THE EFFECTIVENESS OF BIOSORPTION ACTIVATED MEDIA (BAM) TO REDUCE NITRATE AND ORTHOPHOSPHATE IN STORMWATER RUNOFF
PART 1: Literature and Laboratory Results

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Why?

- Some groundwater and surface water supplies are decreasing in quantity and quality
- Stormwater runoff- medium of transport for nutrients and pollutants
- Stormwater runoff may impair groundwater and surface water

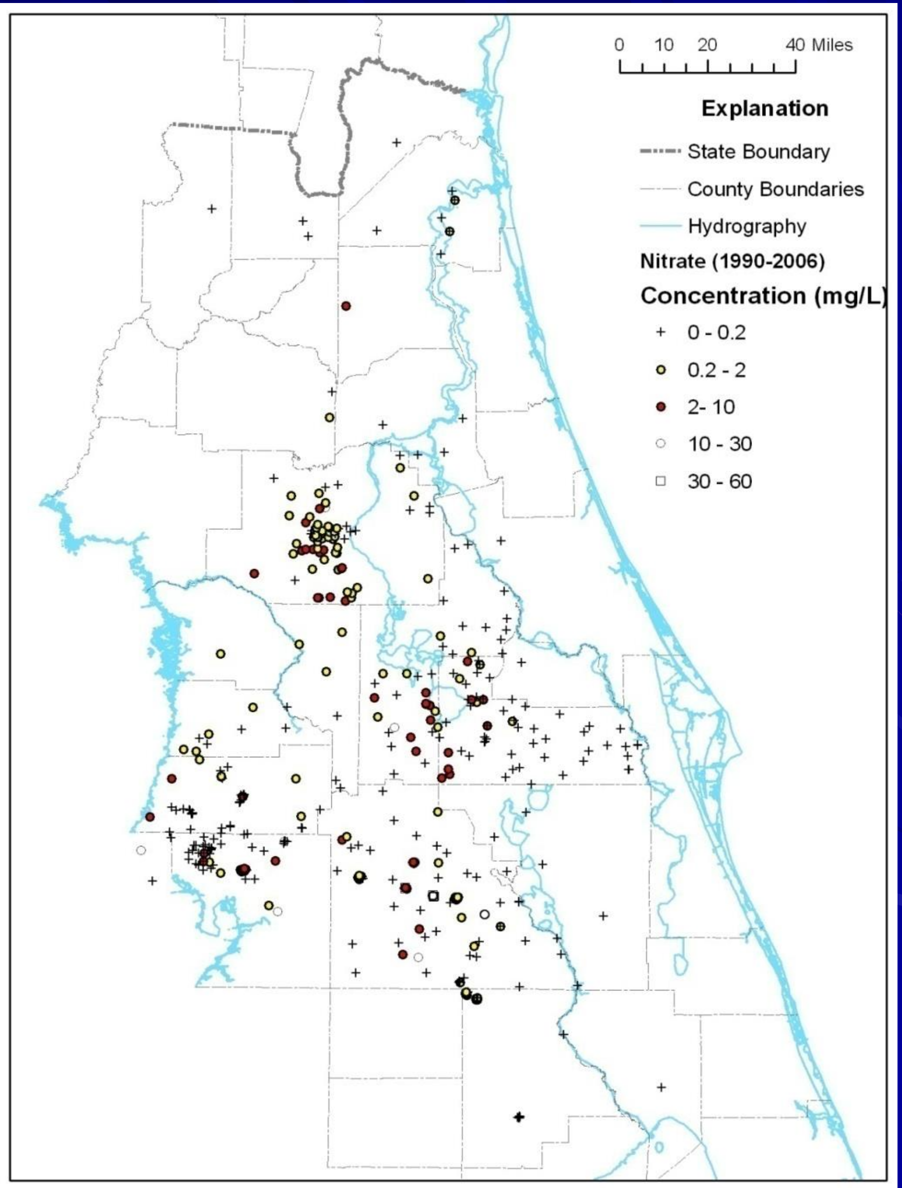
Why?

- Nitrate concentrations in Florida springs have been increasing for 50 years (USGS, 2008)

