“Swirling Currents of Water Quality Regulations"

Performance of a Bio-Retention System Or How Come My Bio-Retention System Works?

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2012 Annual FSA Conference

Sanibel Harbour Marriott , June 2012

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Purpose of Presentation

- Provide data on the water quality and infiltration performance of two retention basins
  - What Site Characteristics are indicators of nutrient removal?
- Detail a Design of a Retention Basin “BAM” filter
  - BAM Basin Performance
  - Relate to other retention systems

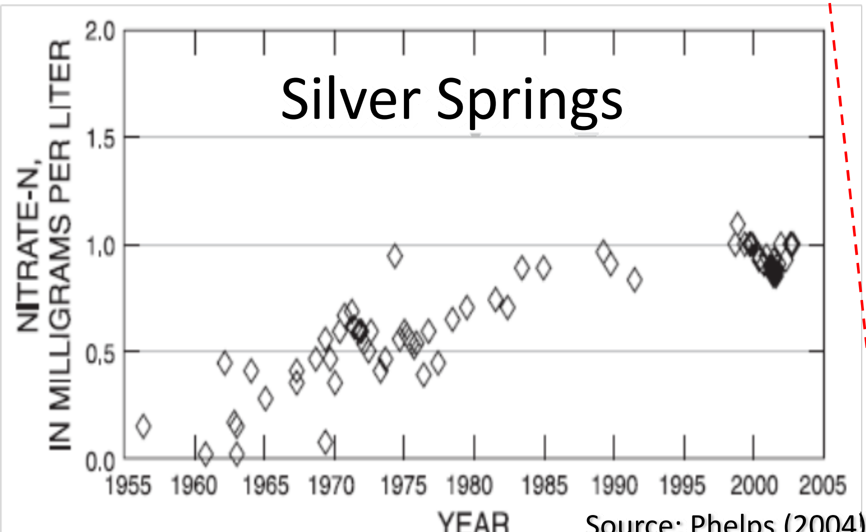
PARTNERS

- Marion County
- Florida Department of Environmental Protection
- Southwest Florida WMD
- St. Johns River WMD
- University of Central Florida
- U.S. Geological Survey
- U.F. Soil and Water Science Department

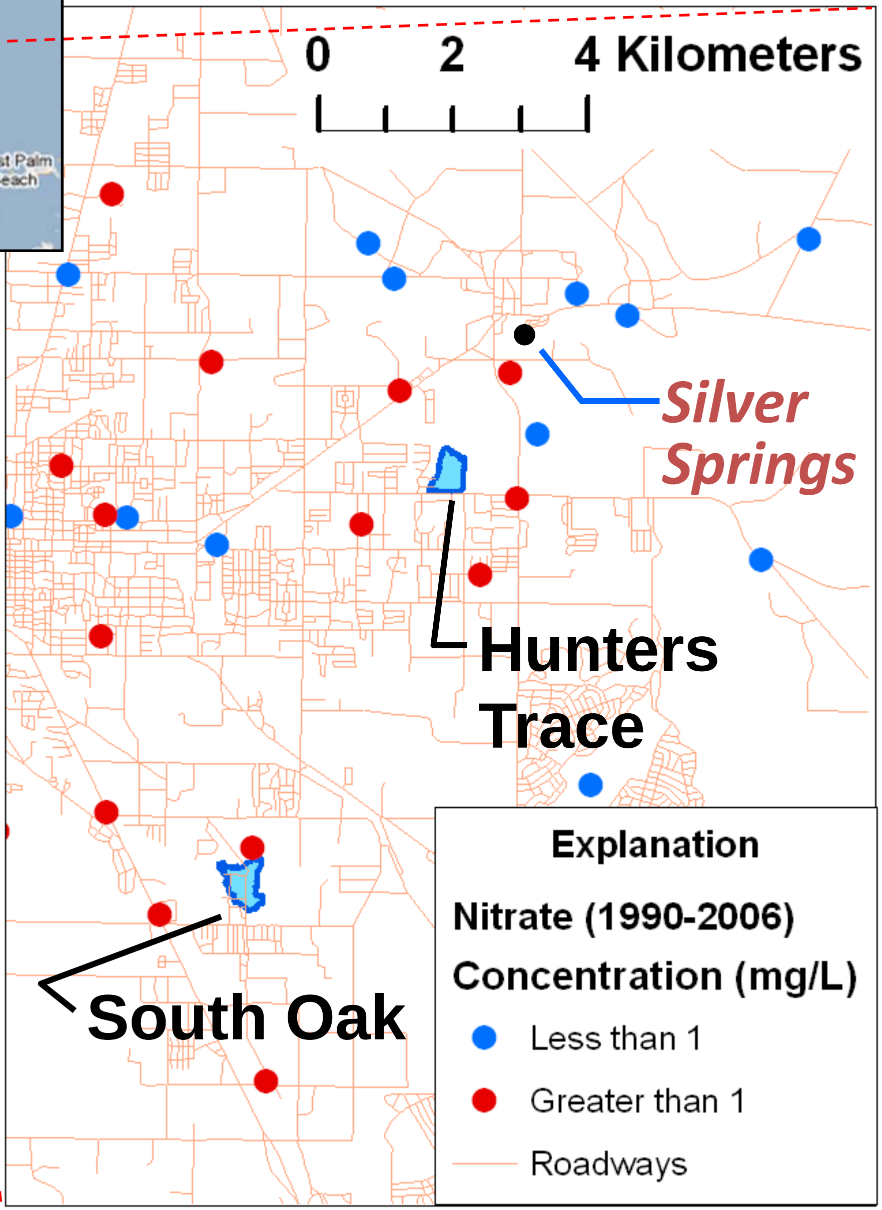
Special recognition to Dr. Andy O’Reilly USGS

STUDY AREA

- 2 stormwater basins studied near Silver Springs ($Q = 22\ m^3/s$).
- Increasing nitrate in Silver Springs.

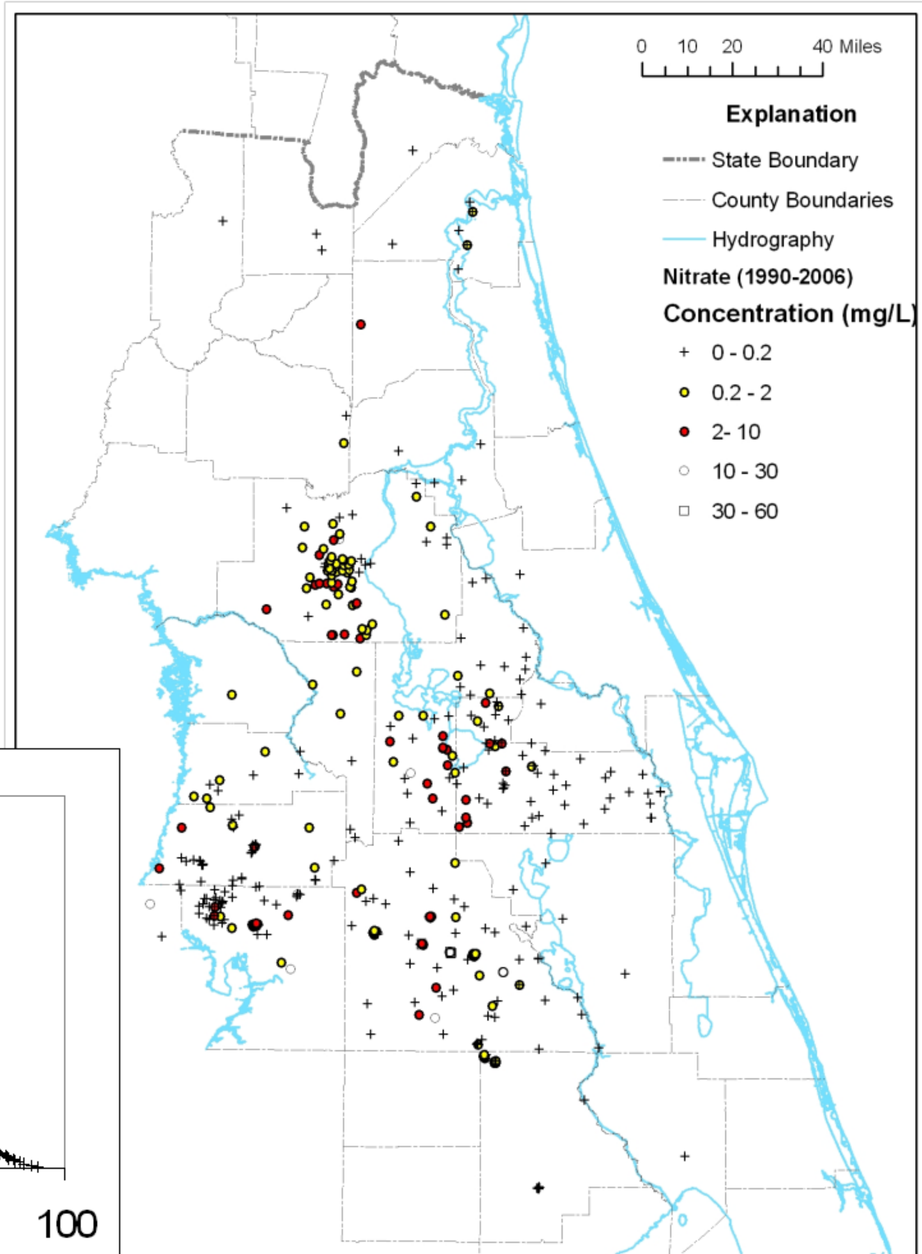


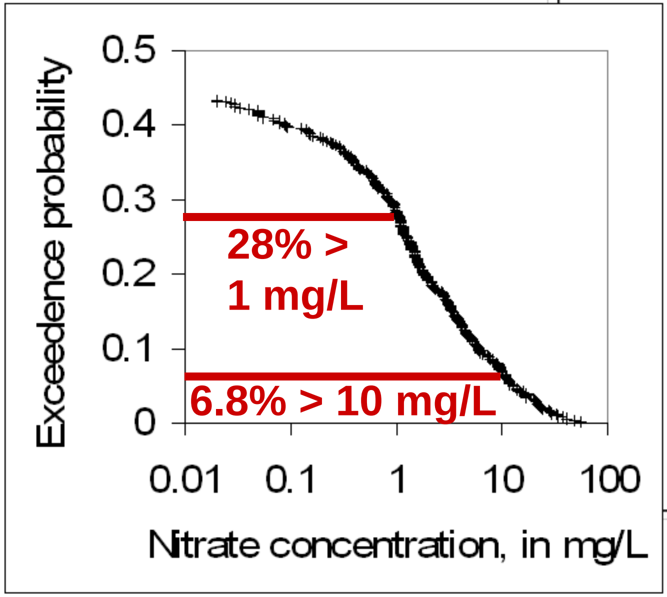
Source: Phelps (2004)



NITRATES IN GROUND WATER

- Elevated nitrate concentrations common.
- Historical data 1990-2006, 569 wells.



