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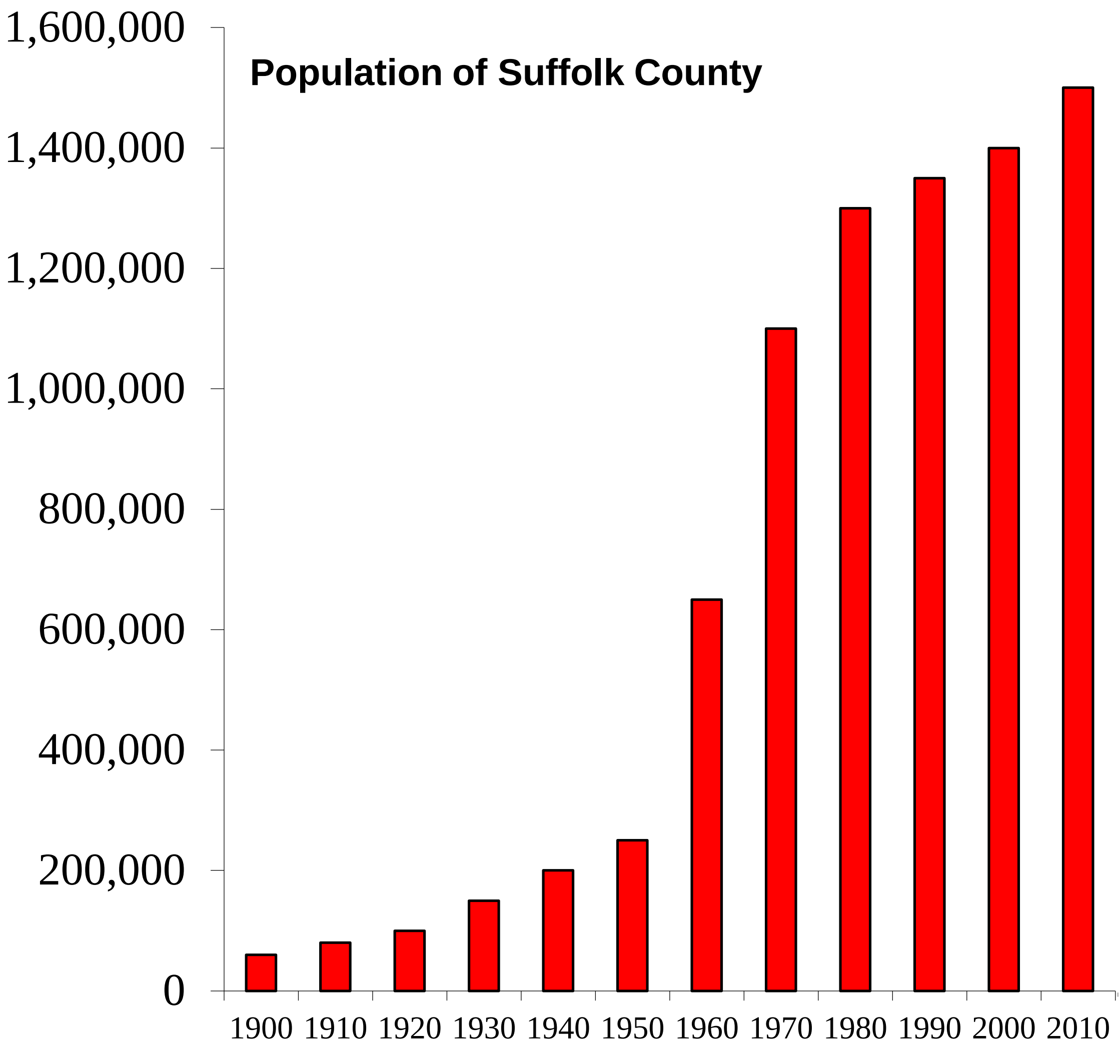
New York State Center for Clean Water Technology

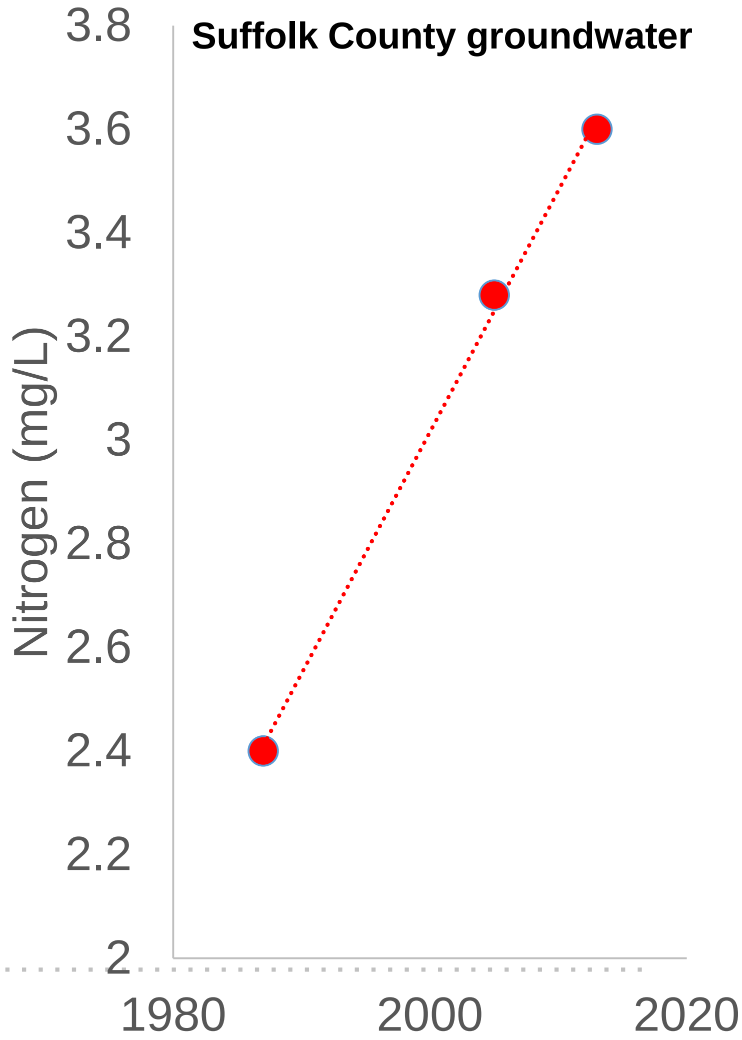
Second Public Symposium

FAR BEYOND

www.stonybrook.edu/cleanwater

Expanding population, nitrogen levels





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Most nitrogen loading on Long Island from wastewater

(Kinney and Valiela, 2011; Lloyd 2014, 2016; Gobler and Stinette, 2016; CDM-Smith, in prep)

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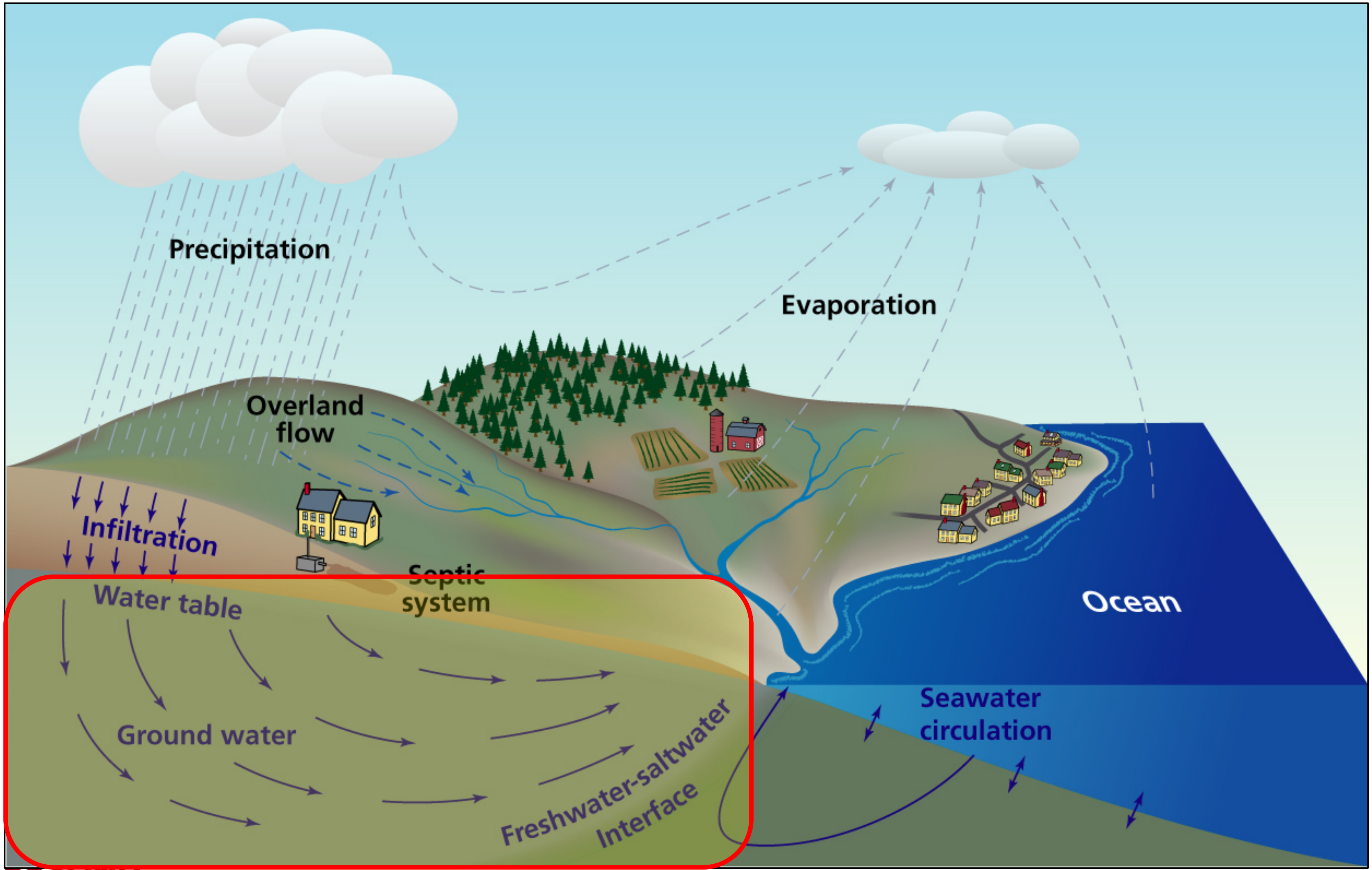
All of Long Island is a watershed -

Materials on land eventually enter our groundwater and surface water.



BEYOND

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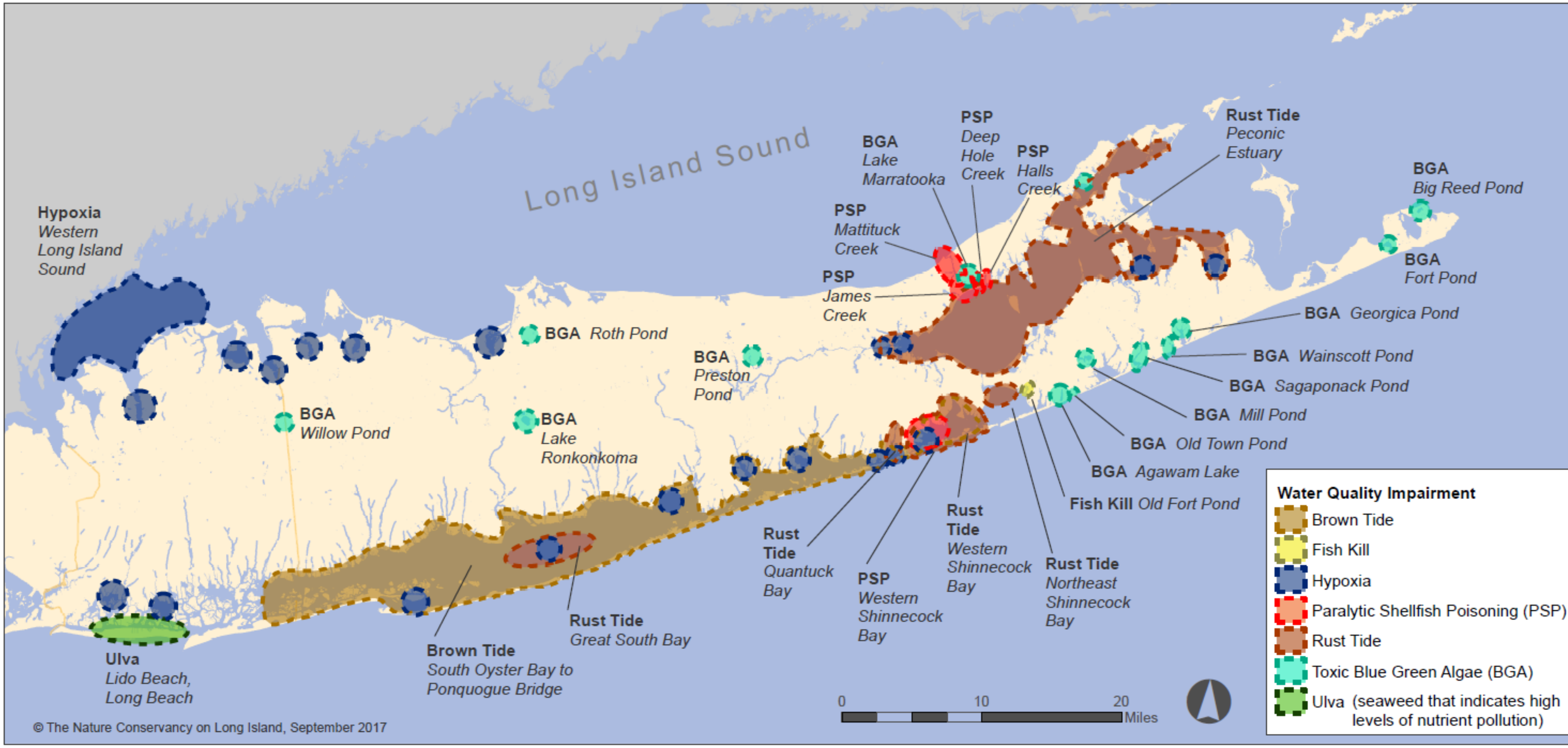
Stony Brook University School of Marine and Atmospheric Sciences

LICCRA

Long Island Water Quality Impairments
Summer 2017

The Nature Conservancy
Protecting nature. Preserving life.



Suffolk County:

500,000 conventional septic systems +

Sole Source Aquifer +

World class beaches, bays and marine resources =

Crisis

And

Opportunity

The Economics of Innovation

Savings of $.9 Billion to $6.8 Billion

	Best Case	Medium Case	Worst Case
Systems replaced/ retrofitted (Total)	297,500	403,750	510,000
Systems benefiting from price reduction	165,600	290,550	408,340
Nominal cost of doing nothing over 30 years	$6B	$9.8B	$14.4B
Nominal costs using new technology over 30 years	$5.1B	$6.6B	$7.6B
Nominal cost savings over 30 years	**$0.9B**	**$3.2B**	**$6.8B**

Center Goal:

To marshal the public and private-sector resources of New York State and beyond to develop more cost-effective technologies that will restore and protect water quality.

What We Do:

- Pursue strategic research that will inform refinements to existing technology;
- Develop novel and affordable approaches for nitrogen and contaminant removal;
- Actively foster collaborations with Suffolk County and beyond that will promote innovation and solutions.

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Who We Are:

- **Co-Directors:** Drs. Chris Gobler and Hal Walker
- **Program Director:** Frank Russo, P.E.
- **Research Coordinator:** Dr. Roy Price
- **Center Administrator:** Ms. Hilary Wolfskill
- **Faculty:** Drs. Xinwei Mao, Jackie Collier, Nils Volkenborn, Laura Wehrmann, Qing Zhu, Bruce Brownawell, Ben Hsiao, Alex Orlov
- **Post-doctoral Scholars:** Drs. Stuart Waugh and Pejman Hadi Myavagh
- **Graduate students:** Molly Graffam, Samantha Roberts, Tricia Clyde, Zoe Smith, Kylie Langlois, Sarah Lotfikatouli, Zahra Maleki Shahraki

Short Term Objectives:

- R & D focus on OWT technology to accelerate innovation in field.
- **10:10:30**
  - ✓Reduce nitrogen levels to **below 10 mg/liter**.
  - ✓**Cost $10,000 or less per** (typical) household to install, and less than $500 per annum to maintain.
  - ✓Have a **life expectancy of at least 30 years**.
- Communicate knowledge and progress to key stakeholders.

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Develop critical facilities at Stony Brook University to support development of I/A OSTS.