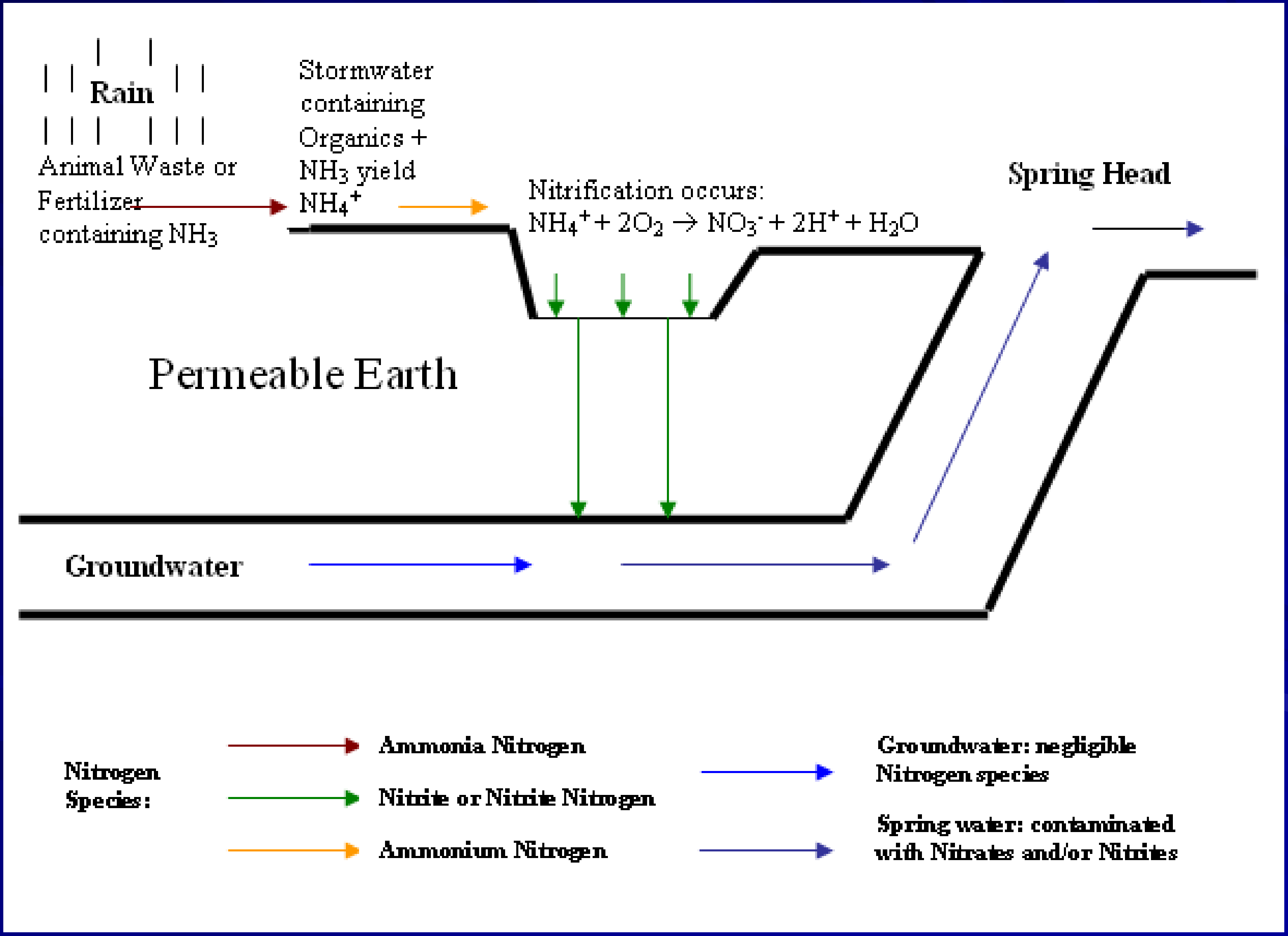
- Nitrate in Silver Springs has increased from 0.5 mg/L NO_3-N (1960) to 1.0 mg/L NO_3-N (2003) (Phelps, 2004)

Why?

- Springs and lakes are currently suffering from reduced water quality caused by excess nutrients
- Elevated nutrient levels are responsible for approximately 45% of lakes and streams listed as impaired by the FDEP



Nitrogen: One possible pathway



Problems

- Stormwater runoff and infiltration provides excess nutrients to lakes, rivers, springs and streams which may lead to Eutrophication
- Algal Growth, degraded aesthetics, lower water quality

Objectives

- Reduction of Nitrate and Phosphorus entering ground water and surface waters
- Reduction of Nitrate and Phosphorus in stormwater runoff
- Reduction of Nitrate and Phosphorus by specifically designed stormwater Biosorption Activated Media filter(BAM)

Background Information

- Nitrogen Removal: typical are filtration, and biological (such as: anammox and nit-denit facultative organisms).
- Nitrification and Denitrification

- Facilitated by bacteria usually attached to a solid
- Requires aerobic conditions for Nitrification
- Requires anaerobic conditions for Denitrification
- Requires an electron donor, examples C, CO_2 for nitrification, S, Fe, Mn
- Can exist for a long time period given proper conditions
- $NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$ (Gas)

Background Information

- Phosphorus Removal: typical are sorption, precipitation, ion exchange, and filtration.
- Sorption
- During infiltration Phosphorus tends to readily sorb onto many soils and media types (Crites, 1985)
- May be removed in either aerobic or anaerobic conditions
- Typically has a life expectancy

Objective

- Reduce Nitrogen (Nitrate) and Phosphorus (Orthophosphate) via BAM

- <u>4 Approached:</u>

  1. Literature Review
  2. Batch Test Experimentation
  3. Material Characterization
  4. Column Test Experimentation

Literature Review

- 32 different types of media were investigated to reduce Nitrogen and or Phosphorus within stormwater runoff (Moberg, 2008)

- Performance assessment of each potential media using Multi-criteria Decision Making

- Qualitatively and Quantitatively evaluated

Literature Review

- Multicriteria Decision Making:

1. Relevance (excellent, very good, good, fair, poor)
2. Permeability (High, medium, low)
3. Cost (High, medium, low)
4. Availability in Florida (yes, no)
5. Additional environmental benefit (yes, no)

Literature Review

- Top seven media from literature review move to the batch test
- Florida peat, sandy loam, woodchips, crushed oyster shell, crushed limestone, tire crumb and sawdust
- All selected media may sorb Phosphorus

