Common Mistakes in Selecting and Implementing BMPs in Florida – Lessons Learned from 40 Years of BMP Monitoring

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ERD
Water Quality Engineering

Introduction

- ERD has conducted ~ 45 sponsored research projects on BMPs
  - Research funded directly by FDEP
  - Projects involving certain grant funding sources require post construction monitoring to evaluate BMP performance

- Projects quantified physical, chemical, and biological processes in various BMPs
  - Identified factors impacting BMP performance
  - Allows predictions on BMP performance under a variety of conditions

Removal Efficiency Definition

- Removal efficiency refers to the mass (volume) of runoff prevented from reaching surface waters by a surface route
  - Ignores sub-surface loadings

Disclaimer

BMP Types Monitored by ERD

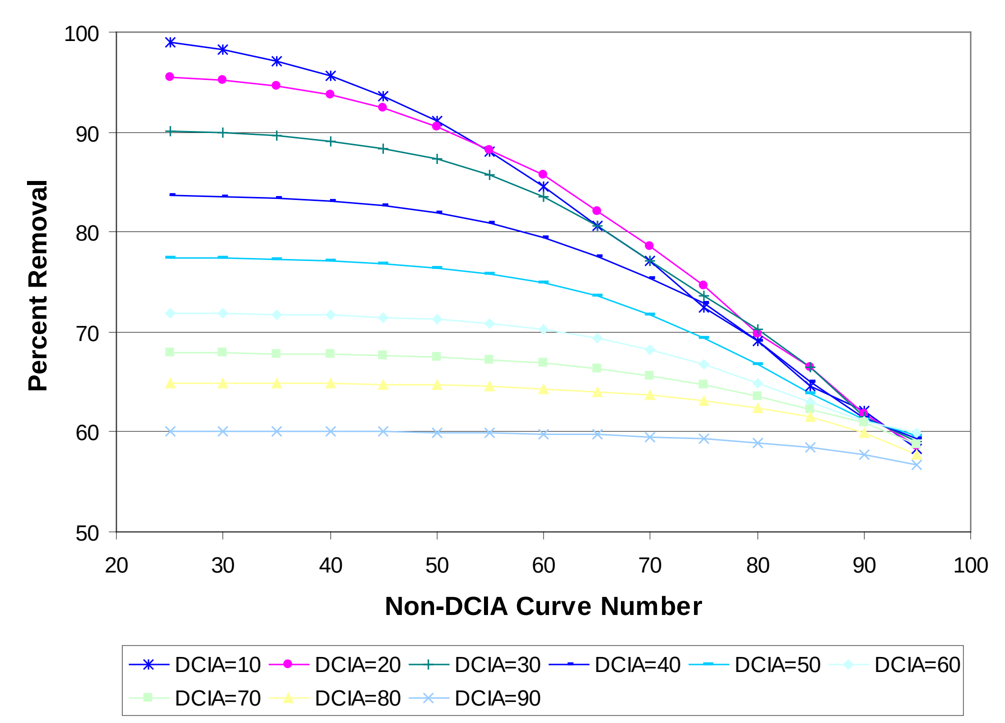
- Dry retention
  - Infiltration ponds
  - Underground chambers
  - Bottom underdrain systems
- Wet detention
  - Standard ponds with and without littoral vegetation
  - Ponds with outlet vegetation
- Gross Pollutant Separators
  - Standard baffle box
  - 2nd Generation baffle box
  - CDS Unit
  - Stormceptor
  - Ecosense – with and without outlet filter
  - Inlet baskets and filters
- Rain gardens
- Permeable pavers
- Alum treatment systems
  - Alum stormwater injection
  - Low dose alum addition
- Wetland treatment
- Vegetated treatment cells
- BAM media
- Floating wetlands
- Trickling filters
- Denitrification filters
- Treatment trains
- Swales
- “Magic” bacteria

1. Dry Retention

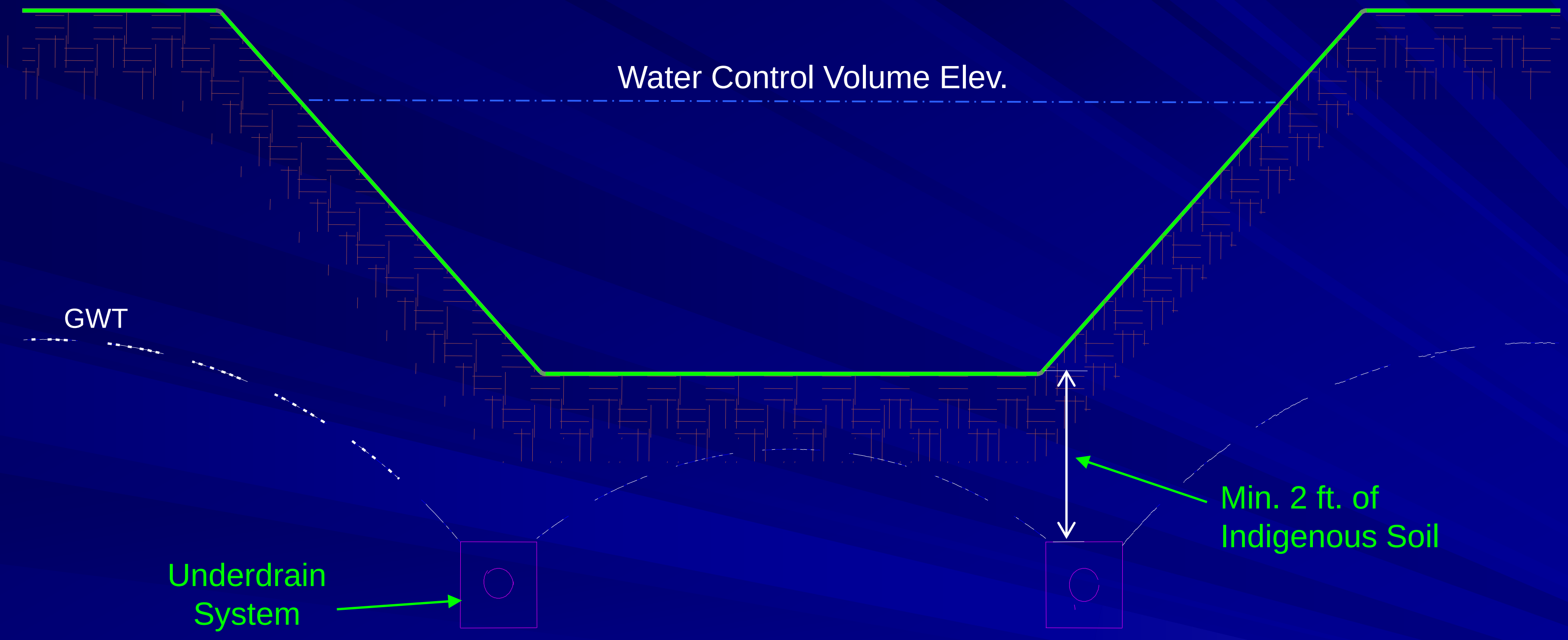
- Family of practices where the stormwater is disposed of by infiltration or evaporation rather than by surface discharge

Dry Retention Summary

- Observations
  - Highly predictable performance
  - Increases in infiltration rates provide only minimal enhancement
  - Infiltration and water table are key to performance
  - Transfers surface loading to groundwater
- Surface Ponds
  - Low maintenance
    - Generally limited to mowing and erosion control
    - Changes in vegetation can signal changes in infiltration
- Underground Systems
  - Moderate to high maintenance
  - Not suited for areas with high solids deposition
    - Residential areas
    - Landscaped parking areas
  - Water table critical to performance
  - Not suited for marginal soils