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Methodological capabilities developed by CCWT

Analyte	Analytical Capabilities
Nutrients	Total N, NOx (NO3- and NO2-, sum), NH4+, N2O, N2, PO4 (Orthophosphate), Total P, DON, PON, TKN
Field Geochemistry	Temp, pH, BOD, Alkalinity, DO, TSS, Turbidity
Nitrogen transformation Rates	Nitrification, denitrification, ANNOMOX, DNR,: N2, N2O, NO (MIMS)
Microbial Diversity and Function	Total and Fecal Coliform, Enterococci, DNA and RNA and functional gene analysis using metagenomics by tag-sequencing of 16S rRNA genes and of whole-metagenome shotgun by Illumina Miseq., quantitative analysis of functional species (qPCR)
Major Cations, Anions	Al, Ba, Ca, K, Mg, Mn, Na, Si, Sr, F, Cl, Br, SO4
Trace Metals	Cu, Fe, Mn, Cd, Pb, Hg, As, Zn
Pharmaceuticals and Personal Care Products	DEET, Bisphenol A, Nicotine, Acetaminophen, Caffeine, Ibuprofen, Warfarin, Acesulfame K, Cotinine, Paraxanthine, DEET, Chlofibric Acid, Primidone, Naproxen, Carbamezapine, Salbutamol (Albuterol), Gemfibrozil, Cimetidine, Sulfamethoxazole, Ketoprofen, Diphenhydramine, Propranolol, Atenolol, Metoprolol, TCEP, Trimethoprim, Diclofenac, Warfarin, Fluoxetine, Ranitidine, Furosemide, Ciprofloxacin, Nifedipine, Fenofibrate, Amoxicillin, Diltiazem, Atorvastatin, Azithromycin, Furosemide, Estrone, β-Estradiol, 17α-Ethynylestradiol, Nonylphenol, more

➢ Conventional parameters:

- Nitrogen species
- BOD (biological oxygen demand)
- TSS (total suspended solids)
- pH
- Alkalinity

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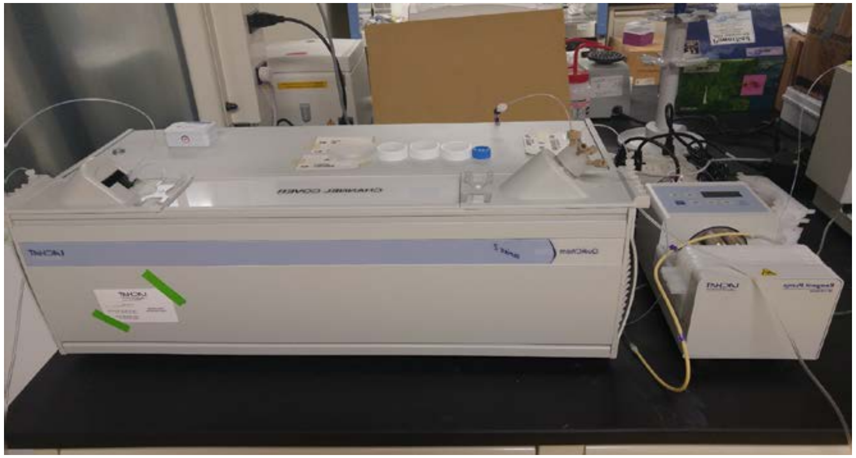
Nitrogen removal efficiency: a basic way to compare different systems

N removal efficiency =
$1 - (N_{out} / N_{in})$

Lachat auto-analyzer



NH_4^+, TkN, NO_3^-, NO_2^- & TN

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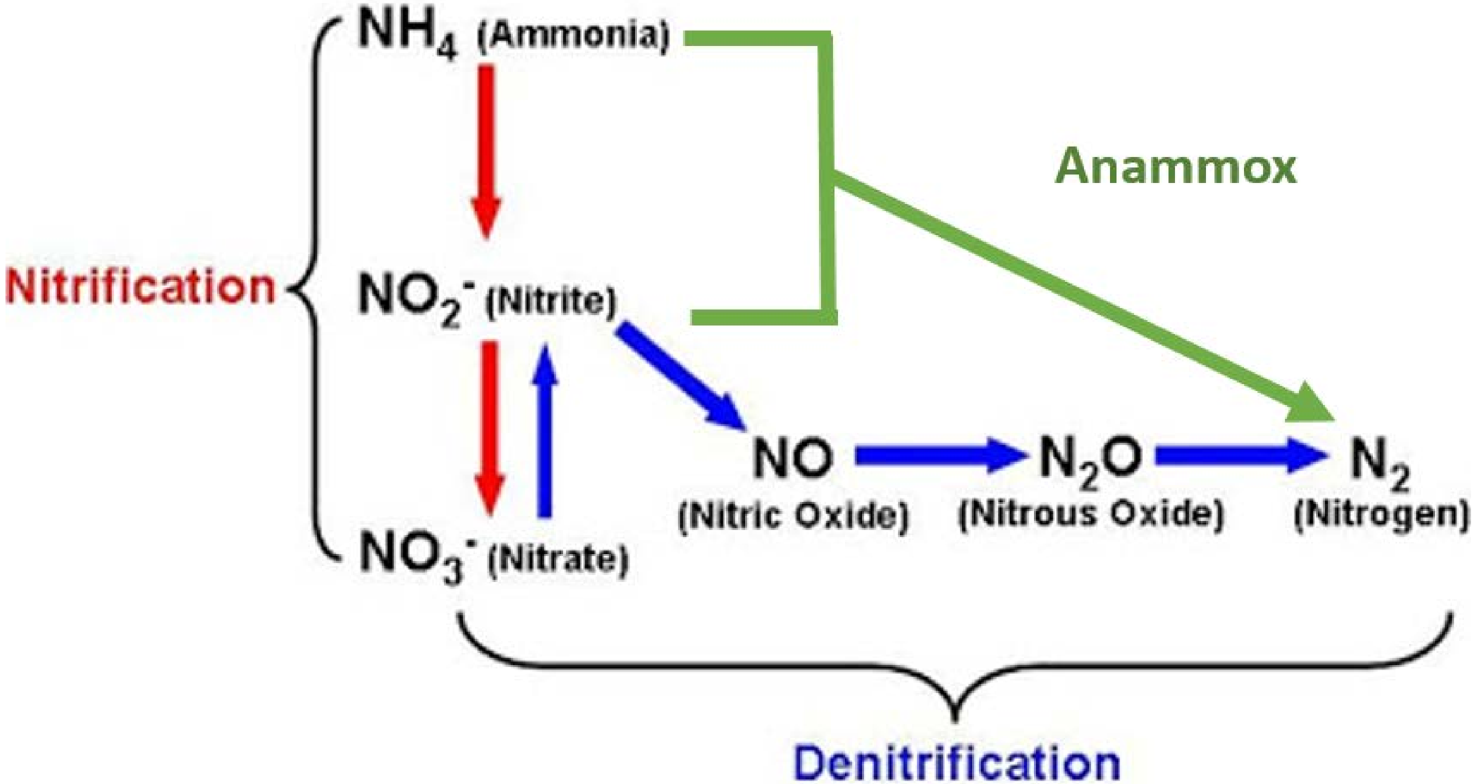
Measure nitrogen transformations in OWTS systems



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Measuring N-transformation rate processes

Membrane Inlet Mass Spectrometer (MiMS) → N_2

Gas Chromatograph

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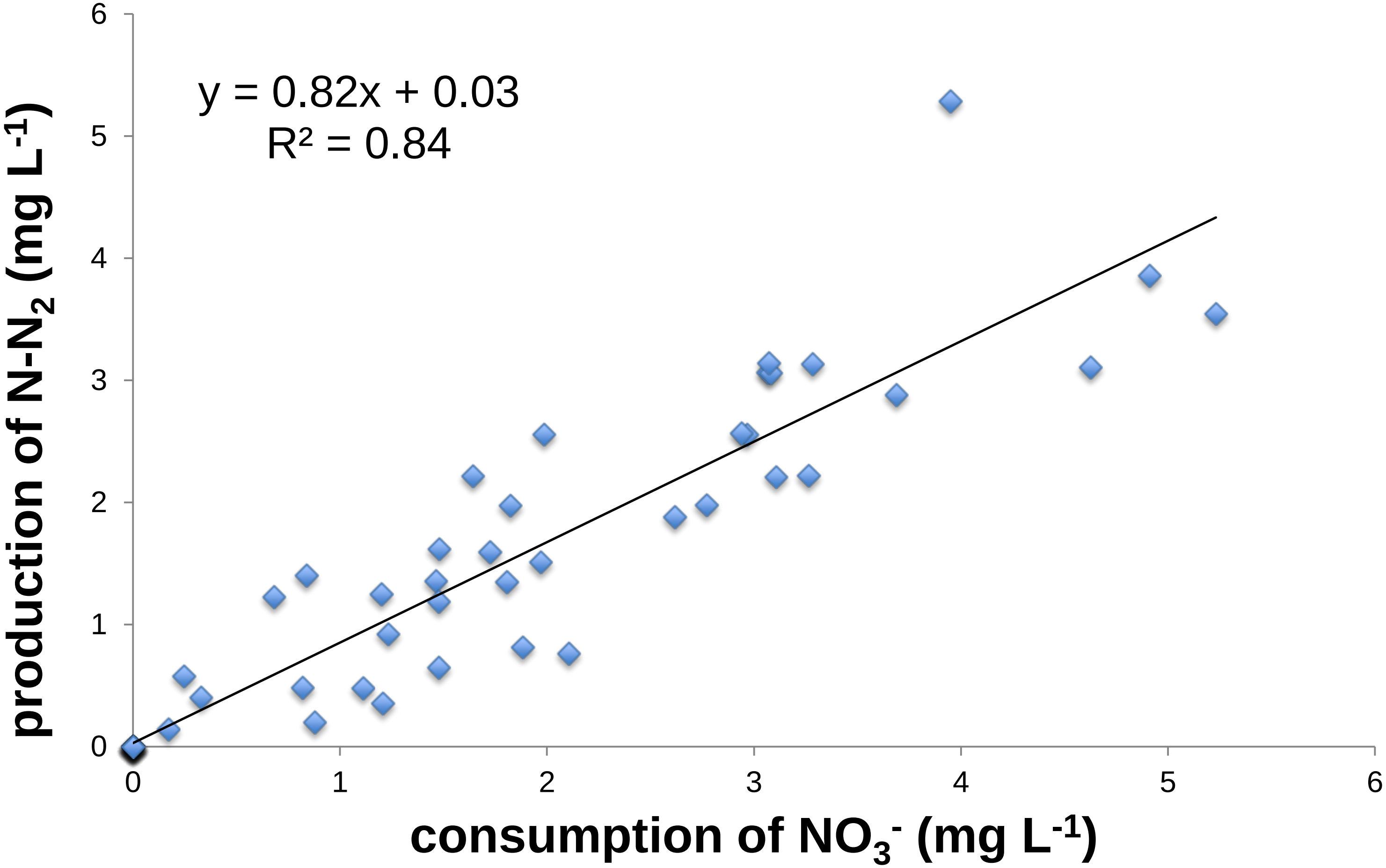
Measuring denitrification rates



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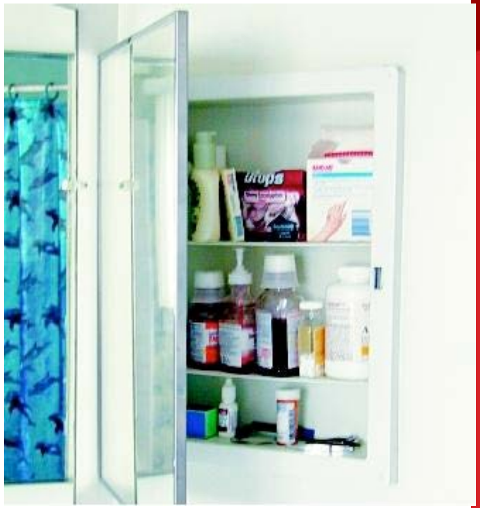
Non-nitrogenous compounds of concern

- Pharmaceuticals and other drugs
- Antibiotics
- Hormones
- Steroids
- Quaternary Ammonium Compounds (QACs)
- Surfactants
- Personal Care Products
- Pathogens
- Metals
- Phosphate and other Anions
- Cations (Boron)

“Contaminants of Emerging Concern”

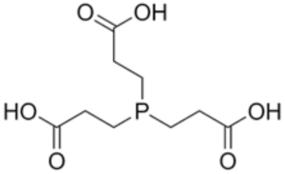


- Includes:
  1. Pharmaceuticals and many other drugs
  2. Personal Care Products
  3. Quaternary Ammonium Compounds

- Concerns
  - Common in many household products
  - Carcinogenic
  - Endocrine disruptors
  - Can disrupt sewage treatment

➢ List of some Contaminants of Emerging Concern that can be measured by CCWT

Acesulfame K	DEET	Nifedipine
Acetaminophen	Diclofenac	Nonylphenol
Amoxicillin	Diltiazem	Paraxanthine
Atenolol	Diphenhydramine	Primidone
Atorvastatin	Estrone	Propranolol
Azithromycin	Fenofibrate	Ranitidine
B-estradiol	Fluoxetine	Salbutamol (Albuterol)
Bisphenol A	Furosemide	Sulfamethoxazole
Caffeine	Gemfibrozil	TCEP
Carbamezapine	Ibuprofen	Trimethoprim
Chlofibric Acid	Ketoprofen	Warfarin
Cimetidine	Metoprolol	
Ciprofloxacin	Naproxen	
Cotinine	Nicotine	



TCEP (*Tris(2-chloroethyl) phosphate*)
A fire retardant found in clothes and many other household products

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Measuring Contaminants of Emerging Concern Requires special instrumentation….

Time-of-flight Mass Spectrometry (TOF-MS) coupled to Liquid chromatography (LC), from Agilent Technologies

Separates and measures the concentration of complex organic compounds intact

Laboratory: Dr. Bruce Brownawell

Students: Patricia Clyde, Ph.D.

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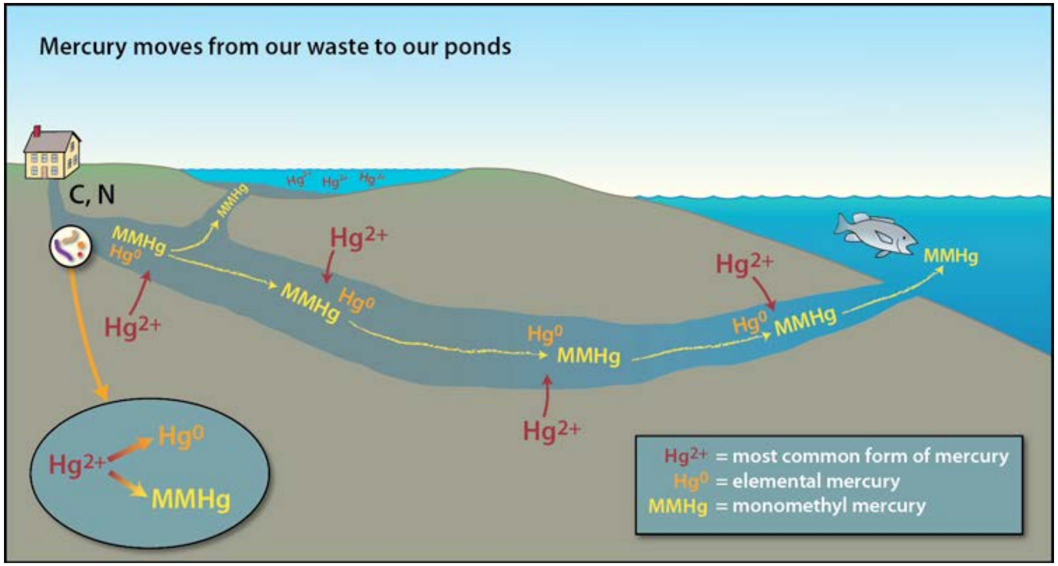
Metals

- Copper
- Manganese
- Lead
- Mercury
- Cadmium
- Zinc



Lamborg et al., 2013

- Concerning for several reasons
  - Can decrease the efficiency of sewage treatment
  - Copper pipes with lead solder in many homes
  - Toxic, Carcinogenic
  - Speciation (oxidation state) important
  - Composting generates can Mn, Cd Contamination

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➢ Total Metals Analyses

Inductively Coupled Plasma – Mass Spectrometry (ICP-MS), Element 2 from Finnigan

Atomic Fluorescence Spectrometer (AFS), Illumina 3300 from Aurora

➢ Metal Speciation

-Couple these instruments to High Performance Liquid Chromatograph, from Shimadzu

Laboratory: Dr. Roy Price

Students: Zoe Smith, M.S.

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Effective Nitrogen Removal is Engineered Microbial Ecology

INFLUENT:
Ammonium (NH_4^+)
Plus Or

N_2

DENITRIFIERS:
Convert Nitrate to
as (N_2)

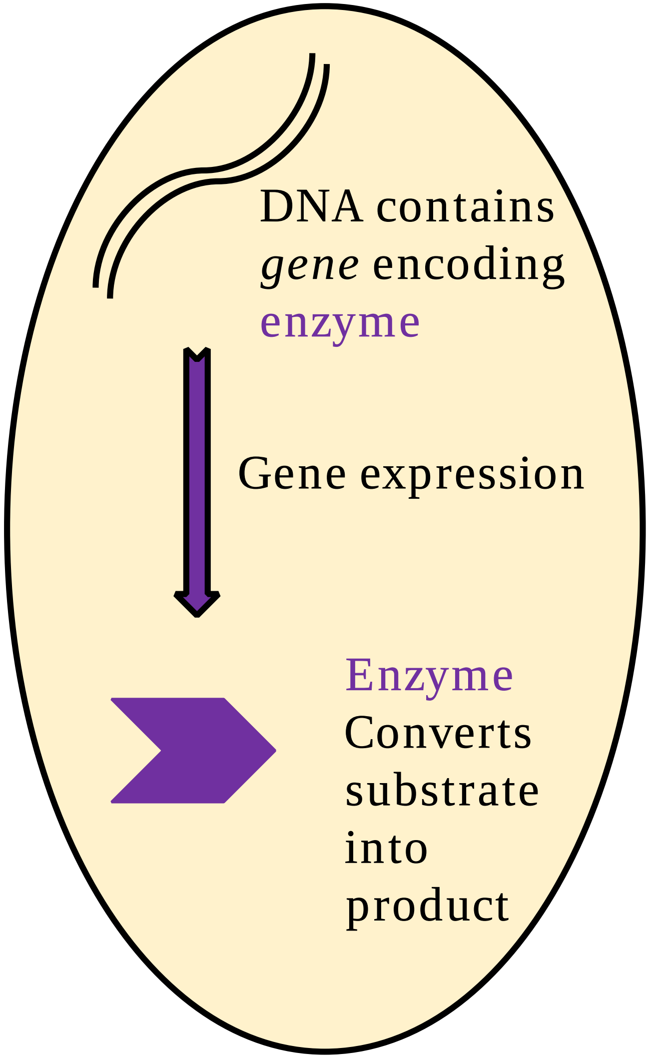
- Using DNA sequencing we can learn what microorganisms are present in different parts of existing OWTS
- We can use this information make more informed engineering choices about how to maximize nitrogen removal during OWTS

N:

FROM PRIMARY TREATMENT:
Ammonium (NH_4^+)

Convert
NH_4^+ to Nitrite (NO_2^-)
Then
Nitrite to Nitrate (NO_3^-)

