Bio-Sorption Activated Media for Control of Nutrients and Fecal Coliforms

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THE RESEARCH TEAM (Partners)

- Florida Department of Environmental Protection
- St. Johns River Water Management District
- City of DeLand
- Marion County
- Southwest Florida Water Management District
- University of Central Florida Stormwater Management Academy

Research Team Members:

Keith Riger, D. Pressley, S. Wahrenberger, Demetris Pressley and Alex Konoval, **DeLand**;
Shane Williams, **Marion County;** Mitch Holmes and Eric Livingston, **FDEP**;
Casey Fitzgerald and Mark Brandenburg, **SJRWMD**;
Ni-Bin Chang, Dingboa Wang, Arvind Singh, and Steve Duranceau, **UCF** Professors;
Dan Wen, and Jessica Cormier, + 8 other **UCF** Students

PURPOSE of PRESENTATION

- **Present data on removal effectiveness using retention basins**
  - Retention refers to those practices that allow for the infiltration of water into the ground,
  - Treatment occurs with Pollution Control Media (an example is BAM),
  - Effectiveness measured by nitrate, phosphorus, and fecal coliforms,
  - During wet periods for stormwater treatment,
  - And during dry periods (no rain) dose with excess reclaimed water

Define Bio-Sorption Activated Media (BAM)

- Sorption is a process that occurs with solid media to build-up or concentrate pollutant(s) for removal from the water. (other processes also)
- Activation occurs when *the media and* the working environment are altered to improve removal, sometimes by physical or chemical methods that lead to removal by biological means. (example: low DO and nitrate removal)
- Thus BAM is a media for pollutant removal that has sorption properties in a specific environment.

Examples of media

Bold identified as tested by this Team

Sorption media	Physical/Chemical Properties	References
Sand filter		Bell et al., 1995
Tire crumbs/Tire chips	D= 20.00 to 40.00 mm	Shin et al., 1999
Zeolite+ Expanded Clay	D= 2.50-5.00 mm	Gisvold et al., 2000
Polyurethane porous media	Porous structure, Average diameter 3.00-5.00 mm,	Han et al., 2001
Limestone	D= 2.38 to 4.76 mm	Zhang, 2002
Sulfur	D= 2.38 to 4.76 mm	
Sand granules		Espino-valdés et al., 2003
Clay		Gálvez., 2003

Examples of media

Bold identified as tested by this Team

High density modules		Rodgers and Zhan, 2004
Sandy clay	Sand (53.28%), Silt (24.00%), Clay (22.72%)	Güngör and Ünlü 2005
Loamy sand	Sand (78.28%), Silt (10.64%), Clay (11.08%)	
Sandy loam	Sand (70.28%), Silt (14.64%), Clay (15.08%)	
Masonry sand	Bulk density of masonry sand is 1670 kg/m^3; Porosity of masonry sand is 0.30.	Forbes et al., 2005
Expanded shale	Expanded shale Bulk density of expanded shale is 728.00 kg/m^3	
Oyster shell	Powder form, 28.00% Calcium,	Namasivayam et al., 2005
Limestone	D =2.38 to 4.76 mm	Sengupta and Ergas, 2006
Oyster shells		
Marble chips	$Mg(OH)_2$ and $CaCO_3$	
Soy meal hulls	D<0.125 mm	Arami. 2006
Clinoptilolite		Hedström et al., 2006

Examples of media

Bold identified as tested by this Team

Perlite	D = 0.30 – 4.76 mm	Rebco II, 2007
Expanded clay	D = 0.40-5.0 mm	
Tire crumb	D = 0.30-5.00mm	
Sulfur	D = 2.00-5.00 mm	
Crushed oyster shell	D = 3.00-15.00 mm	
Utelite (expanded shale)	D = 0.40-4.50 mm	
Crushed shells	D = 4.00-4.75 mm	Li et al., 2009
Sphagnum peat moss		
Three-dimensional plastic media		Jin et al., 2009
Alum sludge		Park, 2009
Peat **Coconut Coir** **Wood Chips**		

Approach to Evaluate Performance

1. LABORATORY – Document the removal of target parameter (bacteria, nitrogen , phosphorus, copper, etc.) and establish design and installation guidance.
2. FIELD – Monitor systems that have Bio-sorption Activated Media (BAM) in Retention Basins*

*To be included in a menu of stormwater BMPs acceptable for regulatory approval, usually need both the laboratory and 2 field site demonstrations

Some Measures for BAM to Indicate Success

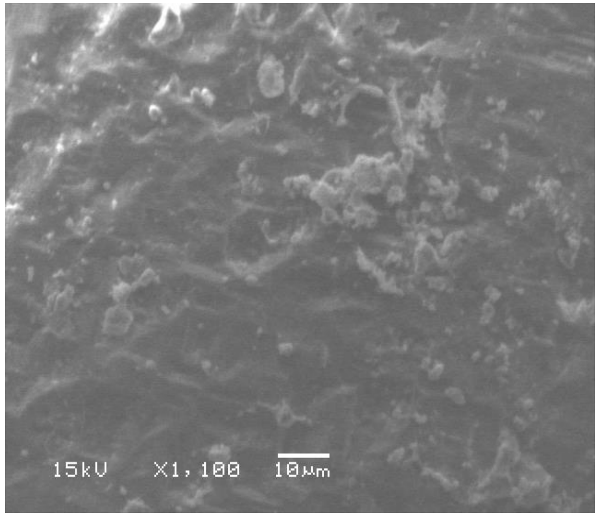
- Removal Kinetics and Life Expectancy.
- High surface area.
- Effluent has no biological toxic effects.
- Ease of filtration.
- Maintenance is low. Reasonably non-degradable or can be rejuvenated in the field.
- Acceptable to installers and low cost

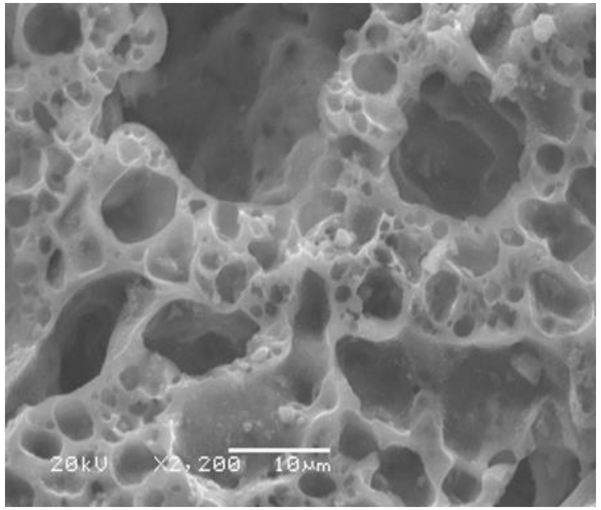
LABORATORY SOIL COLUMNS

- Test selected media mixtures to quantify their nutrient and biological attenuation capabilities, **reaction kinetics**, and **filtration rates**.
- Life Expectancy

Aerobic and Anaerobic Reactors

Bio-Sorption Activated Media (BAM) Scanning Electron Microscope





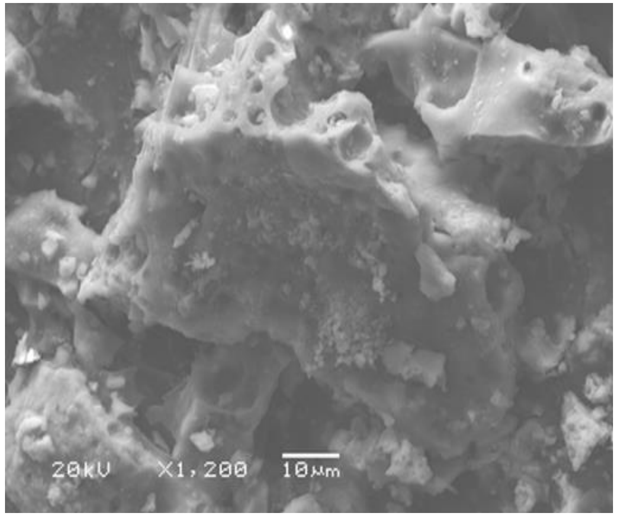


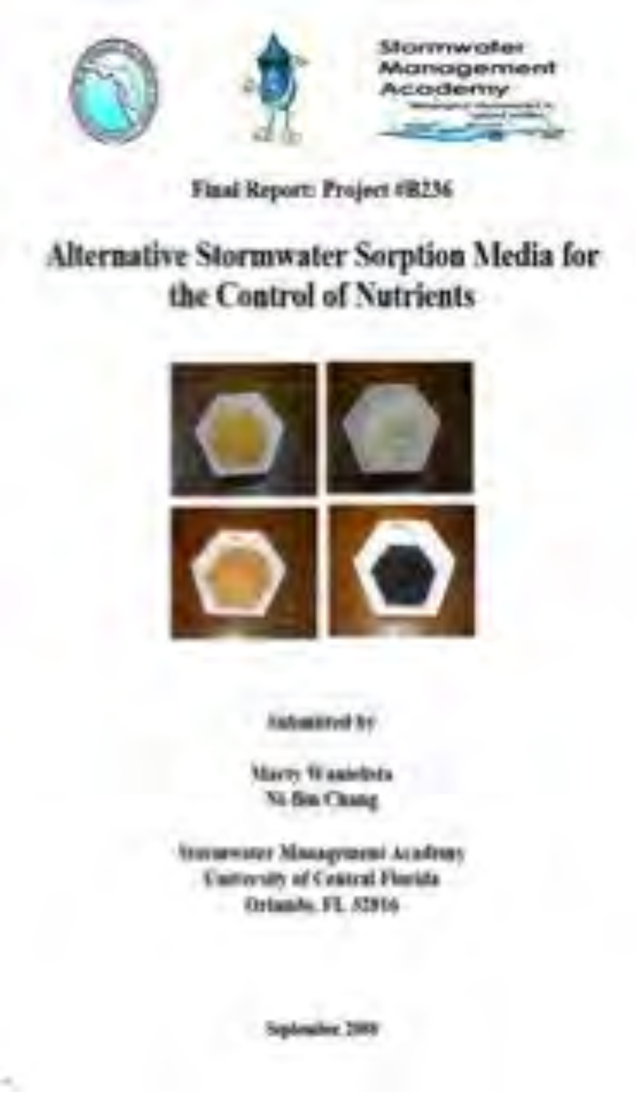
Figure 5.13-15. SEM of *(a)* concrete sand1,000 x, *(b)* expanded clay 2,200 x, and *(c)* tire crumb 1,200 x magnification showing the surface structure and characteristics after residing in the 24 days of column testing.

SHOWS MANY SITES (AREA) FOR SORPTION when using expanded clay and tire crumb

Biofouling did not appear within an equivalent flow of 10 years

BAM Media SELECTION (testing beyond kinetics)

- Expanded Clay
- Peat — Consistenc
- Natural Sandy/Loamy/ Clayey soils
- Sawdust — Toxic Results
- Paper/Newspaper — To Res
- Iron Filings
- Zeolite — Costly


Stormwater Management Academy

Final Report: Project #B236

Alternative Stormwater Sorption Media for the Control of Nutrients

University of Central Florida
Orlando, FL 32816

- b and Chips
- atment Sludge
- Carbon — Costly
- e
- hells
- er/Chips — Toxic Results
- Toxic Results
- oir — Limited availability

What BAM is preferred in field sites? A BAM product which is mineral and thus has minimum degradation in an expected life of over 20 years. It is typically composed of a combination of some of the following materials:

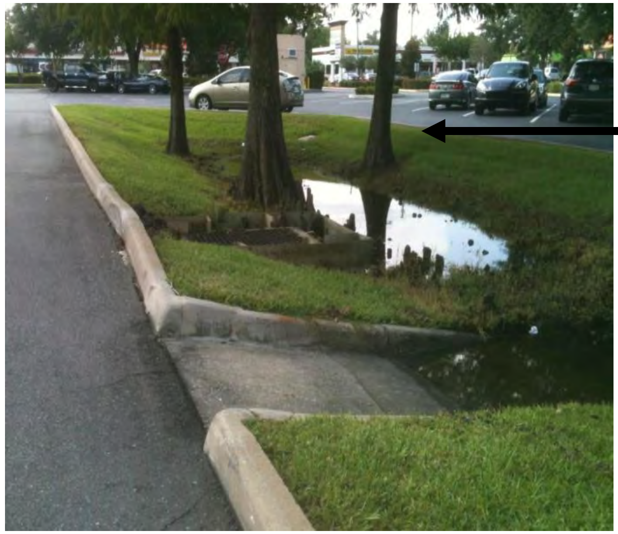
recycled tire, sand, clay, iron, and expanded clay.

