Stormwater Management –
It's All About the Concentration!

Florida Stormwater Association
2024 Winter Conference
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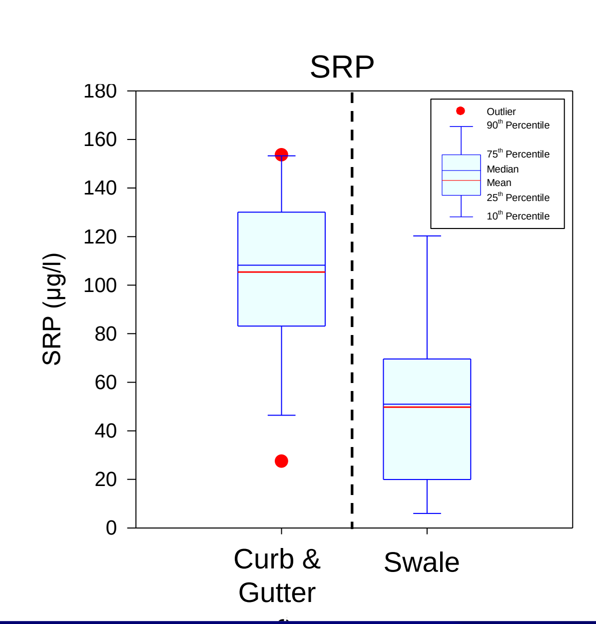
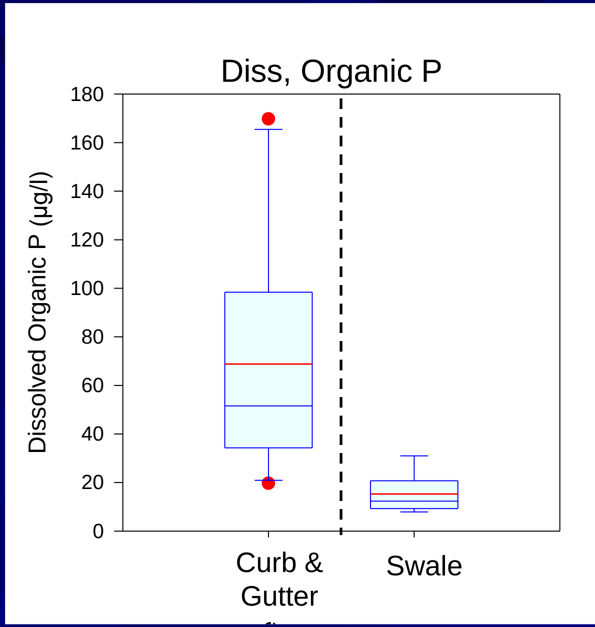
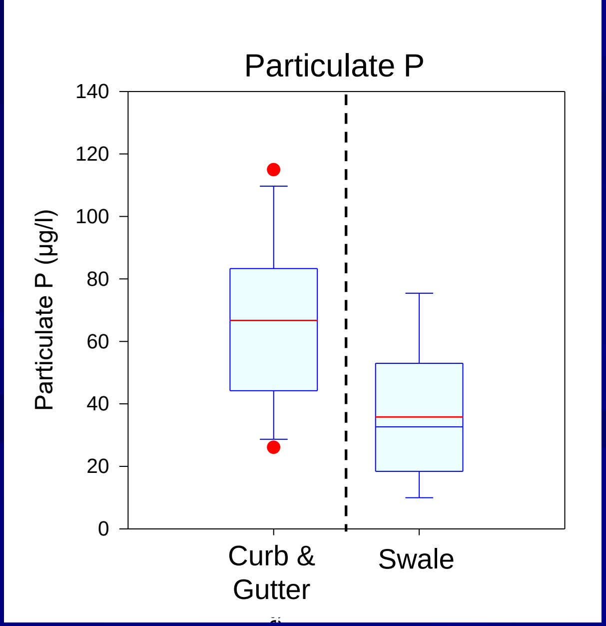
Harvey H. Harper, Ph.D., P.E.
Environmental Research & Design, Inc.

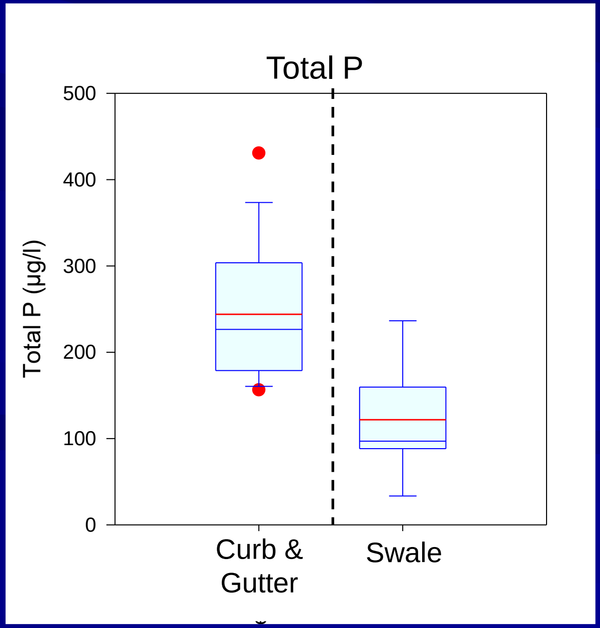
1. Sources of Stormwater Pollutants

- Street pavement
- Motor vehicles
- Atmospheric fallout
- Vegetation debris
- Land surface
- Litter
- Anti-Skid compounds and chemicals
- Construction activities









2. Runoff Concentrations

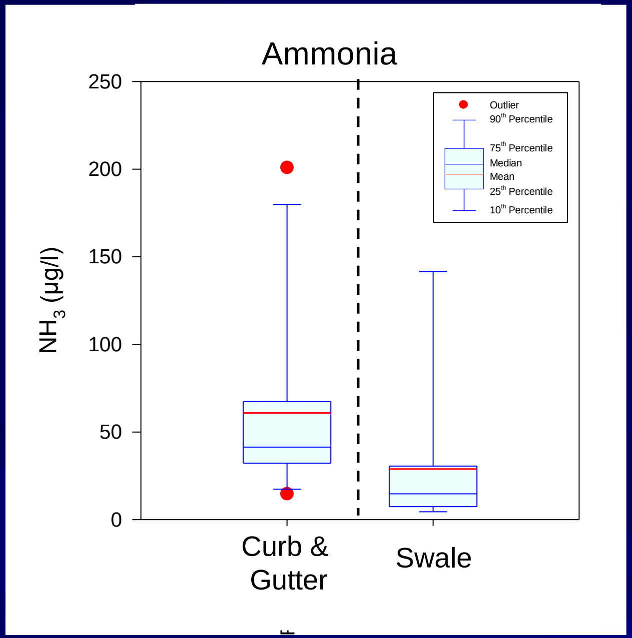
Typical Phosphorus Concentrations in Florida Residential Runoff

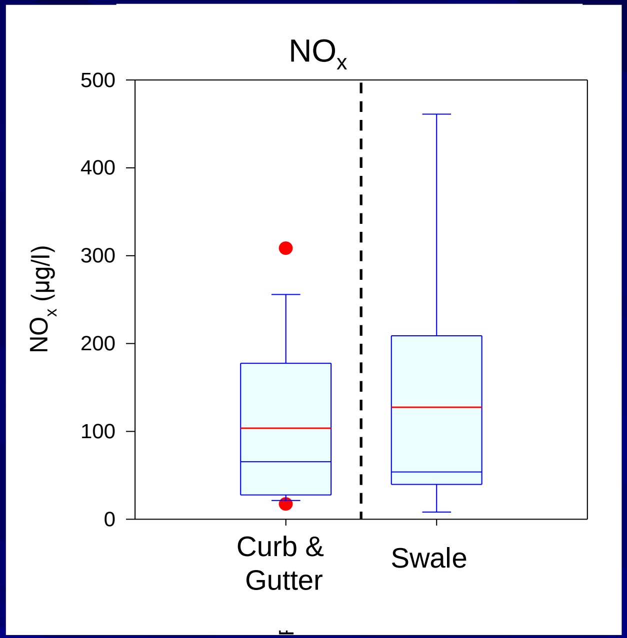
Curb & Gutter
vs. Swale
(n=10 sites)

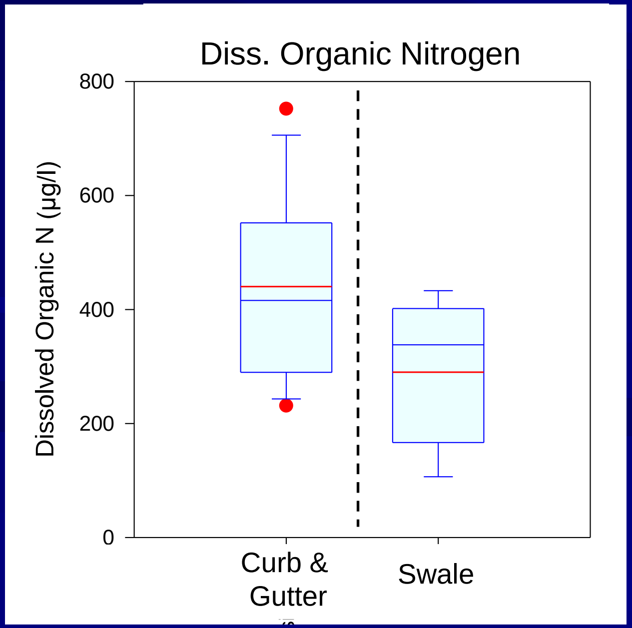
- Concentrations of all phosphorus species are lower in swale runoff than in curb & gutter systems

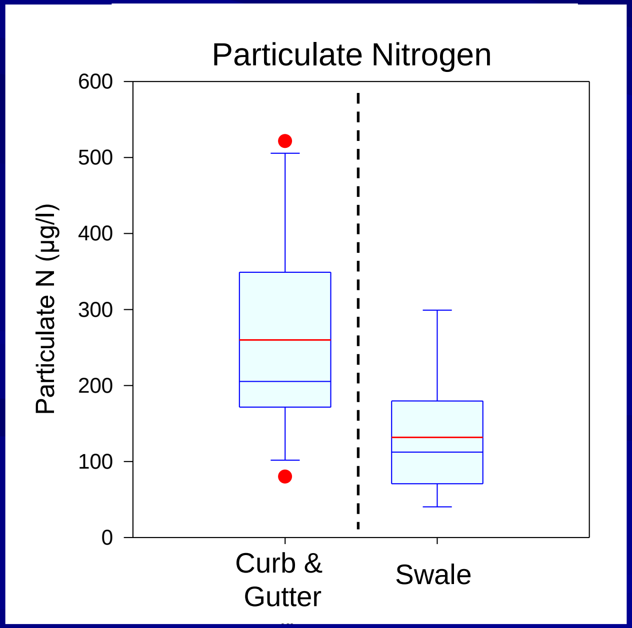
Typical Nitrogen Concentrations in Florida Residential Runoff

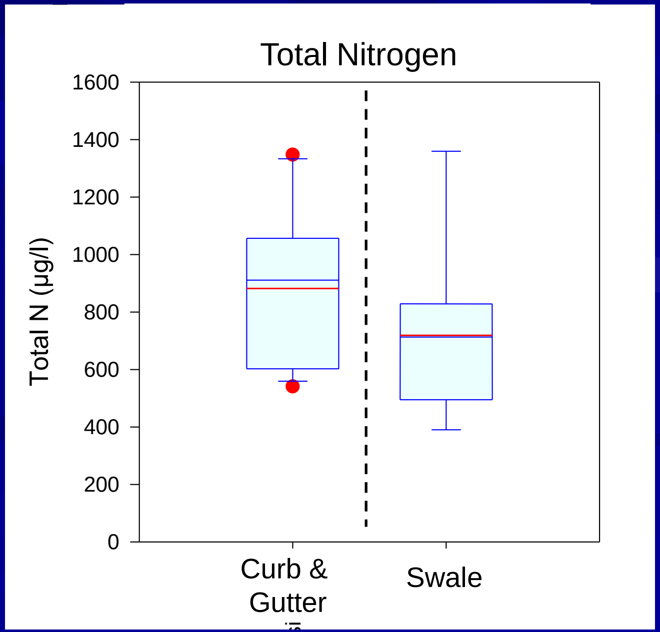
Curb & Gutter vs. Swale (n=10 sites)