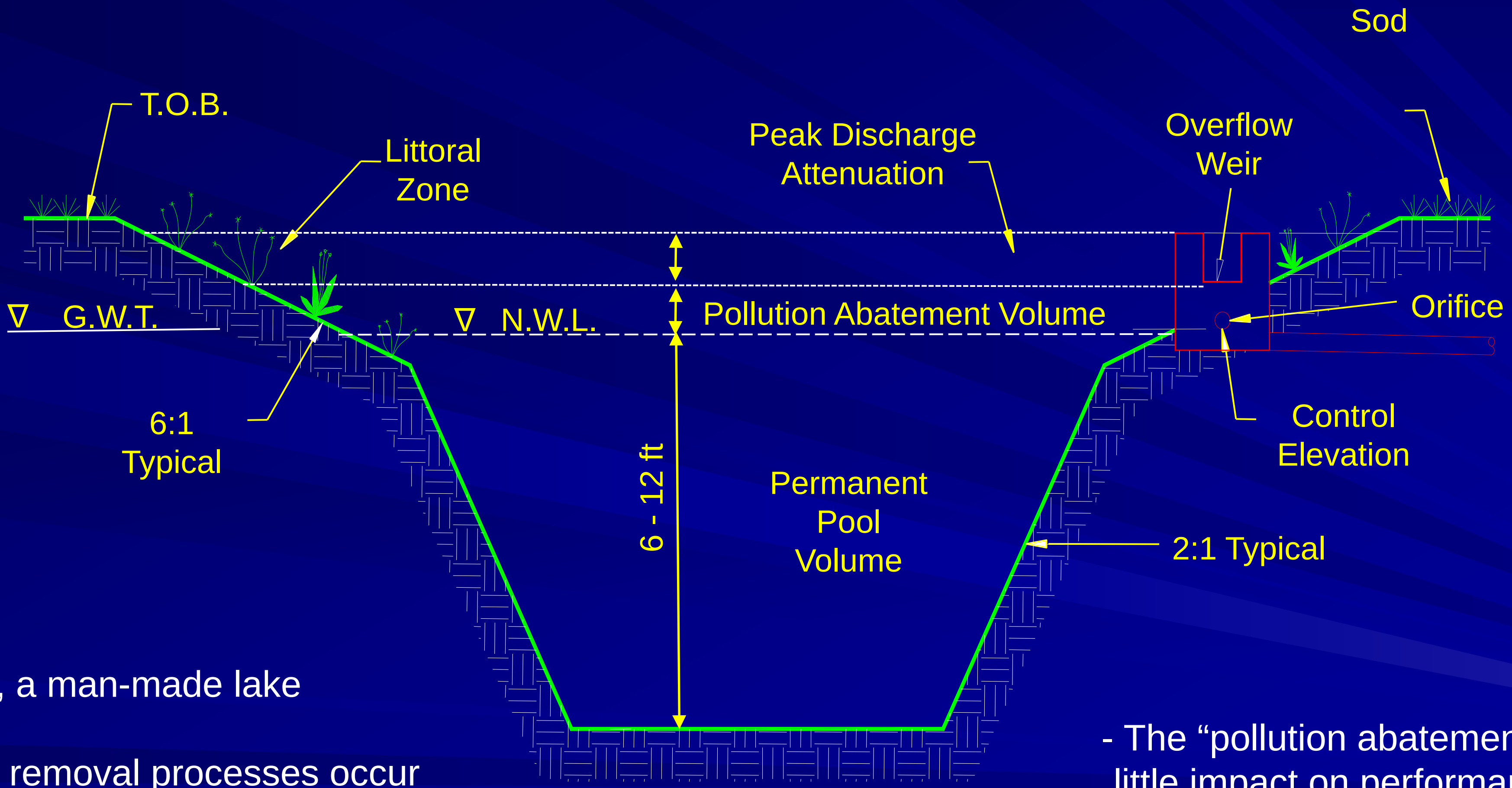
SJRWMD Underdrain Filtration Pond



- Pond in Orlando studies for 12-month period
- 76% of pond inflow discharged through the underdrain
- No change in concentration during movement through soils
- Effective removal efficiency of 24% - amount infiltrated but not captured by underdrain

2. Wet Detention

Wet Detention Pond



- Simply, a man-made lake

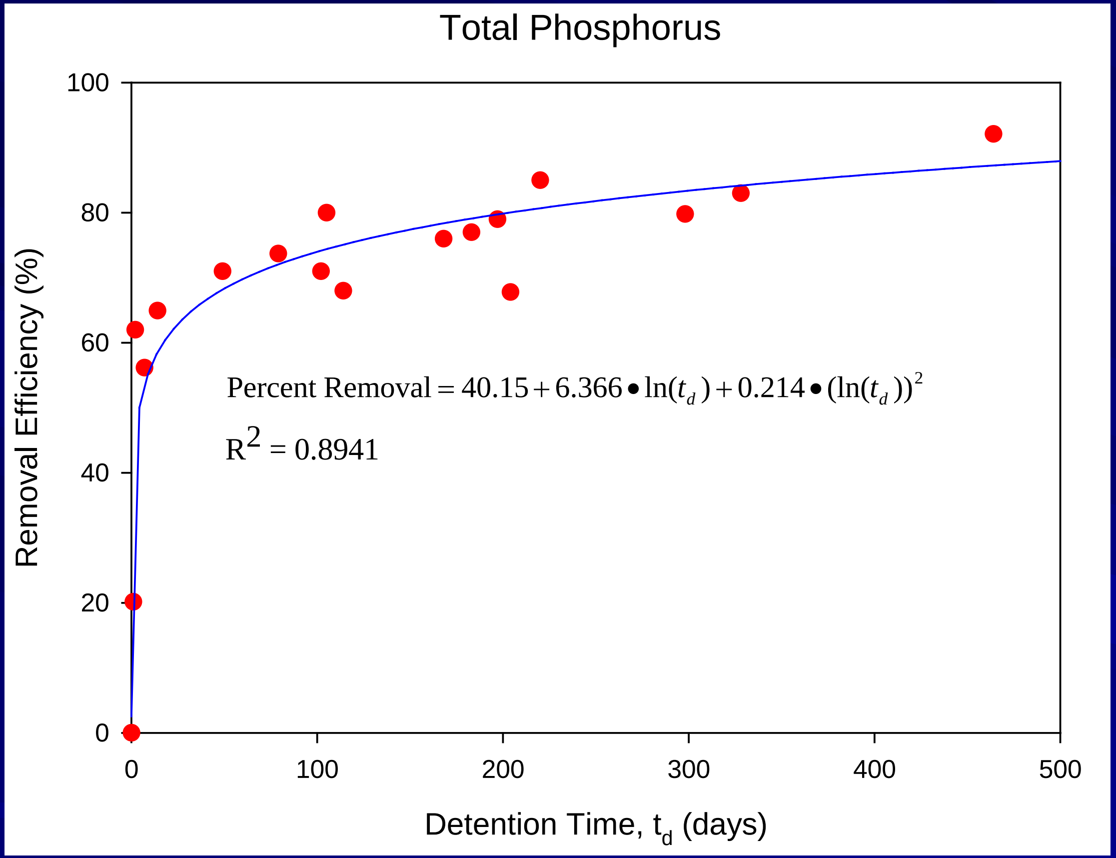
- Most pollutant removal processes occur within the permanent pool volume

- The “pollution abatement volume” has little impact on performance efficiency

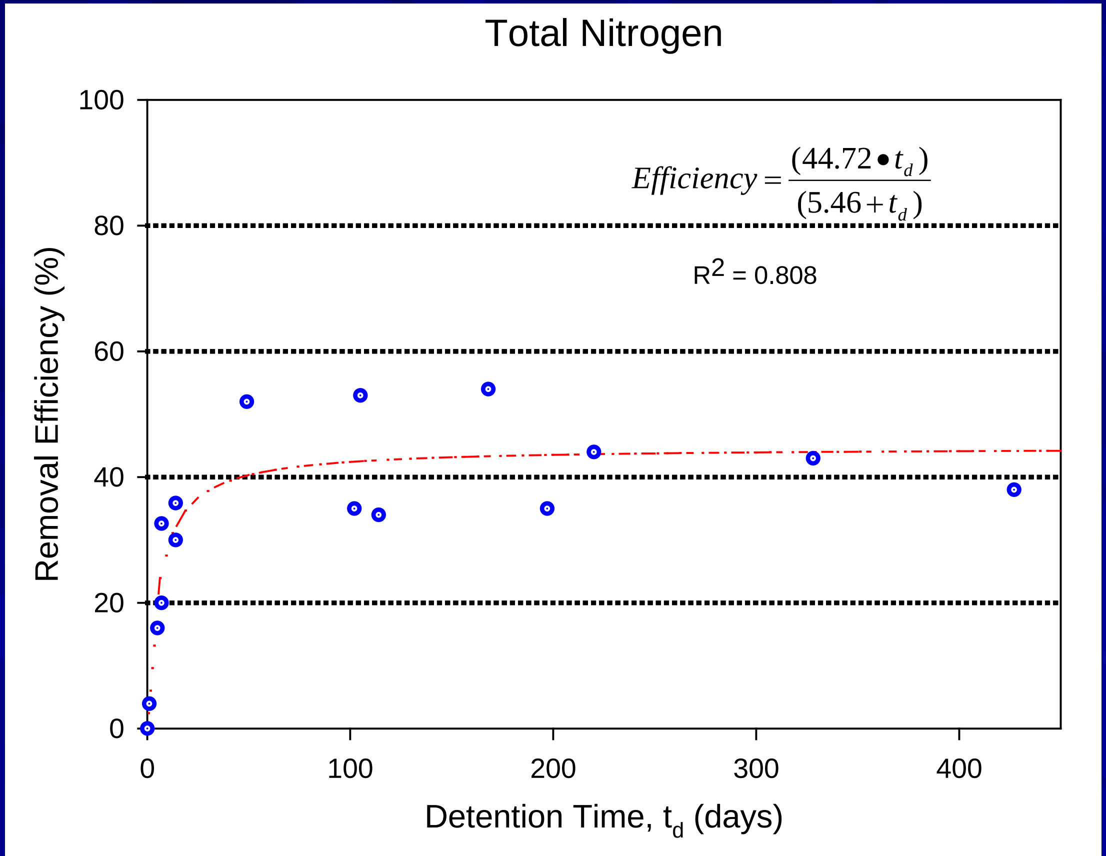
Wet Detention Pollutant Removal Processes