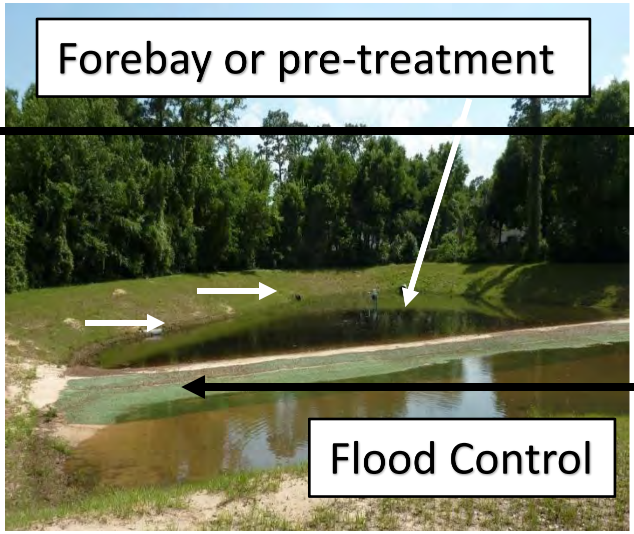
There are commonly used six mixes, all patented by the State University System and available with the trade name of Bold & Gold.

A BLEND for REMOVAL AND FILTRATION
Recent use in States of Pa, NC, SC, Tx, and extensive use in Fl (>400,000 SF).

CTS Media

In Stormwater Management, media is used for LID (Source) and Regional SWM BMPs since 1977





In Orange County Florida since 1977

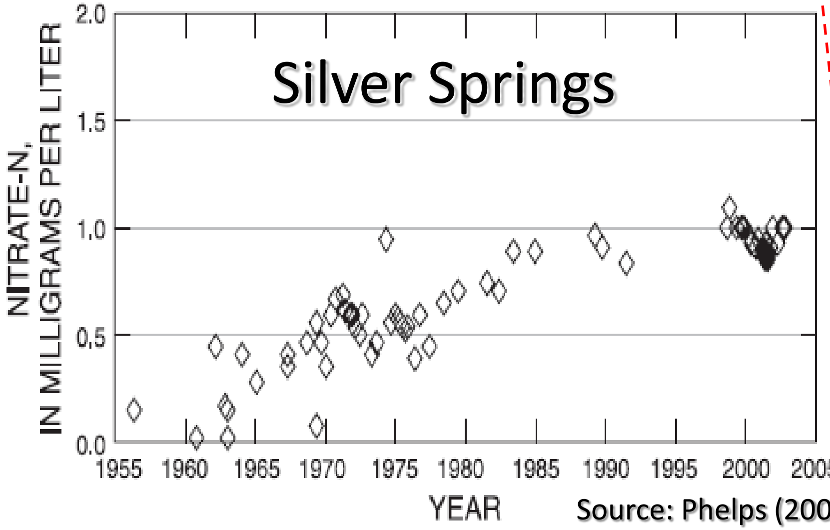
In Marion County Florida since 2011

- **Source control reduces flow to regional BMPs**

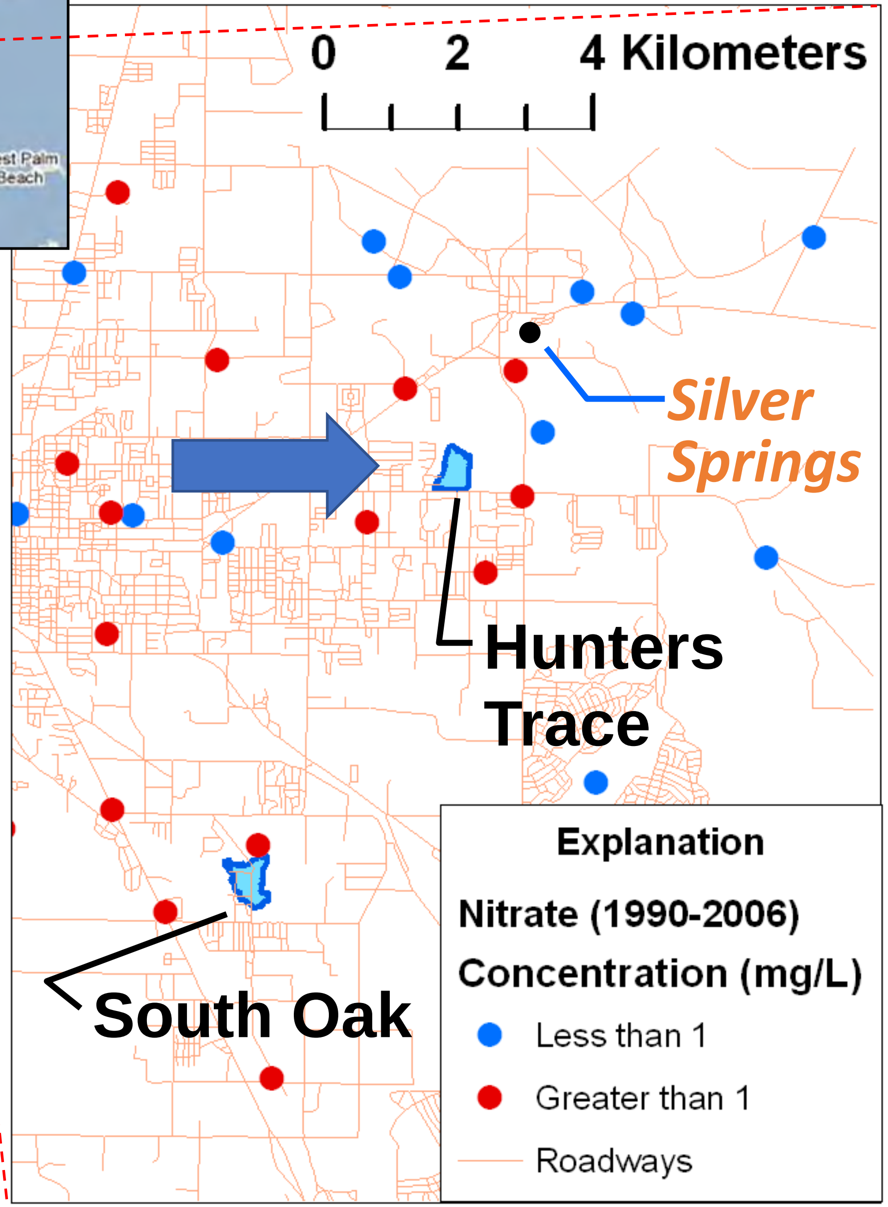
Retention basins used for Stormwater Management

Stormwater 1’ BAM

- 2 stormwater basins studied near Silver Springs (Q = 22 m^3/s).
- Increasing nitrate in Silver Springs.
- One Foot of BAM CTS

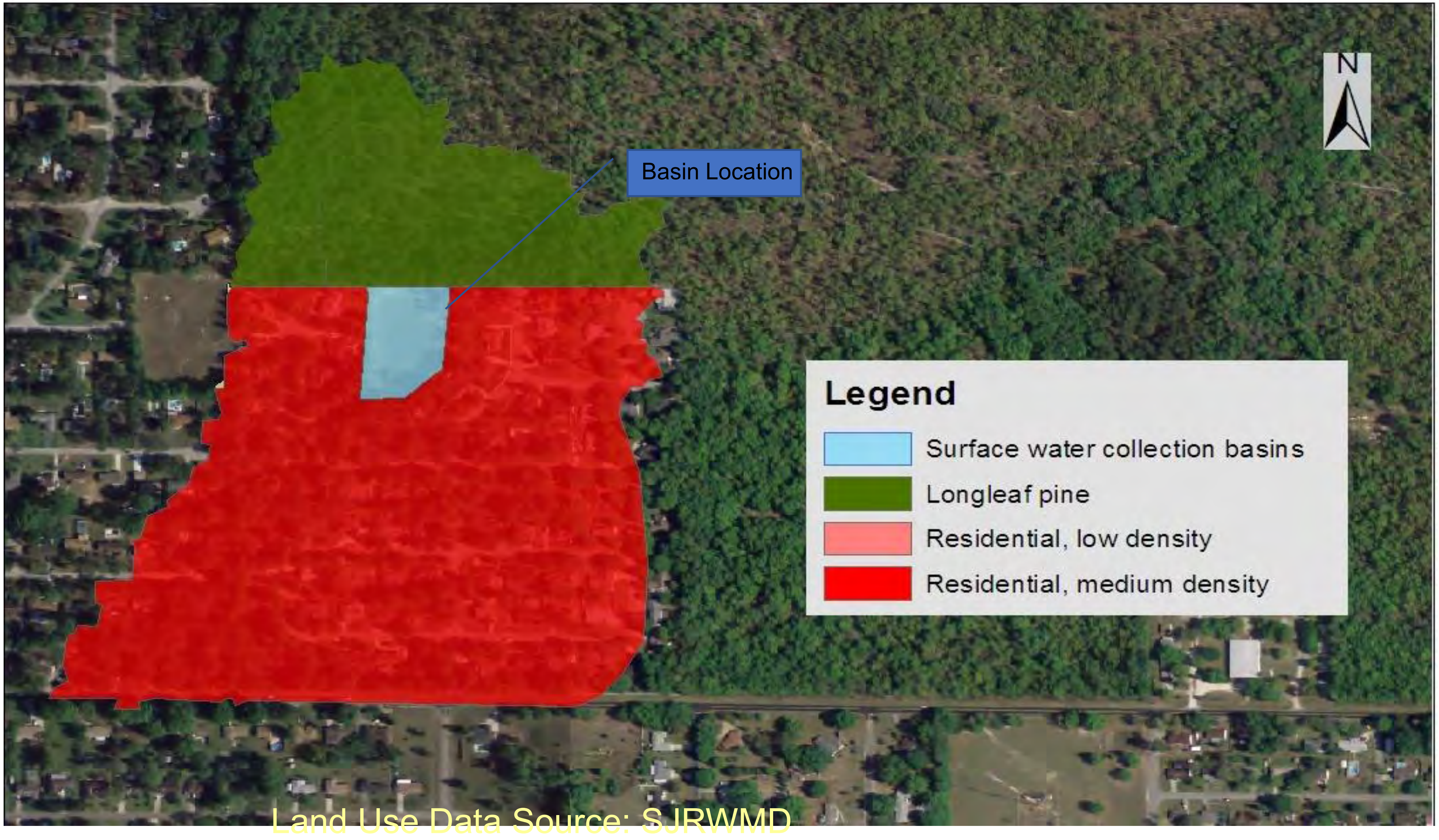


Source: Phelps (2004)



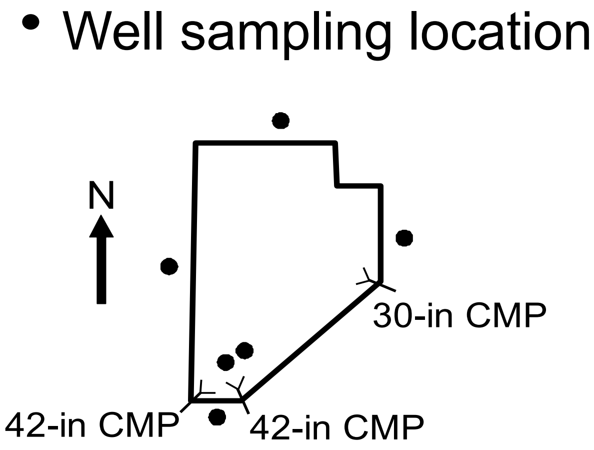
HUNTER TRACE DRAINAGE BASIN LAND USE

2004

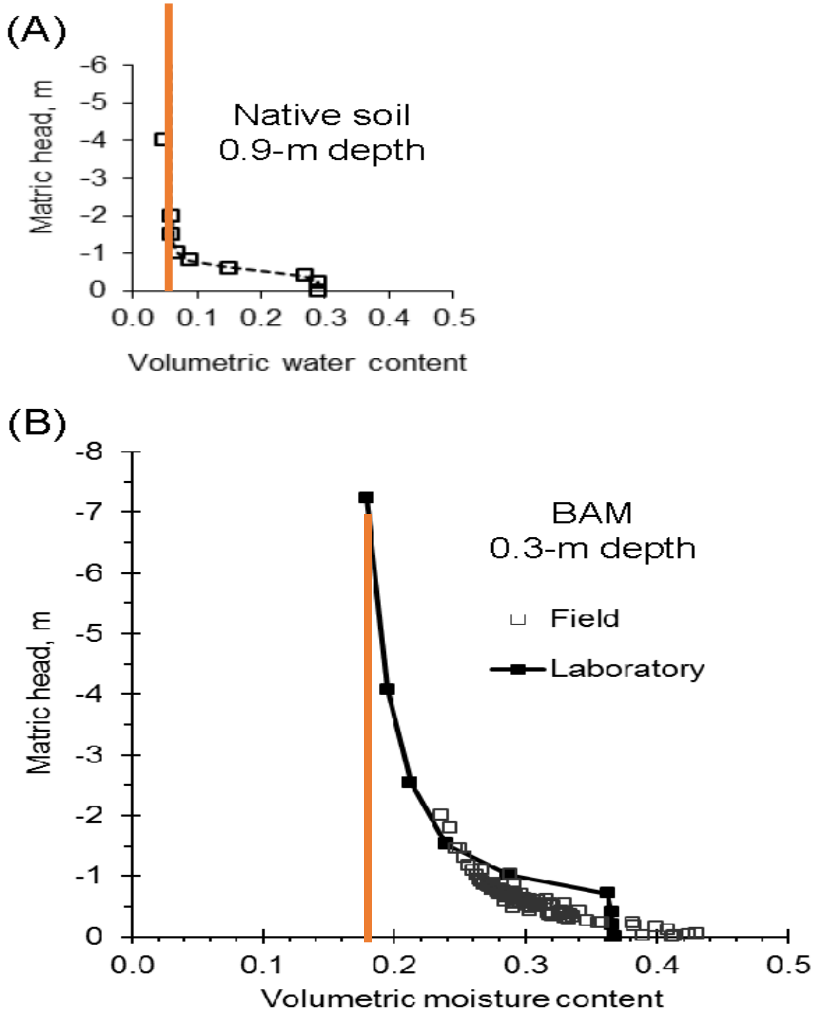


Hunters Trace (HT) Basin

- 0.75 ac basin, "land locked" ~ 15"
- 10 ft deep, 51' bottom ~61-62' at the top
- 56 ac drainage area, only 4.2 ac EIA at 3 inch rainfall
- Water table >10 ft below retention basin bottom
- Soils: Low soil moisture content



Soil Moisture Before and After BAM at HT



Field measurements were obtained by continuous monitoring using time domain reflectometry and tensiometers.