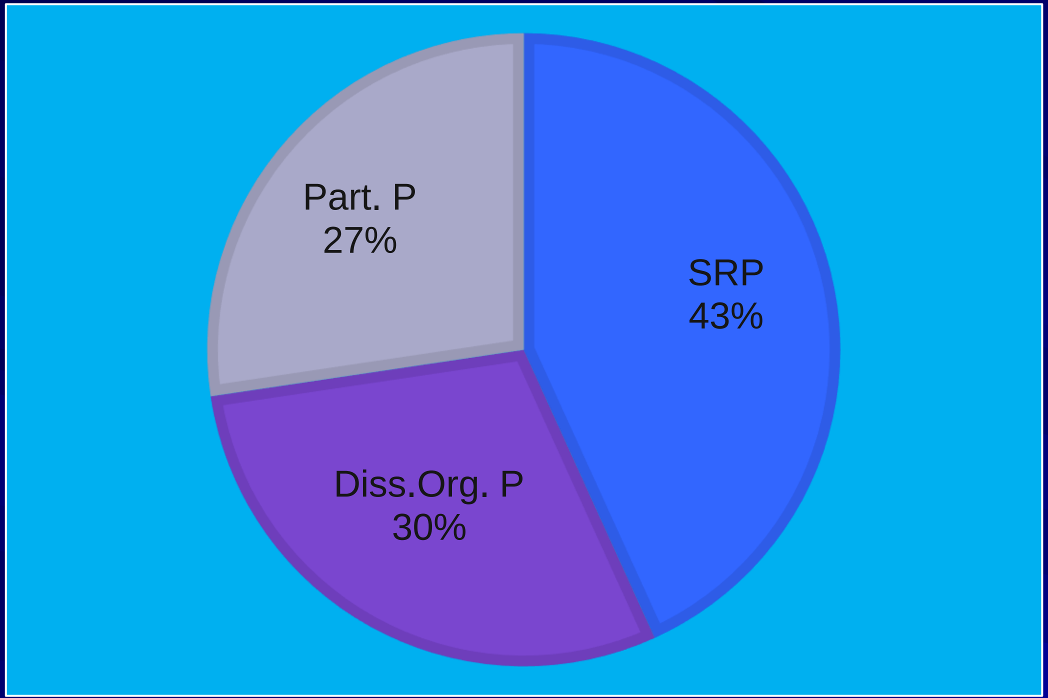






- Concentrations of all nitrogen species are lower in swale runoff than in curb & gutter systems

Typical Distribution of Phosphorus Species in Residential Runoff

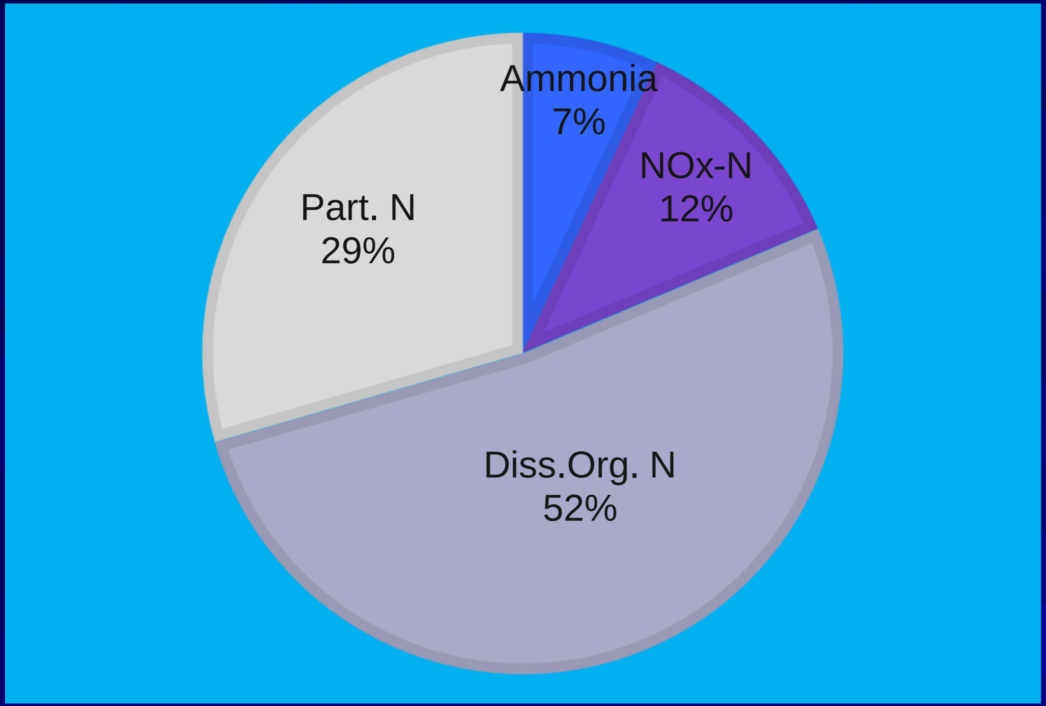


Typical Residential Runoff Phosphorus Concentrations

Parameter	Units	Curb & Gutter
SRP	µg/L	105
Diss.Org. P	µg/L	72
Part. P	µg/L	67
Total P	µg/L	244

- Removeable species include SRP and particulate P – 70%
- Dissolved organic P is removed through biological processes at a slow rate
- If 85% of removeable species are removed, then TP removal is (70% x 0.85) = 60% which is similar to the maximum TP removal achieved in wet ponds with typical detention times
- At long detention times (~ 180 days) a portion of the dissolved organic P may also be removed

Typical Distribution of Nitrogen Species in Residential Runoff



Typical Residential Runoff Nitrogen Concentrations

Parameter	Units	Curb & Gutter
Ammonia	µg/L	61
NOx	µg/L	104
Diss.Org. N	µg/L	457
Part. N	µg/L	260
Total N	µg/L	882

- Removeable species include ammonia, NOx, and particulate N – 48%
- Dissolved organic N is removed through biological processes at a slow rate
- If 85% of removeable species are removed, then TN removal is (48% x 0.85) = 41% which is similar to the maximum TN removal achieved in wet ponds
- At long detention times (~ 1+ yr) a portion of the dissolved organic N may also be removed

3. Removal of Stormwater Pollutants

- Particulates
  - Can be removed by soil filtration or in a wet pond
  - Primary pond removal mechanism is unhindered gravity settling of discrete particles by Newton's Law (turbulent) or Stoke's Law (laminar)
  - Removal of suspended solids also removes other pollutants which may be attached to the solids
- Dissolved nutrients
  - Removal occurs primarily through biological processes and adsorption
    - Wet ponds – both wet detention and wet retention
      - Permanent pool with diverse biota
    - Sorption media
    - Biological beds

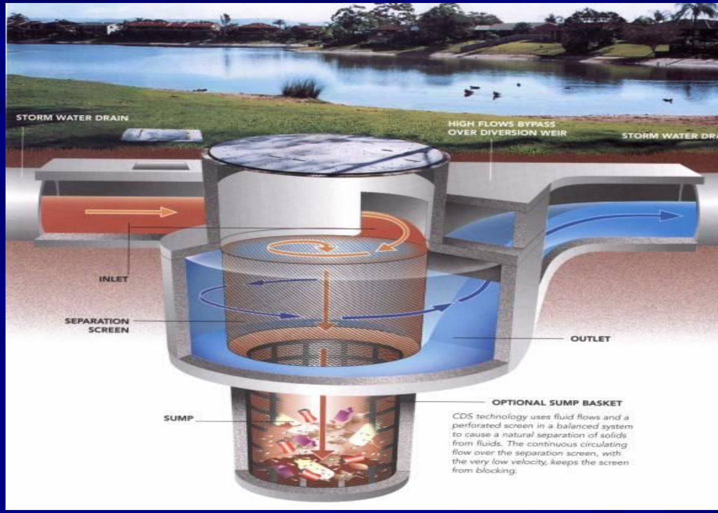
Impacts of Swale Drainage on Residential Runoff

Parameter	Units	Curb & Gutter	Swale	Conc.Change (%)
pH	s.u.	6.70	7.02	5
Alkalinity	mg/L	35.3	56.2	59
Conductivity	µmho/cm	101	178	77
Ammonia	µg/L	61	29	-52
NOx	µg/L	104	127	23
Diss.Org. N	µg/L	457	431	-6
Part. N	µg/L	260	132	-49
Total N	µg/L	882	719	-19
SRP	µg/L	105	50	-53
Diss.Org. P	µg/L	72	36	-50
Part. P	µg/L	67	36	-46
Total P	µg/L	244	122	-50
Turbidity	NTU	7.4	4.6	-38
Color	Pt-Co	41	38	-6
TSS	mg/l	39.1	16.5	-58

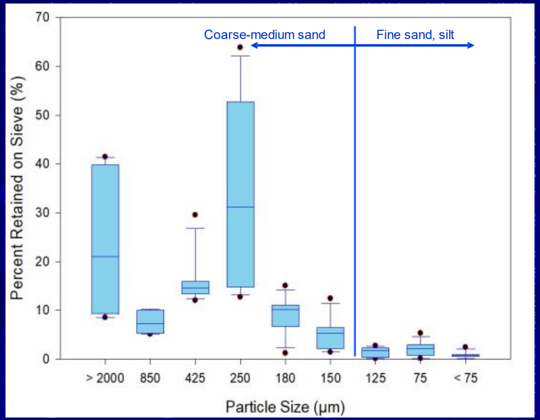
- Swale drainage decreases particulate forms of both N and P and TSS
- Some SRP and ammonia removed by adsorption to vegetation and soils
- Swale drainage reduces both concentrations and runoff volume
  - Reduces treatment requirements
- Gross pollutant separators (GPS) may not be suitable for swale drainage systems
  - Much of the material removed in a GPS will have been removed in the swale
- Swale drainage systems are an excellent method of reducing initial runoff loadings prior to treatment

4. Gross Pollutant Separators

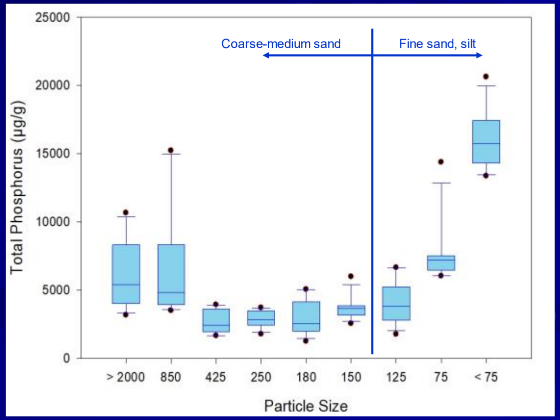
- Remove larger solids, litter, and debris
- Not useful upstream of ponds
  - Collected solids would be collected in the pond
  - May reduce pond maintenance frequency
- Not useful downstream from pond
  - No significant solids to remove
- Useful in watersheds with significant tree cover

