Harper Methodology Workshop
Afternoon Session

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&

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Water Quality Engineering

Afternoon Session Topics

5. Infiltration BMPs
6. Wet Detention
7. Dry Detention
8. Gross Pollutant Separators
9. Street Sweeping
10. Alum Treatment
11. Denitrification
12. BMP Selection Summary
13. BMPs in Series
14. Common Mistakes in BMP Selection
15. Pre vs. Post Design Example

Part 5

Infiltration BMPs

Infiltration/Retention Systems

Description

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

- Removal effectiveness is a function of the runoff volume lost

Purpose

- Reduce total runoff volume
- Reduce pollutant loadings

Pollutant Removal

- Percolation, evaporation
- Filtering and adsorption

Definitions

- Retention - A group of stormwater practices where the treatment volume is evacuated by either percolation into groundwater or evaporation
  - No surface discharge for treatment volume
  - Substantial reduction in runoff volume
  - Retention practices include:
    - Dry retention
    - Harvesting (Reuse irrigation)
    - Underground storage systems

- Detention - A group of stormwater practices where the treatment volume is detained for a period of time before release
  - Discharge of treatment volume over a period of days
  - No significant reduction in runoff volume
  - Detention practices include:
    - Wet detention
    - Dry detention

Common Infiltration Systems

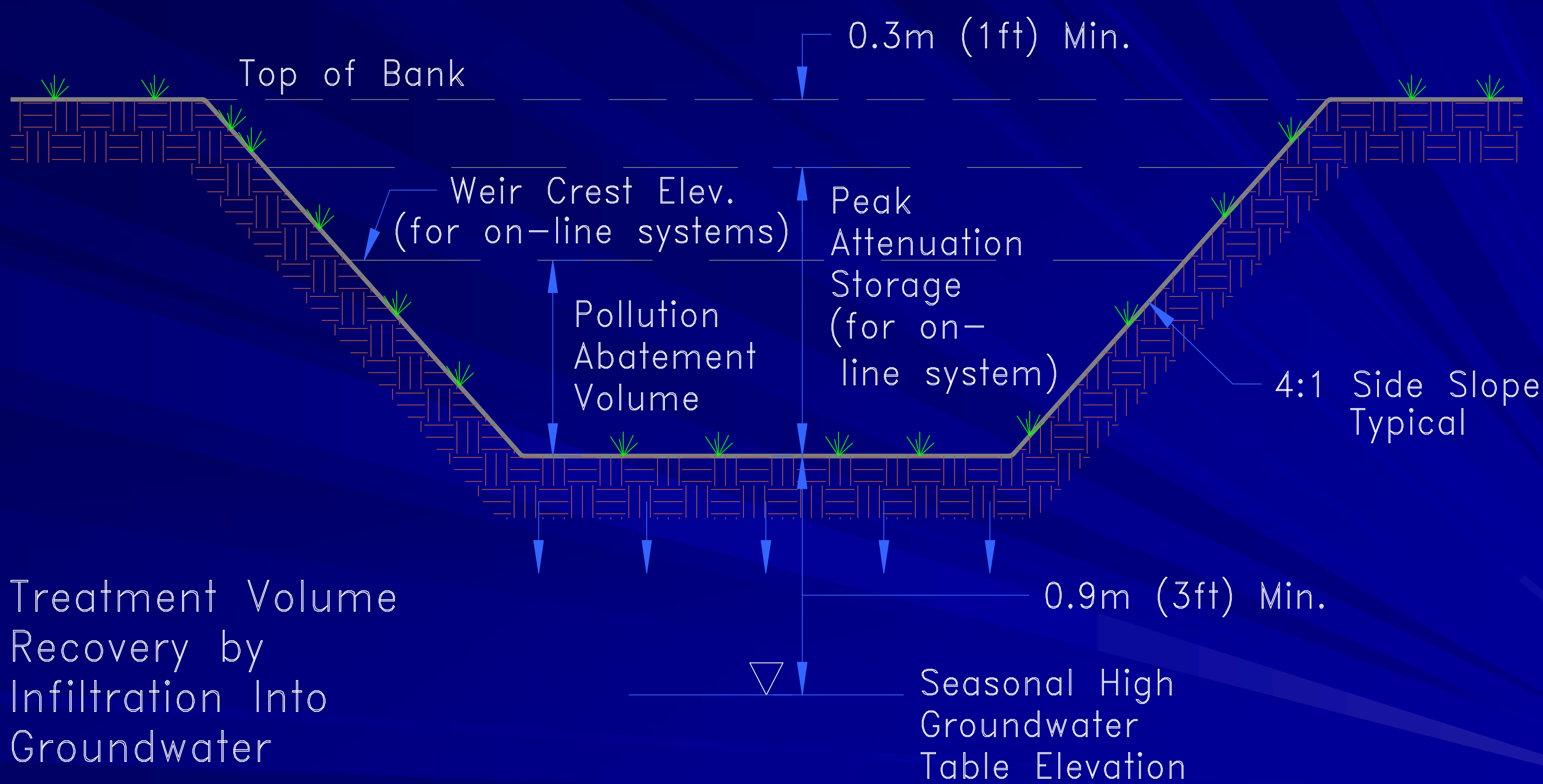

Retention Areas


Roadside Swales


Exfiltration Systems


Permeable Pavements

Dry Retention Pond
(Infiltration Pond)

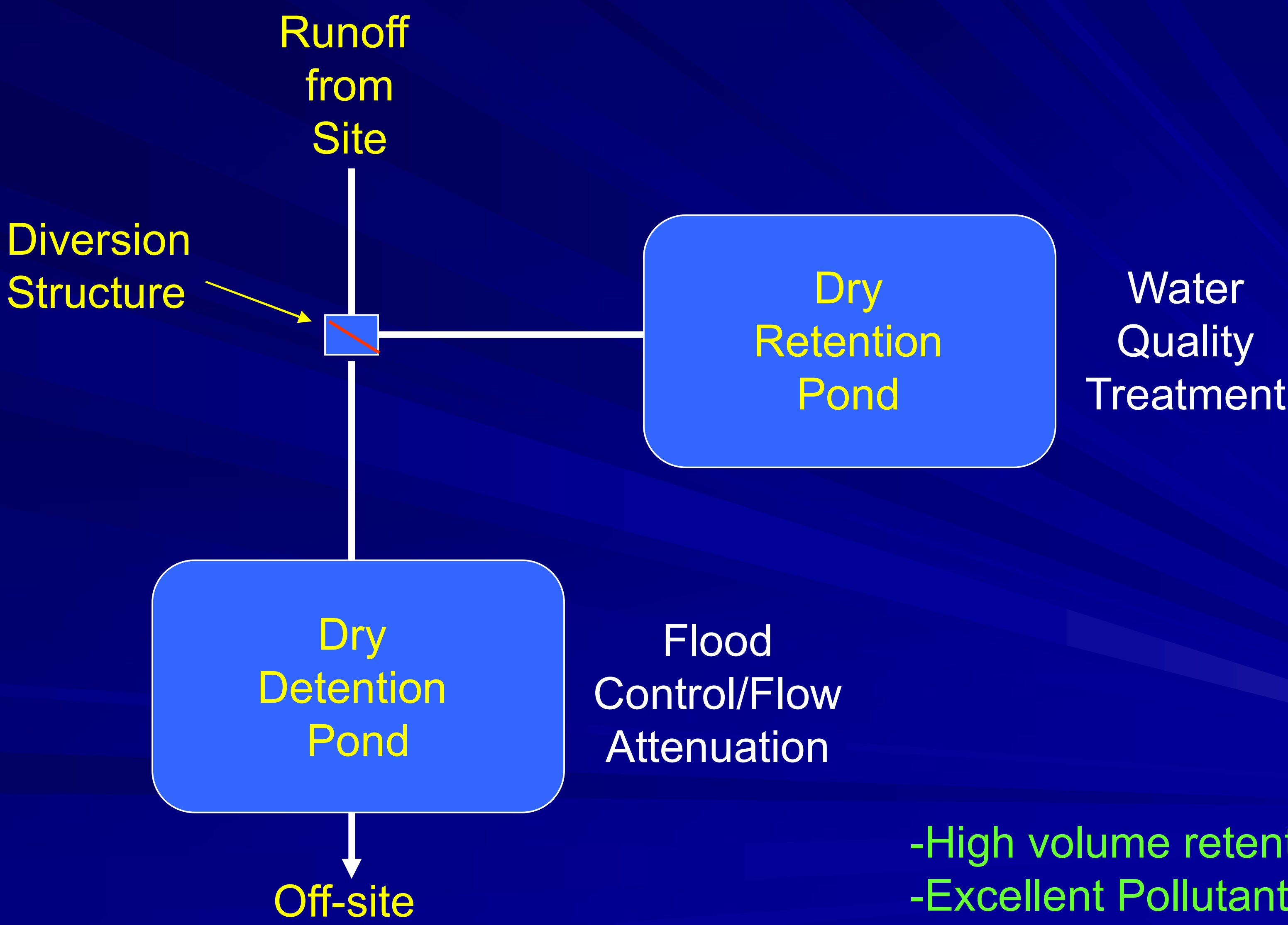


Typical design volumes: - 0.5” of runoff
- 1” of runoff
- 1” of rainfall

Dry Retention
Construction Considerations

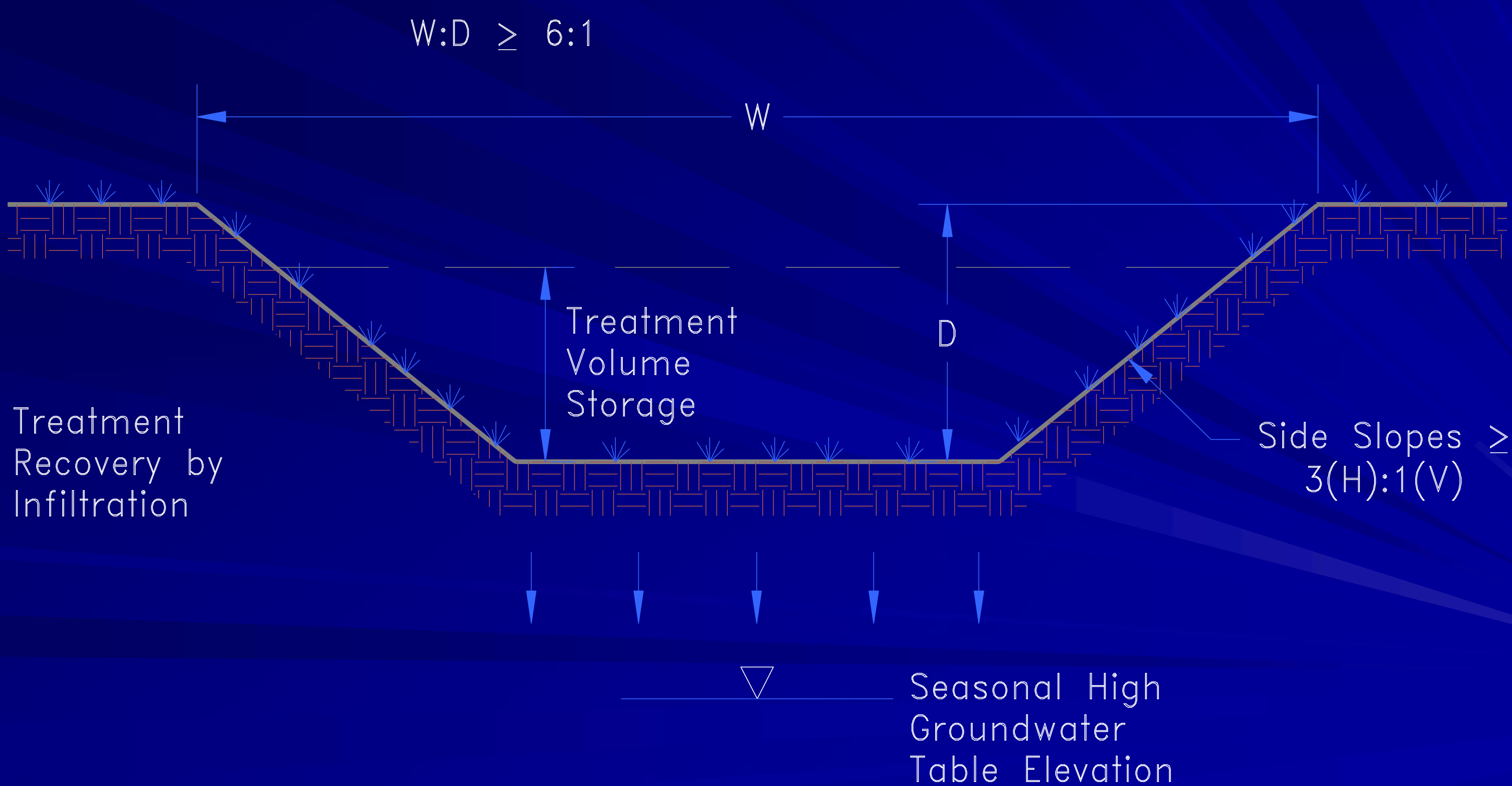
Pond bottom should be horizontal !

Off-line Retention/Detention Systems

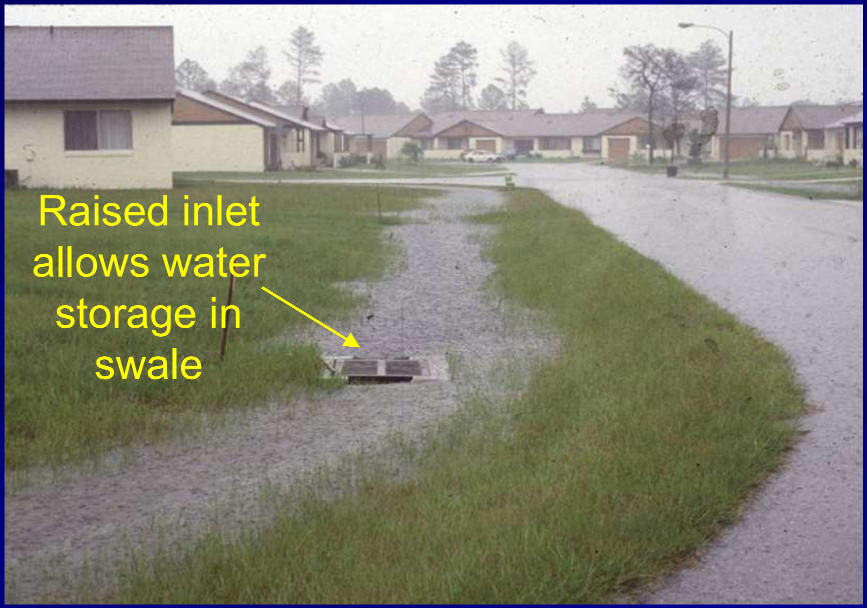


-High volume retention
-Excellent Pollutant Removal

Typical Swale Section



Roadside Swales



- Combine conveyance and treatment

- Used as linear retention systems

- Swale blocks, check dams, or raised inlets may be used to impound water for infiltration

