Validation of Permeable Reactive Barrier Technology for Non-Point Source Groundwater Nitrogen Remediation

Matthew Charette, Kristen Rathjen, Paul Henderson, Paul Dombrowski, Richard Raymond, and Michael Lee

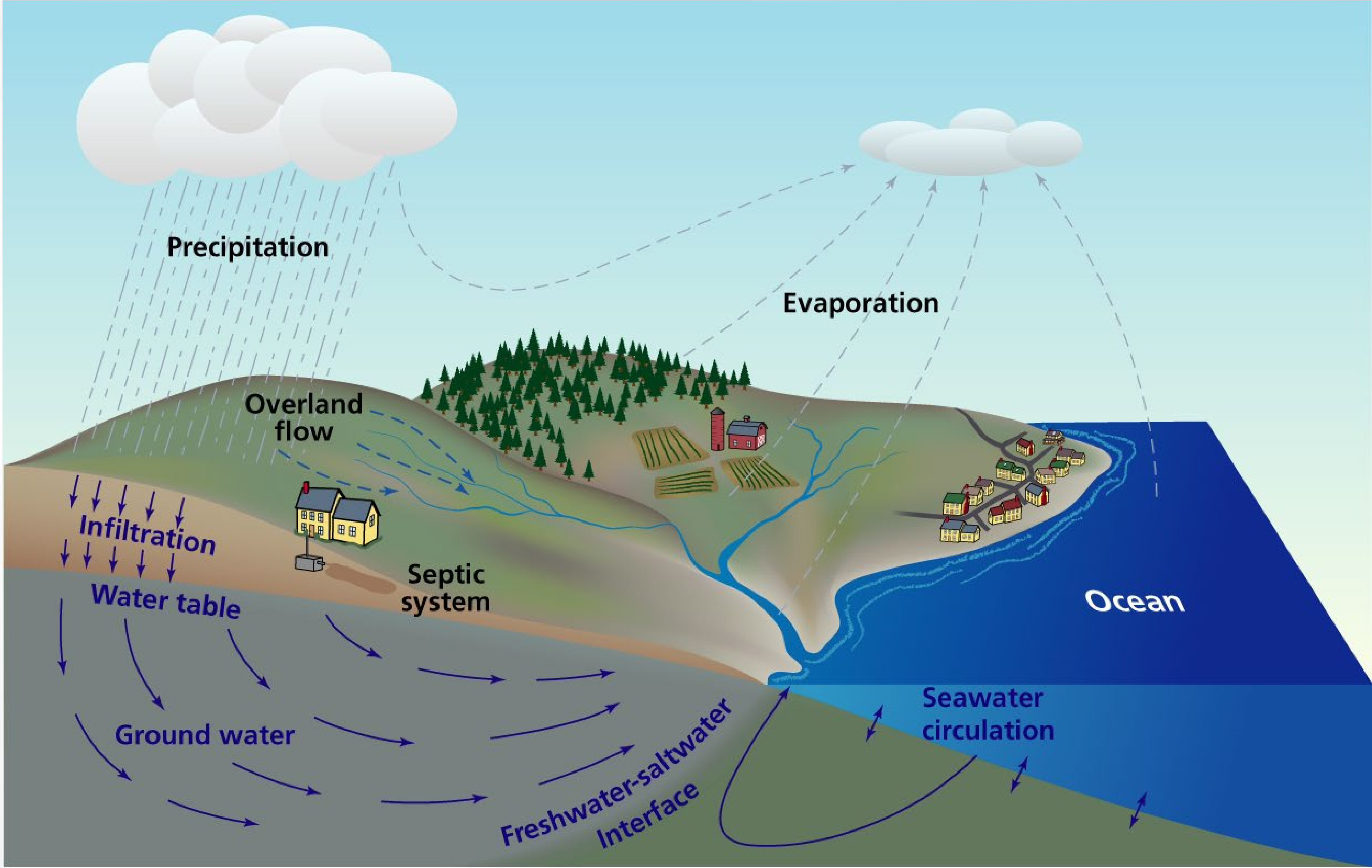
Nitrogen Pollution-A $Multi-Billion Problem on Cape Cod

- Housing boom on Cape Cod has led to severe ecological impacts to coastal water bodies

Lower Great Pond, Falmouth

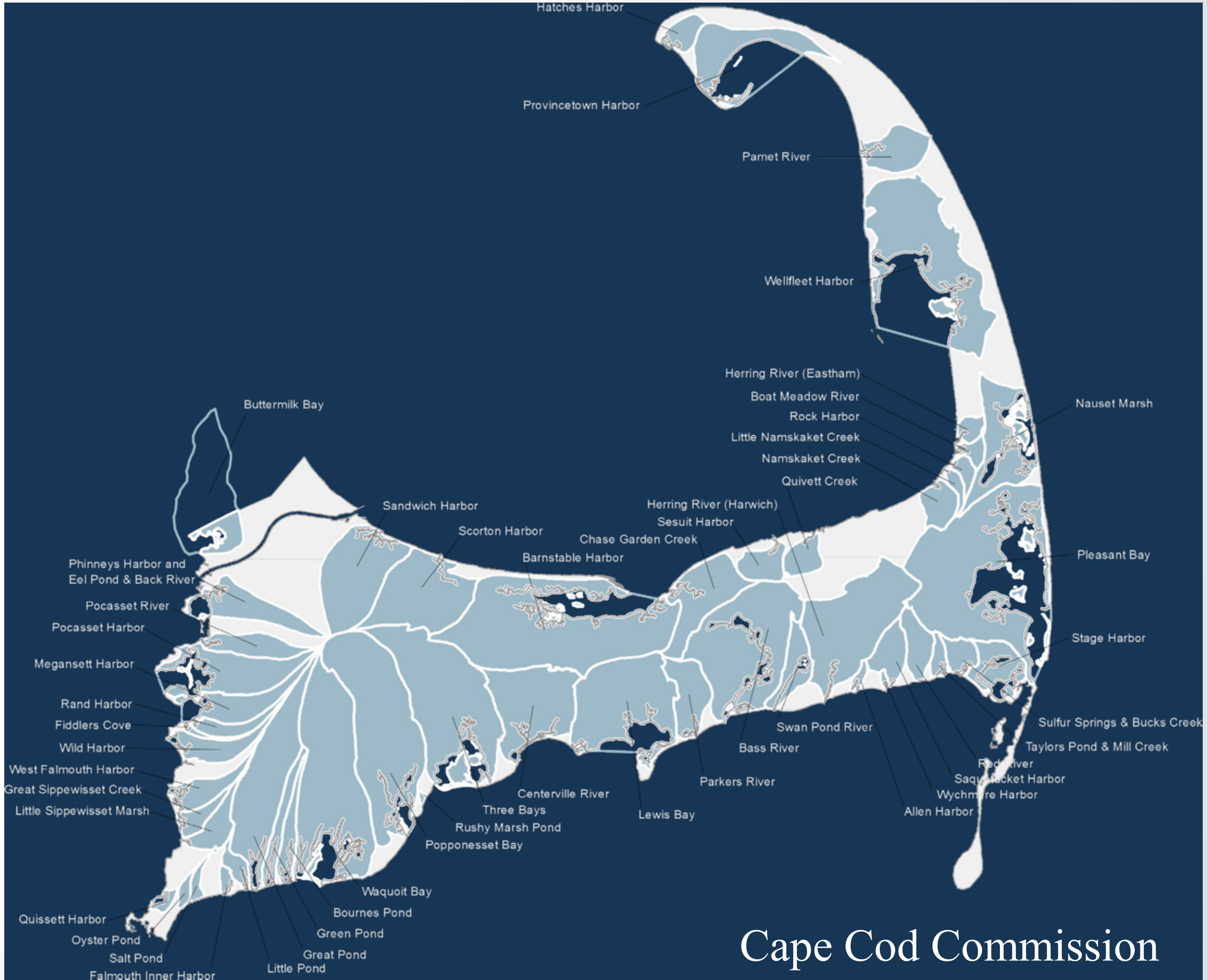
Nitrogen Pollution-A $Multi-Billion Problem on Cape Cod

On Cape Cod, virtually all freshwater that enters the coastline is derived from groundwater – even the rivers are groundwater fed.



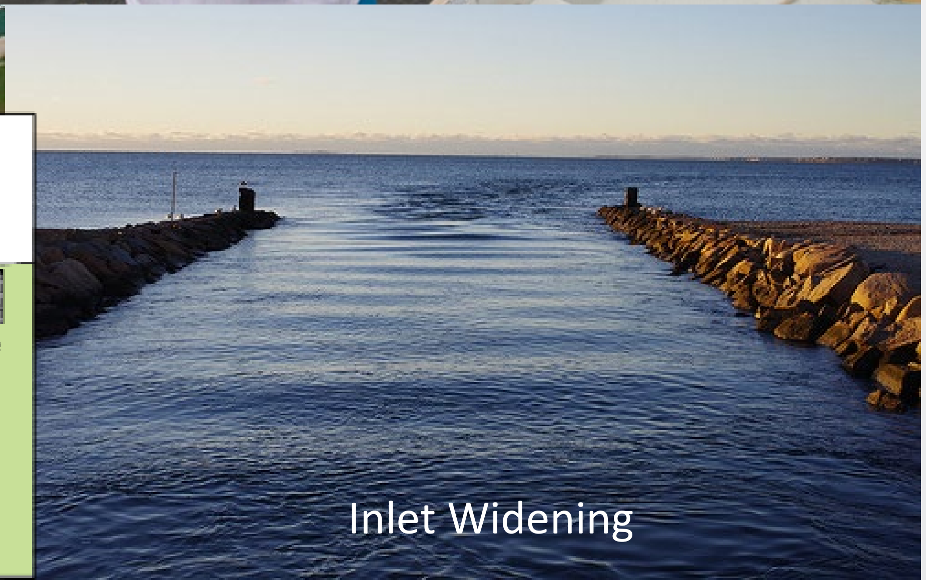
Nitrogen Pollution-A $Multi-Billion Problem on Cape Cod

- Estimated cost of wastewater systems on Cape Cod: $5.2 billion to $7.6 billion (up to $50K per property owner)
- Alternative, lower cost strategies needed, but many need to be validated before they will be adopted by municipalities

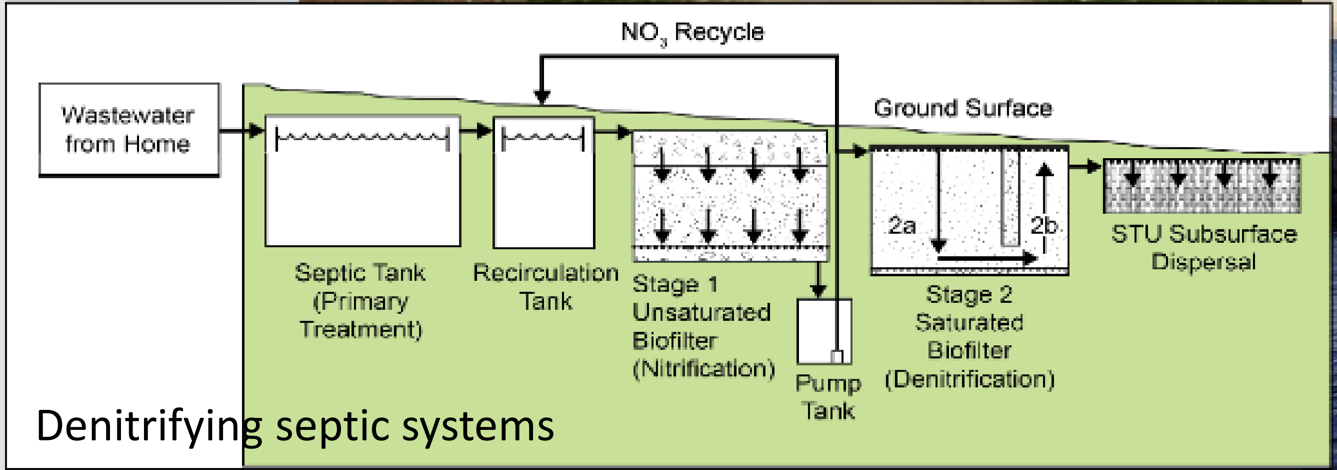


Alternative Approaches Under Consideration

Shellfish

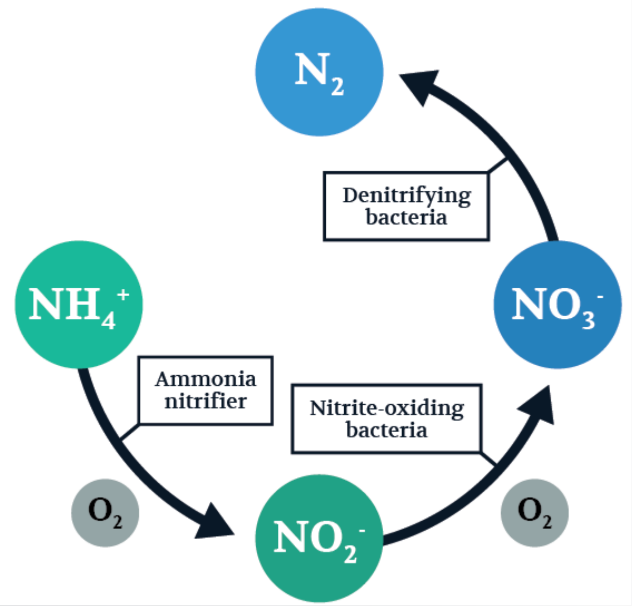


Inlet Widening

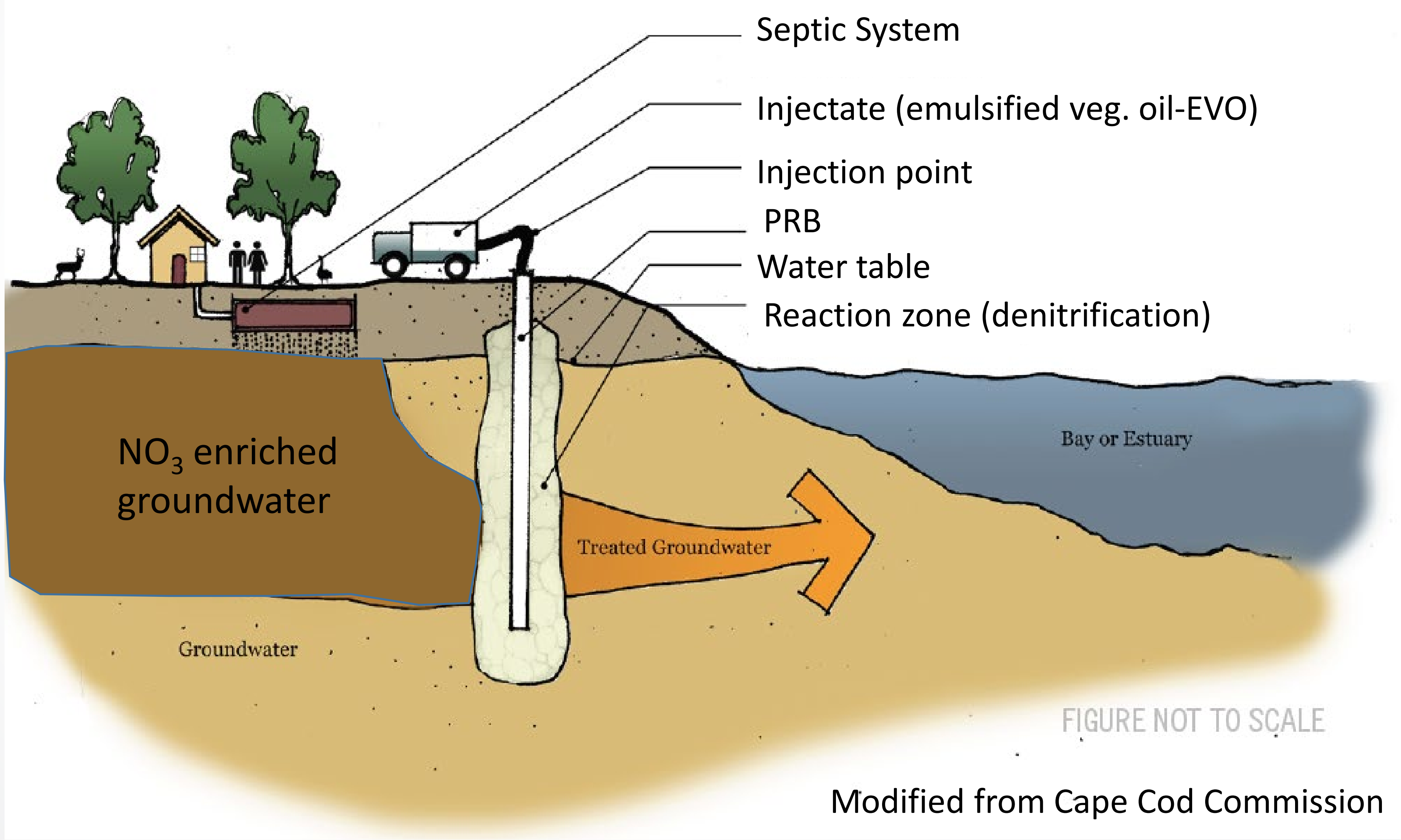


Denitrifying septic systems

Permeable Reactive Barrier (PRB)

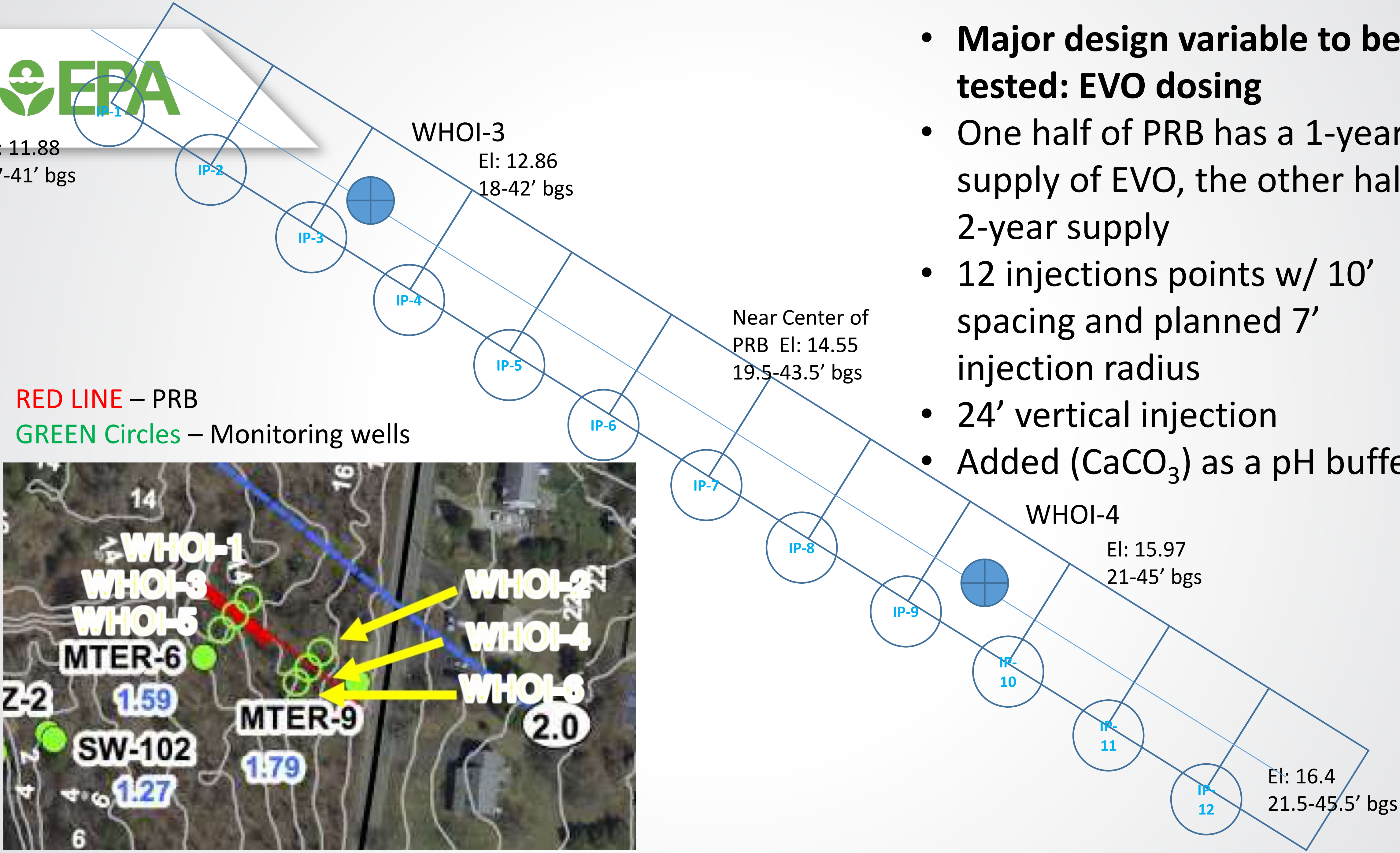


M.S. Urban, 2019



Modified from Cape Cod Commission

- **Major design variable to be tested: EVO dosing**
- One half of PRB has a 1-year supply of EVO, the other half a 2-year supply
- 12 injections points w/ 10’ spacing and planned 7’ injection radius
- 24’ vertical injection
- Added ($CaCO_3$) as a pH buffer



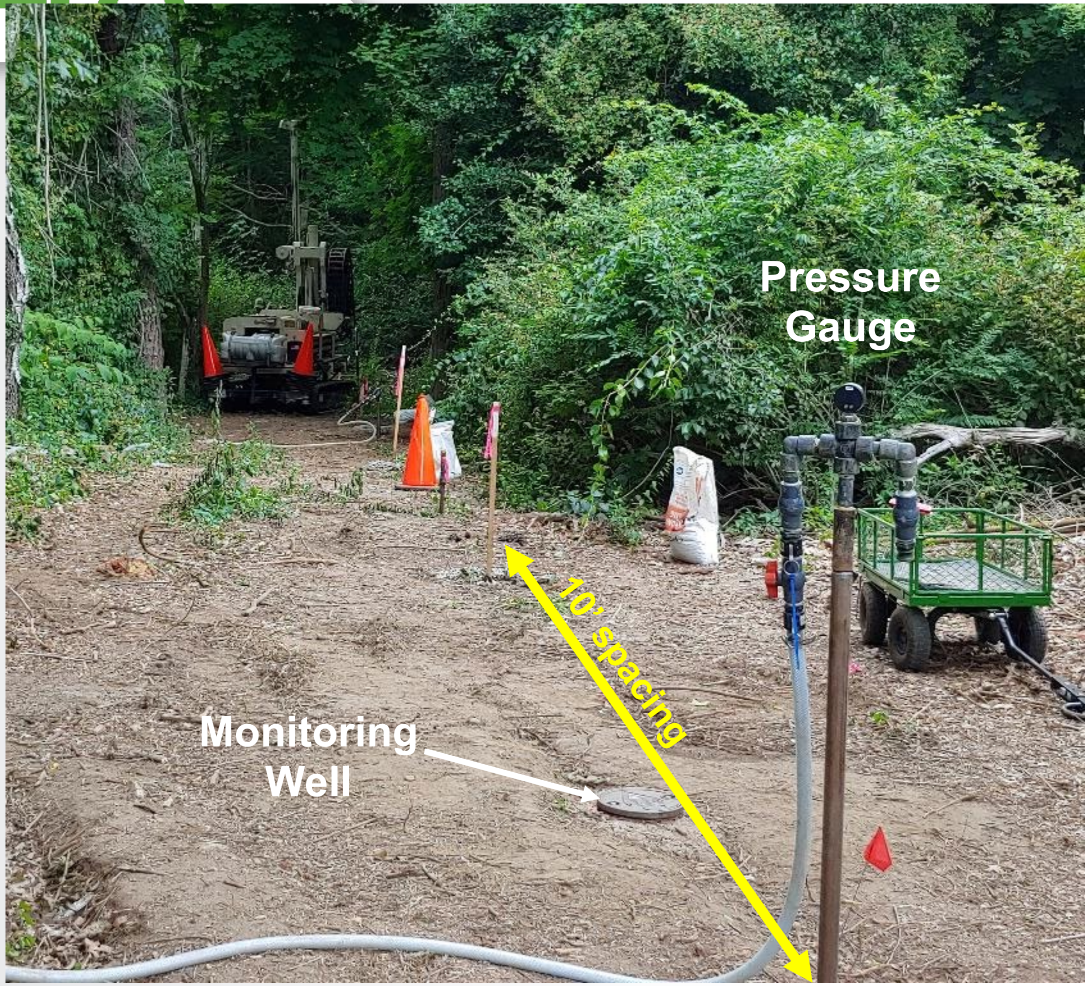
RED LINE – PRB
GREEN Circles – Monitoring wells