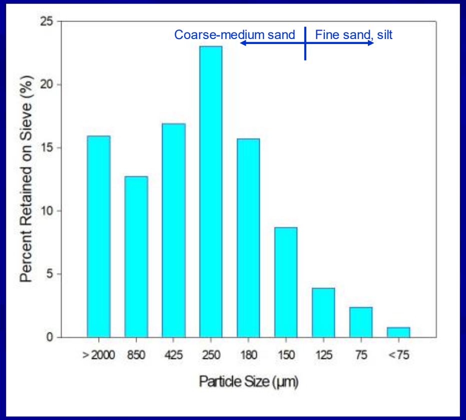


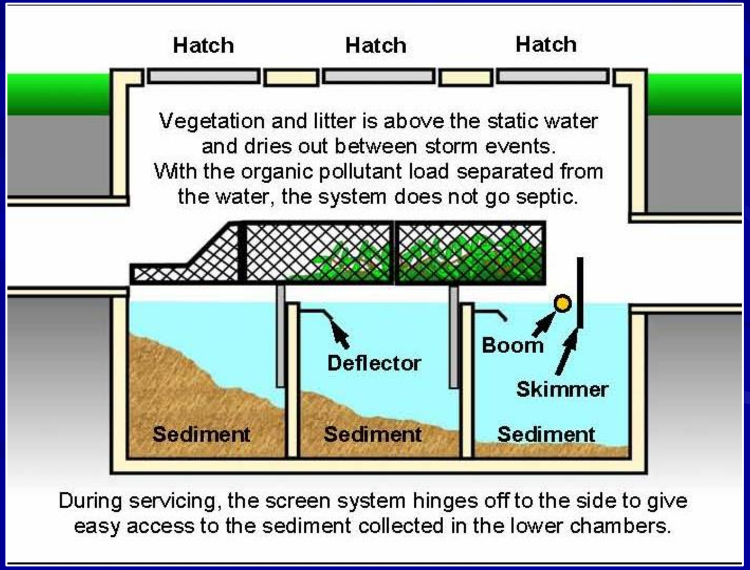
Distribution of Solids in Residential Runoff



Phosphorus Content in Residential Roadway Solids

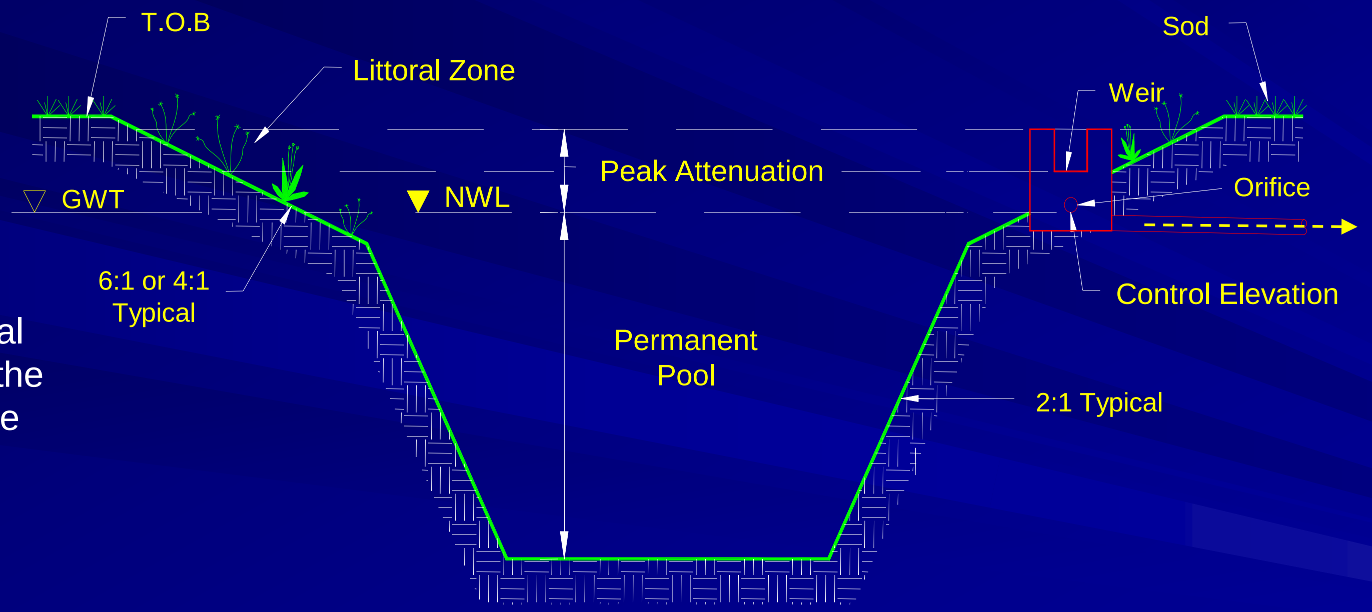






5. Wet Detention Ponds

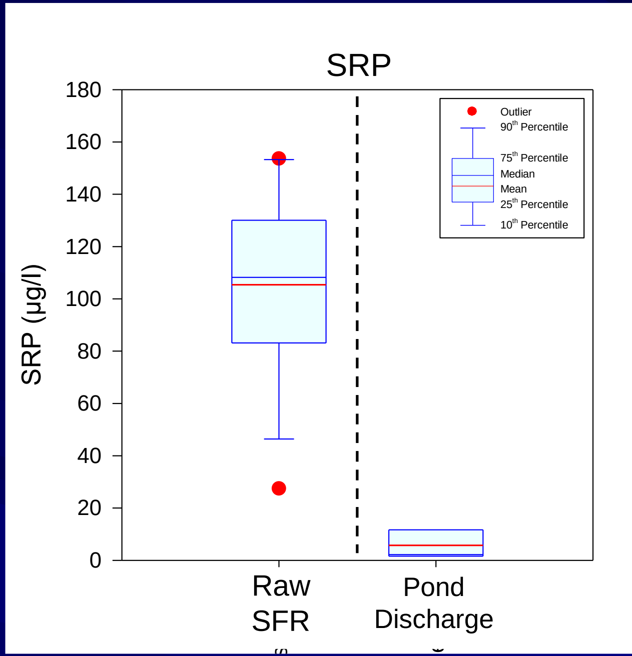
- Essentially man-made lakes
- Subject to all physical, biological, and chemical processes in surface waters

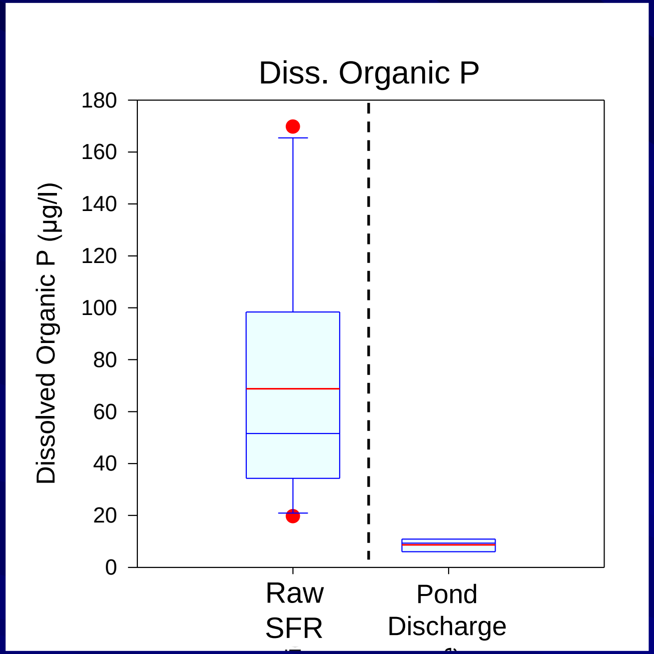


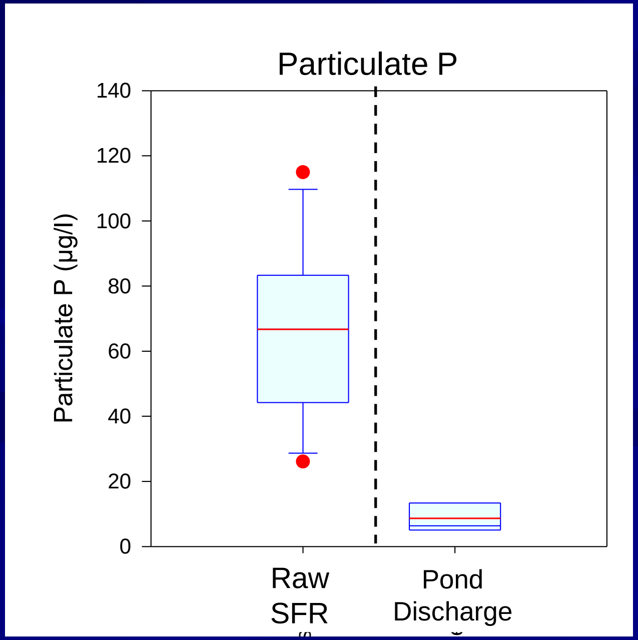
- Most pollutant removal processes occur within the permanent pool volume

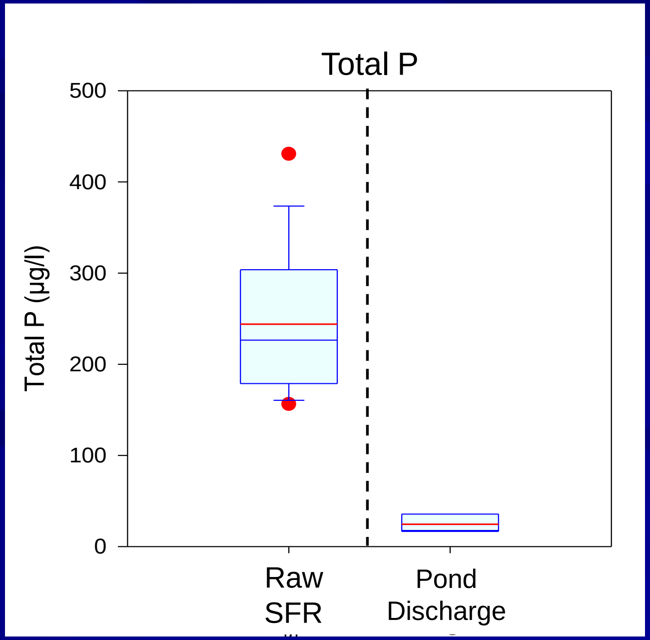
- Physical Processes
  - Gravity settling – primary physical process
    - Efficiency dependent on pond geometry, volume, residence time, particle size
  - Adsorption onto solid surfaces
- Biological processes
  - Uptake by algae and aquatic plants
  - Metabolized by microorganisms
- Chemical processes
  - Co-precipitation by metal oxides