- Large portion of the runoff infiltrates during conveyance

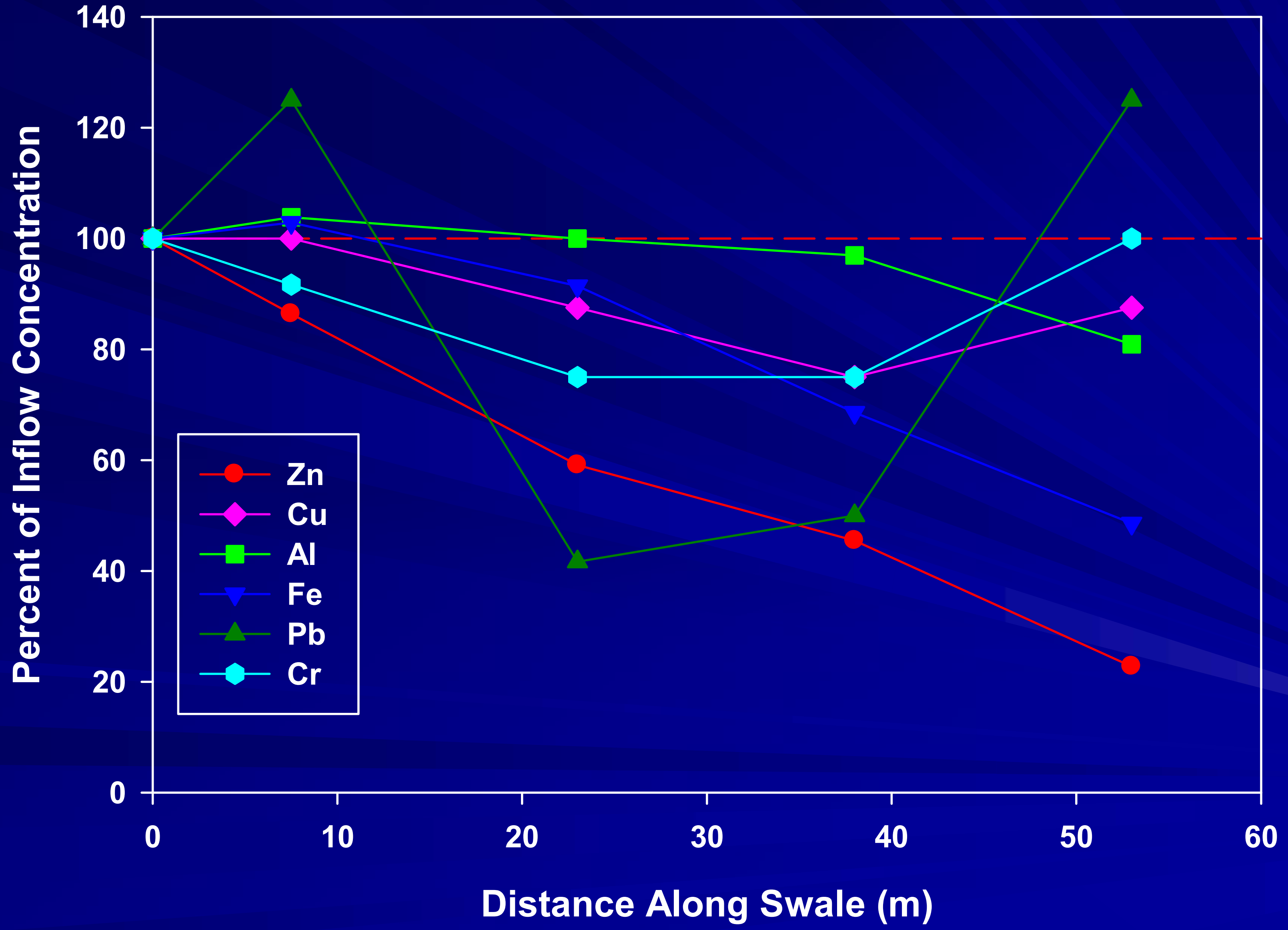
Evaluation of Grassed Swale Performance Efficiency
~ 1982-83


Water source is spiked with nutrients and metals and pumped into swale


Water runs down swale and samples and flow data are collected

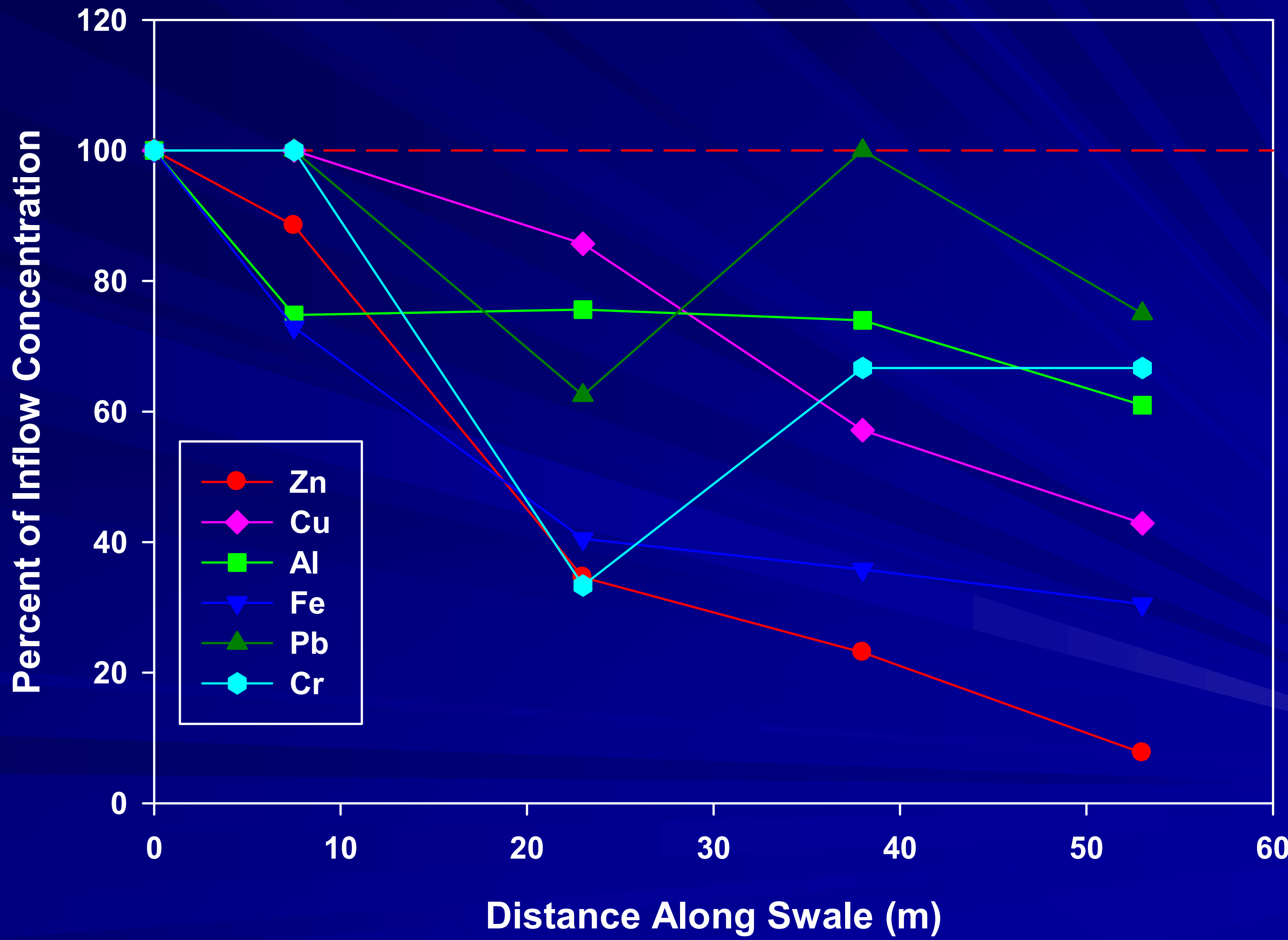
Site: Maitland Blvd.
Soils: Sandy, dry
Vegetation: Bahia Grass

Flow Velocity: 2.58 m/min (0.14 ft/sec)
Hydraulic Depth: 0.038 m (1.5 inches)
Date: 1/24/83



Site: Maitland Blvd.
Soils: Sandy, dry
Vegetation: Bahia Grass

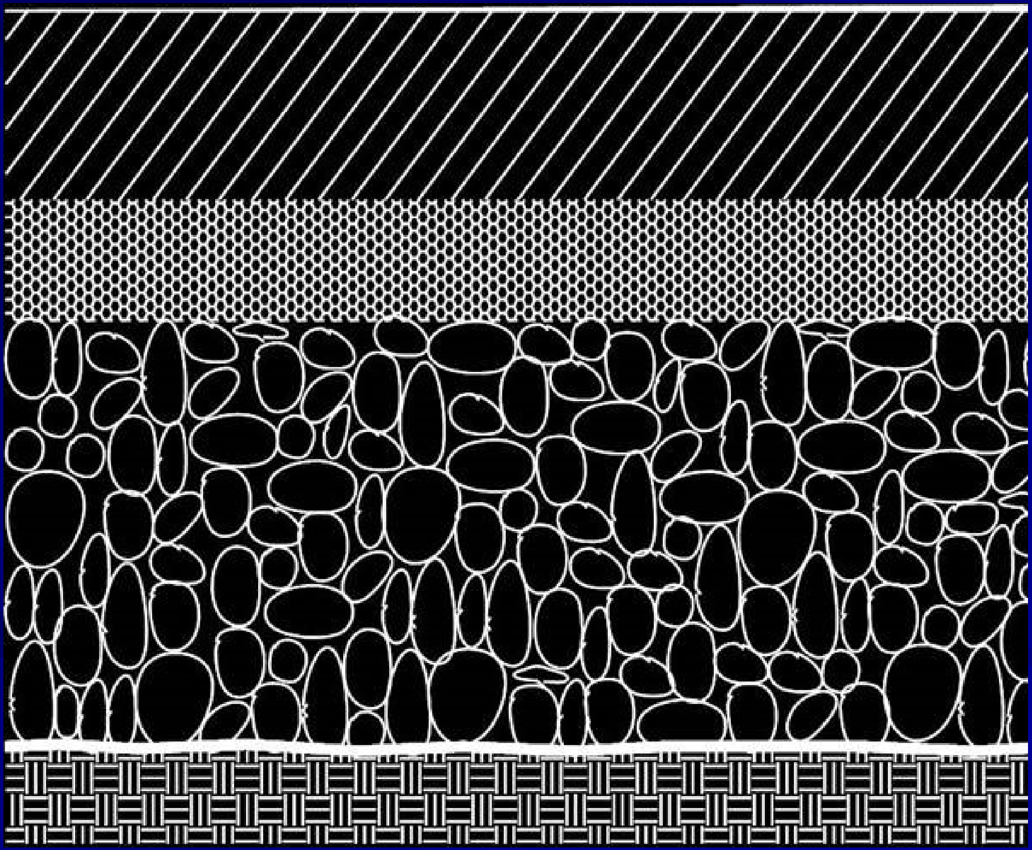
Flow Velocity: 1.37 m/min (0.07 ft/sec)
Hydraulic Depth: 0.033 m (1.3 inches)
Date: 2/07/83



Roadside Swales

- Roadside swale was equipped with swale blocks to retain runoff
  - Prevented a large portion of the roadway runoff from entering the lake
- Drainage "improvements" were installed which converted the swale to a stormsewer system
  - Eliminated runoff retention
  - Leaves previously captured in the swale now discharge to lake

Pervious Pavement



Surface Course
1/2'' to 3/4'' Aggregate mix
2.5 to 4'' thickness typical

Filter Course
1/2'' Aggregate, 2'' thick

Reservoir Base Course
1'' to 2'' Aggregate
Voids volume is designed for retention volume

Thickness based on storage required

Existing Soil
Minimal compaction to retain porosity and permeability

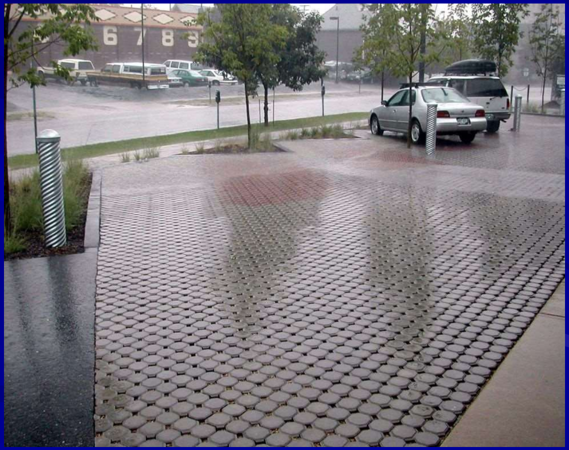
Dry Retention Options

Permeable Pavers

Permeable Asphalt

Permeable Planters

Grassed Parking Areas



Parking Areas

Dry Retention Modeling Methods

- An evaluation of the efficiency of dry retention practices was conducted by Harper and Baker (2007) for FDEP
  - Summarized in the document titled “Evaluation of Current Stormwater Design Criteria within the State of Florida”
- Based on a continuous simulation of runoff from a hypothetical 1-acre site using SCS curve number methodology
- Analysis performed for:
  - DCIA percentages from 0-100 in 10 unit intervals
  - Non-DCIA curve numbers from 30-90 in 10 unit intervals
- Runoff calculated for continuous historical rainfall data set for each of the 45 hourly Florida meteorological sites
  - Generally 30-50 years of data per site

Efficiency Modeling Assumptions

- Analysis assumes that the efficiency of an infiltration/ retention practice is directly related to the portion of the annual runoff volume retained
  - Ex. – If 50% of the annual runoff volume is retained, then the removal for TN and TP is also 50%

- Performance efficiency calculated using a continuous simulation of runoff inputs into a theoretical dry retention pond based on the entire available rainfall record for all hourly meteorological stations

- After runoff enters pond:
  - A removal efficiency of 100% is assumed for all rain events with a runoff volume < treatment volume

  - For rain events with a runoff volume > treatment volume
    - 100% removal for inputs up to the treatment volume
    - 0% removal for inputs in excess of treatment volume – excess water bypasses pond

Efficiency Modeling Assumptions – cont.

- Hypothetical drawdown curve is used to evacuate water from pond based on common District drawdown requirements
  - Recovery of 50% of treatment volume in 24 hours
  - Recovery of 100% of treatment volume in 72 hours
- Modeling assumes no significant “first flush” effect from the watershed
  - Small watersheds (< 5-10 ac.) may exhibit “first flush” for certain rain events, there is no evidence that larger watersheds exhibit first-flush effects on a continuous basis
  - No consistent research to support this concept
- Pond efficiency is equal to the fraction of annual runoff volume infiltrated
- Separate model runs were conducted for the entire period of rainfall record at each of the 45 hourly meteorological sites

Modeled Dry Retention Removal Efficiencies

Tables were generated of retention efficiency for each meteorological zone in 0.25-inch intervals from 0.25 - 4.0 inches - 16 separate tables per zone, 80 tables total