Laboratory derived soil moisture retention curves were measured for the main drying curve on undisturbed soil cores using the pressure cell method.

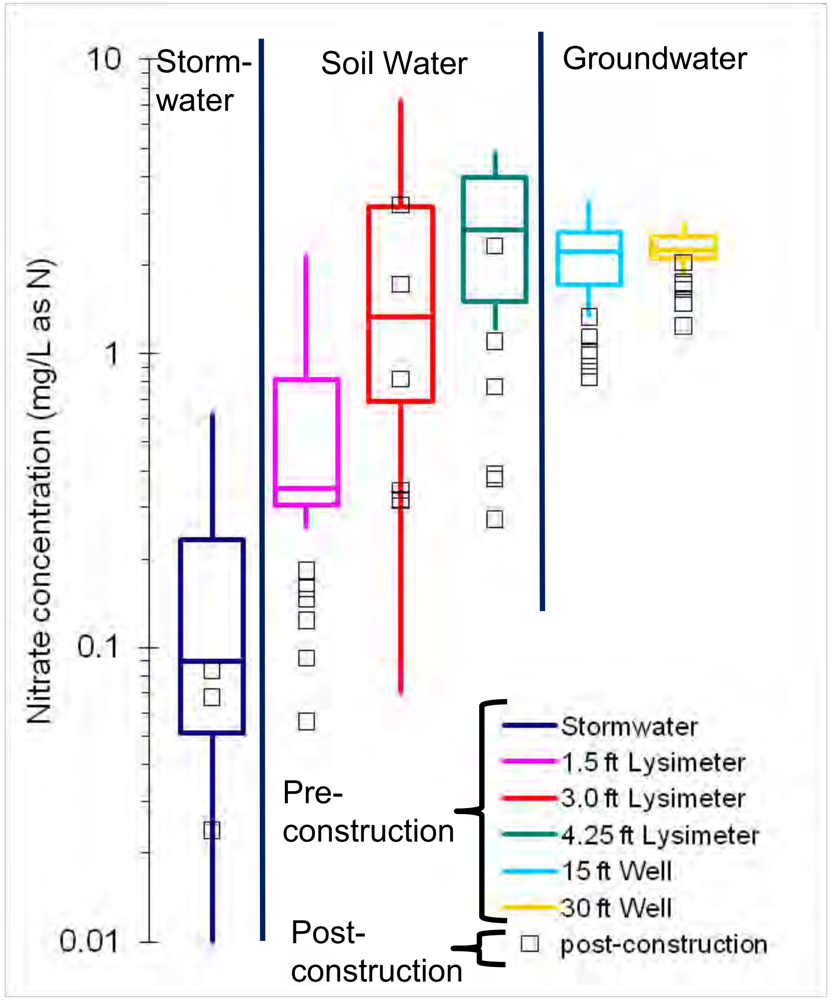
After BAM and 3.7 inches of rain pollution control basin designed for 3 inch rain

Nutrient or Pollution Control Basin

Flood Control Basin

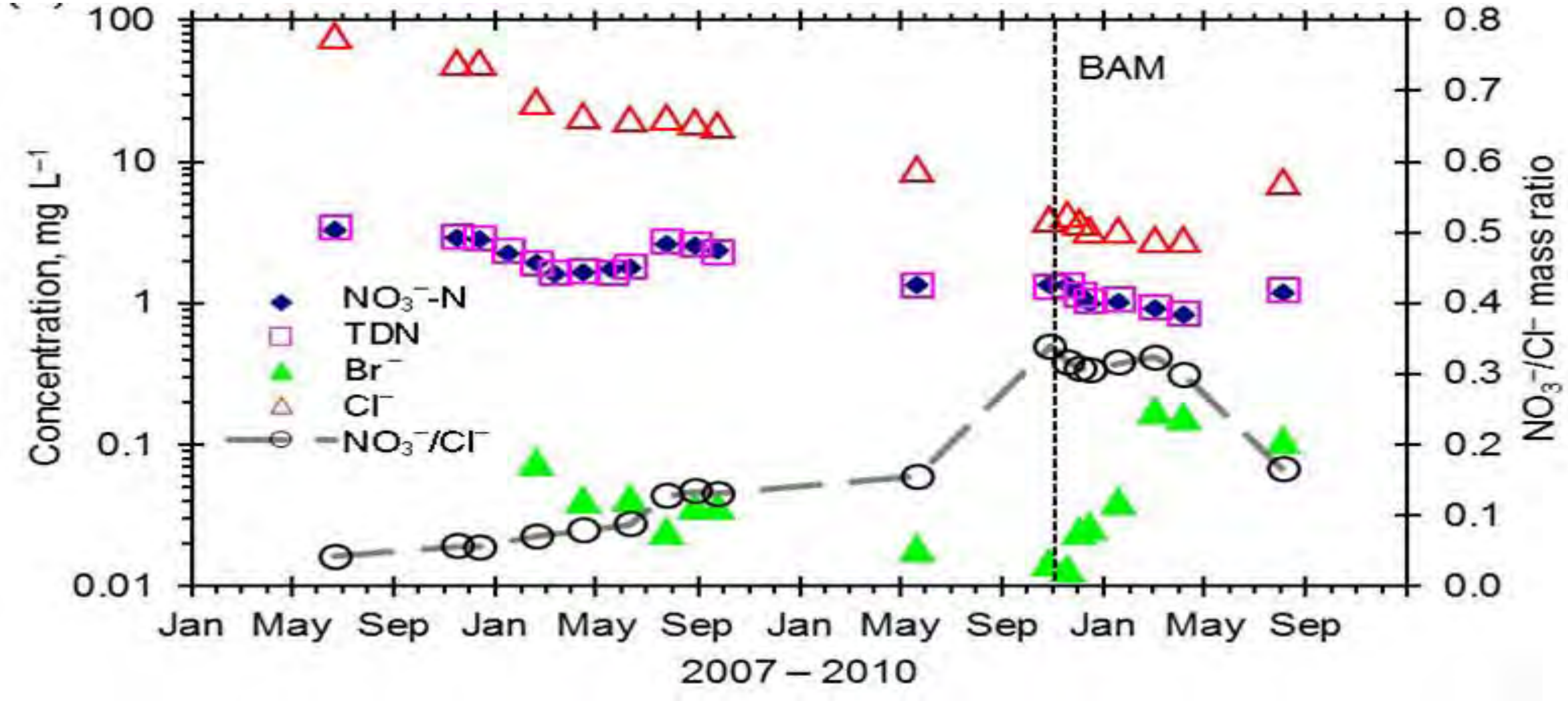
After BAM – Nitrate

- Avg 60% reduction or a range of 50-80% reduction in nitrate.
- pre-construction (2007-2009) to post-construction (2009-2010)
- Nitrate decreases most likely due to dilution, sorption, denitrification, anammox, or some combination of these processes.



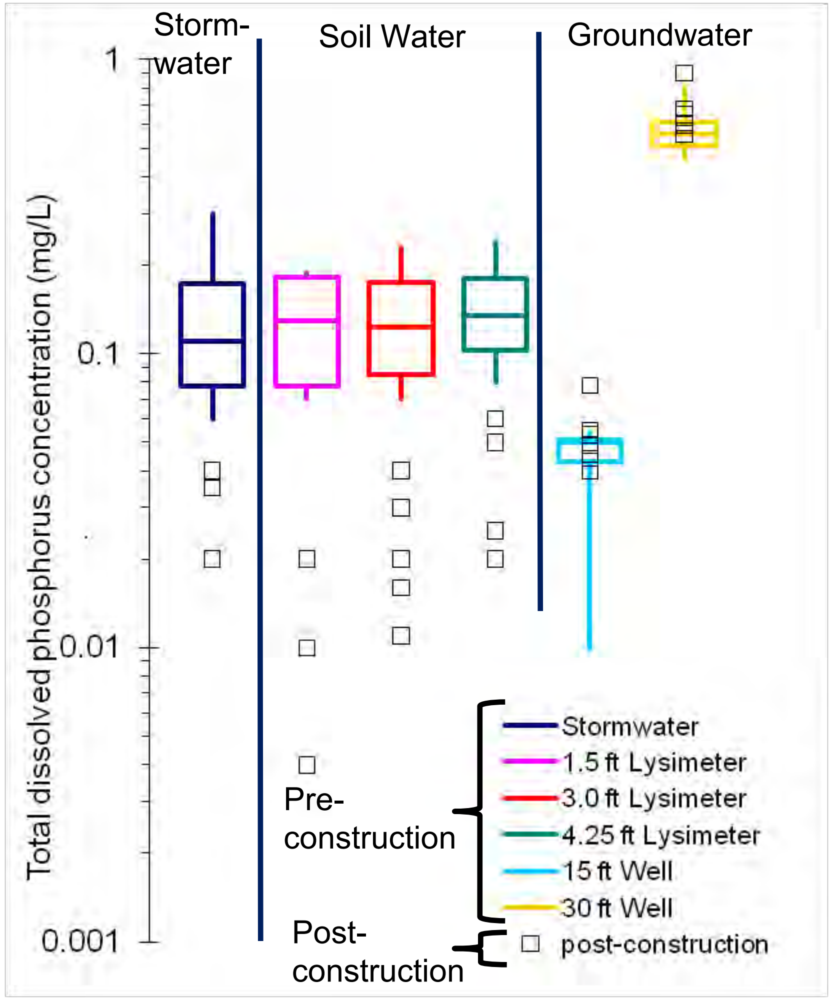
Indication of – NO_3^-/Cl^- Ratios

- Compare NO_3^- and Cl^- to determine dilution effects
- A zero NO_3^-/Cl^- slope indicates NO_3^- and Cl^- are changing at the same rate due to dilution.
- Positive slope (pre BAM) indicates NO_3^- production (low bacteria or denitrification)
- Negative slope (post BAM indicates NO_3^- reduction (possibly bacteria denitrification)