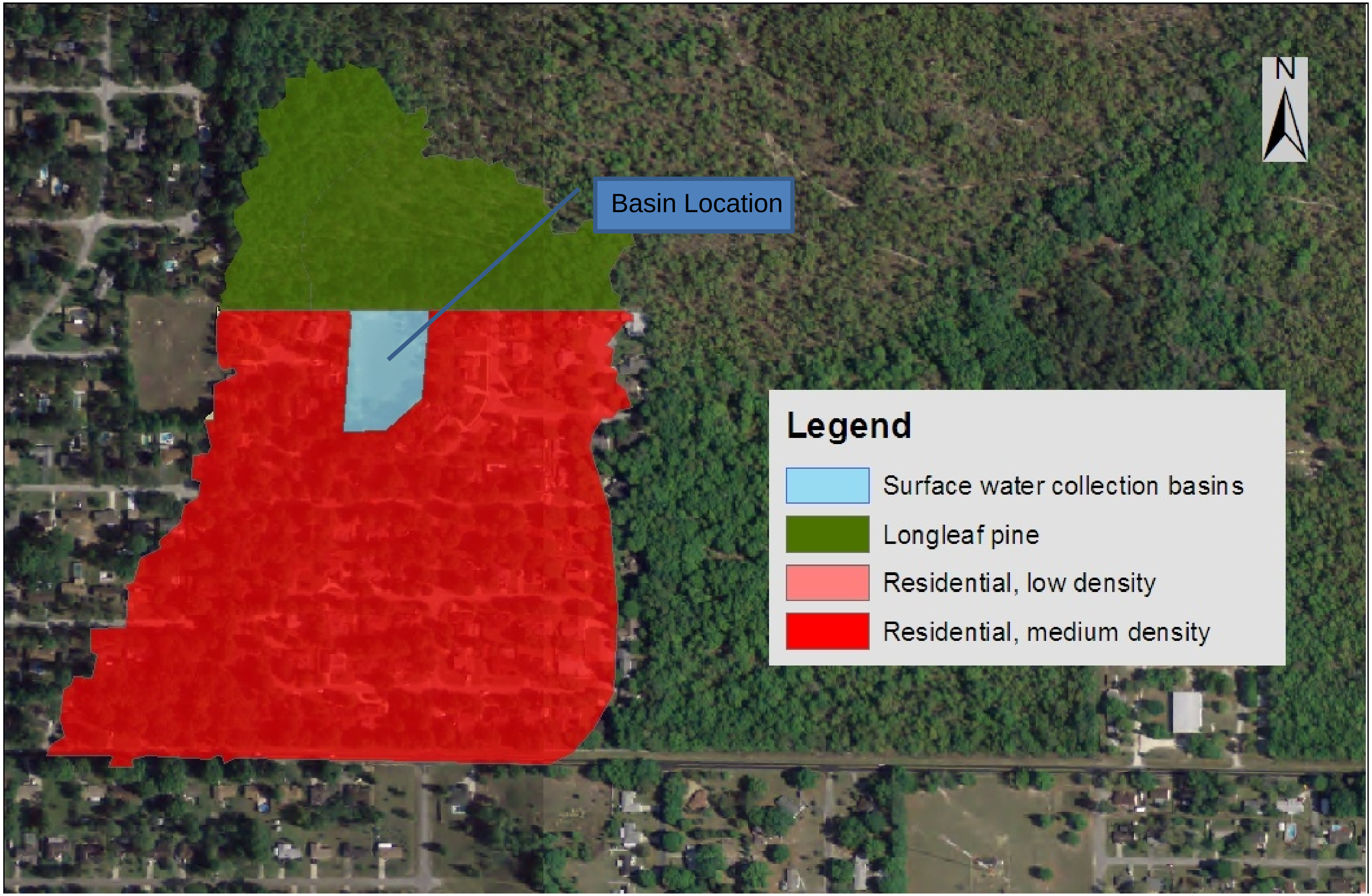


APPROACH

1. LABORATORY – Document the fate of nitrogen.
2. ANALYSIS/DESIGN – Compare pre- and post-bio-sorption activated media (BAM) amendment for attenuation efficiencies. Investigate nitrogen cycling. Identify alternative design criteria for infiltration BMPs.
3. FIELD – Monitor basins before and after incorporating BAM as a soil amendment.

HUNTER TRACE DRAINAGE BASIN LAND USE

2004

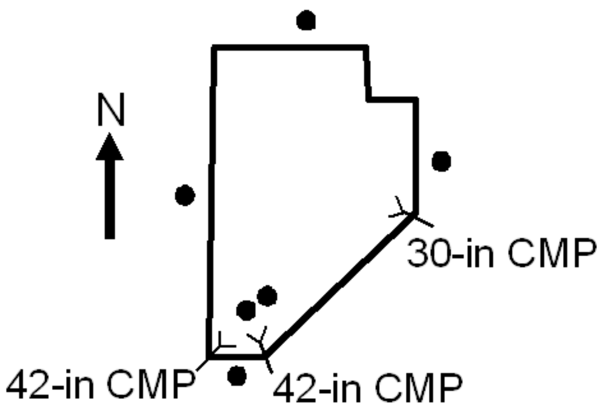


Land Use Data Source: SJRWMD

Hunters Trace (HT) Basin

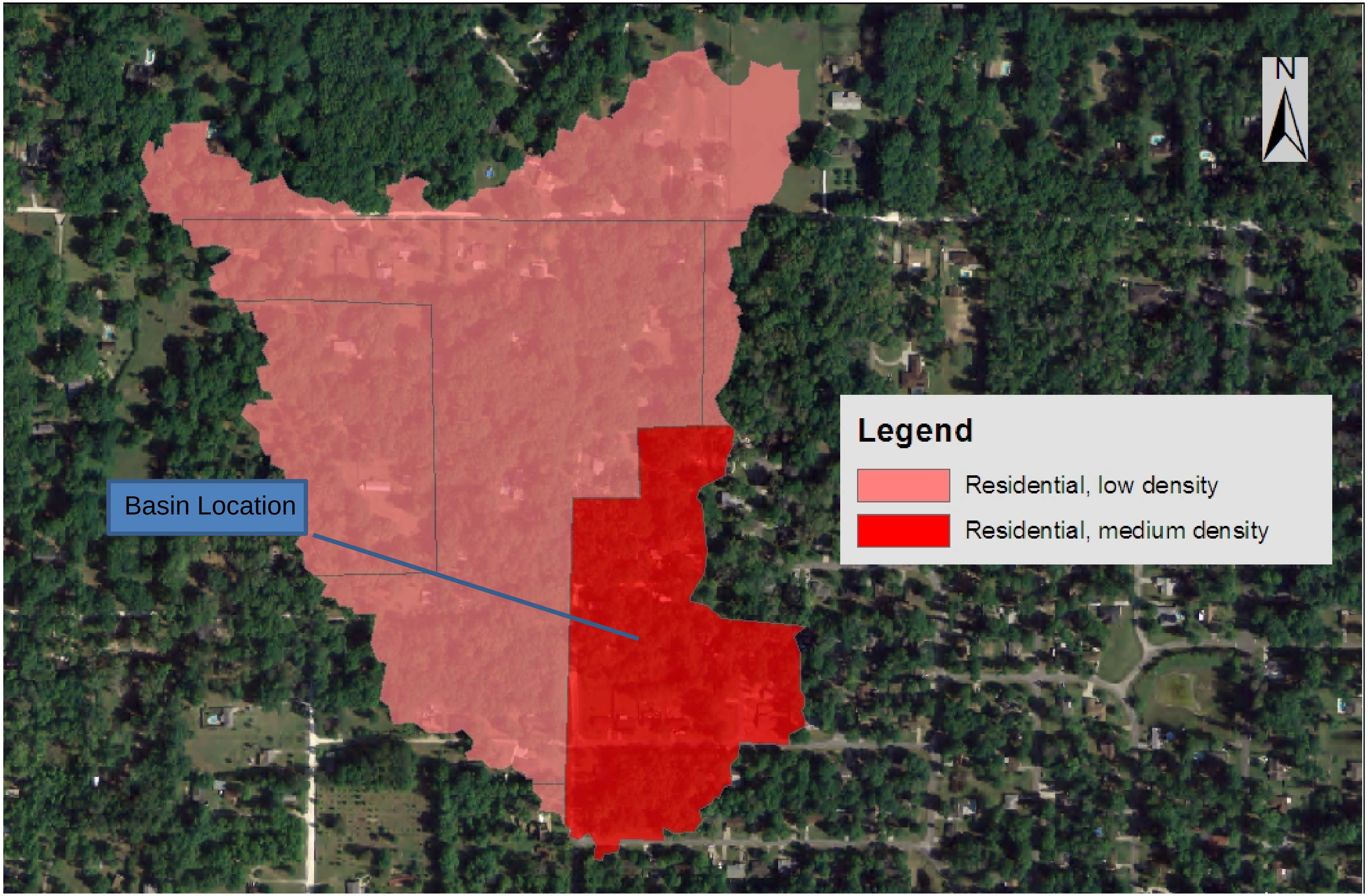
- 0.7 ac basin,
- 10 ft deep, 51’ bottom ~61-62’ at the top
- 56 ac drainage basin, only 4.2 ac EIA
- Water table ~10 ft below basin bottom

  - Well sampling location



SOUTH OAK DRAINAGE BASIN LAND USE

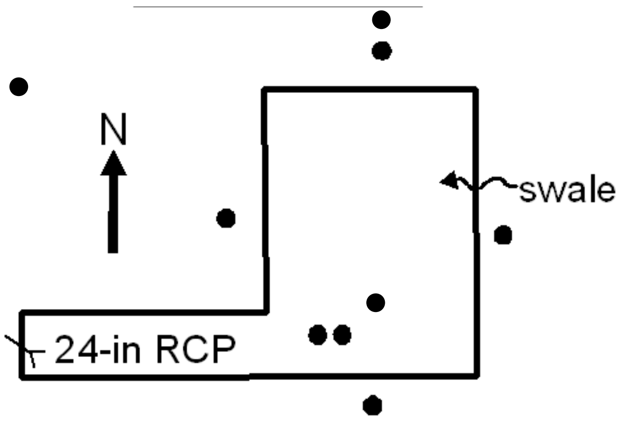
2004



Land Use Data Source: SJRWMD

South Oak (SO)Basin

- 0.4 ac basin,
- 5 ft deep
- 72 ac drainage basin only ~ 3.6 ac EIA
- Water table normally at basin bottom
  - Well sampling location

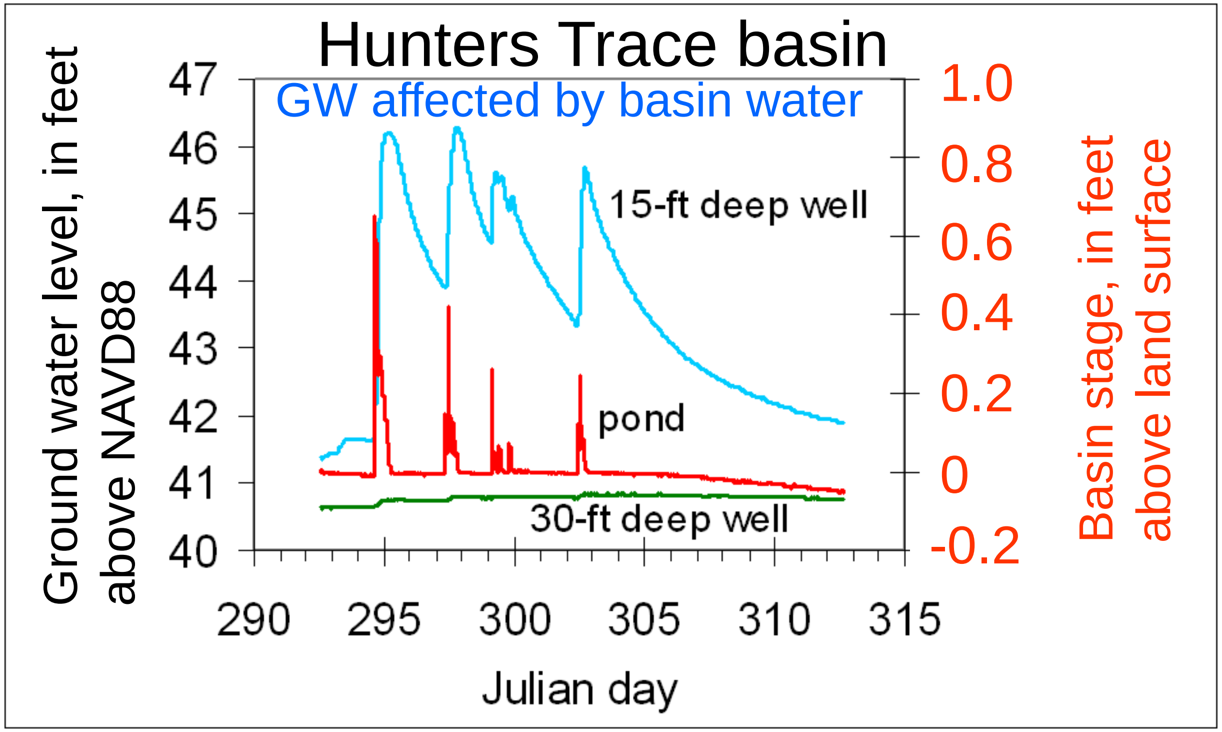


WATER QUALITY MONITORING

- Major elements
- Nutrients (nitrogen and phosphorus)
- Organic carbon
- Trace metals
- Dissolved and soil gases
- Stable oxygen and hydrogen isotopes of water; and oxygen and nitrogen isotopes of nitrate and nitrogen gas
- Soil mineralogy and chemistry
- Nitrite reductase gene density by real-time polymerase chain reaction (RT-PCR)