Injection Event – July 2020

EVO Storage and Batching
within
secondary containment

Water from hydrant with
hose ramps
to cross the road

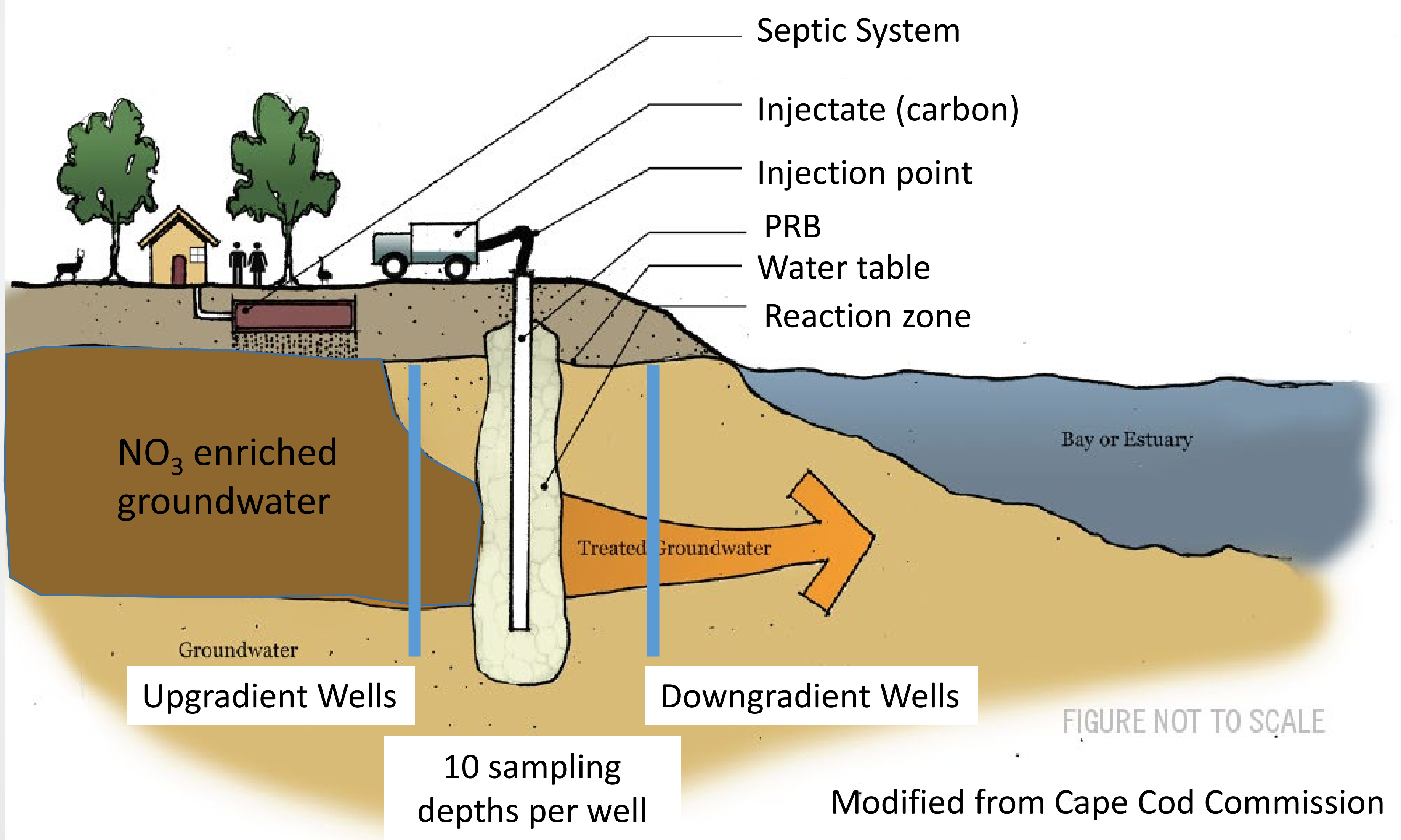
Injection Event – July 2020



EVO Injection Pressures and Flow Rates

		One Year Dosage							Two Year Dosage						
		IP-1	IP-2	IP-3	IP-4	IP-5	IP-6		IP-7	IP-8	IP-9	IP-10	IP-11	IP-12	<10 psi
															10-20 psi
Pressure (psi)	Shallow	5-12	40-56	3	20-28	3	22		5	4	5	5	3	3	20-30 psi
	Intermediate	5-40	42	4	14-18	5	36-58		16	5	10	7	2-5	3	30-40 psi
	Deep	20-24	42	5	55-62	12	No Injection 100+		40-64	40-80	20-72	45-70	10	16-22	40-50 psi
															50-60 psi
															>60 psi
Flow Rate (gpm)	Shallow	5.07	3.07	6.14	3.02	4.49	4.38		4.73	4.79	5.38	5.3	4.93	4.07	>5 gpm
	Intermediate	1.72	2.89	5.07	4.27	5	3.3		7.14	4.61	4.61	5.47	4.49	4.61	4-5 gpm
	Deep	1.98	3.4	6.25	2.43	4.67	No Injection		2.85	3.02	1.37-3.88	2.1	3.76	3.76	3-4 gpm
															2-3 gpm
															1-2 gpm
															<1 gpm

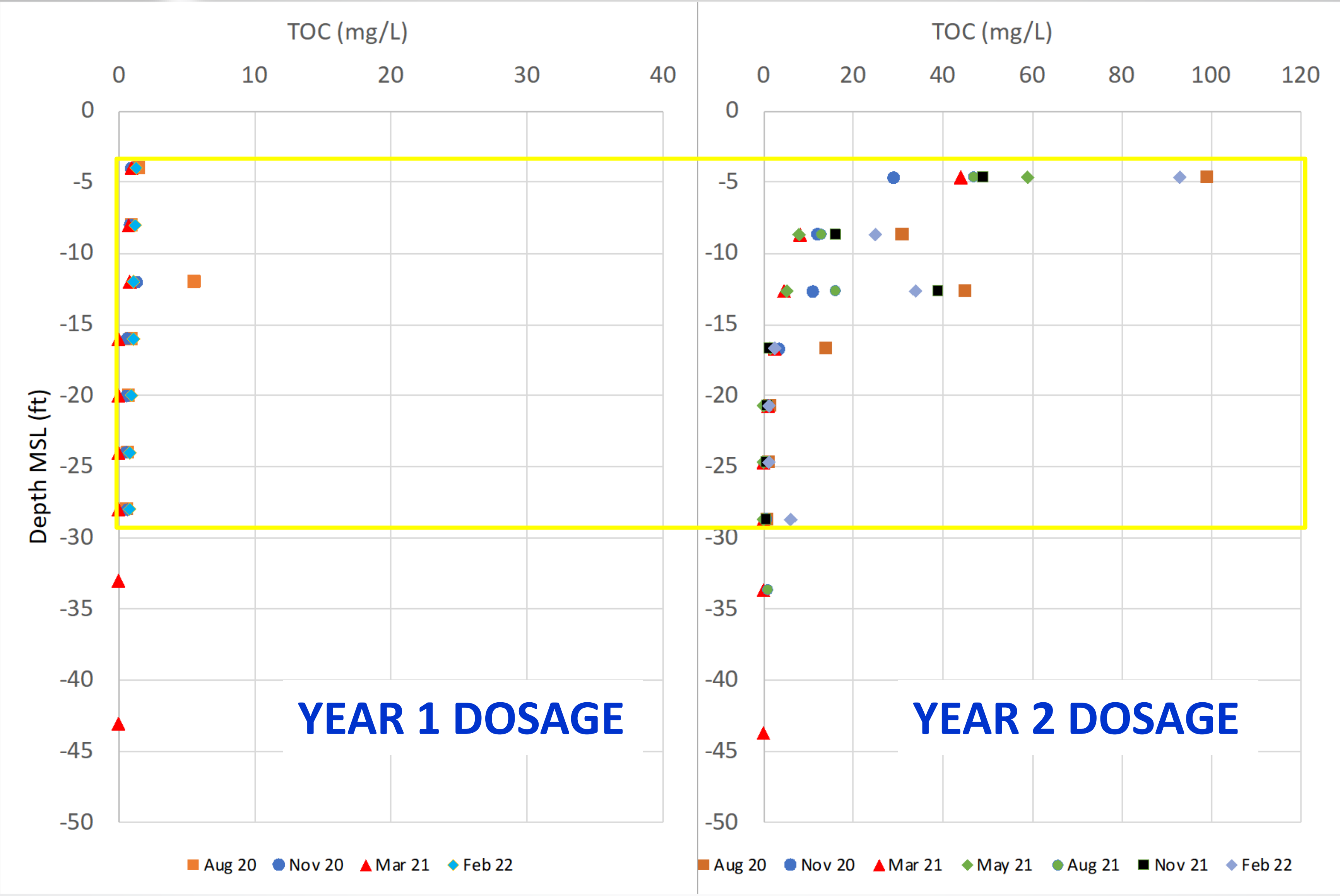
Monitoring Scheme



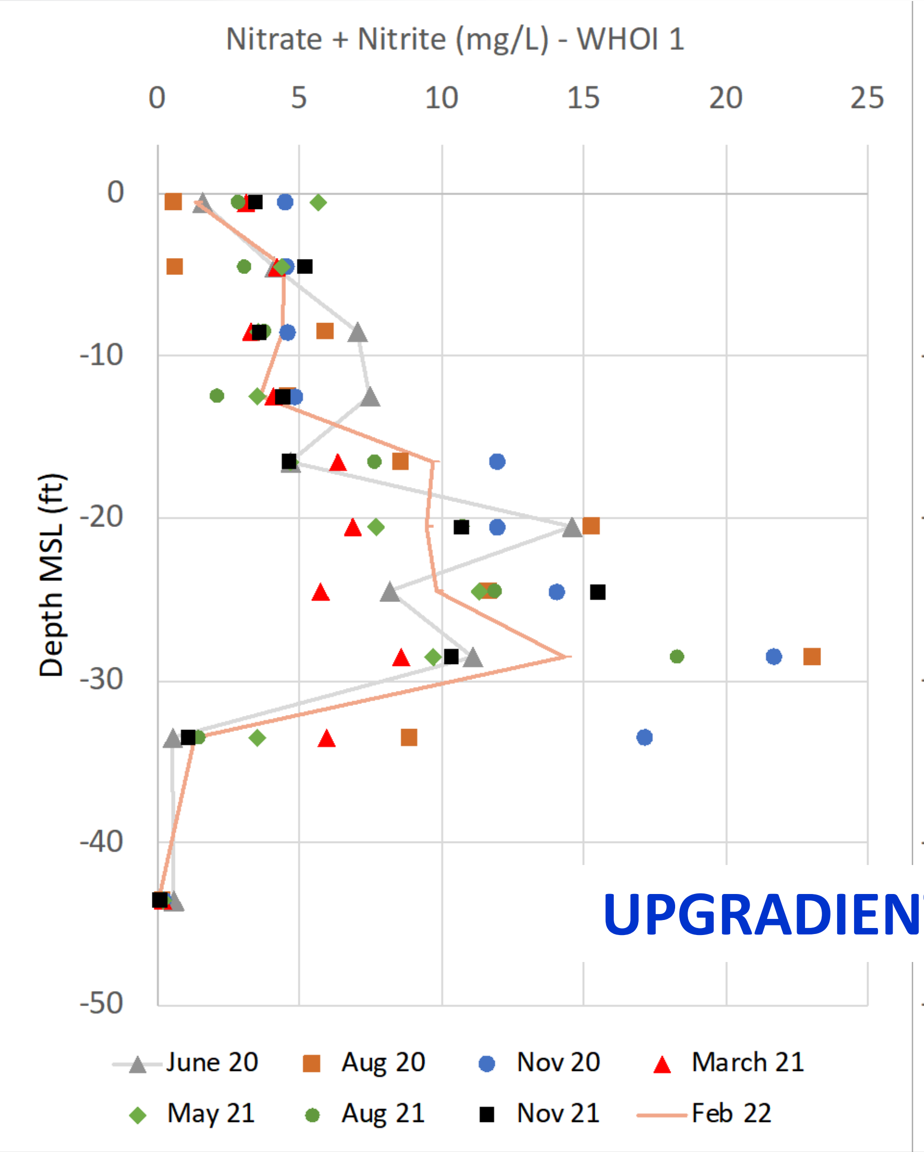
Modified from Cape Cod Commission

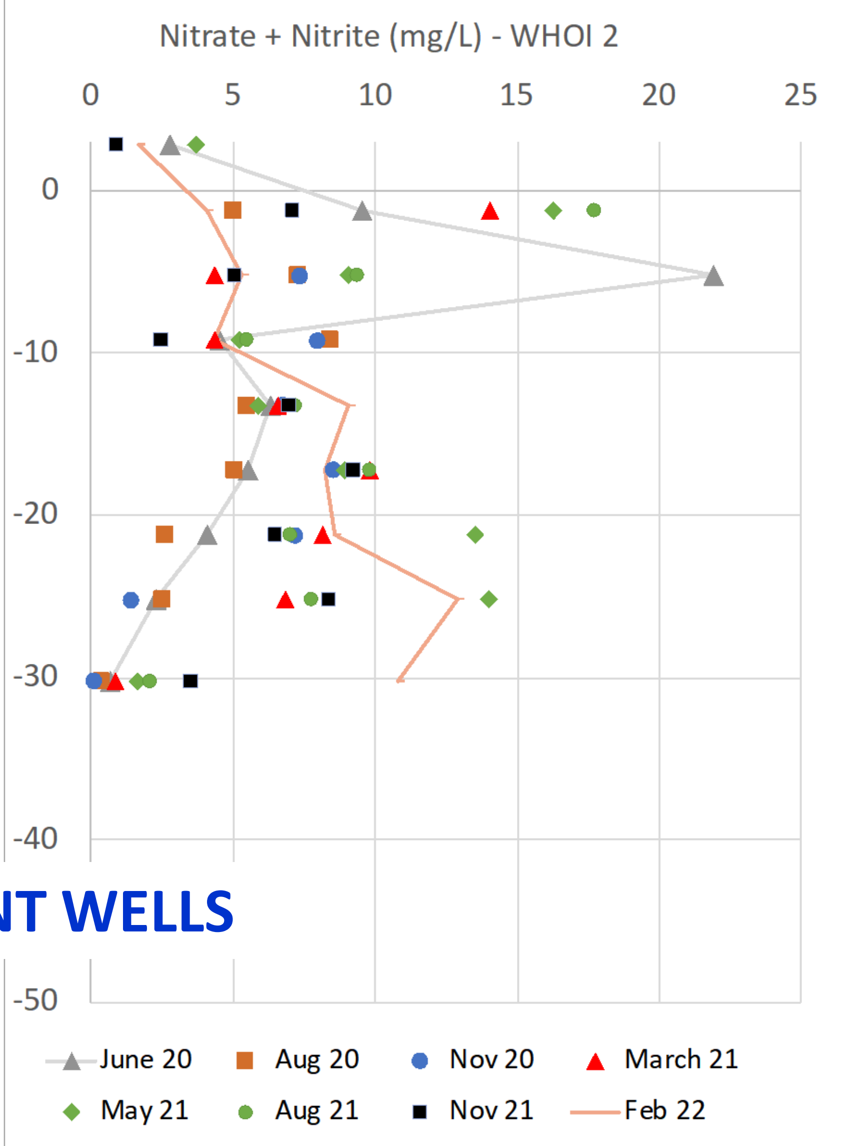
TOC Time Series: Downgradient Wells

BACKGROUND
TOC < 1 mg/L



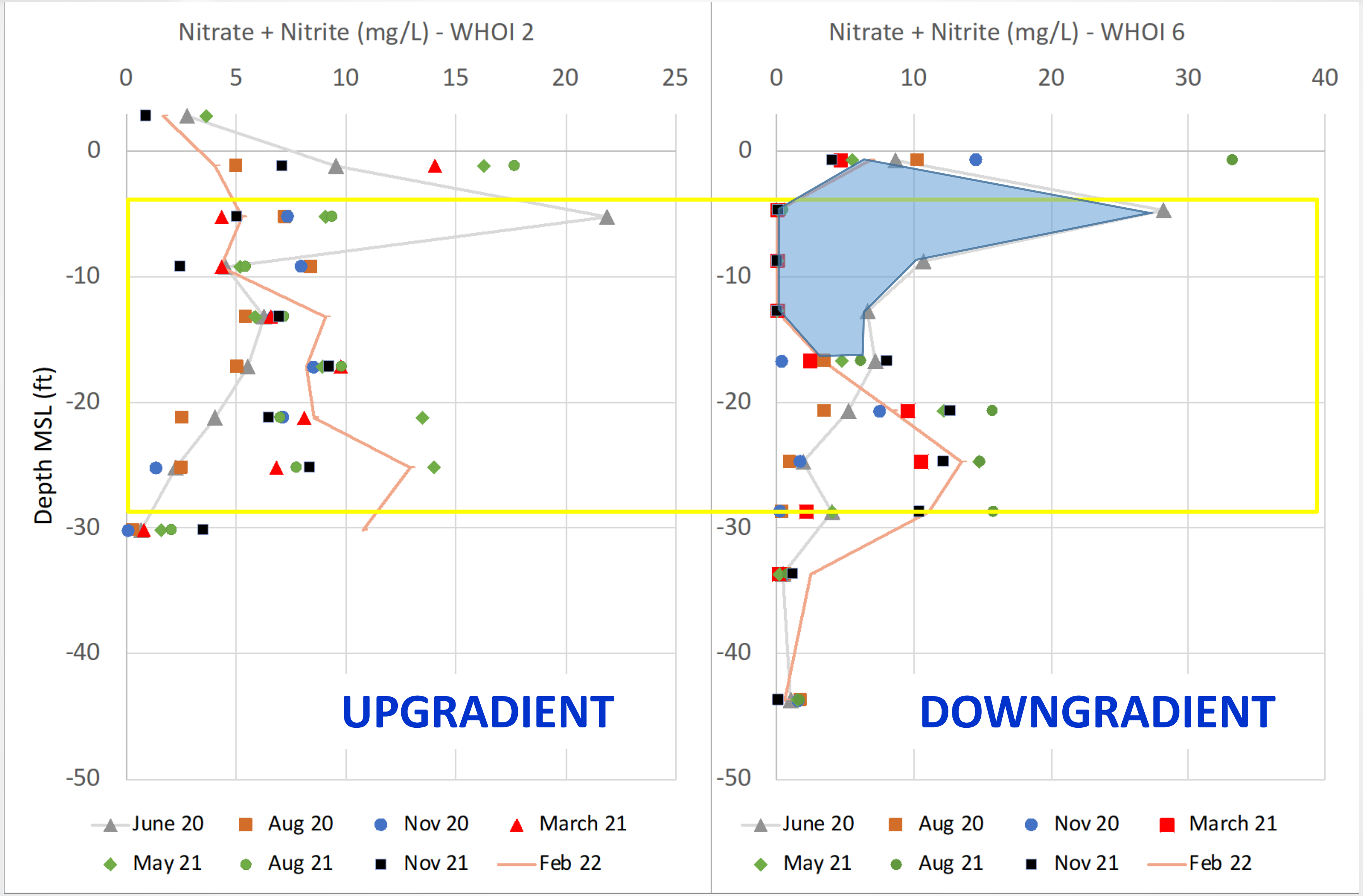
Nitrate+Nitrite Plumes Entering the Site