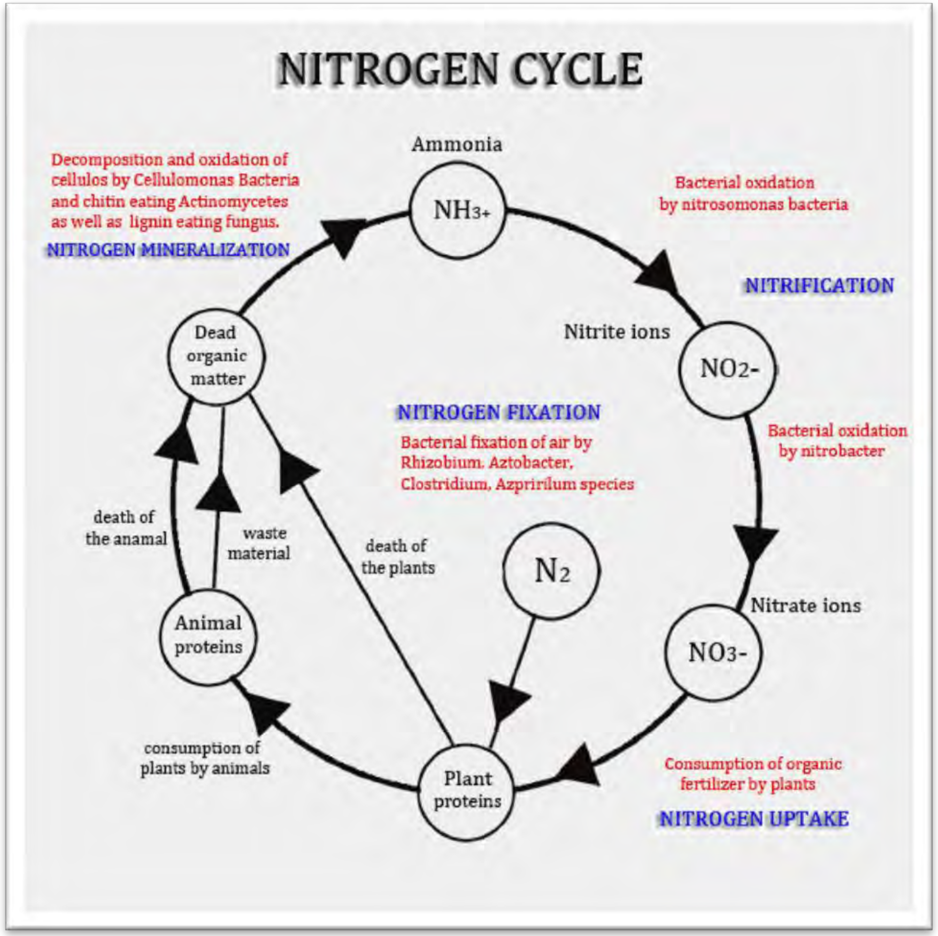
After BAM– Phosphorus

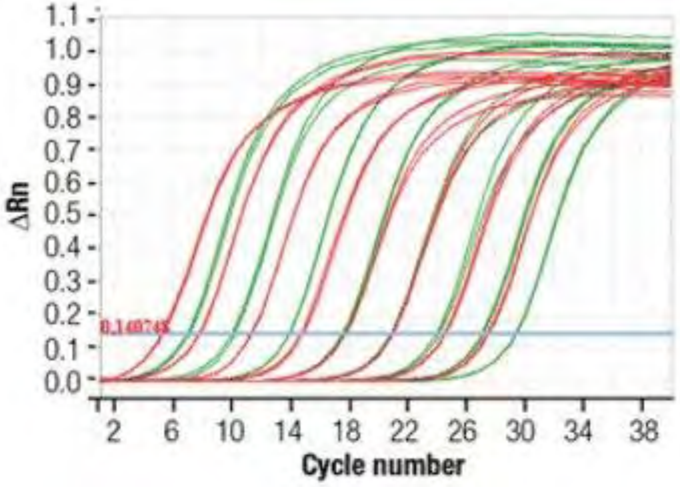
- ~60 % average reduction in total dissolved phosphorus (TDP) from pre-construction (2007–2009) to post-construction (2009–2010) median concentrations in soil water.
- ~90% average reduction in TP.
- TDP decreases may be due to dilution, sorption, precipitation, microbial assimilation, or some combination of these processes.

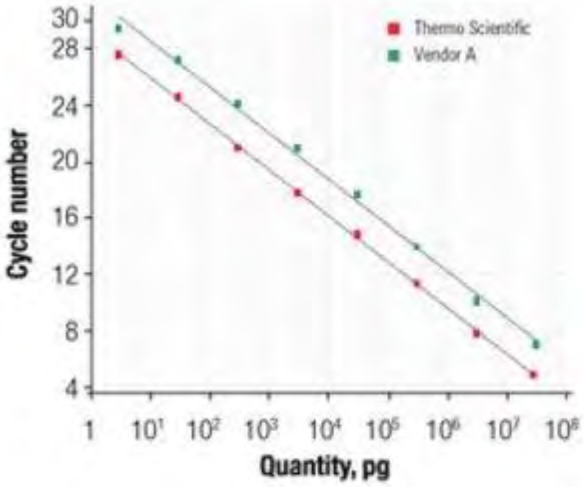


Real-Time PCR

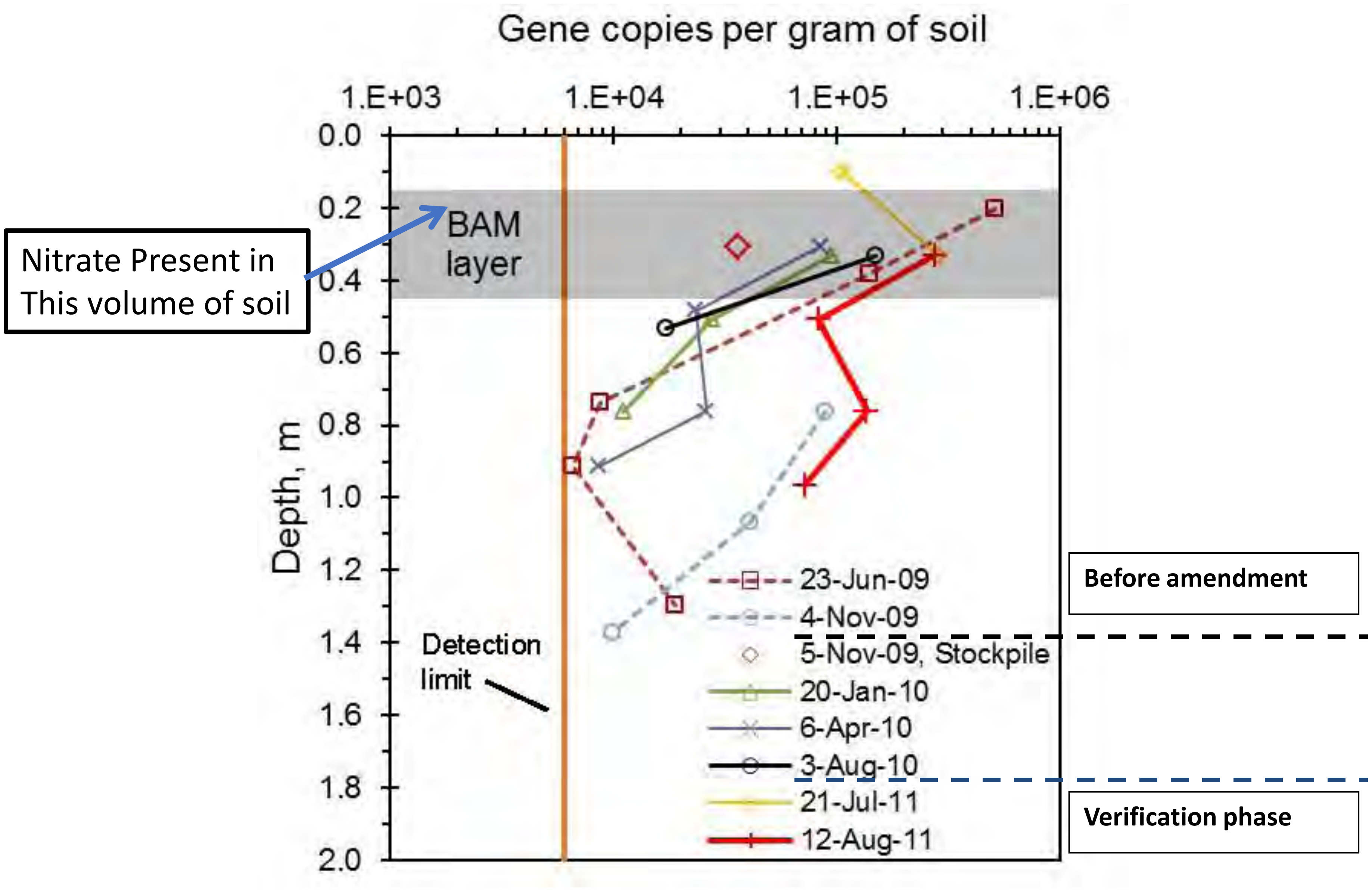
- Determine key N-cycle species quantitively;
- Explore the microecological interactions.







https://organicsoiltechnology.com/nitrogen-cycling-down.html https://www.thermofisher.com/order/catalog/product/K1642



Gene copies per gram of soil
1.E+03
1.E+04
1.E+05
1.E+06
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Depth, m
BAM layer
Nitrate Present in This volume of soil
Detection limit
23-Jun-09
4-Nov-09
5-Nov-09, Stockpile
20-Jan-10
6-Apr-10
3-Aug-10
21-Jul-11
12-Aug-11
Before amendment
Verification phase

Dual Use for Excess Reclaimed Water and Stormwater using a "RIB"

- Can you use retention ponds to treat other water during non-rain conditions?
- WHY? Protection of groundwater quality and increasing water volume to Blue Spring, 5 miles southwest of the RIBs.
- Location in DeLand Florida
- Operating infiltration rate of 0.5 – 1 in/hr.

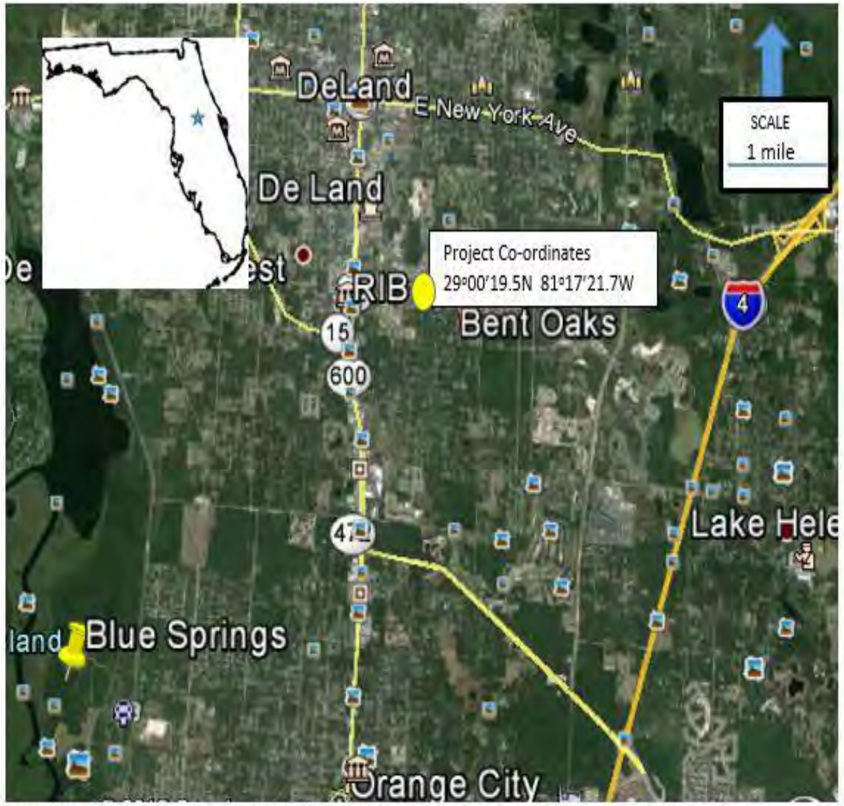
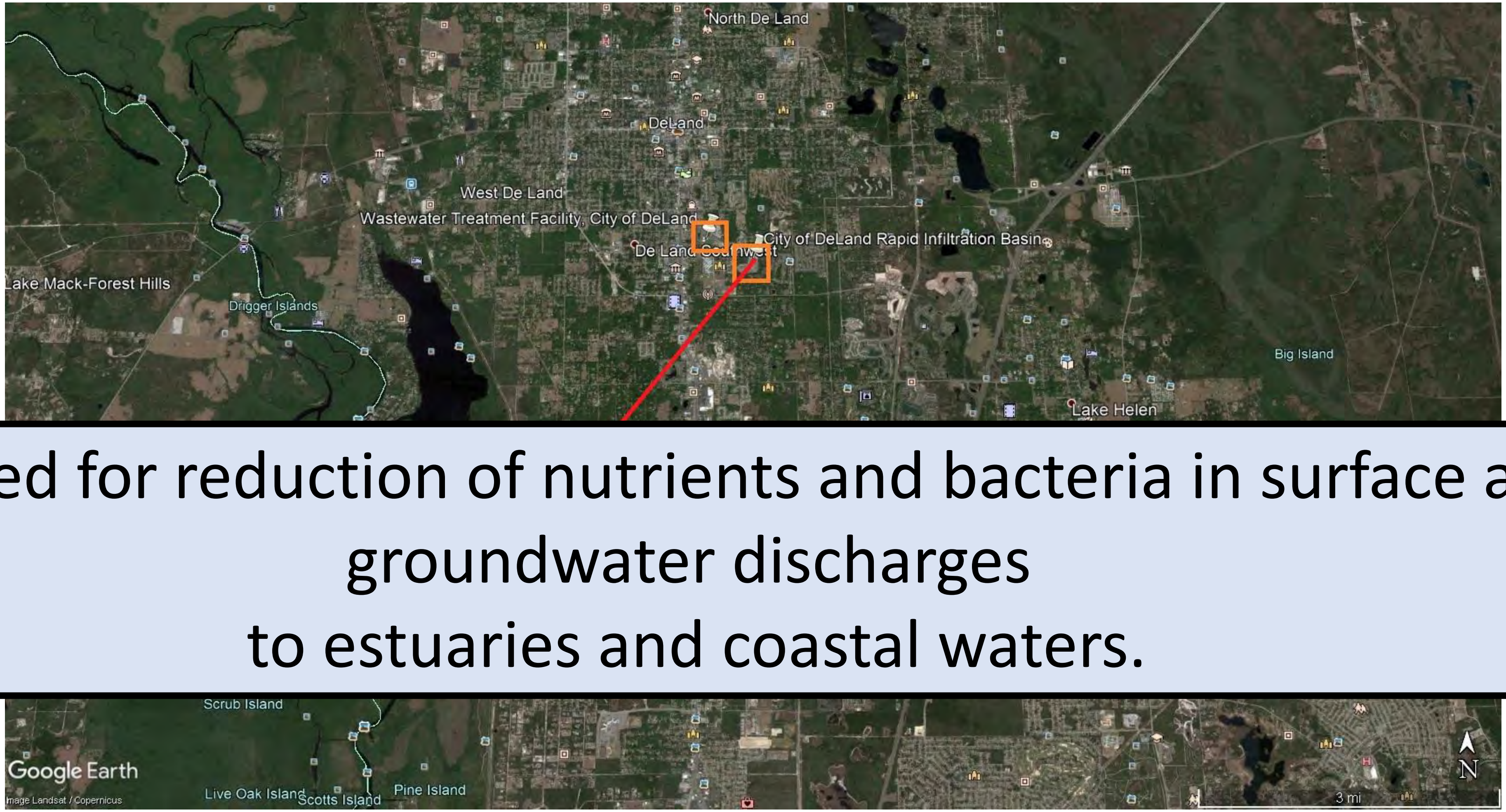