- Physical processes
  - Gravity settling – primary physical process
    - Efficiency dependent on pond geometry, volume, residence time, particle size
  - Adsorption onto solid surfaces
- Biological processes
  - Uptake by algae and aquatic plants
  - Metabolized by microorganisms
- Pollutant removal occurs during quiescent period between storms
- Permanent pool crucial
  - Reduces energy and promotes settling
  - Provides habitat for plants and microorganisms
- Pond depth
  - Most Districts limit pond depth to < 12 ft.
  - No evidence that pond depth > 12 ft reduces performance efficiency
  - Shallow ponds (< 6 ft) have reduced performance and longevity

Phosphorus and Nitrogen Removal for Untreated Runoff in Wet Ponds



- Phosphorus removal is highly predictable



- Nitrogen removal depends on the forms of nitrogen present

$$\text{Detention Time, } t_d \text{ (days)} = \frac{PPV}{RO} \times \frac{365 \text{ days}}{\text{year}}$$

Factors Impacting Efficiencies of Wet Ponds

- Waterfowl waste adds additional nutrients to pond

Waterfowl Loadings

Cattails

- Creates additional organic loading
- Control activities add additional nutrients

- Reduces nutrient removal processes
- Nutrient loadings from management activities

Managing Ponds as Amenities

Use of Copper Sulfate and Herbicides for Algae Control

- Herbicides reduce biological activity important for removal of dissolved nutrients
- Reduces pond performance

Floating Islands

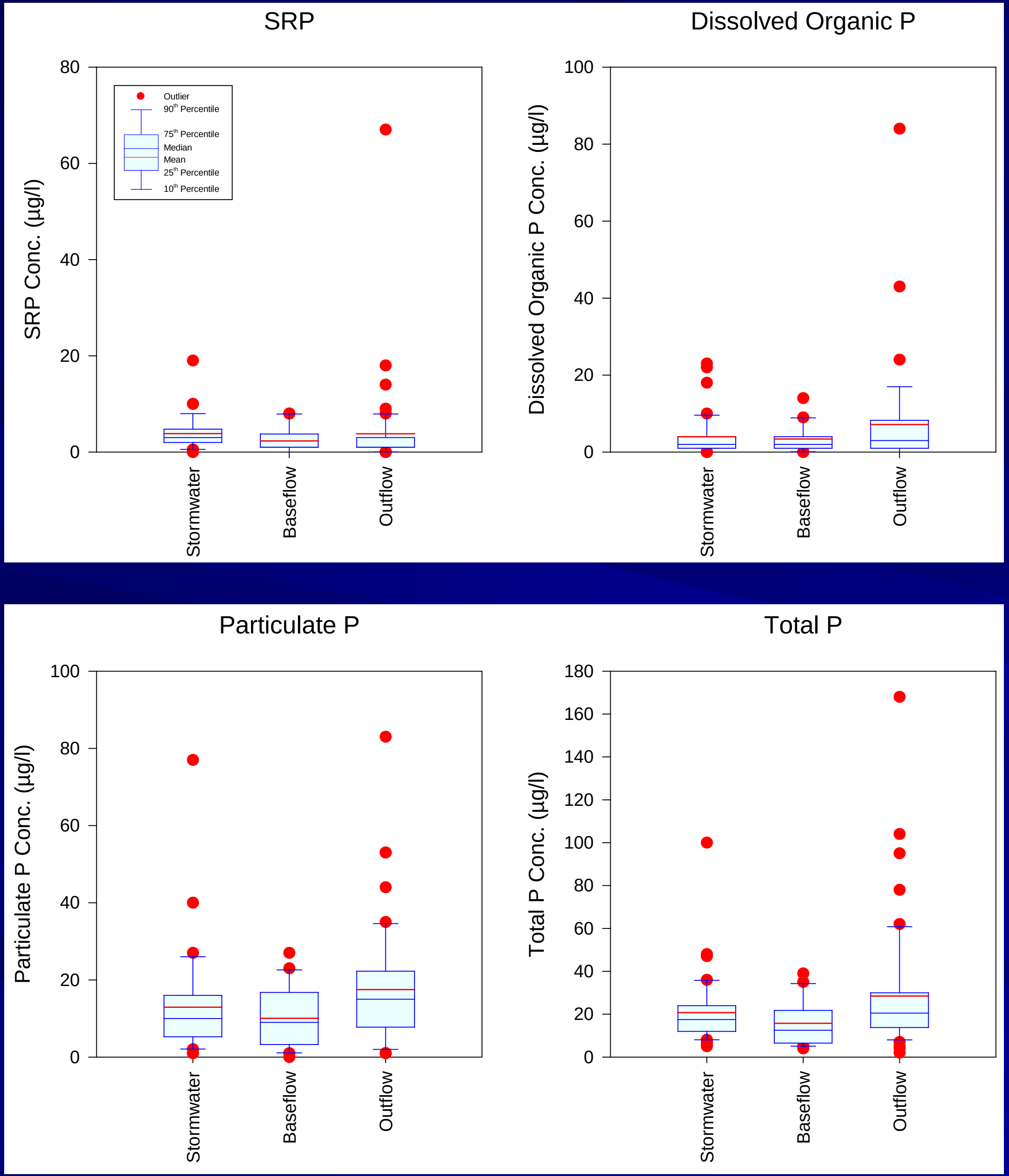
Placing mats in pond

Plants at maturity

- Nutrient removal due to uptake of dissolved nutrients through plant roots
- Nutrient uptake is a first-order rate process
  - Uptake rate varies with concentration
- Most wet ponds have low levels of dissolved nutrients
  - Verify concentrations prior to design
- At concentrations present in most wet ponds
  - 10-15% for TN and TP

Wet Detention Pond Enhancement

- Aeration
  - Generally not necessary
  - Oxygen does not limit biological removal mechanisms in ponds
- Littoral zones
  - Plants themselves provide little nutrient uptake, but do support a diverse biological community
  - Increase removal of TN and TP by about 10%
- Slow rate alum addition
  - Increases pond efficiencies to 80-90%



Comparison of Phosphorus Species Measured at a Wet Detention Pond Site

- No measurable change in phosphorus concentrations within pond

- Input phosphorus concentrations in runoff and baseflow are near irreducible concentrations

Parameter	Units	Total N	Total P
Irreducible Concentration	µg/l	400	10

Impacts of Color on Wet Pond Effectiveness

- Color
  - Caused by dissolved organic molecules
  - Common organics in Florida are tannins and lignins
    - Caused by organic matter from decomposition of leaves, roots, and plant litter
  - Wetlands commonly discharge colored water
- Impacts of color
  - Reduces light penetration into water
    - Reduces depth of photic zone
  - Often reduces pH to values < 5
    - Limits algal species and aquatic plants
  - Some color compounds act as natural algaecides
  - Nutrients may be bound into organic molecules
    - Unavailable for algal uptake and removal
  - Substantially reduces effectiveness of wet ponds
    - ~ 10-15% for TN and TP