No.	Sorption Media	Criteria 1		Criteria 2	Criteria 3	Criteria 4	Criteria 5	Overall*
		1a	1b					
1	Florida Peat	5	5	5	5	5	5	**5**
2	Alfalfa	3	3	1	1	0	5	2
3	Activated carbon	5	1	1	1	0	5	2
4	Carbon sand, Enretech sand, or sand	5	1	1	1	0	5	2
4a	Sandy Loam (SL), Loamy Sand (LS), and Sandy Clay Loam (SCL), Planting soil	5	5	3	5	5	5	**4.6**
5	Sawdust (untreated wood)	3	5	3	5	5	5	**4.4**
6	Lignocellulosic Materials/wheat straw	3	3	1	1	0	5	2
7	Tire Crumb /electron donor	4	5	3	3	5	5	**4.1**
8	Limestone/ electronic donor	2	5	1	5	5	5	**4.88**
8a	Crushed oyster/electronic donor	2	5	1	5	5	5	**4.88**
9	Wood fiber/wood chips/compost	3	4	1	5	5	5	**4.88**

Past Media Investigations:
to illustrate successful removal

- Previous experimentation with sawdust and woodchips has shown Nitrate removals of 95% (Kim, 2000)
- Sand, peat and lime rock column removed approximately 41% of the TP (Debusk, 1997)
- Porous reactive media barriers that consisted of sand, silt, sawdust, peat and gravel and sand achieved between 72% and 97% Nitrate removal (Robertson and Cherry, 1995)

Past Media Investigations:
to illustrate successful removal

- 89% to 96% reduction in ammonium and Nitrate within an infiltration bed comprised of sand and sawdust (Robertson, 1999)

- Average Nitrate removal of 80% for the sulfur/crushed oyster shell filter (Sengupta and Ergas, 2006)

Lab Batch Test Experimentation

- Aerobic conditions
- Denitrification is not possible within batch test experimentation
- Media performance is based on Orthophosphate (OP) and Ammonia Nitrogen removal
- Top performing media mixes for the 48 hour batch test move to column test experimentation

Batch Test Experimentation

- Results:

- Florida peat, woodchips and sawdust add substantial Ammonia Nitrogen to sample
- Cause and effect electron donor and nutrients
- Sawdust adds the least Ammonia
- Tire crumb substantially reduces Orthophosphate
- Crushed oyster shell added considerable Orthophosphate

Batch Test Experimentation

- Media Selection:

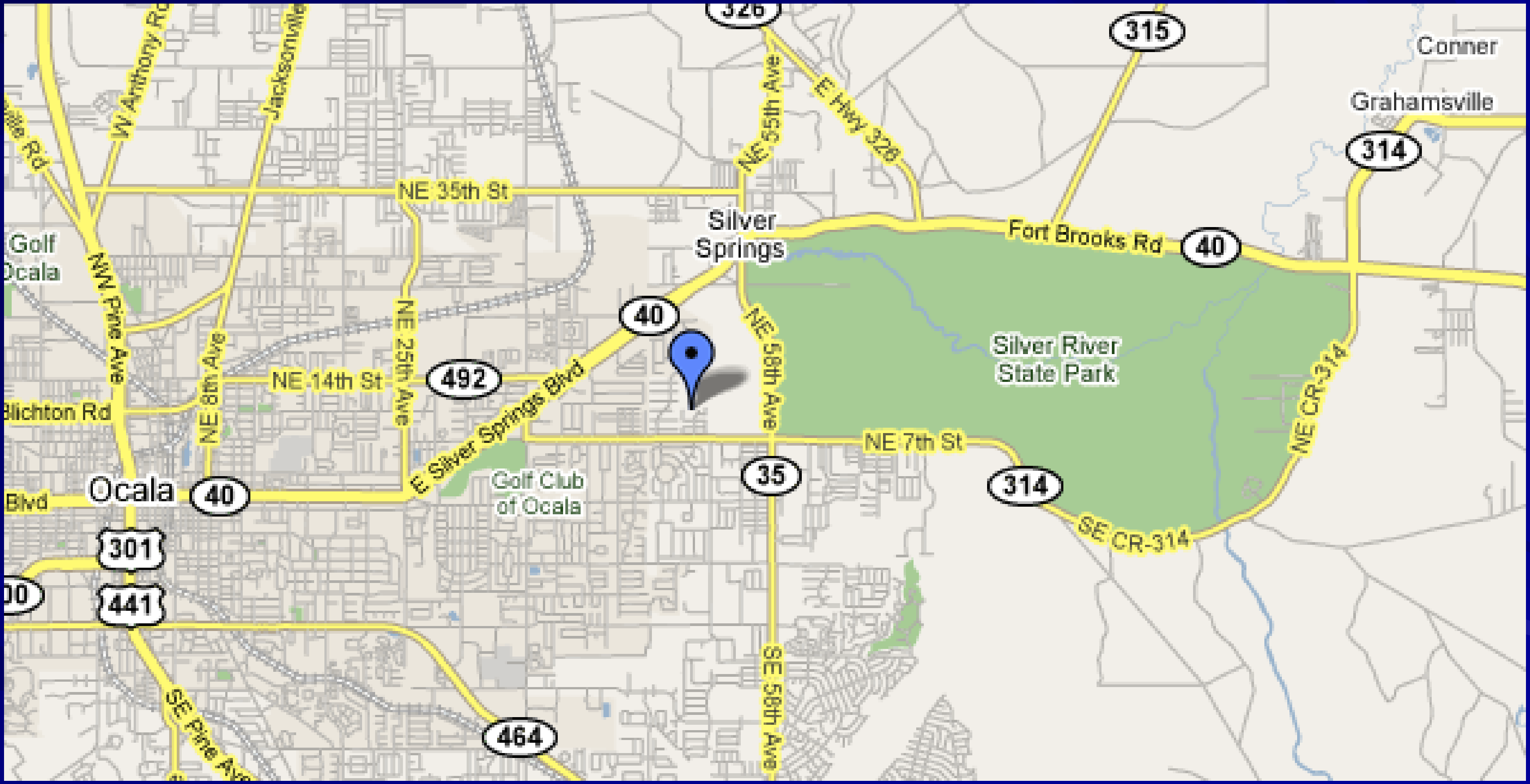
- Optimization of electron donor

- Media Mix 1: 50% sand, 30% tire crumb, 20% sawdust by weight

- Media Mix 2: 50% sand, 25% sawdust, 15% tire crumb, 10% limestone by weight

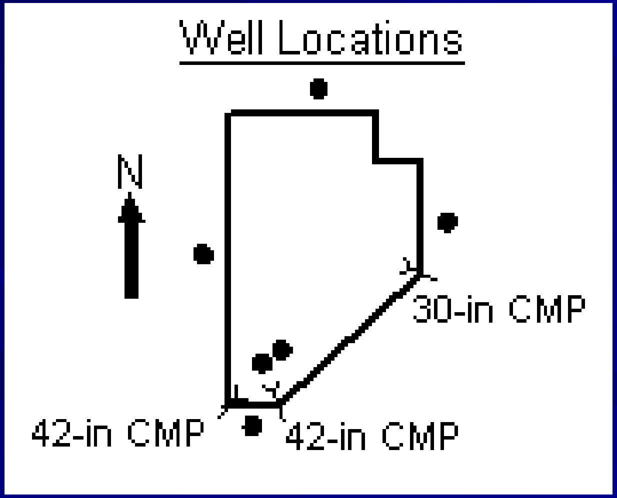
- Control: from Hunters Trace pond in Ocala, FL

Hunter's Trace Location



Hunter's Trace Pond

- ~ 0.8 ac
- 10 ft deep
- Water table ~10 ft below pond bottom



Materials Characterization

- ASTM D-421-85 Standard Practice for Dry Preparation of Soil Samples for Particle-Size Analysis

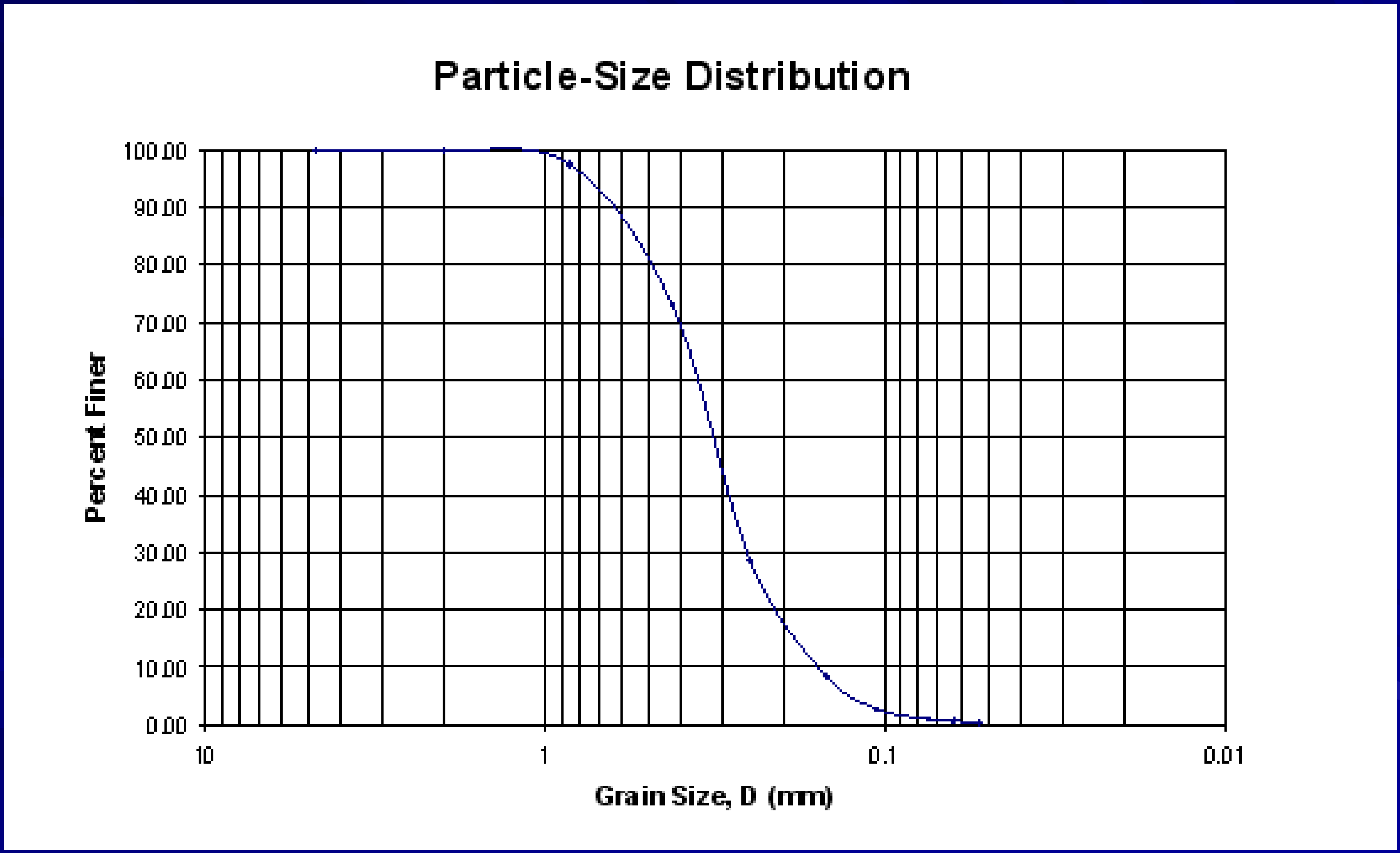
- ASTM C29/C29M-07 for measuring the bulk density ("unit weight")