Figure 1. Location of the Bent Oaks Rapid Infiltration Basin (RIB) and Blue Springs, City of DeLand Florida. Prepared by Martin Wanielista, University of Central Florida, April 28, 2016

DeLand, Florida:

Protecting the Blue Spring

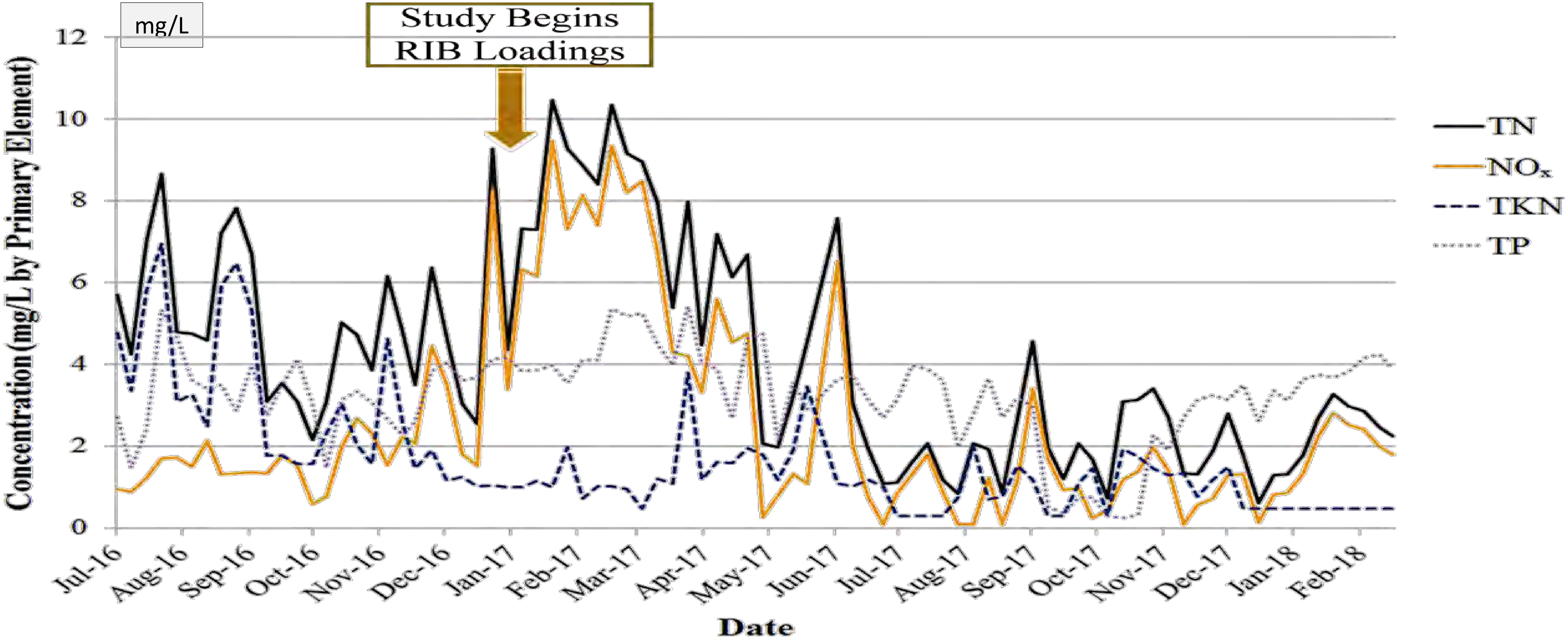


Also used for reduction of nutrients and bacteria in surface and groundwater discharges
to estuaries and coastal waters.

A Closer Look at the DeLand Integrated WRF Site

Sources of water input to the RIBs

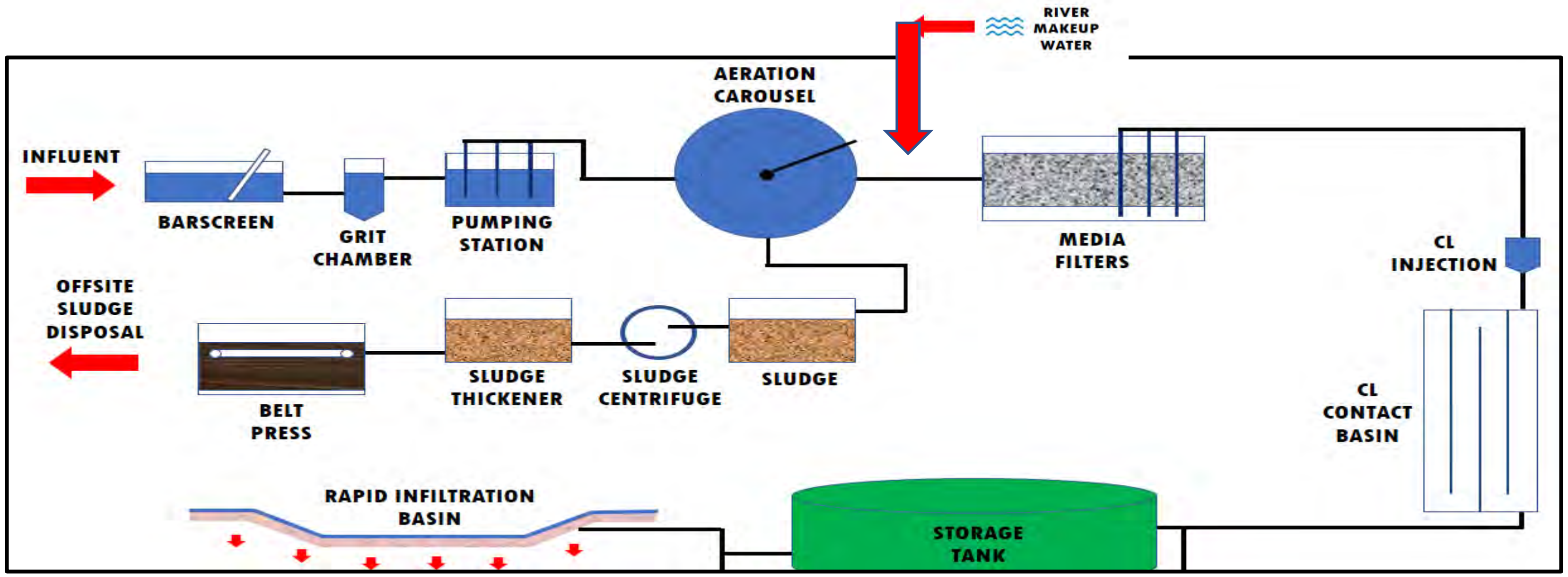
1. Reclaimed Water (from the DeLand Water Reclamation Facility)



Sources of water input to the RIBs

2. River Water: to augment the irrigation water supply during periods of high demand in the summer of 2017. Injection point shown below on the flow diagram of the DeLand Wiley Nash Water Reclamation Facility (WRF).

3. Stormwater: “courtesy“ of Hurricane Irma in September 2017

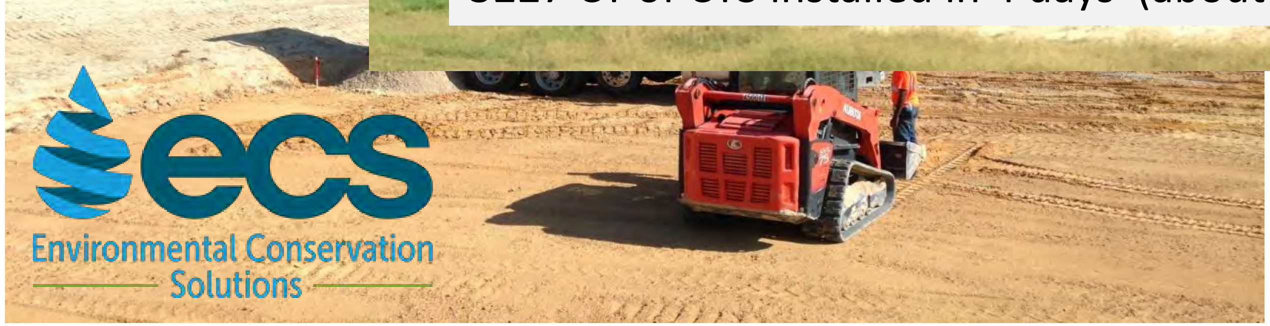


Site Selection using the DeLand RIB

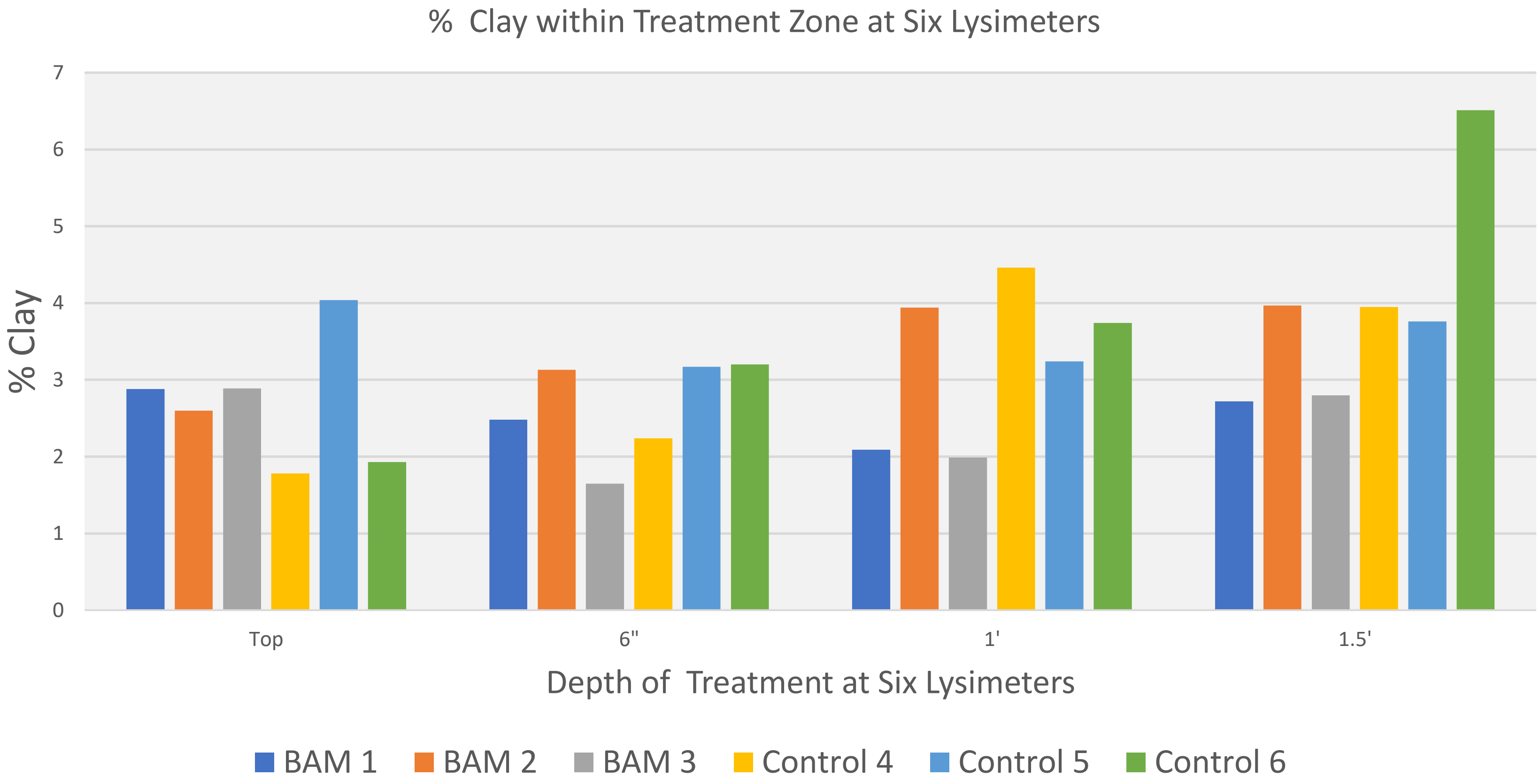
DeLand operates an eleven acre site for a “RIB” that had a loading permit for excess reclaimed water and stormwater disposal.
In one portion of the RIB. There is an existing soil, namely Tavares that has the potential for removal of nutrients.
Note: A sandy soil will normally **not** remove dissolved nutrients.