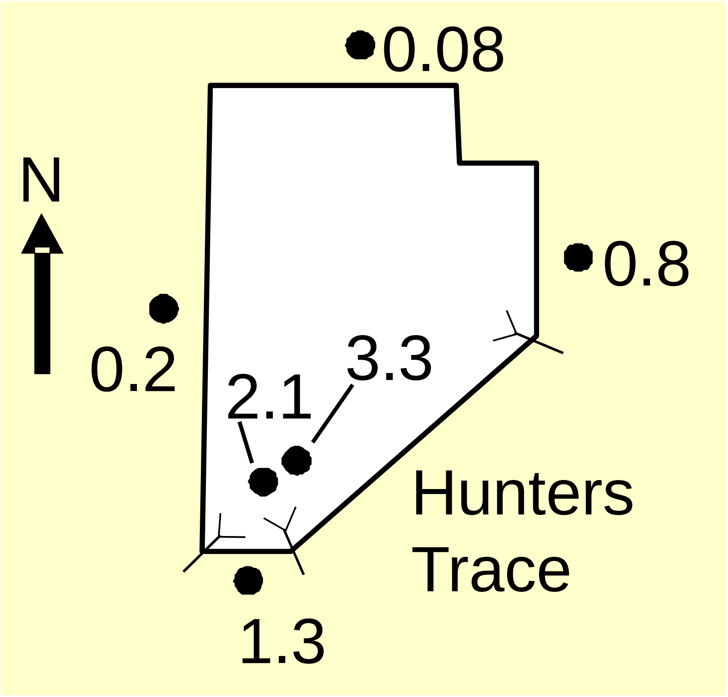
FIELD INSTRUMENTATION

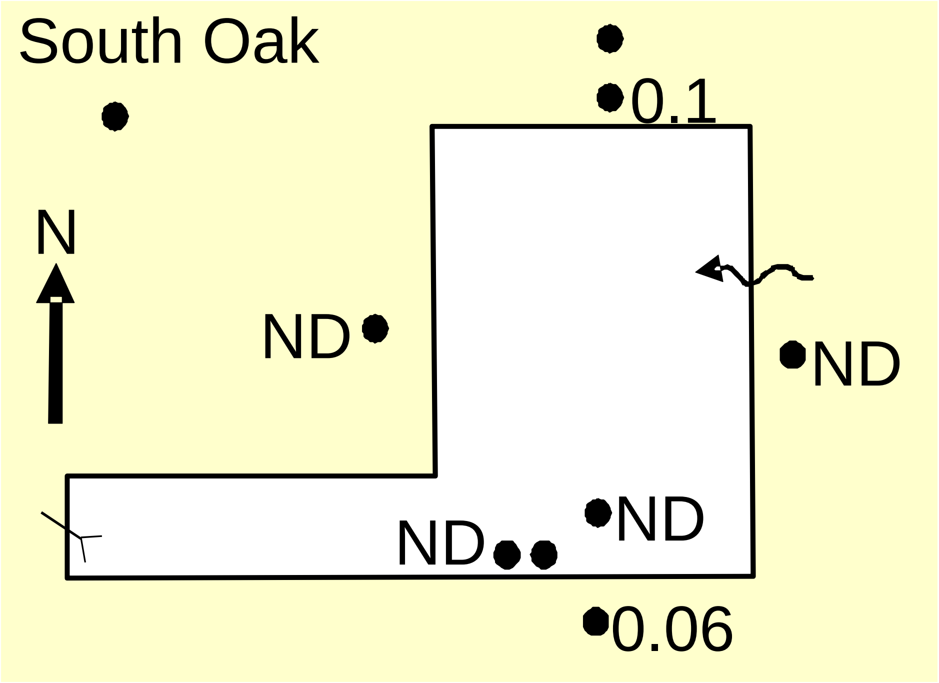
- Ground-water level
- Basin water stage
- Rainfall



NITRATE LEVELS

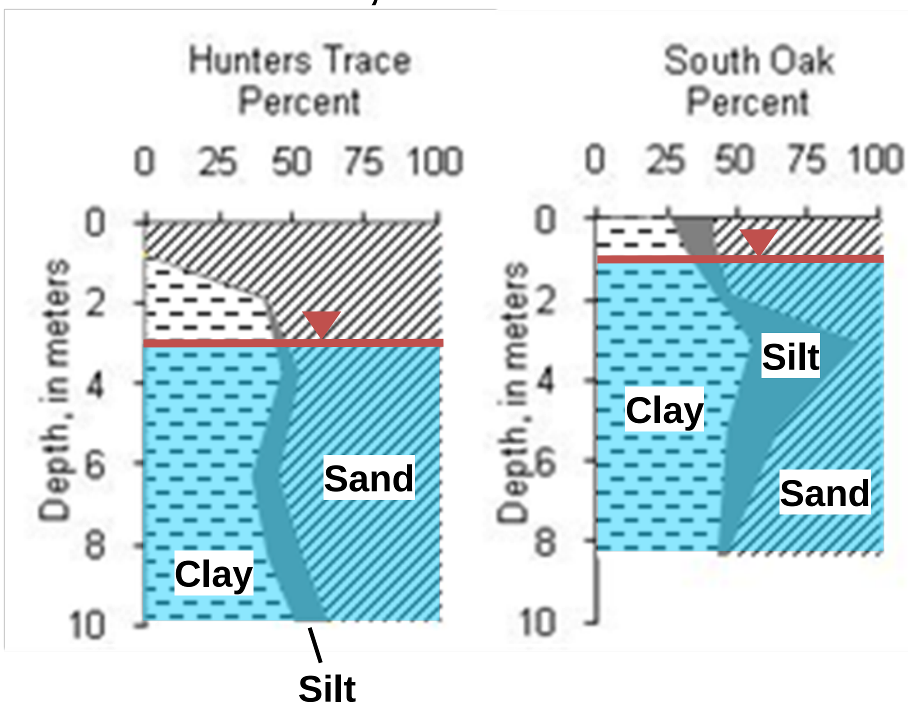
- Nitrate concentrations (mg/L) higher at Hunters Trace than South Oak

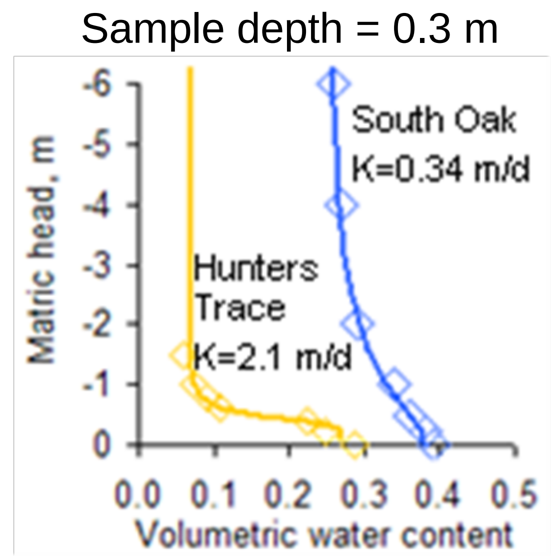




SOIL CHARACTERISTICS

- Textural differences contributed to large differences in the soil moisture retention curves.
- Soil moisture is important because O_2 diffusion through water is 10,000 times less than through air.



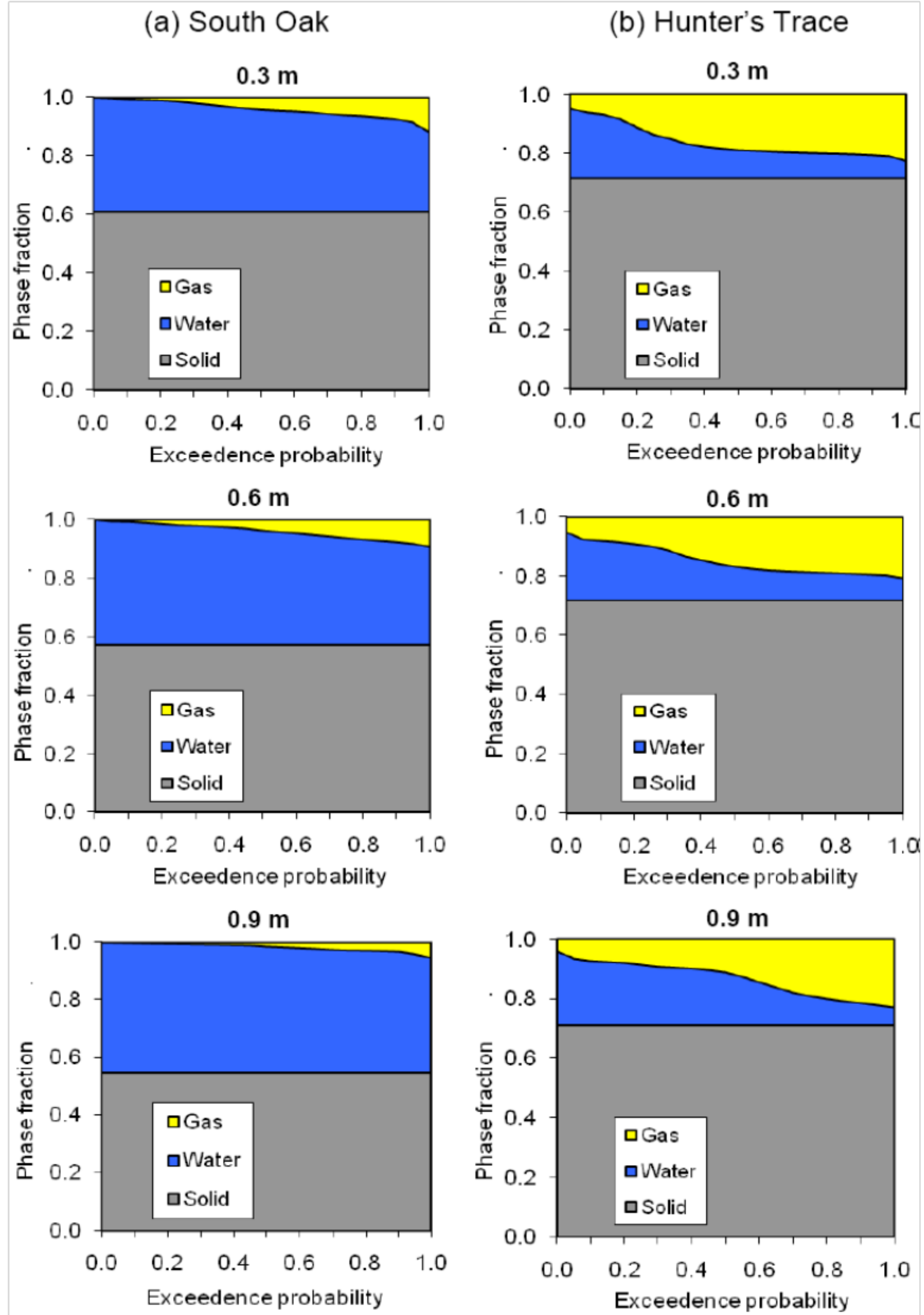


Particle-Size Distribution (PSD) Results

- South Oak soils
  - Uniformly graded
  - Classified Sand on textural triangle
  - 8.5-12.5% silt/clay (USDA)
- Hunter's Trace soils
  - Uniformly graded
  - Classified Sand on textural triangle
  - 1-3.2% silt/clay (USDA)