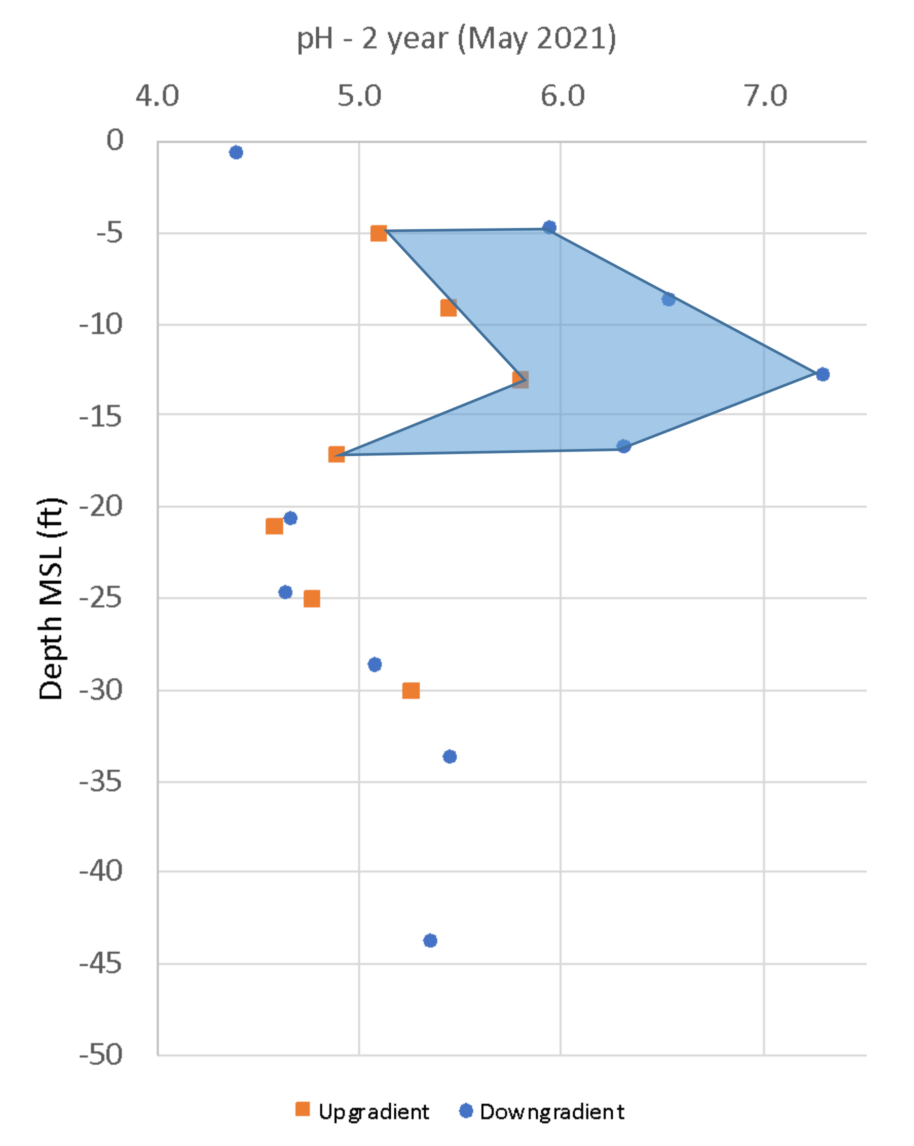
UPGRADIENT WELLS

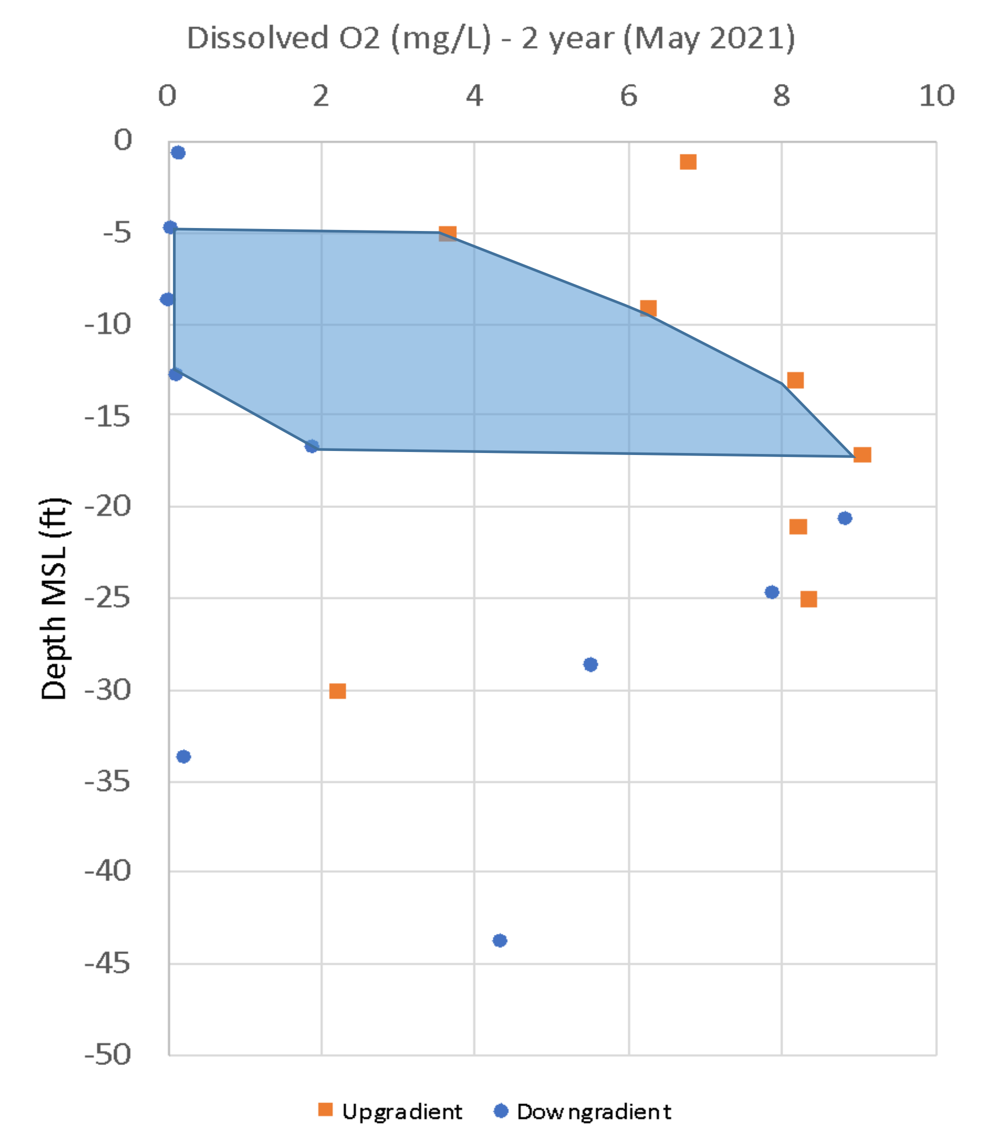
Year 2 EVO Dosage: Nitrate removal



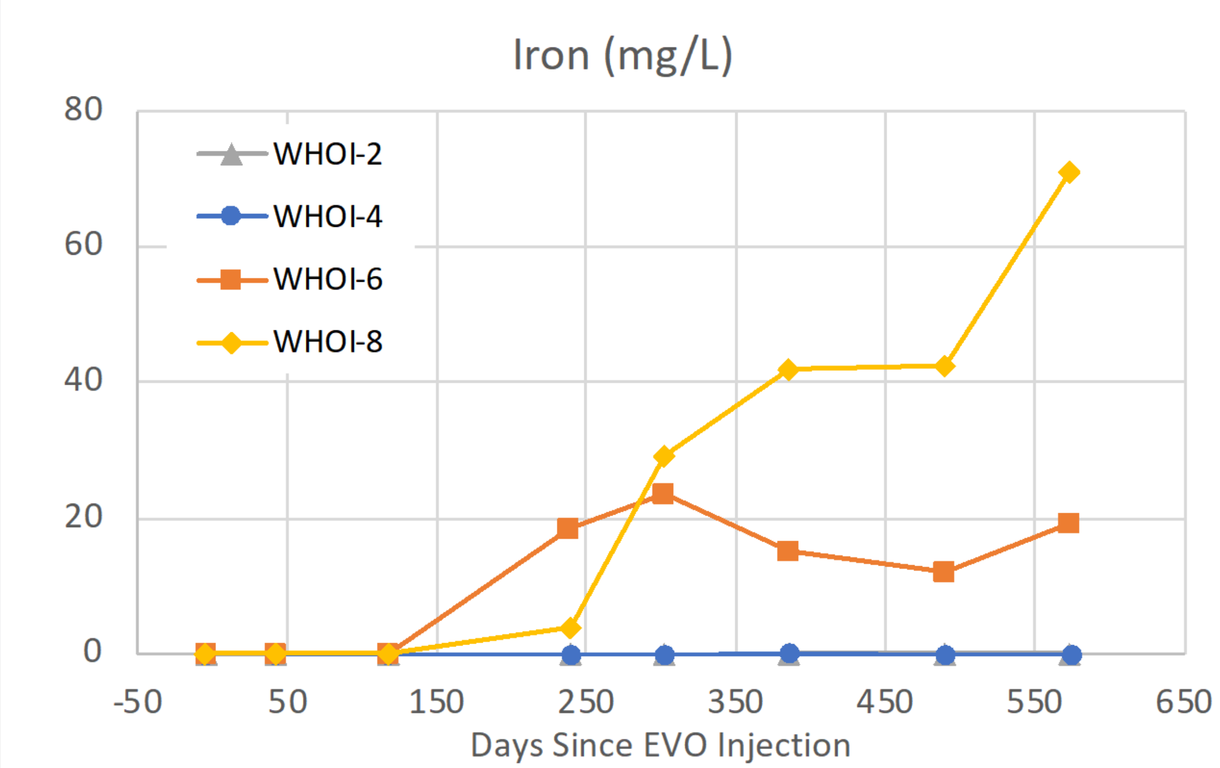
pH and Dissolved Oxygen

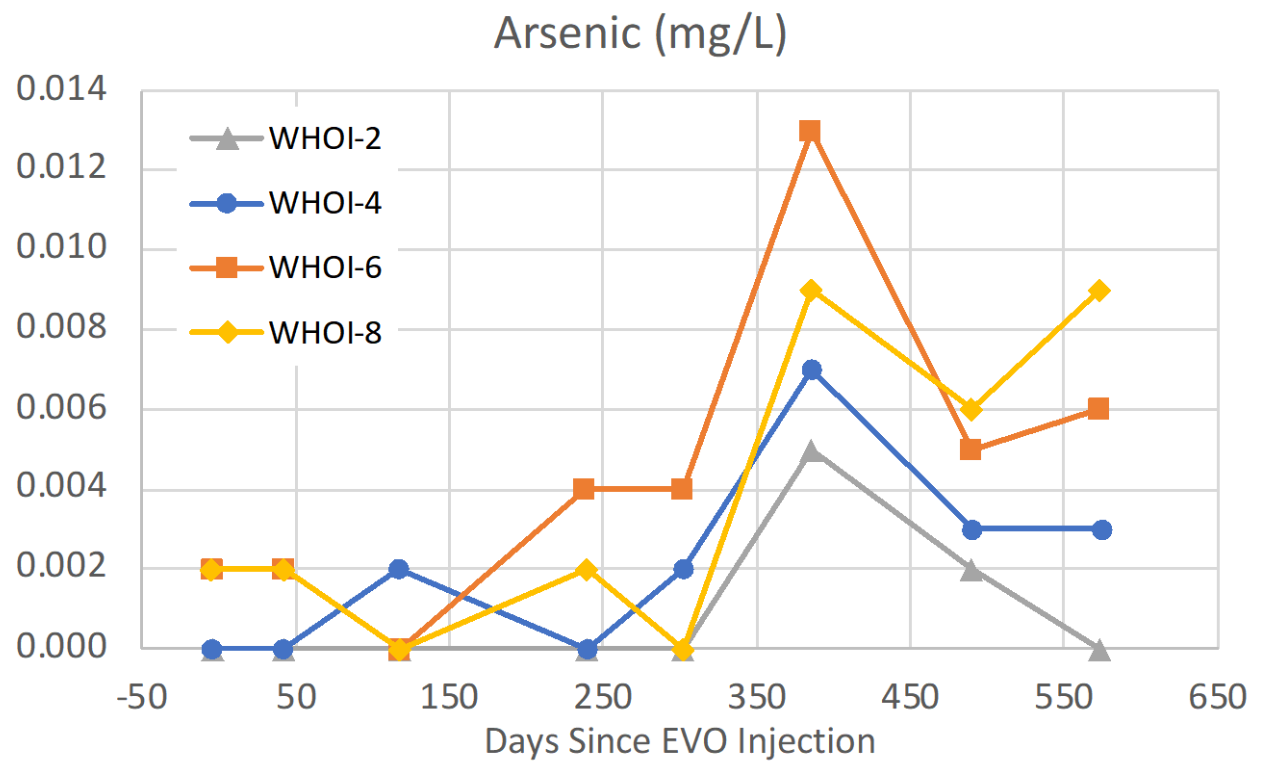
ADD SHADING





Ancillary groundwater chemistry





Arsenic EPA drinking water limit = 0.01 mg/L

Lessons Learned and Next Steps

- Pre-injection hydrogeological survey work is critical
- Significant spatial and temporal variability in groundwater nitrate concentrations
- EVO dosing scheme is meeting minimum expected longevity
- Decrease EVO injection spacing or employ two row injection (sawtooth)

- Calculate nitrate removal due to PRB and compare with model inputs
- Produce a design manual for larger scale PRB installations

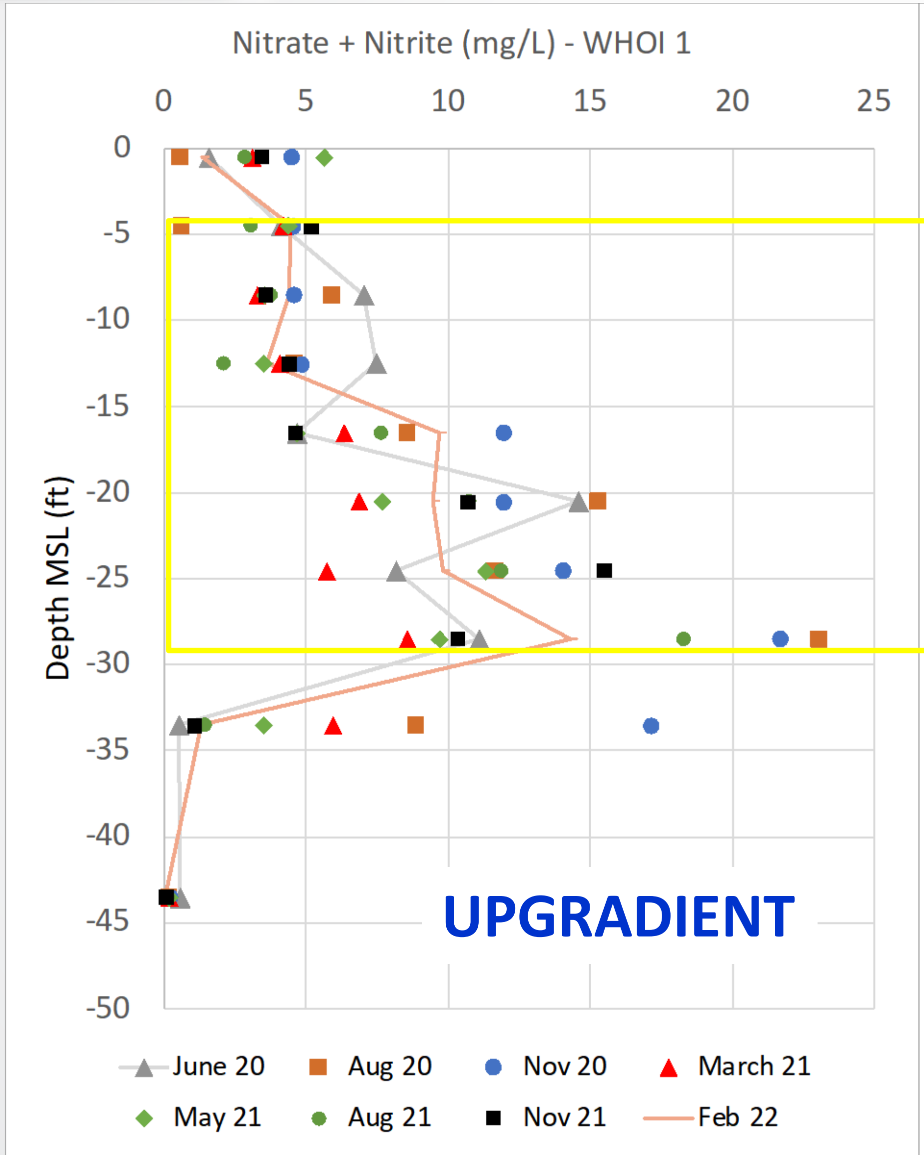
Example Alternative Approach for Nitrogen Removal

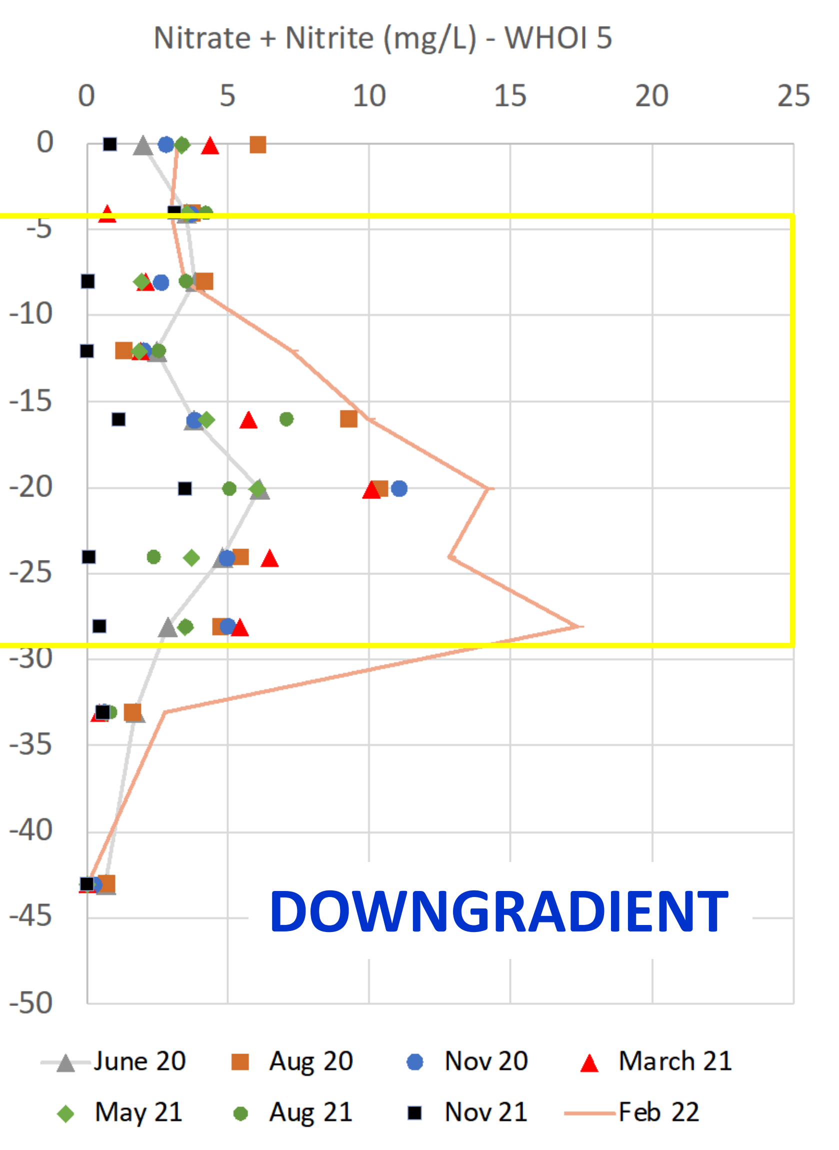
Bournes Pond, Falmouth, MA

Photo credit: Maine Imaging

Excess Nitrogen Load: ~4000 kg N/yr

Year 1 EVO Dosage: Nitrate removal





PRB Design (as installed)

Permeable Reactive Barrier Design Parameters	July 2020 Installation	
PRB Width (ft)	60	60
Vertical Interval (ft)	24	24
PRB Length (ft)	12	12
Porosity	0.3	0.3
PRB Pore Volume (gallons)	38,776	38,776
PRB Design Life (months)	24	12
Total Injection Volume (gallons)[1]	6,300	6,300
	12,600	
Percent of Total Pore Volume to Inject	16.2%	16.2%
Emul. Vegetable Oil Dosage	20%	10%
Emul. Vegetable Oil Stock (gallons)[2]	2,100	1,100
Total $CaCO_3$ Buffer (lbs.)	725	725
	1,450	
Total Injection Points	12	12
	24	
Injection Flow Rate (gal/min)	1 - 7	
Injection Flow Rate (gal/min, average)	3.7	
Injection Days	4	

Tech Transfer

- PRB technology has existed for decades, though most applications are for treating chlorinated solvents in low permeability soils
- A major project deliverable will be an open source design tool for denitrification PRBs in southeastern New England and beyond (e.g. Long Island) including cost of treatment based on EVO longevity

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Example PRB

RETURN TO COVERPAGE

1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	200	feet	61	meters
Length (parallel to groundwater flow)	20	feet	6.1	meters
Saturated Thickness	40	feet	12.2	meters
Design Period of Performance	5	years	5	years

2. Treatment Zone Hydrogeologic Properties

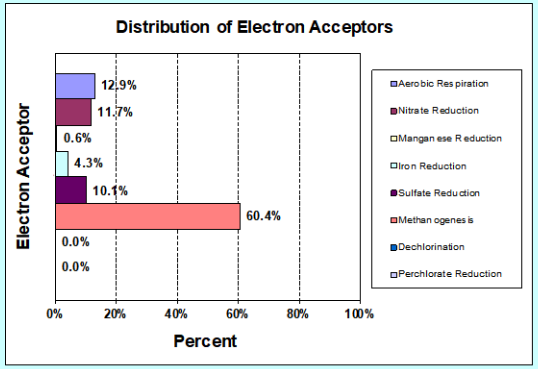
	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.25	percent	0.25	percent
Average Aquifer Hydraulic Conductivity	300	ft/day	1.1E-01	cm/sec
Average Hydraulic Gradient	0.001	ft/ft	0.001	m/m
Average Groundwater Seepage Velocity	1.20	ft/day	3.7E+01	cm/day
Average Groundwater Seepage Velocity	438	ft/yr	133.5	m/yr
Effective Treatment Zone Pore Volume	299,280	gallons	1,132,866	liters
Groundwater Flux (per year)	6,554,232	gallons/year	24,809,774	liters/year
Total Groundwater Volume Treated (over entire design period)	33,070,440	gallons total	125,181,735	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	12.9%	295.421
Nitrate Reduction	11.7%	268.821
Sulfate Reduction	10.1%	231.702
Manganese Reduction	0.6%	14.178
Iron Reduction	4.3%	99.606
Methanogenesis	60.4%	1386.722
Dechlorination	0.0%	0.000
Perchlorate Reduction	0.0%	0.000
Totals:	100.00%	2296.45

Hydrogen demand in pounds/gallon: 6.94E-05

Hydrogen demand in grams per liter: 8.32E-03



4. Substrate Equivalents: Design Factor = 2.0

Effective concentration is for total volume of groundwater treated.

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	
1. Sodium Lactate Product	212,886	19,353	372	as lactic acid
2. Molasses Product	162,466	13,539	353	as sucrose
3. Fructose Product	128,292	11,455	372	as fructose
4. Ethanol Product	65,599	9,507	190	as ethanol
5. Sweet Dry Whey (lactose)	101,189	sold by pound	257	as lactose
6. HRC®	77,785	sold by pound	225	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	39,940	5,121	145	as soybean oil
8. Emulsified Vegetable Oil	66,567	8,534	145	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Parsons Infrastructure & Technology Group, DOD ESTCP Program

Verified Water

We measure

Nitrogen in wastewater

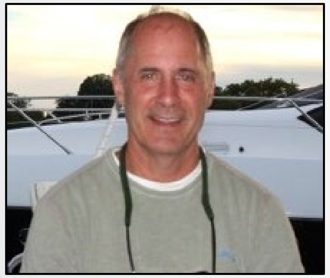
Founders

Dr Qingzhi Zhu – Inventor, R&D

- PhD, Associate Professor, Environmental Analytical Chemist, 100 papers
- 20 years testing and developing instrumentation, previous inventions
- Inventor, Exclusive License of IP from SBU

Dr Chris Gobler – Funding, Oversight, Contacts

- Director: New York State Center for Clean Water Technology at Stony Brook
- Over 20 scientists and engineers focused on advanced septic systems
- Ph.D. ,Endowed Chair at Stony Brook University, water ecosystems



Bud Dunbar – Business Development, Start-Up

- Built a $BB public company, Top 100 Growth Companies in US, Ran M&A
- 7 years sales and business development in wastewater domain
- Principal investor in Early-Stage Tech Venture Capital, Five startups
- MBA, BS Civil/Environmental Engineering

Team - Electro Mechanical Engineer, Informal Advisory Board - CCWT

The Problem: Septic Systems don't work
They don't remove dissolved pollutants

Nitrate flows into Drinking and Surface Water

- Causes cancer in drinking water
- Causes harmful algae blooms like this

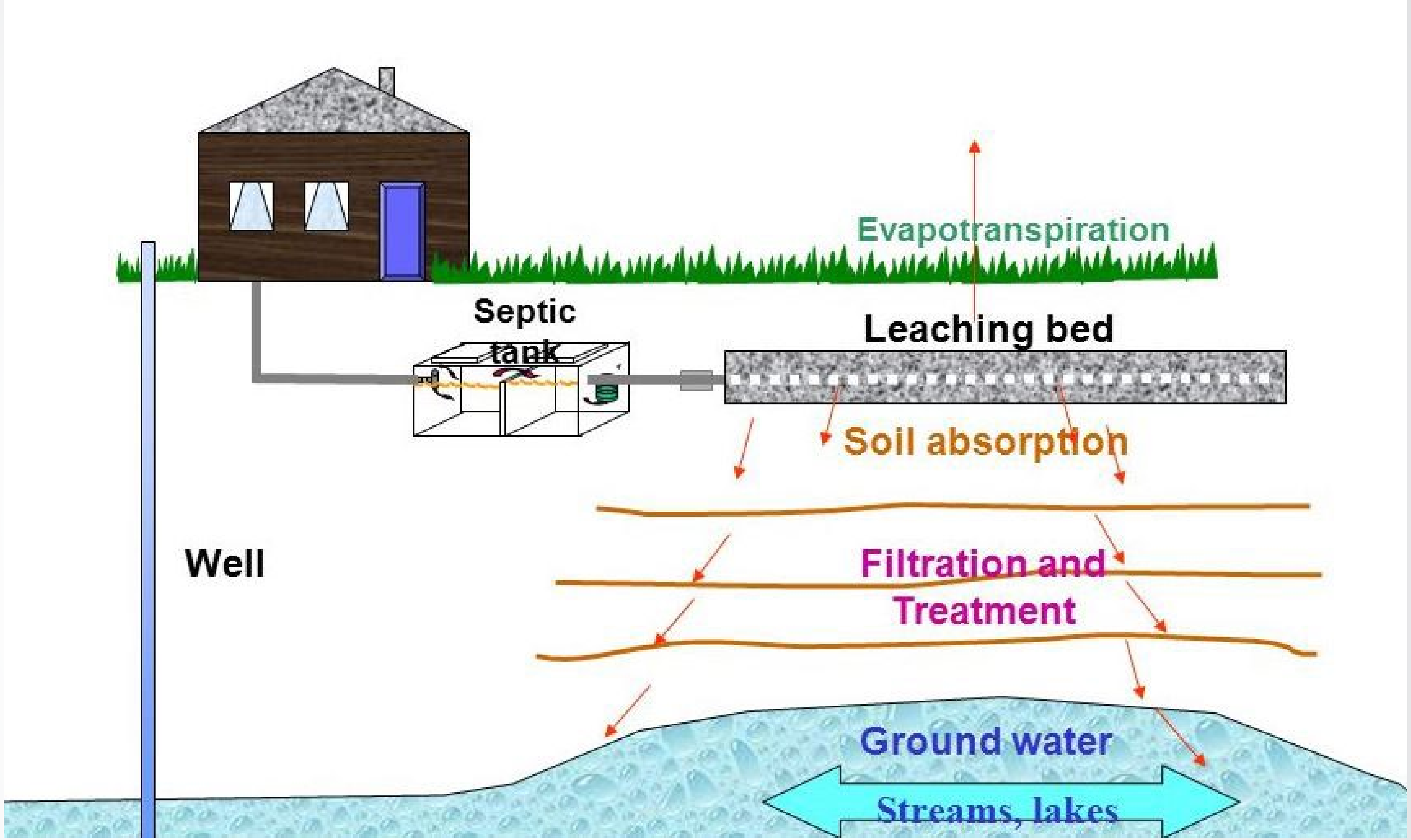
150 Year Old technology

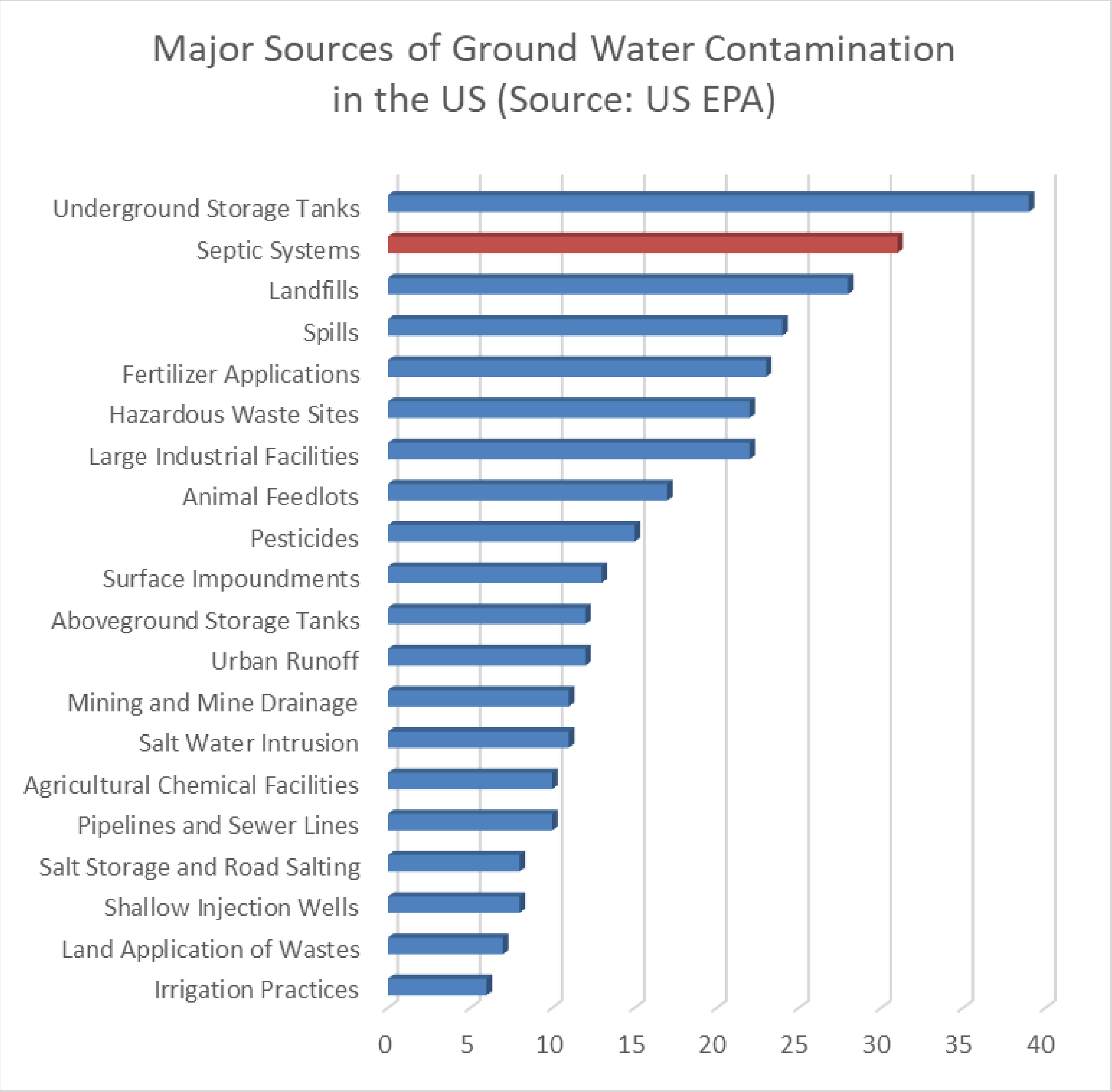
- Used by 26 million (24%) US homes

We can't afford sewers & centralized treatment

Verified Water

Nitrogen flows into ecosystems and well sources




Major Sources of Ground Water Contamination
in the US (Source: US EPA)
Underground Storage Tanks
Septic Systems
Landfills
Spills
Fertilizer Applications
Hazardous Waste Sites
Large Industrial Facilities
Animal Feedlots
Pesticides
Surface Impoundments
Aboveground Storage Tanks
Urban Runoff
Mining and Mine Drainage
Salt Water Intrusion
Agricultural Chemical Facilities
Pipelines and Sewer Lines
Salt Storage and Road Salting
Shallow Injection Wells
Land Application of Wastes
Irrigation Practices
0
5
10
15
20
25
30
35
40