Color caused by dissolved matter: tannins

Beneficial “Magic” Bacteria

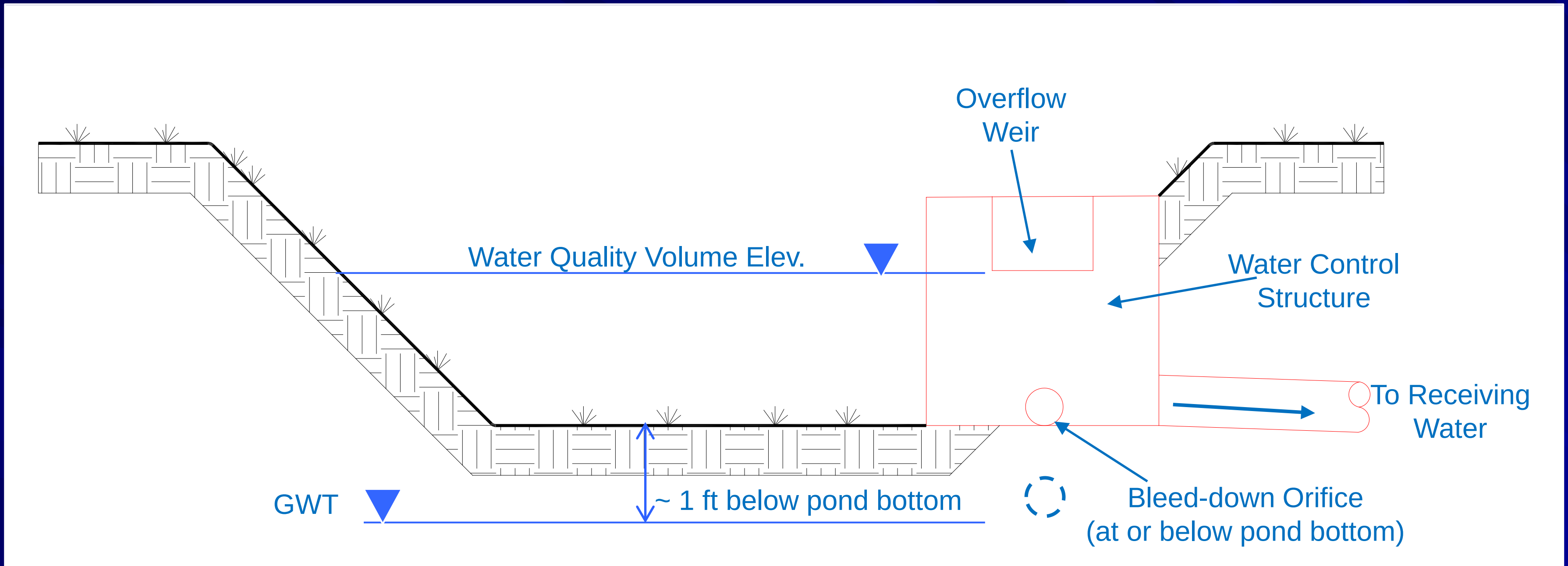
- Concept originated in the wastewater industry
  - Strains of aerobic and anoxic bacteria developed to reduce sludge volume and disposal costs
  - Extended into lake market
  - If the bacteria can eat wastewater sludge, then it should wok on lake sediments too, right?
    - Wastewater sludge is “fresh” organic material that can be easily broken down
    - Lake sediments have been there for decades or centuries
    - Sediments become recalcitrant – no further degradation
    - If an organism exists that could break down lake sediments, then there would not be any lake sediments
- Conducted 3 separate field studies on beneficial bacteria for vendors
  - Underwater staff gauges were installed at multiple locations in each lake
  - Product added, sometimes multiple applications
  - An underwater video camera was used to conduct monthly sediment readings
  - None of the lakes had a measurable decrease in muck depth after 6-12 months
  - All vendors requested that a Final Report not be issued

3. Dry Detention

Dry Detention Removal Study

- Research into dry detention effectiveness have indicated highly variable removals
- Two primary previous studies
  - Bradfordville – Mass load for TN & TP reduced by 80 – 92%
  - Orange Co. – Mass discharge increased by 136 and 86% for TN & TP
- In 2010 ERD was selected by FDEP to conduct an evaluation of the performance efficiency of dry detention ponds (SFWMD criteria) and underdrain filtration systems (SJRWMD criteria)

SFWMD Dry Detention Pond Design



- SFWMD water quality volume equal to 0.75-inch over the basin area
- Discharges to OFWs and Impaired Waters must provide additional 50% treatment volume – 1.125-inch
- Max discharge of 50% of treatment volume in 24-hours

Dry Detention Study Results

Site	Change in Conc. Between Inflow and Outflow (%)	
	Total N	Total P
Bonita Springs	- 23	- 44
Naples	0	- 30
Pembroke Pines	3	-16

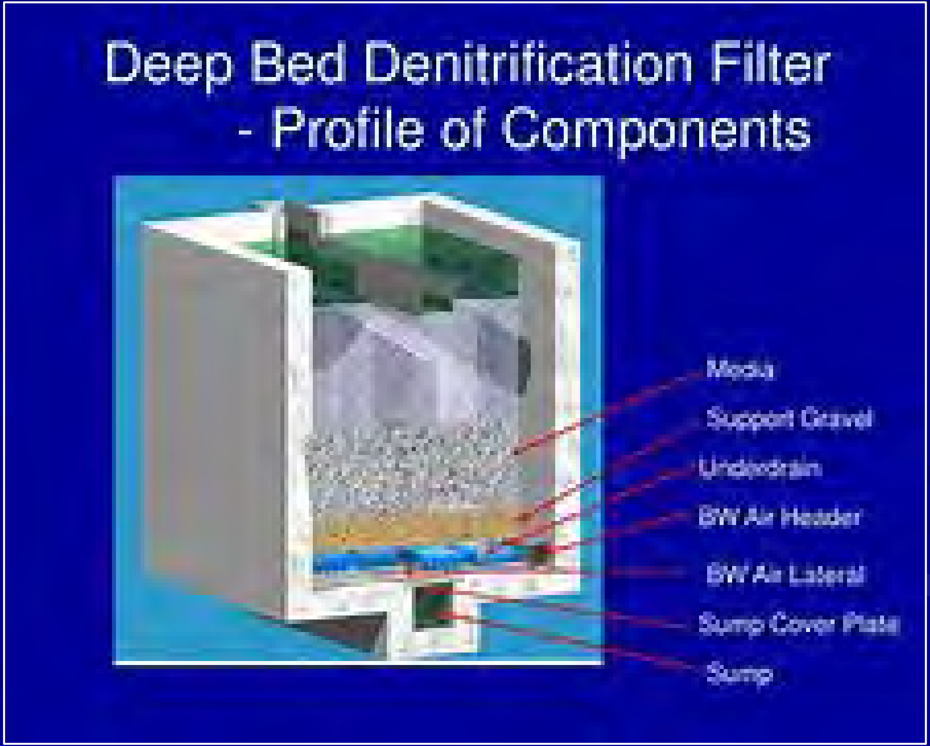
- High variability in concentration reductions

Site	Overall Mass Removal (%)	
	Total N	Total P
Bonita Springs	59	66
Naples	69	80
Pembroke Pines	50	52

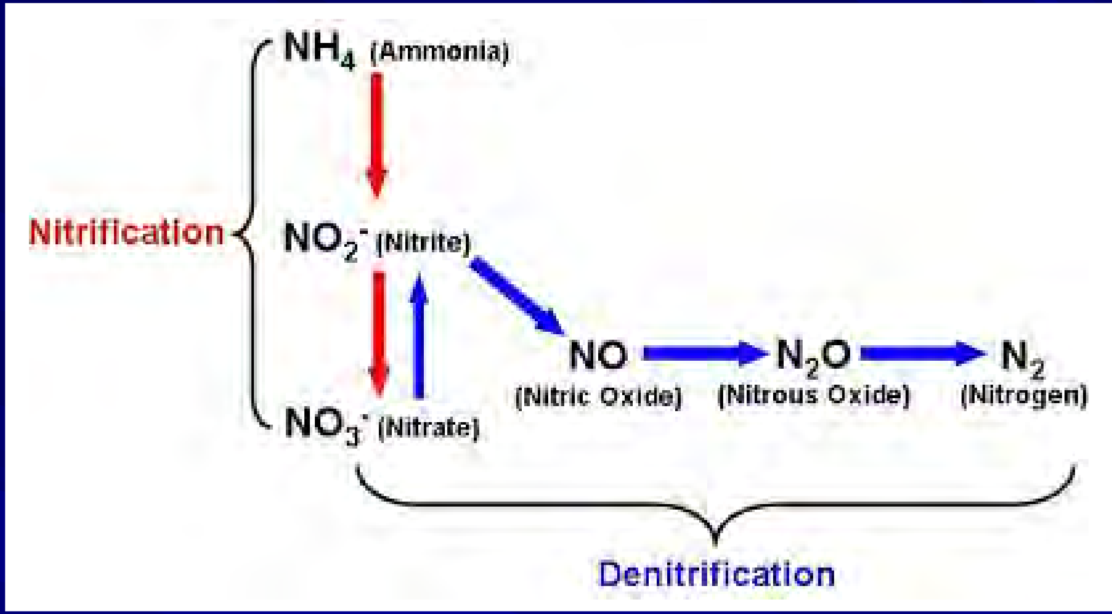
- Larger mass removal efficiencies

- Mass load reduction achieved primarily by runoff losses to groundwater
  - System functions primarily as a retention basis
- Efficiencies are highly variable and depend on the soil characteristics and permeability

