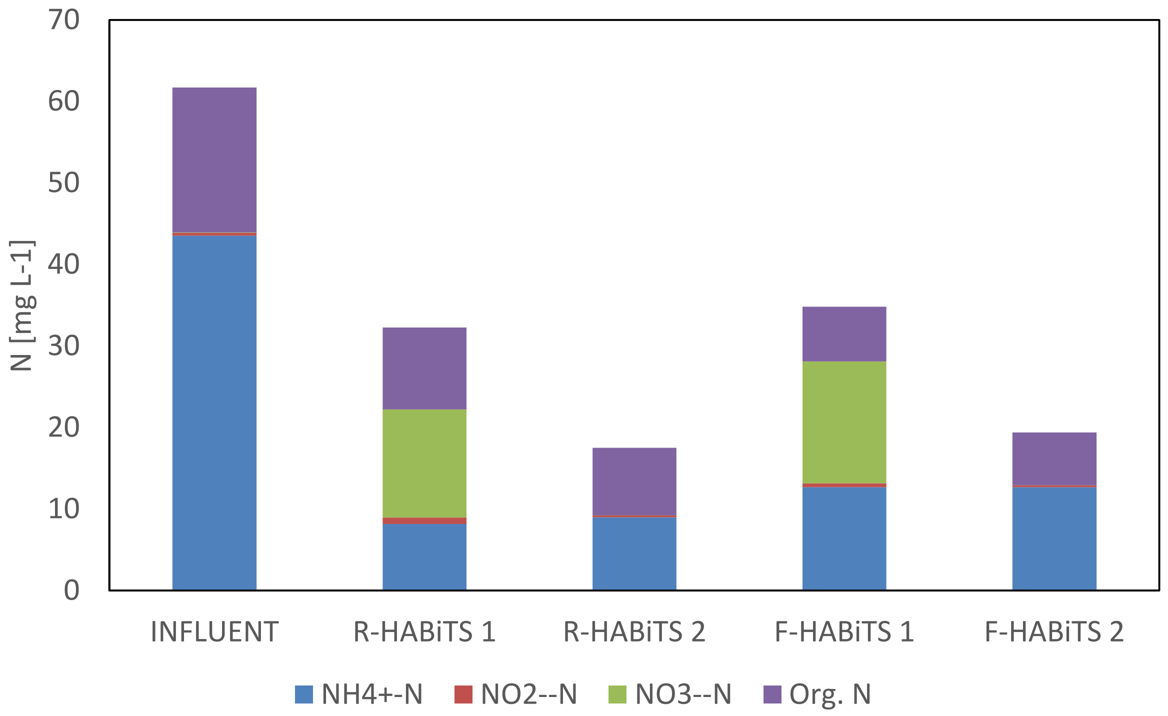


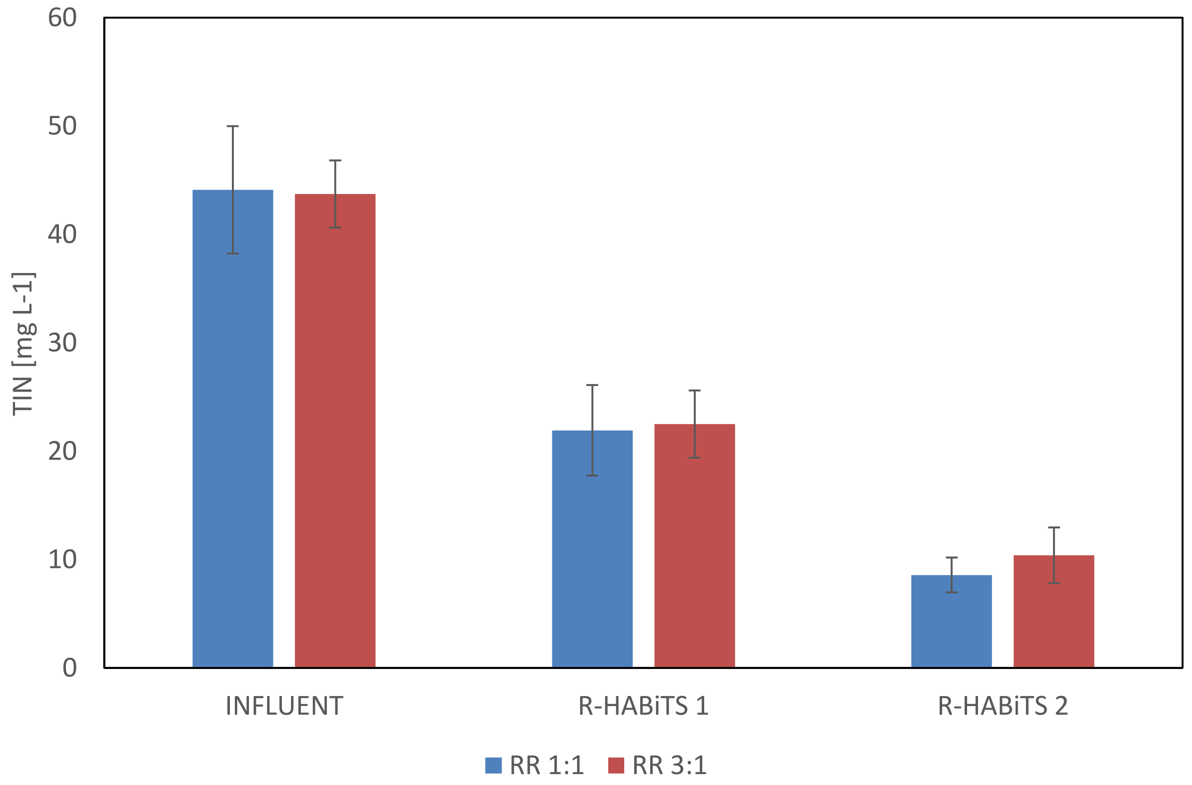
PILOT HABiTS RESULTS

- Recirculation (pre-denitrification) improves N removal.
  - Reduces COD loading to Stage 1
  - Reduces NO_3^- loading to Stage 2.
  - Keeps biofilm moist
  - Improves mass transfer of substrates & oxygen to biofilm.