Top 17 States by Number of Households on Septic

	Population	Counties	% on Septic	Number of Households	Households on Septic	Failed Septic Systems	Failure Rates
Florida	21,944,577	67	25%	8,708,165	2,177,041		
North Carolina	10,701,022	100	45%	4,246,437	1,910,897	334,407	18%
Texas	29,730,311	254	15%	11,797,742	1,769,661	221,208	13%
Pennsylvania	12,804,123	67	25%	5,081,001	1,270,250		
Ohio	11,714,618	88	25%	4,648,658	1,162,164	319,595	28%
New York	19,299,981	62	15%	7,658,723	1,148,808	45,952	4%
Washington	7,796,941	39	35%	3,094,024	1,082,908	357,360	33%
Georgia	10,830,007	159	25%	4,297,622	1,074,405	18,265	2%
Michigan	9,992,427	83	25%	3,965,249	991,312		
Tennessee	6,944,260	95	35%	2,755,659	964,481		
Indiana	6,805,663	92	35%	2,700,660	945,231		
South Carolina	5,277,830	46	45%	2,094,377	942,470	56,548	6%
Alabama	4,934,193	67	45%	1,958,013	881,106	176,221	20%
Virginia	8,603,985	133	25%	3,414,280	853,570		
California	39,613,493	58	5%	15,719,640	785,982	15,720	2%
Illinois	12,569,321	102	15%	4,987,826	748,174		
Massachusetts	6,912,239	14	25%	2,742,952	685,738	171,434	25%

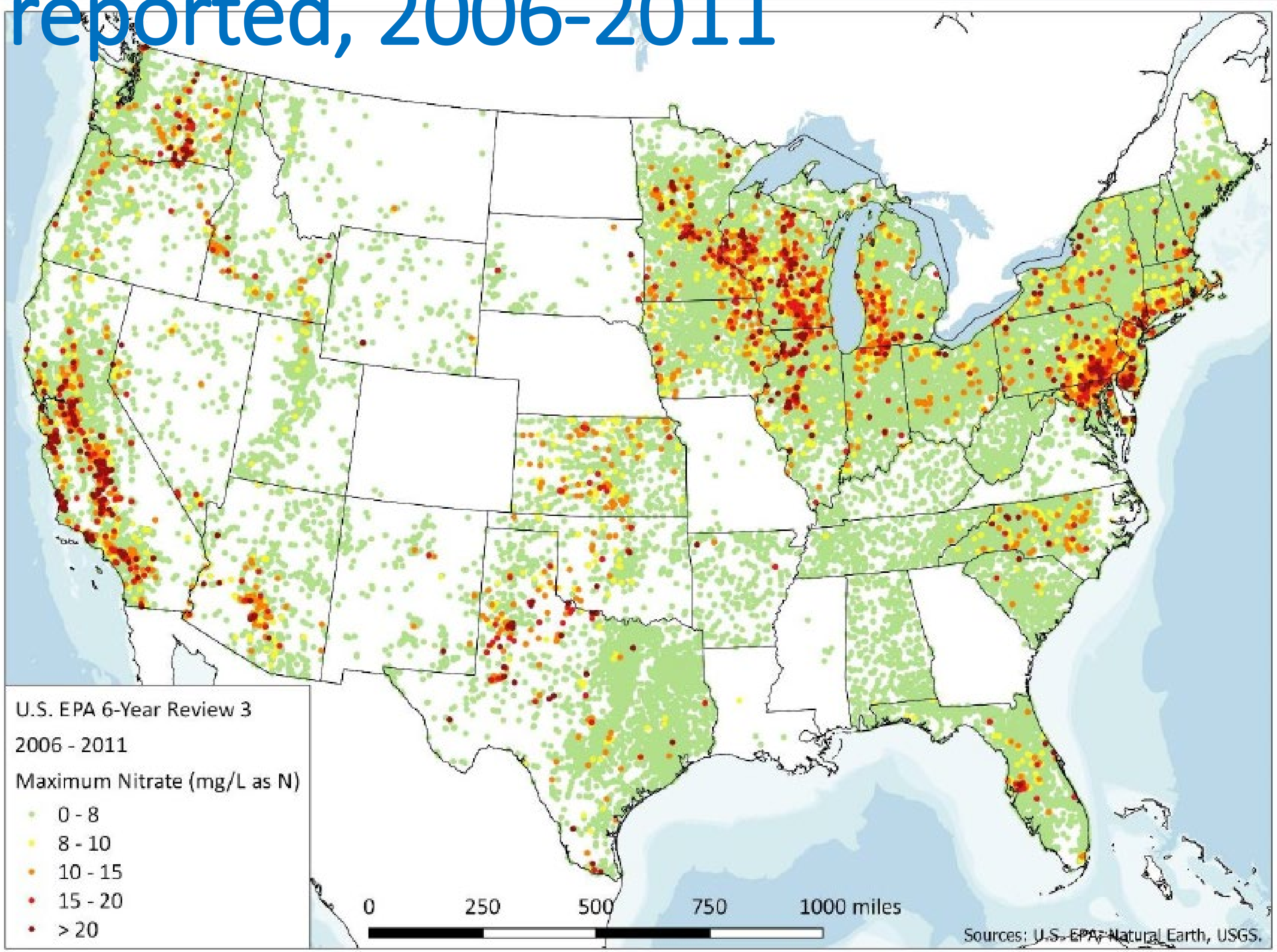
US EPA : Maximum nitrate reported, 2006-2011

There is strong data out of northern Europe that correlates

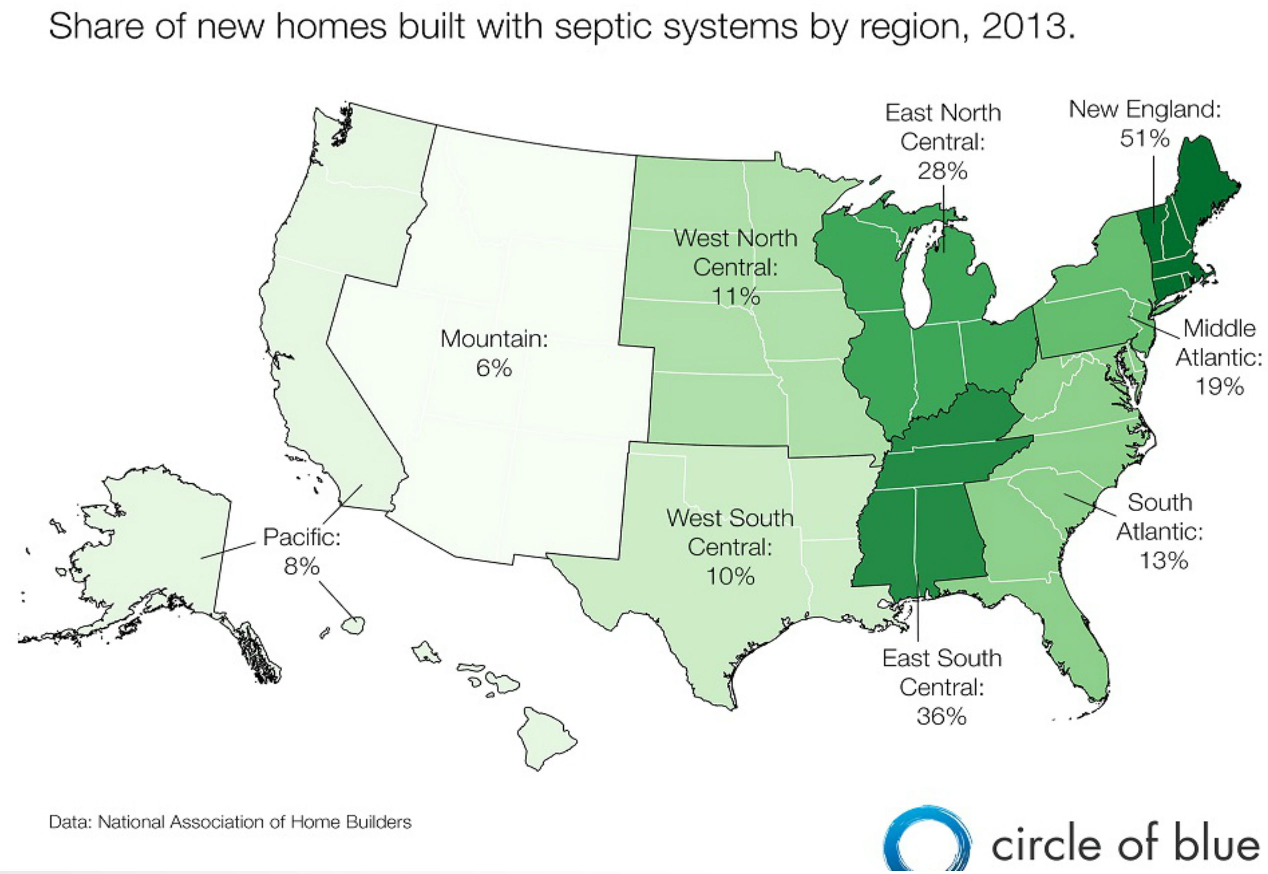
Various forms of cancer to nitrate concentrations in drinking water > 2-3 mg/L

Most US limits are 10 mg/L

If you live near a red dot, you should be concerned



Percent of New Homes with Septic Systems (2013)



This slide shows sewers are a question of political will, not density

New England has the greatest density and therefore the lowest cost of running sewers

But it has the highest percentage of new homes not on sewers

Suffolk County New York has more homes on septic

For Rural and Suburban Homes, Average cost per home Strongly Favors Decentralized Treatment

Centralized Treatment with Sewer Collection **$35,000-$150,000/home**

Decentralized Treatment = **$20,000-$60,000/home**

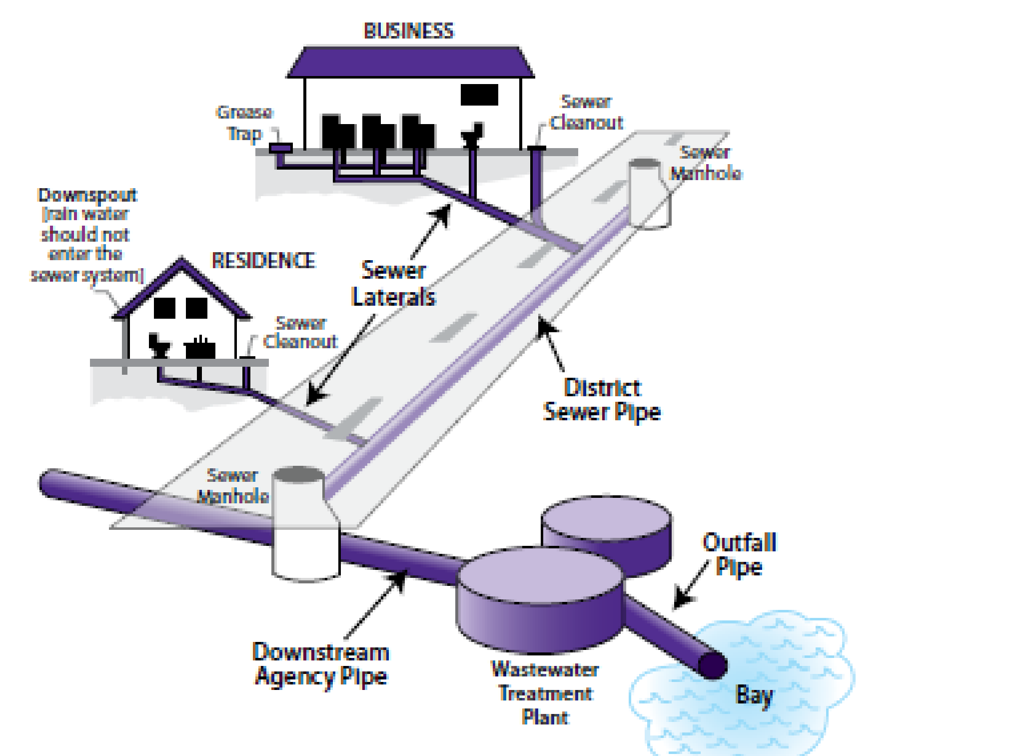
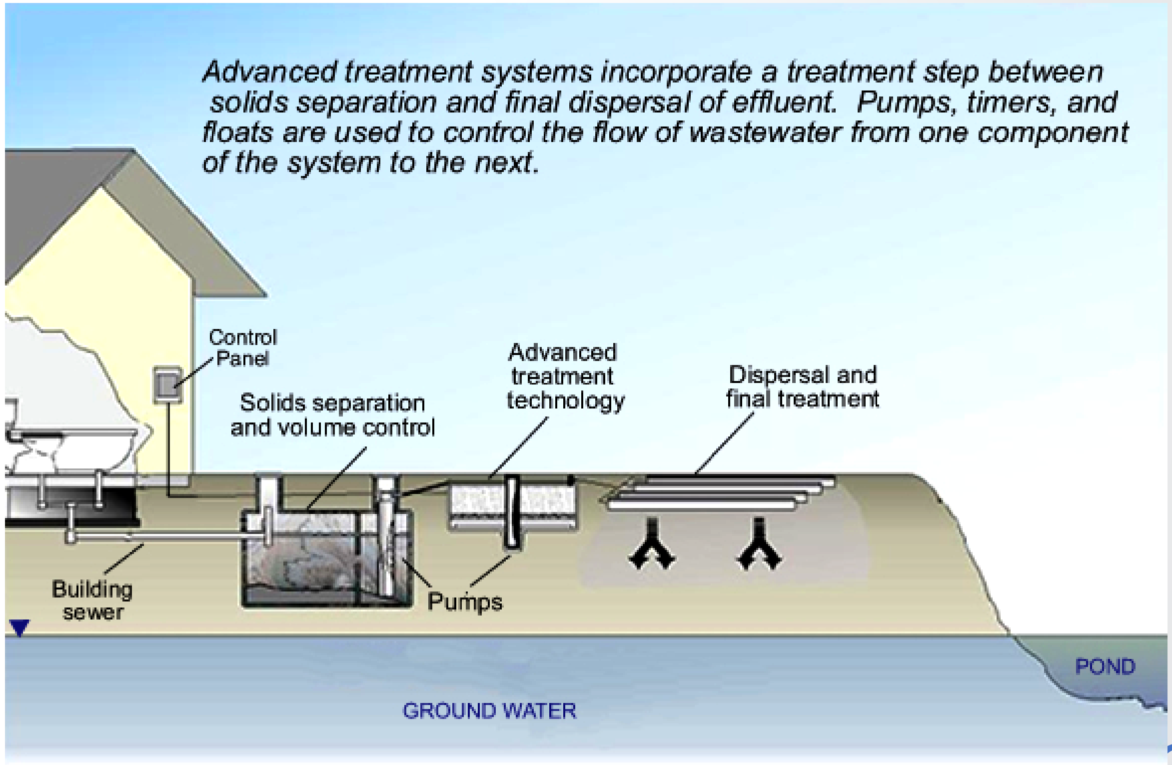
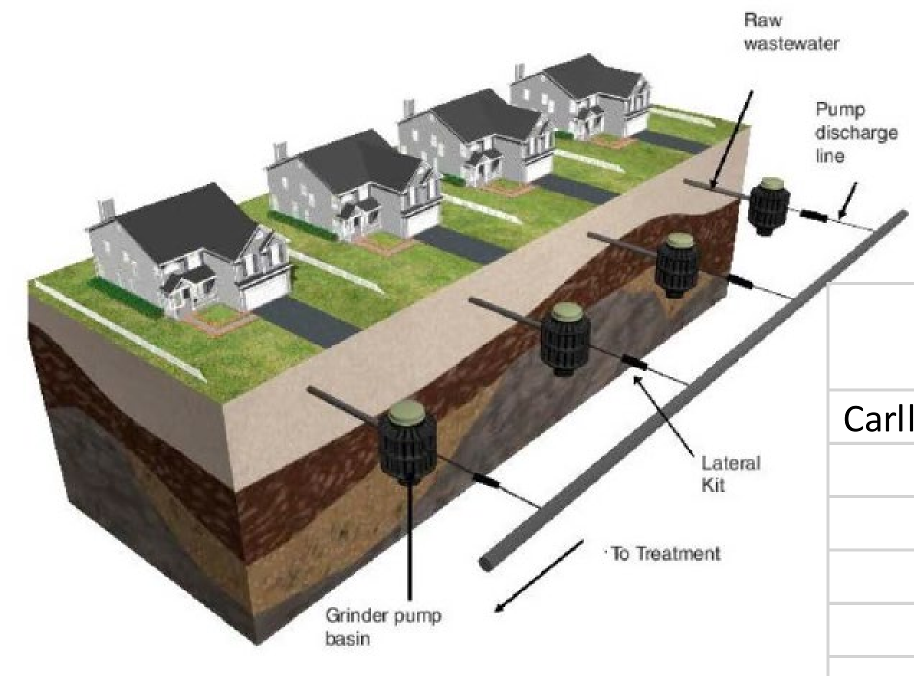


Image #1 – Schematic of a sewer system



High Cost of Centralized Treatment and Sewers



	# parcels	Project Cost ($ MM's)	Cost per Parcel		
Carlls River Watershed - Babylon	3,958	$ 140.2	$ 35,422		
Pathogue River - Patchague	513	$ 29.6	$ 57,700		Average
Oakdale Phase 1A	420	$ 30.2	$ 71,905		$ 59,983
Kings Park Business District	267	$ 20.0	$ 74,906		
Total	5,158	$ 220.0			
Typical OWTS	1		$ 25,000	42%	
	plus $490/year annual sewer fees				

The Answer – Decentralized, Onsite Treatment

This is happening! ½ cost of sewers

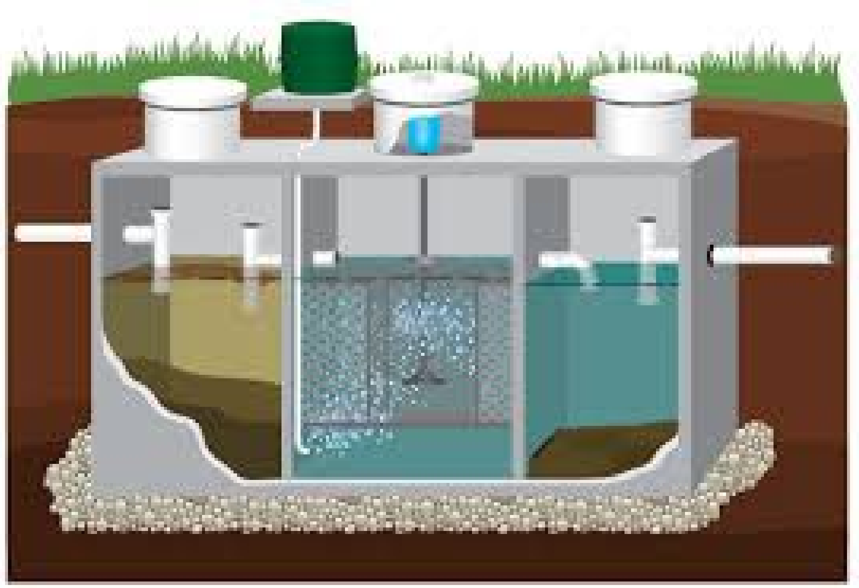
2.6 million drain into impaired water bodies

$65 billion early-stage market

200,000 of these in Suffolk County alone

$40K/home subsidies available

Disruptive Technology – better/cheaper/improving faster



Innovative and Alternative Onsite Wastewater Treatment Systems "I/A OWTS" or Onsite Systems

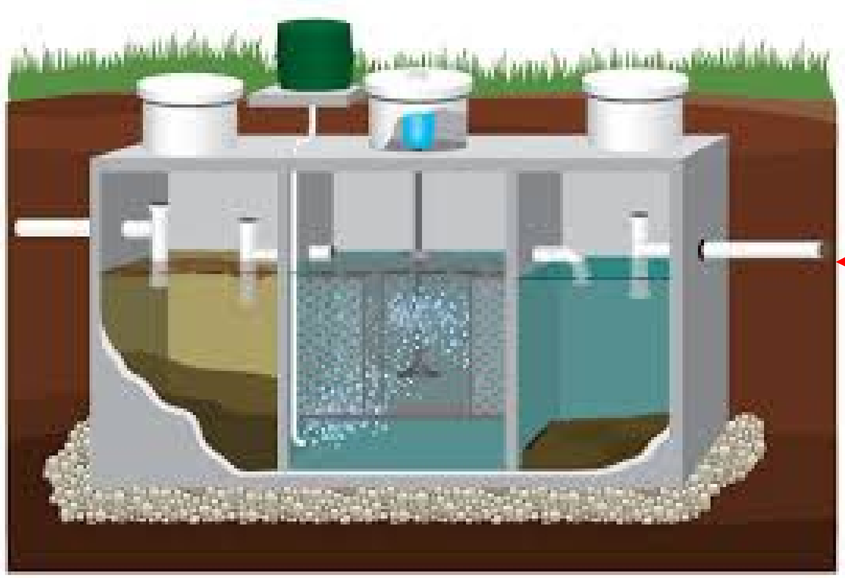
Solution – Decentralized Treatment

Onsite Wastewater Treatment Systems
(“OWTS”)
or “Advanced Septic Systems”

Advanced Septic Systems can already produce effluent TN < 10 mg/L

How are you going to manage millions of mini wastewater treatment plants?