Comparison of Residential Runoff and Wet Detention Pond Discharges







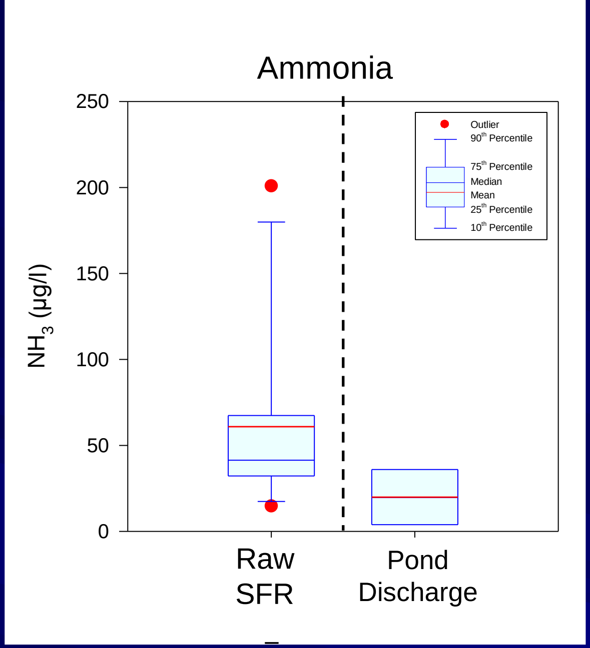


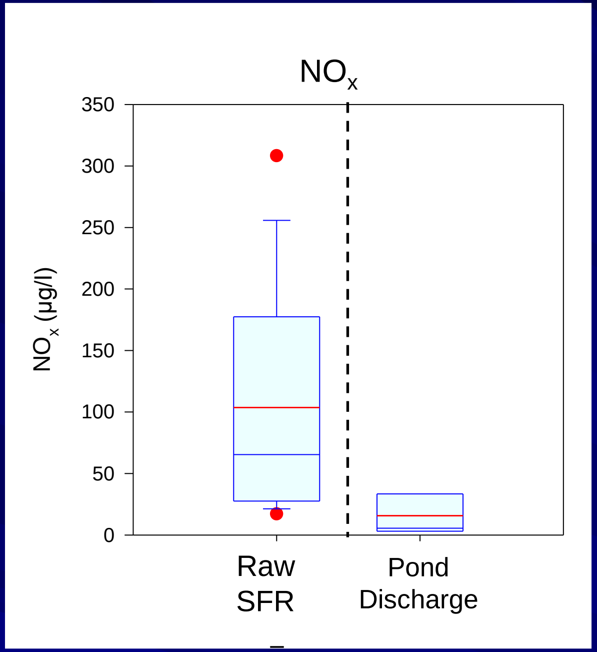
Total P

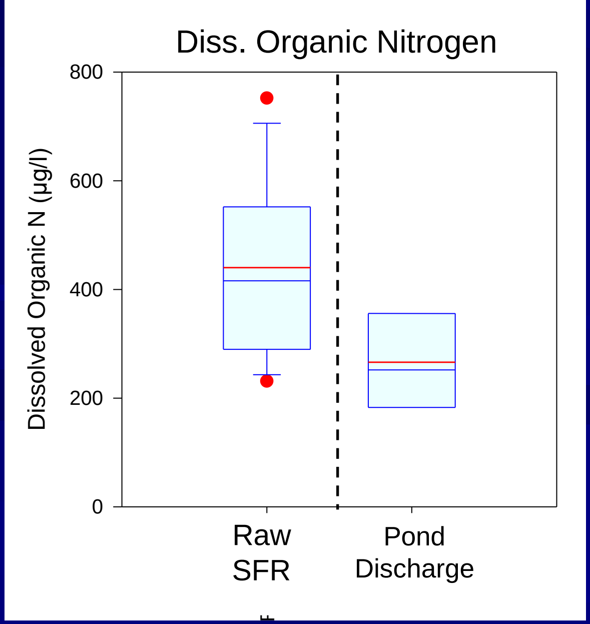
- Most ponds in data had longer detention times (> 100 days)
- Concentrations of all phosphorus species are reduced in wet ponds

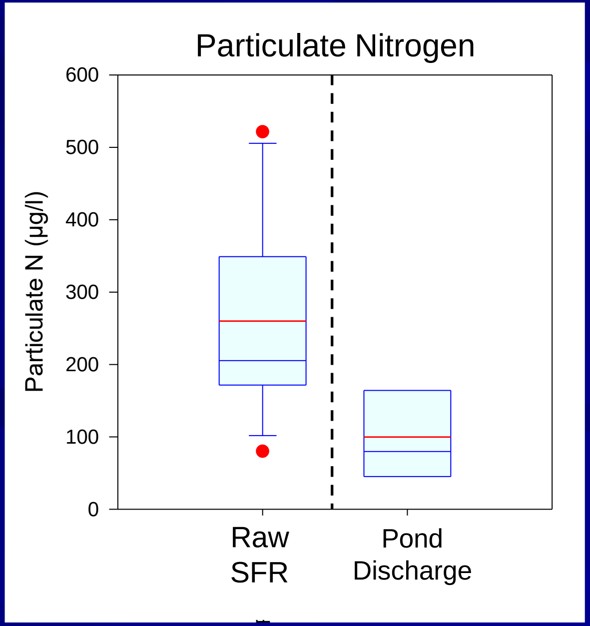
Comparison of Residential Runoff and Wet Detention Pond Discharges

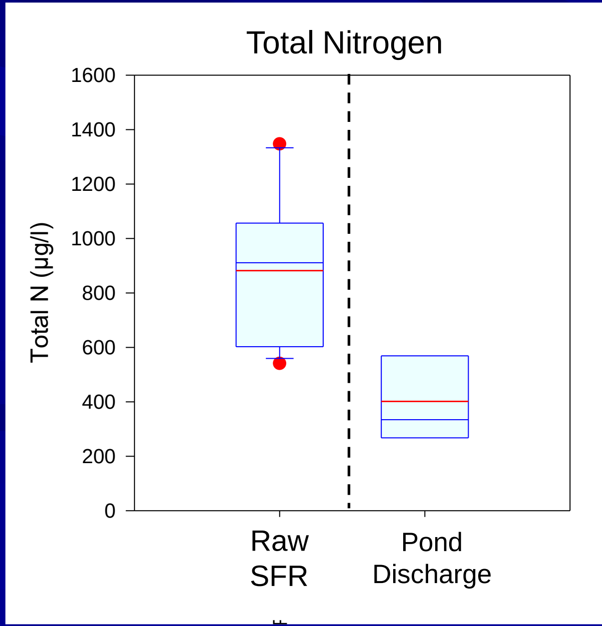
Total N







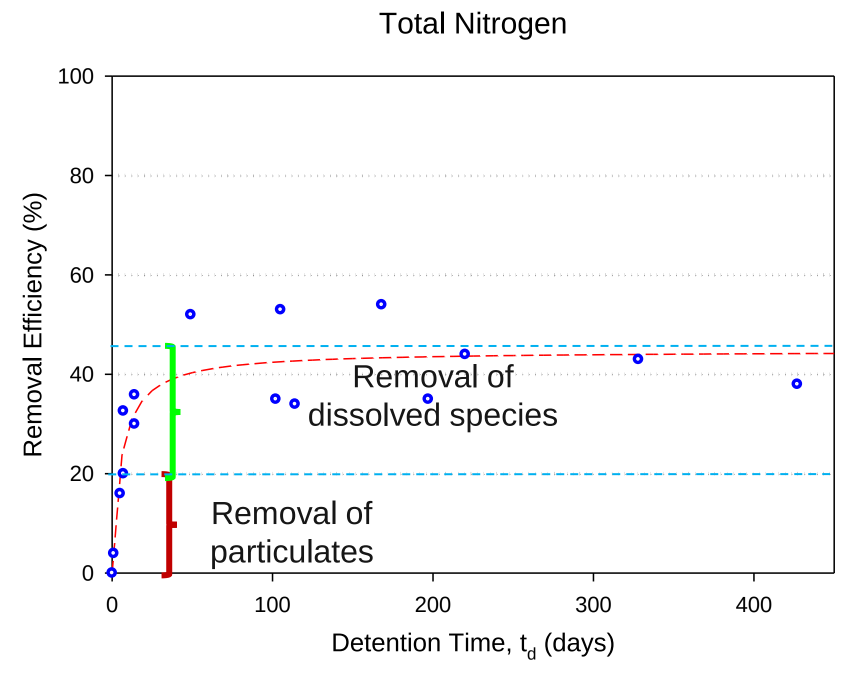


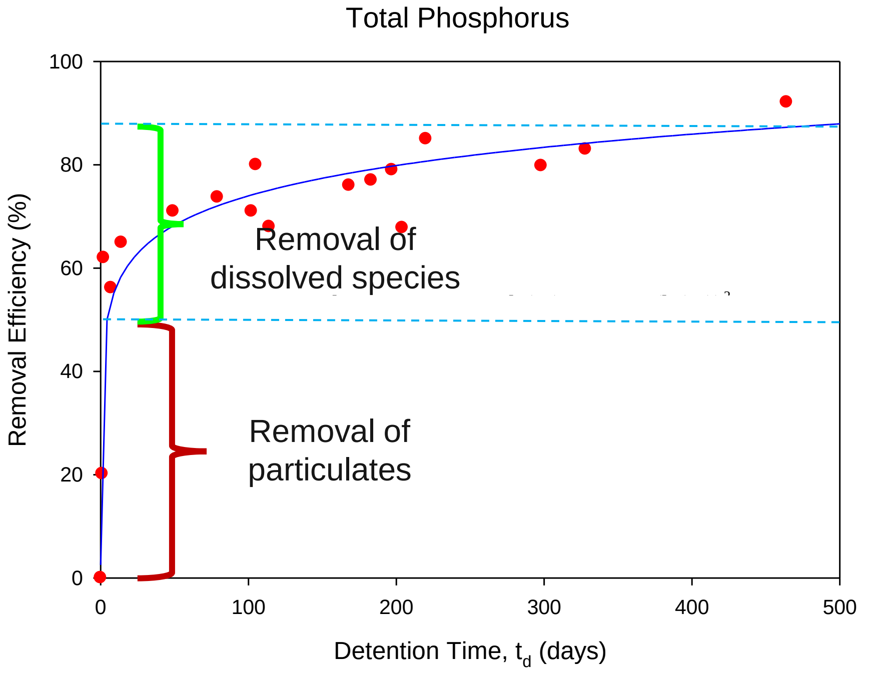


- Concentrations of all nitrogen species are reduced in wet ponds, especially for inorganic nitrogen (ammonia + nitrate) due to biological assimilation

Nutrient Removal Relationships for Wet Ponds

Nutrient Removal is Primarily a Function of Detention Time





- These removal equations include the impacts from littoral zones
- There is no additional “bump” by having littoral for having littoral zones since they are already in the equations
- There should be a 10% subtraction in efficiency if a littoral zone is not present

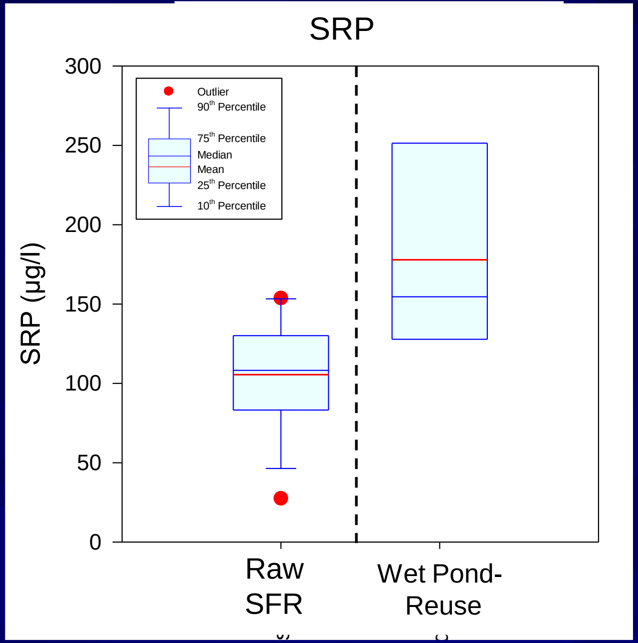
- These relationships were developed for <u>untreated</u> runoff only
- The equations are not directly applicable when the runoff gets pre-treatment
- Removal of dissolved pollutants is a function of concentration
  - Removal rates decrease as the water column concentration decreases
  - Removal stops when Irreducible concentration is reached