Soil Moisture Conditions

- Soil moisture data indicate soil stays wetter longer at the SO site compared to the HT site
- A substantial gas phase fraction is more conducive to O_2 diffusion and aerobic groundwater
- Oxygen availability has important implications for denitrification and other biogeochemical processes

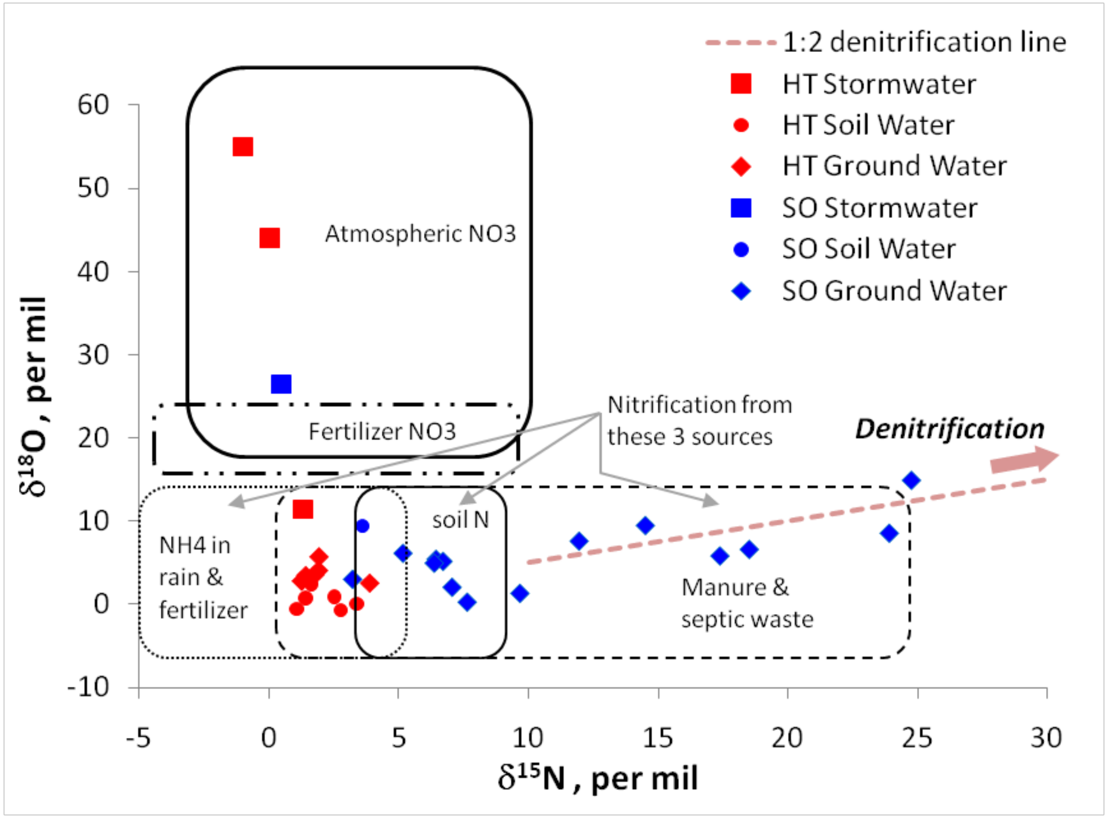


NITRATE TRANSPORT & FATE

At the SO basin, evidence of denitrification is supported by

- Excess N_2 concentrations as high as 3 mg/L; and
- Isotopically heavy ^{15}N and ^{18}O of nitrate (up to 25 and 15‰, δ respectively).

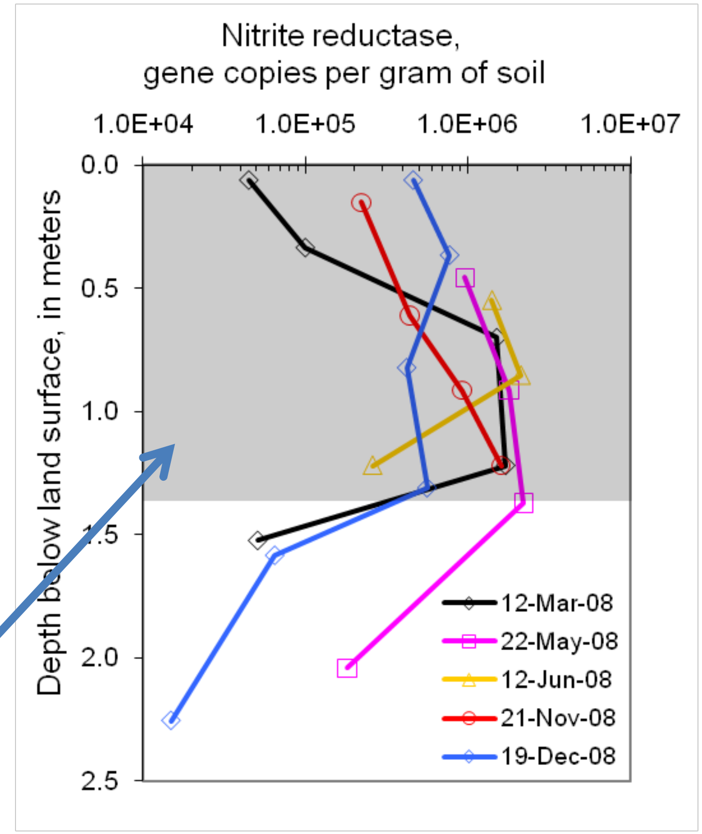
At the HT basin, no excess N_2 and no isotopic enrichment thus minimum denitrification.



Outlines of typical nitrate source ranges from Kendall and Aravena (2000)

Denitrifying Organisms Present

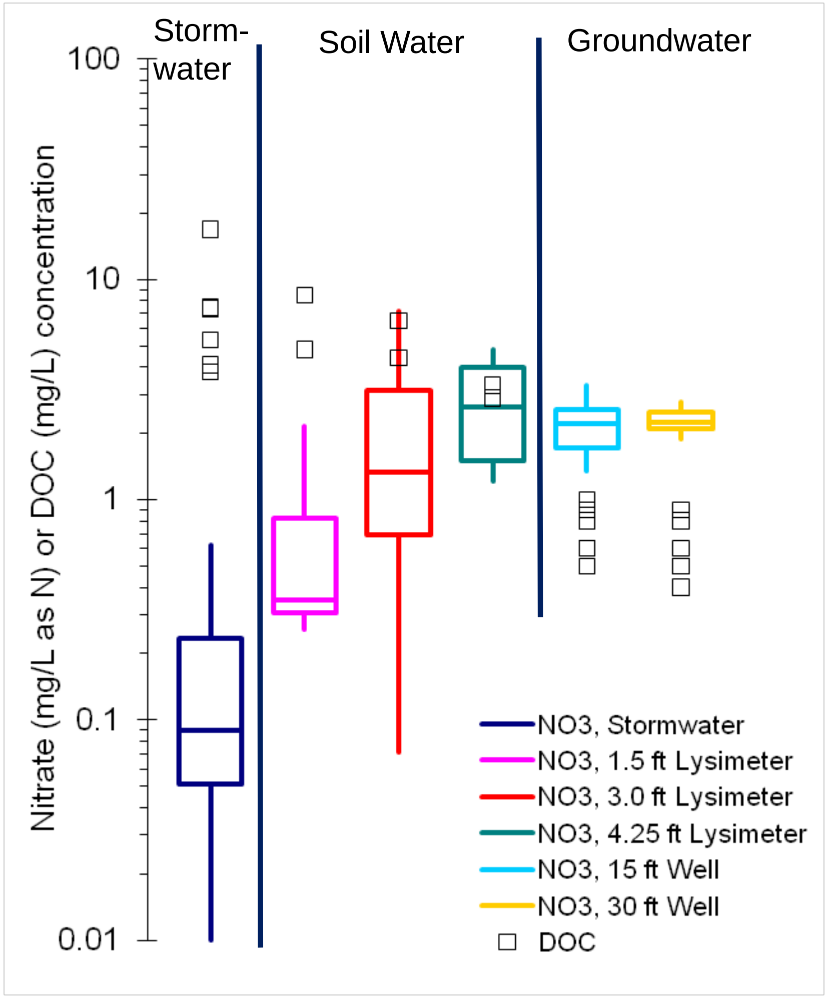
- At the SO basin, evidence of denitrification is supported by real-time PCR (DNA) results indicating elevated nitrite reductase gene densities at depths above 1.4 m.



Nitrate Present in
This volume of soil

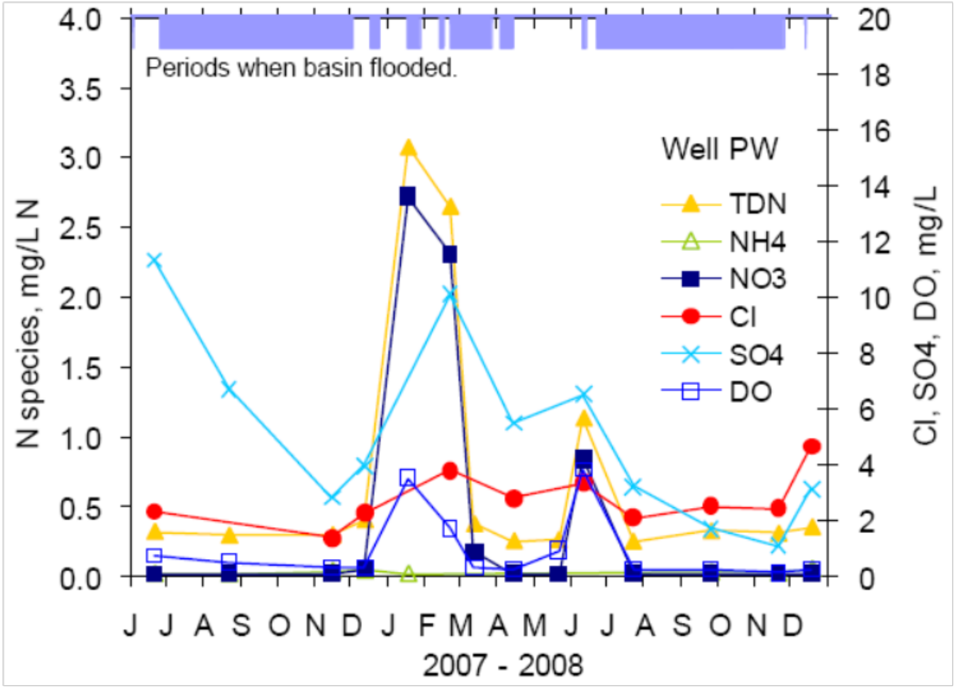
BIOGEOCHEMICAL PROCESSES
Hunter's Trace

- Aerobic conditions (dissolved oxygen 5-8 mg/L) persisted beneath the HT basin, resulting in depletion of dissolved organic carbon (DOC) and NO_3^- leaching.
- Aerobic conditions precluded the reduction of other electron acceptors.