Mean Annual Mass Removal Efficiencies for 0.25-inches of Retention for Zone 1

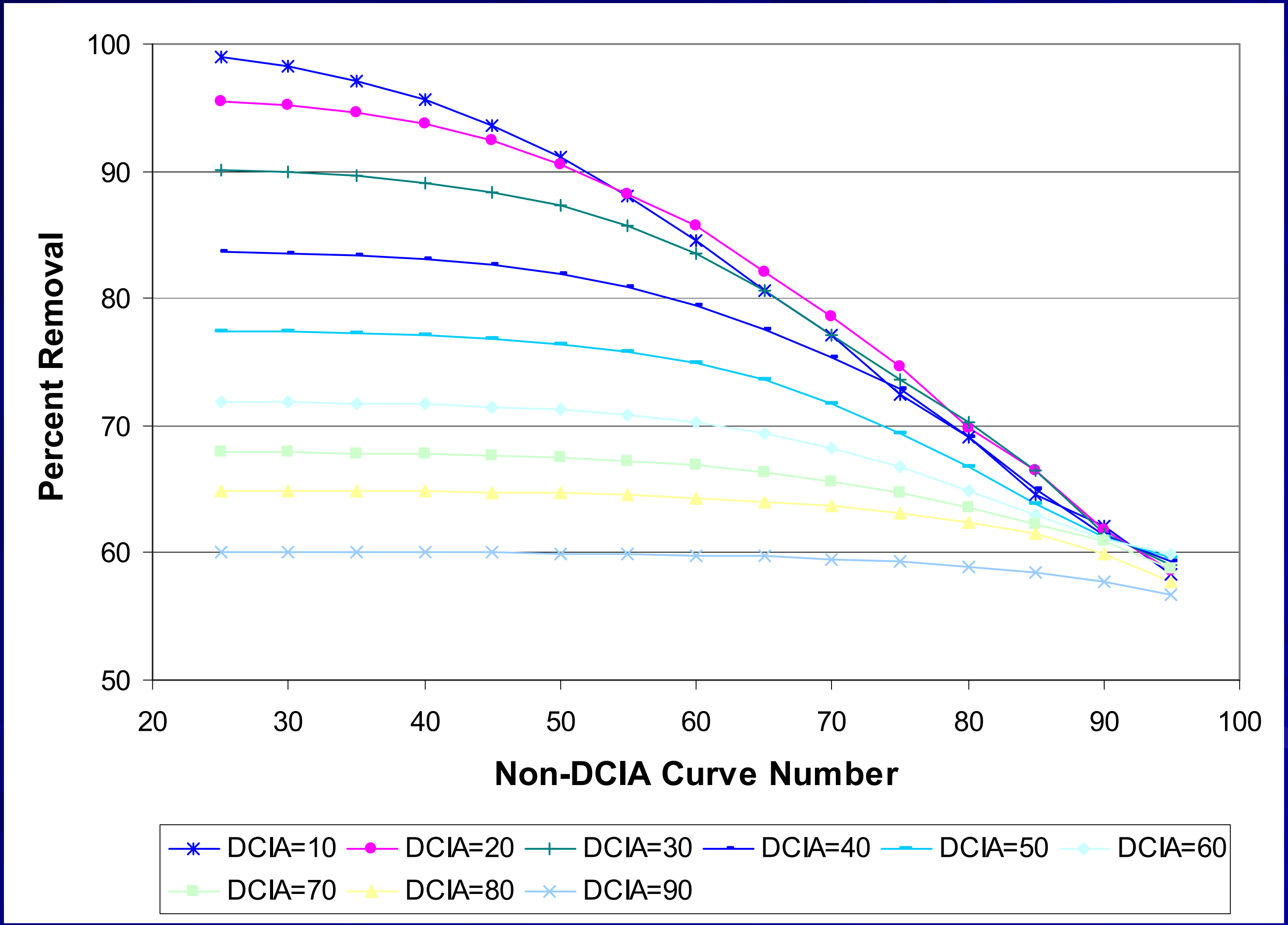
NDCIA	Percent DCIA																			
CN	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
30	86.2	81.3	73.3	65.5	58.7	53.0	48.3	44.2	40.8	37.9	35.3	33.1	31.1	29.4	27.8	26.4	25.1	24.0	22.9	21.9
35	81.6	78.7	71.7	64.5	58.0	52.5	47.9	44.0	40.6	37.7	35.2	33.0	31.0	29.3	27.8	26.4	25.1	23.9	22.9	21.9
40	76.4	75.5	69.6	63.1	57.1	51.9	47.4	43.6	40.3	37.5	35.0	32.9	30.9	29.2	27.7	26.3	25.1	23.9	22.9	21.9
45	70.7	71.7	67.2	61.4	55.9	51.0	46.8	43.1	40.0	37.2	34.8	32.7	30.8	29.1	27.6	26.3	25.0	23.9	22.9	21.9
50	64.7	67.5	64.2	59.4	54.5	50.0	46.0	42.6	39.5	36.9	34.6	32.5	30.7	29.0	27.5	26.2	25.0	23.9	22.9	21.9
55	58.6	62.8	60.9	57.0	52.7	48.7	45.1	41.8	39.0	36.5	34.2	32.3	30.5	28.9	27.4	26.1	24.9	23.9	22.9	21.9
60	52.8	57.8	57.1	54.2	50.7	47.1	43.9	40.9	38.3	35.9	33.8	31.9	30.2	28.7	27.3	26.0	24.9	23.8	22.8	21.9
65	47.3	52.6	53.0	51.1	48.3	45.3	42.5	39.8	37.4	35.3	33.3	31.5	29.9	28.4	27.1	25.9	24.8	23.8	22.8	21.9
70	42.2	47.3	48.6	47.6	45.6	43.2	40.8	38.5	36.4	34.4	32.6	31.0	29.5	28.1	26.9	25.7	24.7	23.7	22.8	21.9
75	37.8	42.2	43.9	43.7	42.4	40.7	38.8	36.9	35.1	33.4	31.8	30.4	29.0	27.8	26.6	25.5	24.5	23.6	22.7	21.9
80	34.0	37.5	39.1	39.4	38.8	37.7	36.4	34.9	33.5	32.1	30.8	29.5	28.3	27.2	26.2	25.2	24.3	23.5	22.7	21.9
85	30.8	33.1	34.3	34.8	34.7	34.2	33.4	32.5	31.4	30.4	29.4	28.4	27.4	26.5	25.7	24.8	24.1	23.3	22.6	21.9
90	27.9	29.2	29.9	30.3	30.3	30.2	29.8	29.3	28.8	28.2	27.5	26.8	26.2	25.5	24.9	24.2	23.6	23.0	22.5	21.9
95	25.3	25.6	25.8	25.9	26.0	25.9	25.8	25.6	25.4	25.2	24.9	24.6	24.3	24.0	23.6	23.3	23.0	22.6	22.3	21.9
98	23.8	23.8	23.8	23.7	23.7	23.6	23.5	23.4	23.3	23.2	23.1	23.0	22.9	22.8	22.6	22.5	22.4	22.2	22.1	21.9

Mean Annual Mass Removal Efficiencies for 0.50-inches of Retention for Zone 1

NDCIA	Percent DCIA																			
CN	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
30	91.8	91.5	88.3	84.0	79.5	75.0	70.7	66.6	62.9	59.6	56.5	53.6	51.1	48.7	46.6	44.6	42.8	41.1	39.6	38.1
35	88.2	89.1	86.6	82.8	78.6	74.3	70.1	66.2	62.6	59.3	56.3	53.5	51.0	48.7	46.5	44.6	42.8	41.1	39.6	38.1
40	84.0	86.3	84.4	81.2	77.4	73.4	69.4	65.7	62.2	59.0	56.0	53.3	50.8	48.5	46.4	44.5	42.7	41.1	39.6	38.1
45	79.6	82.9	81.9	79.3	75.9	72.2	68.5	65.0	61.7	58.6	55.7	53.0	50.6	48.4	46.3	44.4	42.7	41.0	39.5	38.1
50	74.8	79.1	79.0	77.0	74.1	70.8	67.4	64.1	61.0	58.0	55.3	52.7	50.4	48.2	46.2	44.3	42.6	41.0	39.5	38.1
55	70.1	74.9	75.6	74.2	71.9	69.1	66.1	63.0	60.1	57.3	54.7	52.3	50.0	47.9	46.0	44.2	42.5	40.9	39.5	38.1
60	65.5	70.4	71.7	71.1	69.4	67.0	64.4	61.7	59.1	56.5	54.1	51.8	49.6	47.6	45.8	44.0	42.4	40.9	39.5	38.1
65	61.0	65.8	67.5	67.6	66.4	64.7	62.5	60.2	57.8	55.5	53.3	51.1	49.1	47.2	45.5	43.8	42.3	40.8	39.4	38.1
70	56.7	61.1	63.1	63.6	63.1	61.9	60.2	58.3	56.3	54.3	52.3	50.3	48.5	46.8	45.1	43.5	42.1	40.7	39.4	38.1
75	52.7	56.6	58.6	59.3	59.3	58.6	57.5	56.0	54.4	52.7	51.0	49.3	47.7	46.1	44.6	43.2	41.8	40.5	39.3	38.1
80	49.1	52.2	54.1	55.0	55.2	54.9	54.2	53.2	52.1	50.8	49.4	48.0	46.6	45.3	44.0	42.7	41.5	40.3	39.2	38.1
85	46.1	48.3	49.7	50.5	50.8	50.8	50.5	49.9	49.2	48.3	47.3	46.3	45.2	44.2	43.1	42.1	41.0	40.0	39.1	38.1
90	43.5	44.8	45.6	46.1	46.4	46.5	46.4	46.1	45.7	45.2	44.6	44.0	43.3	42.6	41.9	41.1	40.4	39.6	38.9	38.1
95	41.1	41.5	41.8	41.9	42.0	42.1	42.0	41.9	41.8	41.6	41.3	41.1	40.8	40.4	40.1	39.7	39.3	38.9	38.5	38.1
98	39.8	39.8	39.8	39.8	39.8	39.7	39.7	39.6	39.5	39.4	39.3	39.2	39.1	39.0	38.9	38.7	38.6	38.4	38.3	38.1

Source: Harper and Baker (2007) - Appendix D

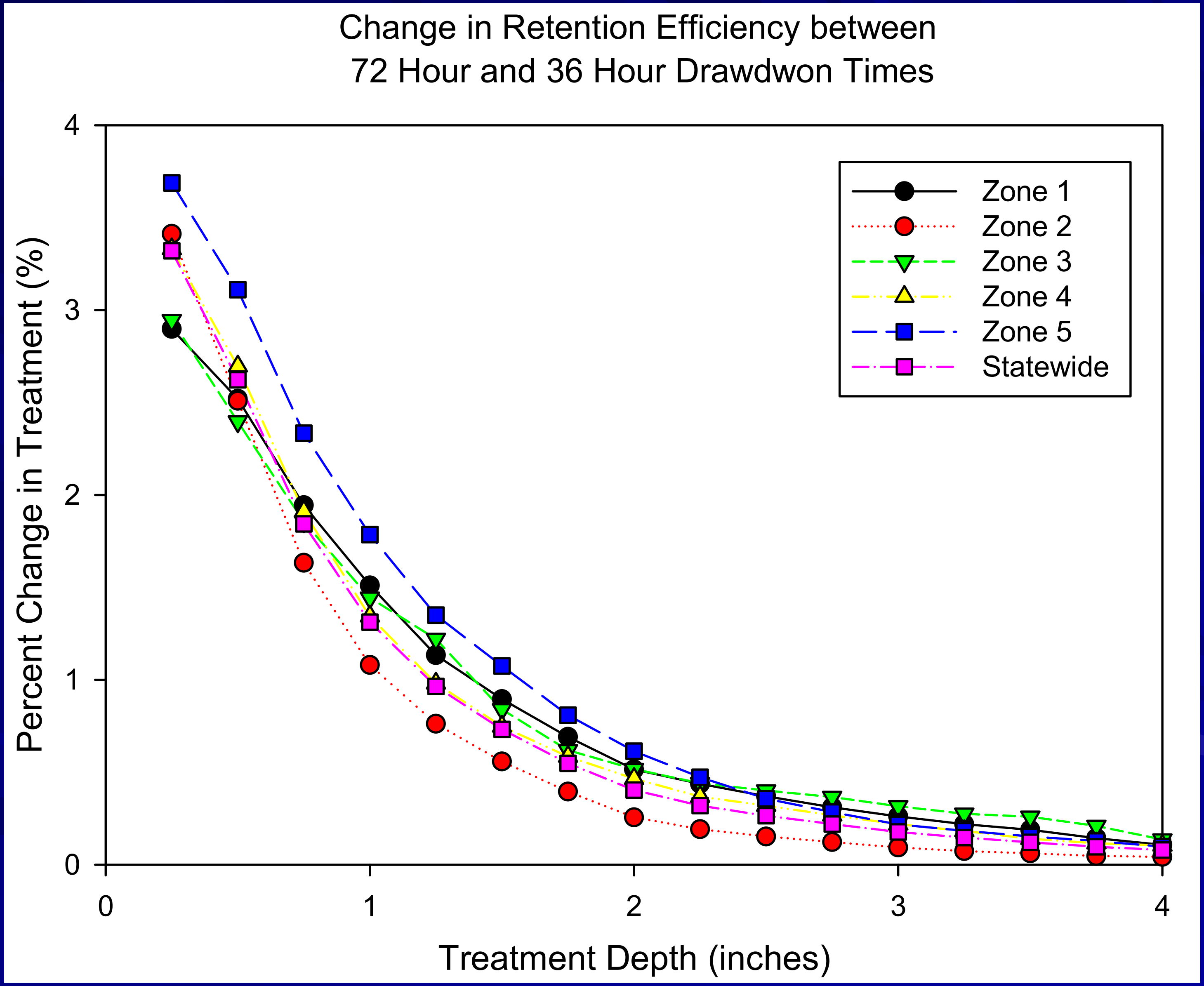
Effectiveness of On-Line Retention
(0.50 Inch over watershed)



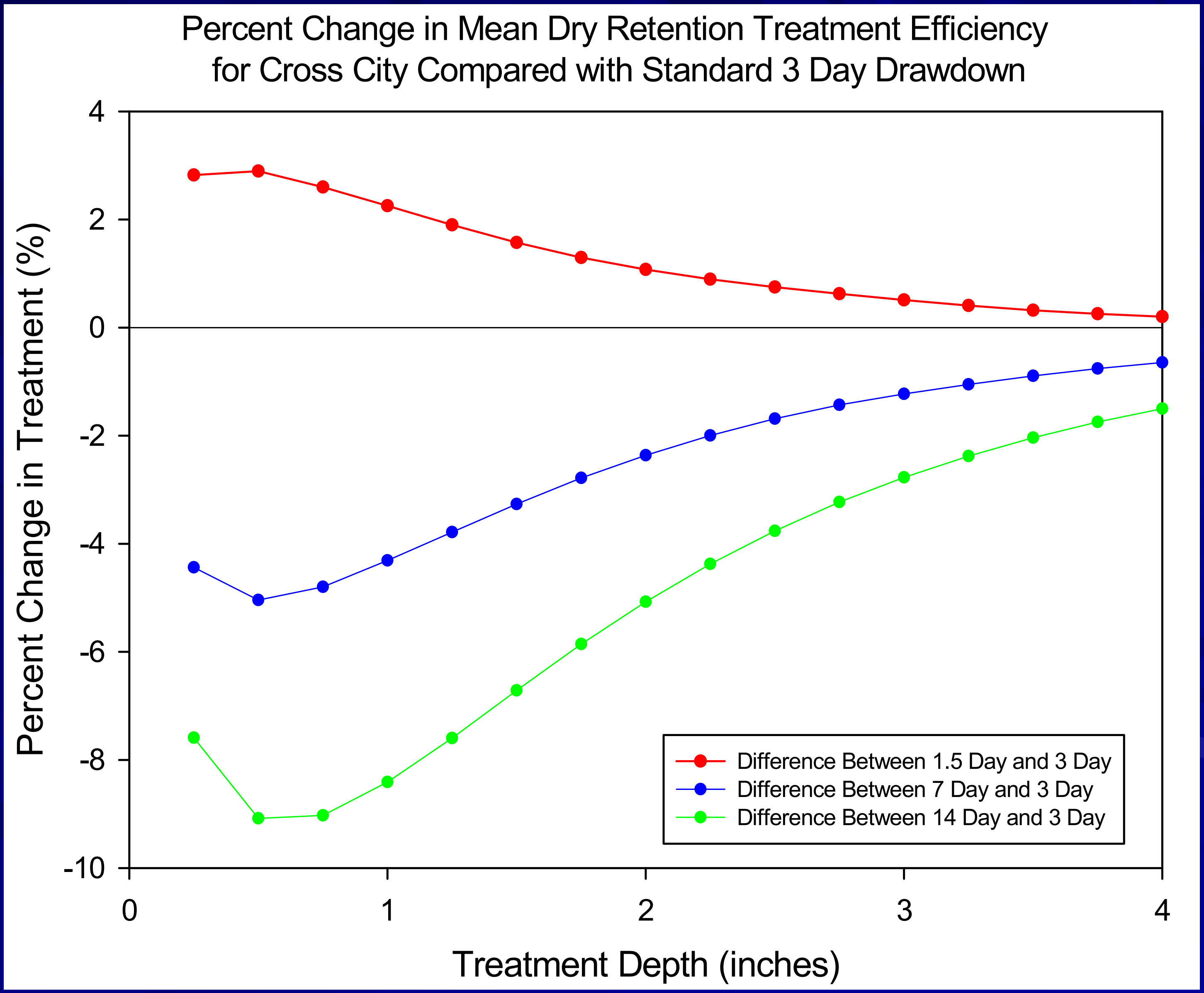
Comparison of Dry Retention Design Criteria for Florida WMDs