You are going to start with getting some data



Our Product

- Measure nitrogen
- In-situ, reliable, accurate
- Long term deployment
- Replace manual sampling and lab work
- Online, real time
- Independent, verified

The Stonybrook Nitrogen Sensor

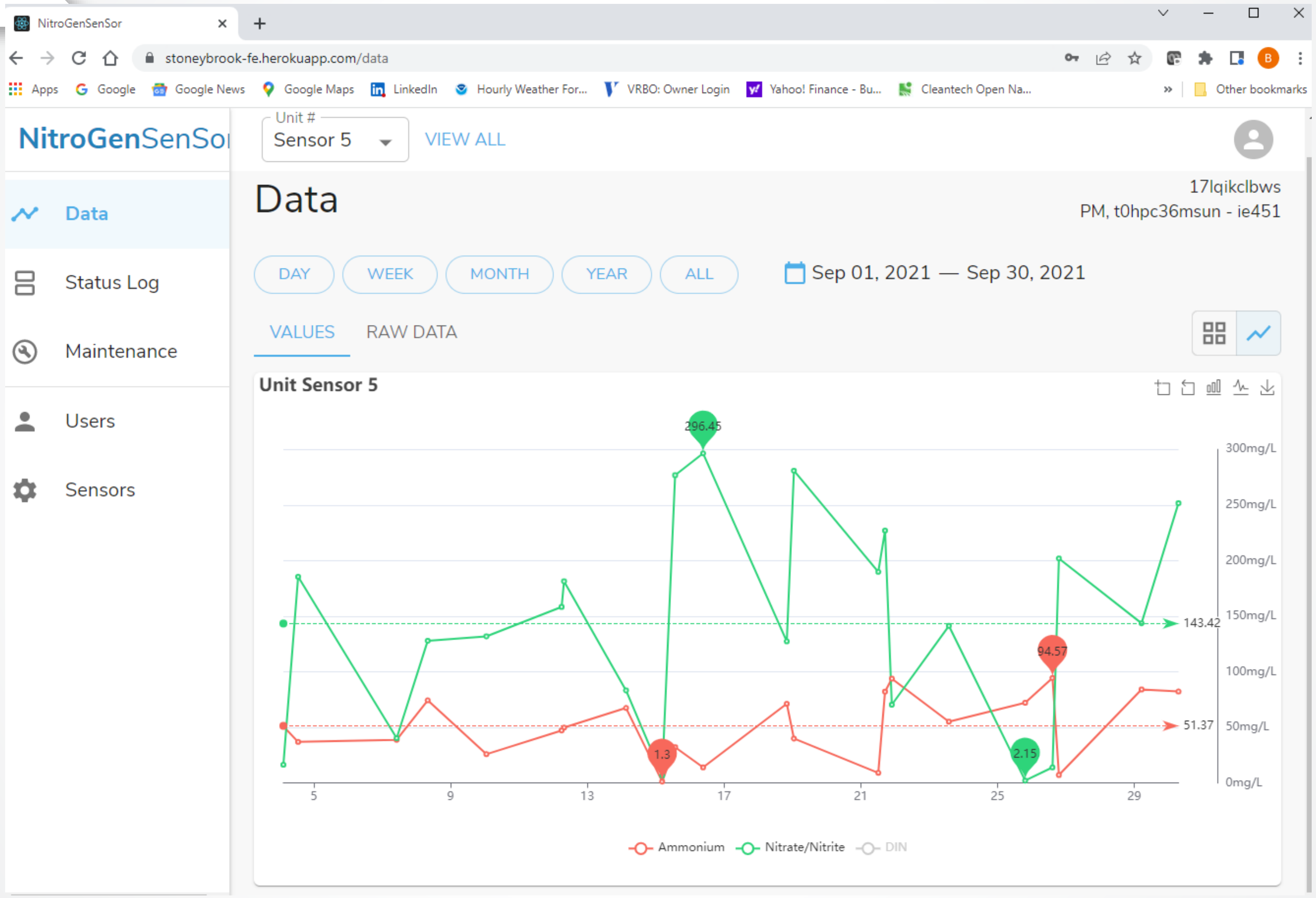
Measures Ammonium and Nitrate/Nitrite separately and simultaneously (2-70 mg/L)

It gets buried at grade level inside of a standard riser. The box is watertight.

In-Situ: sampling system filters and suctions water from the source

Highly reliable: it ran for over 12 months without missing a measurement in six kinds of wastewater, > 450 samples

User Interface – Screen shot of the Data tab



Technology Validation

EPA

Won EPA's "Low-Cost Nitrogen Sensor Challenge"
Nobody else even finished

Our prize:

1. $50,000
2. 6 Month ISO 14034 technology verification
3. 200 Unit Commercial Order to Suffolk County

Verification Results

n=135	NH_4	NO_3/NO_2
R^2	0.997	.986
% Recovery	98.8%	93.5%
Rel.Std.Dev.	3.3%	2.4%

A+

Test Sponsors

EPA
The Nature Conservancy

NSF Certified Test Facilities

BARNSTABLE COUNTY
DEPARTMENT OF HEALTH AND ENVIRONMENT

MASSTC
The Massachusetts Alternative Septic System Test Center

Independent Test Oversight

BATTELLE
VerifiGlobal

Technology Validation

Comparison with Certified Lab data

Completed

- all 449 readings, 6 types of water

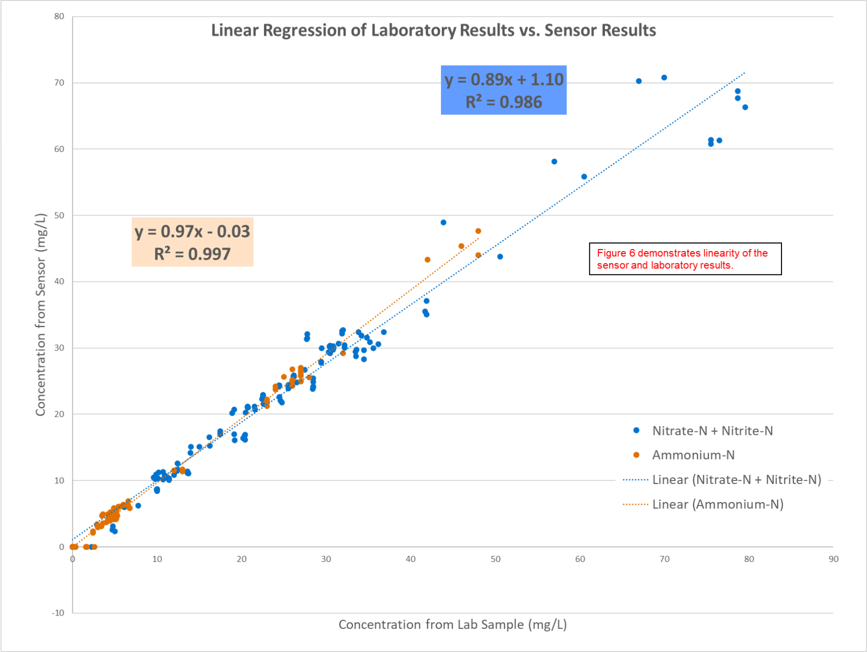
Low Maintenance

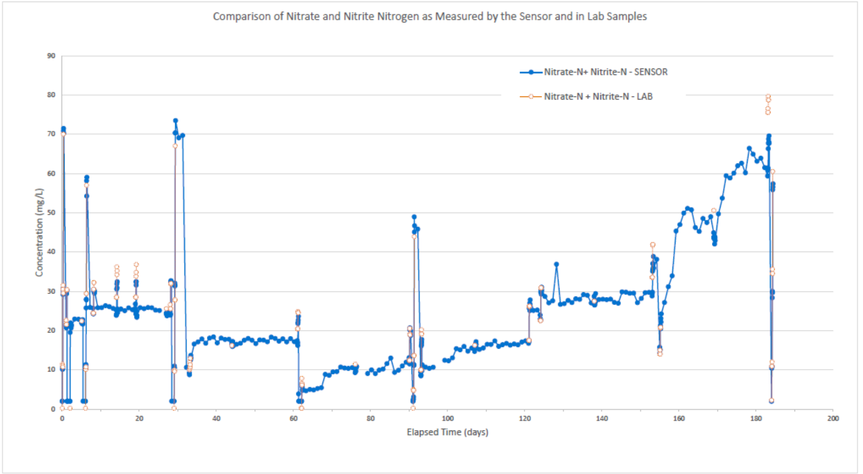
- ran for six months, no problem

Near perfect

- correlation
- accuracy
- precision

We Nailed it!

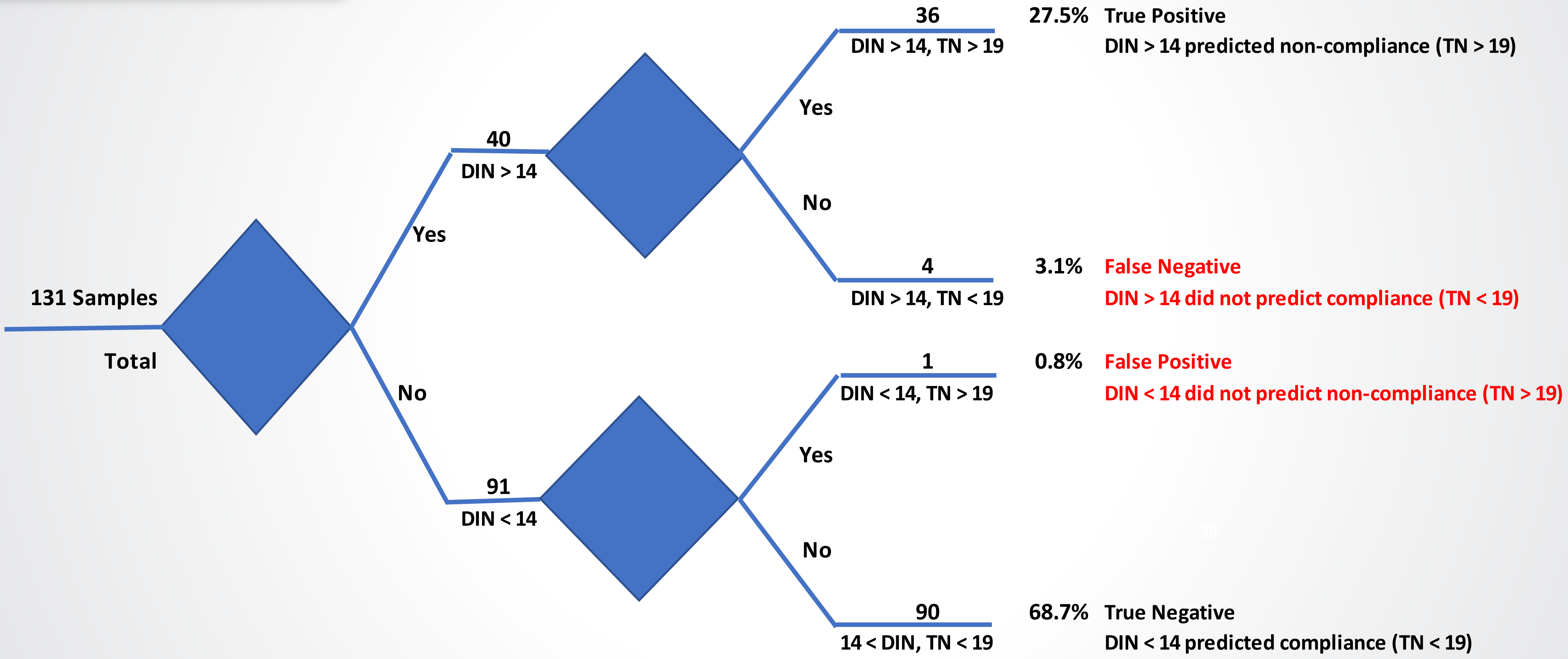




The Nitrogen Sensor is Accurate Proxy for TN in 96% of Samples

DIN is Predictive of TN in 126/131 (96%) of samples

DIN predicted compliance when system was noncompliant 1/131 (0.7%) of samples



Independent 3rd Party Validation

Foresight
science & technology

Trailblazer™ Assessment Report
Low-Cost and Long-Term Deployment Nitro
Simultaneously Measuring Nitrate and Ar
Advanced Septic Systems

Science/Technology Fields: Environmental Management, Environ
Pollution

Technology Type: Product
Geographic Region: USA

Project Number: RFC0165TB
The Research Foundation for State University
050.Zhu TAF Class of 2020
was
Prepared by
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Research Foundation for State University of New

Phase II Advanced Septic System Nitrogen Sensor Project

FINAL

Six-Month Field Performanc Test Report – Stony Brook Nitrogen Sensor

November 2020 – May 2021 Testing Period

Prepared by:

Battelle
505 King Avenue
Columbus, Ohio 43201

Submitted to:

U.S. Environmental Protection Agency
Office of Research and Development

July 27, 2021

U.S. ENVIRONMENTAL PROTECTION AGEN
NEWS RELEAS
WWW.EPA.GOV/NEWSRO

Long Island Scientist Wins EPA Advanced Septic System I

Contact: Sonia Mohabir, (212) 637-3241, mohabir.sonia@epa.gov

NEW YORK (May 5, 2020) Today, the U.S. Environmental Protection A
scientist from Stony Brook University in Stony Brook, NY, has won the
Nitrogen Sensor Challenge, an international competition to advance t
sensors to measure nitrogen levels discharged from advanced home s
with Stony Brook University and the New York State Center for Clean
Challenge's prize of $50,000, the opportunity for commercialization s
testing and verification of the sensor technology's performance by the
International Organization for Standardization (ISO) Environmental Te
14034 standard.

"This competition shows that great innovations start small and can ha
said EPA Regional Administrator Pete Lopez. "EPA encourages the de
sensor technologies to help reduce nitrogen load and protect human

SUNY RF
The Research Foundation for
The State University of New York

SUNY Technology Accelerator Fund
Funding Agreement

This Funding Agreement ("Agreement") sets forth the terms and conditions of a Technology Accelerator Fund ("TAF") Class of 2020 Award ("TAF Award"). The term of the TAF Award shall be March 15, 2021 to March 14, 2021. The Project must be conducted in accordance with State University of New York ("SUNY") and The Research Foundation for The State University of New York ("RF") policies, TAF Class of 2020 Application and Administrative Guidelines, and the objectives, milestones and deliverables identified in the proposal entitled, Low-Cost and Long-Term Deployment Nitrogen Sensor for Simultaneously Measuring Nitrate and Ammonium in Advanced Septic Systems.

I: THE PROJECT

The RF has approved funding to support the research project defined by the Scope of Work specified in Appendix A of this Agreement (hereinafter the "Project"). The Project will be carried out by Dr Qing Zhu (hereinafter the "Principal Investigator"). The Institutional Official for the Project is Donna Tuminello (hereinafter the "Institutional Official").

II: AWARD AMOUNT

The amount of the TAF Award to support the Project is «$50,000. The TAF Award will be audited and any charges not included as eligible expenses under the TAF Class of 2020Application and Administrative Guidelines and in Appendix A will be rejected. Any amounts remaining after termination or expiration of this Agreement or the achievement of each milestone specified in Appendix A shall be reclaimed by the TAF.

III: PROJECT MILESTONES

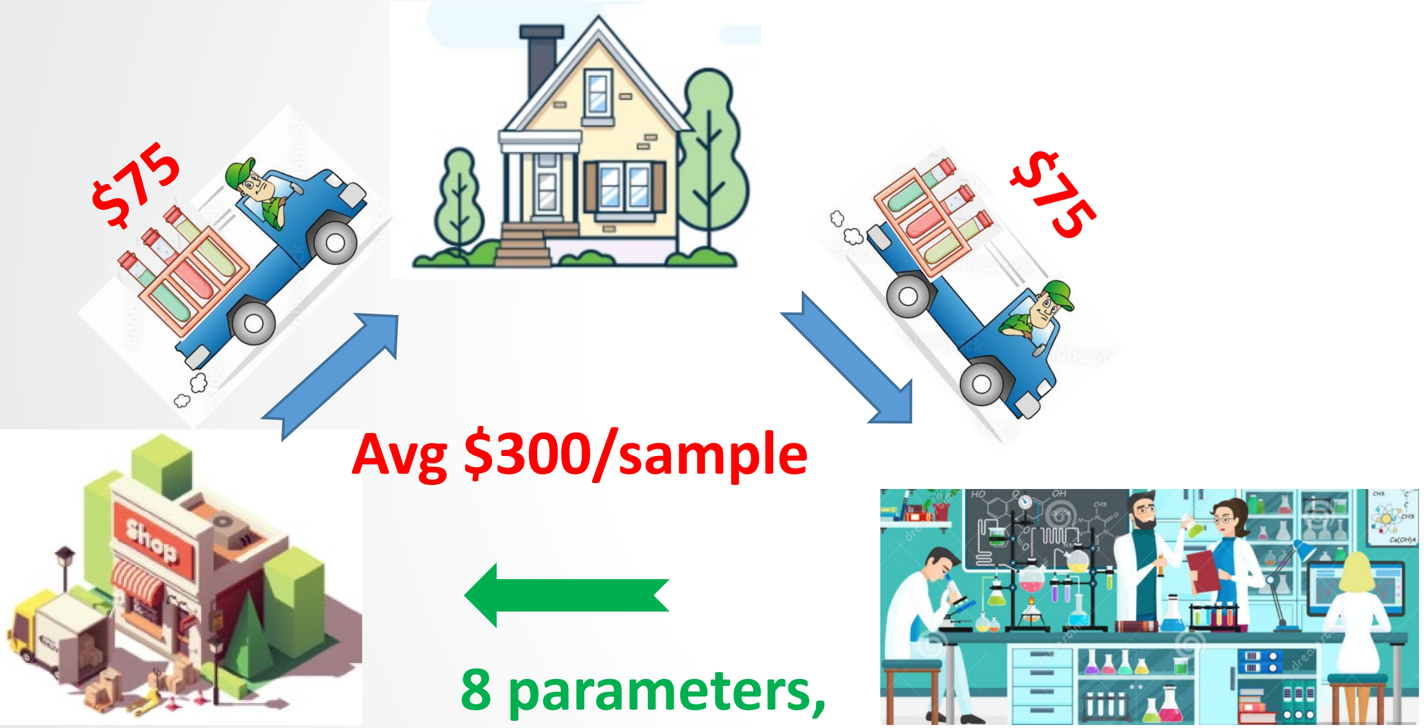
If the Project Milestones specified in Appendix A cannot be achieved within the timelines set forth, the Principal Investigator must notify in writing the Institutional Official, who must then consult with the TAF Managing Director or delegate to determine whether it is possible to modify the Scope of Work. If the progress towards achieving a Project Milestone becomes more than thirty (30) days behind schedule, the TAF Managing Director or delegate reserves the right to terminate this Agreement, discontinue funding the TAF Award, and the remaining TAF Award balance will be reclaimed by the TAF.

IV: FUNDING

A Project account will be funded with an initial amount of $22,500 upon commencement of the Project to cover the anticipated costs of achieving Project Milestone(s) 1,2, 3.2 and 3.3, as specified in Appendix A. Thereafter, funds to support the achievement of milestones will be disbursed after the Principal Investigator and Institutional Official certify that the preceding milestone(s) are successfully achieved by submitting a Milestone Report (see Appendix B) to the TAF Managing Director or delegate. Milestone Reports will be reviewed and accepted or rejected within three (3) business

Verified Water

Sampling and Testing are a huge impediment to widespread adoption of I/A Systems

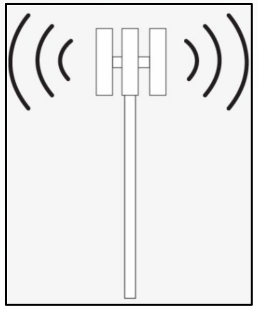


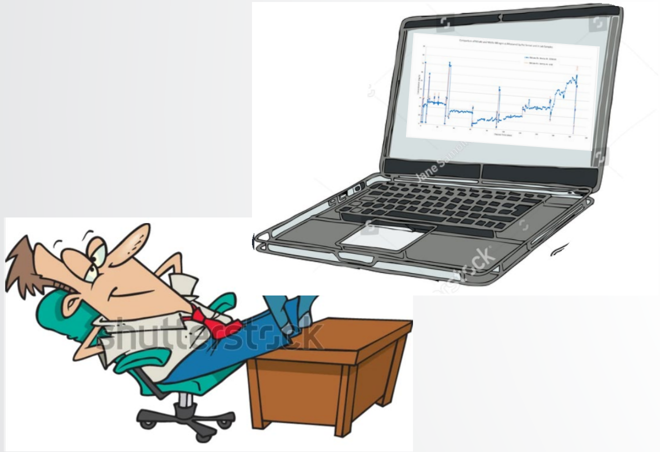
8 parameters,
$150 of lab fees,
a week to report

18 Monthly samples
X $300/sample
$5,400/pilot site
x 12 pilots
+
12 Monthly samples
X $300/sample
$3,600/provisional site
X 38 Provisional sites

> $200,000/vender
And 3 years!
For 1 data point per month

Verified Water





$2.50/data point
Vs
$300/data point

Our Solution

- Real time, on demand
- NH_4+ and NO_3/NO_2

Reusable: OWTS Vendors buy them and reuse them

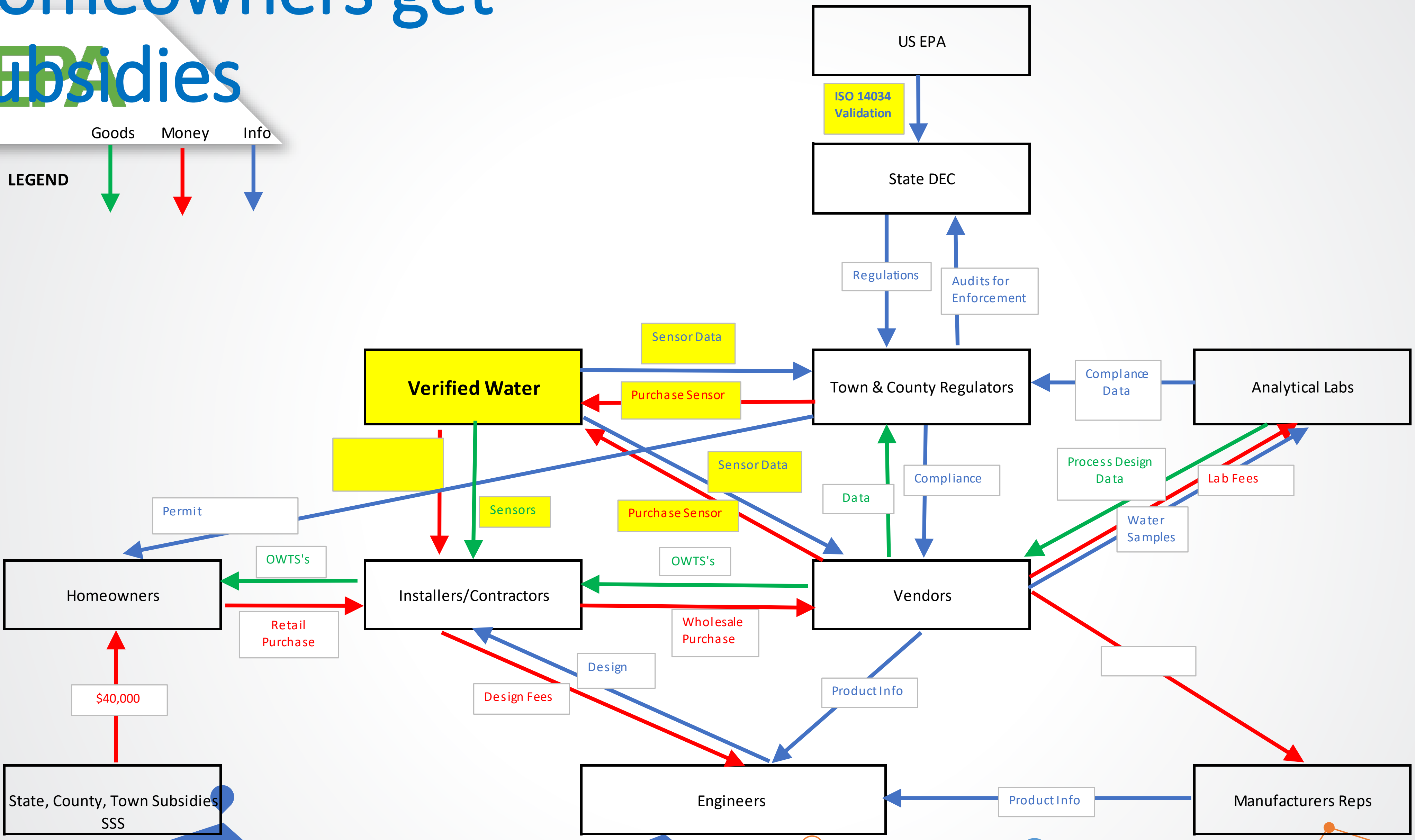
Price/Pilot <$1,000/ site vs $10,800/pilot site for current lab methods

Independent, third party Verified data quality

Comparison	Set up	Frequency of Samples	Cost per Sample	Cost per Pilot per home	Total Number of Samples	Total Cost to Pilot 20 homes	Time to Verify 1 Pilot System	Access to Data	Data management	Alarms	Bias
Real Time Monitor	Install sensor on site, Uninstall after pilot	Hourly, daily, weekly, monthly, or combination	$ 2.50	$1,000	400 per home	$ 20,000	3 months	Real time data, via smart phone or desk top	Data is organized, downloaded to Excel	Yes	Independent Third Party Verification, Vendors cant bias the measurements
Manual Sampling	Send technician to every site	Monthly - random times of day, random days of week	$300 to $500 per sample	$10,800	36 per home	$216,000	3 years	pdf file via email, Available within days	Requires staffing to manage the data	No	Regulators don't have enough staff to send technicians so vendors do the sampling.

Real time data tells a much richer story than a single monthly data point

Homeowners get Subsidies



Some Boring but Important Things to think about:

1. Concentrations vary within a basin. Where does your technician sample from in your system? Same place every time? Same place every technician?
2. Concentrations vary by time of day, day of week, and temperature. What day of the week was the sample taken? What was the temperature?
3. What did the vendor do to the system before the sample was taken?
4. How do you know the sample even came from the OWTS in question?
5. How accurate are commercial labs? If you took the same sample to 3 different labs, how far apart would they be?
6. Given all those variables, how nice would it be to have an independent third party, quality controlled, accurate performance measurement?
7. With hundreds of data points could you better characterize the performance of a system or a vendor than with single samples taken monthly, or quarterly, or annually?
8. How do various vendors perform over many years? How do you compare them when their data is all gathered differently?

More important things to think about
Put yourself in OWTS Vendors' Shoes

1. How can we reduce the cost of pilot testing?
2. How many vendors can afford over $200,000 of pilot testing to enter one jurisdiction? How many jurisdictions can each vendor go after at that cost? Will any one jurisdiction have the best vendors competing for their market?
3. Can you really expect homeowners to pay $10,000/house for lab testing a pilot system?
4. Would it help to have an alarm let you know when an OWTS is not functioning properly?
5. Could you reduce the number of site visits if you knew the system was producing good effluent quality
6. What incentive is there for OWTS Vendors to build quality, reliable, low maintenance, long life cycle products – spoiler: their incentive is to build something as cheap as possible. What incentive is there for vendors to improve from 19 mg/L to 10 mg/L to 5 to 2?