4. Denitrification



Denitrification

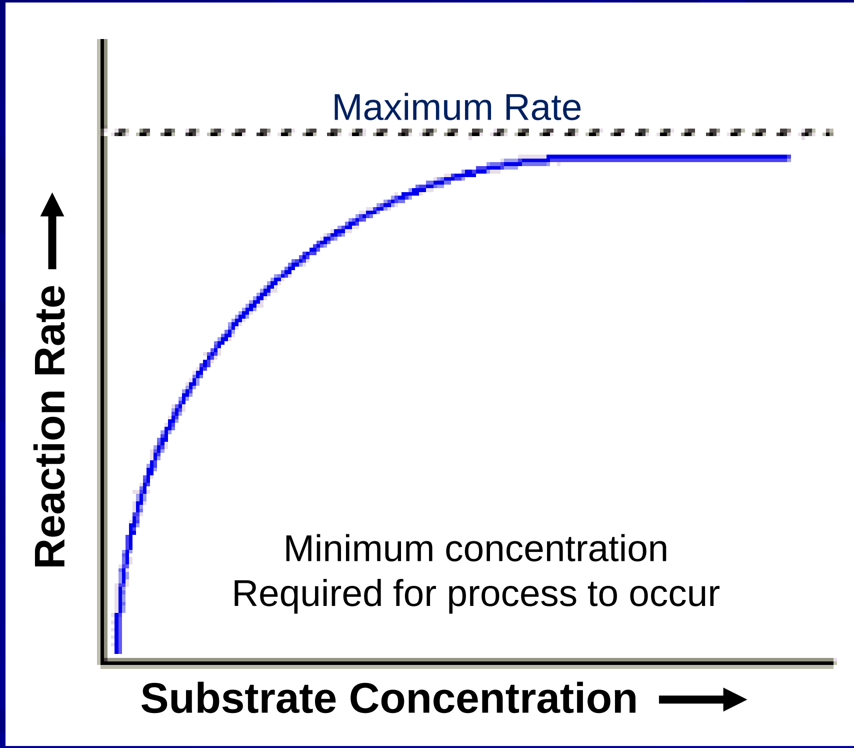


- Biologically mediated process conducted by facultative, heterotrophic bacteria
  - Facultative bacteria –
    - Organism capable of both aerobic and anaerobic respiration
    - Obtain oxygen either by removing dissolved oxygen from water or by removing bound oxygen from inorganic ions, ex. NO_3^-
  - Heterotrophic bacteria –
    - Use carbon containing compounds as a source of carbon and energy

Denitrification – cont.

- Denitrification involves exchange of electrons – redox reaction
  - Carbon source is used as an electron donor
  - Carbon availability can limit denitrification
- Denitrification reaction is a first-order concentration limited reaction
  - Rate of denitrification decreases logarithmically as nitrate concentrations decrease
  - Slow process
    - ~ 90% complete in 3-4 days
- Common denitrification species include:
  - Bacillus
  - Enterobacter
  - Micrococcus
  - Pseudomonas
  - Spirillum

All are common in nature

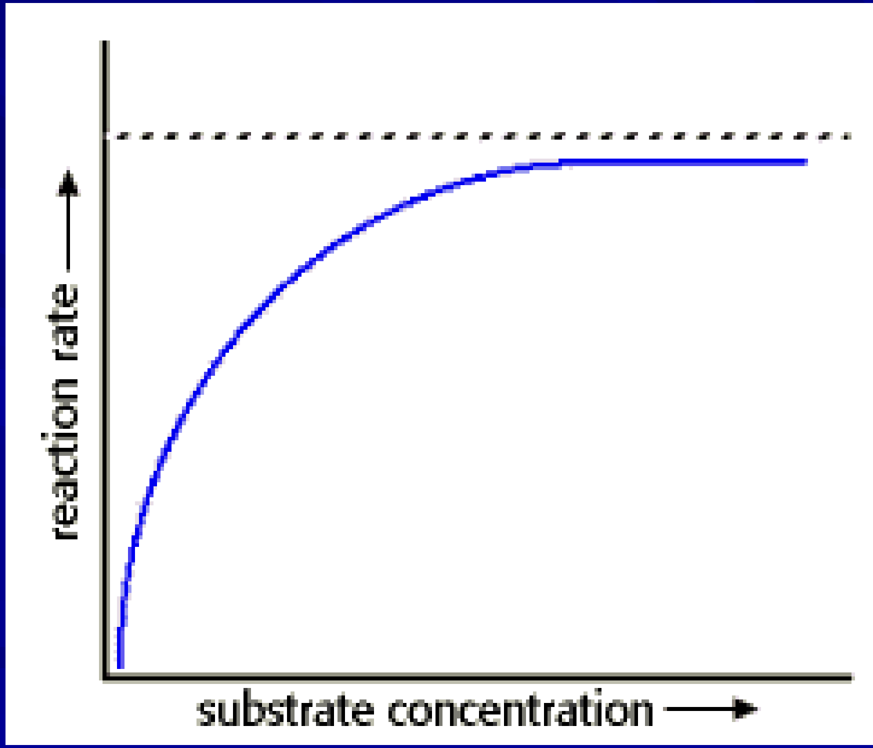


Denitrification Requirements

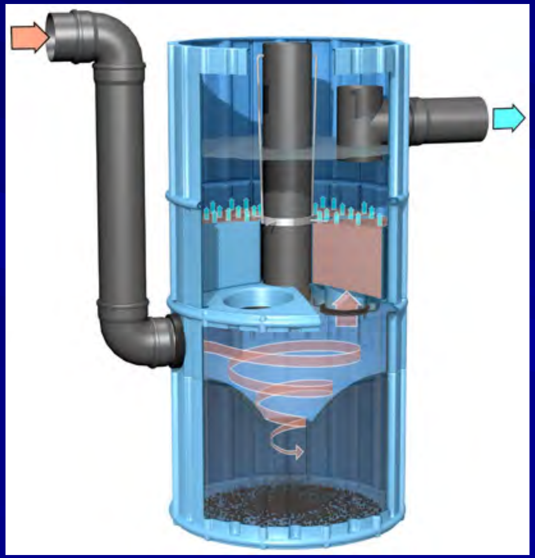
- Degradable carbon source
  - Carbon source must be easily degradable - BOD
  - WWTPs use simple organics such as methanol and acetic acid
  - Urban runoff generally contains low BOD
  - Some systems add sawdust or wood chips as carbon source
  - Quality of carbon source impacts end product (NO, N_2O, or N_2)
- Reduced anoxic environment
  - Minimum redox potential (Eh) of -100 to -200
- Proper environmental conditions
  - pH
    - Optimum range: 7.0 – 8.5
  - Temperature
    - Optimum range: 5 - 30ºC
  - Water-based environment

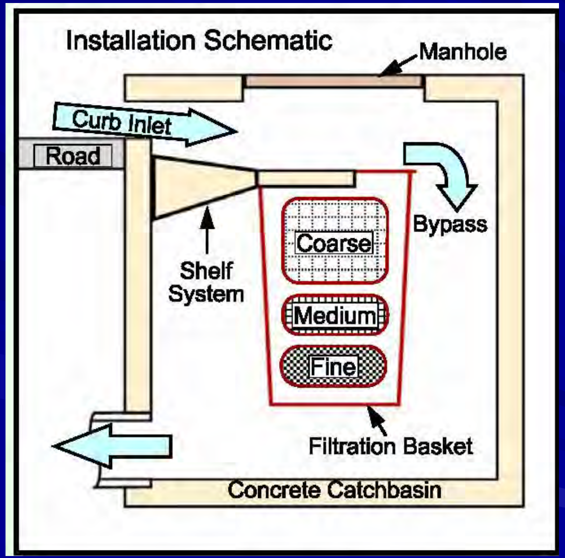
Denitrification Requirements – cont.

- Nitrate concentration is the single most important factor regulating denitrification rate
  - Optimum denitrification rates: NO_3^- concentrations 280 – 840 ug/L (Thomas, et al, 1994)
- Contraindicated conditions
  - High color water with low pH
  - Sources with low nitrate concentrations
- ERD has monitored 4 denitrification beds
  - 3 had insufficient NO_x for denitrification to occur to any significant extent



5. Gross Pollutant Separators

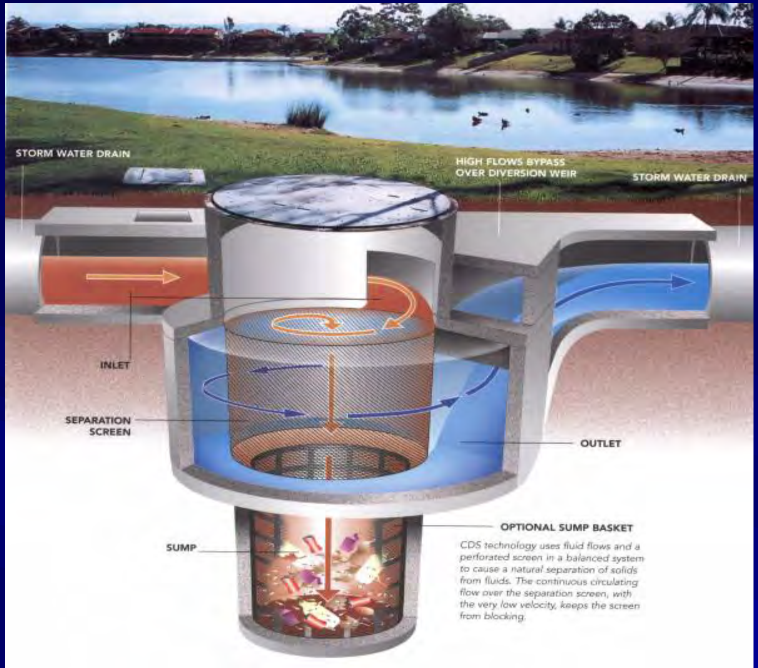




Evaluated BMPs

- Baffle Box
  - Suntree 1st generation baffle box
  - Suntree 2nd generation nutrient separating baffle box
  - Ecosense with outlet filter
  - Ecosense without outlet filter
- Swirl concentrator
  - CDS unit
  - Stormceptor
- Curb Inlet Baskets