- ASTM D-854-92 Standard Test Method for Specific Gravity of Soils

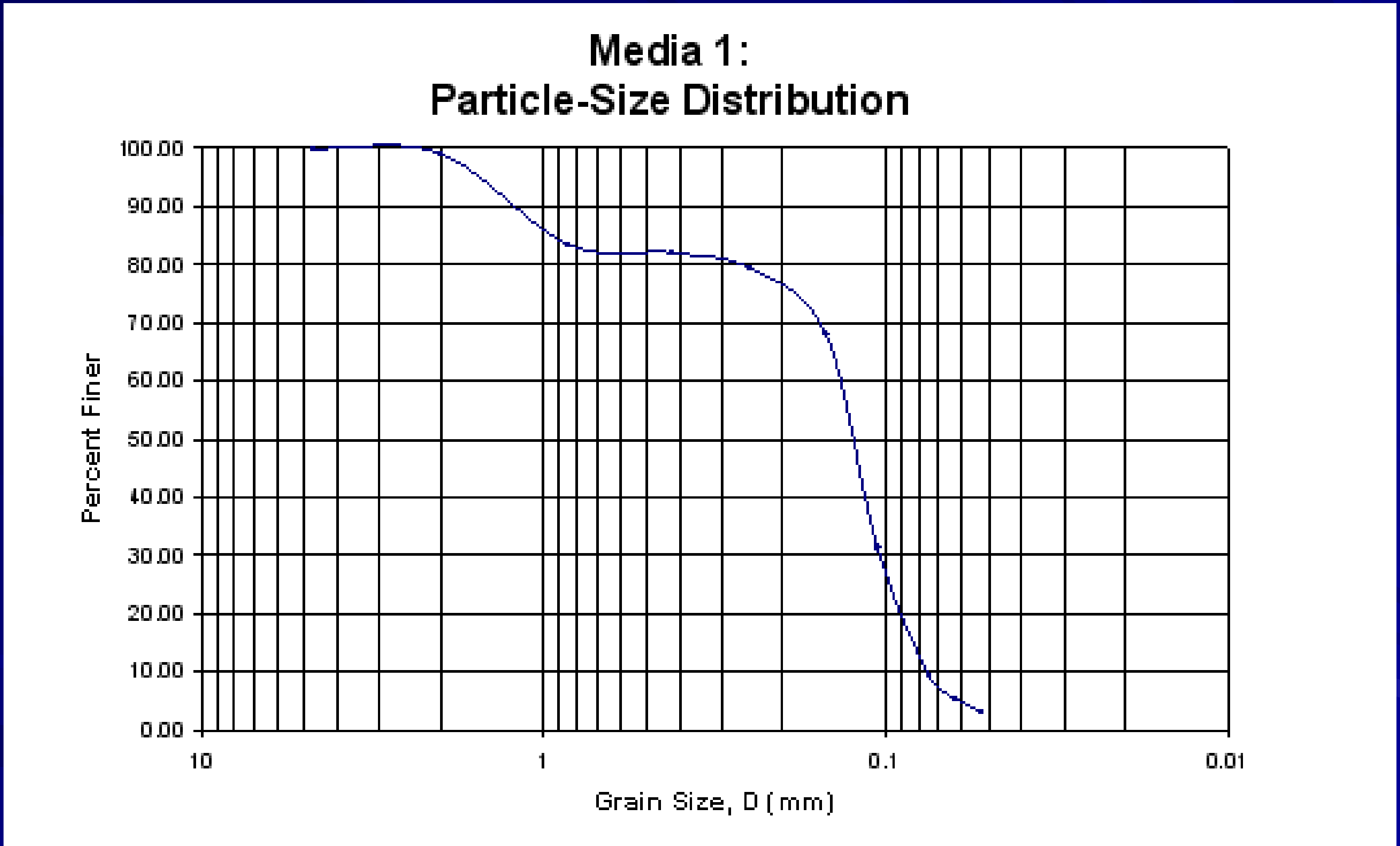
Material Characterization Summary

	Hunter's Trace (dry sample)	Hunter's Trace (moist sample)	Media Mix 1	Media Mix 2
Density (g/cm^3)	1.56	1.73	1.41	1.44
Void Ratio	0.67	0.51	0.56	0.62
Porosity	0.40	0.34	0.36	0.38
Specific Gravity (Gs)	2.62	2.62	2.19	2.33
Surface Area (m^2/g)	-	-	0.129	0.242
Permeability (cm/hr)	62.48	4.47	4.38	3.62