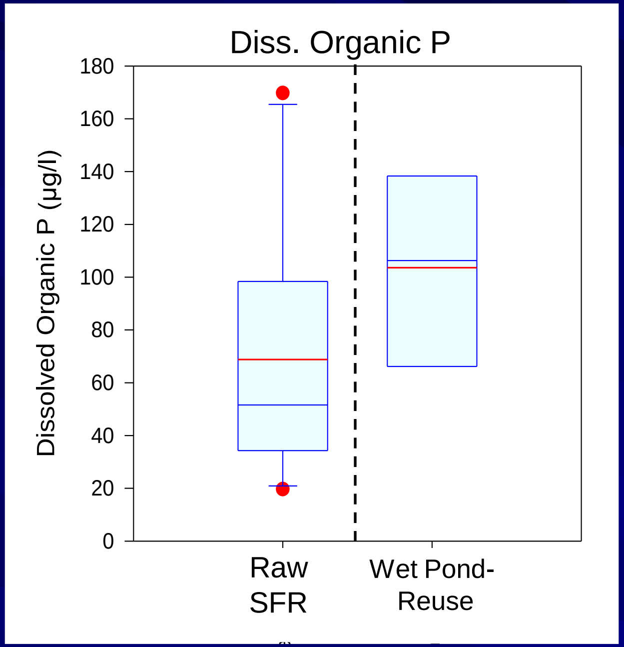
Wet Detention Pond Discharge Concentrations

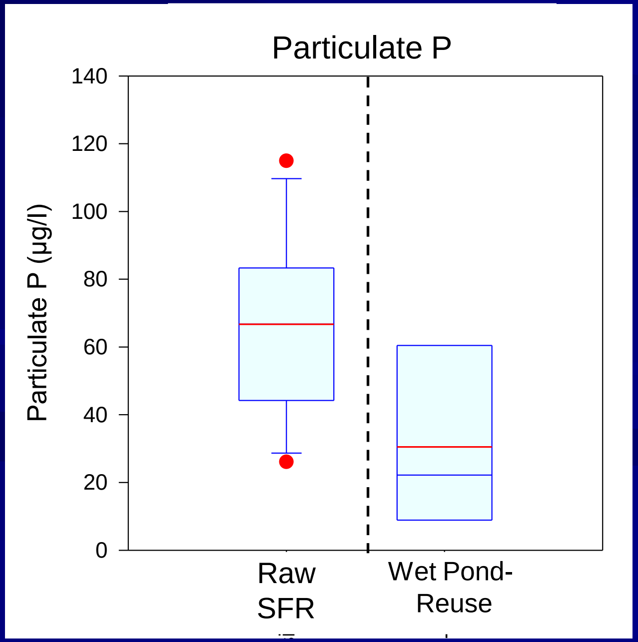
Parameter	Units	Pond Discharge
pH	s.u.	6.87
Alkalinity	mg/L	43.4
Conductivity	µmho/cm	151
Ammonia	µg/L	20
NOx	µg/L	16
Diss.Org. N	µg/L	266
Part. N	µg/L	100
Total N	µg/L	401
SRP	µg/L	6
Diss.Org. P	µg/L	9
Part. P	µg/L	9
Total P	µg/L	24
Turbidity	NTU	2.0
TSS	mg/l	2.3

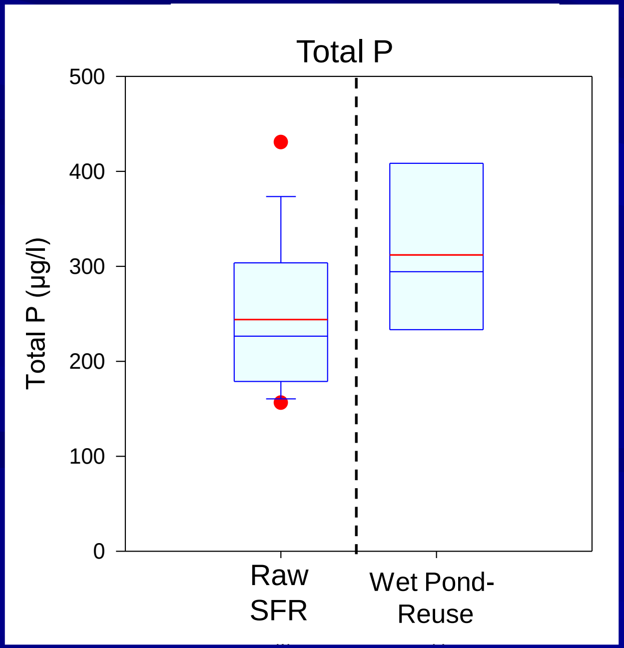
- Extremely low concentrations of inorganic nitrogen
  - Ammonia and NOx concentrations near limit of uptake
- Diss. Organic N is the largest remaining nitrogen species
- Extremely low concentrations of SRP
  - Near limit of uptake ability
- Low concentrations of TSS
- Nutrient concentrations too low for any significant additional removal
  - Irreducible concentrations
    - Total N ~ 400 ug/l
    - Total P ~ 10-15 ug/l

Comparison of Wet Detention Pond Discharges in Watersheds with and without Reuse Irrigation









Total P

- Phosphorus concentrations for most parameters in the pond discharge are higher than typical raw residential runoff
- Requires a much larger runoff treatment volume to achieve post<pre
- May not be possible on wet sites
- Reuse irrigation requirements mean that developer is subsidizing sewage disposal
- Reuse may not be compatible with the new Stormwater Rule

Wet Detention Enhancement - Floating Islands

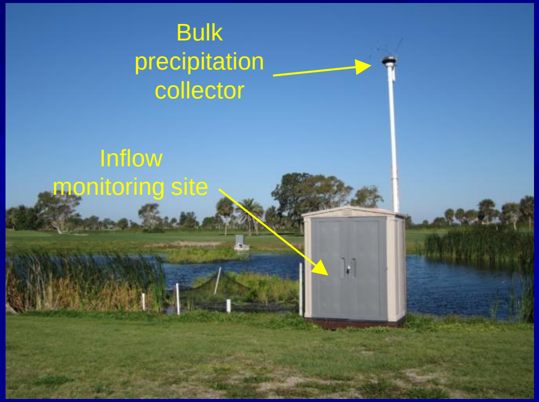
Adding plants to mats

Dragging mats to selected location

Grown plants in mat

Root mass at end of study

Root mass under mat at end of study



Inflow monitoring site

- Elevated water column nutrient concentrations due to reuse irrigation
- Achieved ~ 10% concentration reduction for TP and 12% increase for TN
- Best for applications with elevated nutrients

Typical Wet Pond Concentrations

Parameter	Units	Pond Discharge
Ammonia	µg/L	20
NOx	µg/L	16
Diss.Org. N	µg/L	266
Part. N	µg/L	100
Total N	µg/L	401
SRP	µg/L	6
Diss.Org. P	µg/L	9
Part. P	µg/L	9
Total P	µg/L	24

- Available inorganic nutrient concentrations are too low for additional uptake
- Minimum nutrient uptake concentrations
  - SRP: > 10 ug/l (0.01 mg/l)
  - Nitrogen: >130 ug/l for TIN

Factors Impacting Nutrient Concentrations in Wet Ponds

- Waterfowl can contribute significant additional nutrient loadings

Waterfowl Loadings

Cattails

- Cattails can contribute nutrients and sediment through senescence

- Removes nutrient uptake through littoral zones

Managing Ponds as Amenities

Use of Copper Sulfate

- Copper sulfate inhibits growth of plants and algae and reduces pond performance

- None of these activities are included in wet detention removal models

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 more likely to be bound into organic molecules
    - Unavailable for algal uptake and removal
  - Substantially reduces effectiveness of wet ponds
    - ~ 10-15% for TN and TP

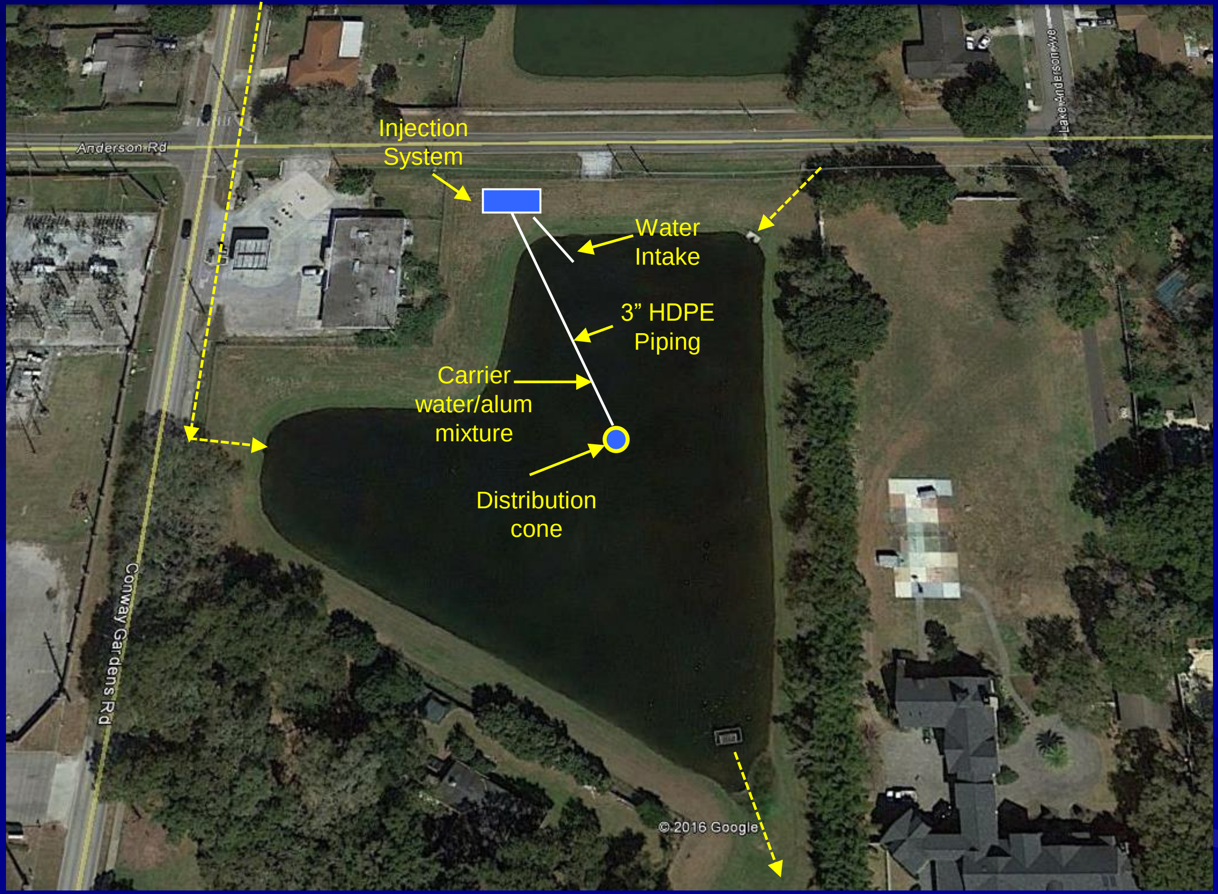
Wet Detention Pond Enhancement

Source	Units	Pond Discharge
Raw Runoff	µg/L	105
Swale	µg/L	50
Wet Pond	µg/L	6

- Aeration
  - Generally not necessary
  - Oxygen does not limit biological removal mechanisms
- Littoral zones
  - Plants themselves provide little nutrient uptake, but the plant stalks and leaves do support a diverse biological community
  - Increase removal of TN and TP by about 10%
- Beneficial bacteria for muck removal
  - Don’t waste your money
- Slow rate alum addition