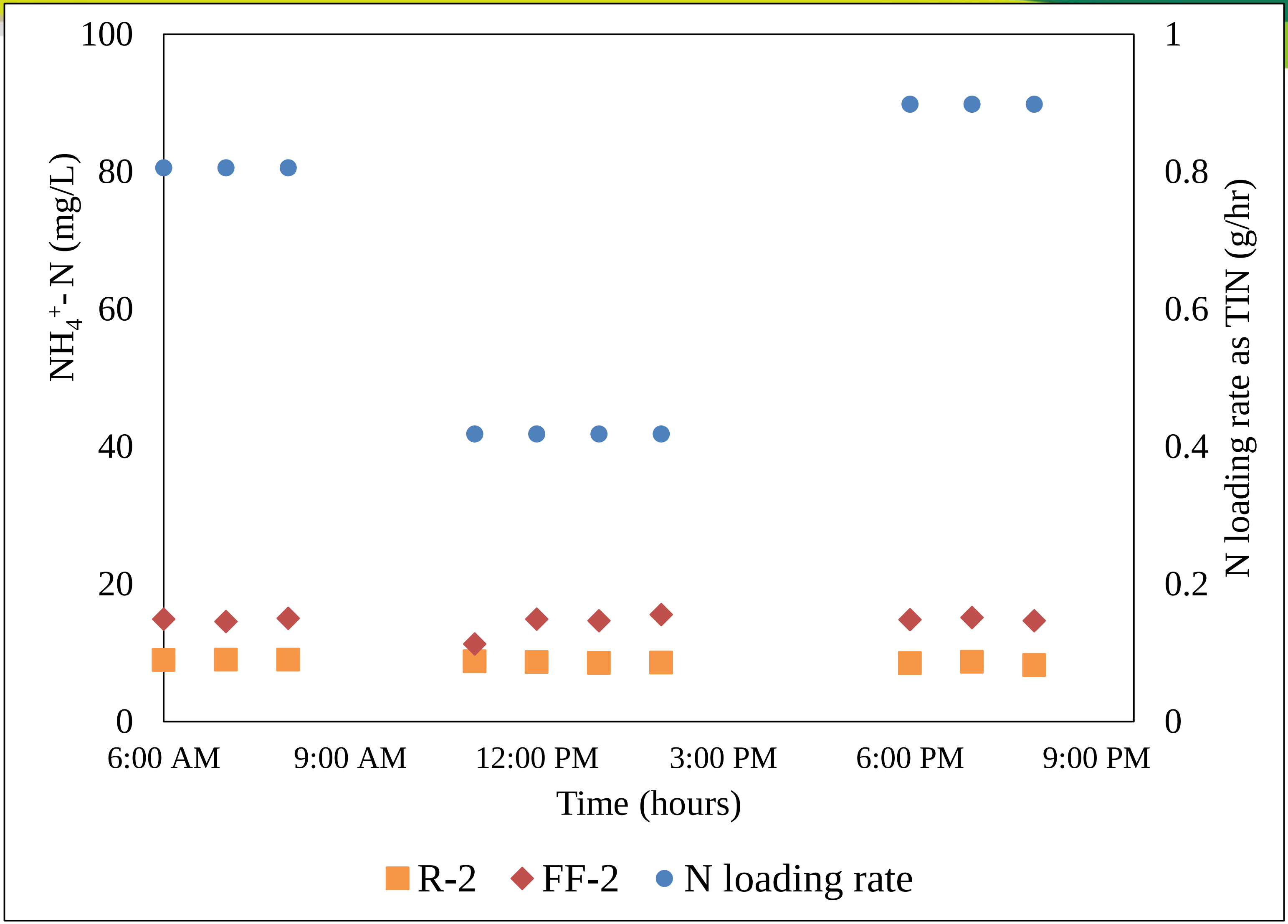
PILOT HABiTS RESULTS





PILOT HABiTS: HOURLY STUDIES

- IX maintains consistent low effluent N concentrations despite variable loads.
- Nitrification limits TN removal.
- Effluent NOx consistently BDL.



Rodriguez-Gonzalez, L., et al. (2020) A Pilot-Scale Hybrid Adsorption Biological Treatment System (HABiTS) for Nitrogen Removal in Onsite Wastewater Treatment, *ASCE-J. Sustainable Water in the Built Environment*, 6(1): 04019014.

Part of a Special Collection on Onsite and Decentralized Wastewater Management Systems:

https://ascelibrary.org/jswbay/onsite_decentralized_wastewater_systems

Check for updates

ASCE

A Pilot-Scale Hybrid Adsorption–Biological Treatment System for Nitrogen Removal in Onsite Wastewater Treatment

Laura Rodriguez-Gonzalez[1]; Amulya Miriyala[2]; Madison Rice[3]; Daniel Delgado[4]; Justine Marshall[5]; Michelle Henderson[6]; Kebreab Ghebremichael[7]; James R. Mihelcic[8]; and Sarina J. Ergas, M.ASCE[9]