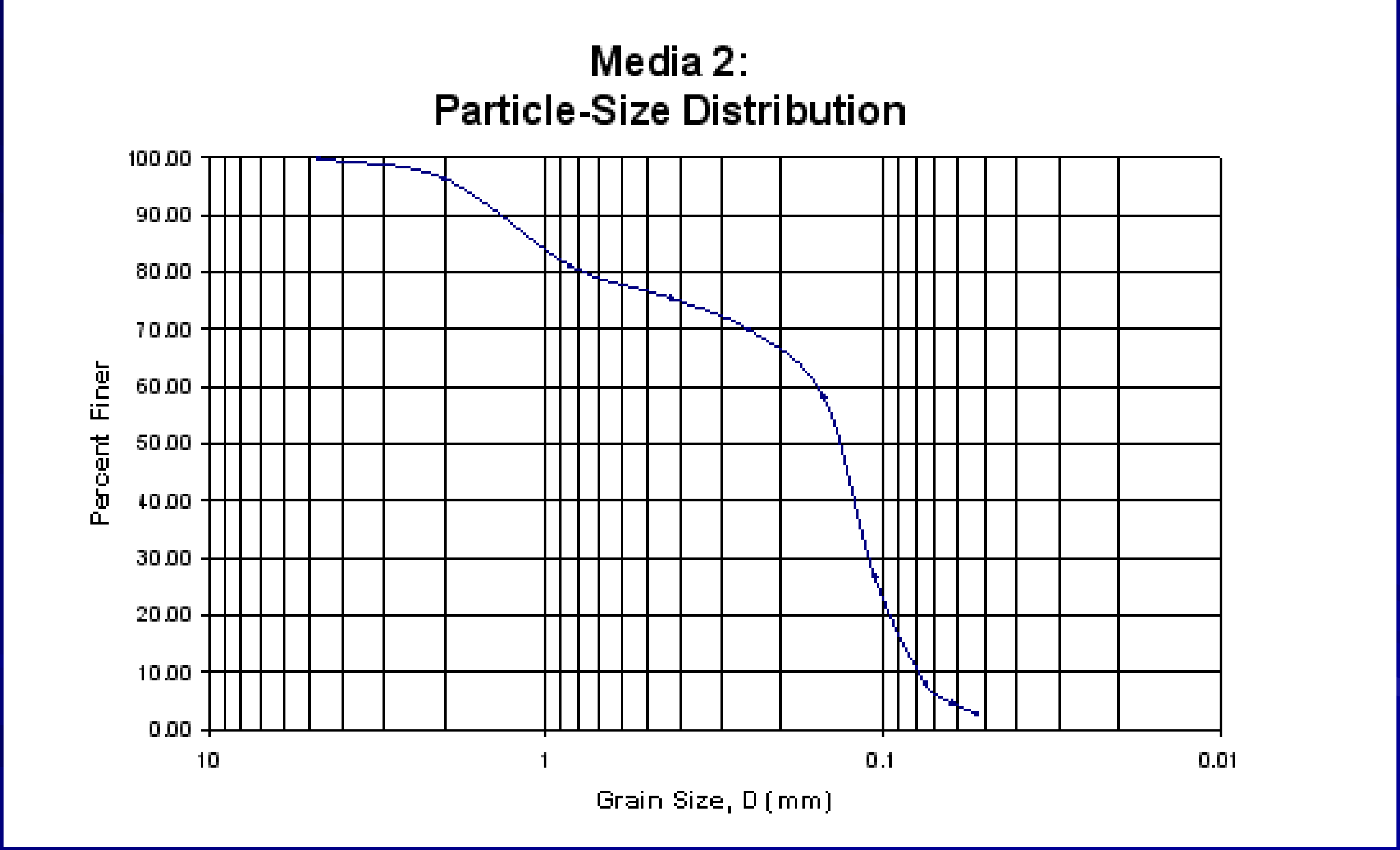
Gradation Curve: the soil in vadose zone at Hunters Trace site