Swirl Separators

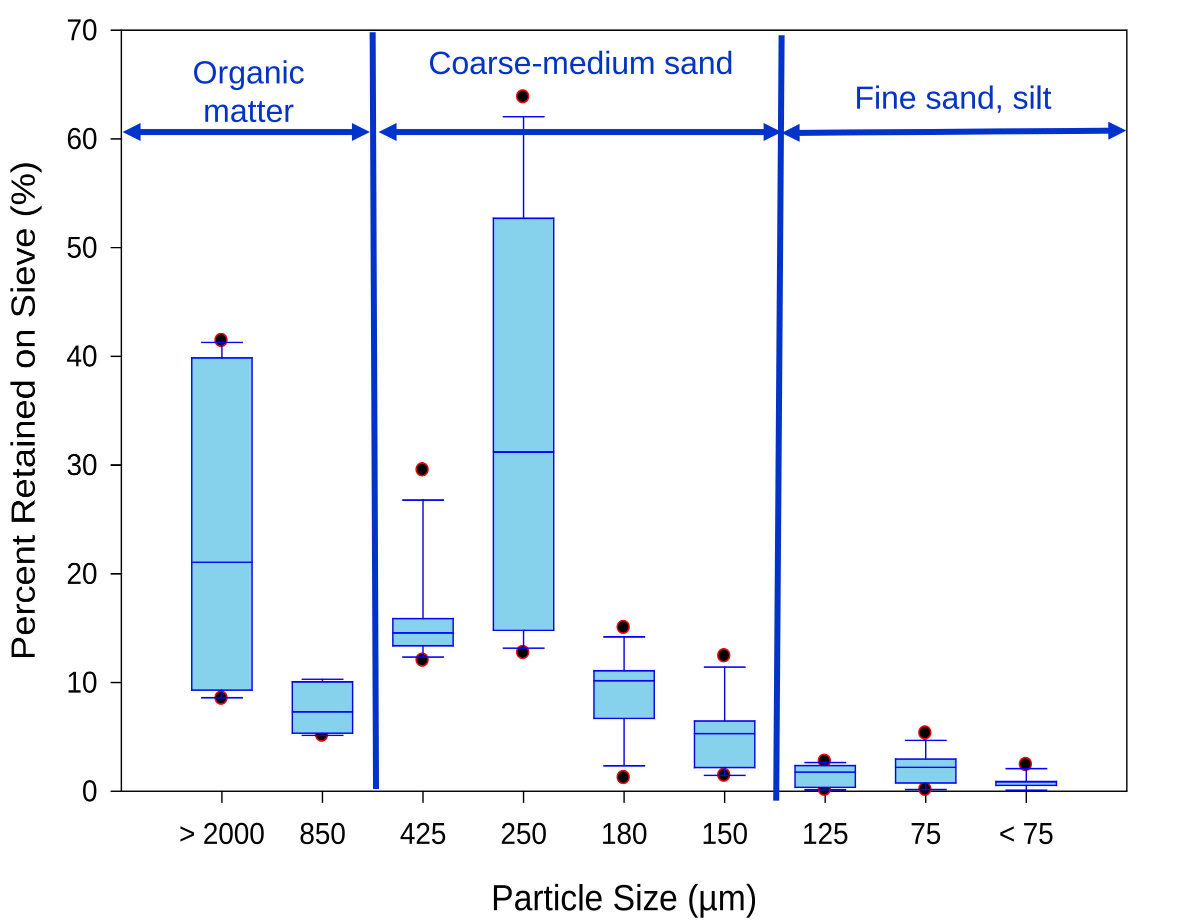


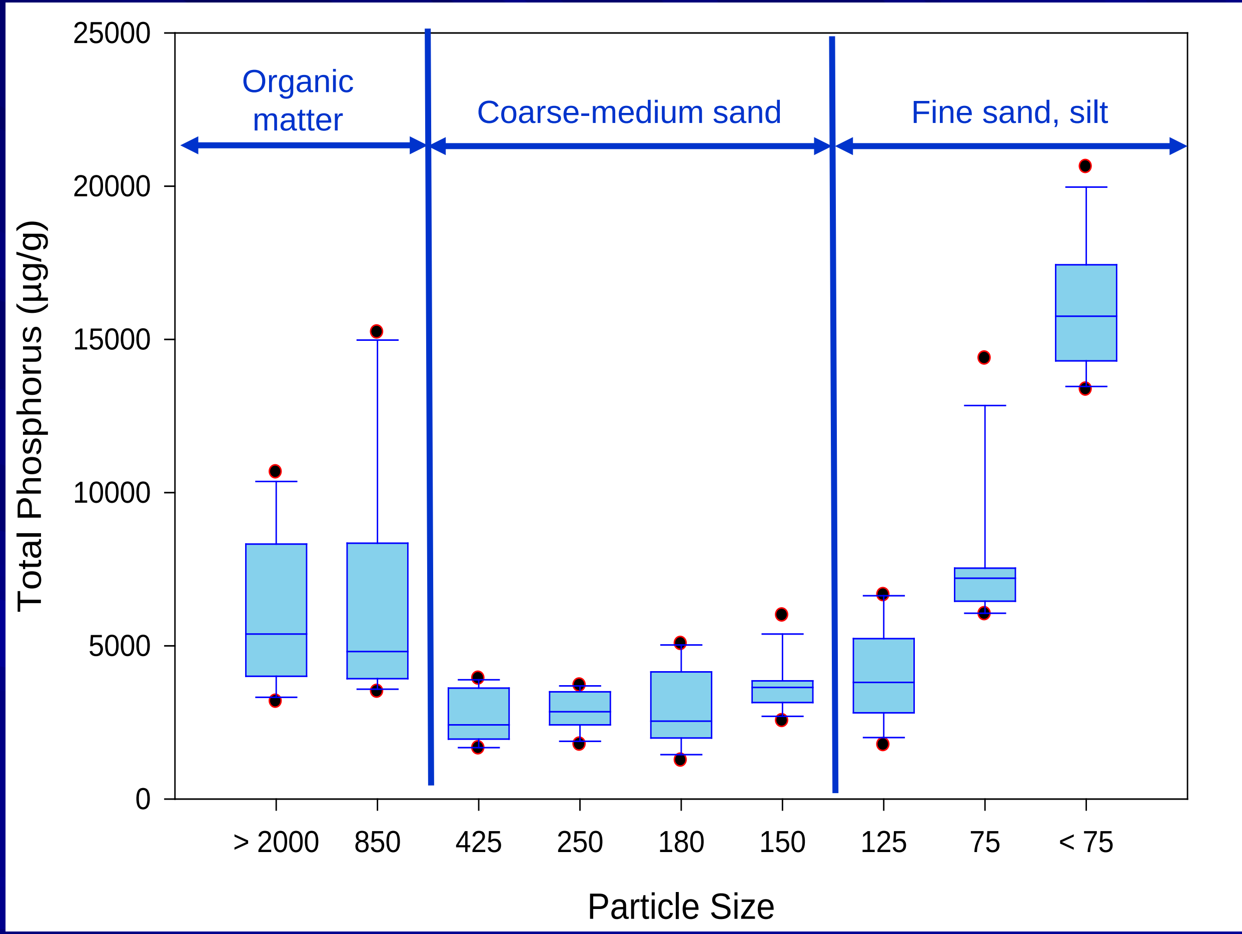
CDS Unit

Stormceptor

- Literature removals are based on inflows at the design capacity
- Swirling motion is required to remove and screen solids
- At lower flow rates the swirling is reduced
- Collected solids are stored in an anoxic sump which decreases nutrient retention

Distribution of Particle Sizes in Residential Roadway Solids





Typical GPS Removal Efficiencies and Costs

- Excellent for solids removal
  - 75–90%
- Poor nutrient removal for standard units
  - 5-15% for TN and TP
- Outlet filters may reduce dissolved fraction
  - Increase removals to 40-50%
- Many types of filter media
  - Highly variable removals
  - Be aware of irreducible concentrations
- Extremely high mass removal costs