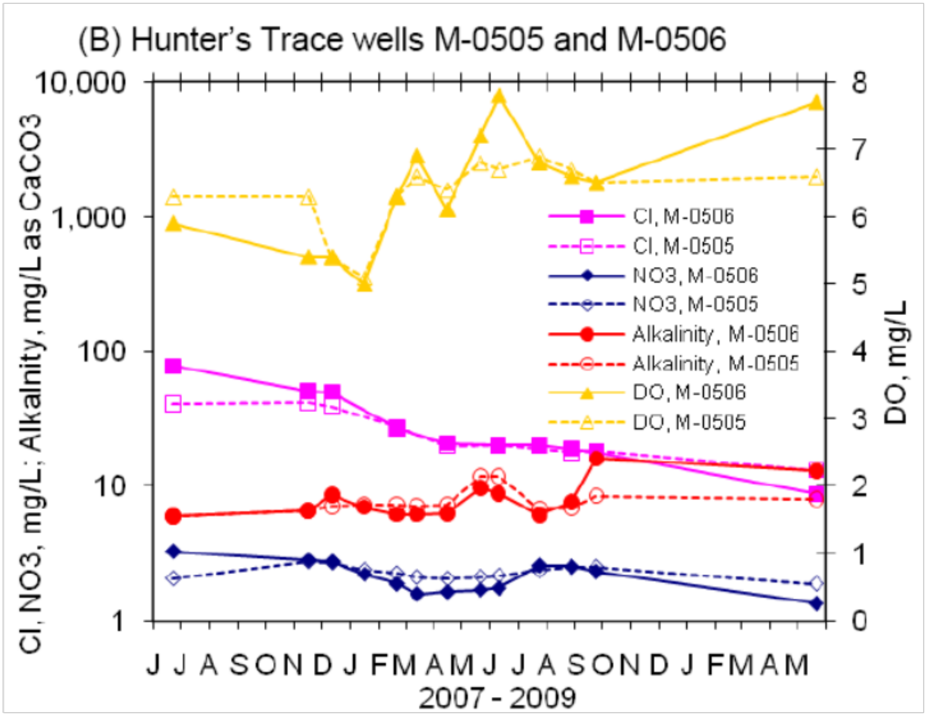
GROUNDWATER QUALITY
South Oak basin

- N primarily in organic form when O_2 low and NO_3^- form when aerobic
- Typically low O_2 or anoxic
- GW DOC ~½ of SW DOC
- Cl and NO_3^- variations dissimilar (r^2 = 0.21 for well PW) suggests ***reaction***-dominated N fate



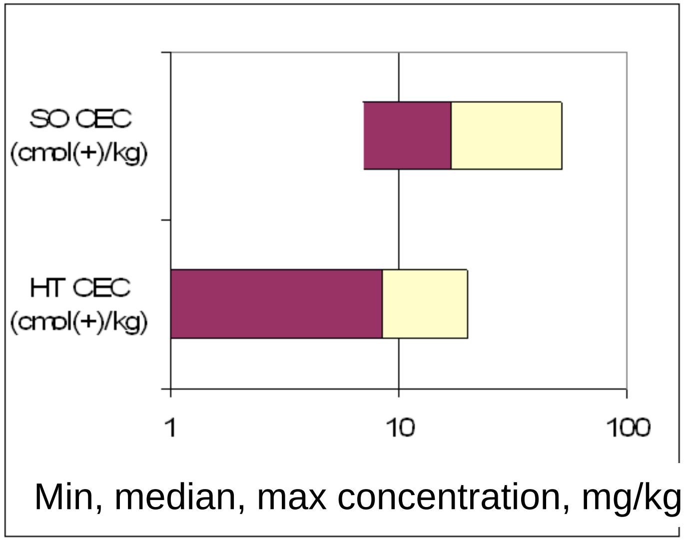
GROUNDWATER QUALITY
Hunter's Trace Basin

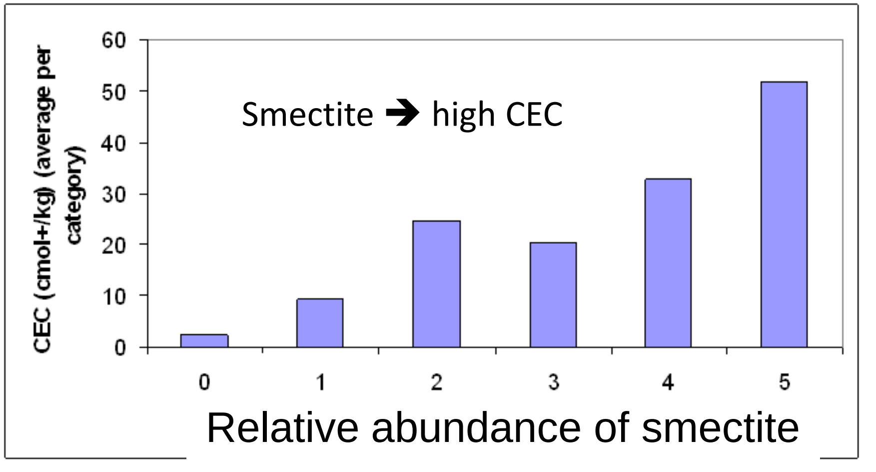
- N nearly exclusively in NO_3^- form
- Aerobic, DO 5–8 mg/L
- Low DOC 0.5–1.0 mg/l
- Cl and NO_3^- variations very similar (r^2 = 0.64 for M-0506) suggests ***advection***-dominated N fate



SOIL ANALYSIS – Chemistry

- CEC higher at South Oak
- Higher CEC than typical Florida soils, likely due to prevalence of clay mineral smectite





Site Comparisons

Hunters Trace (HT)	Parameter	South Oak (SO)
Lower	Water Table	**Higher**
Higher	Infiltration Rate	**Lower**
Lower	Clay soils	**Higher**
Lower	CEC	**Higher**
Higher	DO	**Lower**
Lower	Alkalinity	**Higher**
Lower	Organic Carbon	**Higher**
Higher	Nitrate	**Lower**
No	Nitrate Decline with Time	**Yes**

DENITRIFICATION SUMMARY

The four conditions required for denitrification are:

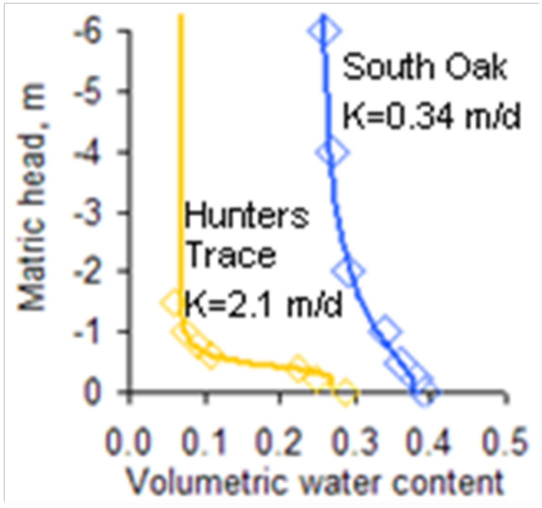
(1) Nitrate present (electron acceptor);
(2) Oxygen very low or absent;
(3) Electron donor present (typically an organic carbon compound); and
(4) Denitrifying bacteria present.

- Conditions 2, 3, and 4 exist at the SO basin, therefore when nitrate is present denitrification occurs rapidly.
- At the HT basin, data indicate condition 2 is the critical missing condition.
- Differing oxygen levels between the two basins likely are due to soil textural characteristics. The fine-textured soil at the SO basin retains moisture, thereby substantially *reducing oxygen transport* into the subsurface.

Soil Texture and Bio Chemical Properties

- Can we replicate the conditions at the SO basin at the HT basin?
  - Soil Moisture is the primary goal.
  - Reproduce the soil conditions found at SO at HT
  - Soil amendment that is economical.

Sample depth = 0.3 m



SOIL AMENDMENT SELECTION

Some Promising Recycle and Natural Options

- Florida Peat
- Sandy/Loamy/ Clayey soils
- Sawdust (untreated wood)
- Paper/Newspaper
- Palm Tree Frauds
- Tire Crumb
- Limestone
- Crushed Shells
- Wood Fiber/Chips/
- Compost

LABORATORY SOIL COLUMNS

- Test selected media mixtures to quantify their nutrient attenuation capabilities
- More closely resemble natural conditions than batch tests

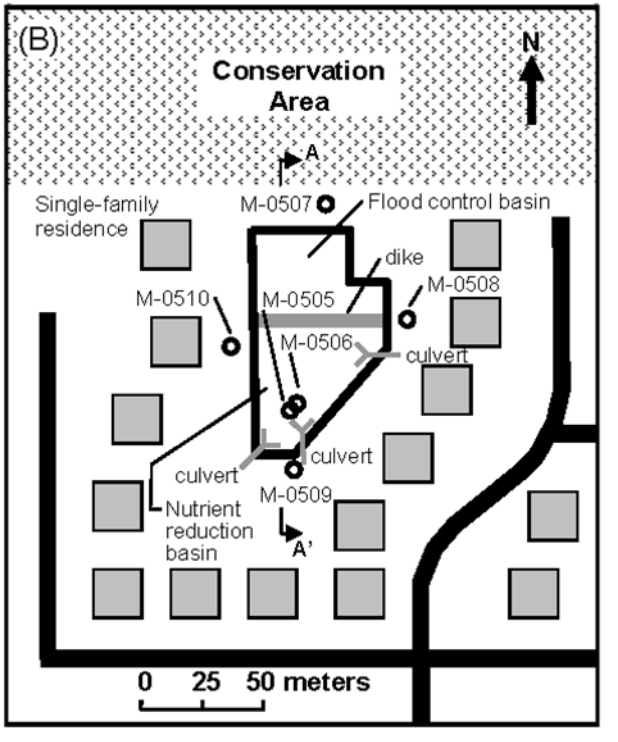
Amended Soils Basin Installation

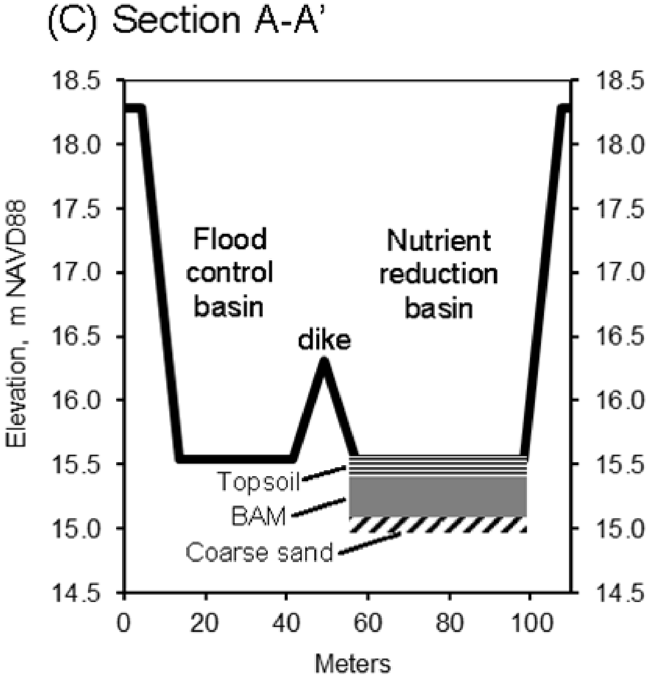
BAM was developed based on and to “mimic” the natural biogeochemical processes identified at SO Basin:

1. Excavation of native soil in the bottom of a portion of the HT existing basin.
2. Re-placement of a 1 foot (0.3 m) thick amended BAM soil layer: 1.0:1.9:4.1 mixture (by volume) of tire crumb (for sorption capacity), to clayey sand (for soil moisture retention); and sand (for infiltration rate).
3. Construction of a berm forming separate pollution (nutrient) control and flood control basins.
4. Cost was $6/SF of nutrient control area (not including permit and other related fees).