<table>
<tr><th>Design Parameter</th><th>SJRWMD</th><th>SWWMD</th><th>SWFWMD</th><th>SFWMD</th></tr>
<tr><td rowspan="4">Treatment Volume</td><td>Off-line: 0.5” of runoff or 1.25” from imp. Area</td><td>Runoff from first 1” of rainfall</td><td>On-line: Runoff from 1” of rainfall</td><td rowspan="4">Retention of the first 0.5” runoff or 1.25 times imp.%</td></tr>
<tr><td>On-line: 1” of runoff or 1.75” from imp. area</td><td rowspan="3">If discharges to sink, then first 2” of rainfall</td><td>If project<100 ac. on-line retention of 0.5” runoff</td></tr>
<tr><td>On-line: percolate runoff from 3-year, 1-hour storm</td><td>Off-line: Runoff from 1” of rainfall</td></tr>
<tr><td>If project < 40% imp. and HSG A soils: 1” rainfall or 1.25” x imp.</td><td>If project < 100 ac.: off-line retention of 0.5” runoff</td></tr>
<tr><td>Volume Recovery</td><td>< 72 hours by perc, evap. or ET</td><td>< 72 hours by perc, evap. or ET</td><td>< 72 hours</td><td>50 % in < 24 hours</td></tr>
</table>

Impacts of Accelerated Drawdown on Retention Efficiencies



Impacts of Accelerated Drawdown on Retention Efficiencies

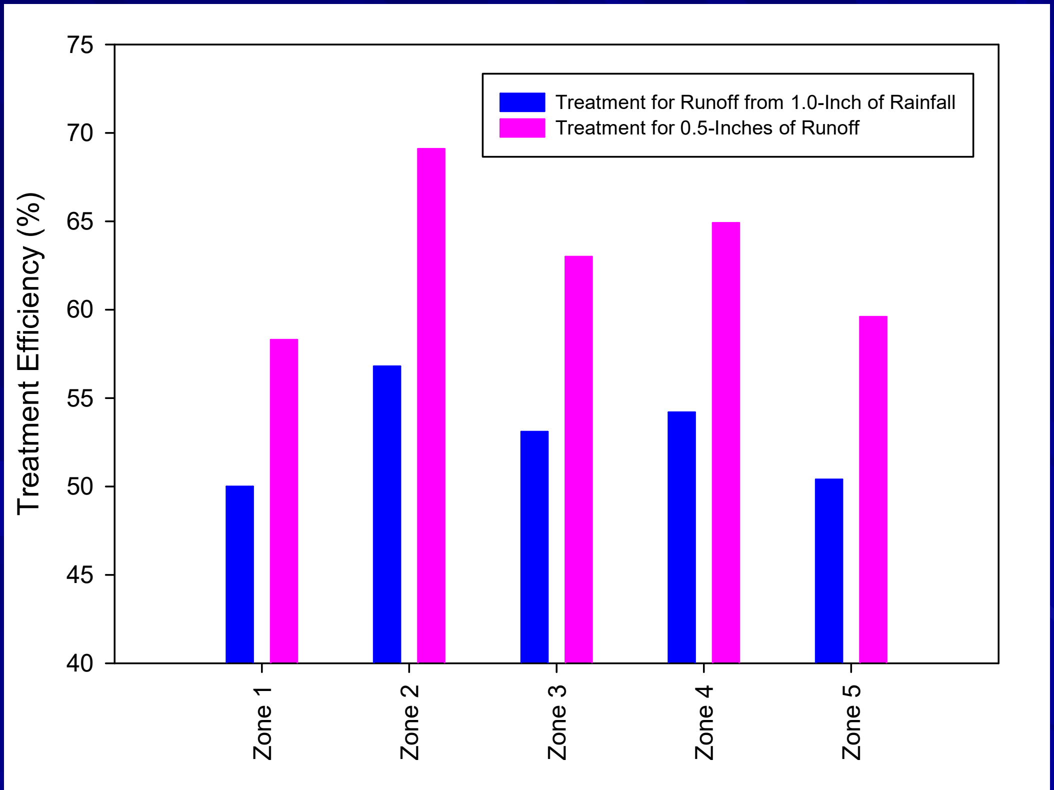


Regional Variability in Treatment Efficiency of Dry Retention

Treatment of 0.5-inch Runoff vs. Treatment of 1 inch of Rainfall
(40% DCIA and non-DCIA CN of 70)

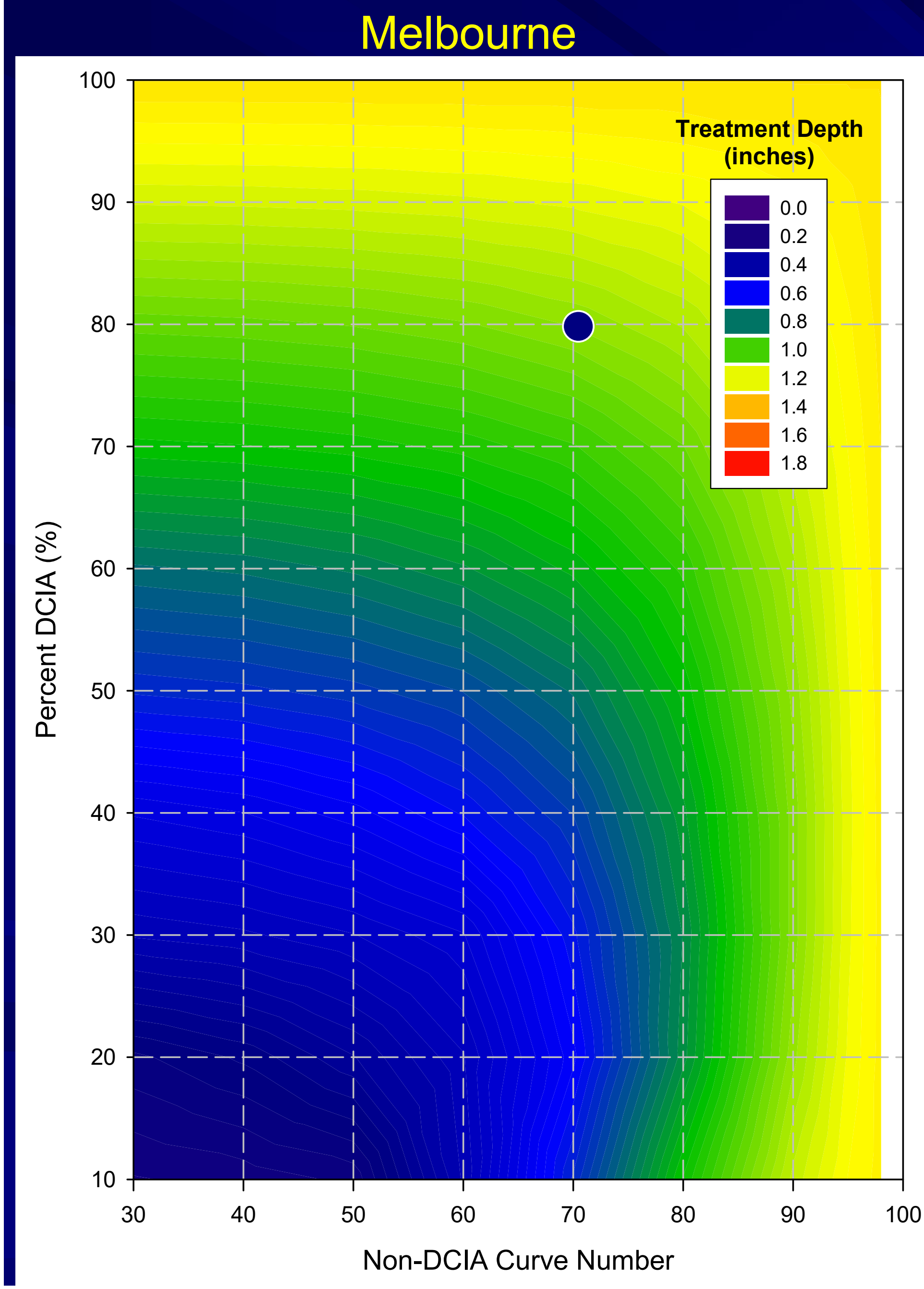
- Performance efficiency of retention systems varies throughout the State

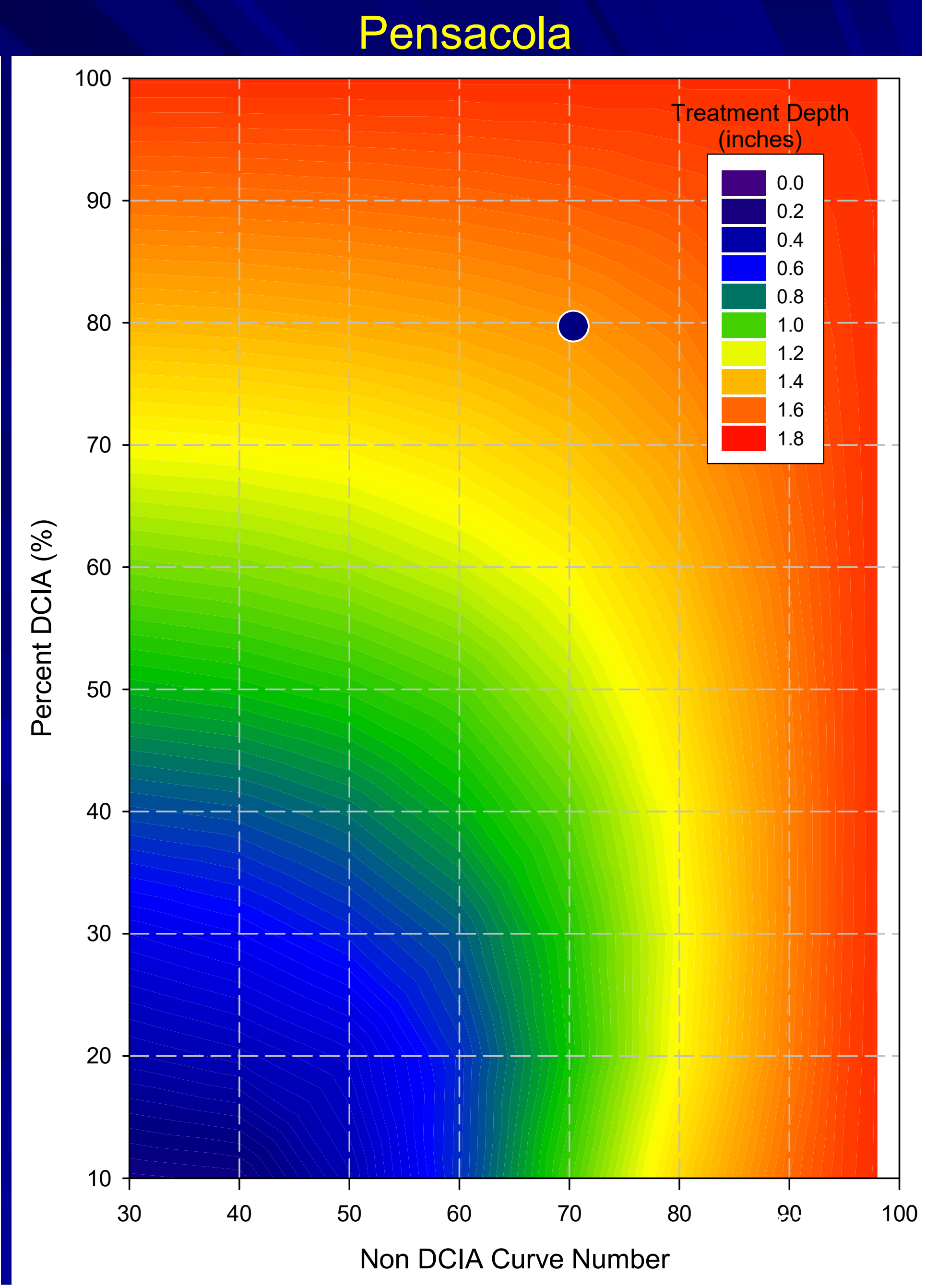
- Design criteria based on treatment of 0.5 inch of runoff provide better annual mass removal than treatment of 1 inch of rainfall



Conclusion: Design criteria based on retention of 0.5 inch of runoff or runoff from 1-inch of rainfall fail to meet the 80% treatment objective

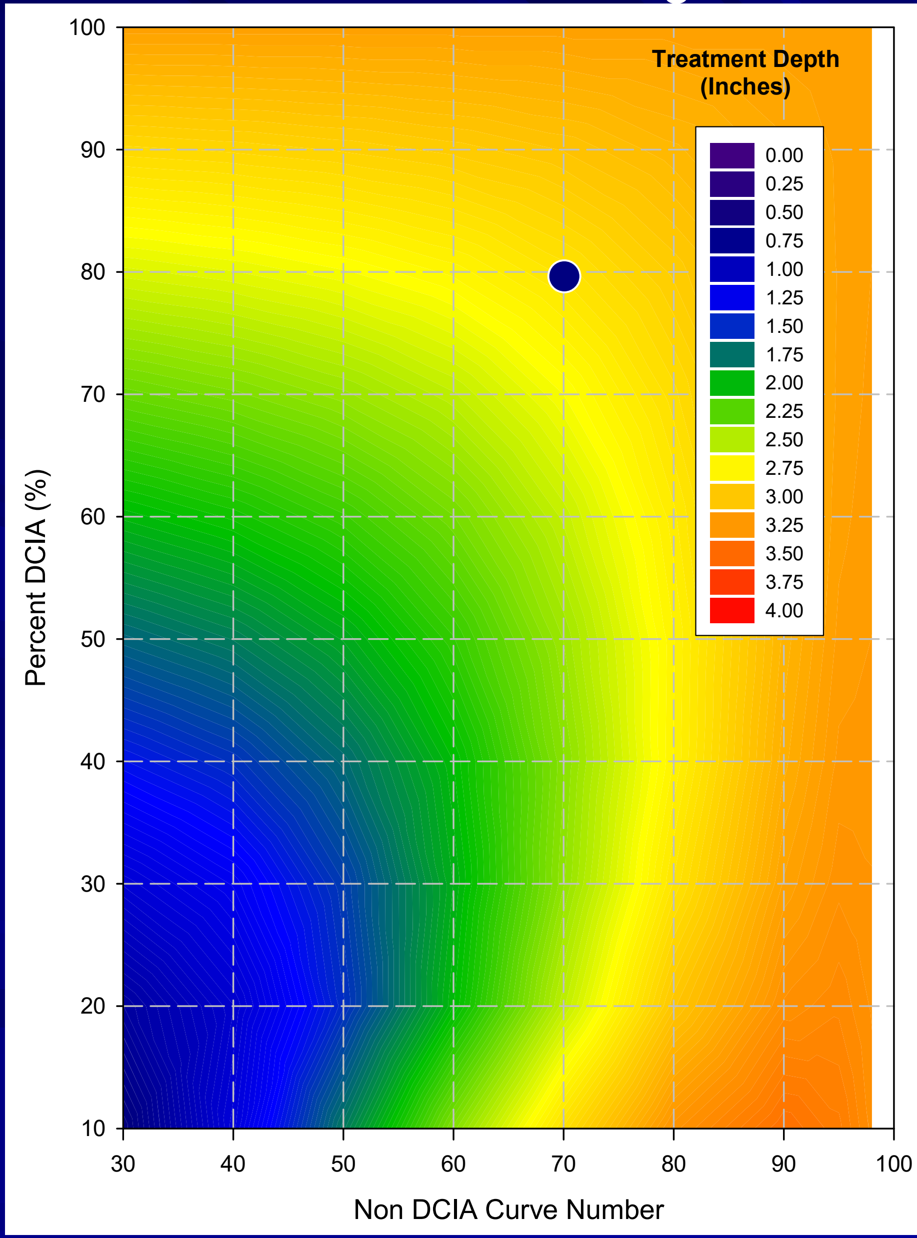
Retention Depth Required for 80% Removal