Abstract: Onsite wastewater treatment systems (OWTS) are significant nonpoint sources of nutrients to surface and groundwater worldwide. Advanced OWTS are challenged by highly transient nutrient loads, long idle periods (e.g., during vacations), and inadequate maintenance. This study investigated the nitrogen transformation mechanisms and performance of novel two-stage hybrid adsorption and biological treatment systems (HABiTS) that combine biological nitrogen removal and ion exchange to enhance OWTS under transient loading conditions. In the first stage, the natural zeolite mineral, clinoptilolite, which has a high capacity and selectivity for NH_4^+, was included in a passively aerated nitrifying biofilter. In the second stage, recycled tire mulch, which has a high adsorption capacity for NO_3^-, was combined with elemental sulfur pellets in a submerged anoxic biofilter for autotrophic sulfur-oxidizing denitrification. Two pilot-scale HABiTS were tested for 434 days, with and without Stage 1 effluent recirculation and predenitrification. Both pilot-scale HABiTS removed >50% of total nitrogen from septic tank effluent. Stage 1 recirculation significantly improved NH_4^+ removal at both a 1:1 (84%) and a 3:1 (87%) recirculation ratio compared to HABiTS without recirculation (~50%). Recirculation and predenitrification reduced the organic load to the nitrifying biofilter, resulting in increased nitrification and reduced clogging and maintenance requirements. Consistently low effluent NO_3^- and NO_2^- concentrations were observed throughout the study in both pilot HABiTS under all conditions applied. The results show that HABiTS is a low-cost, low-energy, and robust process that can consistently achieve advanced secondary OWTS standards under transient loading conditions. **DOI: 10.1061/JSWBAY.0000898.** *© 2019 American Society of Civil Engineers.*

Author keywords: Biological nitrogen removal; Ion exchange; Recirculating trickling filter; Septic system; Transient loading.

uth Florida on 12/08/19. Copyright ASCE. For personal use only; all rights reserved.

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Introduction

Onsite wastewater treatment systems (OWTS) (also known as septic systems) treat approximately one-fifth of domestic wastewater in the United States, particularly in rural and suburban areas, due

UNIVERSITY/UTILITY PARTNERSHIPS

UNIVERSITY/UTILITY PARTNERSHIPS: WHY?

“Applied research in water and wastewater conveyance and treatment is critical to address many short-term problems encountered by utilities and identify longer-term research needs and fundamental issues. ***Universities local to utilities have a great role to play in conducting such applied research and developing site-specific solutions to technical problems.*** *A university–utility collaboration is a win–win combination for both and* ***has synergistic benefits in terms of technical problem solving directly applicable to utility operations and training future professionals for the same utility****.”*

Pagilla, K. "University–Utility Collaborative Applied Research—A Win–Win Combination." *Water Environment Rese*arch 79.6 (2007): 579-580.

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Feature
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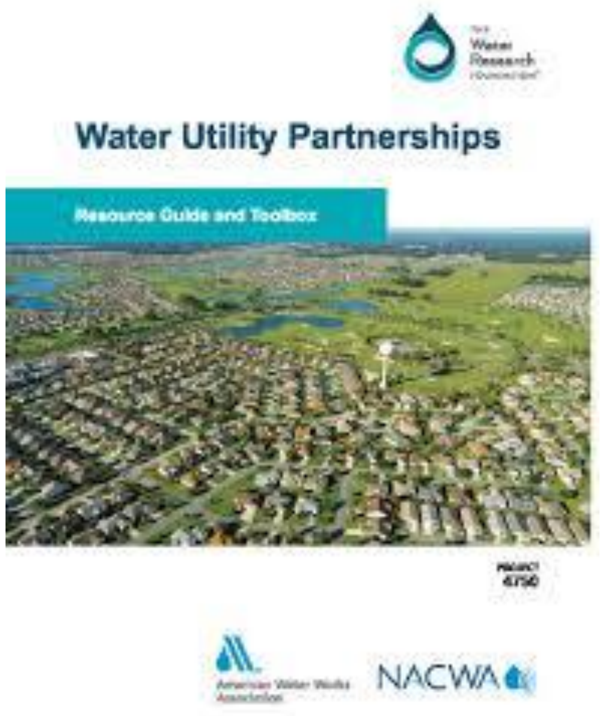
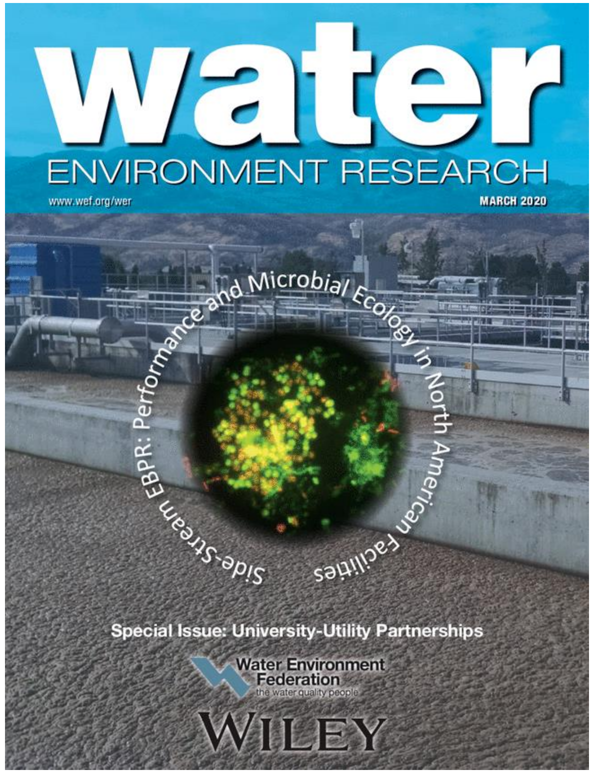
Accelerating Innovation that Enhances Resource Recovery in the Wastewater Sector: Advancing a National Testbed Network