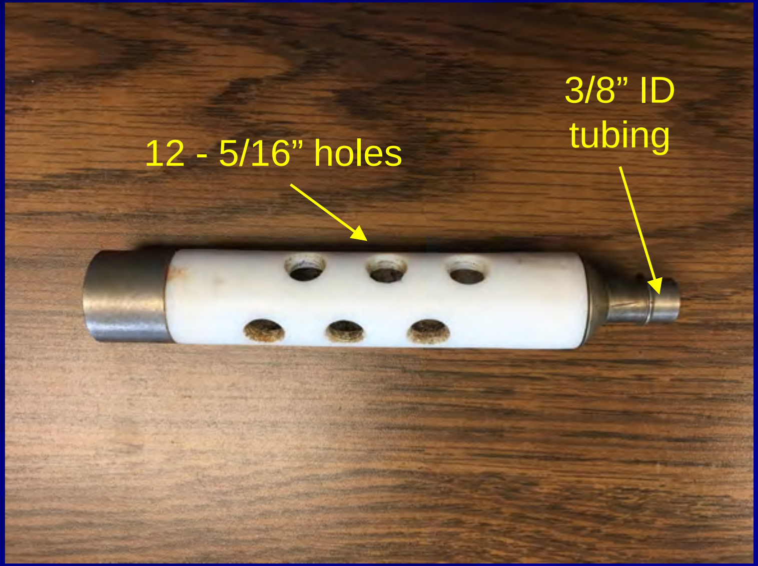
Unit	Mass Removal (%)			Present Worth Removal Cost ($/kg) (20-yr, i = 2.5%)		
	Total N	Total P	TSS	Total N	Total P	TSS
EcoVault with Outlet Filter	14	57	90	3,433	1,755	4.89
EcoVault with Outlet Filter	2	41	78	34,377	10,188	14.05
EcoVault	14	11	89	3,393	25,582	14.49
Suntree Baffle Box	2	7	73	6,110	15,928	11.20
CDS Unit	5	12	94	5,699	23,252	43.32

Conclusions

- Gross pollutant separators remove litter, leaves, gravel, and coarse-medium sand
  - Provide low removals for nutrients
    - Total N: 10-12% removal
    - Total P: 8-12% removal
    - TSS: 30-80% removal
  - Extremely high mass removal costs
    - 1-2 orders of magnitude greater than wet detention
- Gross pollutant separators are suited only for areas where solids are a significant problem
  - Residential areas with large tree canopy
  - Urban areas with litter issues
- Should not be used for nutrient removal projects
  - Provide poor nutrient removal at an extremely high mass removal cost

Field Monitoring for Runoff

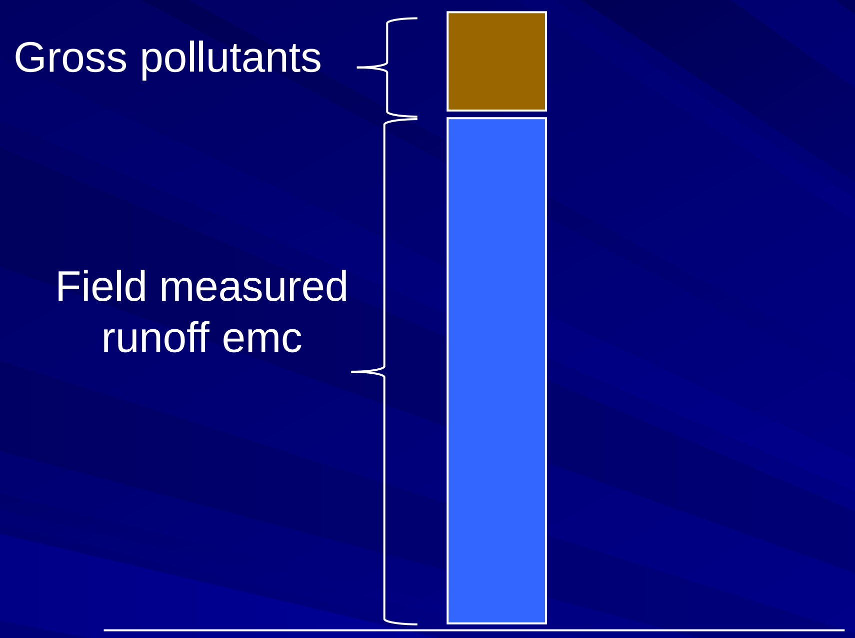
- Auto-samplers do an extremely poor job of collecting representative sample of runoff solids
- Manufacturers claim that water moves through the suction tubing at a rate of 2 fps
  - Minimum velocity required to transport most solids
- Velocities through strainer holes are much lower
  - ~ 0.24 fps (12% of required velocity)



Typical stormwater collection strainer

- Auto-samplers cannot collect solids greater than fine particles
  - Coarse sand, leaves, roadway residue, trash
- Sometimes the strainer is placed in an area where solids accumulate and may collect more solids than are representative

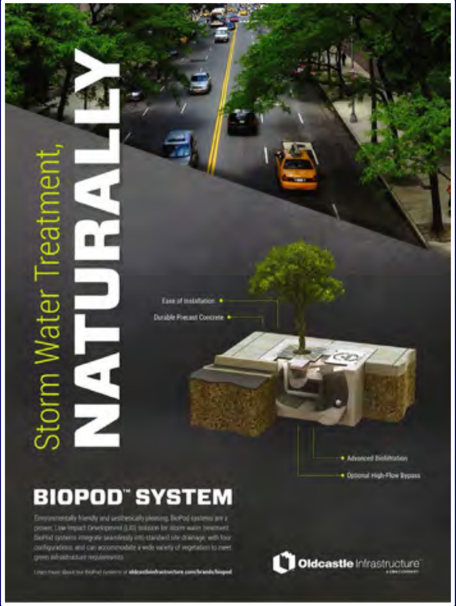
Load Reductions for Gross Pollutant Removal

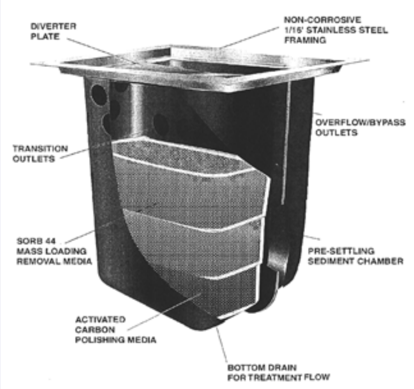


- During 2011, FSA funded a study to estimate effectiveness of street sweeping for removing gross pollutants
- Many gross pollutants cannot be collected with common stormwater monitoring equipment
  - Impacts of these gross pollutants are not included in emc data
- When TMDL credits are provided for gross pollutant devices, the loads are subtracted from loads which did not include them

6. LID Systems

Limitations of LID Systems





- LID systems are usually designed for small catchments with small loadings
- Most LID devices are not designed with Florida conditions in mind
- Florida rainfall depths and intensities often exceed the capacity of devices designed for northern climates
- Concentration based removal systems require a minimum concentration to perform effectively
- Florida conditions may reduce effectiveness of the system
  - Manufacturer's efficiencies will over-estimate achieved efficiencies

7. Treatment Trains

Source: Minnesota Stormwater Manual

BMP Treatment Train

- One or more components that work together to remove pollutants utilizing combinations of hydraulic, physical, biological, and chemical methods
  - Concept has been around for several decades
- Processes combined in a manner that ensures management of all target pollutants
- Generally, the highest level of pollutant reduction is achieved in the first BMP, with each successive BMP becoming less effective
- Subsequent BMPs in the treatment train receive runoff that has lower concentrations of pollutants
  - Downstream BMPs must be capable of operating effectively at the lower concentration levels

Efficiency Calculation for Treatment Trains in Series

Overall Treatment Train Efficiency

$$= Eff_1 + (1 - Eff_1) \times Eff_2 + (1 - (Eff_1 + Eff_2)) \times Eff_3 + \ldots.$$

where:

Eff_1 = efficiency of initial treatment system
Eff_2 = efficiency of second treatment system
Eff_3 = efficiency of third treatment system

Assumptions:

- Each BMP acts independently of upstream BMPs
- Upstream BMPs do not impact performance of downstream BMPs

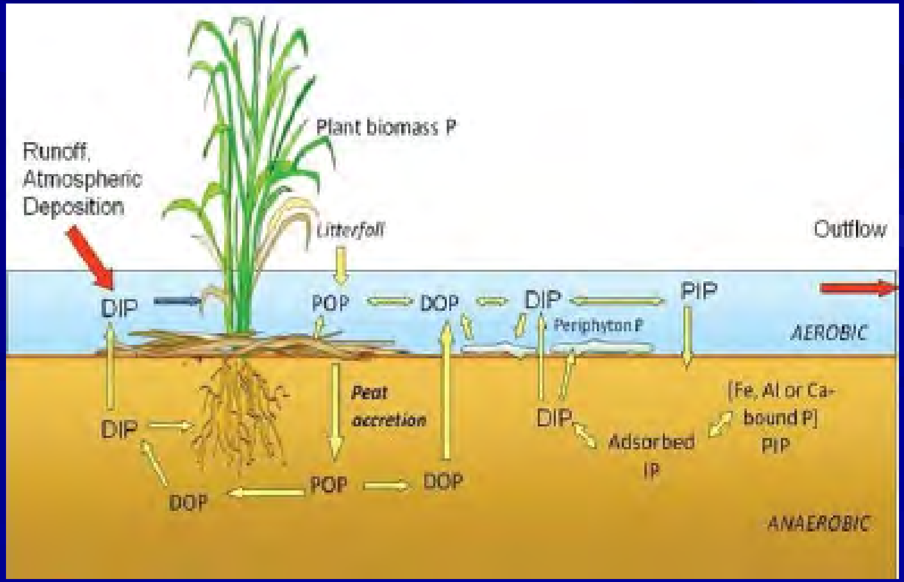
Complimentary BMPs

- For a treatment train to be effective, the individual BMPs need to be complimentary
  - No significant overlap in types of pollutants removed
  - Upstream BMPs should not reduce the efficiency of the downstream BMPs
- Volume reduction BMPs
  - Almost always complimentary
- Concentration reduction BMPs
  - Almost never complimentary
  - Ex. Baffle box prior to dry or wet detention pond