Functional Genes

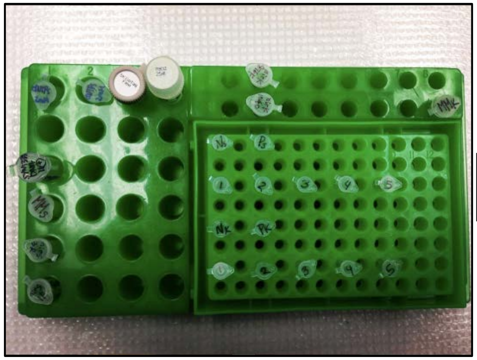


Example: Denitrification

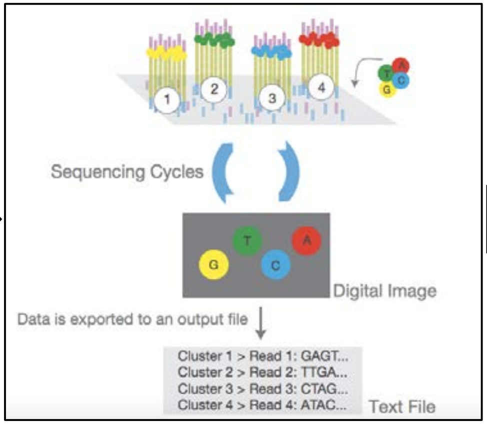
Gene = *NirS*

Enzyme NirS (nitrite reductase)

NO_2^- -> -> N_2



Samples collected
DNA extracted



DNA sequenced

Sequences analyzed
Diversity calculated

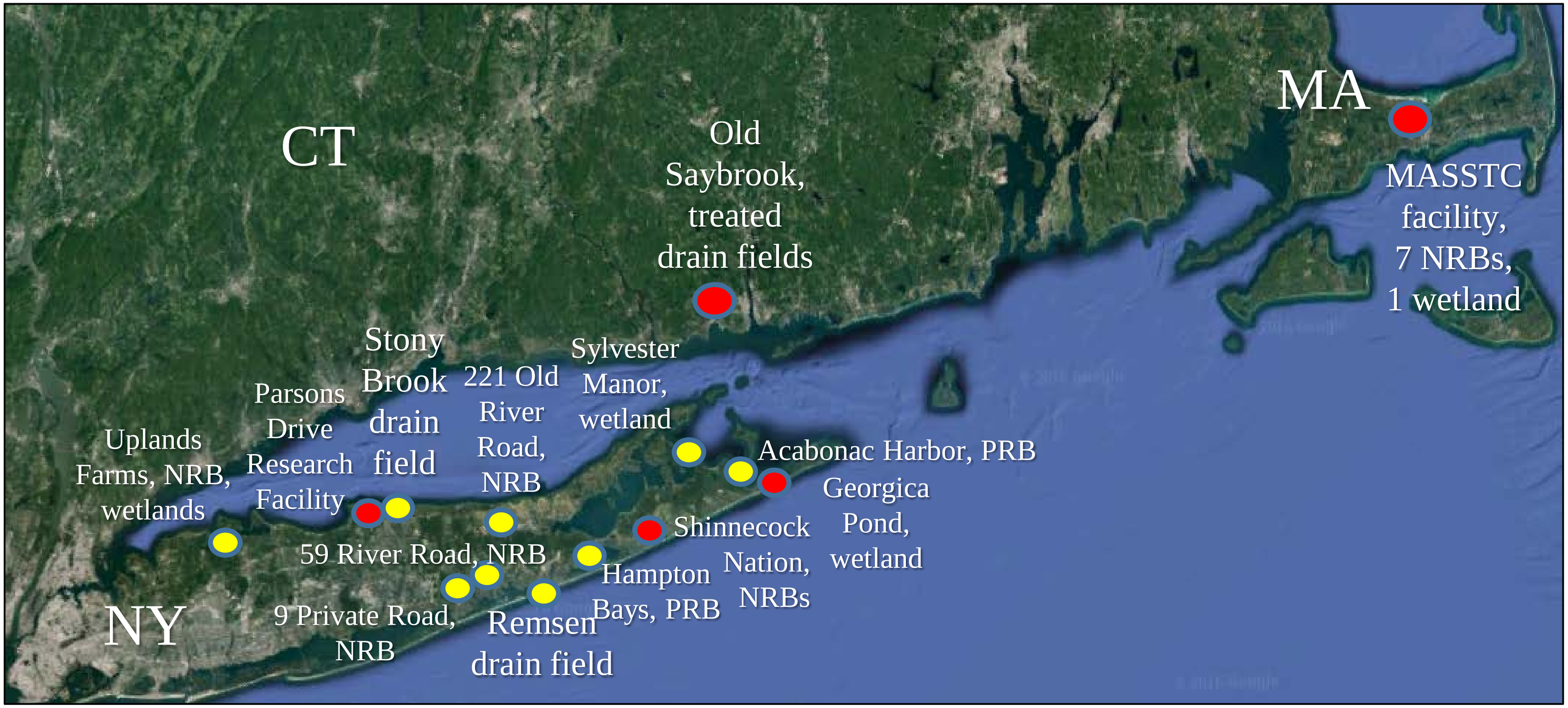
- NRBs rely on microbial processes, so characterizing the microbial community can potentially diagnose the “health” of an NRB.
- Answer: “**Is the NRB working as designed?**”

Nitrogen Reducing Biofilters

Pilot Installations Underway & Planned

	Nitrogen removing Biofilters	Permeable reactive barriers	Constructed Wetlands
Installed	• MA Test Center (7) • Suffolk County Pilot Program (3)	• Hampton Bays (1)* • Acabanoc Harbor (1)* *with Cornell CE	• Shelter Island, Sylvester Manor (1) • MA Test Center (1)
In progress	• Suffolk County Pilot Program (6)	• East Hampton (1)	• Uplands Farm (1)
Planned, next 6 – 12 months	• Shinnecock Indian Nation (10 – 20)	• Wainscott Pond	• Georgica Pond

CCWT regional projects

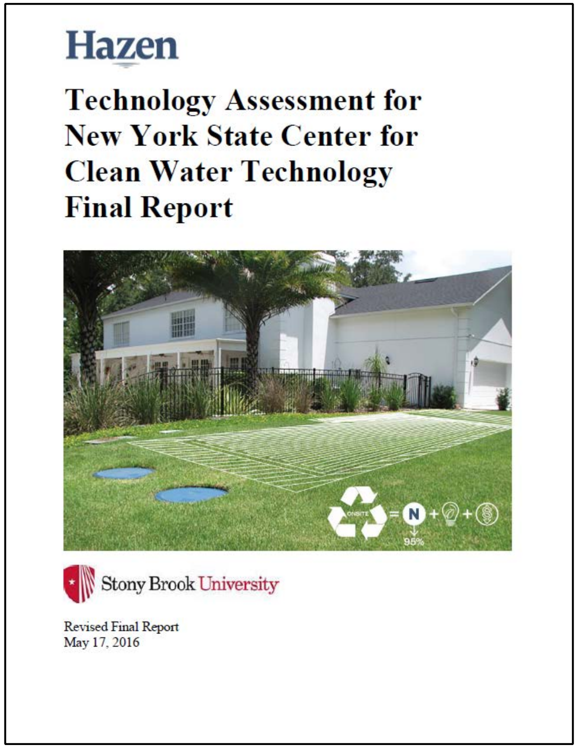


= Collaborative project with Suffolk County

= Project informing Suffolk County projects

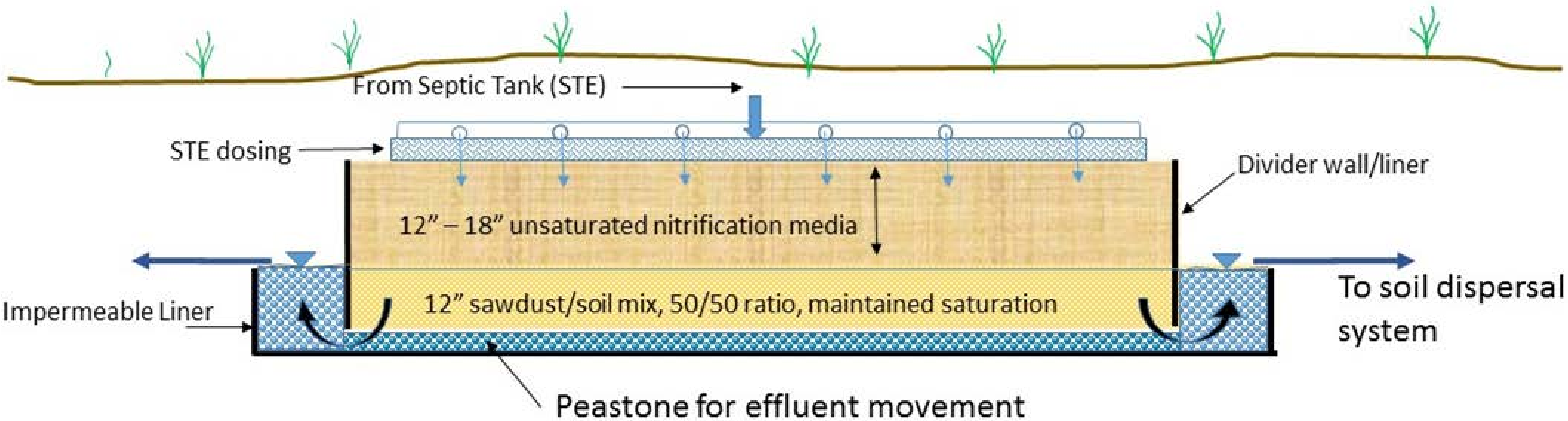
Technology Assessment

- Reviewed manufacturer information, research literature, past technology reviews
- Met with practitioners, researchers in the field, other stakeholders
- Engaged Hazen and Sawyer to compile existing information and develop a technology assessment



Nitrogen reduction soil, plant and wetland processes technology ranking summary

Top ranked = **nitrogen removing biofilter (NRB)**



CCWT NRB Design Charrette, 2016

- Two-day gathering of regional and national experts on NRBs.
- Consensus on testing Long Island native materials.
- Consensus building on function and optimal, next generation design.

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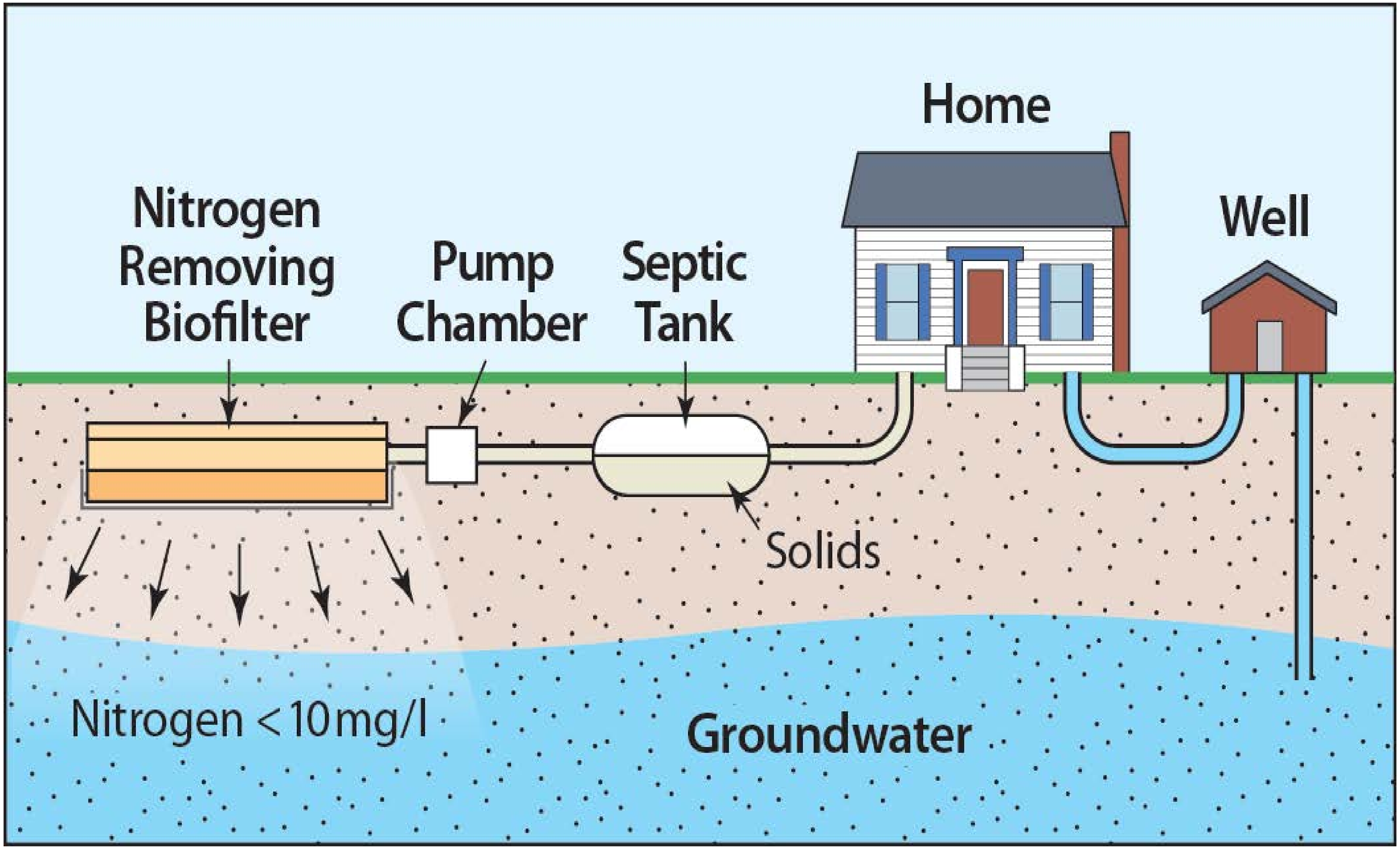
Nitrogen Removing Biofilters (NRB)



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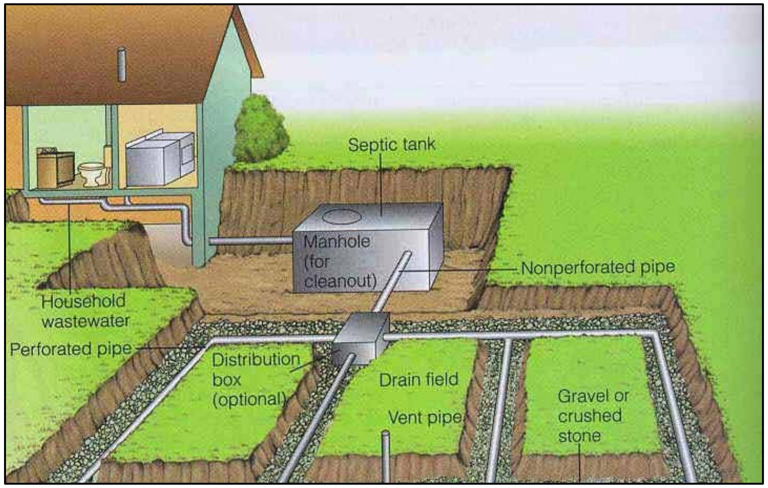
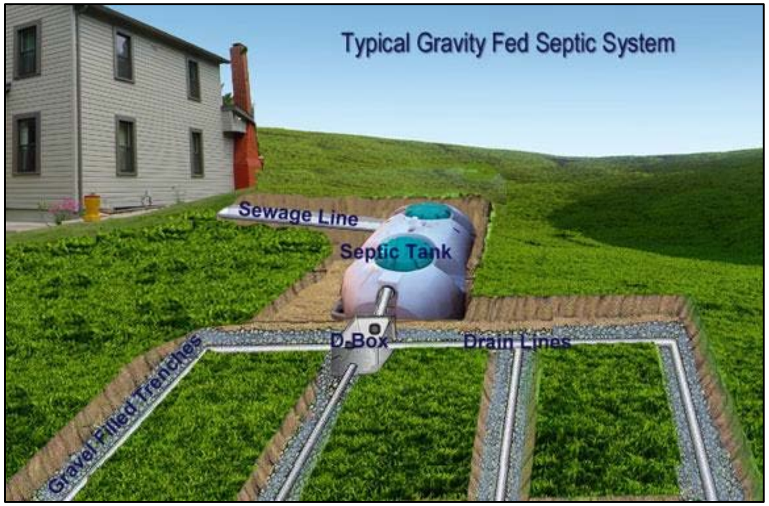
Standard drain field system

- Most common on-site wastewater disposal approach in US.
- Very rarely used on Long Island.
- More nitrogen removal than Long Island leaching ring systems due to proximity to surface.
- Shallow depth (< 2 ft) well-suited for coastal regions experiencing sea-level rise.