James R. Mihelcic,[*,†] Zhiyong Jason Ren,[*,‡] Pablo K. Cornejo,[§] Aaron Fisher,[#] A. J. Simon,[||] Seth W. Snyder,[⊥] Qiong Zhang,[†] Diego Rosso,[▽] Tyler M. Huggins,[‡] William Cooper,[▽] Jeff Moeller,[#] Bob Rose,[○] Brandi L. Schottel,[◆] and Jason Turgeon[¶]





WHAT MAKES A SUCCESSFUL PARTNERSHIP?

In our case, Hillsborough County (FL) Public Utilities has a focus area of:

1. Optimize current treatment processes.
2. Identify future processes to achieve environmental sustainability.
3. Research and Education that leads to: a) advanced technology, b) educating customers and public about local resource recovery facility, c) educating K-12 and university students in environmental STEM, and, d) educate and mentor students for staff succession planning

County staff serve on thesis and dissertation committees and co-author publications with USF students.

We also recognize the importance of expanding the partnership with consultant when their technical expertise, cost estimate, or business case analysis is needed.

(adapted from University-Utility Collaborative Partnerships, WSEC-2017-TR-005, WEF 2017)

MORE THAN TWO PEOPLE!
ENTITIES THAT PARTICIPATE IN OUR PARTNERSHIP

- A PE with the Utility manages the contract and project
- PE and University PI develop and execute project, coordinate documents, and activities
- Main focus is to support Operational Divisions
- Engineering Planning, Regulatory, and Laboratory Service groups all provide technical expertise and data required for systems evaluations
- Other County departments such as Public Works use the partnership for stormwater, wetlands, and ponds surveys.

CONCLUSIONS

- OWTS are a significant source of nutrients in many areas.
- Not cost-effective to convey wastewater to centralized systems in rural or suburban areas, developing countries.
- Passive OWTS can provide effective onsite treatment with low complexity, O&M, energy and chemical requirements.
- IX media (zeolite, scrap tire chips) provide consistent low effluent N concentrations despite highly variable loading rates and long idle periods.
- Ongoing research on performance, reuse potential and modeling.
- University-Utility Partnerships have synergistic benefits, resulting in a win-win for both partners.