8. Wetland Polishing

Shallow Hardwood Wetlands

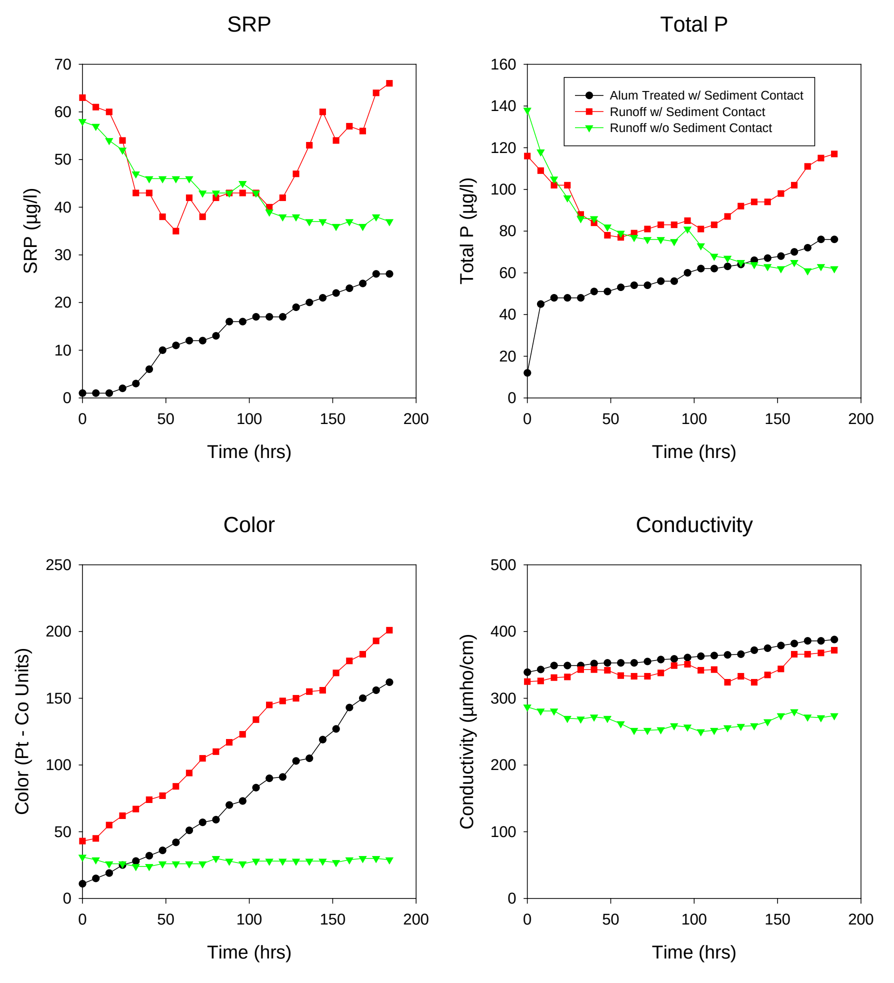
- Shallow waterbody with nutrient rich, acidic, and typically anoxic soils
- Used extensively by the wastewater industry to "polish" treated wastewater
- Water quality of wetland discharges is based primarily on an equilibrium between the soils and the water column
  - First-order reaction rate based on concentration
  - Equilibrium reached in 3-4 days
  - High concentrations will be reduced
  - Low concentrations will be increased

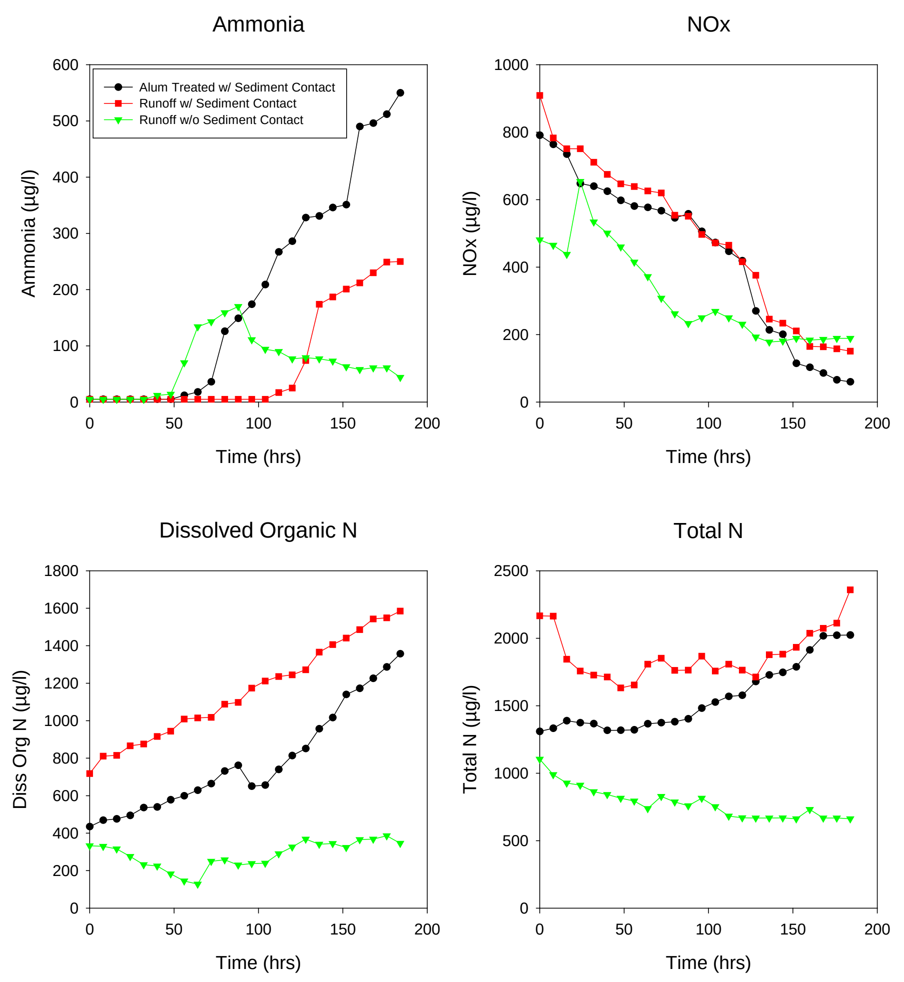


Nutrient Equilibrium in Hardwood Wetlands

- Mesocosm studies conducted to evaluate impacts of wetland on alum treated runoff
- Treated runoff added to mesocosm and concentrations monitored for 7-10 days

Nutrient Equilibrium in Hardwood Wetlands





- Nutrients inputs reach equilibrium with wetland soils
  - Total P - ~ 0.100 mg/L (100 ppb)
  - Total N - ~ 1 – 2 mg/L

Nutrient Equilibrium in Herbaceous Wetlands

- Shallow waterbody with dense herbaceous vegetation
- Vegetation provides a large amount of structure which supports a large population of algae, bacteria, and micro-organisms
- Water meanders around stalks
  - Provides large opportunity for uptake processes
- Soils are anoxic, but the have little contact with water

Shallow Herbaceous Wetland

9. Vegetated Stormwater Treatment Areas (STA)

Vegetated Stormwater Treatment Areas

- Nutrient occurs through 2 primary processes
  - Uptake through plant roots
  - Biological communities attached to plant stalks
- Typically add organic muck soils to aid plant growth
- Large evapo-transpiration losses reduce runoff volume

Vegetated Stormwater Treatment Areas – con't.

- Monitored 5 STA systems
  - Each imported muck soils to increase plant growth
- All exhibited net loss of runoff volume, but concentrations increased between inflow and outflow
- Mass removal effectiveness
  - 1 site had a net removal of TN but exported TP
  - 2 sites had net export of both TN and TP
  - 2 sites had net retention of TN and TP
    - TN ~ 25%
    - TP ~ 45%

10. Grant Process

Observations

- Virtually all applications over-estimate nutrient loadings
  - Primarily a result of over-estimation of runoff volume
  - Many estimates are very general
- Only a small portion of load estimates are based on actual data
- Removal efficiencies generally based on manufacturer’s data
  - Often based on research conducted with ideal conditions and high loading
- Over-estimates for load and removal efficiency lead to exaggerated load reduction estimates
- In 40 BMP monitoring projects, only 6 achieved the projected nutrient load reduction

Observations – con't.

- Very few designs confirm anticipated loading prior to BMP selection

- Most BMP system designs and stated removal efficiencies are based on characteristics of untreated raw runoff
  - Pre-treatment of any kind may impact removal prosses and load reductions

Questions?