HUNTER'S TRACE – NEW BMP

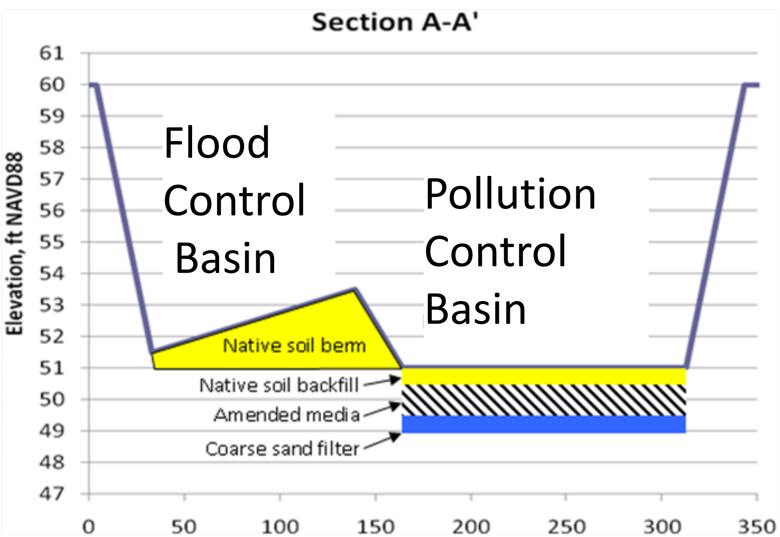
- Reproduce soil conditions that exist at the SO basin by using an amended soil layer (BAM):
  - Increase soil moisture thus
    - Reduce oxygen transport
    - Increase sorption capacity
    - encourage denitrifier growth

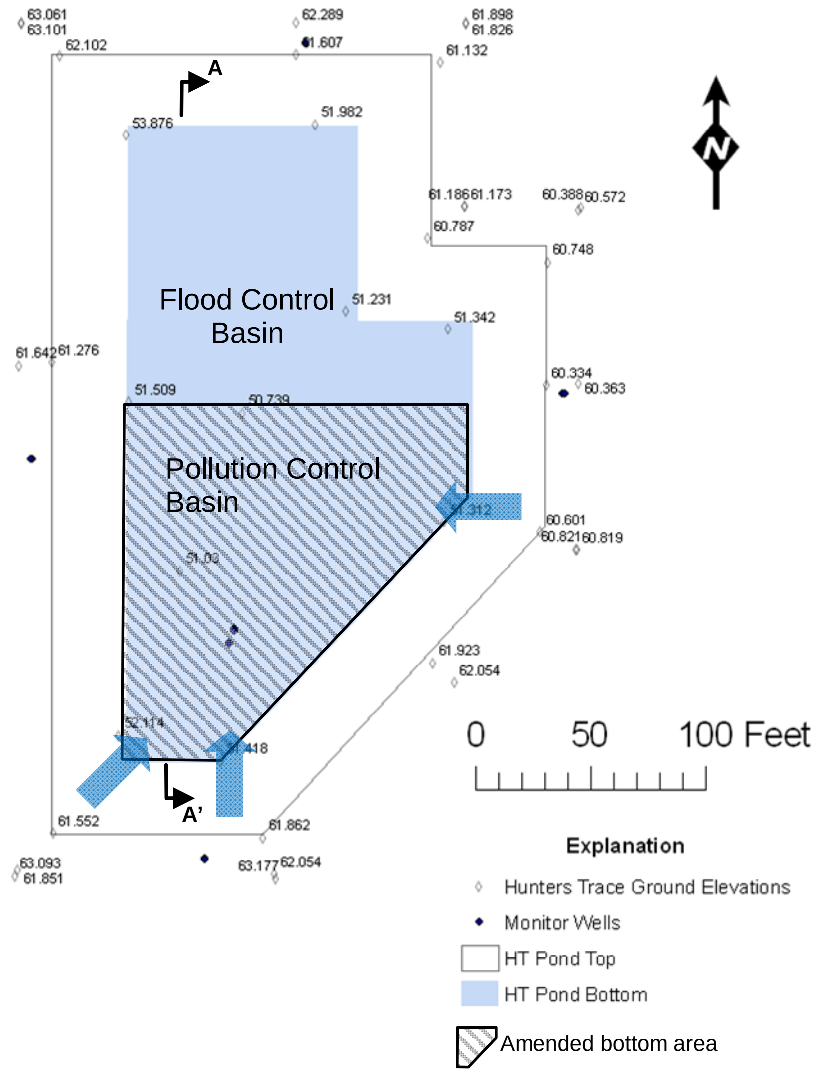




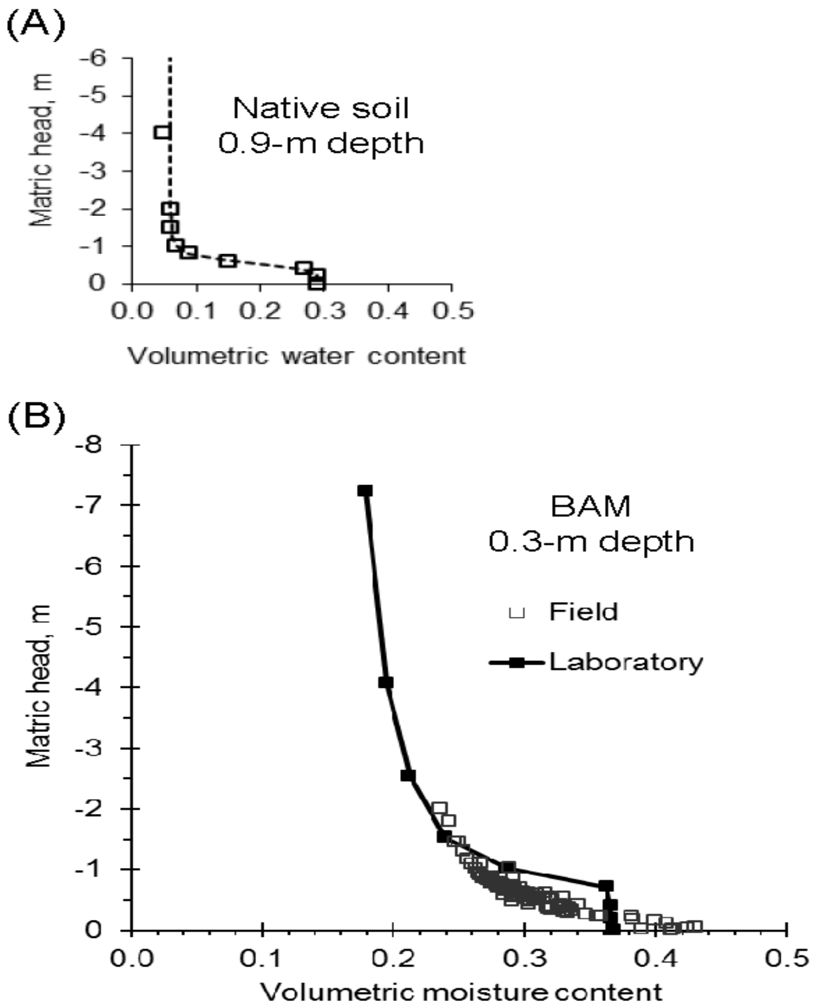
HUNTERS TRACE – NEW BMP

- Reproduce soil conditions that exist at the SO basin by using an amended soil layer:
  - Increase soil moisture
  - Reduce oxygen transport
  - Increase sorption capacity





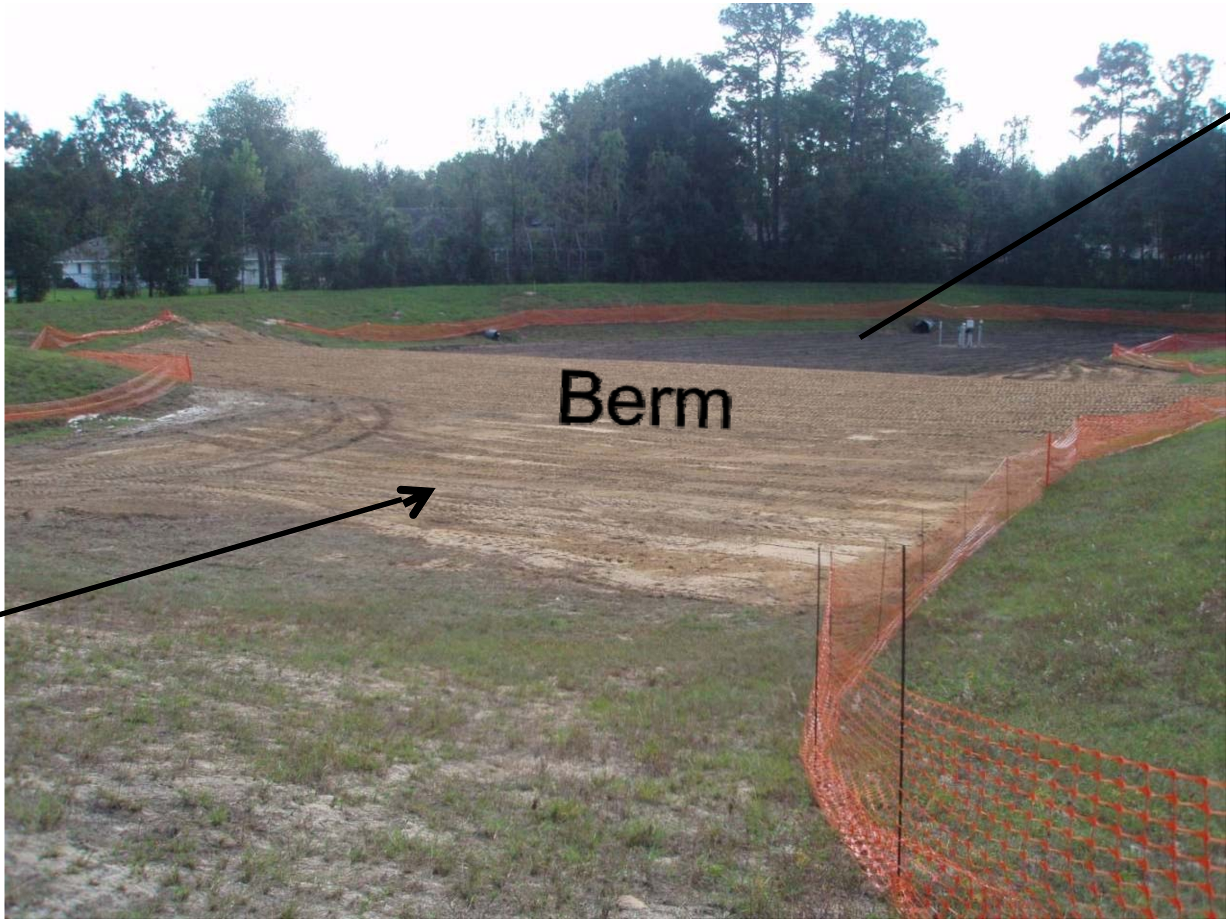
Before and After BAM at HT



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.