Retention Depth Required to Achieve 95% Mass Removal

State-Wide Average



BMPTRAINS Retention Efficiency Calculations

- Calculation of runoff in the BMPTrains model uses the tabular retention efficiency relationships developed by Harper and Baker (2007) – App. D

Mean Annual Mass Removal Efficiencies for 0.25-inches of Retention for Zone 1

NDCIA	Percent DCIA																			
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35	81.6	78.7	71.7	64.5	58.0	52.5	47.9	44.0	40.6	37.7	35.2	33.0	31.0	29.3	27.8	26.4	25.1	23.9	22.9	21.9
40	76.4	75.5	69.6	63.1	57.1	51.9	47.4	43.6	40.3	37.5	35.0	32.9	30.9	29.2	27.7	26.3	25.1	23.9	22.9	21.9
45	70.7	71.7	67.2	61.4	55.9	51.0	46.8	43.1	40.0	37.2	34.8	32.7	30.8	29.1	27.6	26.3	25.0	23.9	22.9	21.9
50	64.7	67.5	64.2	59.4	54.5	50.0	46.0	42.6	39.5	36.9	34.6	32.5	30.7	29.0	27.5	26.2	25.0	23.9	22.9	21.9
55	58.6	62.8	60.9	57.0	52.7	48.7	45.1	41.8	39.0	36.5	34.2	32.3	30.5	28.9	27.4	26.1	24.9	23.9	22.9	21.9
60	52.8	57.8	57.1	54.2	50.7	47.1	43.9	40.9	38.3	35.9	33.8	31.9	30.2	28.7	27.3	26.0	24.9	23.8	22.8	21.9
65	47.3	52.6	53.0	51.1	48.3	45.3	42.5	39.8	37.4	35.3	33.3	31.5	29.9	28.4	27.1	25.9	24.8	23.8	22.8	21.9
70	42.2	47.3	48.6	47.6	45.6	43.2	40.8	38.5	36.4	34.4	32.6	31.0	29.5	28.1	26.9	25.7	24.7	23.7	22.8	21.9
75	37.8	42.2	43.9	43.7	42.4	40.7	38.8	36.9	35.1	33.4	31.8	30.4	29.0	27.8	26.6	25.5	24.5	23.6	22.7	21.9
80	34.0	37.5	39.1	39.4	38.8	37.7	36.4	34.9	33.5	32.1	30.8	29.5	28.3	27.2	26.2	25.2	24.3	23.5	22.7	21.9
85	30.8	33.1	34.3	34.8	34.7	34.2	33.4	32.5	31.4	30.4	29.4	28.4	27.4	26.5	25.7	24.8	24.1	23.3	22.6	21.9
90	27.9	29.2	29.9	30.3	30.3	30.2	29.8	29.3	28.8	28.2	27.5	26.8	26.2	25.5	24.9	24.2	23.6	23.0	22.5	21.9
95	25.3	25.6	25.8	25.9	26.0	25.9	25.8	25.6	25.4	25.2	24.9	24.6	24.3	24.0	23.6	23.3	23.0	22.6	22.3	21.9
98	23.8	23.8	23.8	23.7	23.7	23.6	23.5	23.4	23.3	23.2	23.1	23.0	22.9	22.8	22.6	22.5	22.4	22.2	22.1	21.9

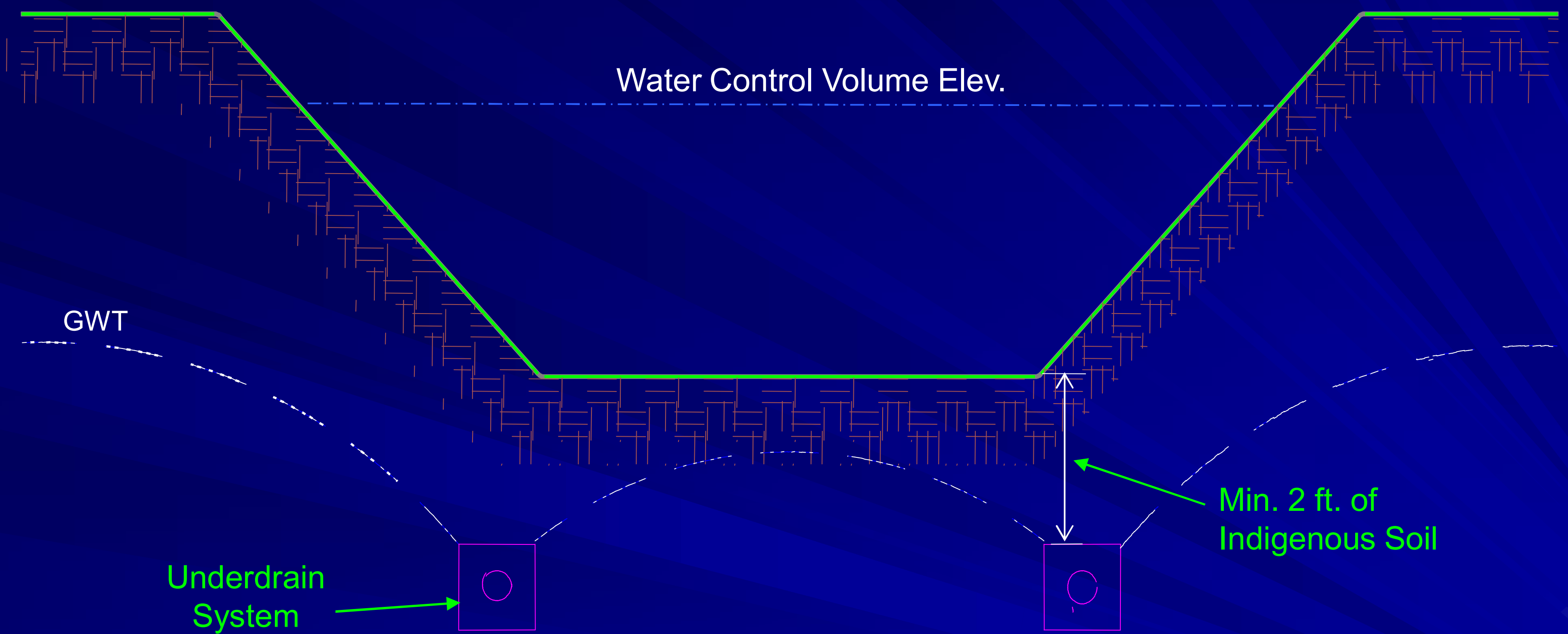
- Required input data include:
  - Rainfall meteorological zone based on rainfall zone map
  - Annual rainfall depth from isopleth maps
  - Project DCIA
  - Non-DCIA curve number
  - Retention provided or desired performance efficiency
- BMPTrains conducts iterations within and between tables

Swale Treatment Efficiencies

- Swales used for permitted stormwater treatment are generally required to infiltrate the runoff from a 3-year, 1-hour storm

FDOT 3-yr, 1-hr Storm (in)	Annual dry retention mass removal by zone (%) Mean Value, (Range of Values)				
	1	2	3	4	5
2.45	74.7 (54.5-79.1)	84.2 (64.9-87.1)	84.2 (64.9-87.1)	80.5 (60.0-84.3)	75.3 (52.4-80.7)
2.50	75.4 (56.4-79.6)	84.8 (67.2-87.6)	84.8 (67.2-87.6)	81.2 (62.1-84.8)	76.0 (54.2-81.2)
2.55	76.0 (58.5-80.1)	85.3 (69.6-88.0)	85.3 (69.6-88.0)	81.8 (64.3-85.3)	76.6 (56.2-81.7)
2.60	76.7 (60.6-80.7)	85.9 (72.1-88.4)	85.9 (72.1-88.4)	82.3 (66.7-85.8)	77.2 (58.2-82.2)
2.65	77.3 (62.8-81.2)	86.4 (74.8-88.9)	86.4 (74.8-88.9)	82.9 (69.1-86.3)	77.7 (60.3-82.7)
2.75	78.4 (67.4-82.2)	87.3 (80.3-89.7)	87.3 (80.3-89.7)	83.9 (74.1-87.2)	78.8 (64.7-83.7)
2.85	79.5 (68.3-83.1)	88.2 (81.0-90.4)	88.2 (81.0-90.4)	84.9 (74.9-87.9)	79.8 (65.6-84.5)
2.95	80.5 (69.2-83.9)	89.0 (81.7-91.0)	89.0 (81.7-91.0)	85.7 (75.7-88.7)	80.8 (66.4-85.3)

SJRWMD Underdrain Filtration Pond



- Off-line water quality volume equal to 0.50-inch runoff or 1.25 inches over impervious area
- On-line water quality volume additional 0.5 inch above
- Drawdown of treatment volume in 72-hours
- Underdrain designed with safety factor of 2

Example Calculation

Calculate Retention Requirements for No Net Increase

A summary of pre- and post-loadings and required removal efficiencies for hypothetical projects in different meteorological zones is given in the following table:

Project Location	Total Nitrogen			Total Phosphorus		
	Pre-Load (kg/yr)	Post-Load (kg/yr)	Required Removal (%)	Pre-Load (kg/yr)	Post-Load (kg/yr)	Required Removal (%)
Pensacola (Zone 1)	140	381	63.2	6.64	60.2	89.0
Orlando (Zone 2)	76.2	242	68.5	3.62	38.2	90.5
Key West (Zone 3)	69.2	179	61.4	3.29	28.3	88.4

Calculate Retention Requirements for No Net Increase – cont.

Dry Retention: For dry retention, the removal efficiencies for TN and TP are identical since the removal efficiency is based on the portion of the annual runoff volume which is infiltrated. The required removal is the larger of the calculated removal efficiencies for TN and TP.

A. **Pensacola Project:** For the Pensacola area, the annual load reduction is 63.2% for total nitrogen and 89.0% for total phosphorus. The design criteria is based on the largest required removal which is 89.0%. The required retention depth to achieve an annual removal efficiency of 89.0% in the Pensacola area is determined from Appendix D (Zone 1) based on DCIA percentage and the non-DCIA CN value. For this project:

DCIA Percentage = 18.75% of developed area

Non-DCIA CN = 81.4

From Appendix D (Zone 1), the required removal efficiency of 89.0% is achieved with a dry retention depth between 2.25 and 2.50 inches.

Calculate Retention Requirements for No Net Increase – cont.

For a dry retention depth of 2.25 inches, the treatment efficiency is obtained by iterating between DCIA percentages of 10 and 20, and for non-DCIA CN values between 80 and 90. The required removal efficiency for the project conditions is 87.8%.

For a dry retention depth of 2.50 inches, the treatment efficiency is obtained by iterating between DCIA percentages of 10 and 20, and for non-DCIA CN values between 80 and 90. The efficiency for a retention depth of 2.50 inches is 89.6%.

By iterating between 2.25 inches (87.8%) and 2.50 inches (89.6%), the dry retention depth required to achieve 89.0% removal is 2.42 inches.

BMPTRAINS Model performs iterations and calculates the treatment efficiency

Summary

- Efficiencies of retention systems vary throughout the State due to variability in meteorological characteristics
- BMPTrains Model calculates efficiencies of dry detention systems based on location, hydrologic, and meteorological characteristics of the project site

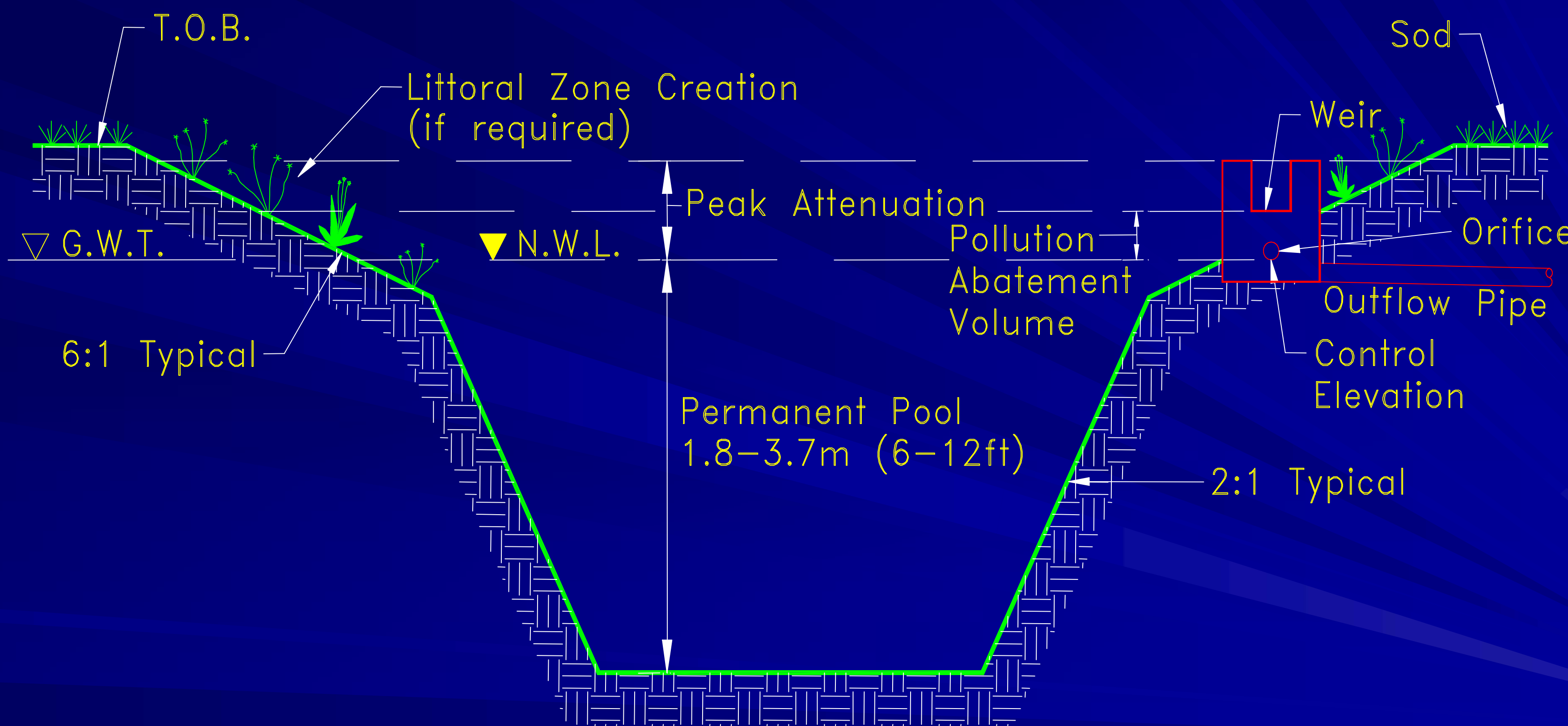
Part 6

Wet Detention

Definitions

- Retention - A group of stormwater practices where the treatment volume is evacuated by either percolation into groundwater or evaporation
  - No surface discharge for treatment volume
  - Substantial reduction in runoff volume
- Detention - A group of stormwater practices where the treatment volume is detained for a period of time before release
  - Continuous discharge of treatment volume over a period of days
  - No significant reduction in runoff volume

Wet Detention



- Most pollutant removal processes occur within the permanent pool volume

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

Wet Detention Ponds

Wet detention ponds are essentially man-made lakes

Wet Detention Ponds Can Be Constructed as Amenities

Wet Detention Lakes Can Be Integral to the Overall Development Plan

Wet detention ponds are governed by the same physical, biological, and chemical processes as natural lakes

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
- Occur during quiescent period between storms
- Permanent pool crucial
  - Reduces energy and promotes settling
  - Provides habitat for plants and microorganisms

Detention Time

Performance efficiency is a function of detention time:

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

where:

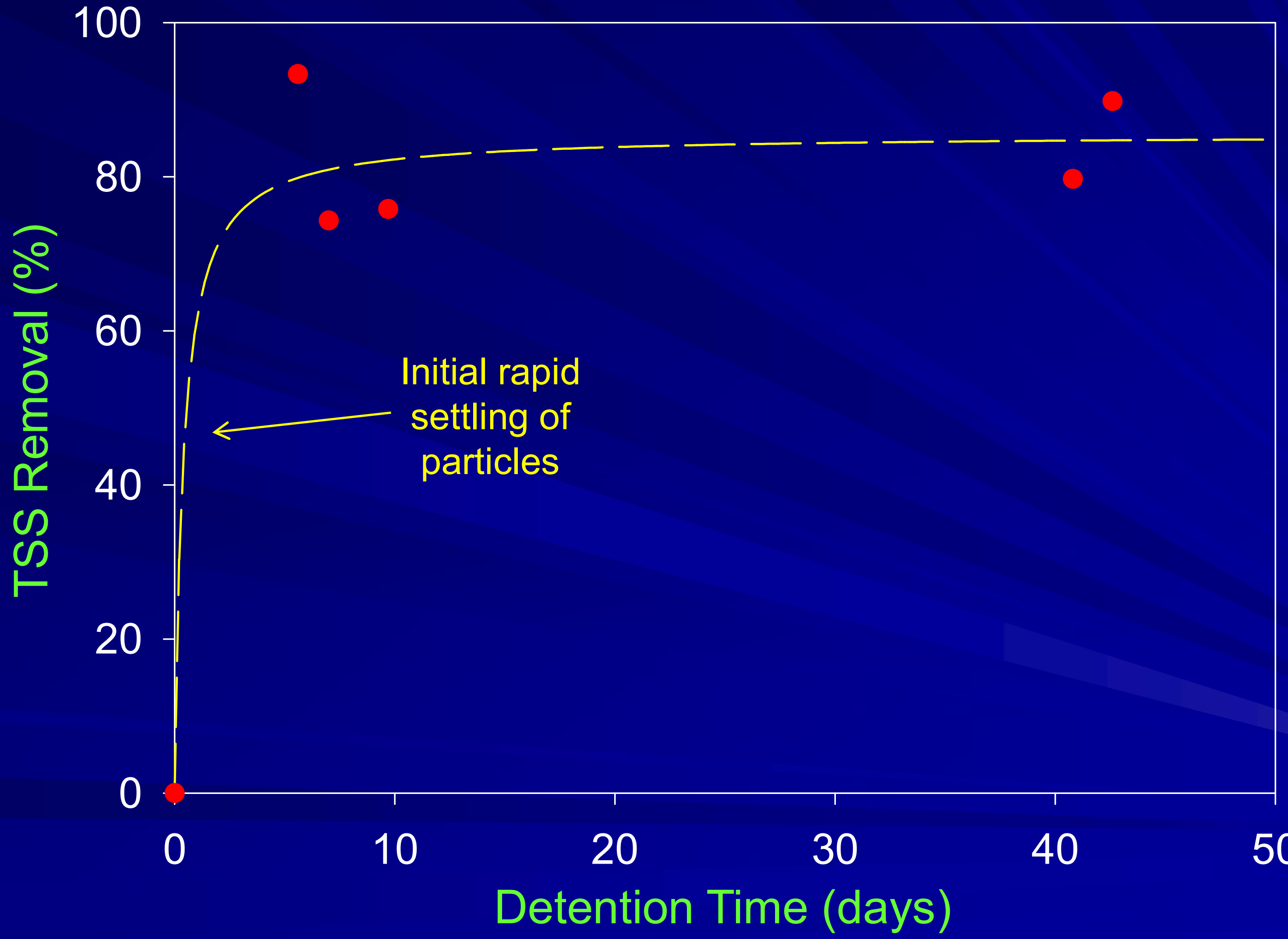
PPV = permanent pool volume below control elevation (ac-ft)
RO = annual runoff inputs (ac-ft/yr)

Typical Treatment Efficiencies for Wet Detention

Reference	Study Site/ Land Use	Type of Efficiencies Reported	Mean Removal Efficiencies (%)							
			Total N	SRP	Total P	TSS	BOD	Total Cu	Total Pb	Total Zn
PBS&J (1982)	Brevard County/ Commercial	Surface Water	--	--	69	94	--	--	96	--
Cullum (1984)	Boca Raton/ Residential	Surface Water Overall	12 15	93 82	55 60	68 64	-- --	-- --	-- --	-- --
Yousef, et al. (1986)	Maitland/ Highway	Surface Water	35	94	81	--	--	56	88	92
Yousef, et al. (1986)	EPCOT/ Highway	Surface Water	44	92	62	--	--	0	0	88
Martin & Miller (1987)	Orlando/ Urban	Surface Water	--	57	38	66	--	--	40	--
Harper (1988)	Orlando/ Residential	Surface Water	--	--	91	82	90	90	90	96
Harper & Herr (1993)	DeBary/ Commercial & Residential	Overall t_d = 7 days t_d = 14 days	20 30	40 60	60 70	85 85	50 60	40 50	60 85	85 95
Rushton & Dye (1993)	Tampa/Light Commercial	Surface Water	--	67	65	55	--	--	--	51
Mean Values			26	73	65	75	67	59	77	85

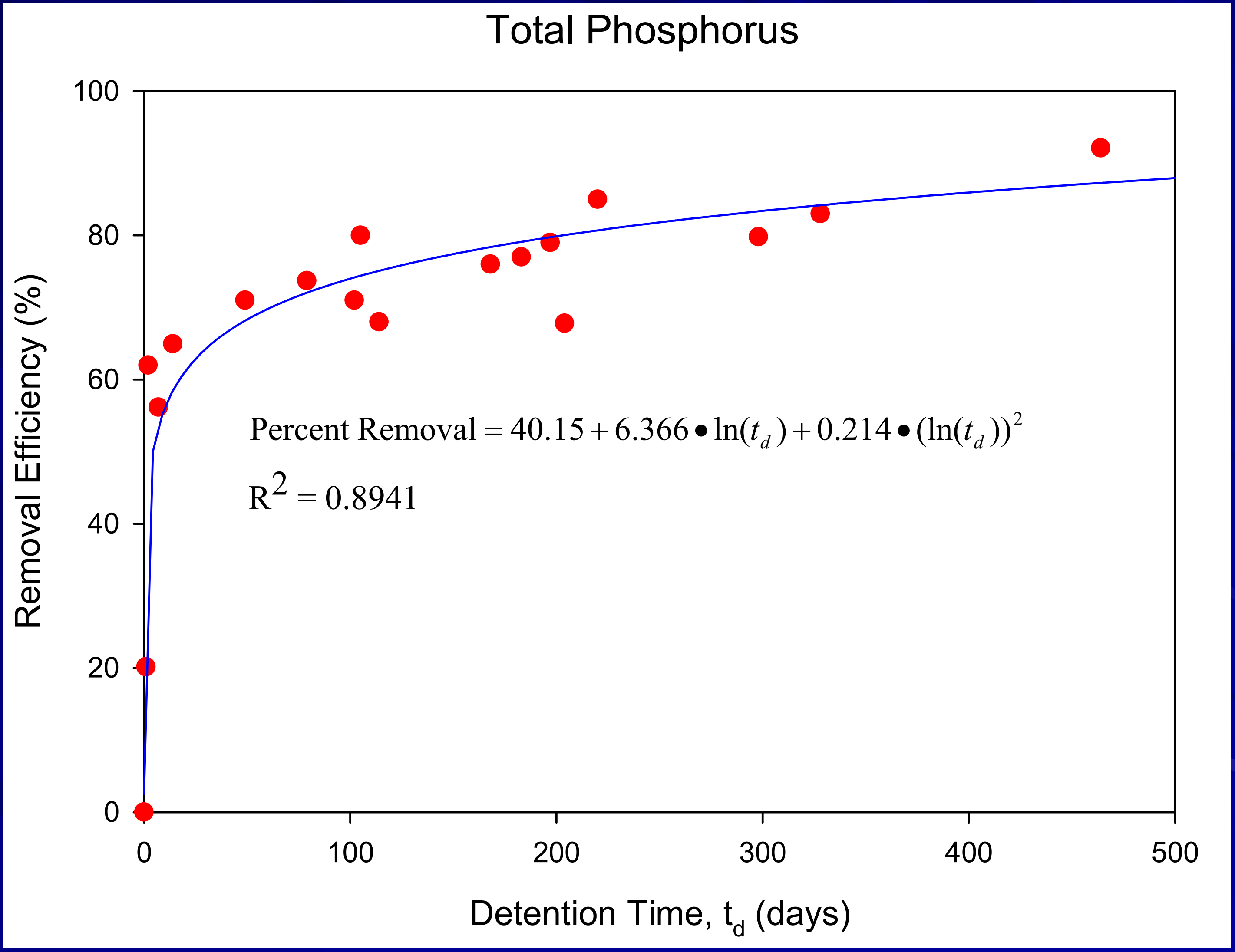
A number of studies have been conducted

TSS Removal as a Function of Detention Time



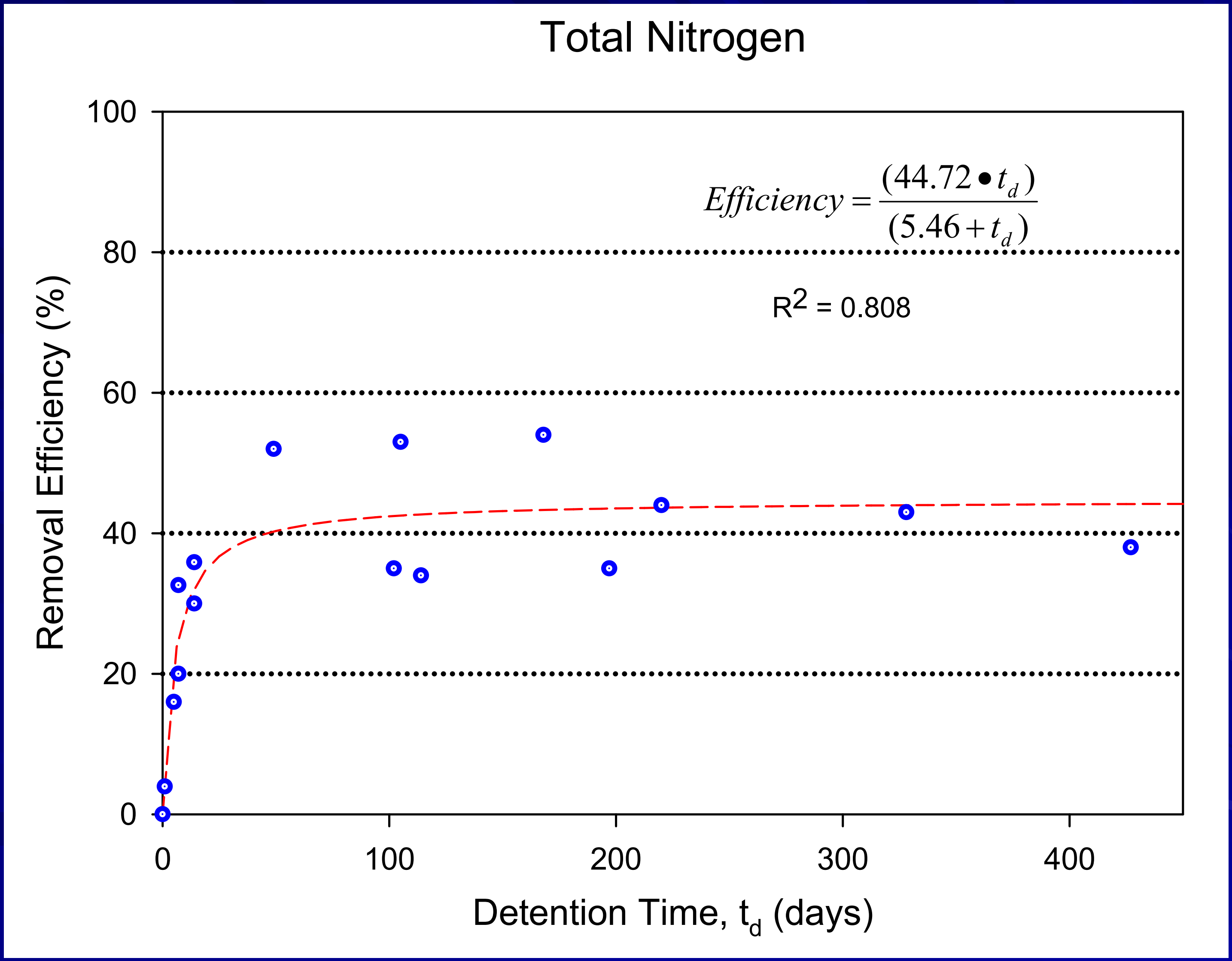
Phosphorus Removal for Untreated Runoff in Wet Ponds

- Phosphorus removal is highly predictable



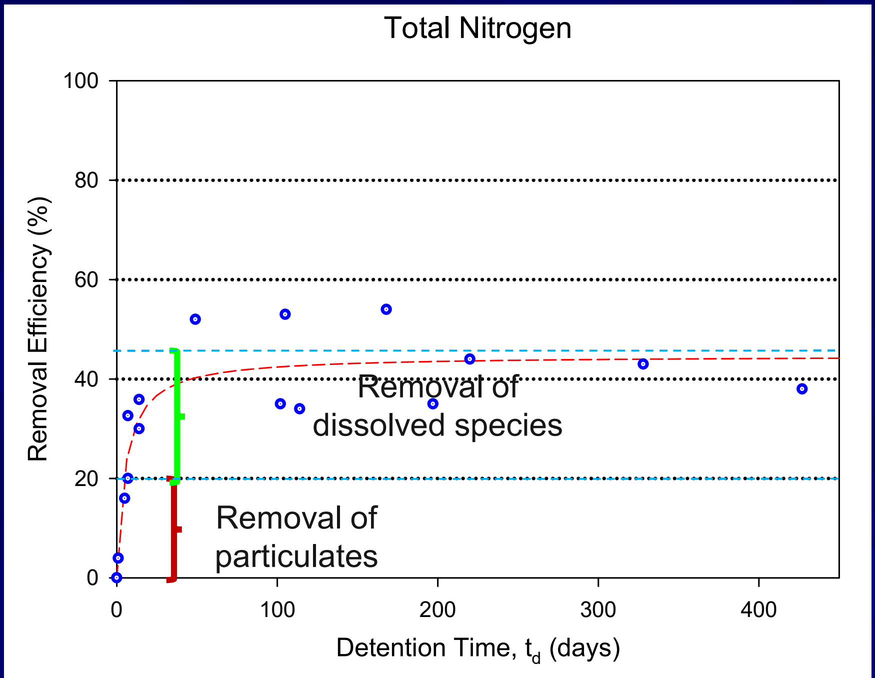
Nitrogen Removal for Untreated Runoff in Wet Ponds