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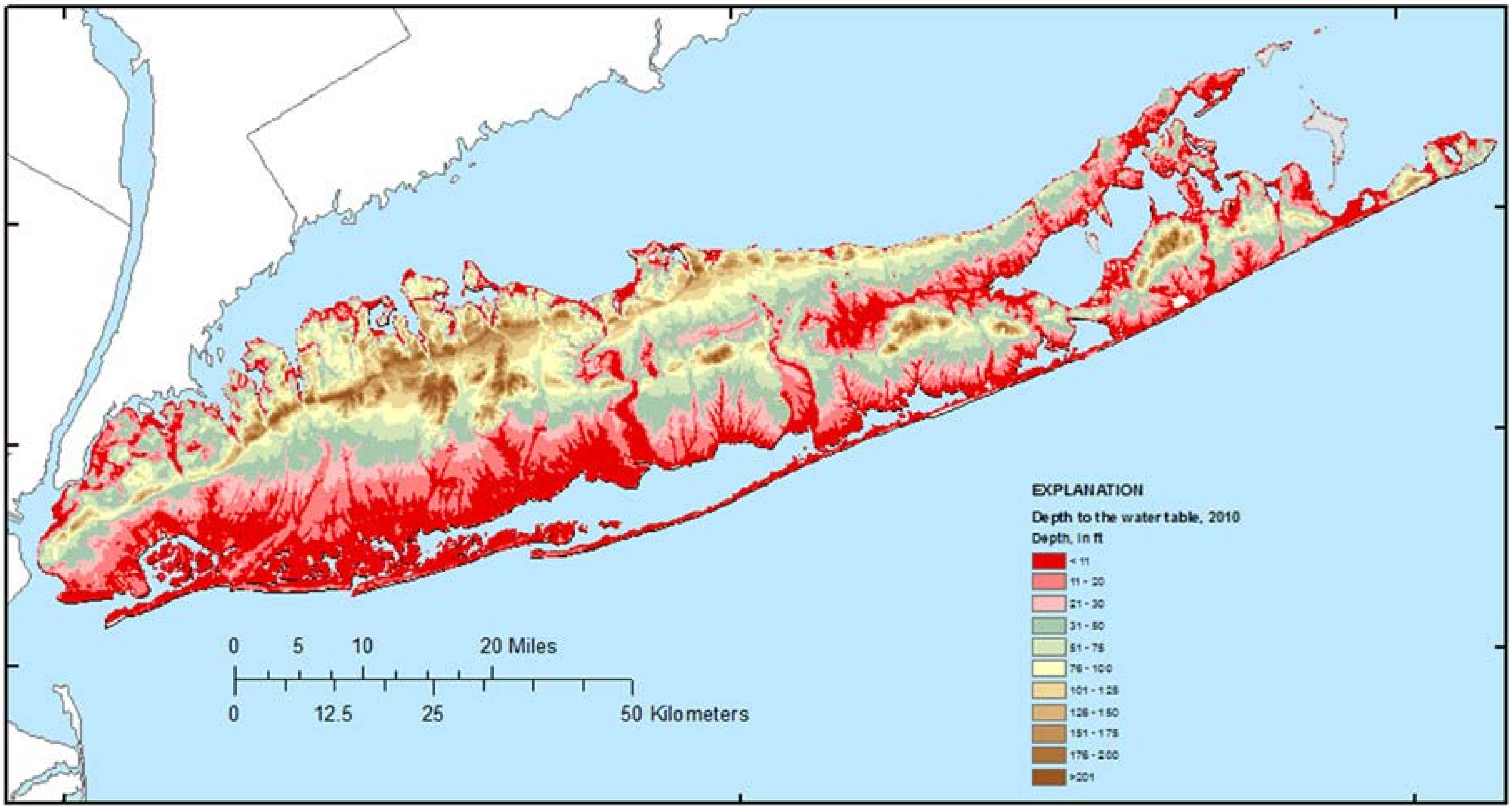
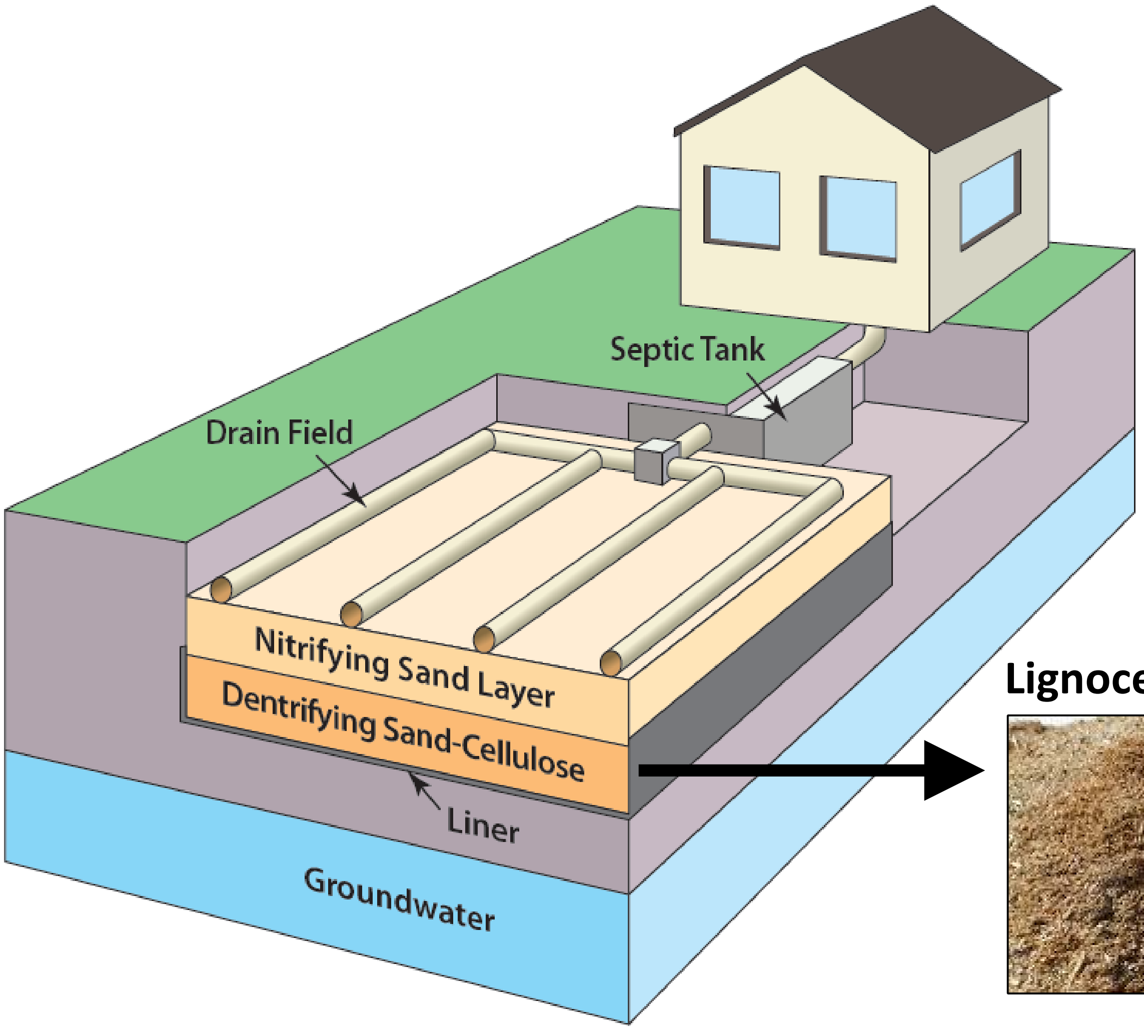
Depth to groundwater on Long Island



SoMAS estimates 7 ft of sea level rise this century.

FAR BEYOND

Nitrogen Removing Biofilters (NRB)



Lignocellulose = wood, chips, dust, etc

Carbon source to promote denitrification

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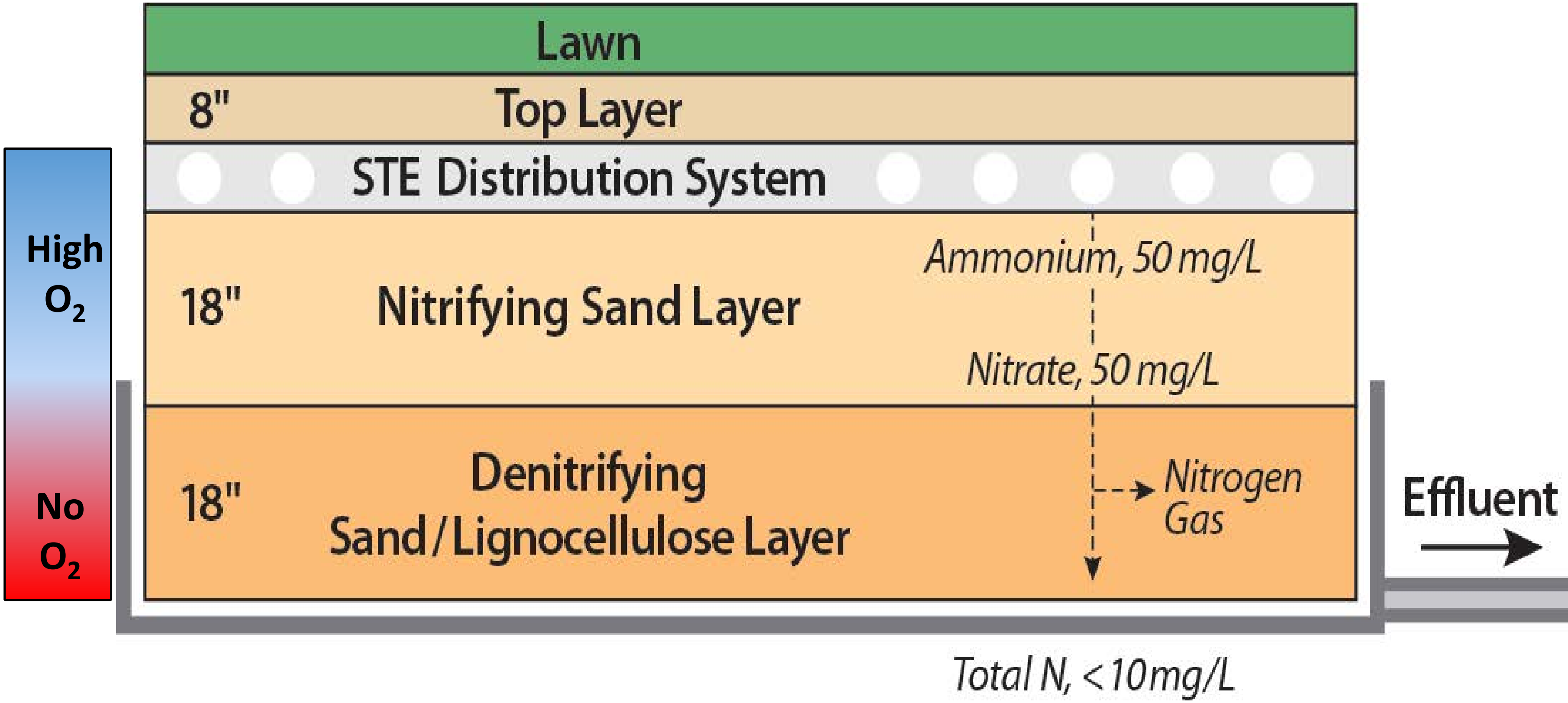
Nitrogen Removing Biofilters (NRB)



FAR BEYOND

MASSTC

Massachusetts Alternative Septic System Test Center

Director, George Heufelder

BCDHE

Barnstable County Department of Health and Environment

Promote - Protect - Support

90 YEARS OF SERVICE

1926 - 2016

MASSTC

The Massachutess Alternative Septic System Test Center was constructed on a site adjacent to the Massachusetts Military Reservation Wastewater Treatment Plant. The Center intercepts wastewater on its way to the treatment plant and distributes it to the test cells. Wastewater is from residential households and a county jail.

The graph is from G. Heufelder, Barnstable County

Long Island native sands and wood chips delivered to Massachusetts to create "NY NRBs"

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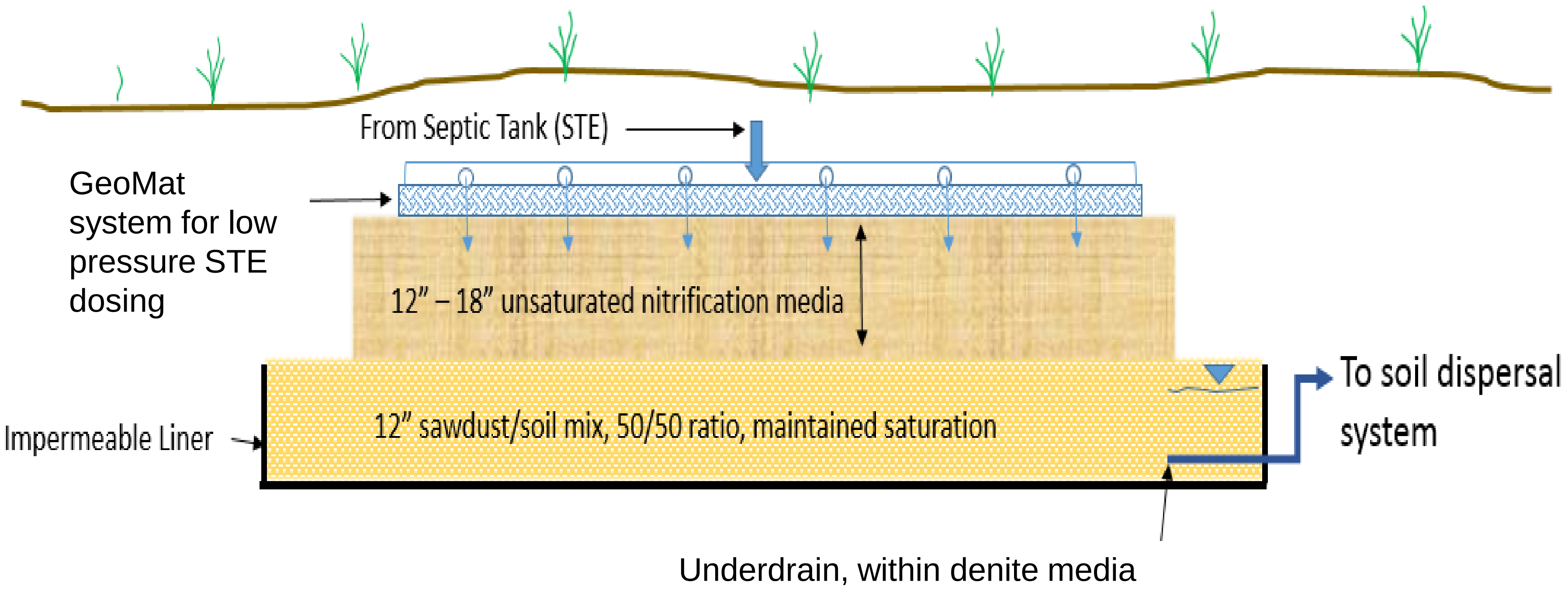
Unintended benefits of NRBs…

Lined, saturated NRB



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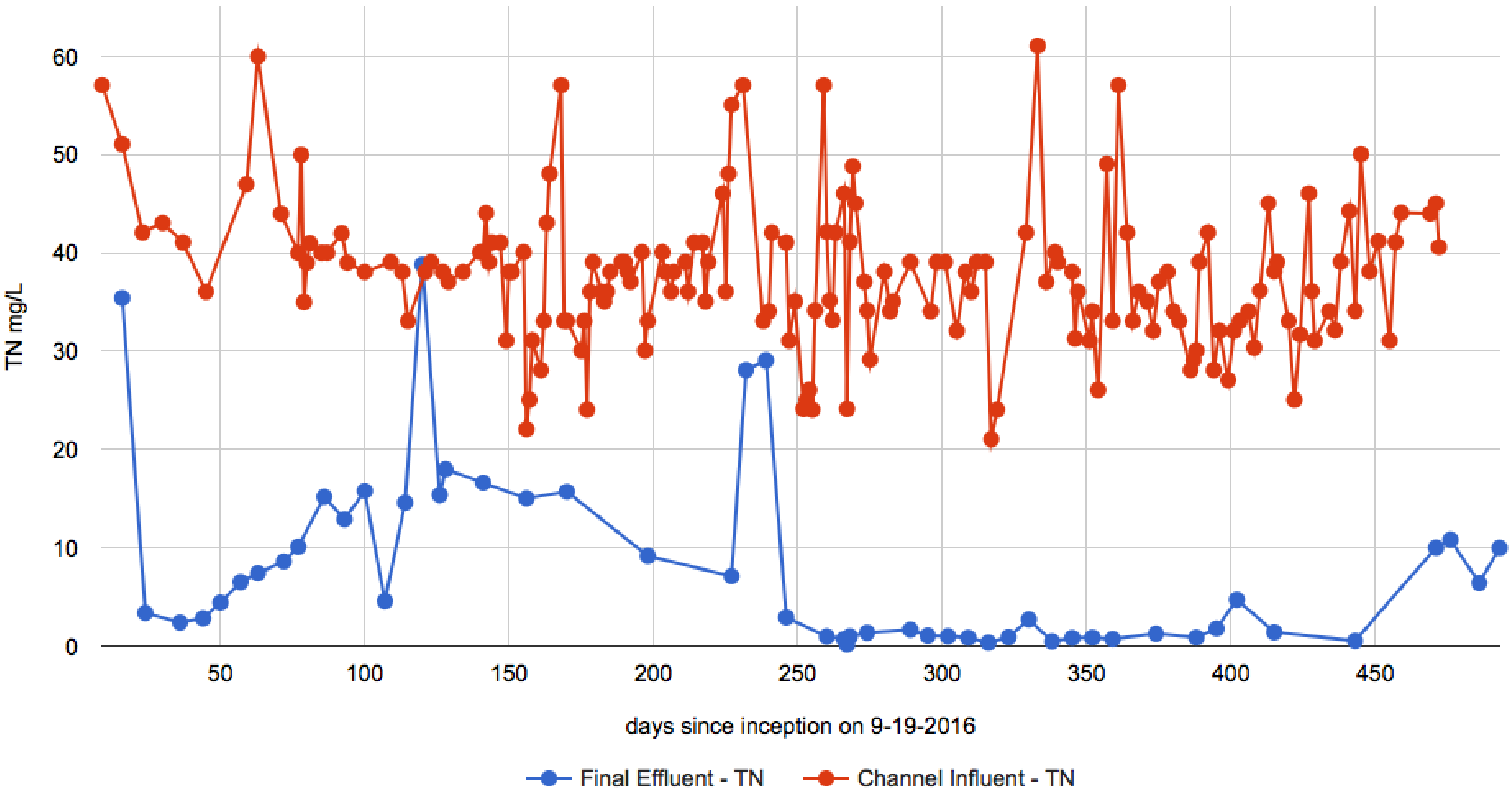
Lined, saturated NRB