HUNTERS TRACE – NEW BMP



Nutrient Control Basin

Flood Control Basin

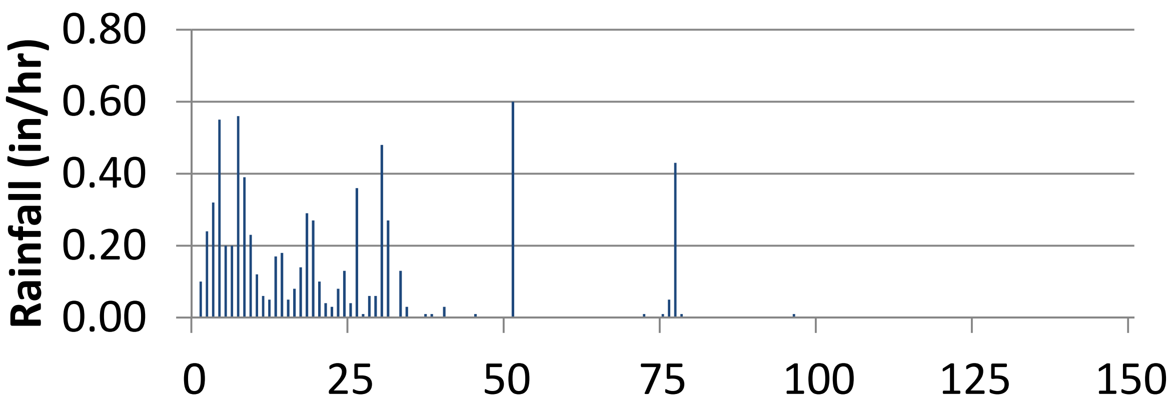
HUNTERS TRACE – Design Model Testing

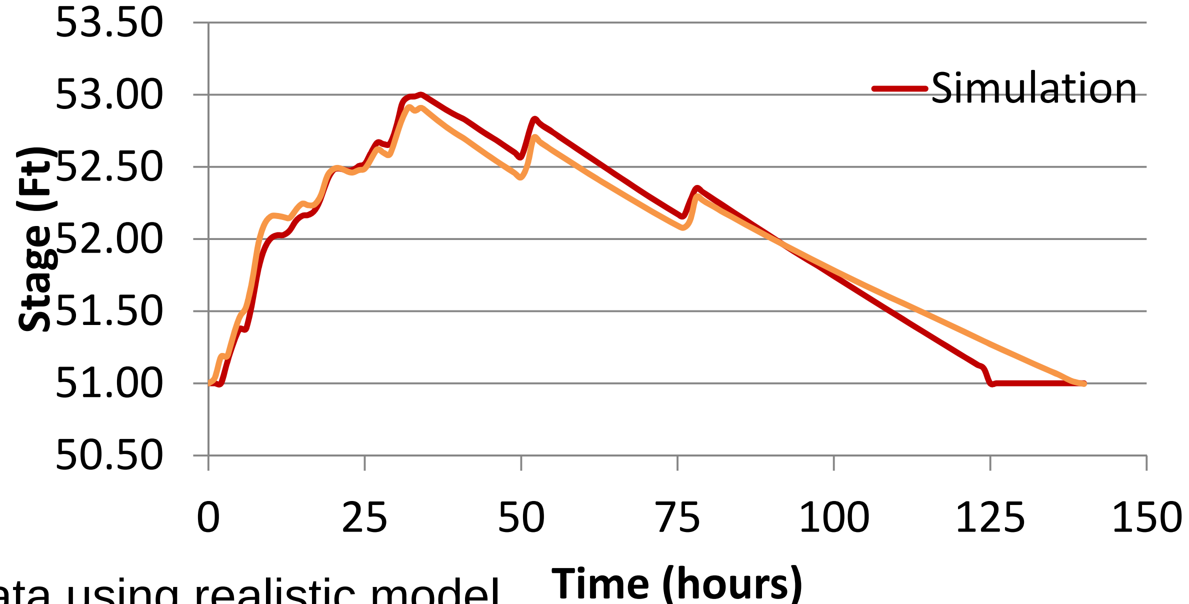
Simulate August 2008 Tropical Storm Fay event.

The EIA was 1.67 ha
(~20% larger than the DCIA)

Rainfall (inches)	7.30
Infiltration rate (ft/hr)	0.029
Early infiltration (ft/hr)	0.120

- Runoff/water-balance model:
  $R \times EIA - \text{Infil.} = \Delta\text{Storage}$

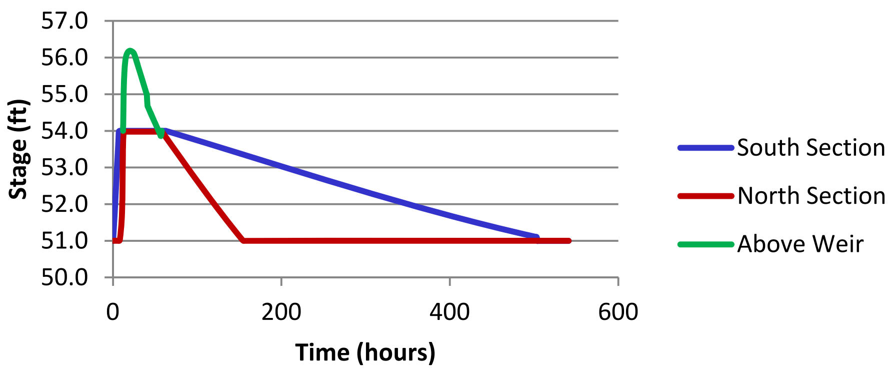


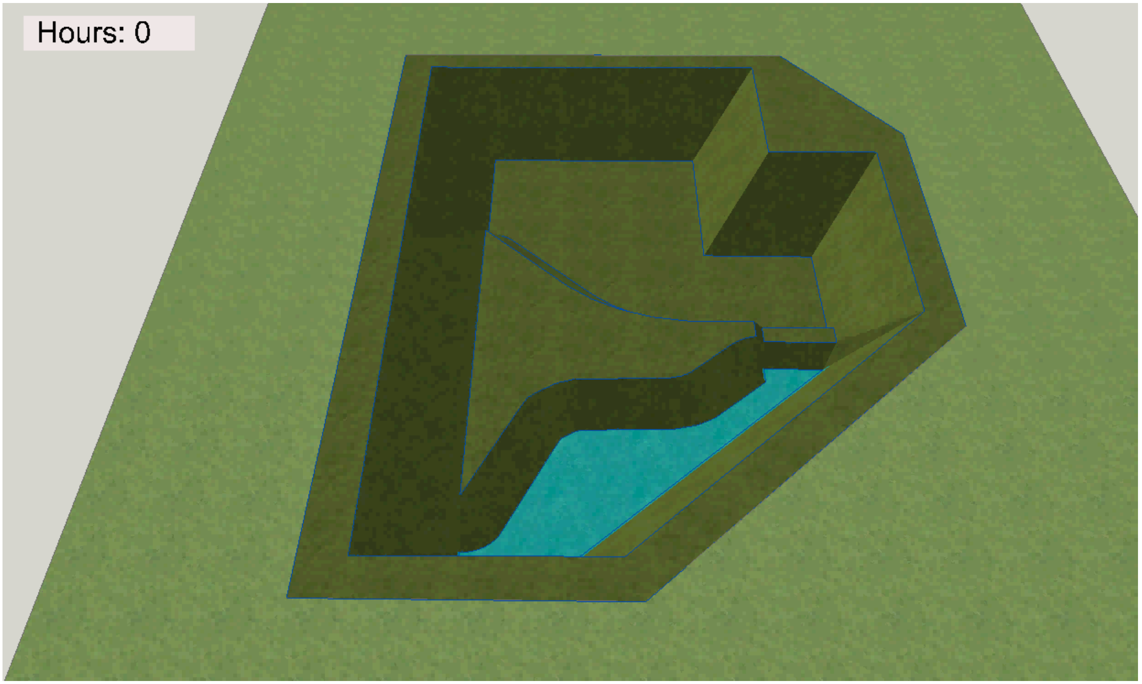


Good match to field data using realistic model parameters indicates model is suitable for design purposes.

HUNTERS TRACE – Design Simulation Modified Basin

- Simulate 100-yr (11-inch) 24-hr storm event (type 2)
- Peak stage = 56.2 ft
- Basin capacity was not exceeded up to a 26 inch 24-hr storm.





Operating Photo

After placement of erosion control blanket on berm and 3.7 inch storm

Flood Control Basin

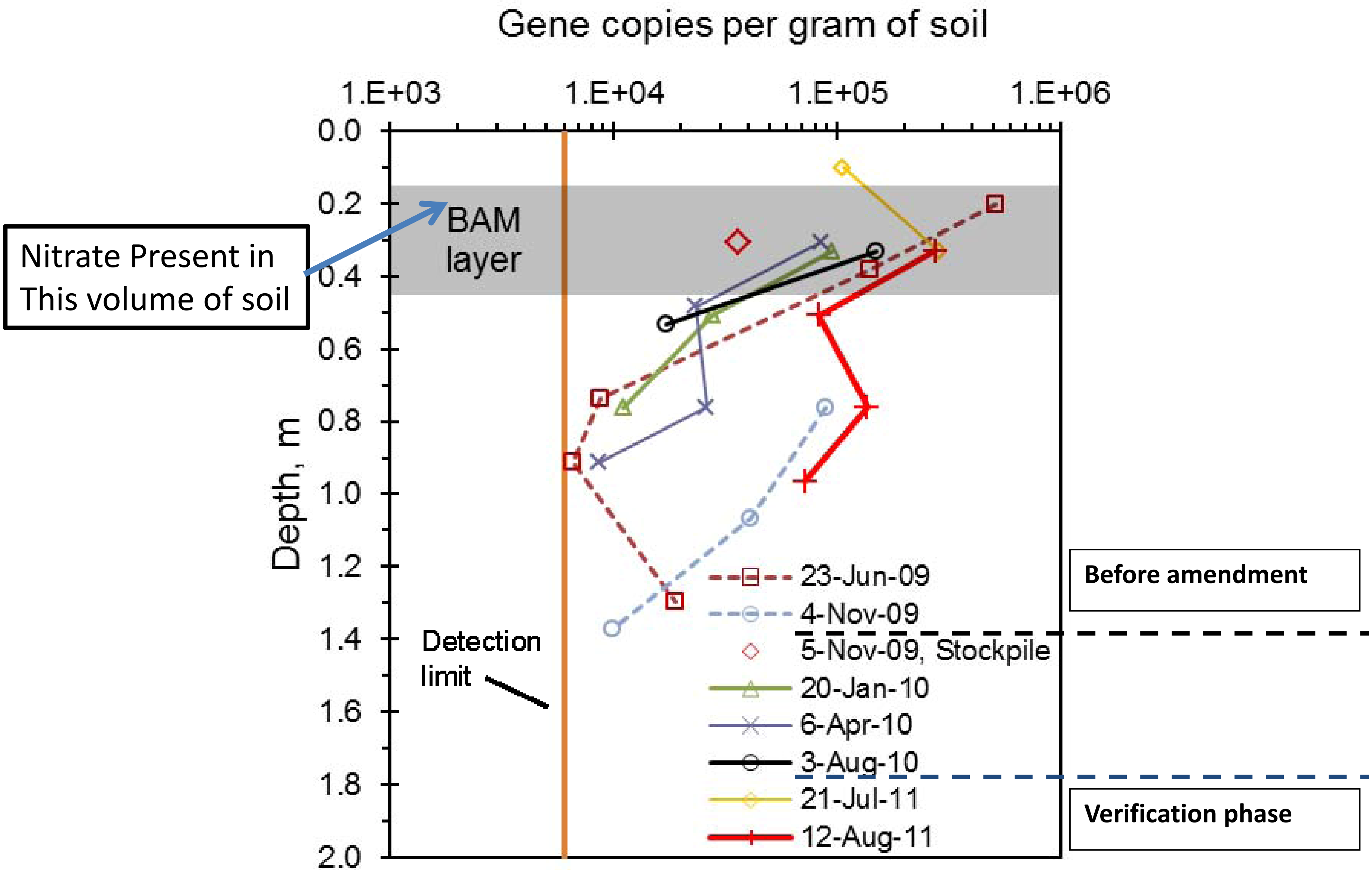
Nutrient or Pollution Control Basin

Limiting Infiltration Rates Double Ring and Operational

- SO Double Ring
  0.3 ft/hr (7.2 ft/day)
- SO Operational
  0.05 ft/day

- HT Double Ring
  1.1 ft/hr (26.4 ft/day)
- HT Operational 0.03 ft/hr or 0.35 in/hr or 0.72 ft/day