Some Bigger things to think about

New product Development Policy

1. We have three options. Centralized, Decentralized, and Do Nothing. Those of us who know, know “Do Nothing” should not be an option. How are we going to get everyone to see that?
2. Under current and proposed regulations, what incentive is there for vendors to build quality products that achieve TN of 5
3. Why would the performance data of an OWTS in Massachusetts not be applicable in New York? Why would the performance data of an OWTS in New York not be applicable in Massachusetts? How can we fix that? Who needs to fix that?
4. In Sweden, they have been implementing OWTS’s for 30 years. They have a national testing service where new products get thoroughly independently vetted and certified once and for all. It works fine.
5. What could the EPA do to support nationalized OWTS certification that is rigorous enough for states to rely on it?
6. How could NSF testing be improved so all jurisdictions could accept it?
7. What can the states do to support, encourage, and streamline new technology development and promulgate either centralized or decentralized treatment?
8. If “Yes” is adopting new disruptive OWTS technologies, what can the local jurisdictions do to “get to ‘yes’”

Some Even Bigger things to Think About

Politicians' Perspective

1. George Hawkins is a highly respected municipal utility operator who ran DC Water for a long time and "made it sexy". He would say one of his greatest accomplishments was getting an average of 4.5% rate increase every year for 6 years. Sewage treatment infrastructure has been underfunded for decades.
2. How are we going to muster political support for $billions of expenditures? How are we going to "make it sexy"
3. How much non-point nitrogen is dumping into a water body? Is 19 mg/L enough to save the water bodies? 10 mg/L? 5 mg/L?
4. Who is going to own responsibility for maintaining decentralized infrastructure?
5. How are regulators going to staff to oversee 100,000 mini wastewater treatment plants in one county? The installation of 5,000 new WWTP's per year?

I searched for a man among them to repair the wall and stand in the gap before Me on behalf of the land... Ezekiel 22:30

Special thanks to all these people who helped us get this far:

Pioneers

Maggie Theroux Fieldsteel, Retired US EPA **

Dr. Chris Gobler, Director NYS Center for Clean Water Technology *

Donna Tuminello, Director, Stony Brook Univ. Research Foundation

Gail DeRuzzo, ASQ CQM/OE Sr Quality Officer Envir & Ag, Battelle

Kristina Heinemann, US EPA

Kevin McDonald, Project Director, The Nature Conservancy

Nicholas Calderon, Policy Advisor, The Nature Conservancy

John Neate, Verify Global

Walter Dawidiak, Suffolk County

* Funded the team to startup

**Championed The Challenge through EPA Funding

***Special thanks

Nitrogen Sensor Challenge Technical Panel

- Jose Amador, Univ Rhode Island, Professor, Soil Science and Microbial Ecology
- Brian Baumgaertel, Assoc. Director, Massachusetts Alternative Septic System Test Center
- Jim Bell, Retired VP Engineering, BioMicrobics, Inc
- Christopher Clapp, The Nature Conservancy ***
- Ian Dombroski, US EPA
- Brian Dudley, Massachusetts State DEC
- George Heufelder, Retired Director, MASSTC
- Justin Jobin, former manager, Suffolk County Dept Health Services I/A OWTS program ***
- George Loomis, Research and Extension Soil Scientist and the Senior Program Advisor to the New England Onsite Wastewater Training Center at URI.
- Brian Pellerin, USGS
- Hal Walker, Professor Envir. Engr, Worcester Polytech Inst.

THANKS!

Any questions?

You can find us at

robert.dunbar@stonybrook .edu

qing.zhu@stonybrook.edu

The following slides provide additional perspective for Q&A

Who is the Buyer, who pays, why do they buy

Customer: OWTS Vendors

I get a call a week – when can we get one

Funding Source:

Reduced cost of Lab work, Vendors pay for lab work, not the homeowner

They buy to:

- Reduce # of site visits during piloting
- Speed up regulatory approval, Enter markets faster
- Process Design, Trouble shooting
- Real time provides more and better data

Customer: Regulators

Suffolk County buying 200 sensors

Funding Source:

Federal, State and Local Programs

They buy to:

- Manage non-point sources for TMDL credits
- Reduce work, better data mgmt
- Hold vendors accountable
- Real time data is much better

Our Value Proposition

For Vendors

Reduce number of site visits ($300-500/ea)

- From 36 to 6 in first 3 years

Avoided cost of entry

- $216,000 = cost to Vendor to enter a market
- $60,000 = cost using our 10 of our Sensors
- 3 years = time it takes to pilot test
- 1 year = time it would take us

Improve process design

- 600 data points 24/7 = what we can provide
- 36 data points, 1/month = what they get now
- Helps with process design, troubleshooting

For Regulators

Easier access to better Vendors

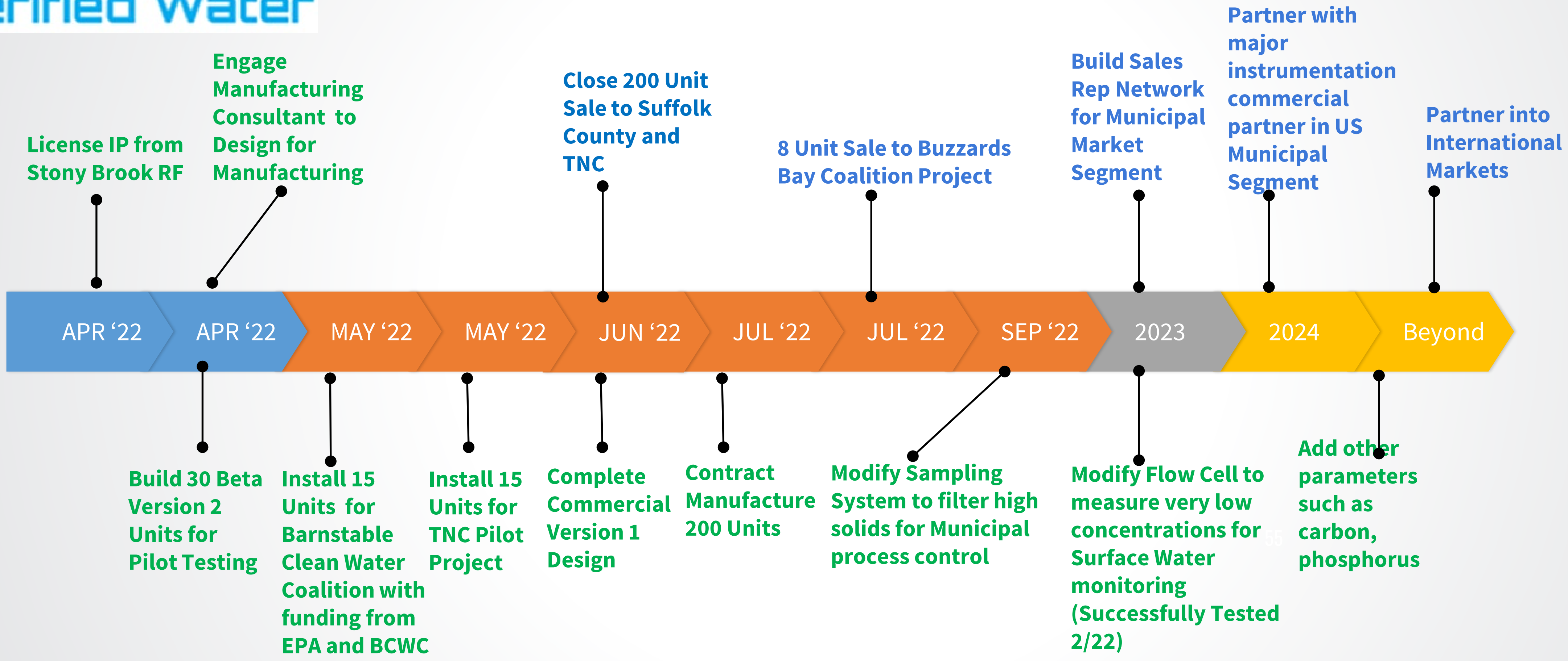
- New Vendors can enter the market sooner
- Regulators can really understand which Vendors do a good job
- Can influence Engineers

Better ecosystem management for Regulators' Funding Sources

- We can aggregate data by vendor, water shed, and time of year
- Better manage ecosystems
- Better return on investment metrics

Verified Water

TIMELINE



Competitive Analysis – Municipal Segment

Key Driver is Market Share	Long Island Clean Water Technology	#1 Competitor is manual Lab Analyses	Market Share Leaders (Municipal)	Other Market Share Lagards (Municipal)	New Entrant competes on price (Municipal)
Price	$	$$$$$	$$$$	$$$	$$
Maintenance Cost	$	$	$$$$	$$$	$$$
Product Reliability	5	5	3	1	3
Market Share	**1**	**5**	**3**	**2**	**2**
Sales Channel	1	5	5	3	2
Depth of Product Line	1	5	4	3	2
Service	1	2	5	3	2

SWOT

Our **Strength** is the low price, reliability, and low maintenance, **no one can do what we do**

Our **Weakness** is lack of **market share** which impacts sales channel, service, and breadth of product line

The **Threat** is we **can't reach or serve our market**

We have an **Opportunity** to establish a market share **beachhead** then attack the **multiple market segments**

Our Customer Segments

Decentralized Residential Onsite Systems

Target Market Segment

$250 MM

Centralized

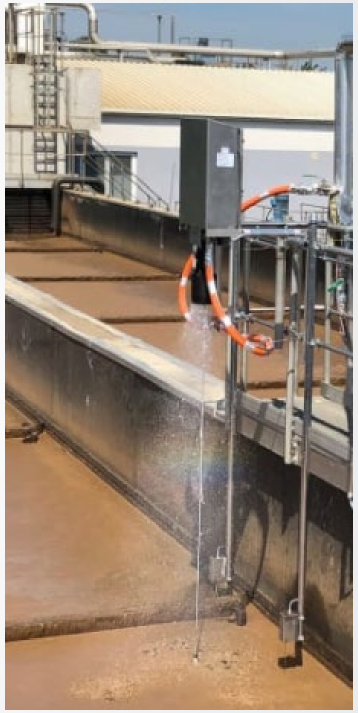
Municipal WWTP's

$1.2 Billion, g= 7%

Environmental Monitoring

< $50 MM

Industrial process control



We will partner in these over time

How we plan to Go to Market

Year 5 Unit Volume

Early Adoptors
(NGO's)

Word of Mouth

20 Units

Vendors
20-30 Companies

Direct Sales

500 Units

Regulators &
Early Municipal
>3000 jurisdictions

Manufactures' Reps

250 Units

Website

200 Units

Municipal Market

License Agreement with
Market Share Leader
e.g. Hach, YSI

Exit Strategy

Nitrate levels in Drinking Water Need to be Addressed

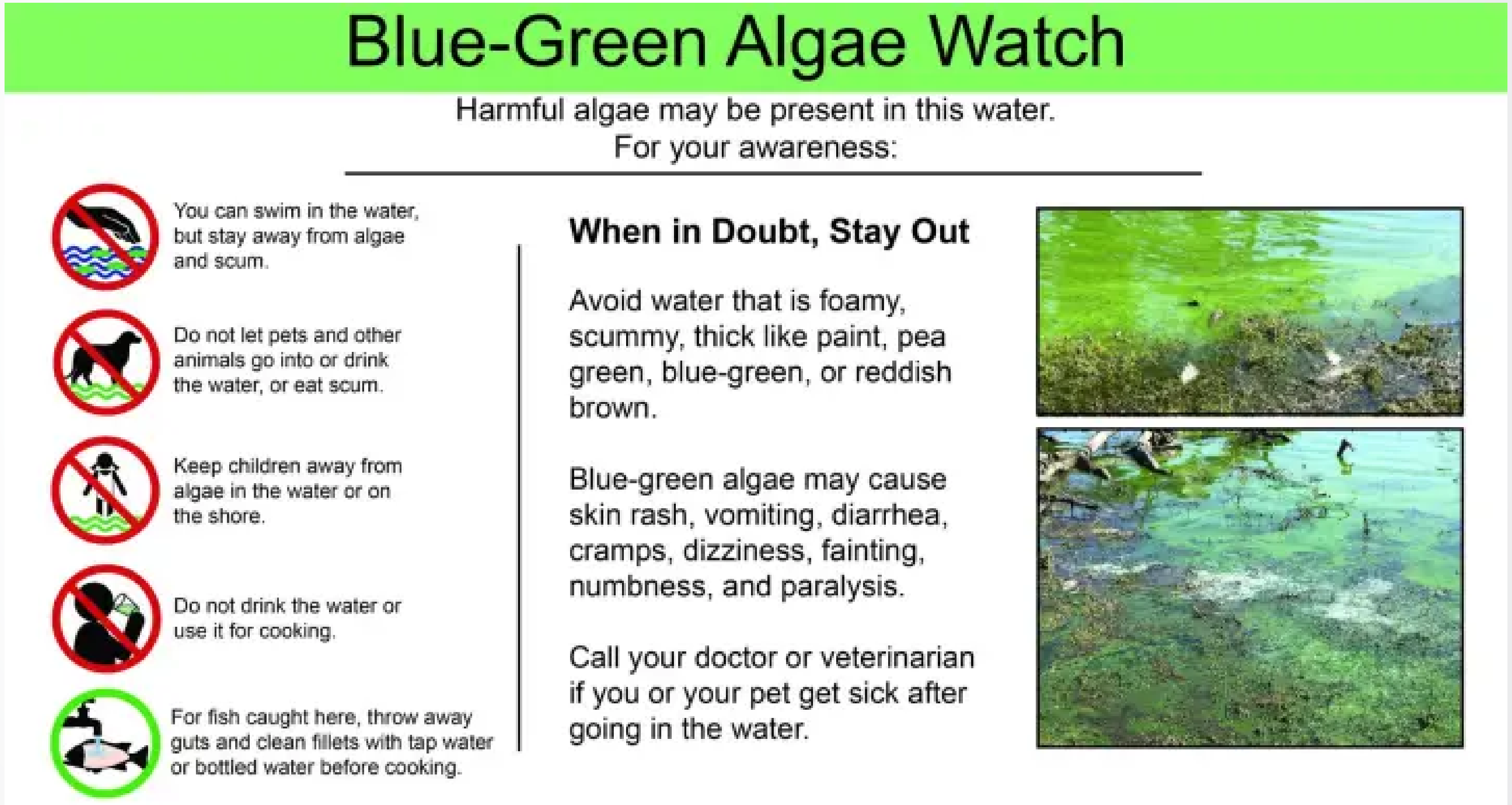
- "Increased **nitrate** in water supplies has been **linked to** colon, ovarian, thyroid, kidney and bladder **cancers** with the strongest association with colon cancer resulting in an estimated 6,500 cases of nitrate-attributable cancers." **
- A study from Denmark reported a statistically significant increase in colon cancer with nitrate in drinking water at levels of **0.7-2 PPM**
- **Most jurisdictions in the US only limit nitrate to 10 PPM.**
- **Those limits are likely to get tighter**

** https://www.unitypoint.org/desmoines/services-cancer-article.aspx?id=6c79a192-ecbd-48e5-bdcd-f4d399d2801e


HIGH
BACTERIA
COUNT
NO
WATER
CONTACT

Too much Nitrogen causes Harmful Algae Blooms

Warning sign
One of
thousands



Micro-siting and Nitrogen Removal Efficiency of a Liquid Injection Permeable Reactive Barrier (PRB)

Jessica Thomas

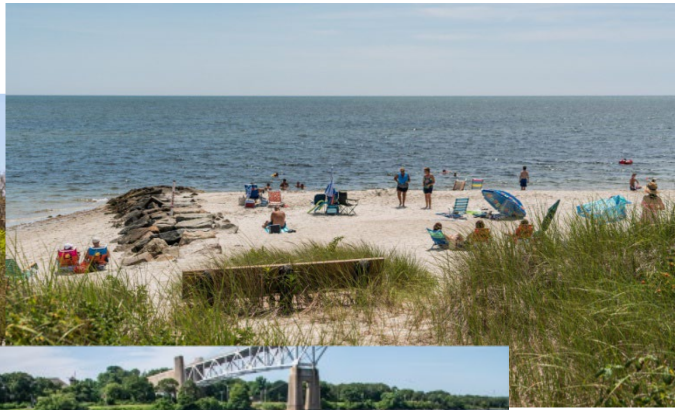
Advisors: Dr. Brian L. Howes and Dr. Miles Sundermeyer

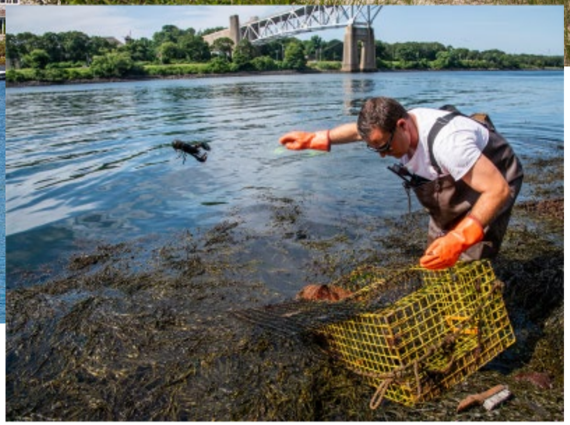
Problems with Nitrogen Enrichment

- Nitrogen inputs to estuaries can lead to eutrophication
- Estuarine eutrophication is a global environmental problem

Eutrophication in Coastal Communities Can Cause:

- Loss of water and habitat quality
- Financial Impact to
  - Tourism
  - Fisheries
  - Property Values
- Quality of Life
  - Beach Use
  - Native American Subsistence Rights





Nitrogen Enrichment

While eutrophication is a natural process, anthropogenic sources of nutrients can exacerbate the process

Point Sources:

- **Wastewater Treatment Facility Discharges**
- **Stormwater Discharges**

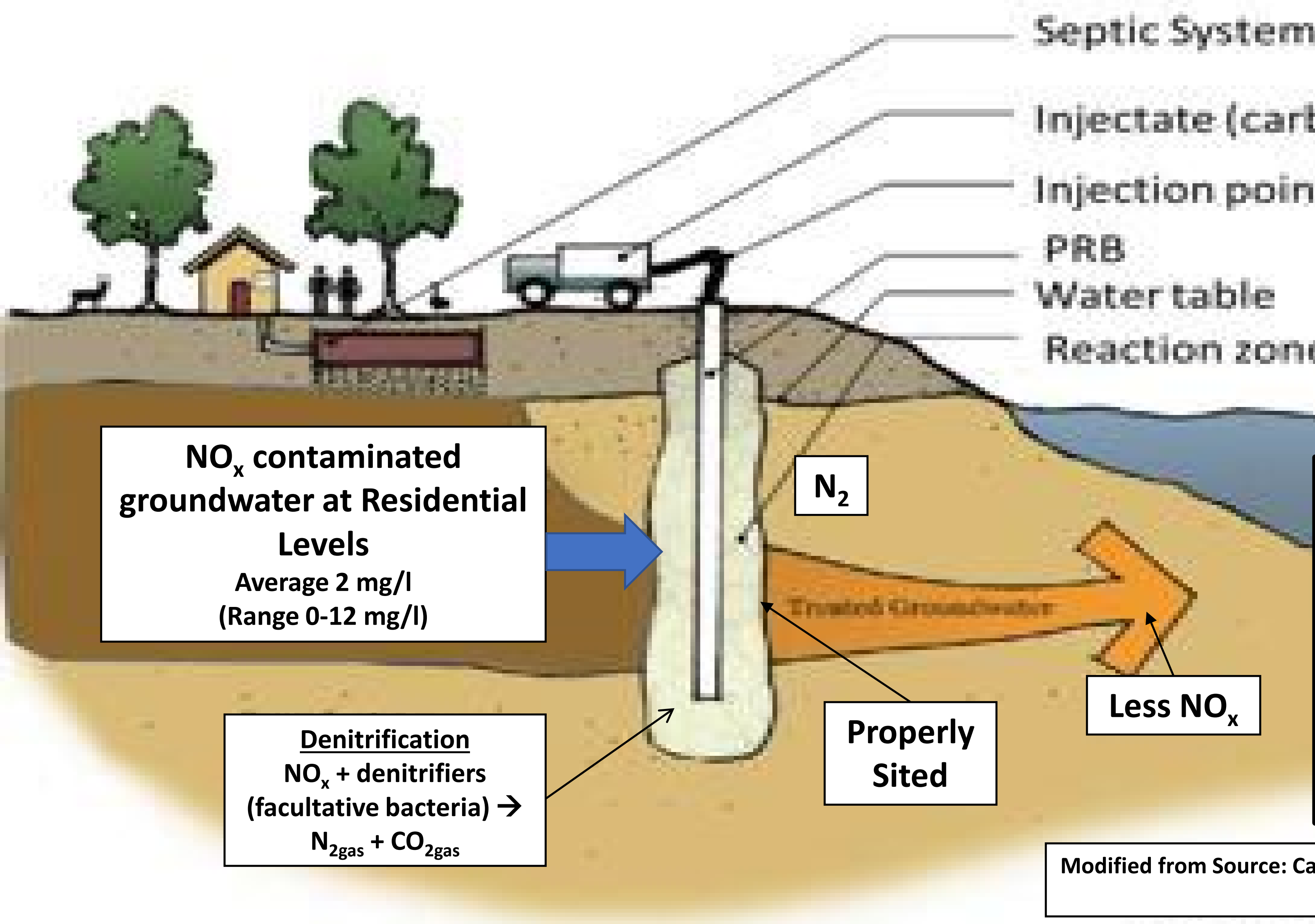
Non-Point Source:

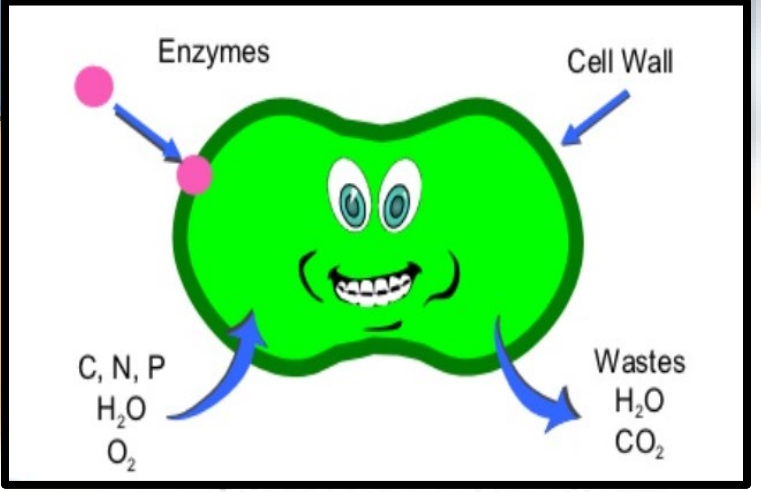
- **Atmospheric Deposition**
- **Agricultural (Crop/Animals)**
- **Lawn Fertilization**
- **Septic Systems**

What is a Liquid Injection PRB?