Average total N = 7.9 mg/L

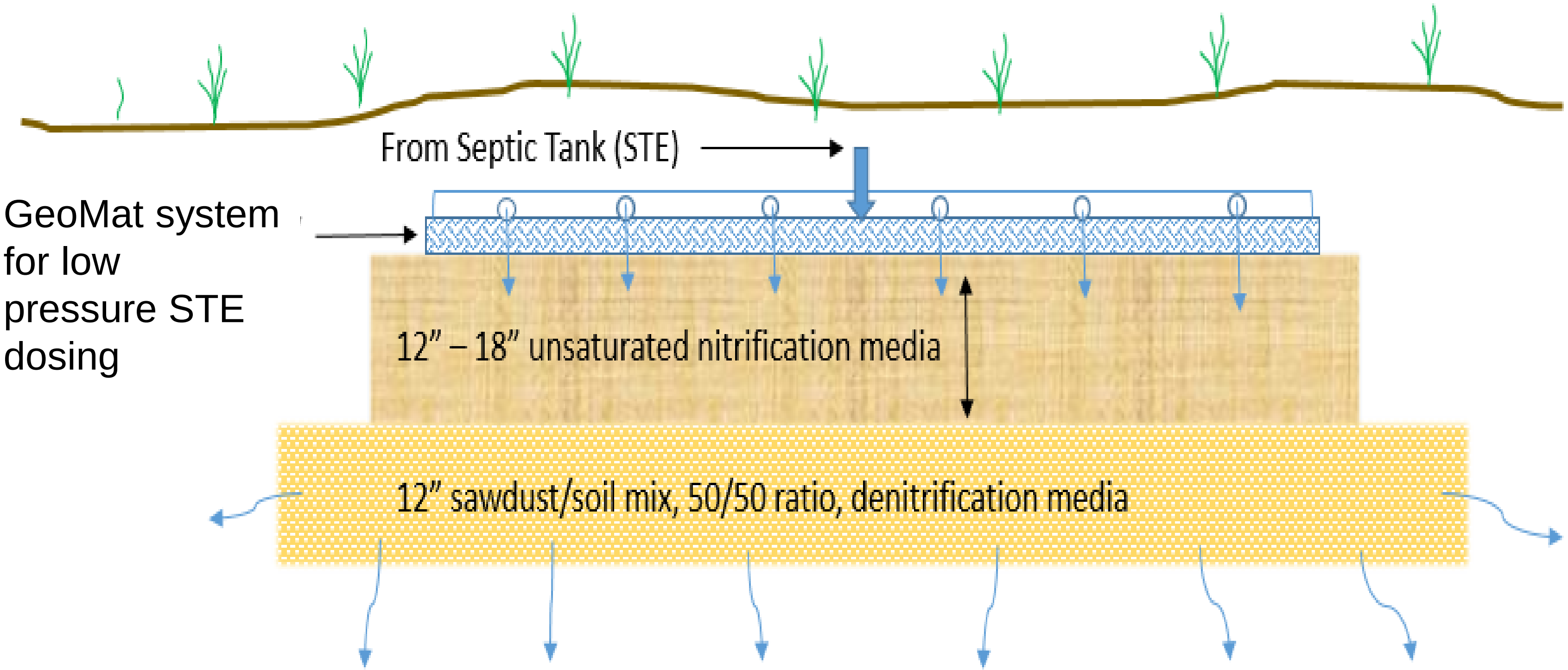
NY1



FAR BEYOND

Unlined, unsaturated NRB

GeoMat system for low pressure STE dosing



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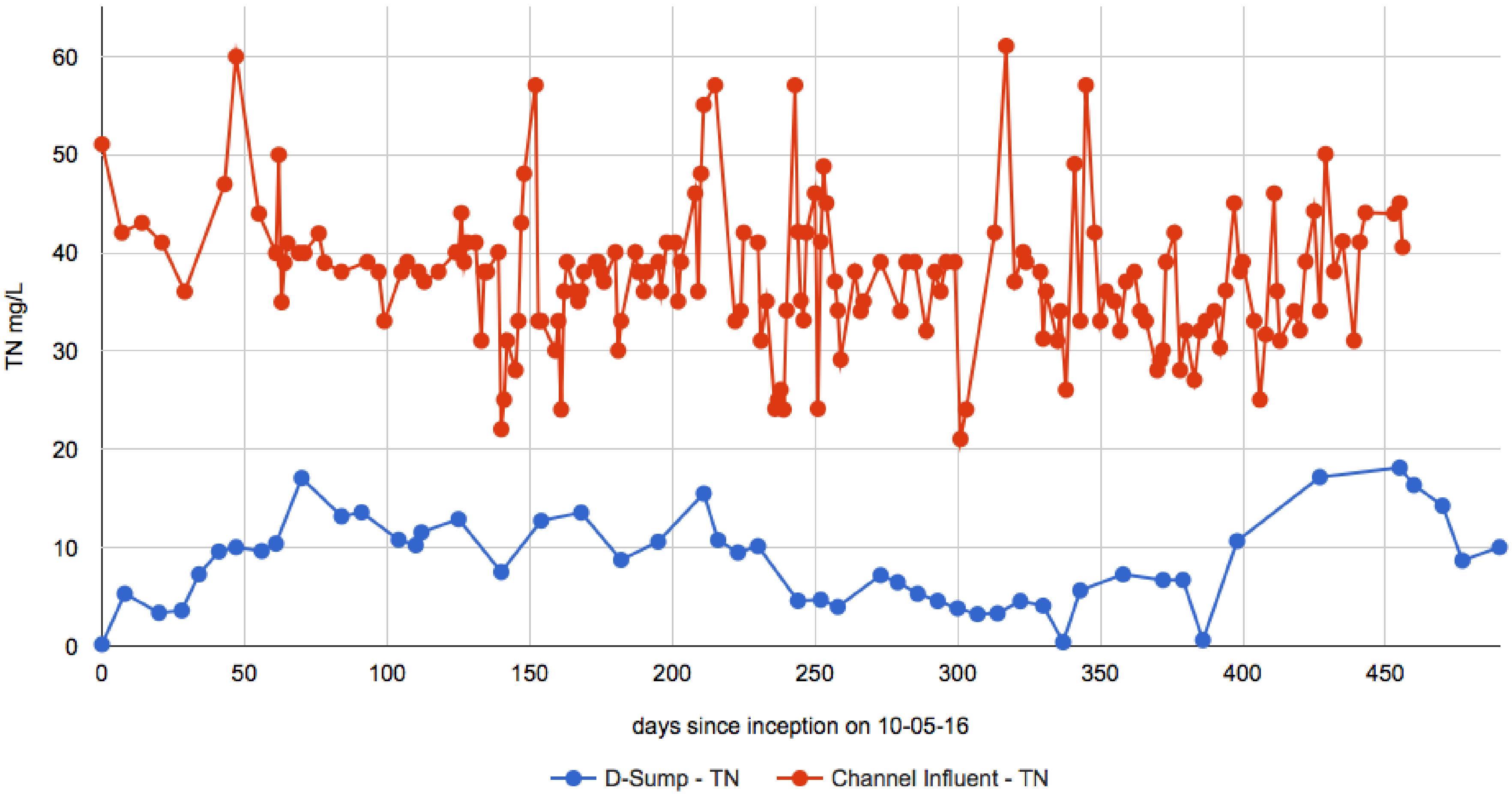
Unlined, unsaturated NRB

NY3

Average total N = 8.5 mg/L



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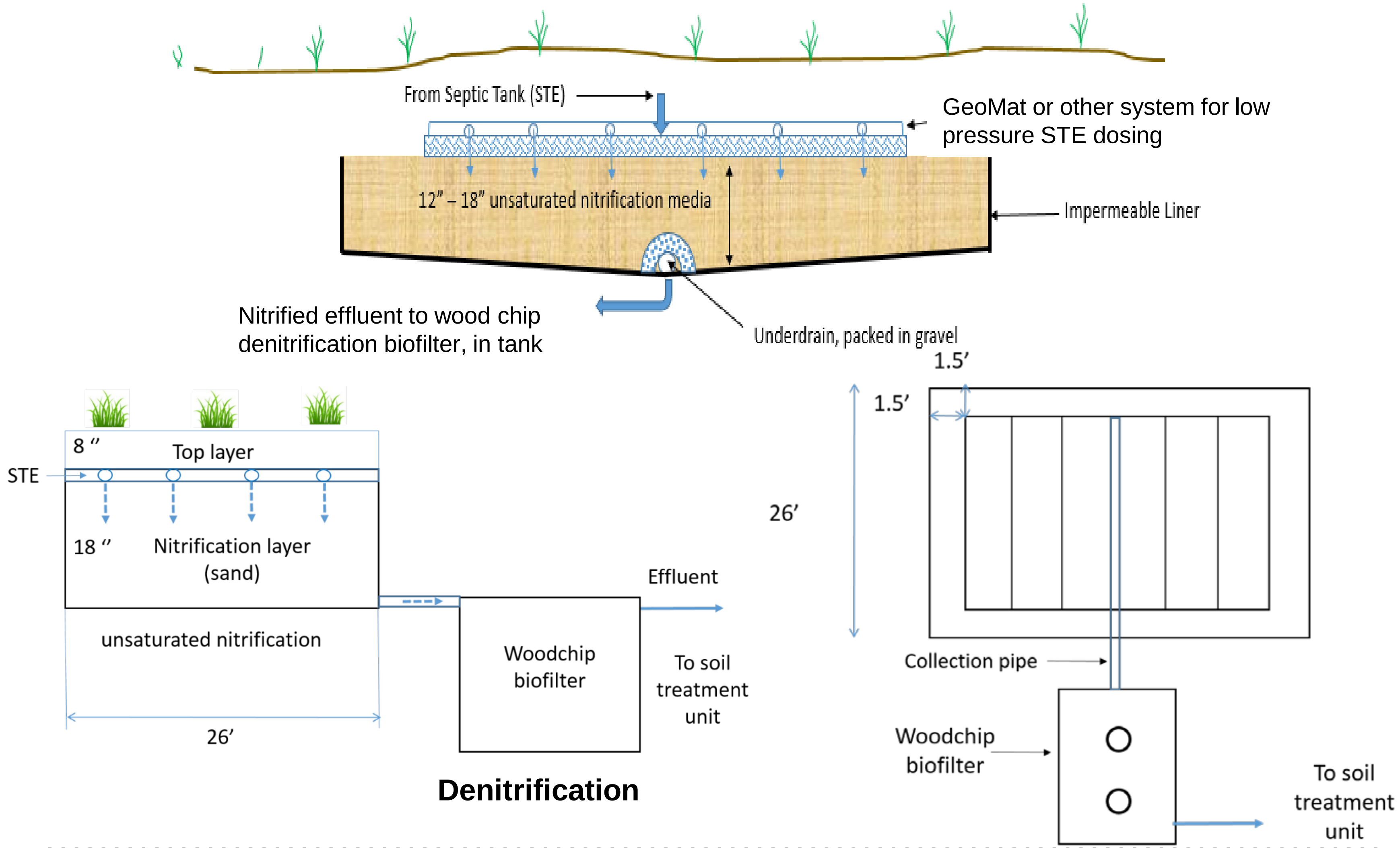
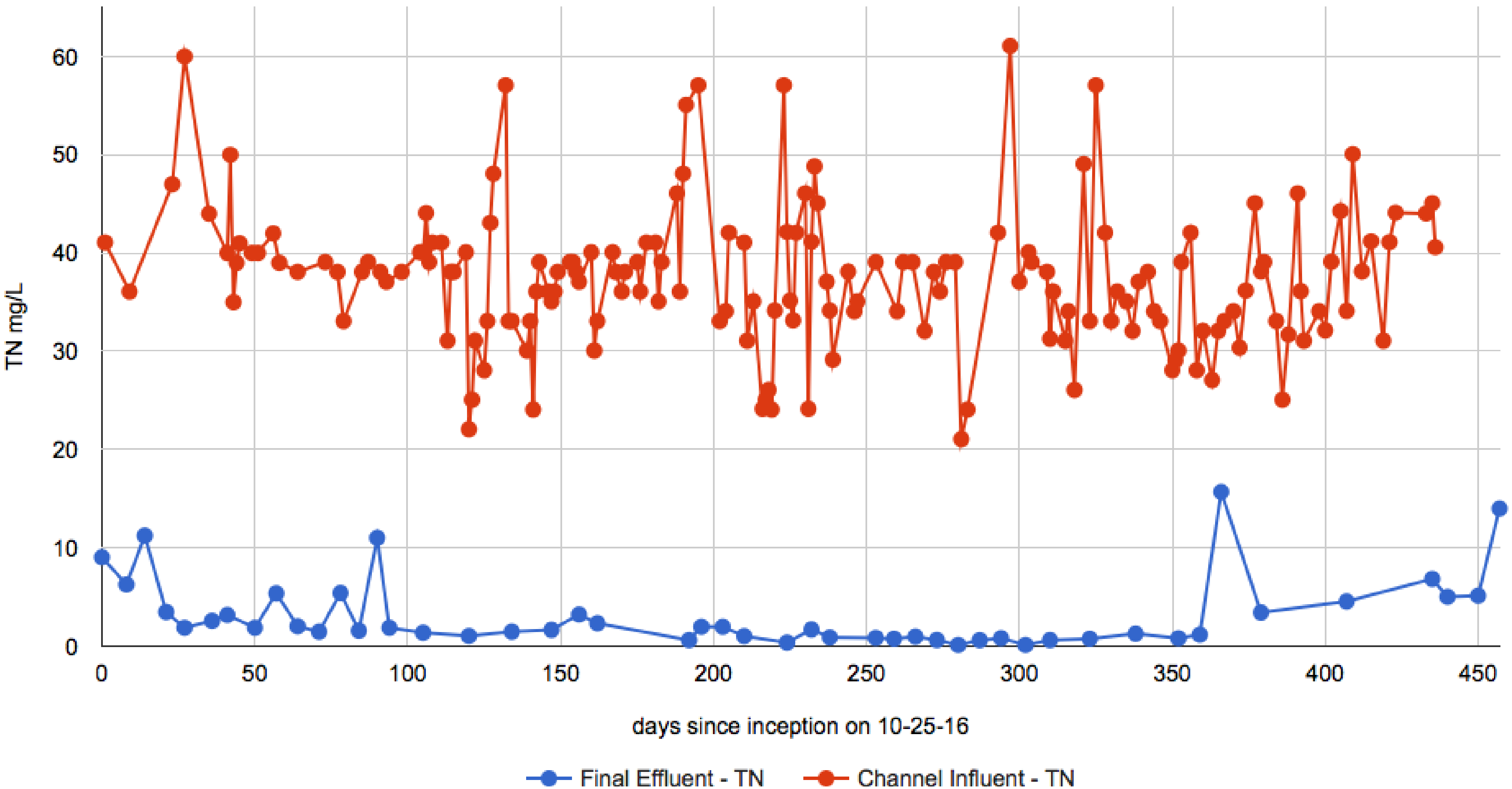
Replaceable woodchip biofilter



Replaceable woodchip biofilter

NY2

Average total N = <u>3.2 mg/L</u>



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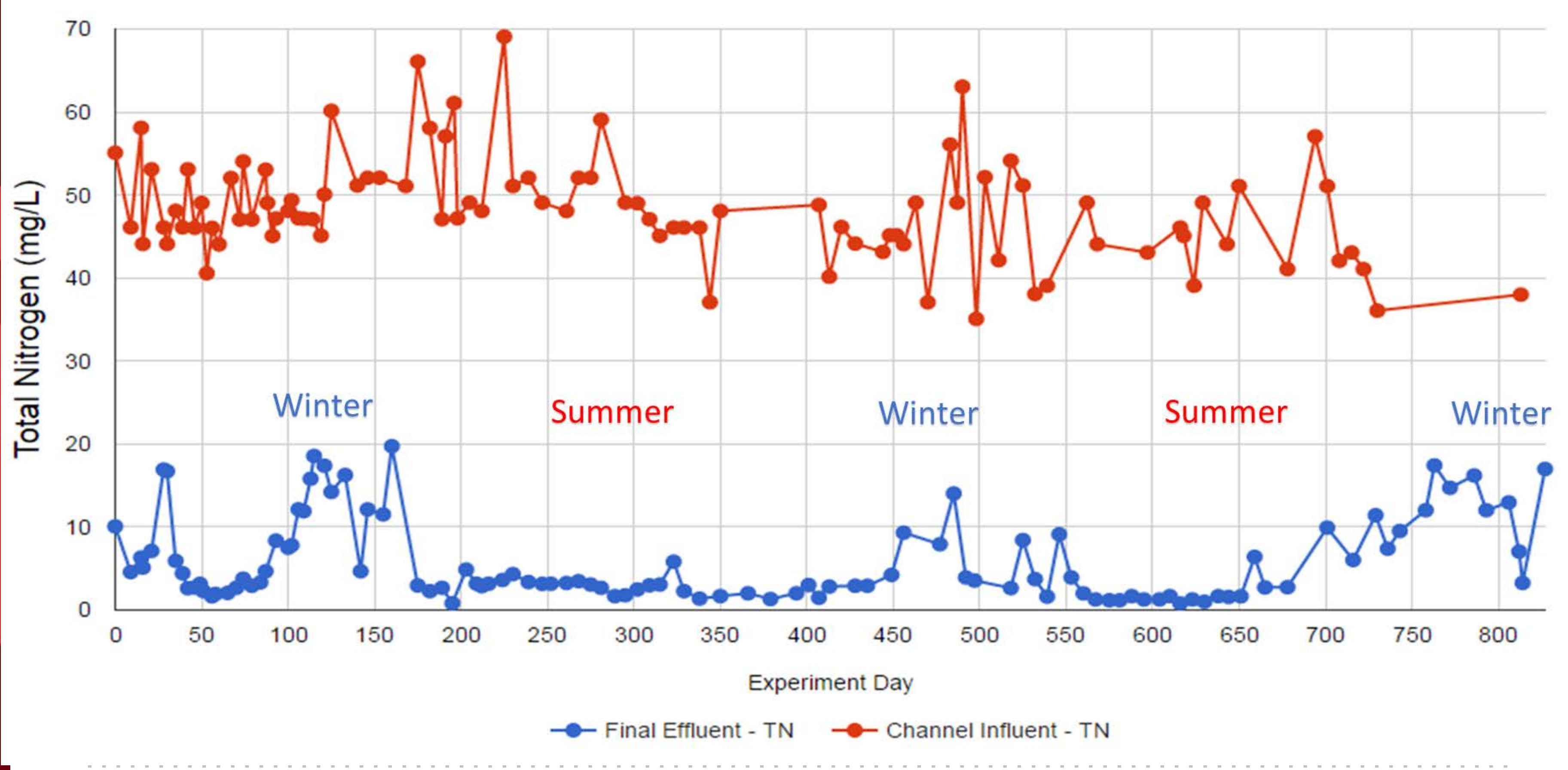
Two years of data from MASSTC system