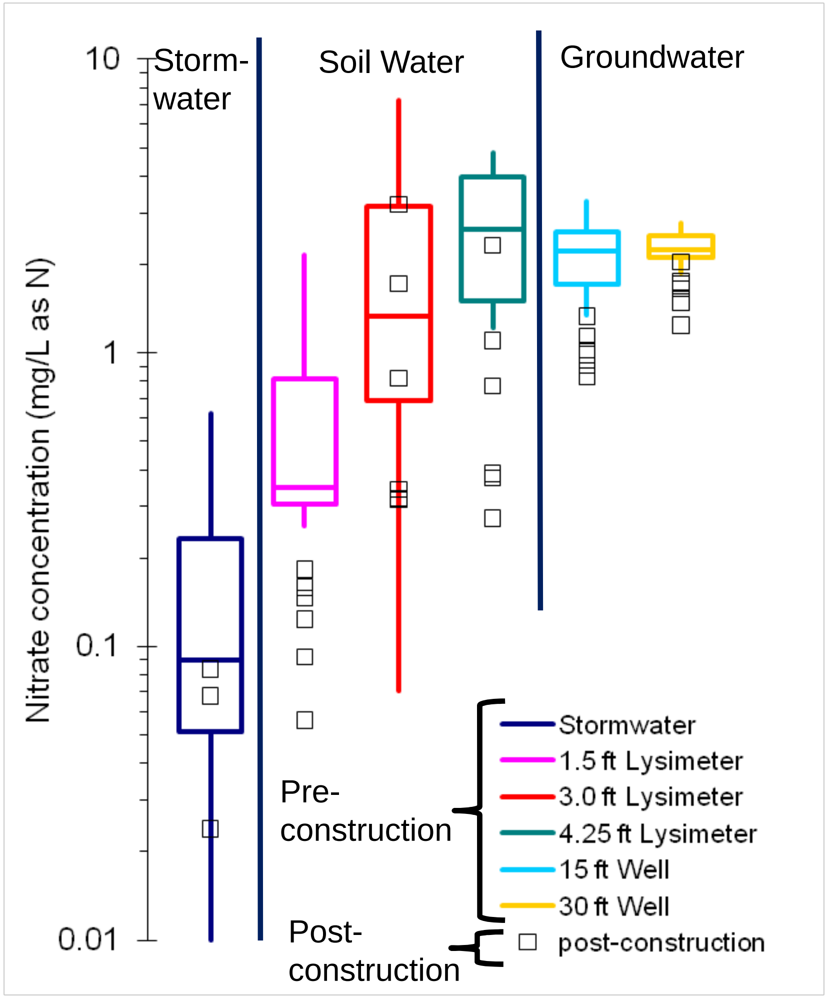
- After BAM Operational
  0.26-0.44 in/hr
  (0.52 – 0.88 ft/day)



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

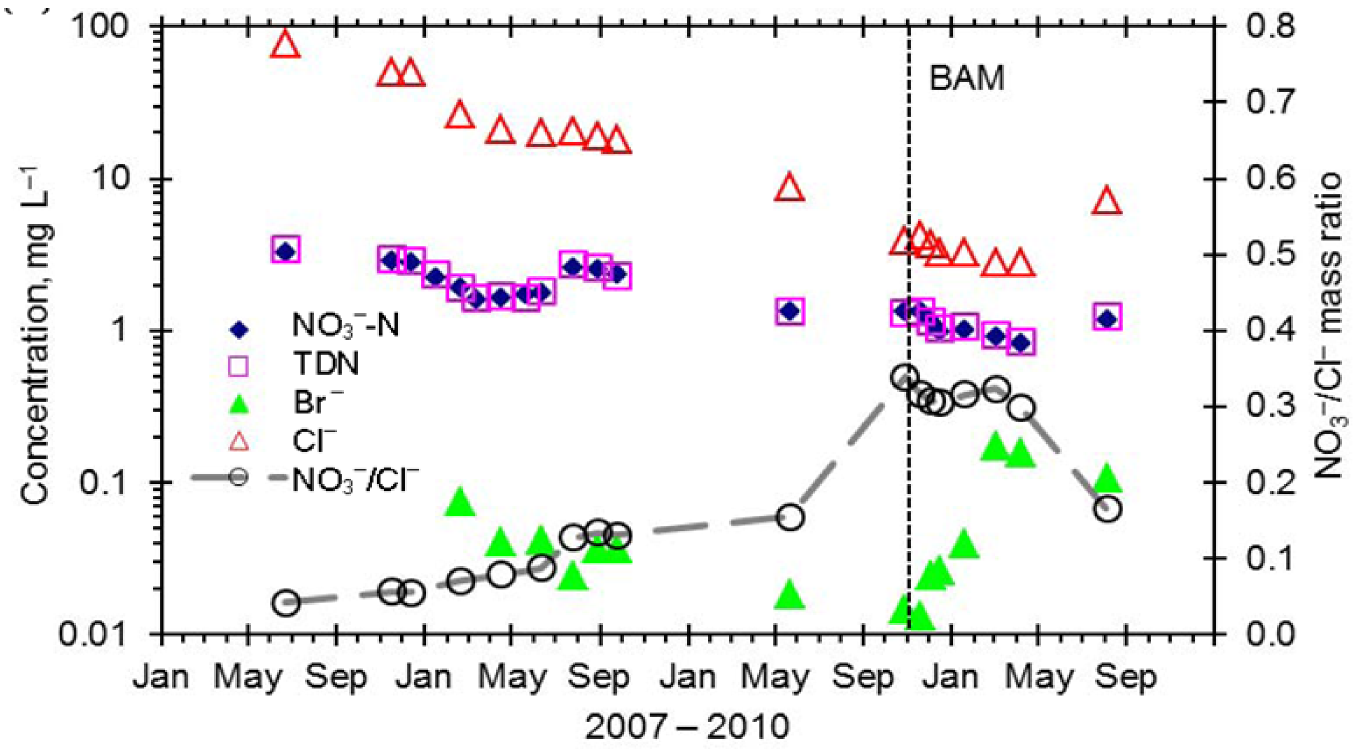
After BAM – Nitrate

- 50-80% reductions in nitrate from pre-construction (2007-2009) to post-construction (2009-2010) median concentrations in soil water and at the water table.
- Nitrate decreases most likely due to dilution, sorption, reduced nitrification, denitrification, or some combination of these processes.



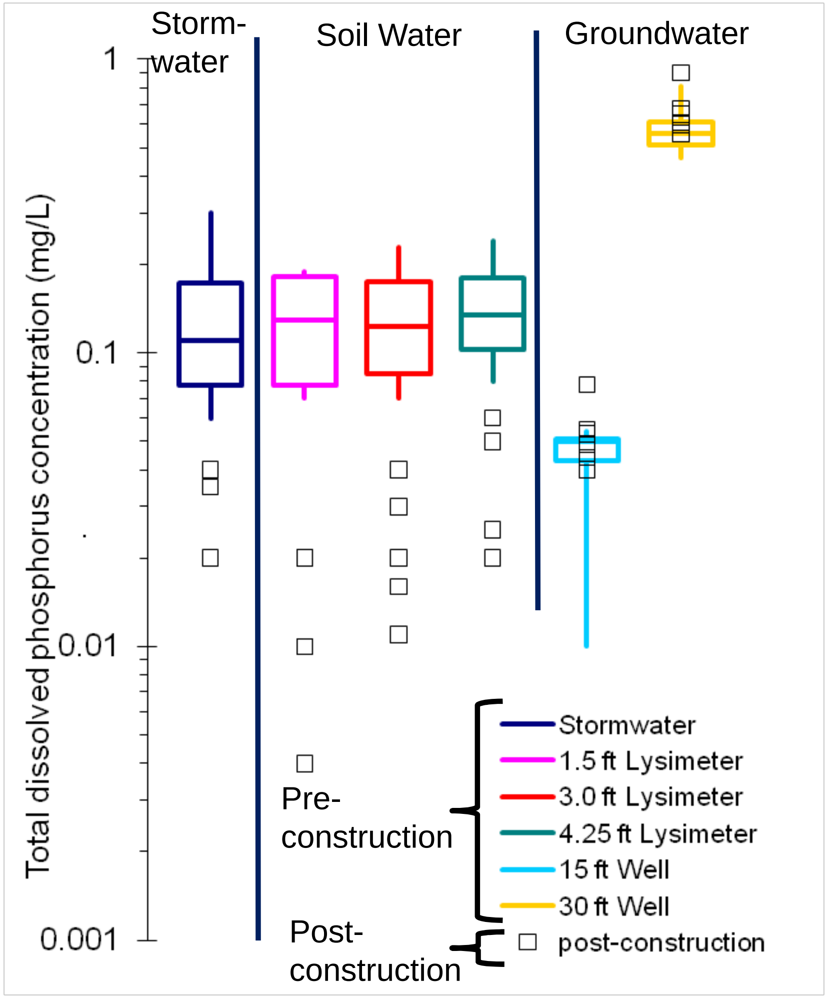
After BAM – NO_3^-/Cl^- Ratios

- 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 (no denitrification)
- Negative slope (post BAM indicates NO_3^- reduction (possibly denitrification)



After BAM– Phosphorus

- 70–90% reductions in total dissolved phosphorus (TDP) from pre-construction (2007–2009) to post-construction (2009–2010) median concentrations in soil water
- No change in TDP at water table.
- TDP decreases may be due to dilution, sorption, precipitation, microbial assimilation, or some combination of these processes
- ortho-P > 80% TDP, total P (unfiltered) is ~1–10x TDP



CONCLUSIONS

- Fine-textured soil controls surface/subsurface oxygen exchange by maintaining elevated moisture content, thereby controlling biogeochemical processes.
- Implementation of a modified infiltration basin using BAM resulted in decreased nitrate concentrations and is expected to be a viable alternative for improving and protecting groundwater quality.
- Examination of major elements, isotopes, dissolved gas, soil chemistry, real-time PCR, and soil gas sampling results provide greater insight into the biogeochemical processes controlling nitrate fate and the environmental and cost effectiveness of the new basin with BAM.

Recommendations in general or for other retention sites

- For infiltration basins or areas, use soil media mixes that can remove nutrients in areas where the parent soils are not capable of doing so.
- The soil mix should include materials to insure high moisture content. Or how come my system works? It has BAM in it.

Thanks for the Opportunity
~ Questions ~

“Swirling Currents of Water Quality Regulations"

Performance of a Bio-Retention System Or How Come My Bio-Retention System Works?

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Thank You and Discussion

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