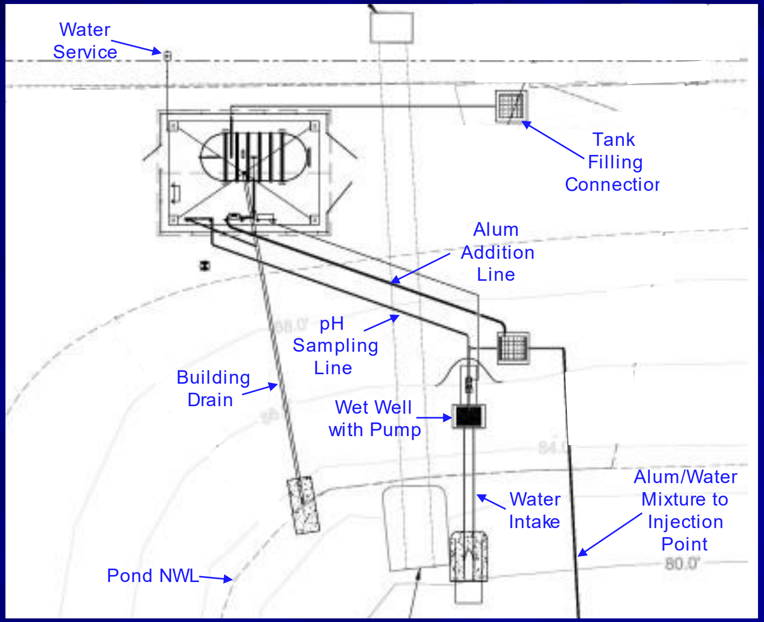
Wet Detention Enhancement - Alum Addition System

- Aluminator system is designed to treat the pond water rather than the runoff inflow
- Alum addition is based on the water column pH
  - Increases in nutrients result in increases in algal growth which results in a proportional increase in pH
  -
  - pH is used as a surrogate for nutrient concentrations
  - Alum is added to achieve a pre-set pH value of 6.5 or less
  - System is designed to distribute floc throughout the water column and maximize the contact time between the floc and water
  - Floc containing nutrients settles on the pond bottom
- System provides a low-cost enhancement in pond performance

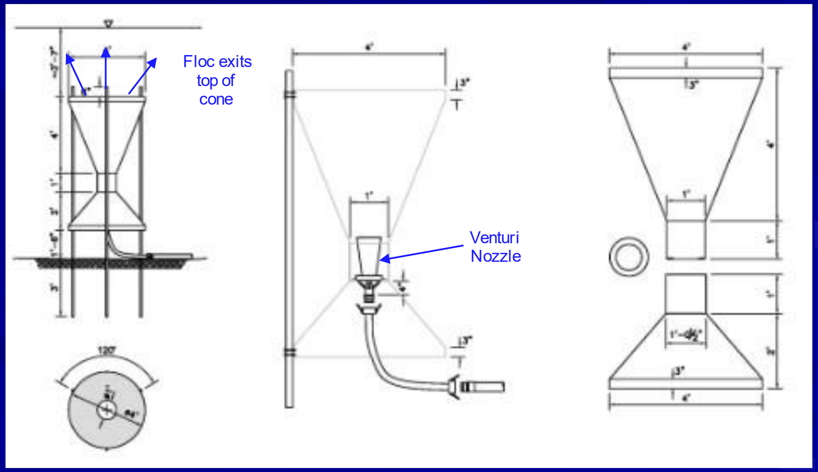


Aluminator System Overview

- Required modification to the stormwater permit for the pond
- Construction cost ~ $220,000
- Alum use estimated to be ~ 5,200 gal/year



Distribution cone



Lake Anderson Aluminator System

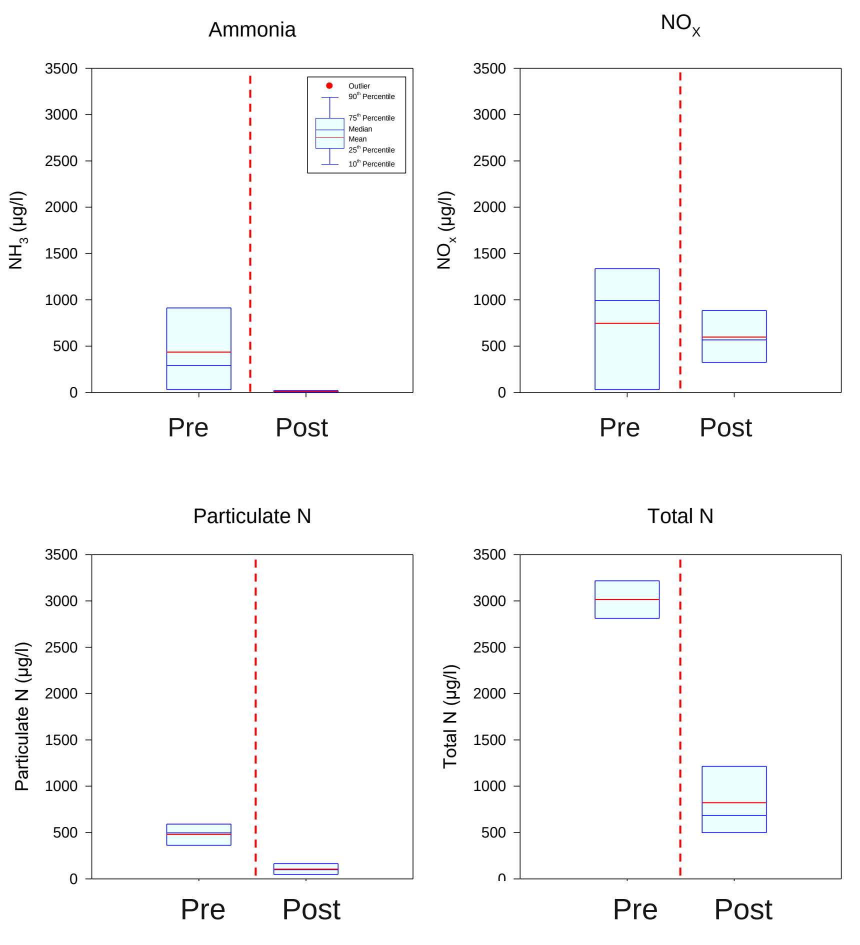
Control System

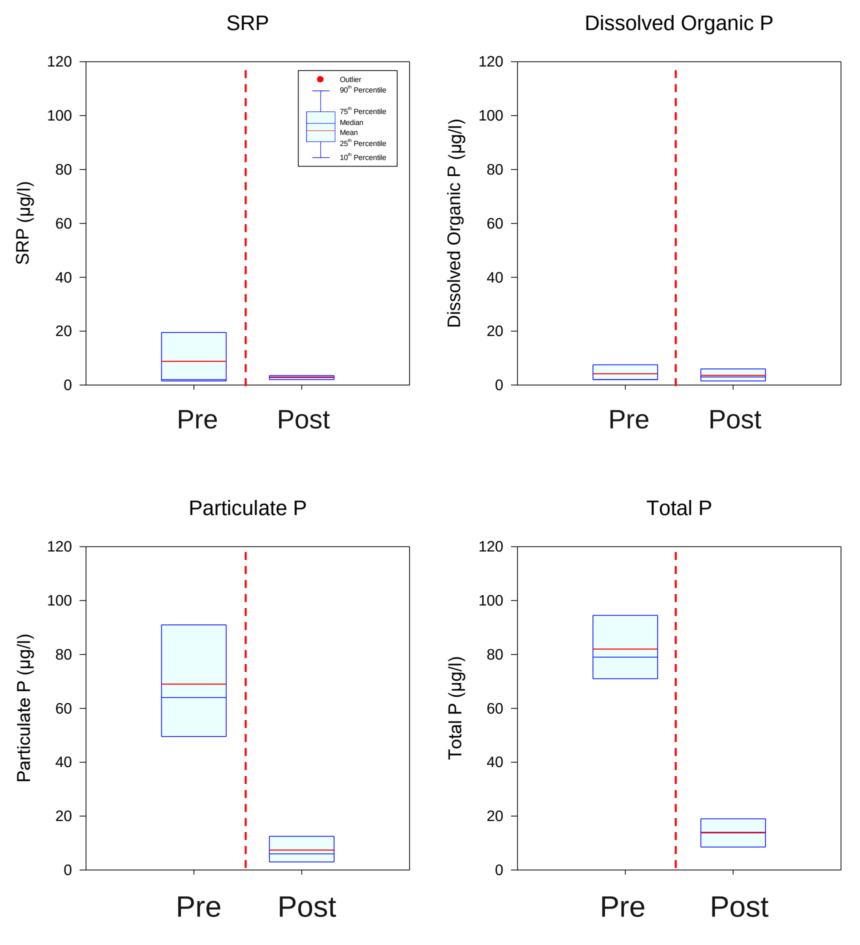
Venturi for Air Addition

Pond following startup

Fish bedding along pond bank

Lake Anderson Pond System Performance



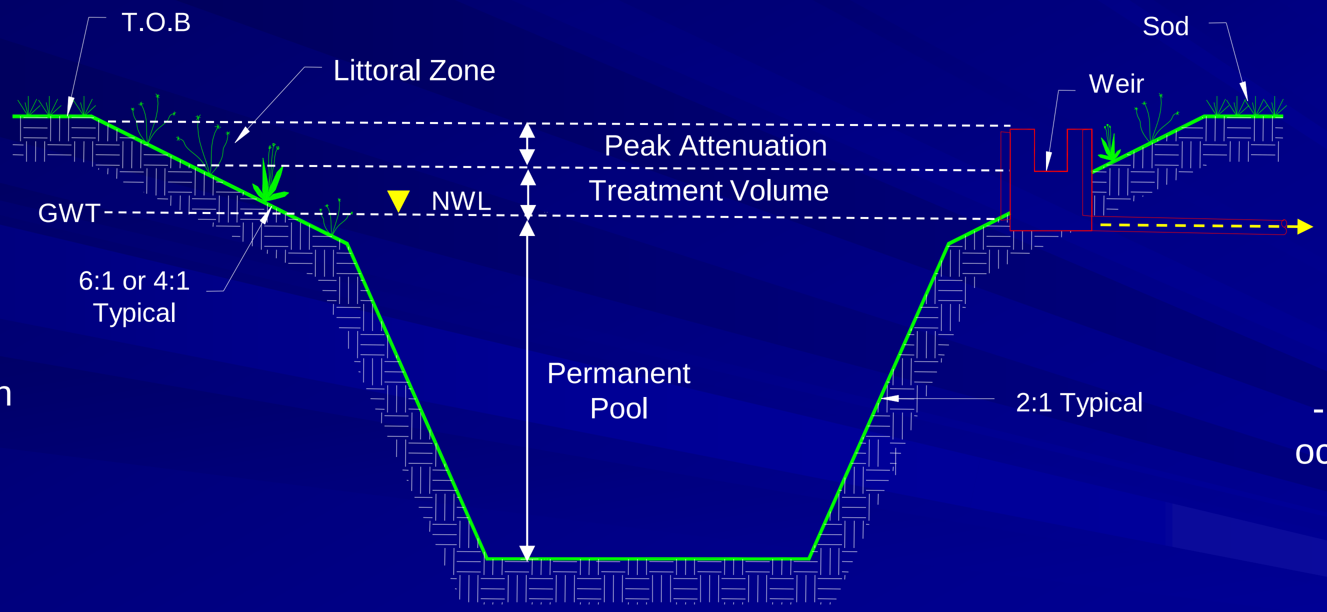


- System increased overall pond efficiency to 80% for TN and 85% for TP
- Combined with reuse irrigation, efficiency can be increased to > 95%

6. Wet Retention Ponds

- Combine aspects of both retention and wet detention
- Required treatment volume is infiltrated into groundwater
- Discharged water receives benefit of concentration reductions is permanent pool
- Somewhat popular in early days of stormwater management