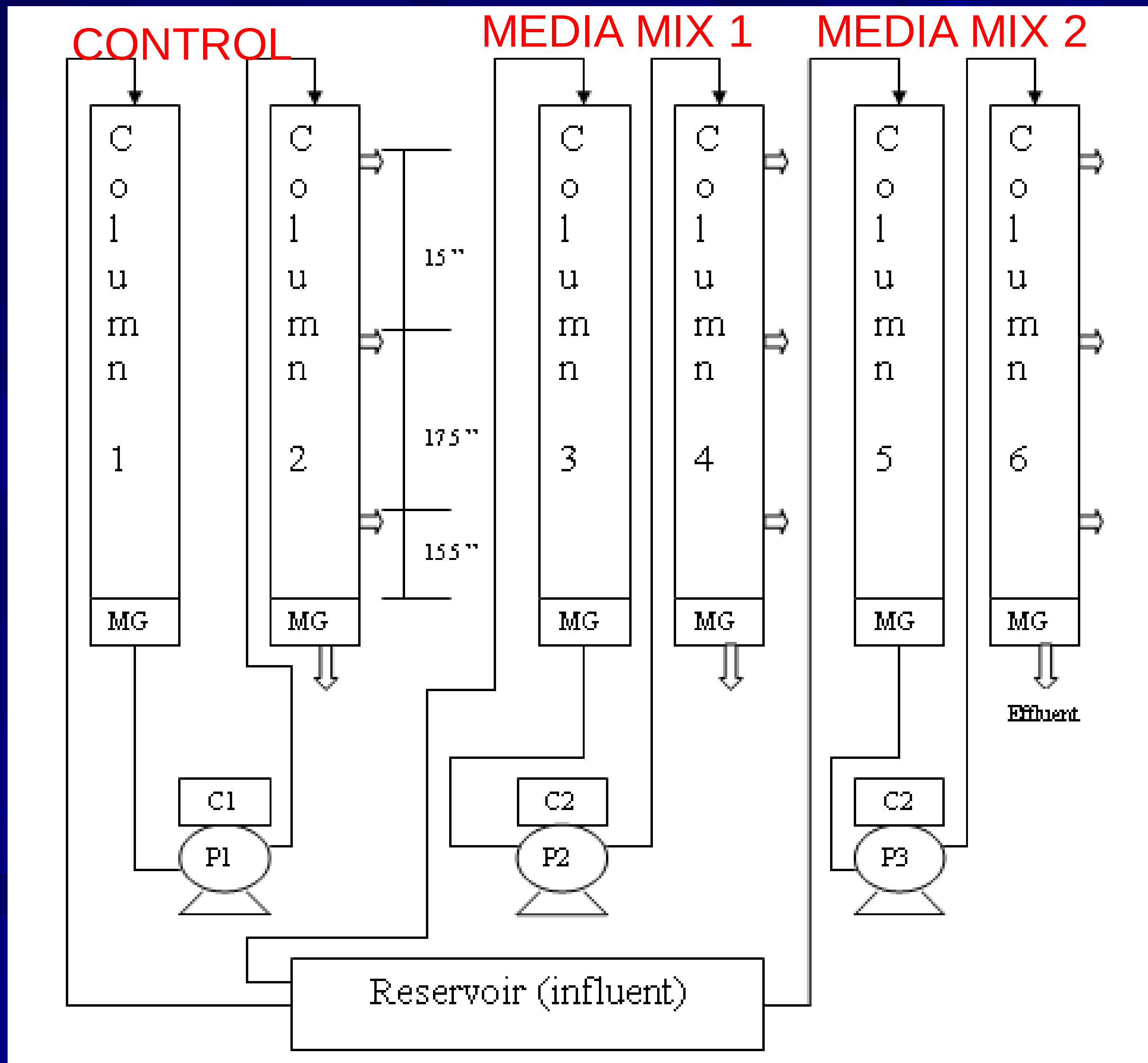
Gradation Curve: Media Mix 1



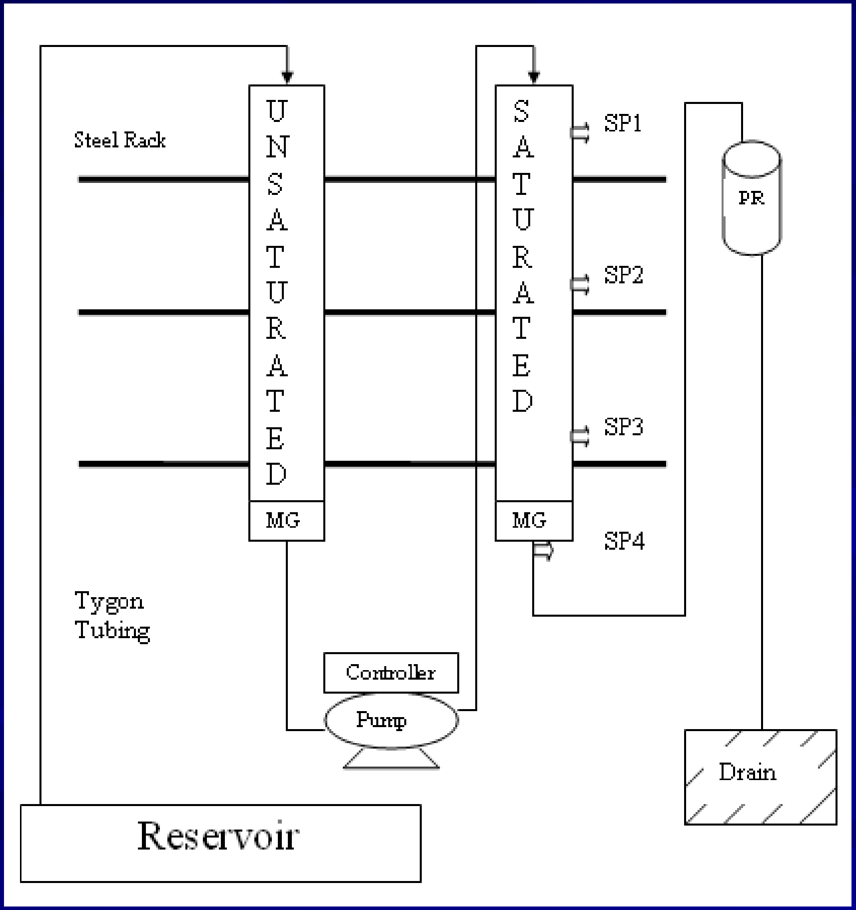
Gradation Curve: Media Mix 2



Six Column Test Setup



Column Test Setup



Column Test Experimentation

- Augmented stormwater Nitrate concentration: 0.38, 1.26, 2.53 mg/L NO_3-N
- Average land use Nitrate values: 1.24 - 3.1 mg/L NO_3-N (Pitt, 2004)
- Overall average Nitrate: 2.66 mg/L as NO_3-N (Pitt, 2004)