Carbon Source is used for:

- **Creation of anaerobic conditions**
- **Bacterial substrate**





Modified from Source: Cape Cod Commission

Micro-Siting PRBs

1. Select desired Site
2. Determine depth to groundwater
3. Determine groundwater flow direction and hydraulic conductivity
4. Establish nitrogen concentration levels and vertical profiles
5. Establish soil type
6. Quantify any tidal influence on groundwater
7. Finalize PRB design and placement

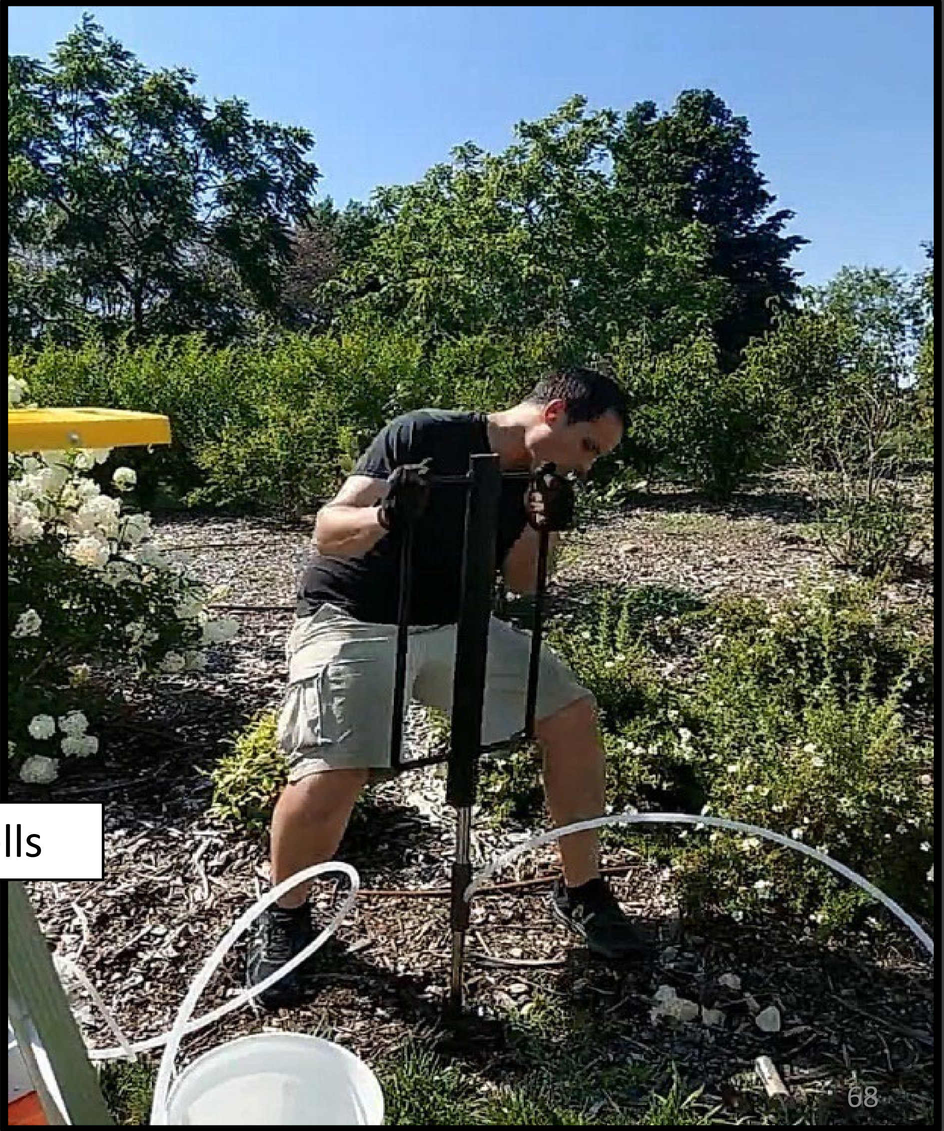
Site Selection: Locus Map

Lagoon Pond Estuary

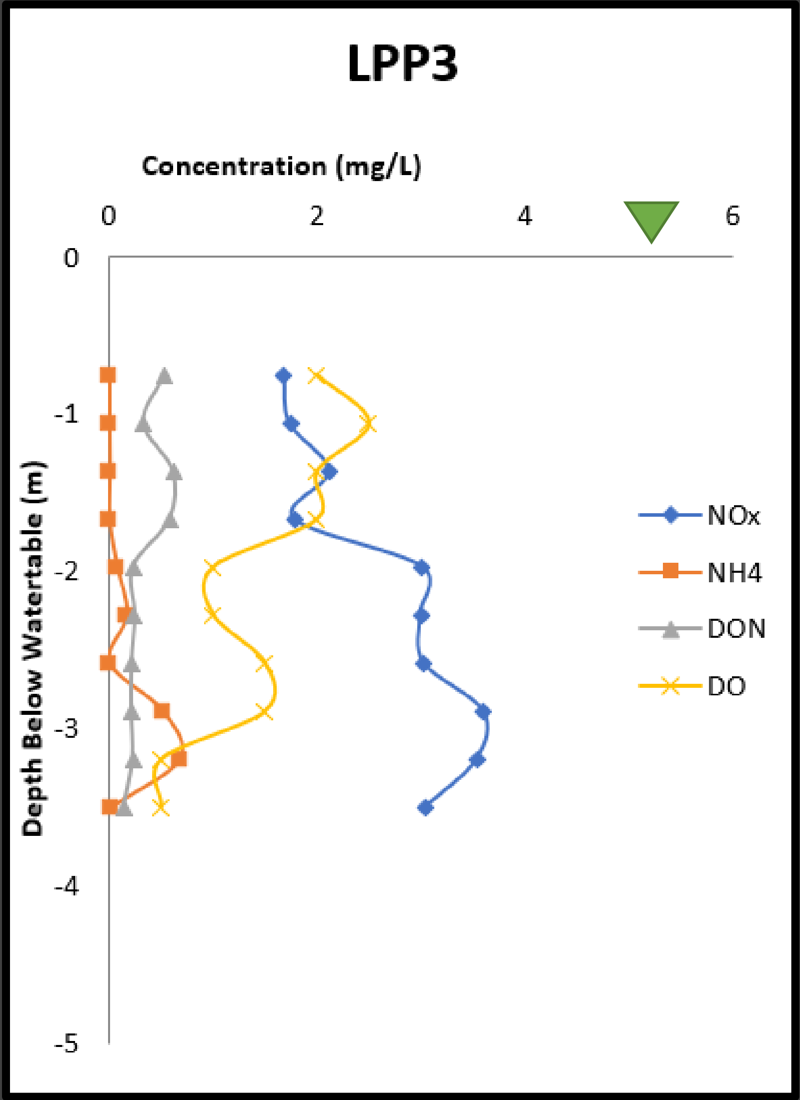
- Coastal Systems Program (CSP): MEP Assessment
- Impaired by N enrichment:
  - TMDL [N] Target = 0.33-0.42 mg/L
- CSP N loading to meet TMDL for N:
  - 74.1 kg/day
- Nitrogen Removal Goal:
  - 5,900 kg/y
- Stewards:

  Oak Bluffs
  Tisbury
  MV Commission

Site Selection: Site Map

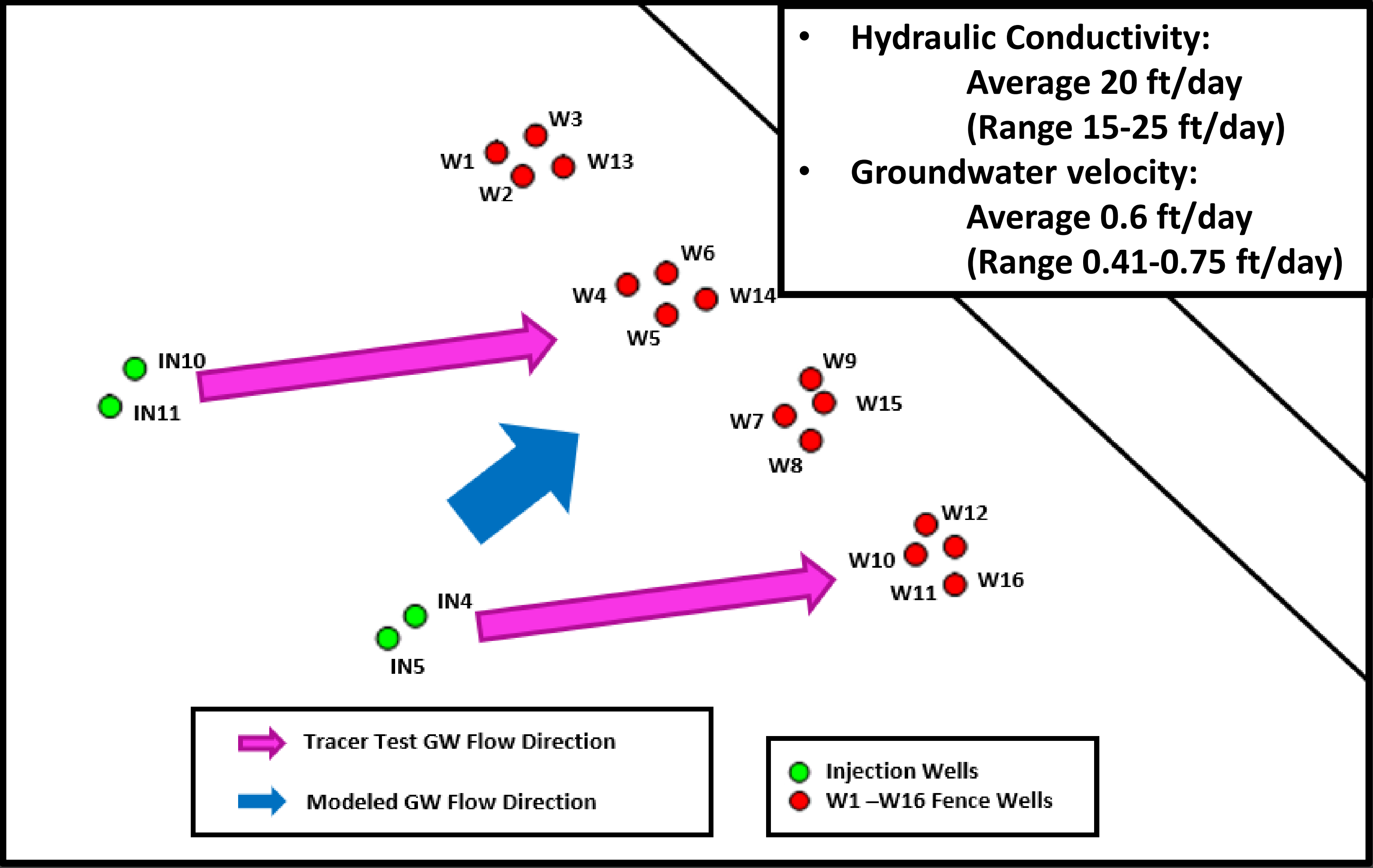


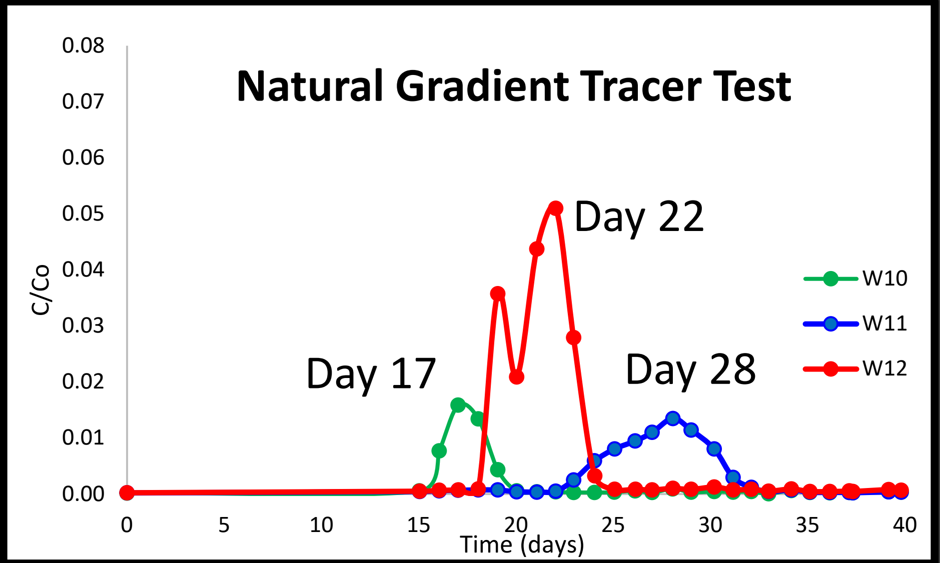
Groundwater Flow & Nitrate Profiles

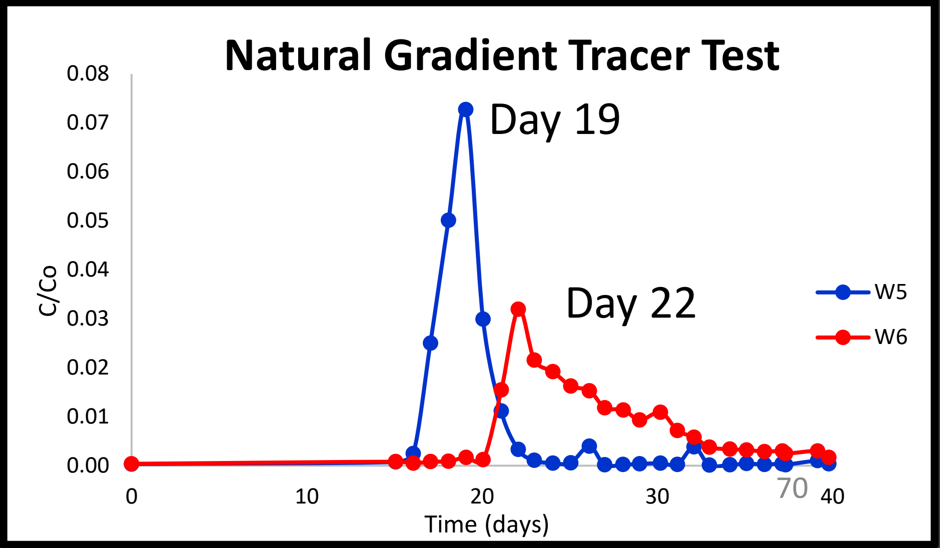


GW Flow: Natural Gradient Tracer Test

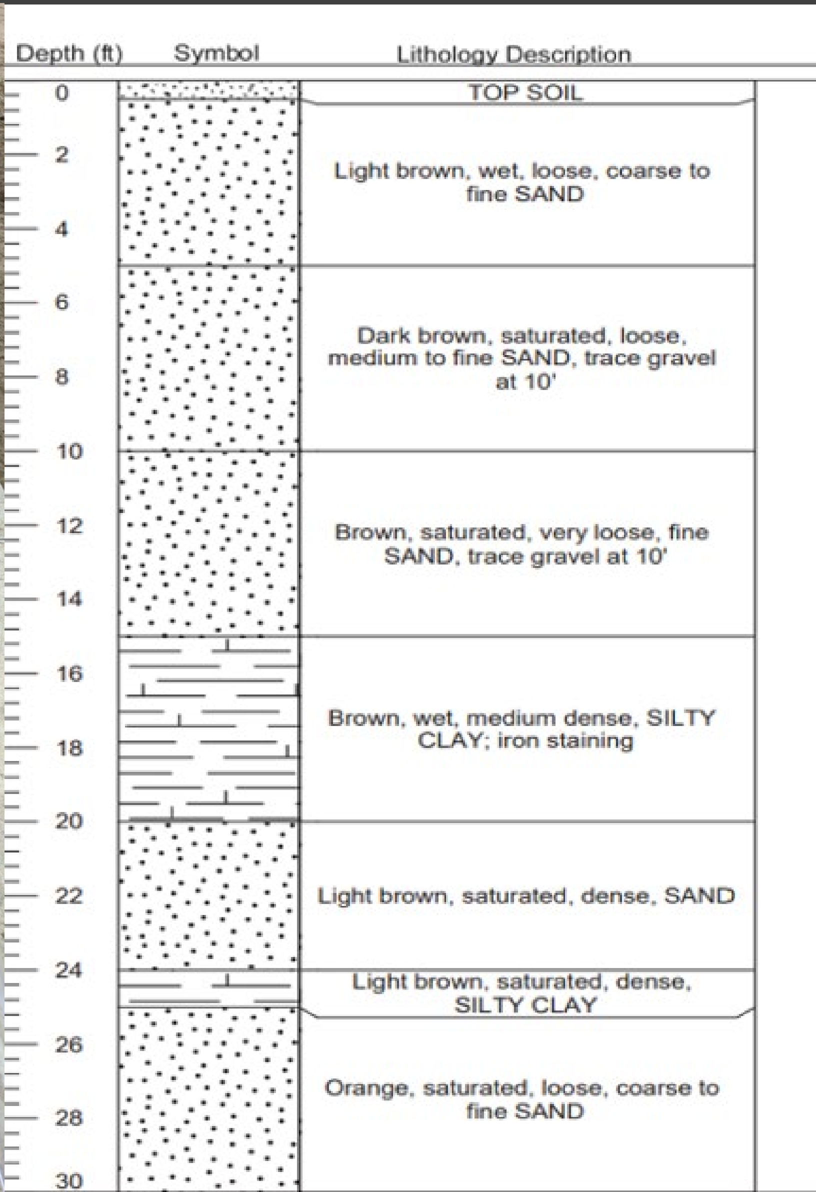
- **Hydraulic Conductivity:**
  Average 20 ft/day
  (Range 15-25 ft/day)
- **Groundwater velocity:**
  Average 0.6 ft/day
  (Range 0.41-0.75 ft/day)







Establish Soil Type: Soil Borings



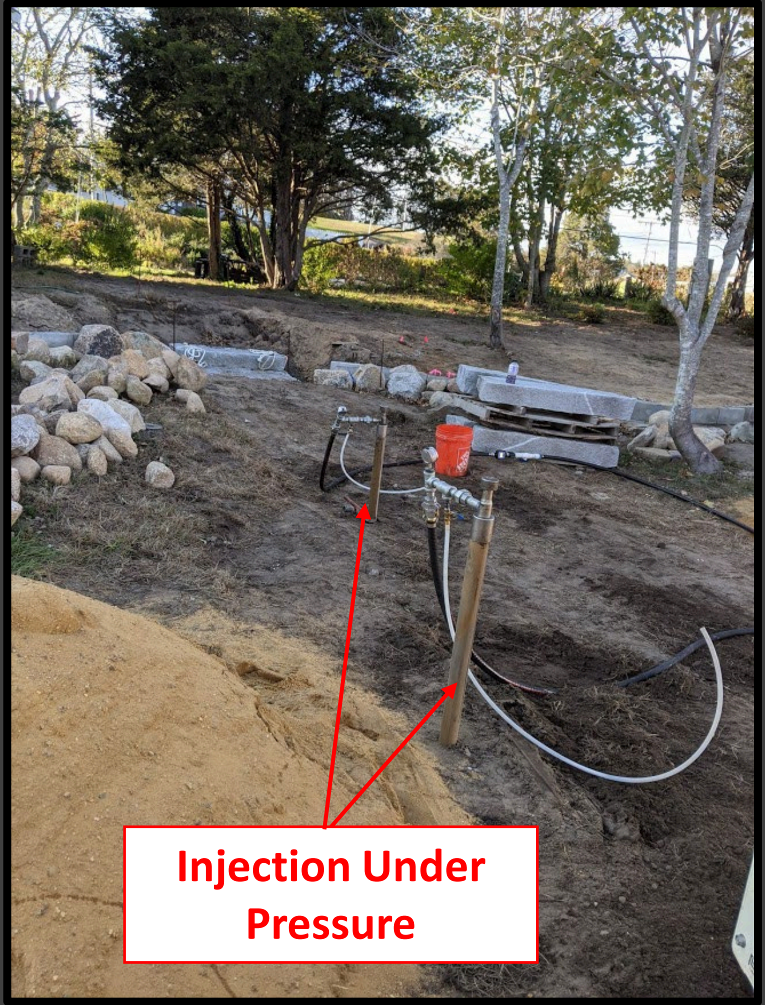
PRB Pre-Installation Findings

- Groundwater only 0.5 – 2.5 m below ground surface
- Soils are coarse to fine sand with some silty/clay
- Nitrate is the dominant form of N and corresponds with typical residential levels
  - Total Dissolved Nitrogen: Average 2.7 mg/L (0-13 mg/L)
  - Nitrate + Nitrite: Average 2.0 mg/L (0-12 mg/L)
  - Ammonium: Average 0.3 mg/L (0-0.68 mg/L)
- Freshwater (Salinity <0.2 PSU)
- Hydraulic Conductivity: 20 ft/day (15-25 ft/day)
- Groundwater velocity: Average 0.6 ft/day (0.41-0.75 ft/day)
- Elevated levels of Mn, Fe, and As were observed downgradient in the root zone of *Phragmites* bordering Lagoon Pond

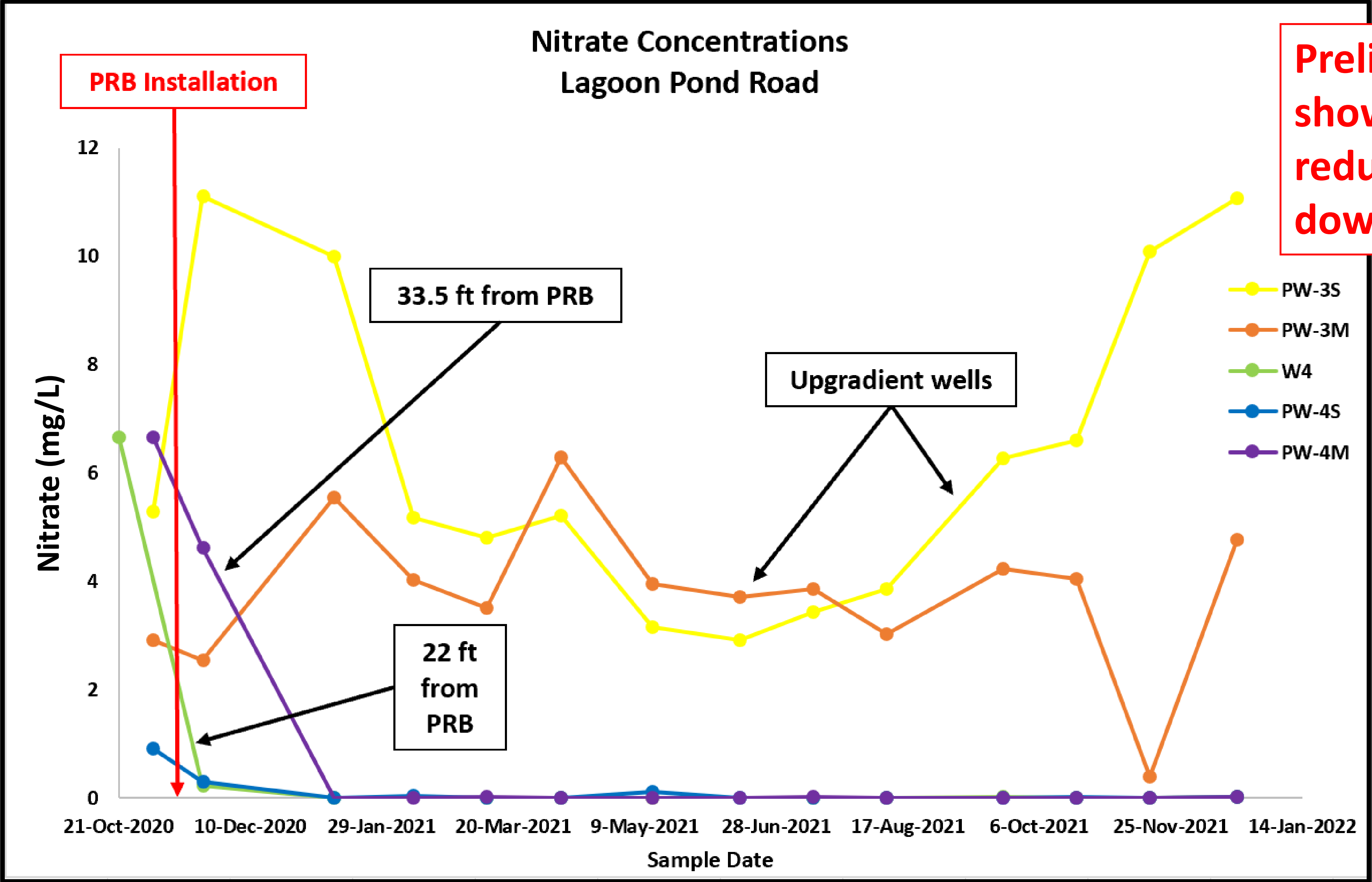
PRB Design

- 150 linear ft
- 80 ft from Pond
- Fence of Injections 10 ft & 15 ft apart
- 17,155 Gal Total Injected (4:1 Water:EVO)

Liquid Injection PRB Installation

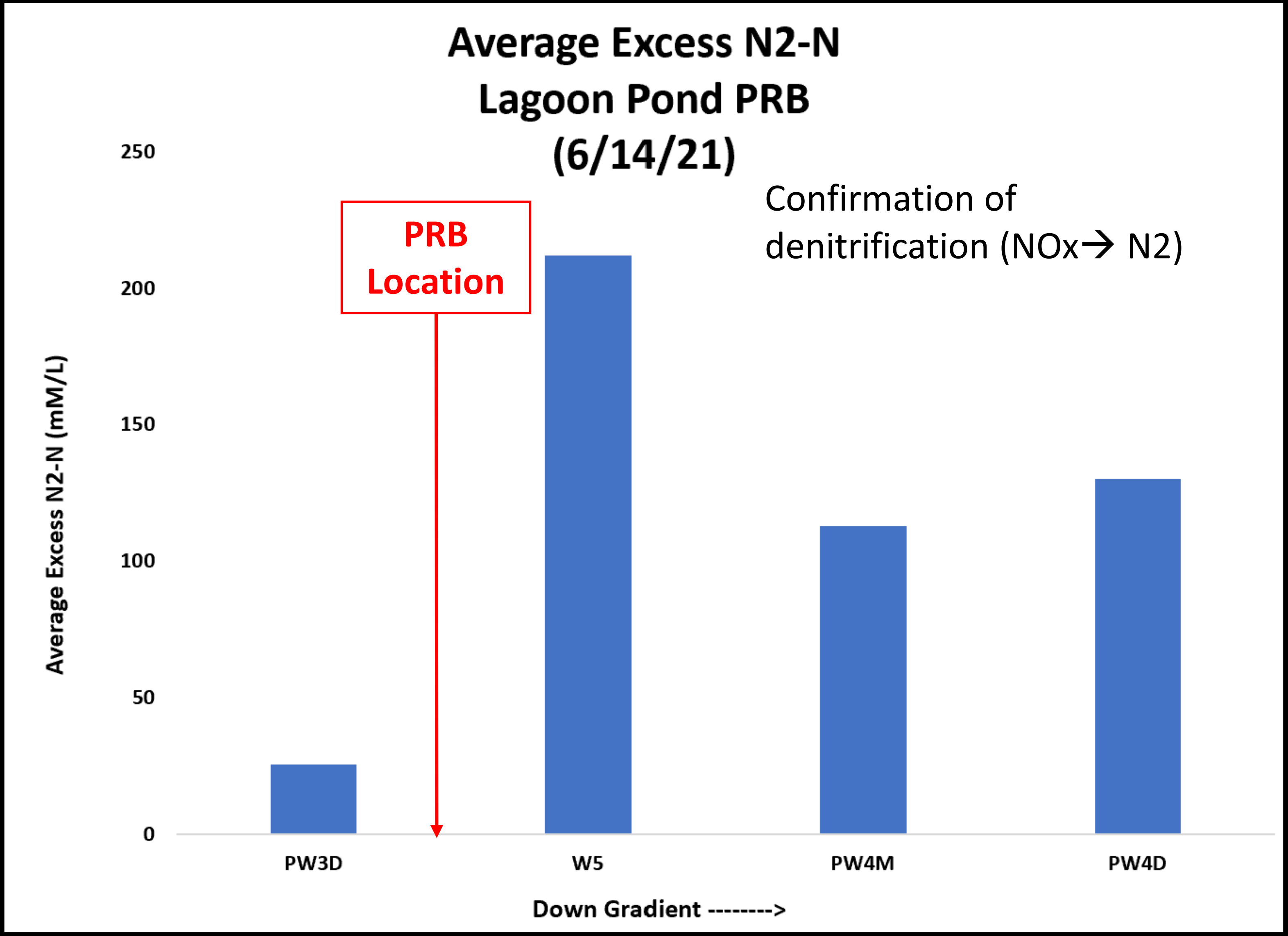


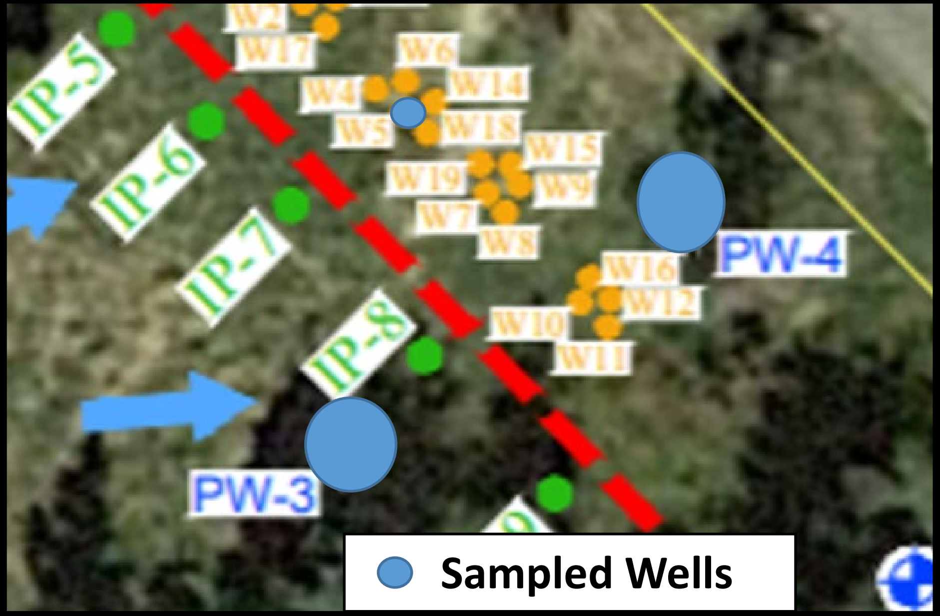
Post Injection Findings



Preliminary results show a significant reduction of nitrate in downgradient wells.