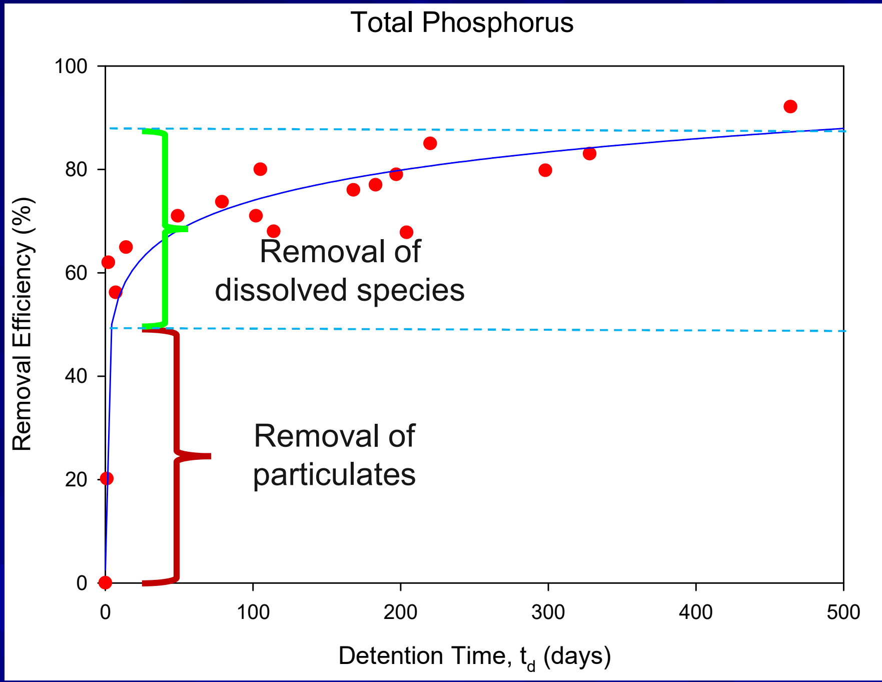
- Nitrogen removal depends on the forms of nitrogen present



Nutrient Removal Relationships for Wet Ponds

Nutrient Removal is Primarily a Function of Detention Time





- These relationships were developed for untreated runoff only
- The relationships do not apply 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

Factors Impacting Efficiencies of Wet Ponds

Waterfowl Loadings

Cattails

Managing Ponds as Amenities

Use of Copper Sulfate and Herbicides for Algae Control

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%
- Beneficial bacteria for muck removal
  - Don't waste your money
- Slow rate alum addition

Short Circuiting
Concept of Flow Path Ratio

- Wet ponds are commonly designed with a 2:1 dimensional ratio

- Short-circuiting is discouraged, but no specific criteria

- Flow Path Ratio (FPR) can be used as a quantitative value for measuring short-circuiting potential

Flow Path Ratio (FPR) = A/LP

Values range from 0 -1

FPR for Fig. 2 = $2/\sqrt{(2^2+1^2)}$ = <u>0.89</u>

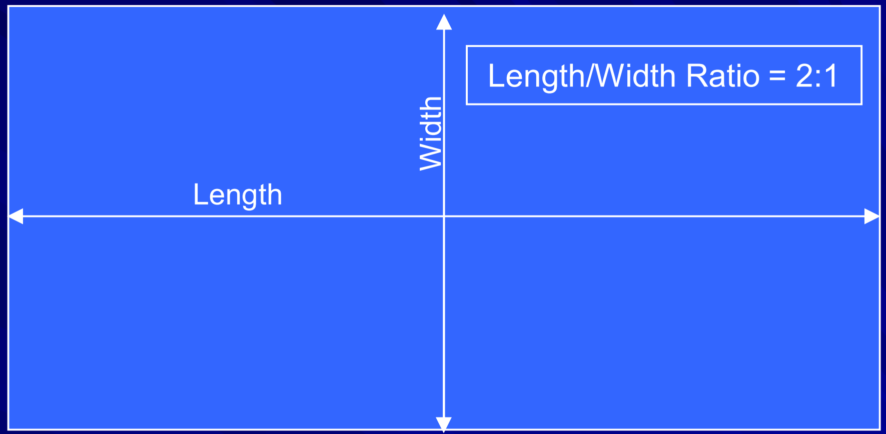


Figure 1

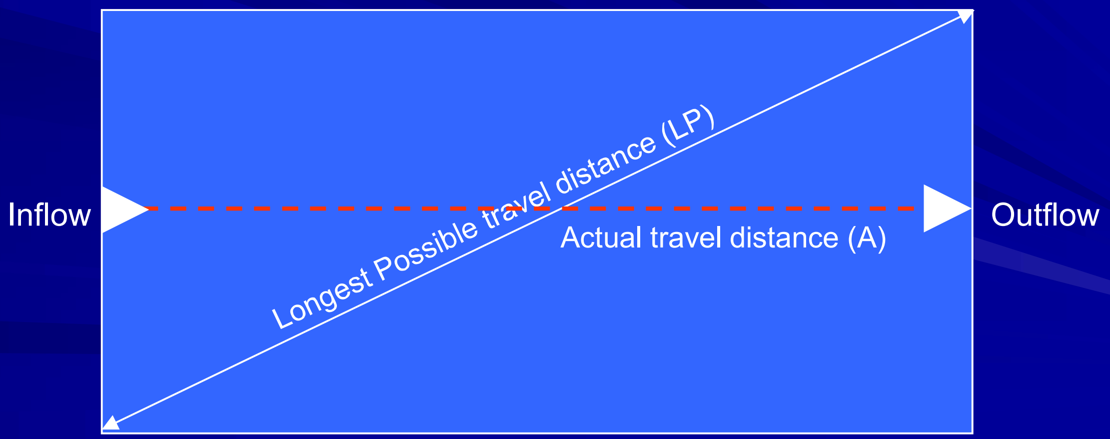


Figure 2

Concept of Flow Path Ratio – cont.

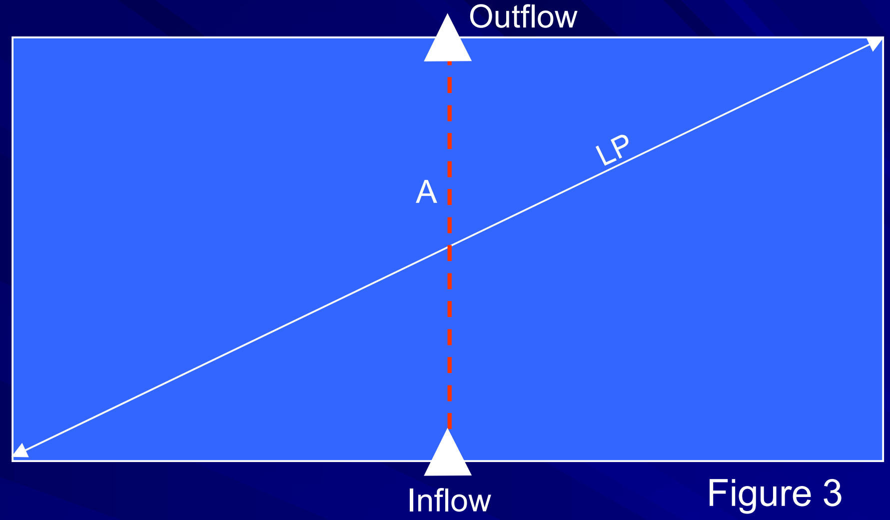


Figure 3

FPR for Fig. 3 = $1/\sqrt{(2^2+1^2)}$ = <u>0.45</u>

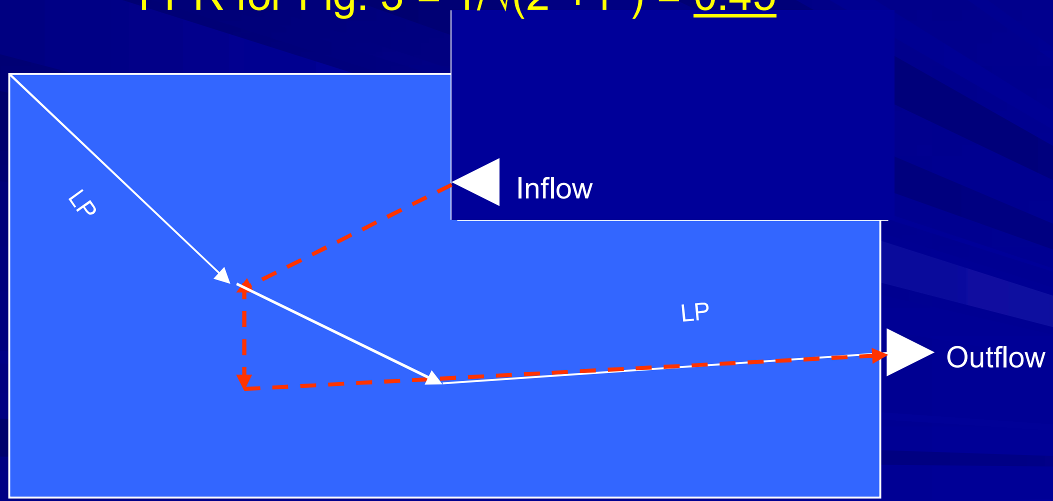


Figure 4

FPR for Fig. 4 = 11.6/11.8 = <u>0.95</u>

Concept of Flow Path Ratio – cont.

Ponds with multiple inflows

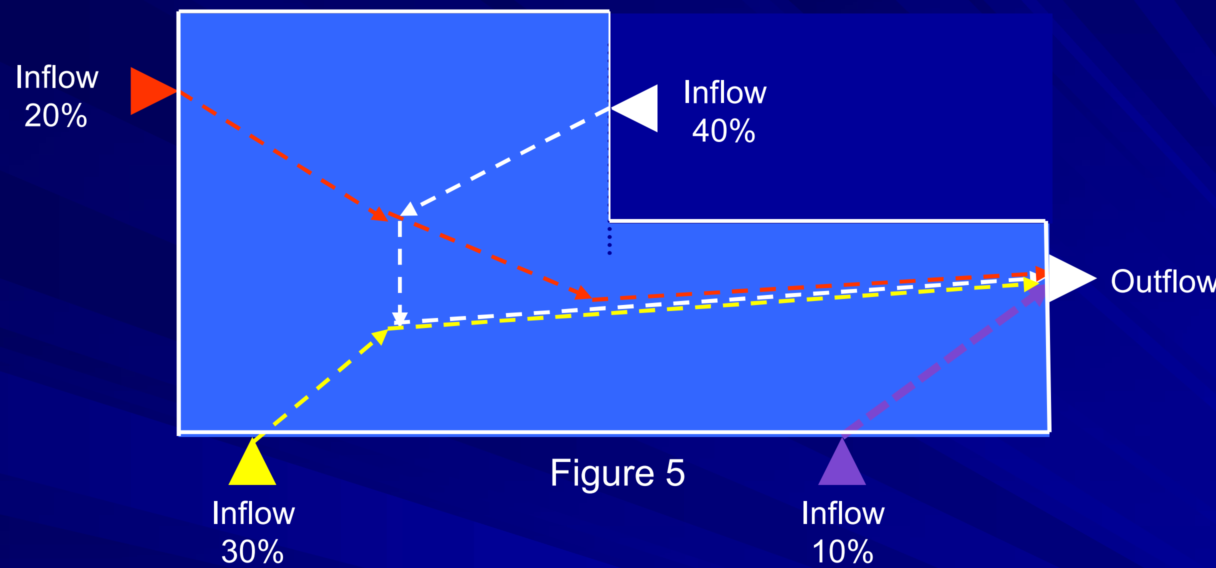


Figure 5

For multiple inflows, calculate FRP based on weighted average

$$FRP = [(4.3*0.2)+(4.55*0.4)+(3.8*0.3)+(1.3*0.1)]/4.8$$

$$= 3.95/4.8$$

$$= 0.82$$

Concept of Flow Path Ratio – cont.

Impacts of changing runoff inflows

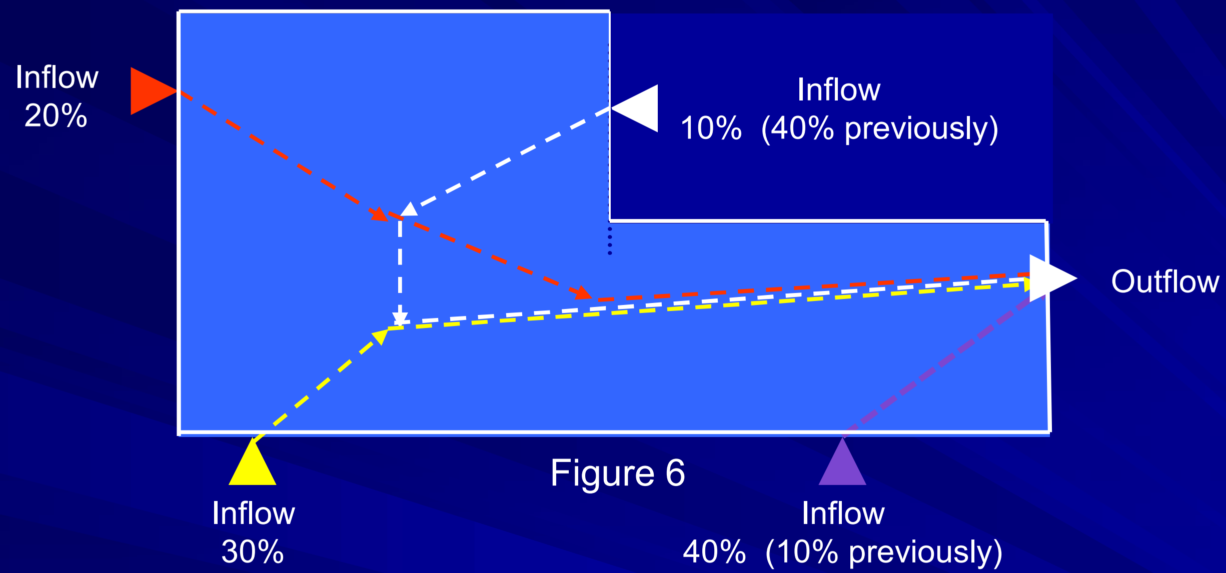


Figure 6

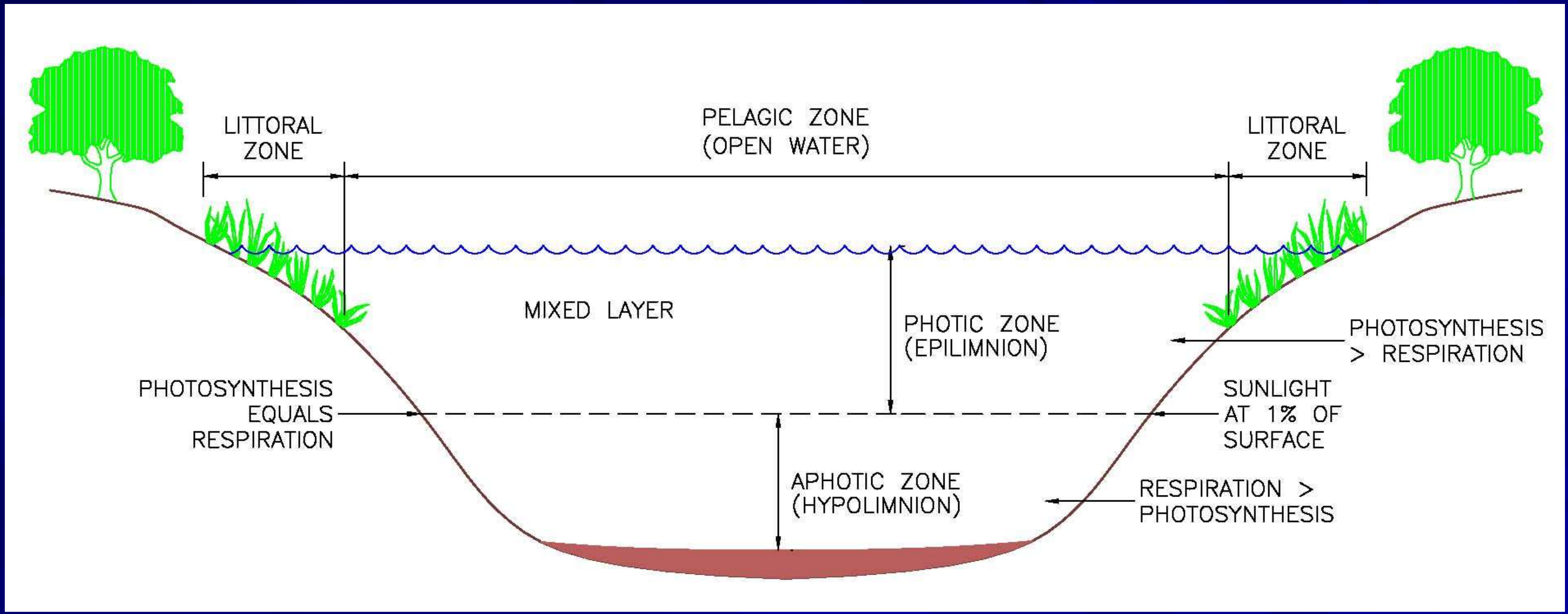
FRP = [(4.3*0.2)+(4.55*0.1)+(3.8*0.3)+(1.3*0.4)]/4.8