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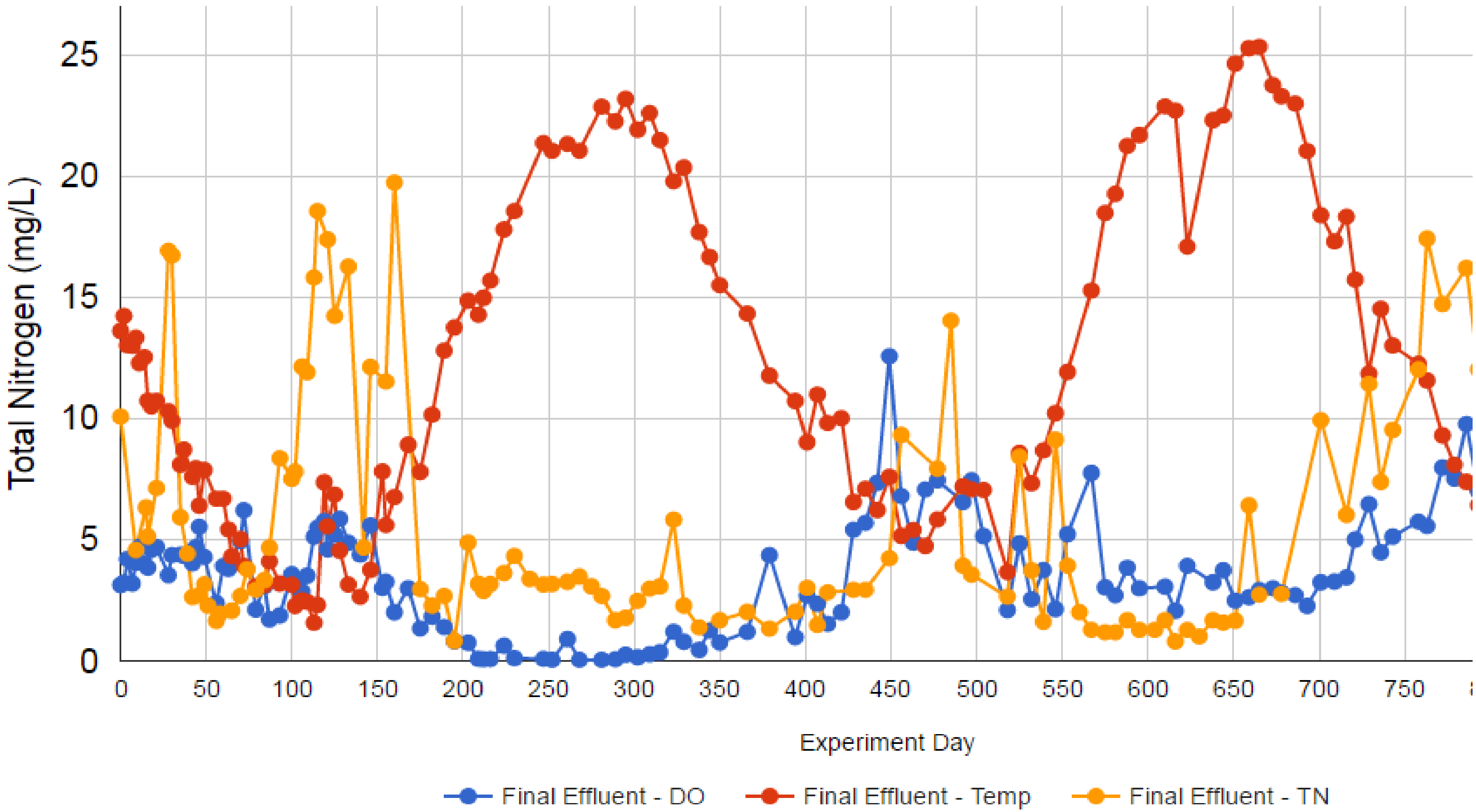
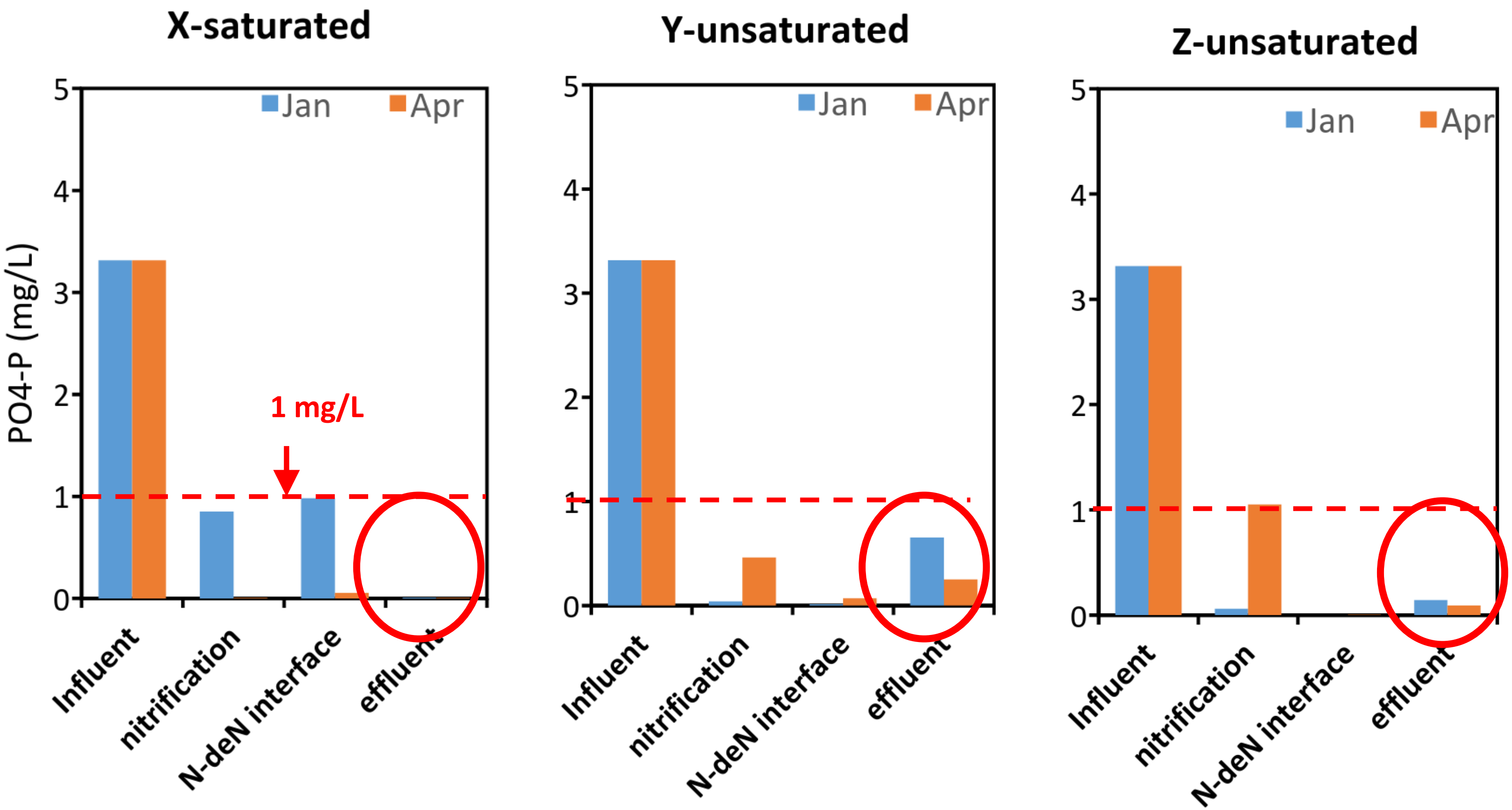
Two years of data from MASSTC system



FAR BEYOND

Phosphorus removal



~99-100% removal **~80-92% removal** **~96-97% removal**

– – 30-day average effluent TP requirement for surface water discharge, New York State

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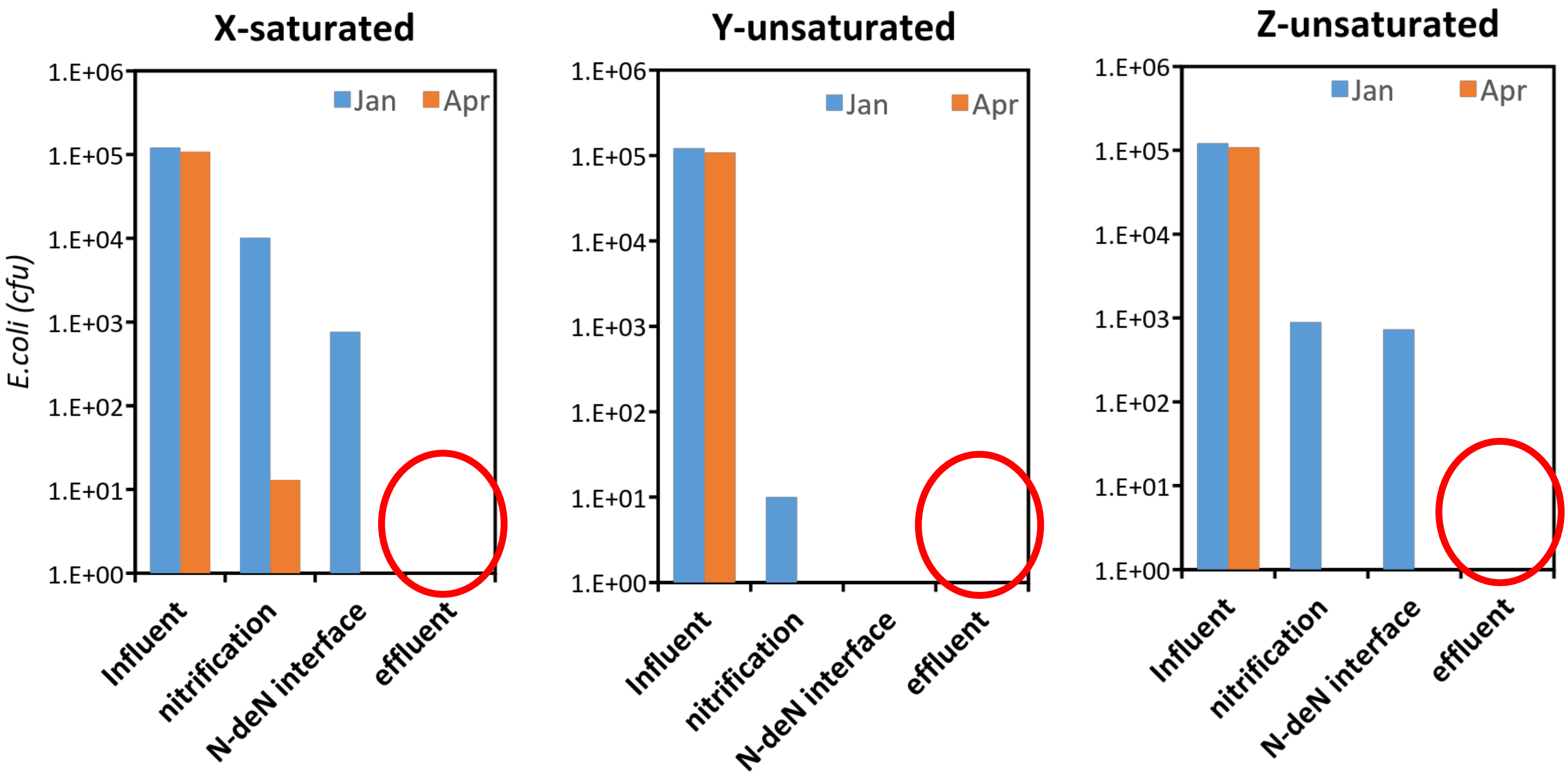
Microbial analysis----*E.coli* *(indicator of pathogens)*



100% removal **100% removal** **100% removal**

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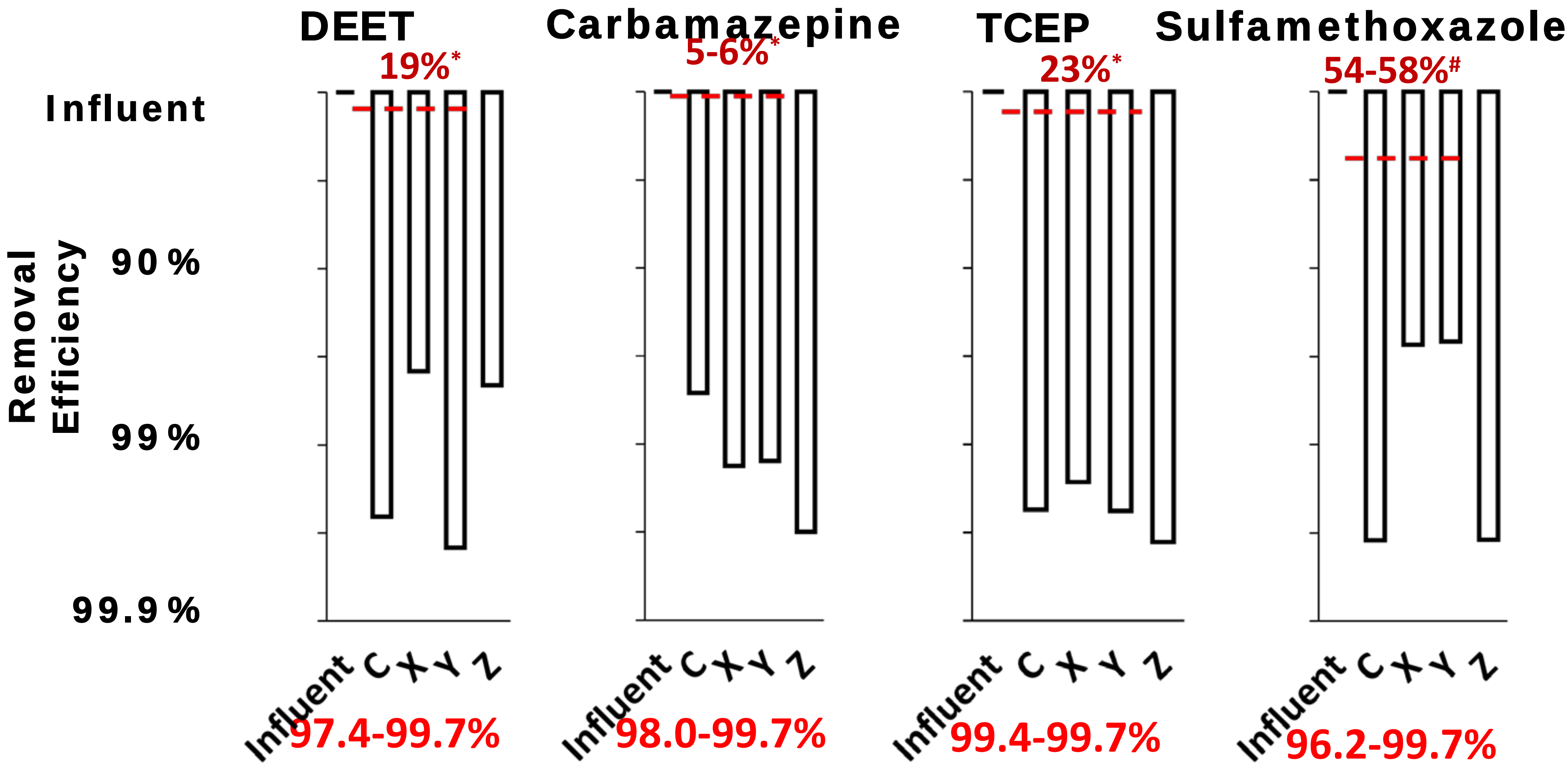
PPCPs (Pharmaceuticals and Personal Care Products)



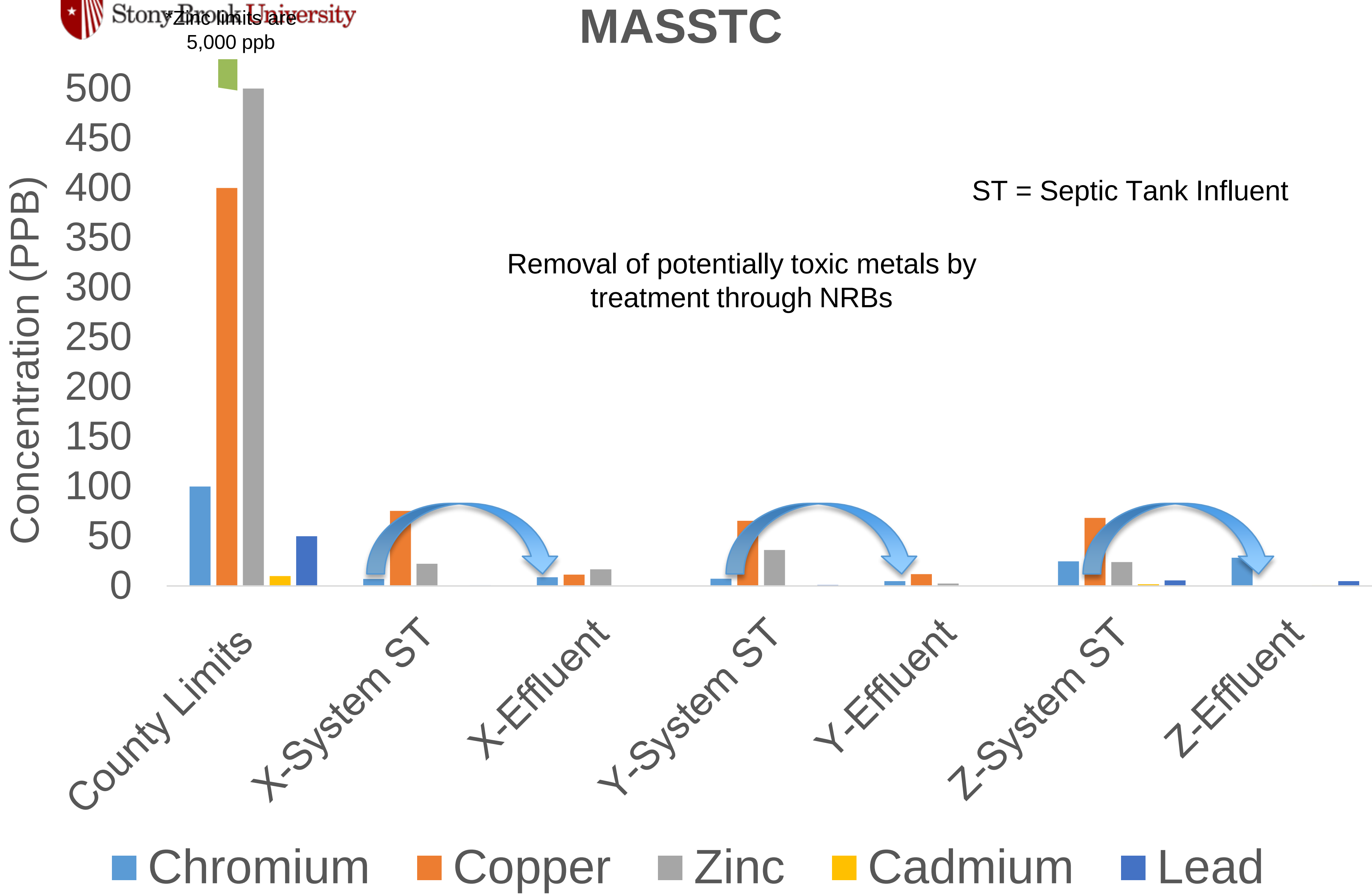
Over 95% *removal of 30 PPCPs detected in influent*