- Runoff infiltrates through pond sides and pond bottom

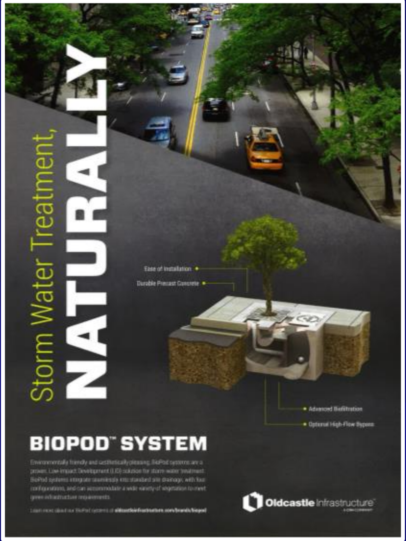


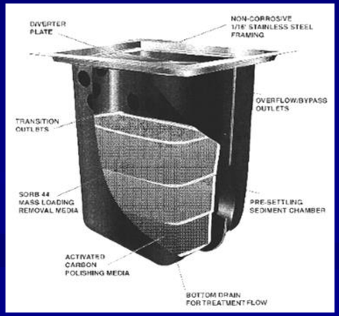
- Biological processes occur in permanent pool

- Removal efficiency based on runoff volume infiltrated
- Reduced concentrations in water discharged from pond
- Provides an amenity rather than a dry pond
- Increased efficiency compared with dry pond

7. LID Systems

a. Limitations of LID Systems

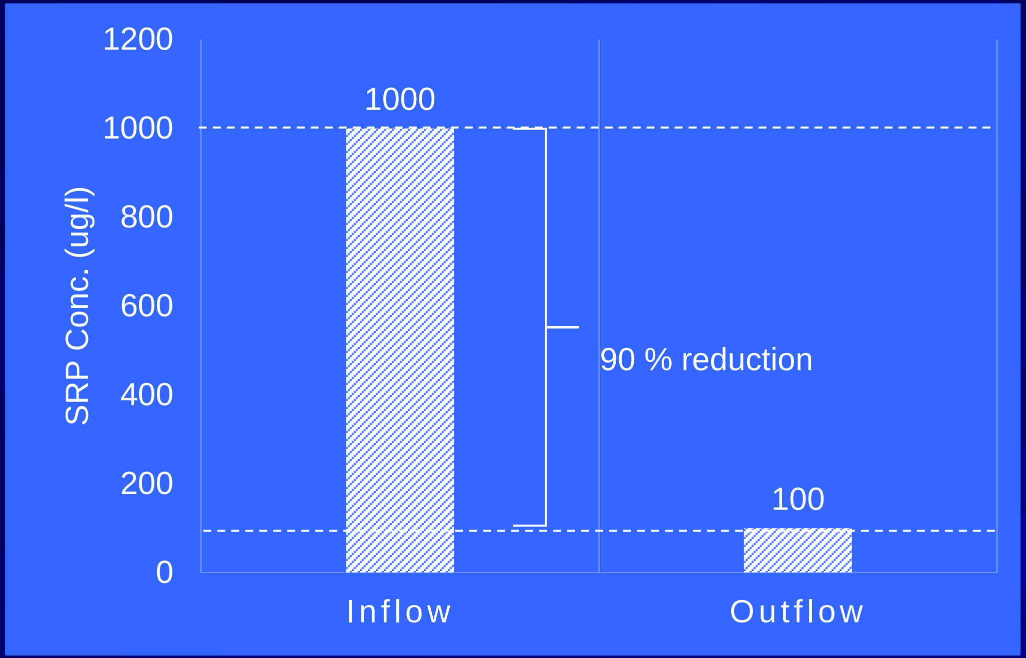




- LID systems are usually designed for small catchments with small loadings
- Most LID devices are not designed with Florida conditions in mind
- Florida rainfall depths and intensities often exceed the capacity of devices designed for northern climates
- Concentration based removal systems require a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

7. LID Systems – con't.

b. Manufacturer's Removal Claims



- Many product testing studies are conducted using concentrations much higher than observed in runoff
  - Wastewater technologies
  - Agriculture
- Product efficiency claims are commonly based on the most favorable testing results
- Products which work for wastewater or other high nutrient streams may not work on runoff
  - Generally, runoff concentrations are an order of magnitude lower than wastewater
- Similar products have been proposed for metals removal
  - Tested at elevated concentrations
- When evaluating a new product always ask for information on the concentrations used in the testing

- For the example above, a 90% SRP reduction was achieved in product testing
- Actual removal would be near zero

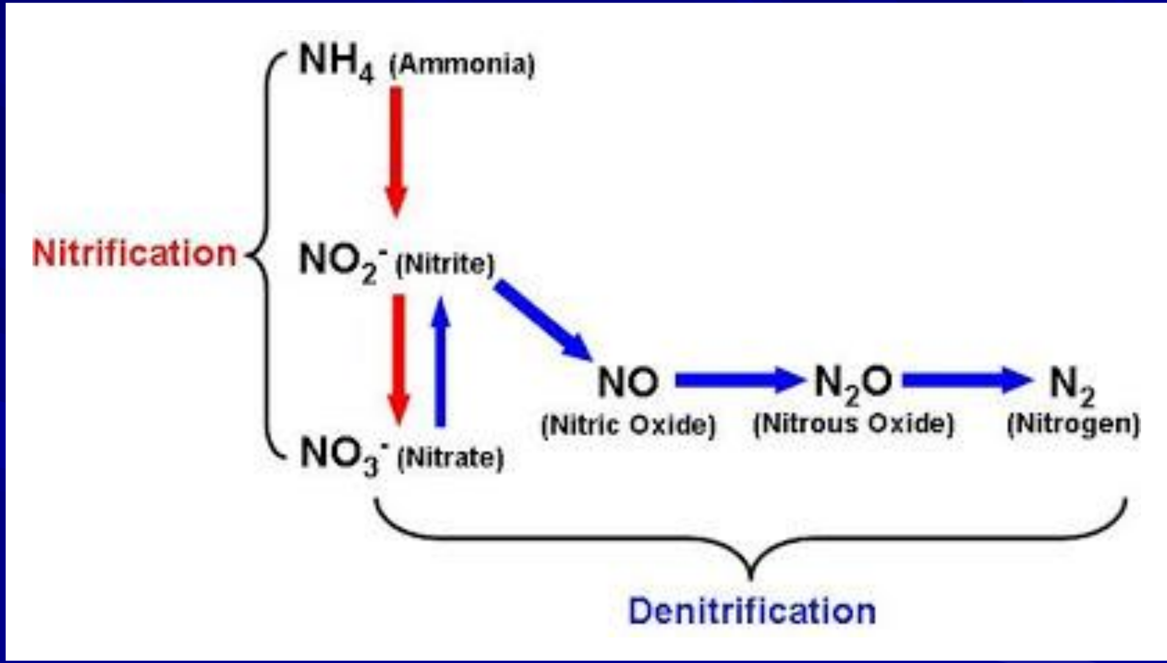
Source	SRP (µg/L)
Raw Runoff	105
Swale	50
Wet Pond	6

8. Denitrification

- BMP designed to reduce nitrogen concentrations
- Used mostly in filter bed systems
  - Beneath ponds
  - Dedicated structures

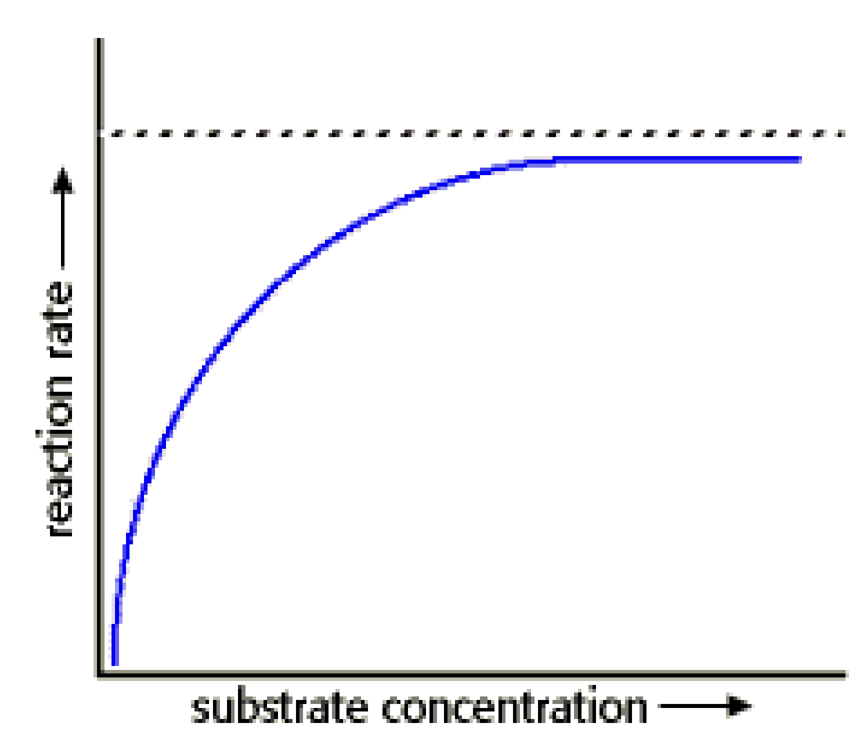
Denitrification

- 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 (E_h) of -100 to -200 mV
- Proper environmental conditions
  - pH
    - Optimum range: 7.0 – 8.5
  - Temperature
    - Optimum range: 10-25ºC
  - Water-based environment



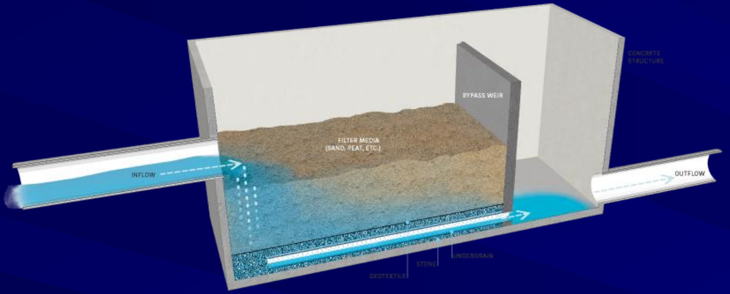
Denitrification Requirements – cont.