BAM installation (2 feet depth of CTS Media)

3227 CY of CTS installed in 4 days (about 25-30 trucks per day)

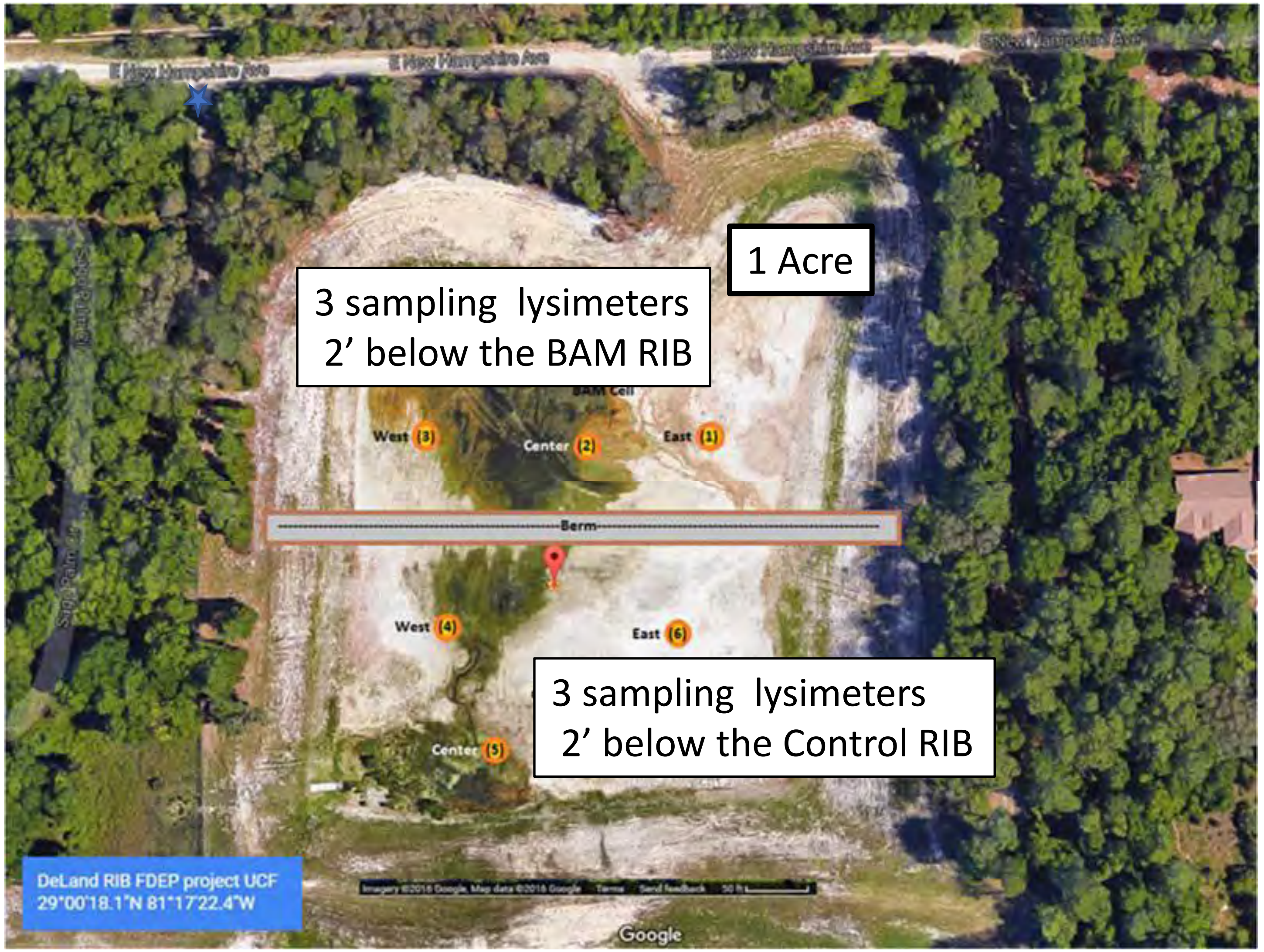


Clay in Treatment Zone (0-2 feet)
(both the BAM CTS and Natural Control RIBs)

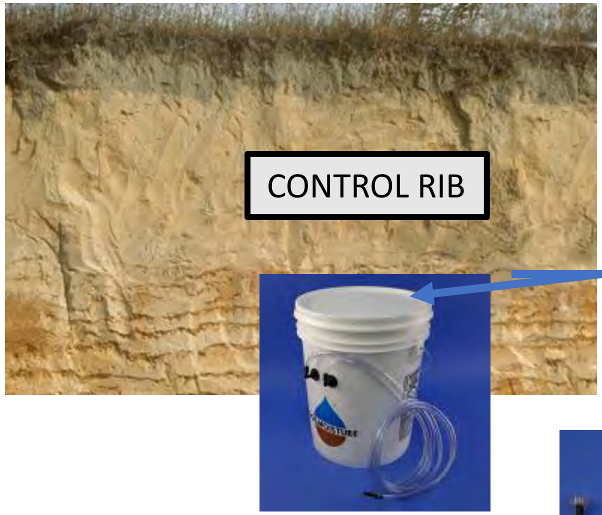


Note: native soils not always homogeneous (well mixed) and has preferred pathways

Lysimeter locations for Water Quality

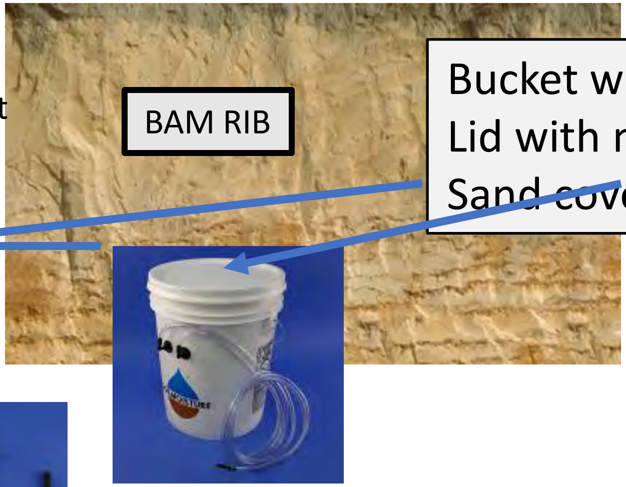


Installation and Sampling of Lysimeters



CONTROL RIB

2 feet



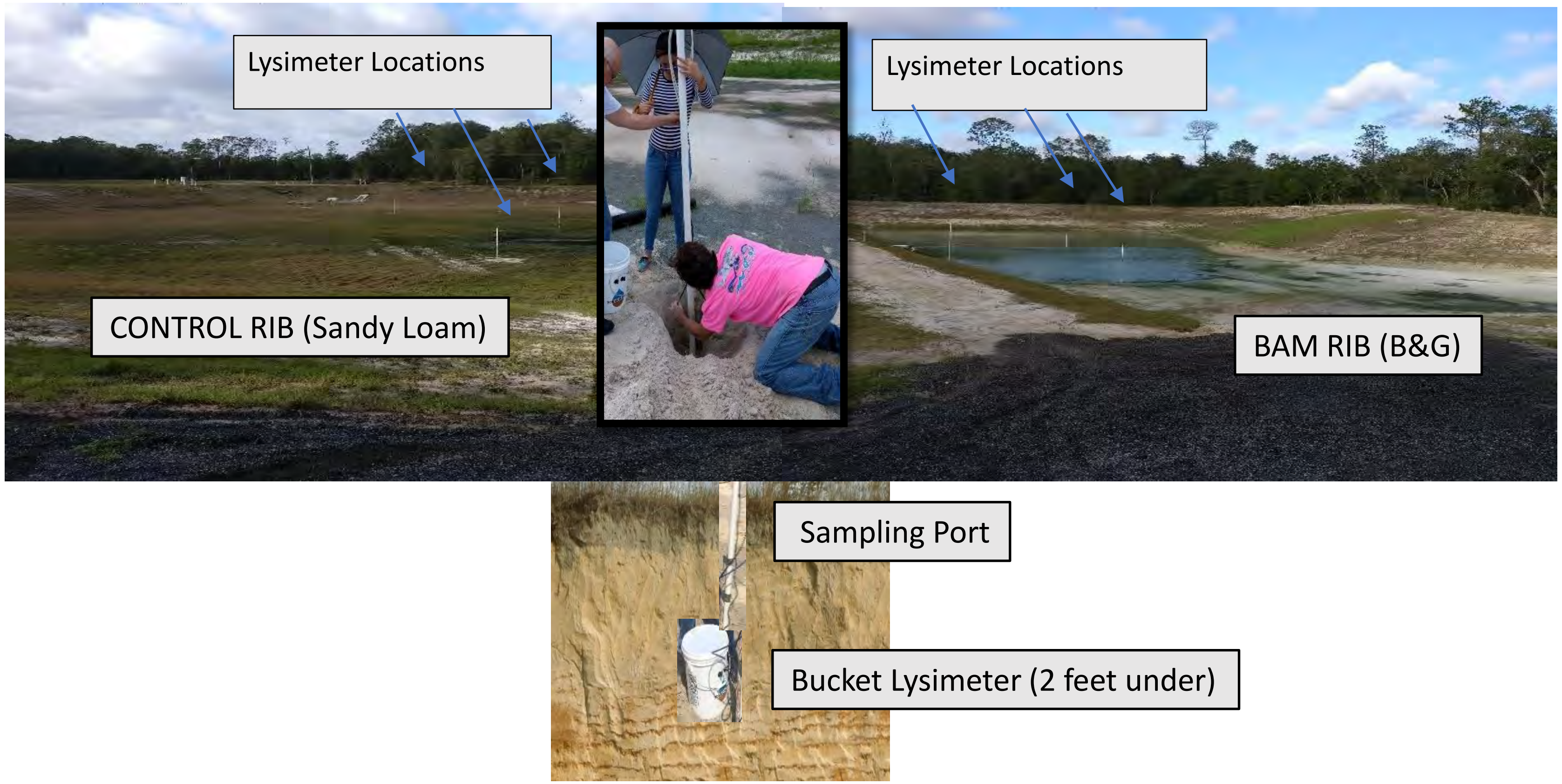
BAM RIB

Bucket with perforated
Lid with non-reactive
Sand cover

Before each sample, the lysimeter is evacuated of residual water, then the RIBs are loaded and the percolate goes into the lysimeter.