– – Removal efficiency in full scale wastewater treatment plants

*Reemtsma, 2008 #EPA, 2010; Lara-Martin, 2014

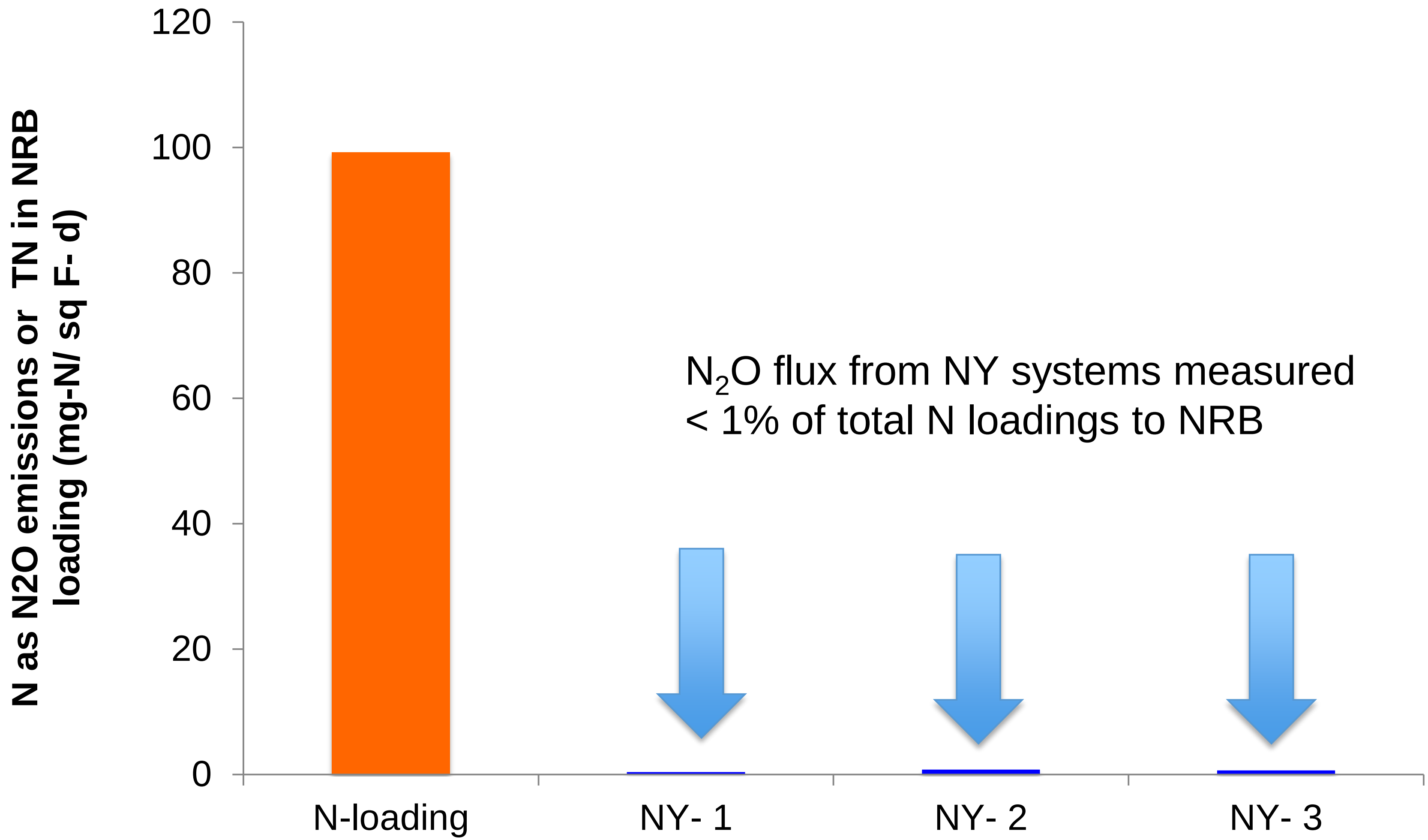
FAR BEYOND

MASSTC



*Zinc limits are 5,000 ppb
Concentration (PPB)
500
450
400
350
300
250
200
150
100
50
0
ST = Septic Tank Influent
Removal of potentially toxic metals by treatment through NRBs
County Limits
X-System ST
X-Effluent
Y-System ST
Y-Effluent
Z-System ST
Z-Effluent
Chromium
Copper
Zinc
Cadmium
Lead

Preliminary N_2O emissions measured from CCWT NRB installations at MASSTC in December 2017



First NRB installed on Long Island March, 2018

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Research to inform innovation…

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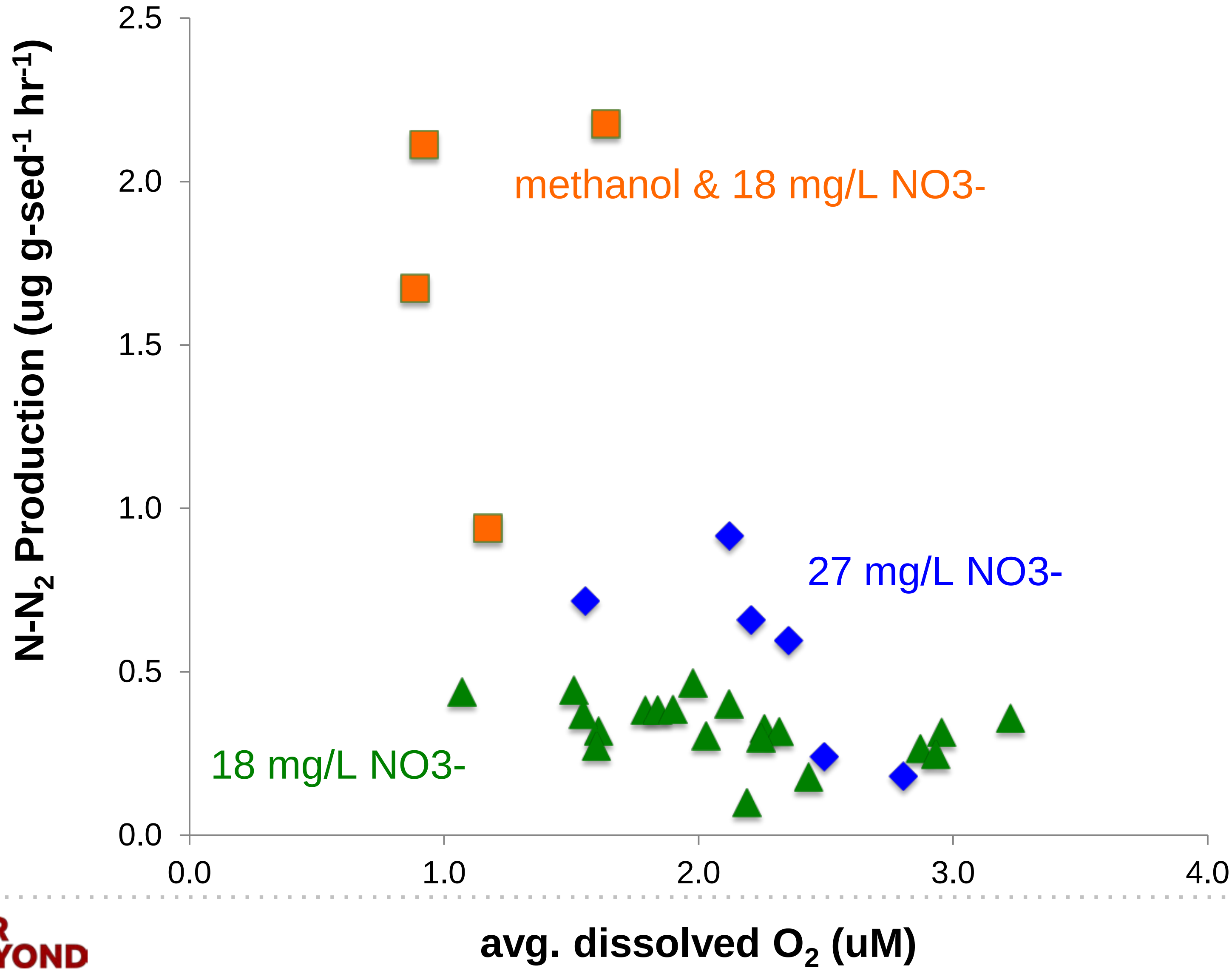
Bench-scale experiments isolate controls on denitrification in NRBs



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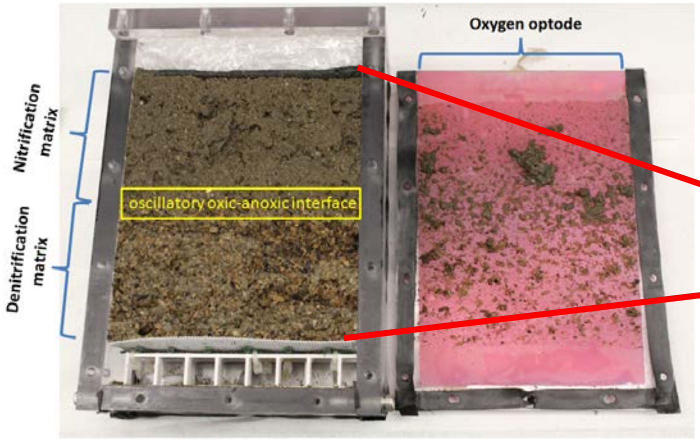
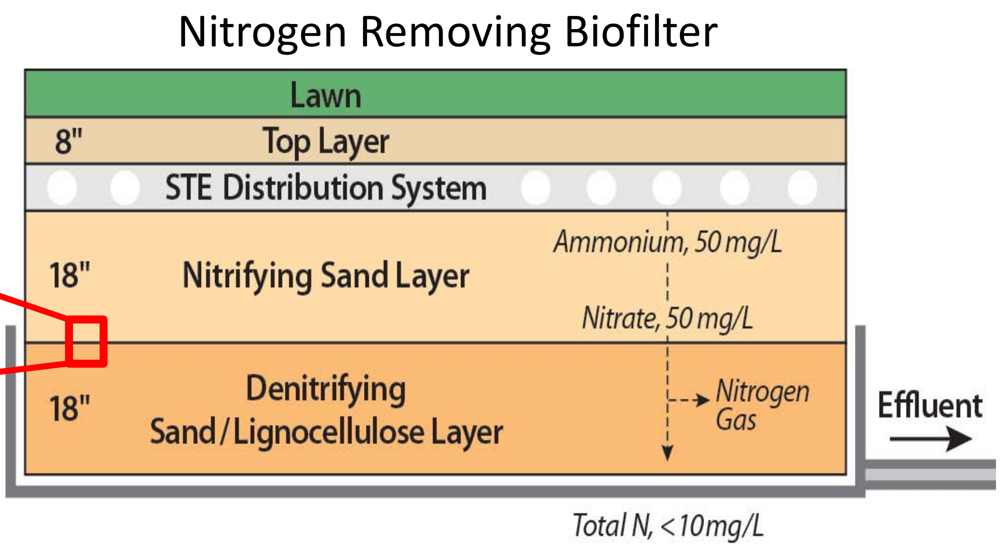
Optocosm experiment: Oxygen, microbial and nitrogen dynamics



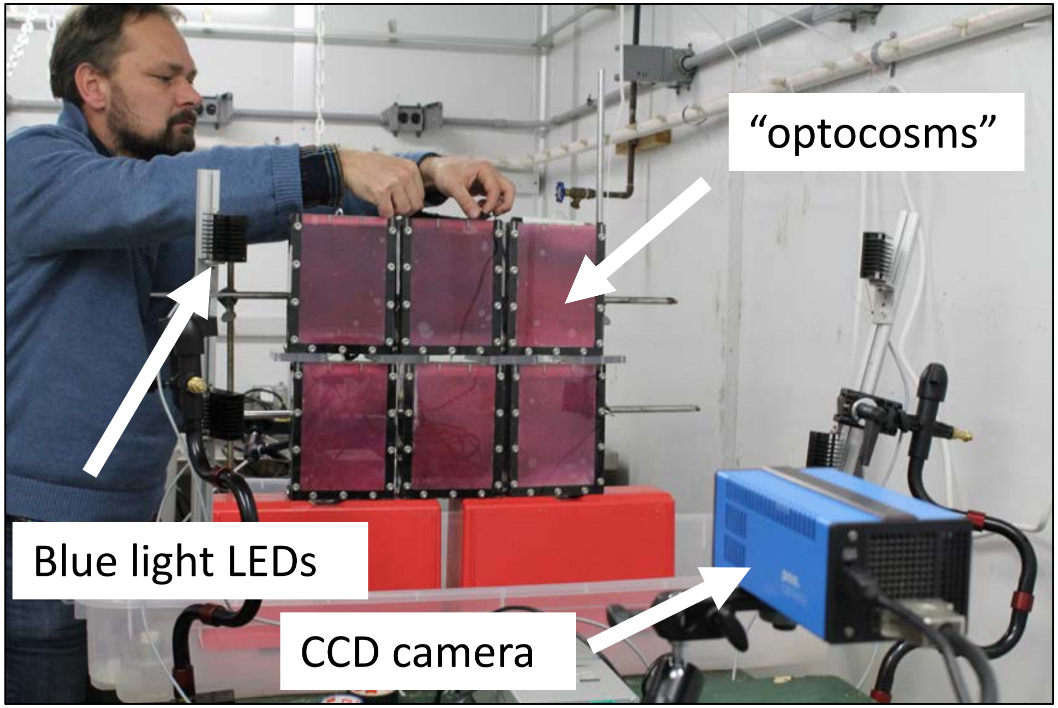


Drs. Nils Volkenborn, Jackie Collier, Stuart Waugh

Graduate students: Kylie Langlois, Molly Graffam

FAR BEYOND

Optocosm experiment: Oxygen, microbial and nitrogen dynamics



1 dose of 15mL every 3hours over 11 days
→ 0.5 Gal sqft^{-2} day^{-1}

Artificial “wastewater”:
20 mg L^{-1} NH_4NO_3

O_2 images taken very 30 seconds (≈30k images)

11 days in 60 seconds (16,000-fold speed)

Optocosms #1- #3 (upper row): never fully recovered from intentional short-term water saturation. Some regions remained anoxic until the end of the experiment.

Optocoms #4 & #5 reproducible and consistent O_2 dynamics over 11 days

Optocoms #6
Unintended clogging towards the end of the experiment

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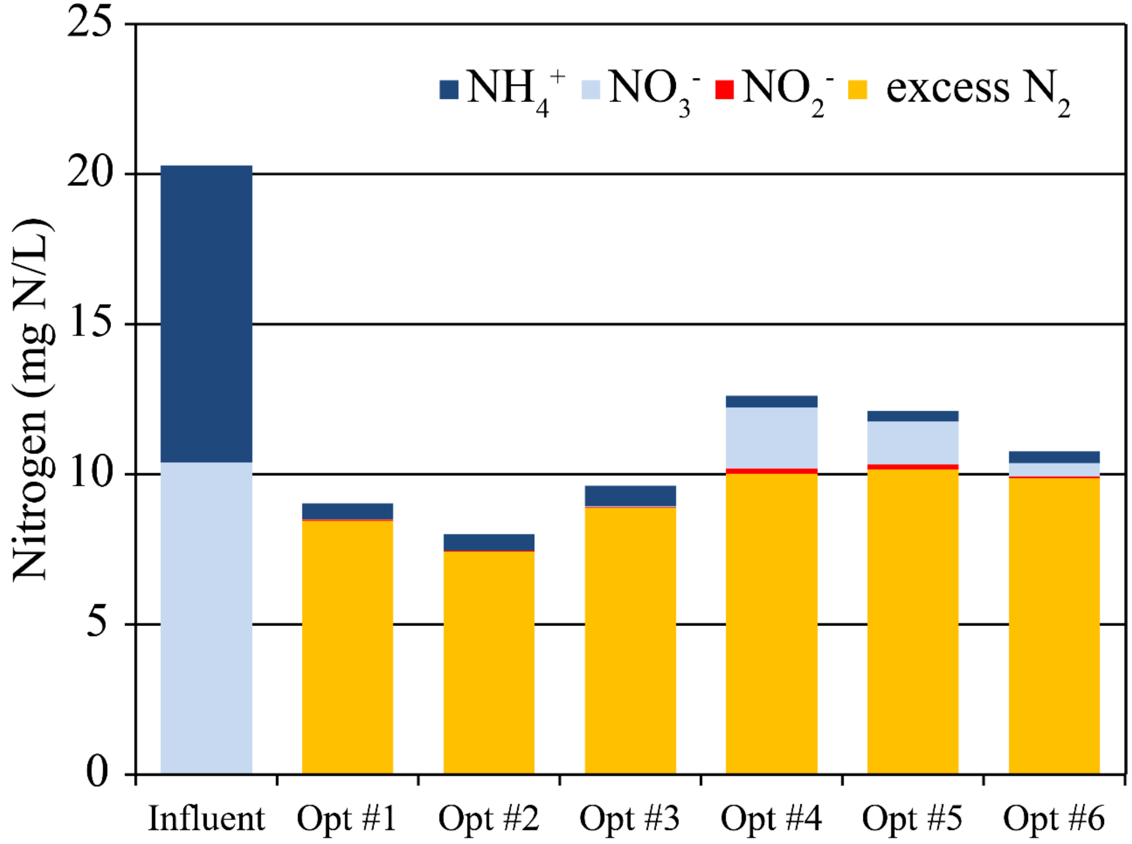
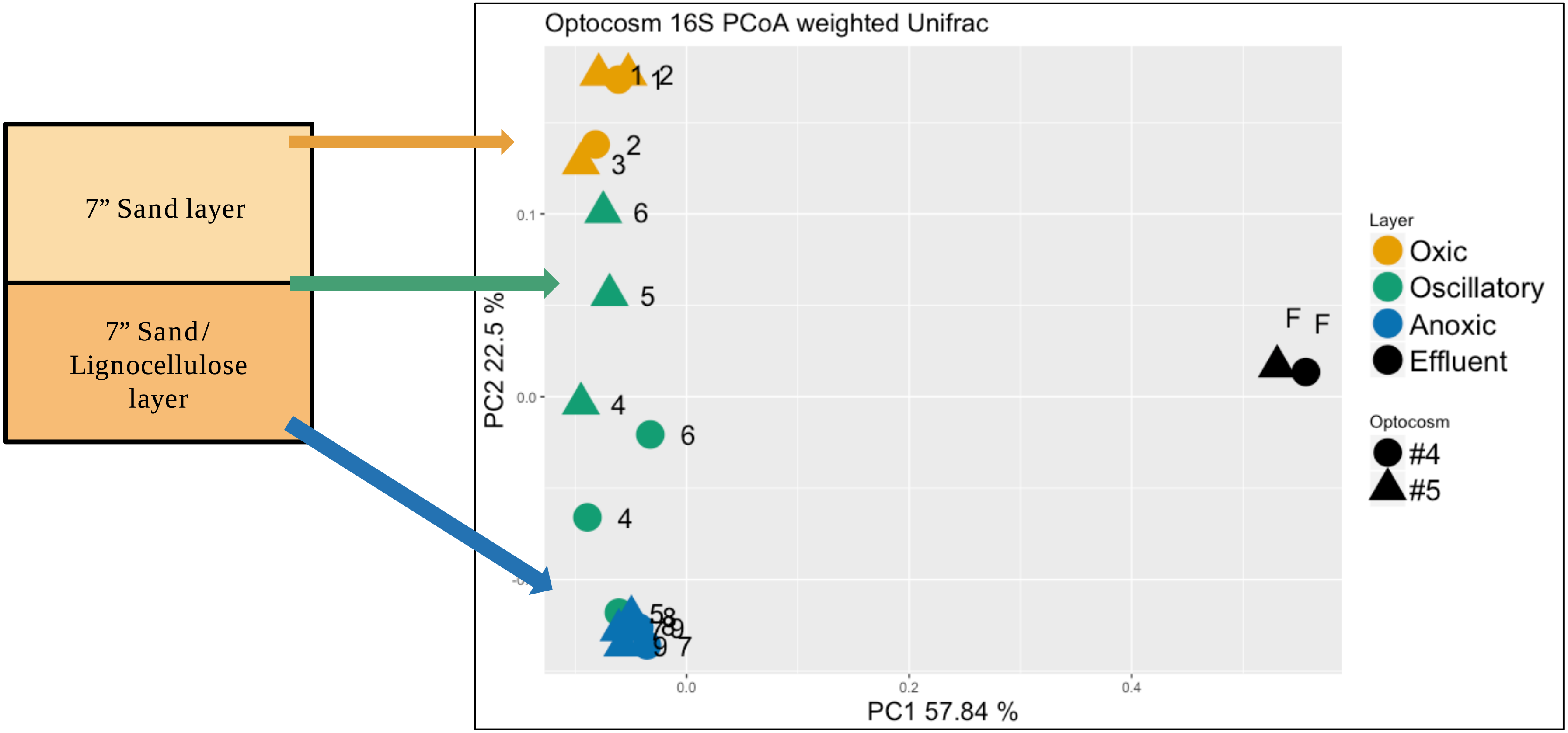
N-removal