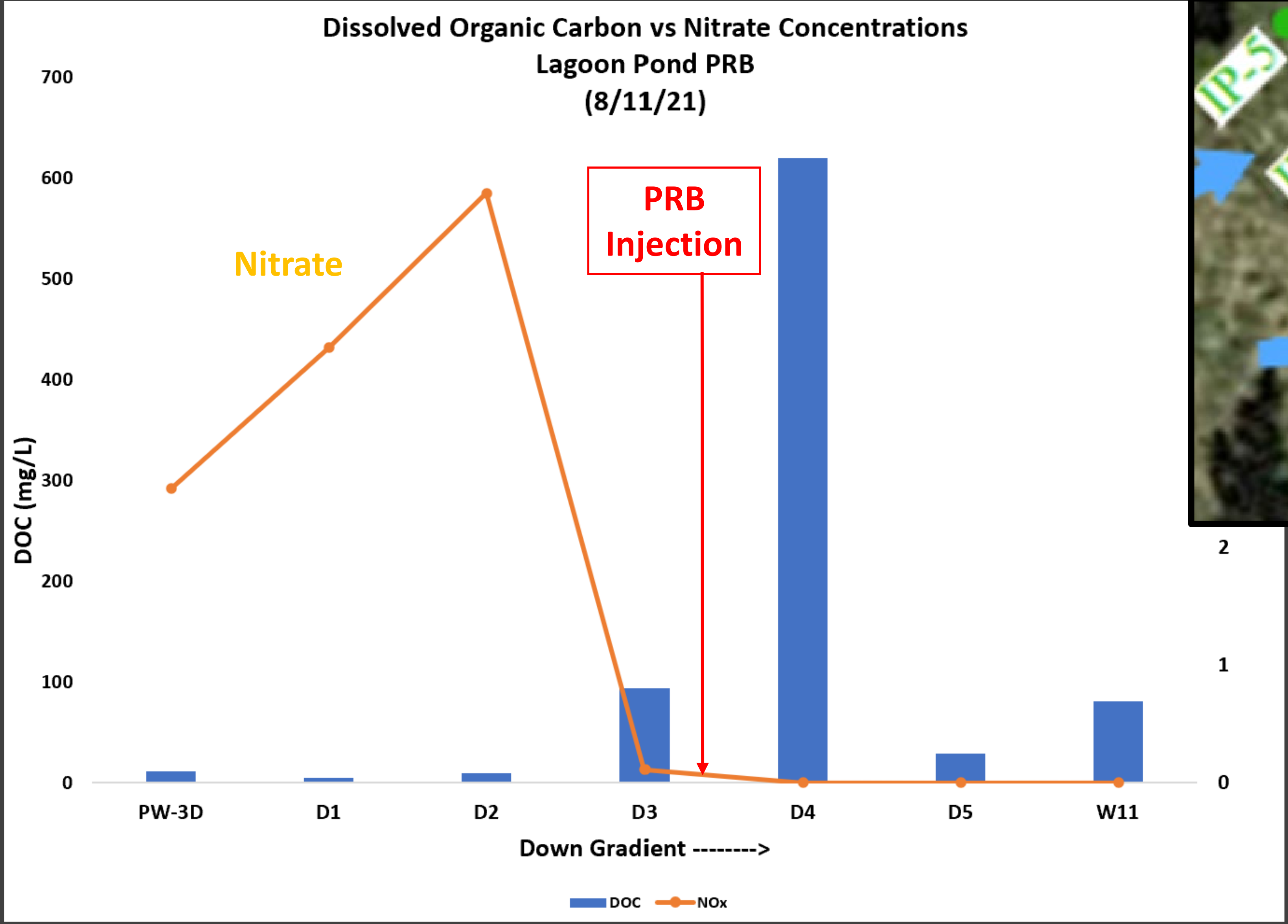
Post-Injection Findings

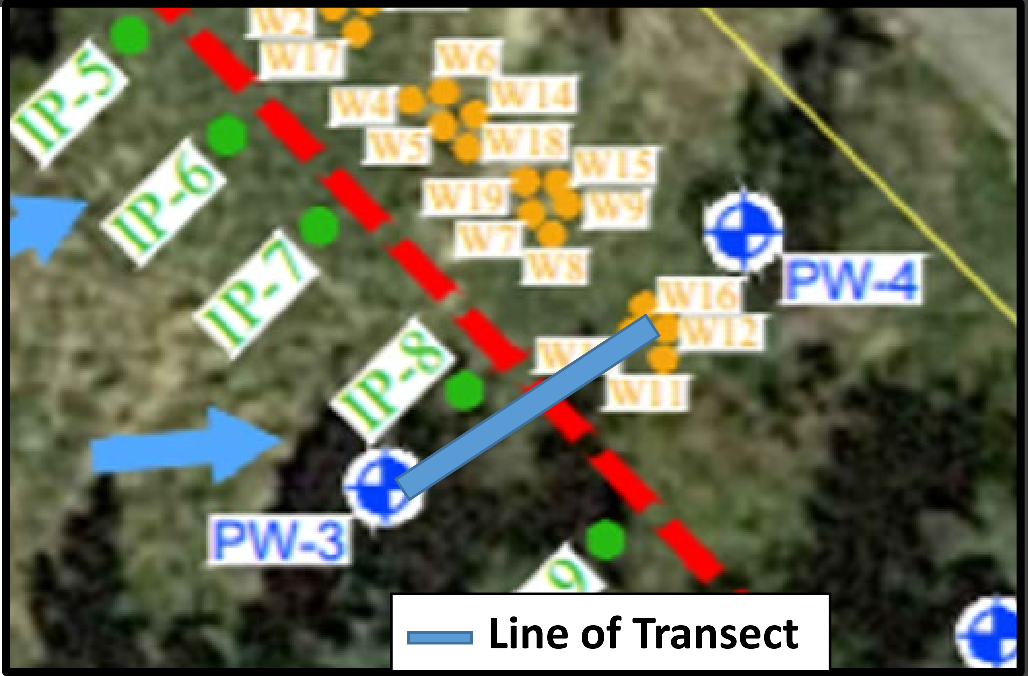




A mass balance approach will be utilized to confirm amount of denitrification.

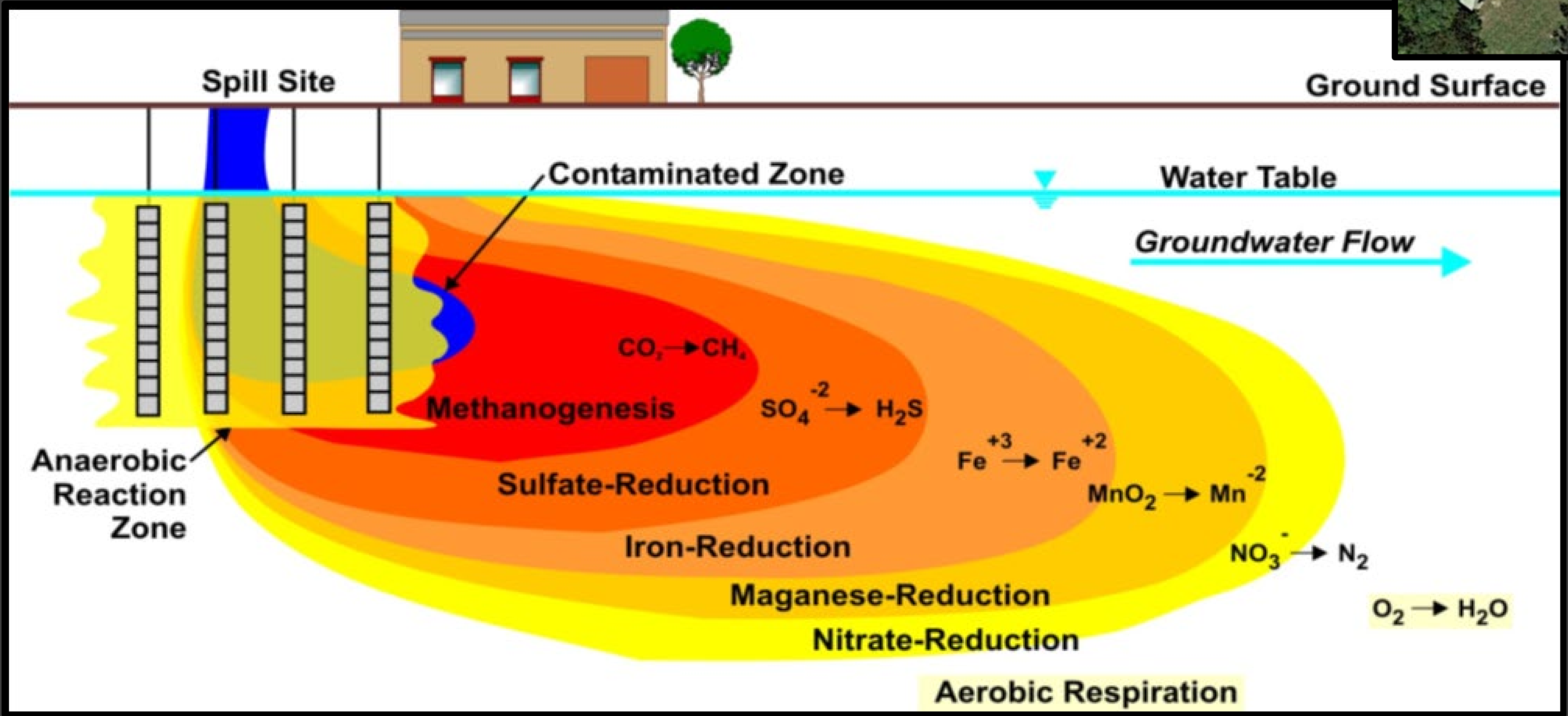
Optimizing PRB Design: Downgradient Movement



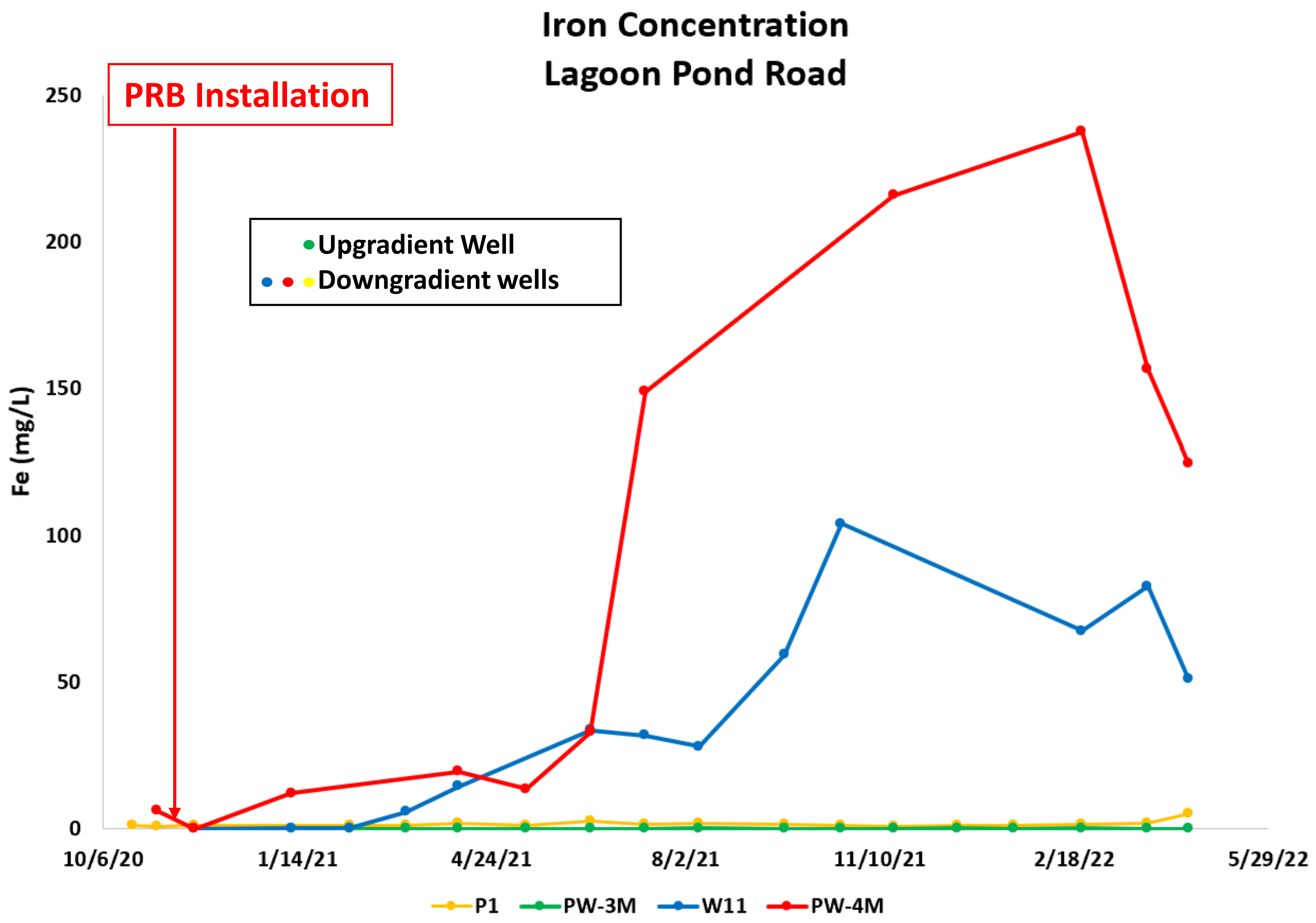


A lighter fraction of the liquid injectate appears to have traveled farther downgradient than a heavier fraction.

Secondary Reactions



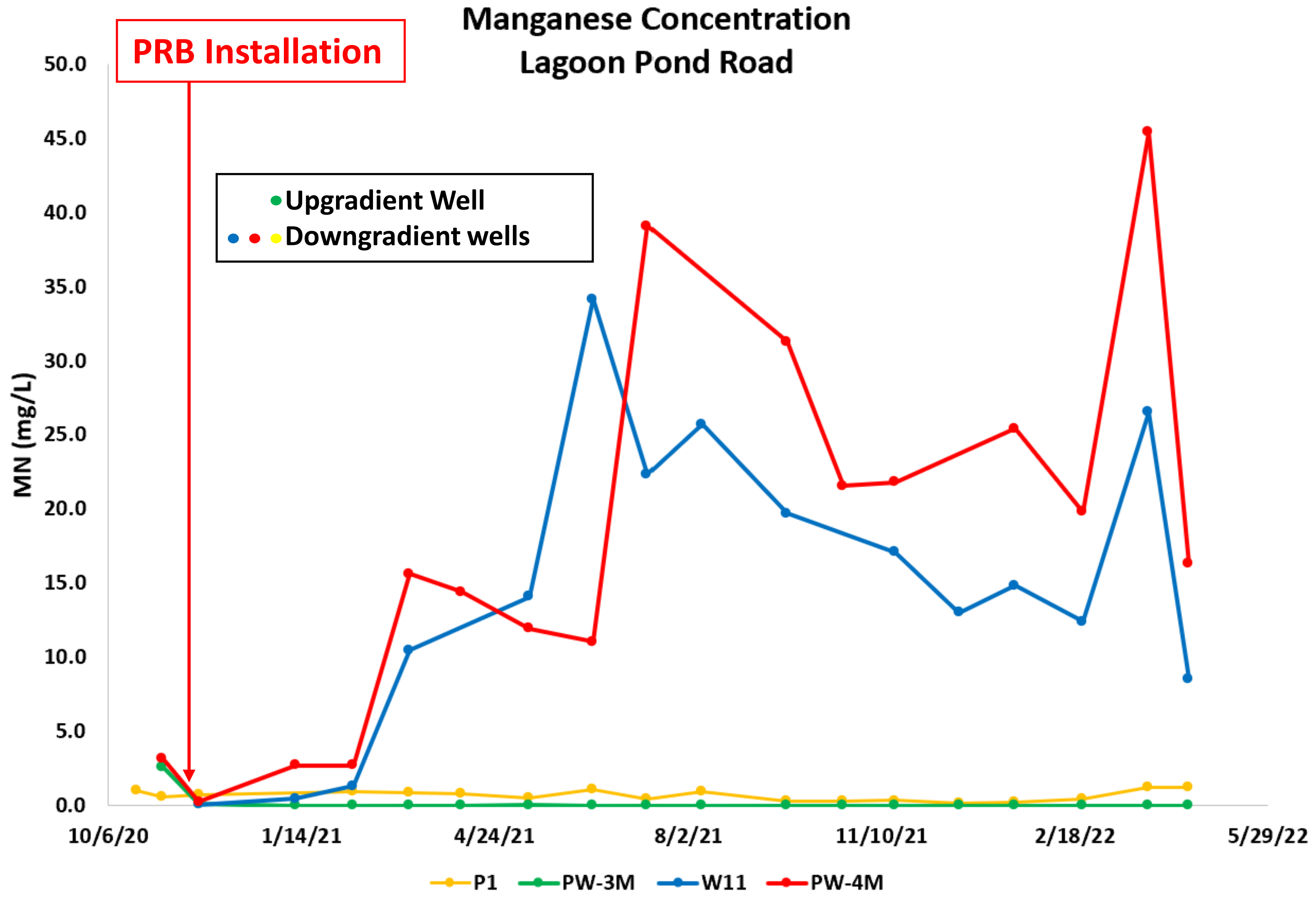
Secondary Reactions: Iron



Iron

- Naturally present in its insoluble oxidized forms
- Highly mobile in water in its reduced state Fe(III) -> Fe(II)
- Can cause:
  - Residential and commercial plumbing issues.
  - Staining of beaches

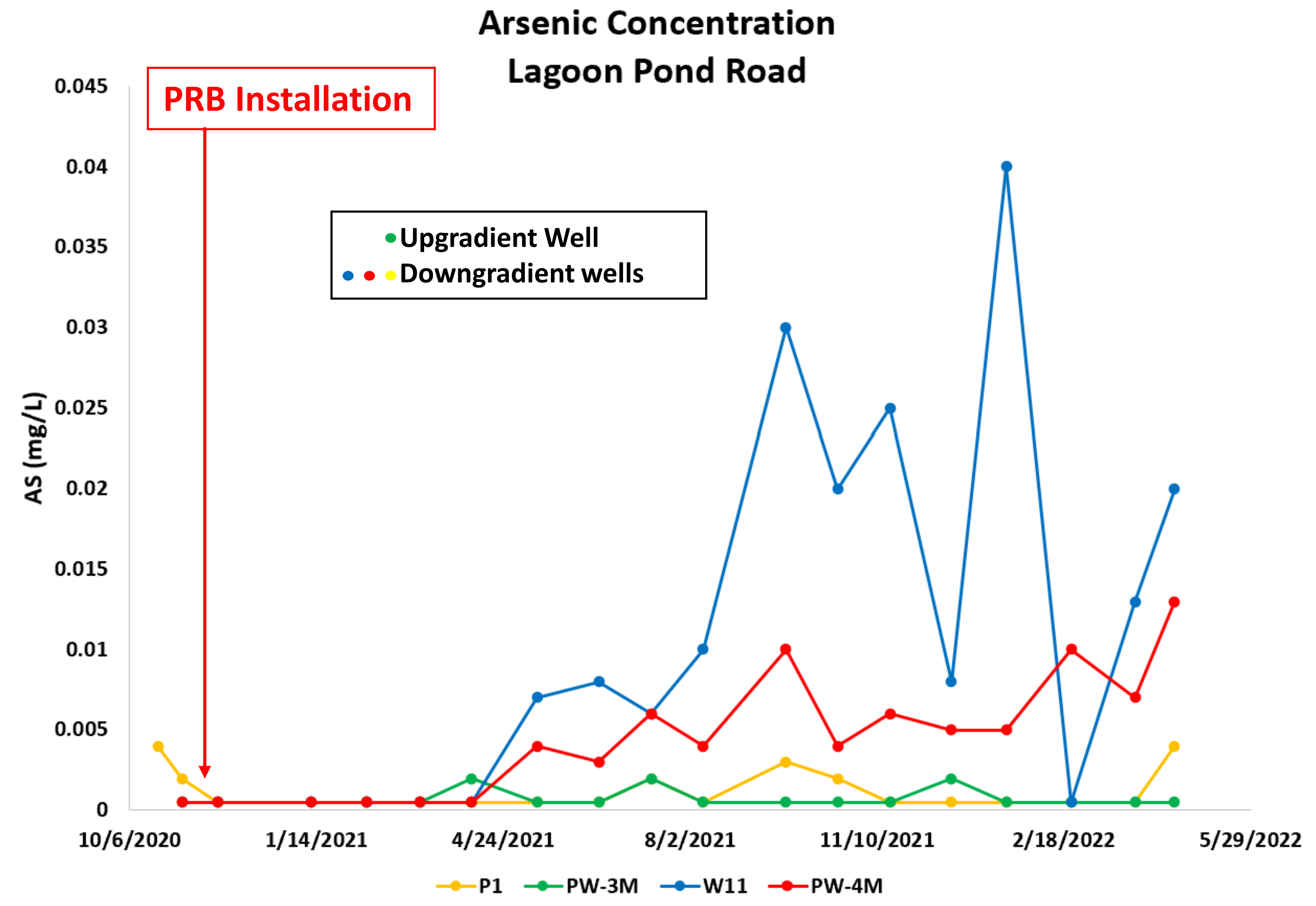
Secondary Reactions: Manganese



Manganese

- Naturally present in soils in insoluble oxidized forms
- Highly mobile in water in its reduced state Mn(IV) -> Mn(II)
- Can be toxic at high levels in its inorganic form

Secondary Reactions: Arsenic



Arsenic

- Naturally Present in some soils
- Highly mobile in water in its reduced state
  As(V) -> As(III)
- Highly toxic at elevated levels in its inorganic form if ingested.
- Freshwater ecological limit: 0.34 mg/L
- Maximum on-site level: 0.095 mg/L

Conclusions

- Installation of the liquid injection PRB was straight forward
- The PRB began removing Nitrate within days of installation
- Nitrate was reduced to very low levels
- Secondary reduction products were produced at low levels and did not travel far downgradient

Thank You!

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