Hand pump was used to
Evacuate and to sample
New percolated water

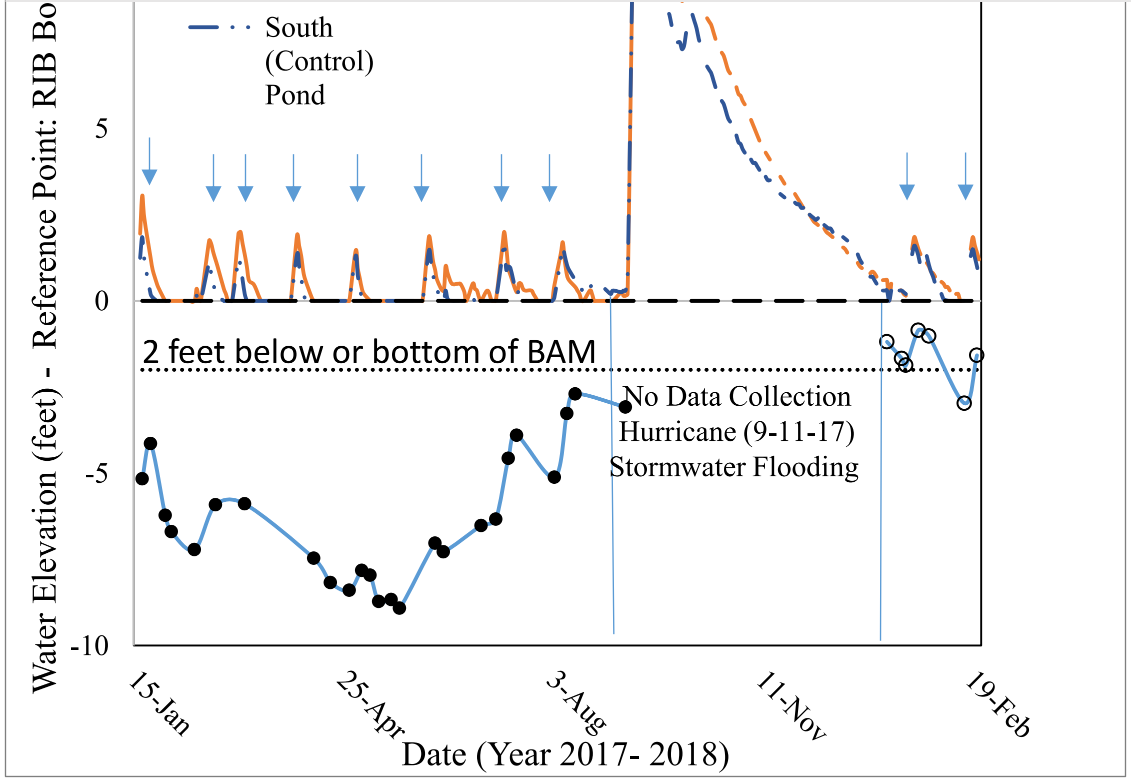
Lysimeters for Sampling Water Quality



Loading of RIBs

For Reclaimed Water
Historical loading = 0.26 MG/Acre/month
Study loading = 0.45 MG/Acre/month
Similar infiltration rates for BAM and Control

12 Events in 13 months
10 Reclaimed
2 Stormwater courtesy of:
hurricane Irma

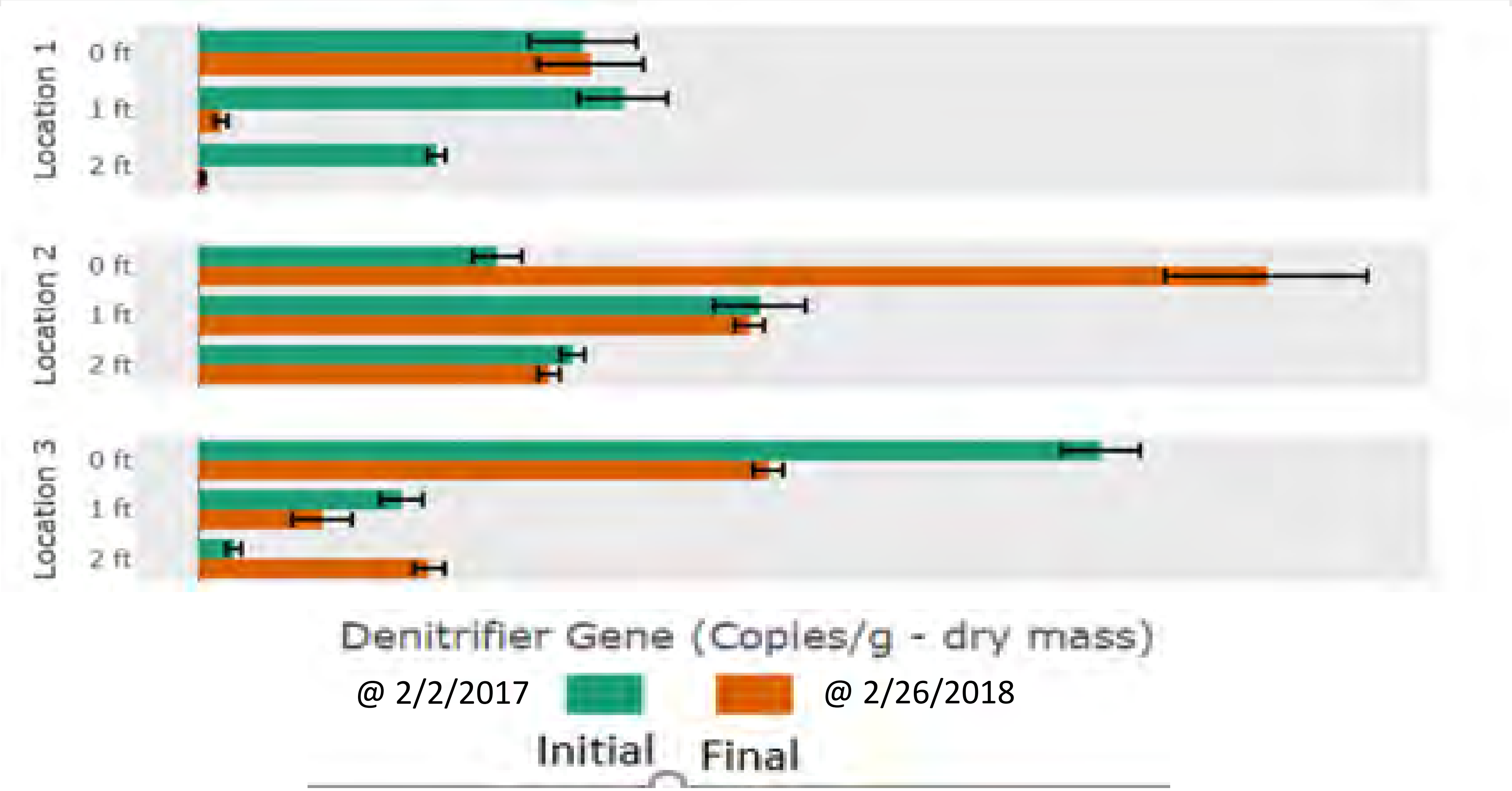


Reclaimed load such that the volume per acre was the approximately the same or 5.39 MG/Ac for the BAM RIB (16.5 feet) and 5.35 MG/Ac for the Control RIB (16.4 feet)

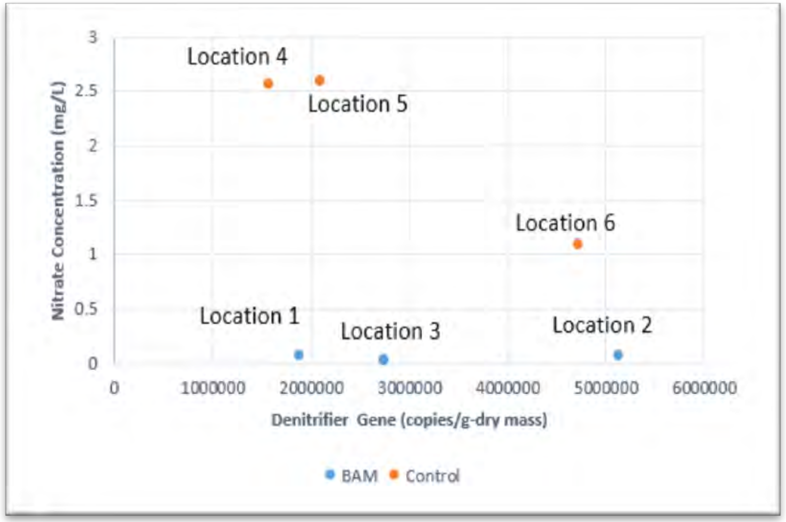
Stormwater load was 4.0 MG/Ac
And 12 feet deep.

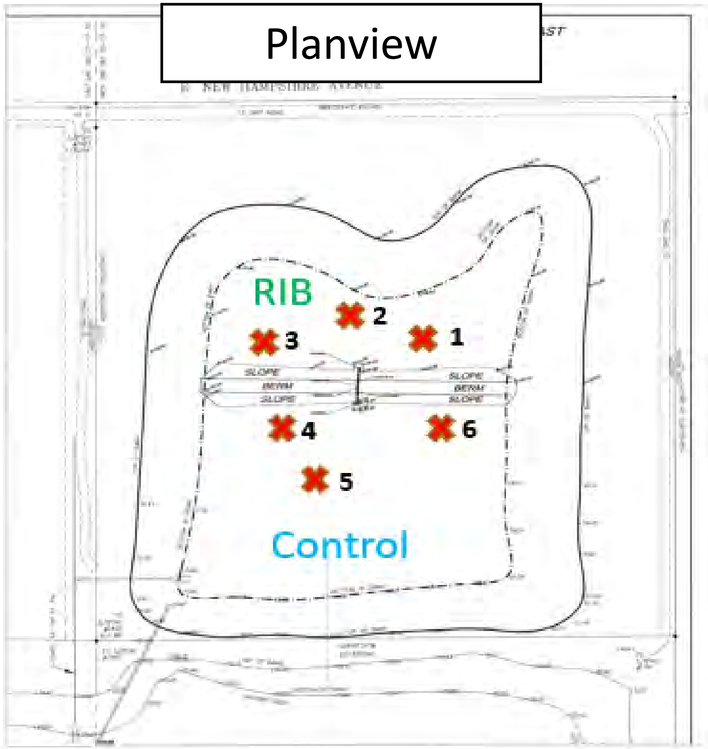
Recharge of Groundwater increased from 3.12 MG/ac/yr to 5.4 MG/ac/yr

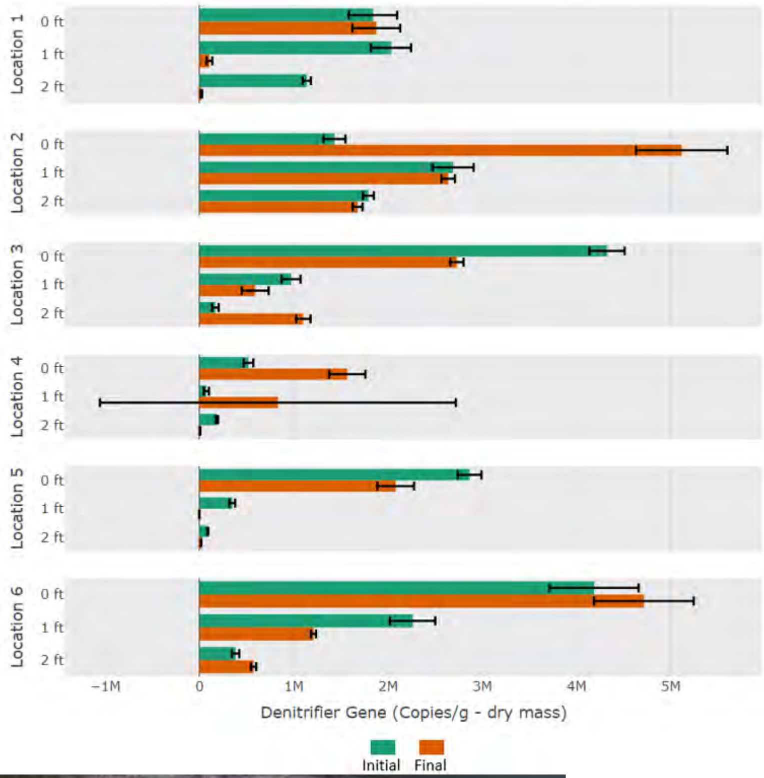
Micro-organism Counts at 3 BAM Lysimeters