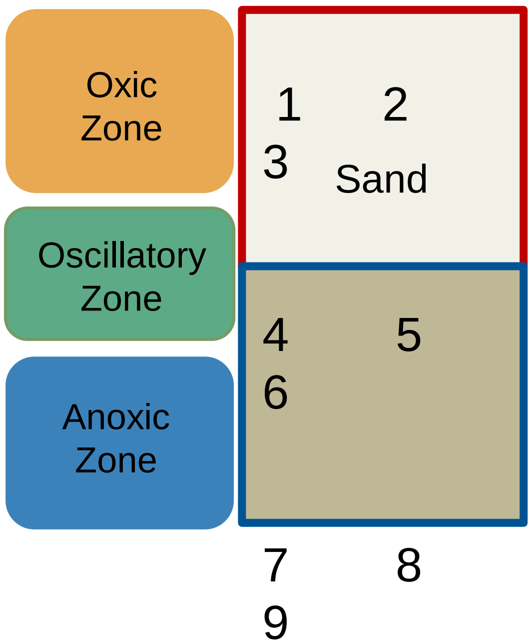
- Efficient nitrogen removal in all optocosms (**87-97%**)
- ~ 50% of nitrogen loss, most likely as N_2 to the atmosphere

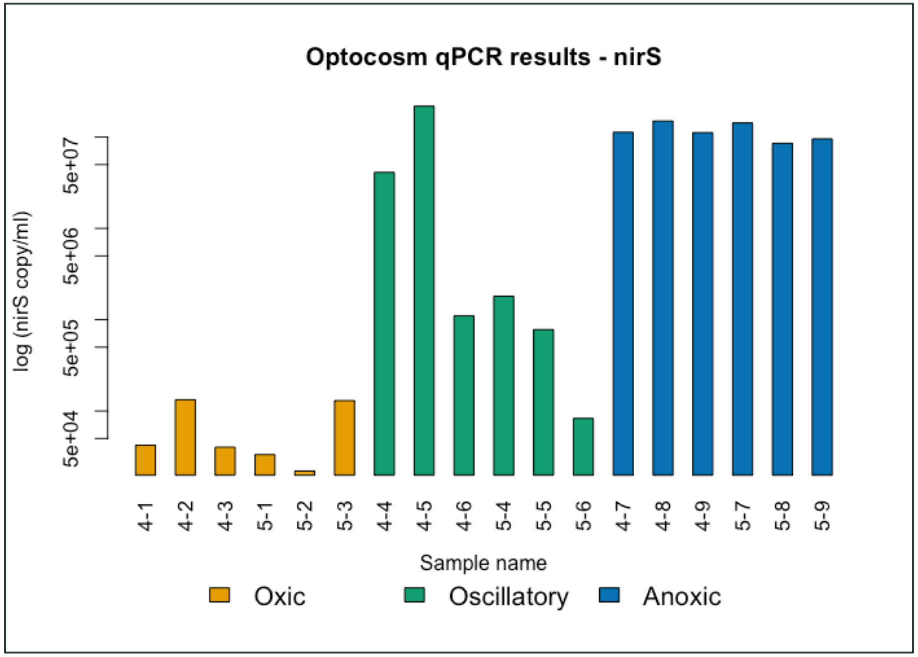
FAR BEYOND

Microbial community diversity



Difference in denitrfying bacteria between layers





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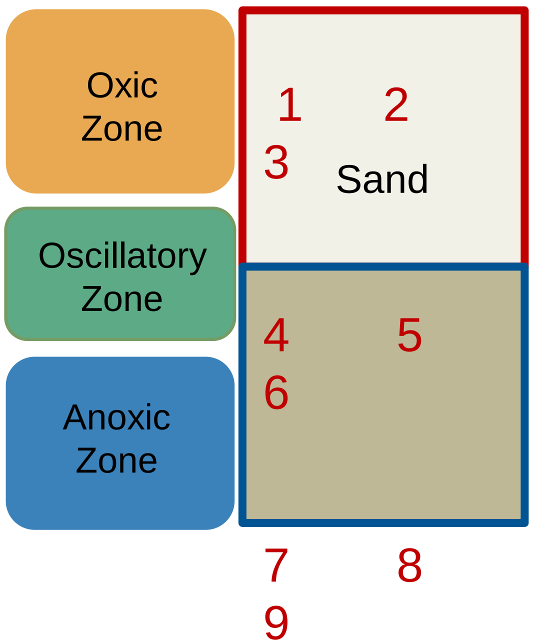
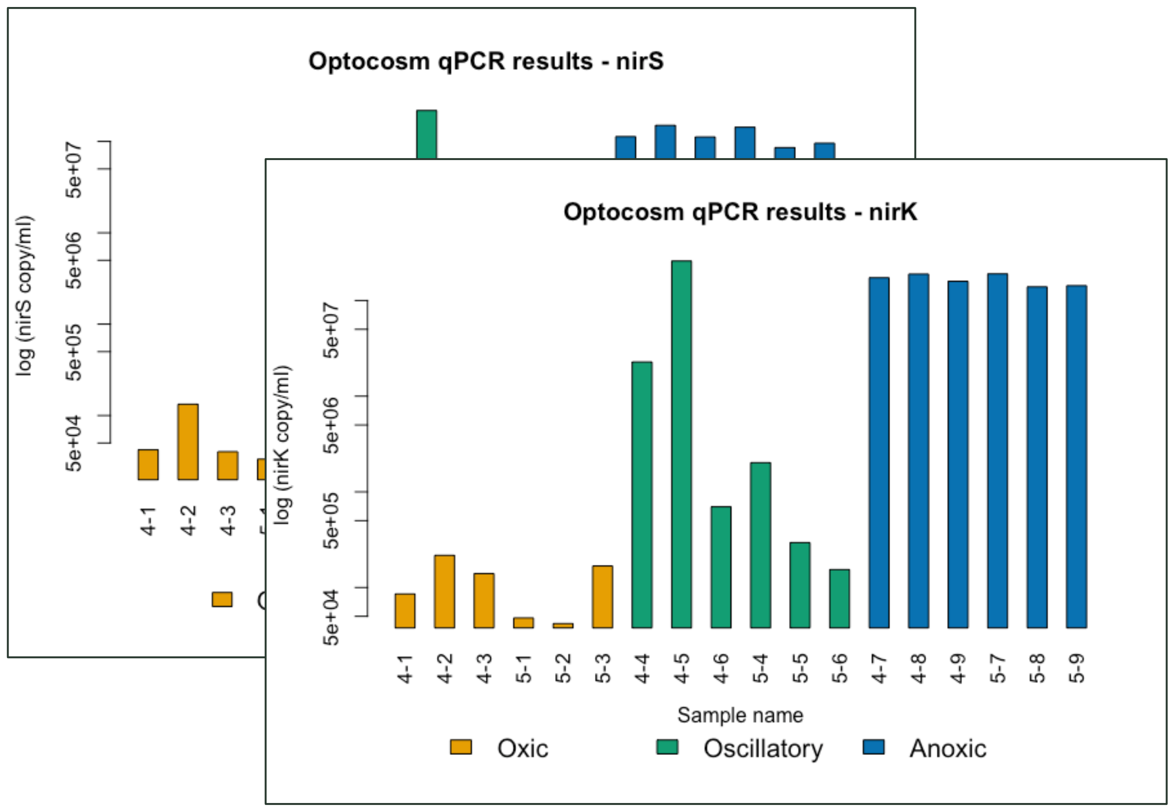
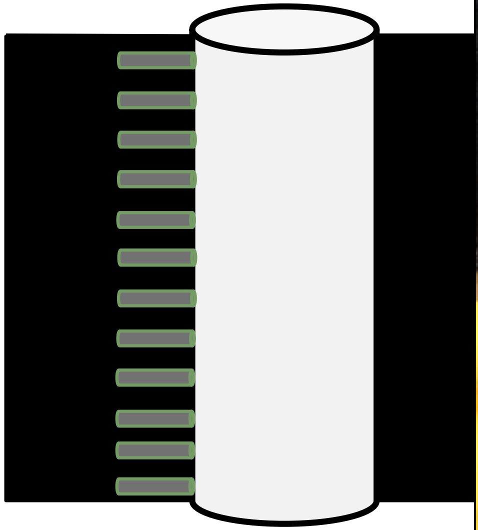
Difference in denitrfying bacteria between layers



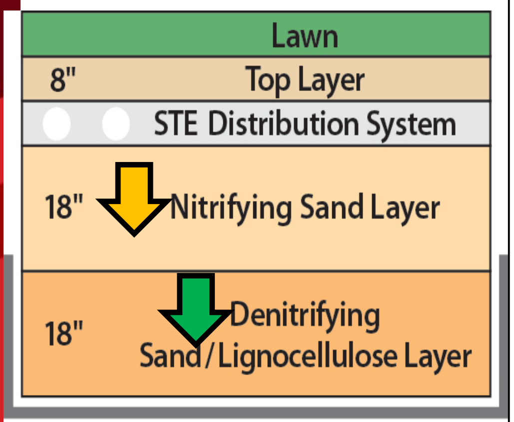


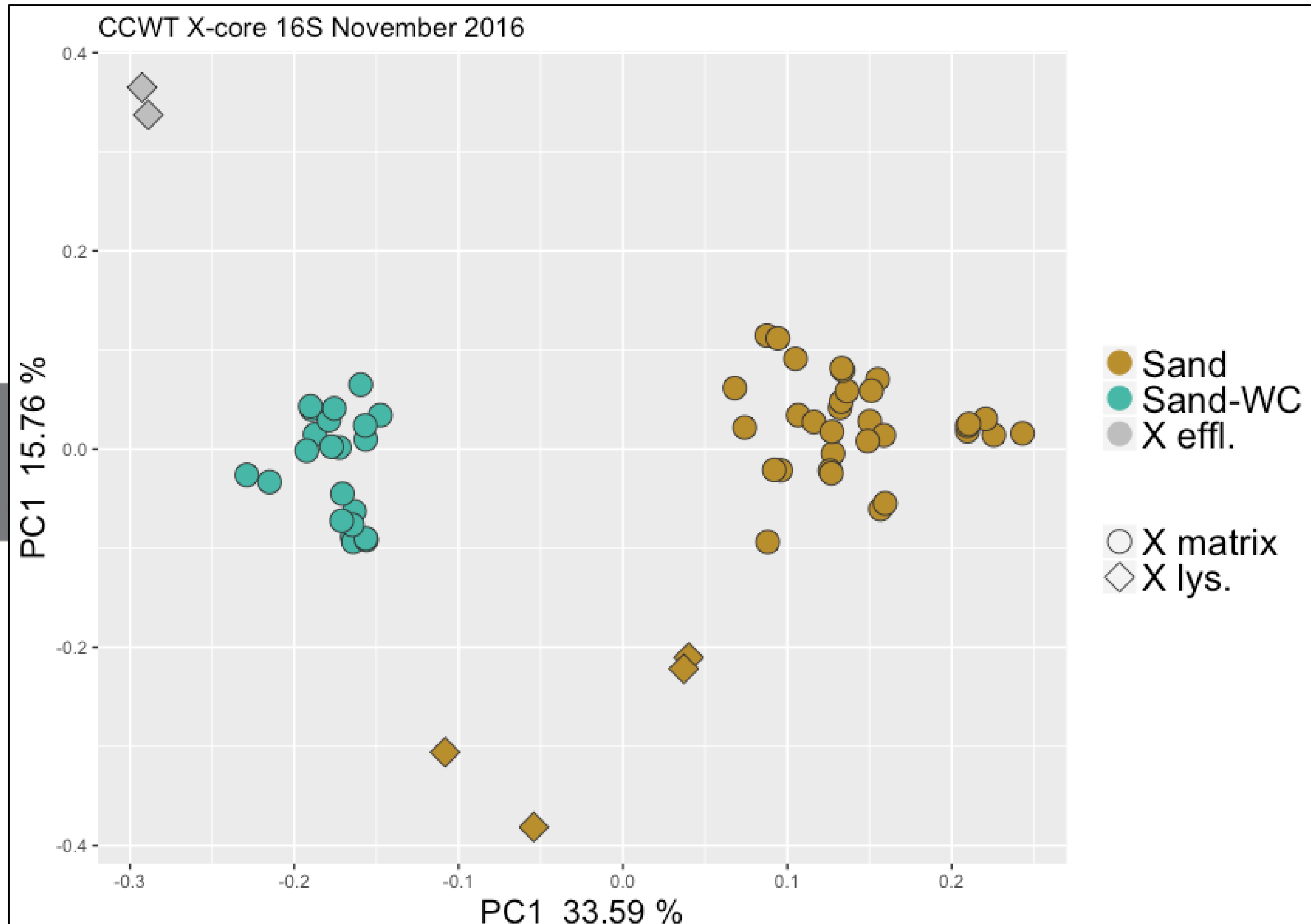
Attached bacteria within NRBs

- System X at MASSTC cored November 2016
- 27 “mini-cores”



Microbes within the NRB sediments





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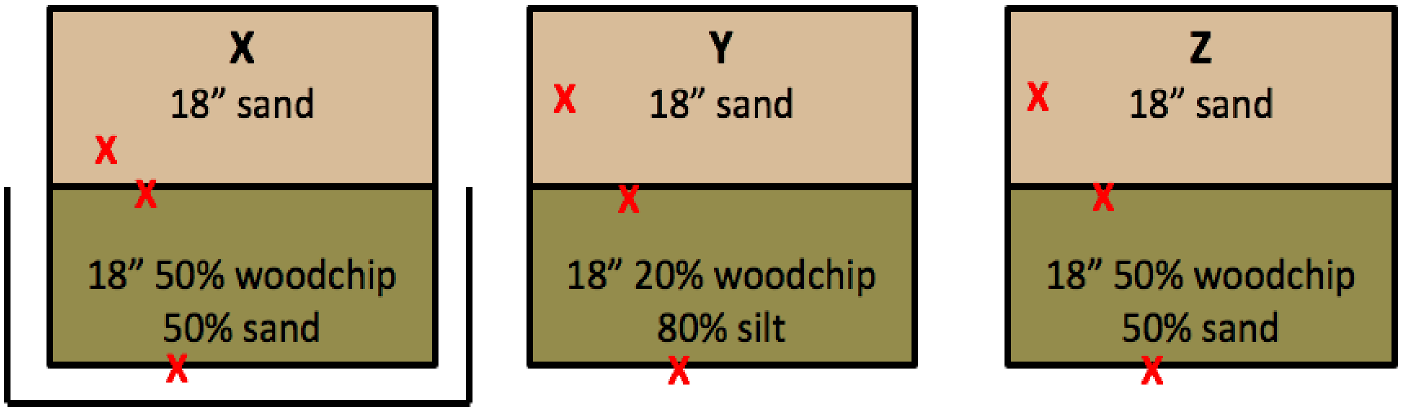
Microbes within the NRB lysimeters

- Liquid samples collected from MASSTC (3 systems + influent channel/septic influent)
- January, April, July, November 2016



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Microbes within the NRB lysimeters