Column Test Experimentation

- Augmented stormwater Orthophosphate concentration 0.125, 0.361, 0.785 mg/L PO_4-P
- Average land use Orthophosphate values: 0.123 - 0.613 mg/L PO_4-P (Pitt, 2004)
- Overall average Orthophosphate 0.40 mg/L PO_4-P (Pitt, 2004)

Column Test Experimentation

- Column test flow rate 10mL per minute
- 1.38 inches per hour
- Typical retention basin infiltration 0.25 - 2 inches per hour (Wanielista, et.al. 2011)
- 3 runs for each Nitrate and Orthophosphate concentration

Overall Nitrate Reduction

Control Column 1,2	Initial Concentration (mg/L NO3-N) Top Column 1	Final Concentration (mg/L NO3-N) Bottom Column 2	Removal Efficiency (%)
Average n=3	0.382	0.233	38.9
Average n=3	1.269	0.380	70.0
Average n=3	2.529	1.529	39.5

MEDIA MIX 1

Media Mix 1 Column 3,4	Initial Concentration (mg/L NO3-N) Top Column 3	Final Concentration (mg/L NO3-N) Bottom Column 4	Removal Efficiency (%)
Average n=3	0.382	0.022	94.2
Average n=3	1.269	0.023	98.2
Average n=3	2.529	0.021	99.2

MEDIA MIX 2

Media Mix 2 Column 5,6	Initial Concentration (mg/L NO3-N) Top Column 5	Final Concentration (mg/L NO3-N) Bottom Column 6	Removal Efficiency (%)
Average n=3	0.382	0.023	94.1
Average n=3	1.269	0.024	98.1
Average n=3	2.529	0.023	99.1

Unsaturated Nitrate Changes

Control Column 1	Initial Concentration (mg/L NO3-N) Top Column 1	Final Concentration (mg/L NO3-N) Bottom Column 1	Removal Efficiency (%)
Average n=3	0.382	0.626	-63.9
Average n=3	1.269	1.868	-47.3
Average n=3	2.529	2.526	0.1
Control Column 3	Initial Concentration (mg/L NO3-N) Top Column 3	Final Concentration (mg/L NO3-N) Bottom Column 3	Removal Efficiency (%)
Average n=3	0.382	0.362	5.2
Average n=3	1.269	0.921	27.4
Average n=3	2.529	1.958	22.6
Control Column 5	Initial Concentration (mg/L NO3-N) Top Column 5	Final Concentration (mg/L NO3-N) Bottom Column 5	Removal Efficiency (%)
Average n=3	0.382	0.141	63.1
Average n=3	1.269	0.268	78.9
Average n=3	2.529	0.798	68.5

MEDIA MIX 1

MEDIA MIX 2

Saturated Nitrate Reduction:

DO concentrations at bottom of saturated columns 0.10- 0.19 mg/L

Control Column 2	Initial Concentration (mg/L NO3-N) Top Column 2	Final Concentration (mg/L NO3-N) Bottom Column 2	Removal Efficiency (%)
Average n=3	0.626	0.233	61.6
Average n=3	1.868	0.380	79.6
Average n=3	2.526	1.529	39.5

MEDIA MIX 1

Media Mix 1 Column 4	Initial Concentration (mg/L NO3-N) Top Column 4	Final Concentration (mg/L NO3-N) Bottom Column 4	Removal Efficiency (%)
Average n=3	0.362	0.022	93.9
Average n=3	0.921	0.023	97.4
Average n=3	1.958	0.021	98.9

MEDIA MIX 2

Media Mix 2 Column 6	Initial Concentration (mg/L NO3-N) Top Column 6	Final Concentration (mg/L NO3-N) Bottom Column 6	Removal Efficiency (%)
Average n=3	0.141	0.023	78.0
Average n=3	0.268	0.024	90.7
Average n=3	0.798	0.023	97.1

Overall Orthophosphate Reduction

Control Column 1,2	Initial Concentration (mg/L PO4-P) Top Column 1	Final Concentration (mg/L PO4-P) Bottom Column 2	Removal Efficiency (%)
Average n=3	0.125	0.304	-143.1
Average n=3	0.361	0.294	18.7
Average n=3	0.785	0.351	55.2

MEDIA MIX 1

Media Mix 1 Column 3,4	Initial Concentration (mg/L PO4-P) Top Column 3	Final Concentration (mg/L PO4-P) Bottom Column 4	Removal Efficiency (%)
Average n=3	0.125	0.061	51.2
Average n=3	0.361	0.050	86.1
Average n=3	0.785	0.068	91.4

MEDIA MIX 2

Media Mix 2 Column 5,6	Initial Concentration (mg/L PO4-P) Top Column 5	Final Concentration (mg/L PO4-P) Bottom Column 6	Removal Efficiency (%)
Average n=3	0.125	0.084	32.7
Average n=3	0.361	0.058	83.9
Average n=3	0.785	0.106	86.5

Literature Review and Lab Summary

- Literature Review
- Lab Batch Test Experimentation
- Material Characterization
- Lab Column Test Experimentation

Laboratory Conclusions

- Media Mix 1 and Media Mix 2 are more effective than the control for nutrient reduction
- Wet conditions are necessary for denitrification
- Biosorption media mixes may be used to manage nutrients.

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BAM PART 1 Literature and Laboratory

Questions and Comments

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Information abstracted from student theses, dissertations and refereed publications at UCF.