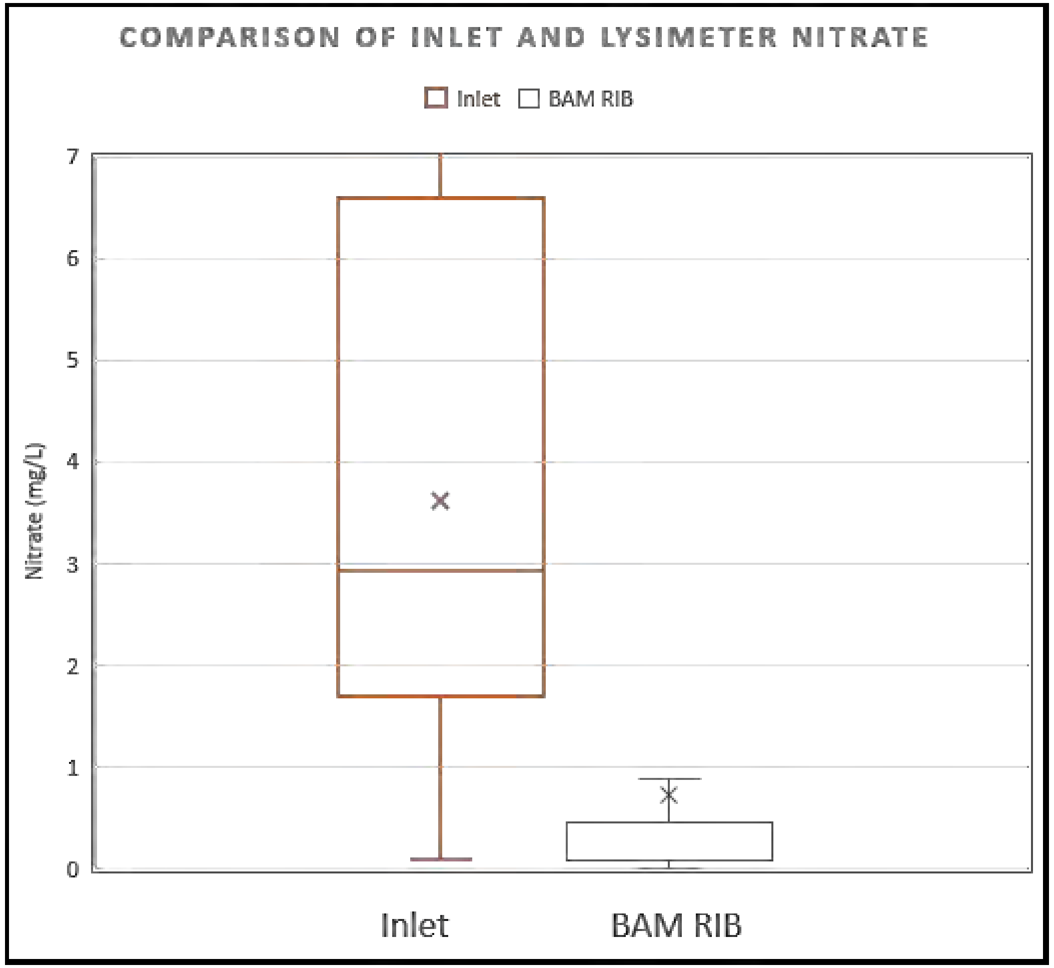
Microorganisms in BAM







Nitrate Inlet and Outlet Comparison - Reclaimed Water



Legend: Reference EXCEL 2016: average x, minimum ⊥, maximum ⊤, Quartiles -----

Figure 14 Comparison of Inlet and Lysimeter Nitrate Concentrations Using Reclaimed Water

NELAC Certified Reclaimed Measures (DeLand WRF)
NELAC Certified Stormwater Measures (ERD, Orlando)

Parameter	Method/Instrument	Detection Limit
Reclaimed Water		
Nitrate-Nitrite (NOx)	EPA Method 353.2: DeLand Lab	0.079 mg/L N (0.134 mg/L)*
Storm Water		
Nitrate and Nitrite (NO_2 and NO_3)	Standard Method 4500 F: ERD Lab	0.002 mg/L N

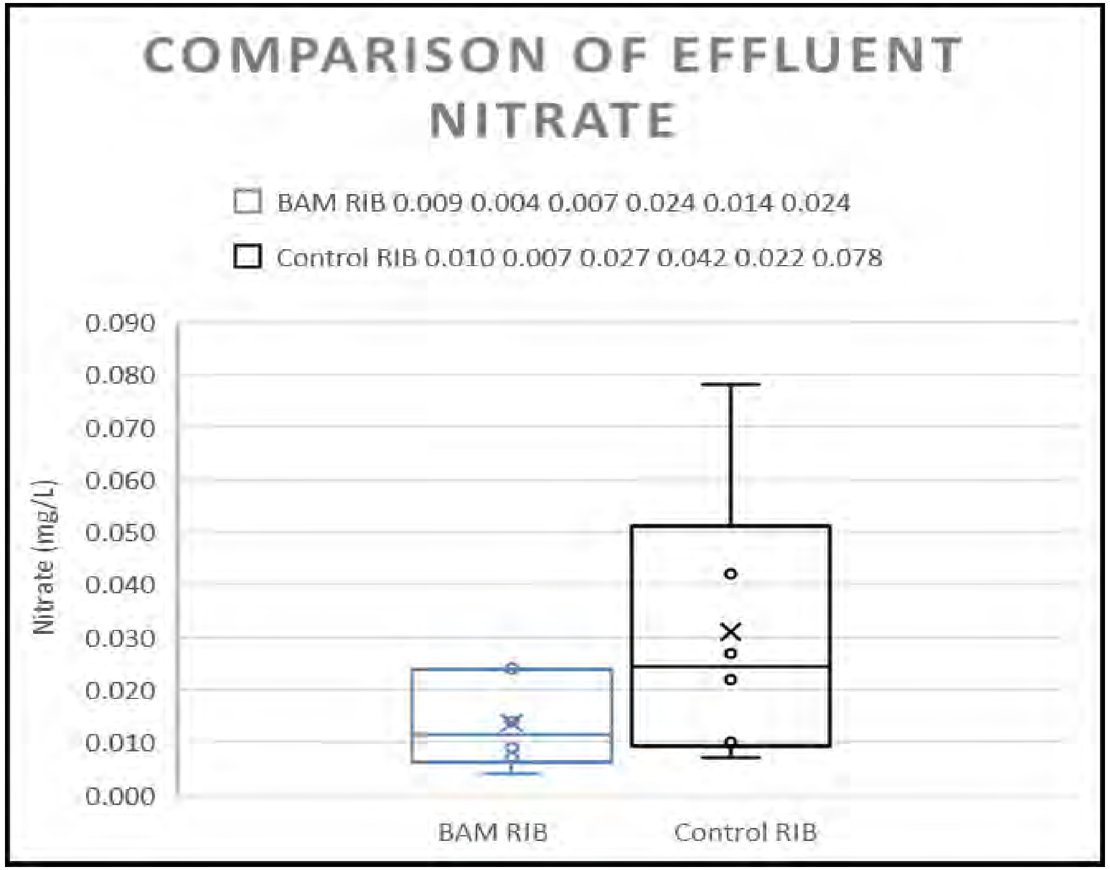
* Change in personnel conducting tests

73% Outlet sample concentration <detection

Box Plot is a visual representation for the difference in concentration

Removal using Reclaimed Water with BAM: Average = 83%

Comparison of Nitrate in BAM and Control (Lysimeters) Data When loading with Stormwater



Legend: Reference EXCEL 2016: average x, minimum ⊥, maximum ⊤, Quartiles -----

Figure 14 Comparison of Inlet and Lysimeter Nitrate Concentrations Using Reclaimed Water

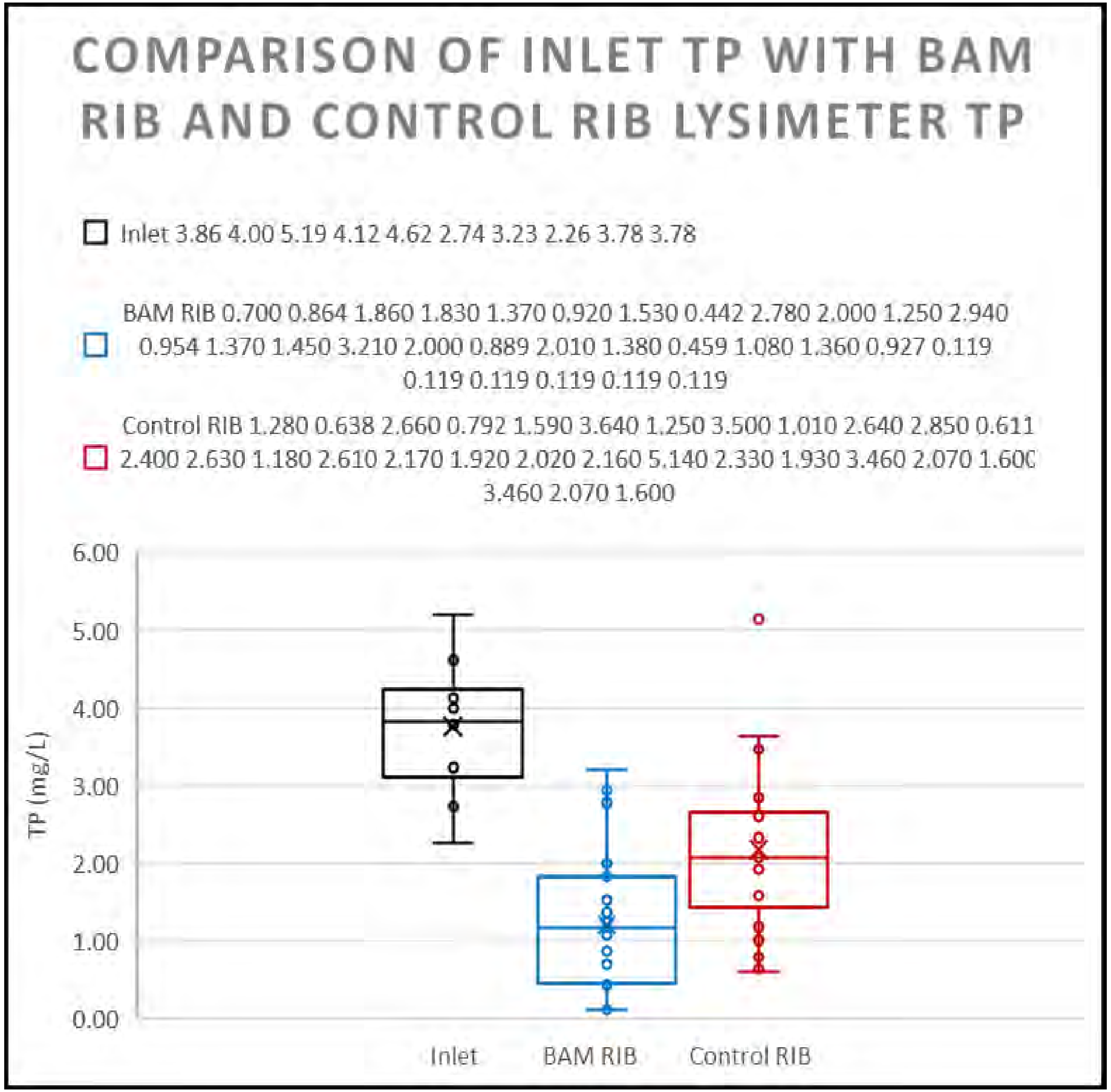
Assumed inlet concentration of 0.303 mg/L
And all measurements above detection limit

Removal with Stormwater Loading with BAM: Average = 95%

Removal using 1–[C_{out}/C_{in}]

Comparison of TP using Reclaimed Water

Average removal of 66%
Almost all DP



Fecal Coliform Removal

- There were 36 measurements for the input and 36 lysimeter output measurements.
- Inputs averaged ~ 5000 CFU/100 ml. There were 5 measures too numerous to count. The samples were taken at least 2 days after end of loading. The residual Chlorine was zero.
- Output from the BAM lysimeters averaged 31 CFU/100 ml.
- Output from the native soil averaged 609 CFU/100 mL.

COST based on NOx and Recharge Volume

For 5 MG loading/acre/year, and average reclaimed input of 3.6 mg/L
The removal is 125 pounds/acre/year or 2500 pounds/acre in 20 years.

The installation and product cost of BAM is $400,000 per acre.
Thus unit removal cost is $160/pound of NOx in 20 years.
There is no additional operating and maintenance cost for the BAM modified RIB

Benefits from the recharge of the surficial aquifer in terms of water quantity are assessed on the opportunity cost of suppling an equal amount of water (or 5.4 MG/Ac/year) which is about $10,800/Ac/year ($2/1000 gal) or $118,800/year for the eleven acre RIB site.
For 20 years, the value is $2.38 million dollars. B/C = 6/1

Conclusions and Remarks

1. CTS BAM removes nitrate, DP and fecal coliforms in reclaimed and stormwater.
2. 2 feet of BAM removed ~ 83% nitrate in reclaimed water and ~ 95% nitrate in stormwater. 1 foot of BAM removed about 60% nitrate with stormwater input.
3. 2 feet of BAM removed ~66% of DP using reclaimed water. 1 foot of BAM removed ~ 60% DP using stormwater input. TP removal was about 90-95% with two foot depth of CTS .
4. Fecal Coliform reduction was measured at the RIB site. Outlet average CFU/100 ml were 31 with media compared to 609 from the native soil.
5. Biological activity was documented in both of the basins.

Bio-Sorption Activated Media for Control of Nutrients and Fecal Coliforms

Questions and Comments