THANK YOU:

- **Grad Students and Post Docs**
  - Lucie Krayzelova
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  - Michelle Henderson
  - Justine Stocks
  - Madison Rice
  - Daniel Delgado
- **Hazen & Sawyer**
  - Damann Anderson
  - Josefin Hirst
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  - Diarra Thomas
  - Joseph Capodice
  - Lensey Casimir
  - Zachary Carroll
- **USF Faculty**:
  - James Mihelcic
  - Maya Trotz
  - Kebreab Ghebremichael

CENTER FOR REINVENTING AGING INFRASTRUCTURE FOR NUTRIENT MANAGEMENT (*RAINmgt*)

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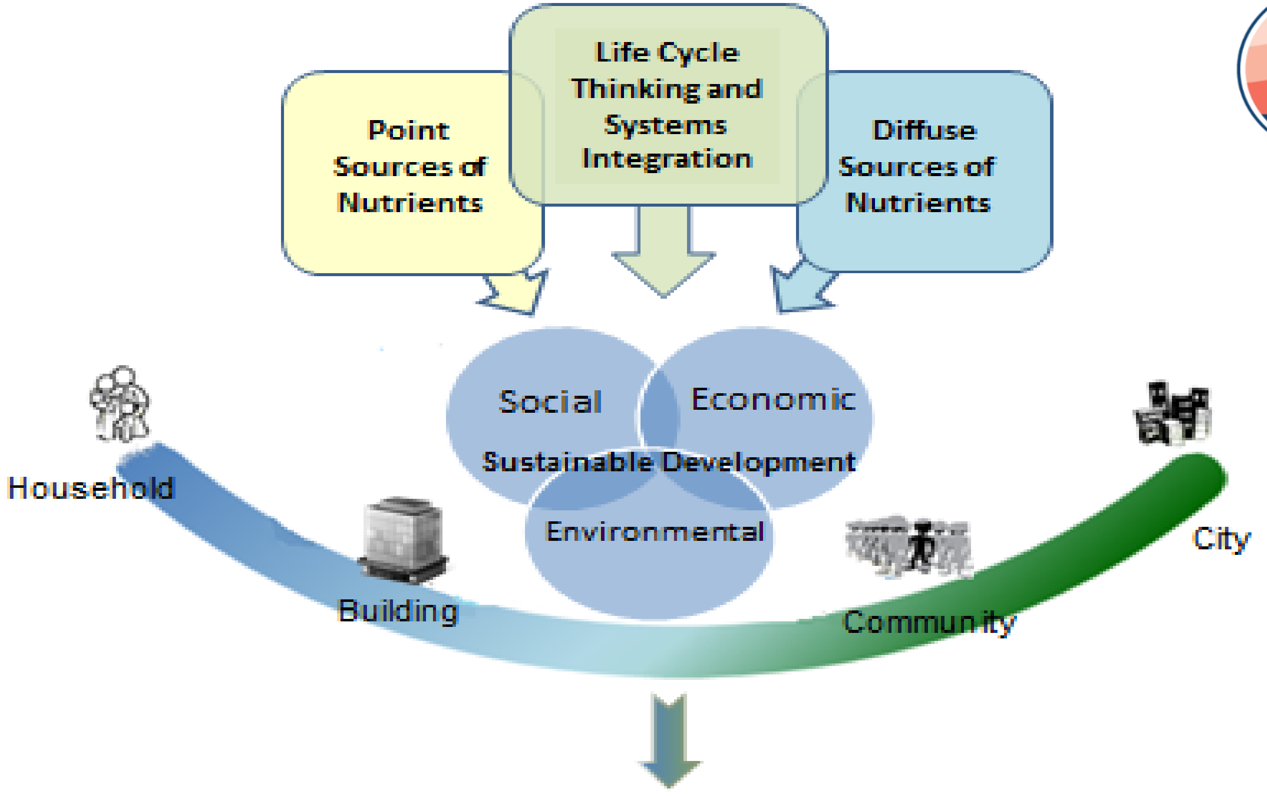

Science, Demonstration, Education, and Outreach to achieve sustainable and cost effective health and environmental outcomes by reinventing aging coastal urban infrastructure for management of nutrients

Low Cost Biofilters for Onsite Wastewater Nitrogen Removal

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