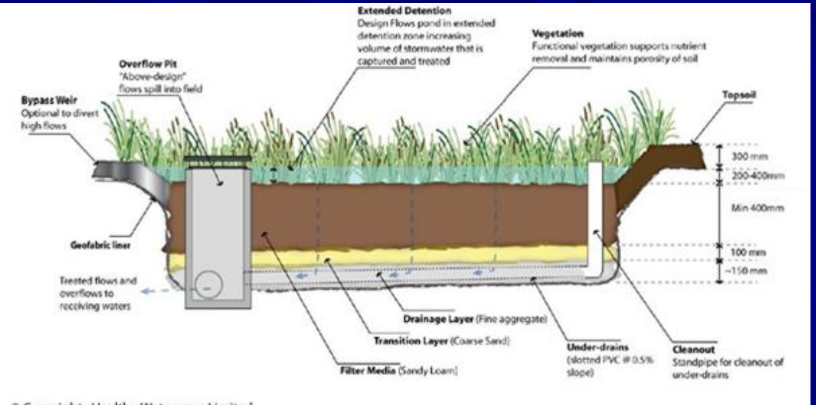
- Denitrification reaction is a first-order concentration limited reaction
  - Rate of denitrification decreases logarithmically as nitrate concentrations decrease
  - Slow process
    - ~ 90% complete in 3-4 days
- Nitrate concentration is the single most important factor regulating denitrification rate
  - Optimum denitrification rates: NO_3^- concentrations 280 – 840 ug/L (Thomas, et al, 1994
  - Minimum concentration ~ 100 ug/l (0.01mg/l)
- 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
- Important to verify adequate NO_x prior to design



Parameter	Units	Curb & Gutter	Pond Discharge
Ammonia	µg/L	61	20
NOx	µg/L	104	16

9. Adsorption Media





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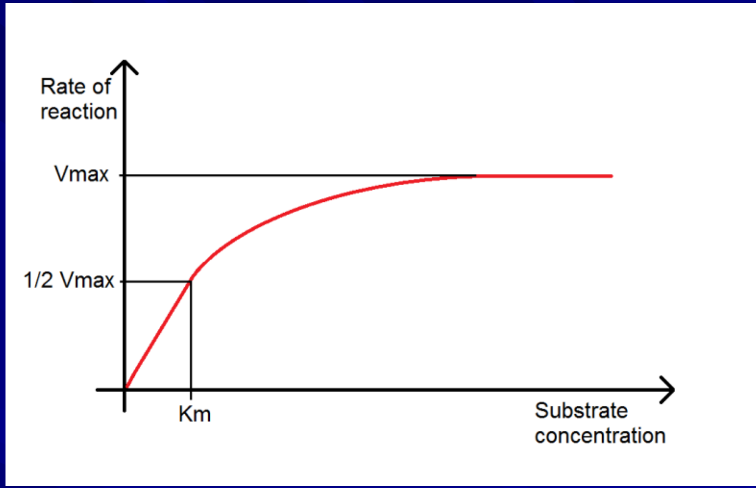
(Construction and Establishment Guidelines V1.1 April 2010; Image 3.1, Typical cross section through a bioretention system)

Description

- Removal of stormwater pollutants by sorption onto solid surfaces
- Removal of particulate matter by entrapment
- Media are developed to maximize removal of target pollutants
- Typical media include
  - Sand
  - Clay
  - Carbon sources (compost, sawdust, cardboard, paper, agricultural residue, etc.)
  - Lime rock
  - Mulch

Adsorption Media – con't.

- All sorption processes are concentration based
  - Sorption rates increase as concentrations increase
  - At low concentrations, the rate decreases until it stops
  - Minimum uptake concentrations vary depending on media type and constituent to be removed
  - All media have a minimum required concentration
- Manufacturer's efficiency claims often lack info on the range of concentrations treated
- Product testing conducted by UCF on Bold & Gold
- Media composition
  - 50% sand in natural soil
  - 30% tire crumb
  - 20% sawdust



Nitrate Removal			SRP Removal		
Inflow Conc. (ug/l)	Outflow Conc. (ug/l)	Eff. (%)	Inflow Conc. (ug/l)	Outflow Conc. (ug/l)	Eff. (%)
382	22	94.2	361	50	86.1
1,269	23	98.2	785	68	91.4
2,529	21	99.2			

Parameter	Units	Pond Discharge
NOx	µg/L	16
SRP	µg/L	6

10. Wetland Stormwater Treatment

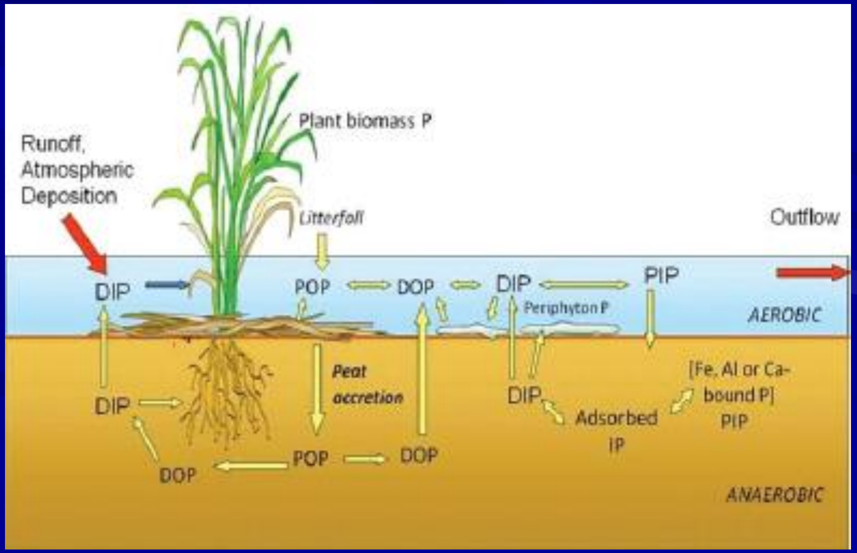
- Effectiveness of wetland stormwater treatment depends on the type of wetland used

Shallow hardwood wetland

Shallow vegetated wetland

Shallow Hardwood Wetlands – con't.

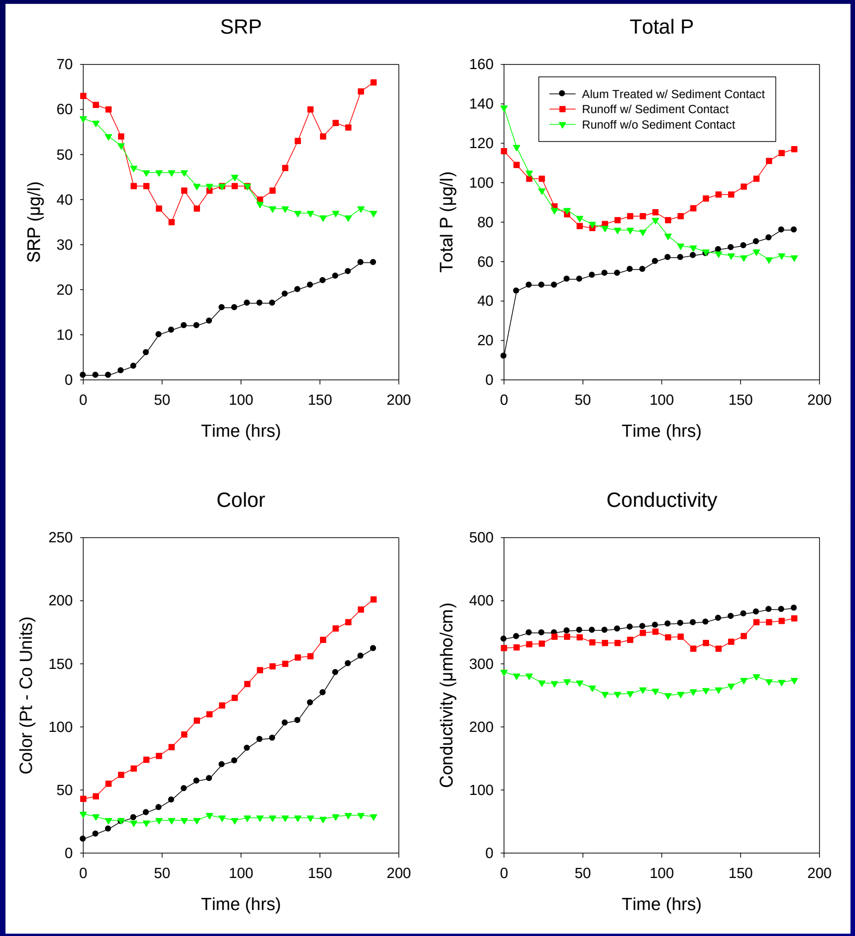
- Shallow waterbody with nutrient rich, acidic, and typically anoxic soils
- Used extensively by the wastewater industry to "polish" treated wastewater
  - Runoff nutrient concentrations are ~ 1 order of magnitude lower than wastewater
- Water quality of wetland discharges is based primarily on an equilibrium between the soils and the water column
  - First-order reaction rate based on concentration
  - Equilibrium reached in 3-7 days
  - High concentrations will be reduced
  - Low concentrations will be increased

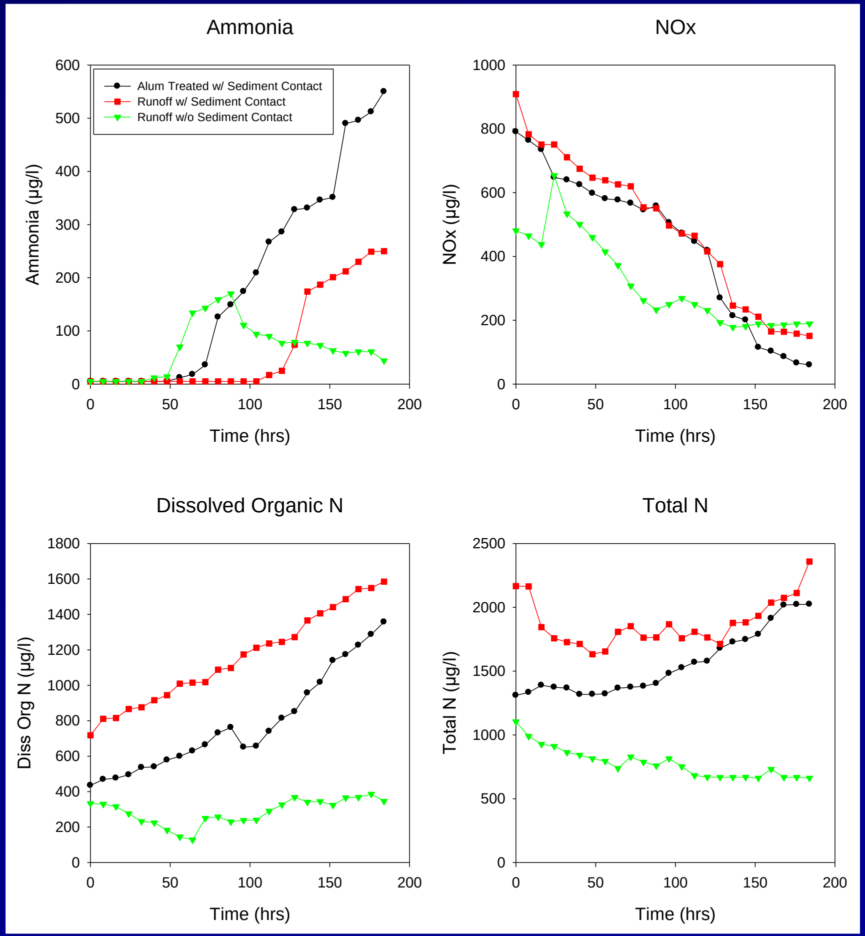


Nutrient Equilibrium in Hardwood Wetlands

- 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
- Historical wetland monitoring data indicate similar values

Nutrient Equilibrium in Herbaceous Wetlands

- Shallow waterbody with dense herbaceous vegetation
- Plant uptake is small
- 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 below surface, but have little contact with water
- May achieve low concentrations

Shallow Herbaceous Wetland

11. Vegetated Stormwater Treatment Areas

- Nutrient uptake 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 nutrient 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%

- Organic soils released both TN and TP in excess of plant uptake
- Vegetated STAs should be constructed without supplemental organic soils

Summary

- Concentration reductions are an important part of stormwater management systems
  - Two most common concentration reduction methods
    - Biological uptake
    - Adsorption media
- Removal processes observe first order rate kinetics
  - Removal rate increases and decreases as concentrations increase and decrease
  - Biological, physical, and chemical processes require minimum concentrations to initiate
  - Likely concentrations of target pollutants must be considered when selecting a BMP
- Beware of manufacturer's marketing claims
  - Literature removal efficiencies are often based on elevated nutrient concentrations where removals are greatest
  - Ask about product performance at typical stormwater concentrations
- Techniques which are successful in wastewater may not be transferable to stormwater
  - Wastewater nutrient concentrations are about 1 order of magnitude greater than stormwater
- Field testing is essential prior to implementing retrofit BMPs

Questions?