= 2.98/4.8 = 0.62

Recommendations

1. Incorporate the FRP concept into pond design
2. Minimum FRP value of 0.8

Zonation in a Wet Detention Pond



- Water quality can deteriorate in deep areas that become anoxic
  - Anoxic conditions causes release of ammonia, phosphorus, and gases from sediments
- To optimize pond performance, all portions of the water column should maintain aerobic conditions
- The pond depth should not exceed the depth at which anoxic conditions develop

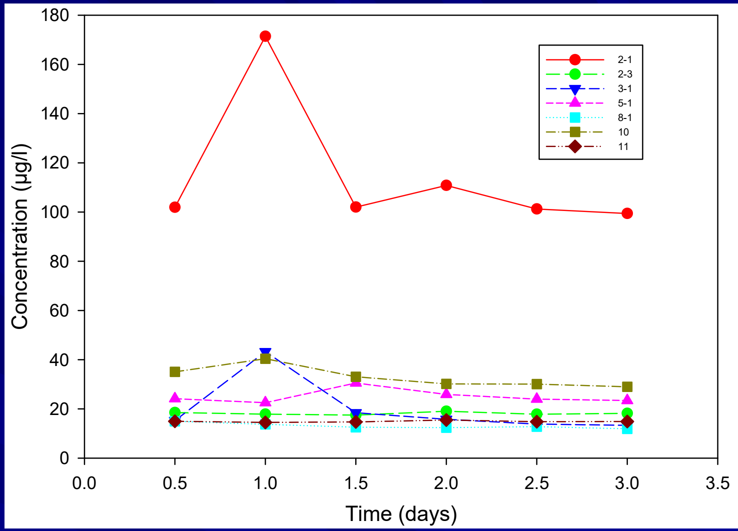
Mean Water Quality Characteristics of Wet Detention Ponds in the Stoneybrook Development from 8/01 – 12/07
(n=27 events)

- Pond depths ranged from 20-25 ft

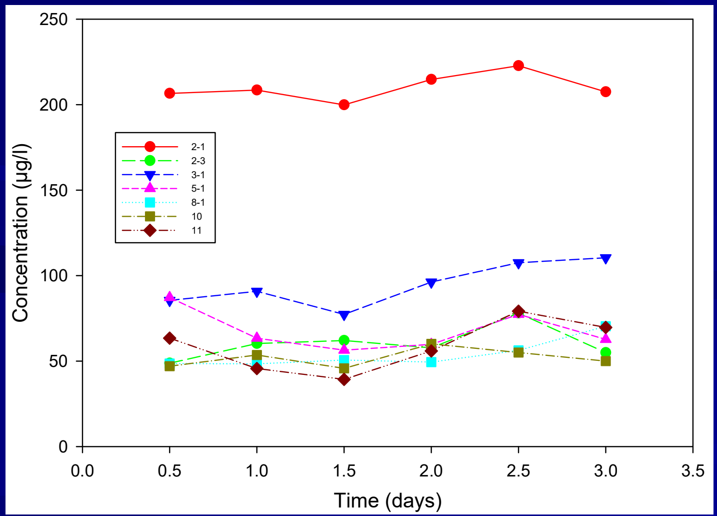
- Water quality monitoring conducted at pond outfalls for 72 hours following rain events of 0.5 inch or more

- No change in concentration over time

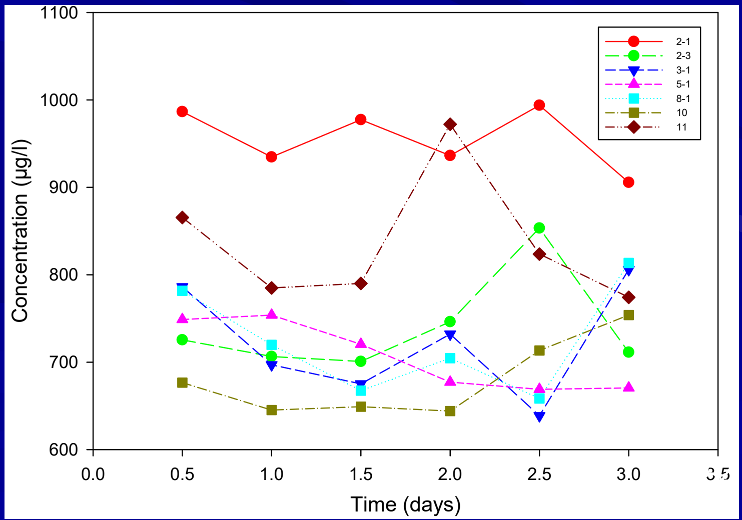
Total Copper



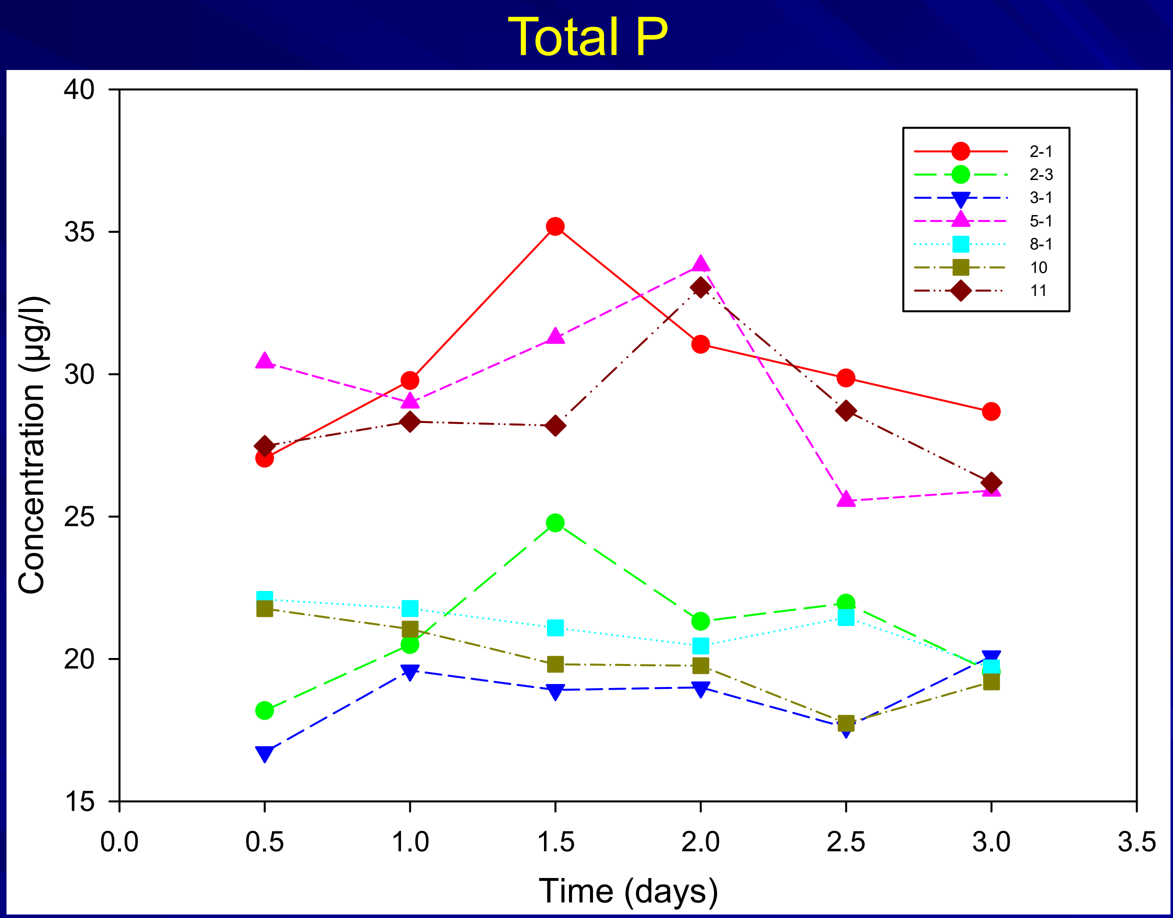
Ammonia



Total N



Mean Water Quality Characteristics of Wet Detention Ponds in the Stoneybrook Development from 8/07 – 12/07
(n=27 events)



- No significant change in outfall concentration over time

Relationships Between Lake Parameters

- P regulates the growth of algae in most freshwater lakes
- Data collected from more than 1,000 lakes in Florida and relationships developed between trophic state parameters

1. Relationship between TP and chlorophyll-a:

$$\ln(\text{chyl-a}) = 1.058 \ln(\text{TP}) - 0.934$$

where: chyl-a = chlorophyll-a concentration (mg/m^3)
TP = total P concentration ($\mu g/l$)

2. Relationship between chlorophyll-a and Secchi disk depth:

$$SD = \frac{24.2386 + [(0.3041)(\text{chyl-a})]}{(6.0632 + \text{chyl-a})}$$

where: SD = Secchi disk depth (m)

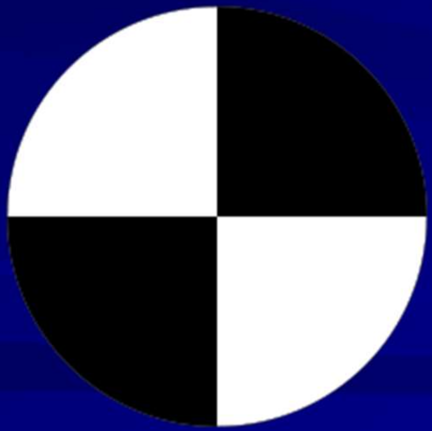
chyl-a = chlorophyll-a concentration (mg/m^3)

Secchi Disk Depth

- Measure of water transparency
- Measurement is conducted by lowering a 20 cm diameter disk into water
- Disk is lowered until it is no longer visible. Disk is then raised until it is visible again. The Secchi disk depth is the average of the two depths

Father Pietro Secchi
Scientific advisor to the Pope
(1818-1878)

Measured water clarity in Mediterranean Sea from Papal yacht

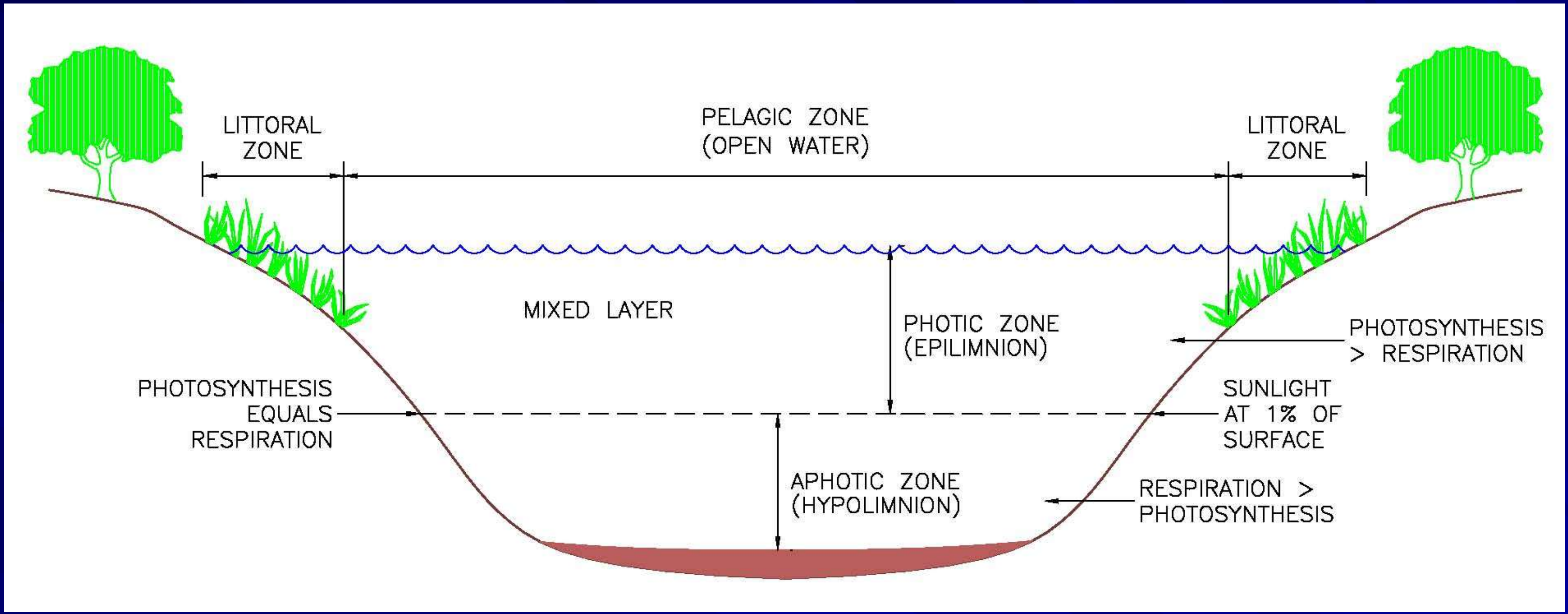


Standard 20 cm Disk

Estimation of Anoxic Depth

- The depth at which anoxic conditions (DO < 1 mg/L) occurs in a lake or pond is a function of the water quality characteristics
- Since anoxia is related to the penetration of sunlight, factors which impact light penetration should have a predictable relationship with anoxic depth
- A data set was developed to evaluate relationships between anoxic depths and related water quality parameters
  - Collected data included
    - Chlorophyll-a – measure of algal biomass which can shade light
    - Secchi disk depth - measure of light penetration
    - Total P – most stormwater ponds and lakes are phosphorus limited, and algal productivity is regulated by the amount of P available
    - Anoxic depth – the depth at which dissolved oxygen concentrations reduce to < 1 mg/L
  - Data were obtained from more than 100 ponds and lakes in Florida
- A regression analysis was conducted to evaluate relationships between these variables

Calculation of Anoxic Depth



Anoxic Depth (m) = 3.035 x Secchi (m) – 0.004979 x Total P (mg/l) + 0.02164 x chyl-a (mg/m³)

(R^2 = 0.951)

The above equation is valid for: 0.25 m < anoxic depth < 9.0 m
0.09 m < Secchi disk depth < 3.49 m
0.001 mg/l < Total P < 0.498 mg/l
1 mg/m^3 < chly-a < 332 mg/m^3

Example of Monthly Anoxic Depth Calculations

Month	Initial P Conc. (mg/l)	Hydrologic and Mass Inputs									
		Direct Precipitation		P Inputs from Bulk Precipitation		Inputs from Runoff			Total Inputs		
		(in)	(ac-ft)	(mg/l)	(kg P)	(ac-ft)	(mg/l)	(kg P)	(ac-ft)	(kg P)	(mg/l)
January	0.031	3.19	5.9	0.045	0.32	28.6	0.329	11.6	34.4	11.9	0.281
February	0.036	3.41	6.3	0.045	0.35	30.5	0.329	12.4	36.8	12.7	0.281
March	0.039	3.78	6.9	0.045	0.38	33.9	0.329	13.7	40.8	14.1	0.281
April	0.040	2.97	5.4	0.045	0.30	26.6	0.329	10.8	32.1	11.1	0.281
May	0.036	3.40	6.2	0.045	0.35	30.5	0.329	12.4	36.7	12.7	0.281
June	0.038	5.59	10.3	0.045	0.57	50.1	0.329	20.3	60.3	20.9	0.281
July	0.048	6.48	11.9	0.045	0.66	58.1	0.329	23.6	69.9	24.2	0.281
August	0.049	7.05	12.9	0.045	0.72	63.2	0.329	25.6	76.1	26.4	0.281
September	0.051	7.78	14.3	0.045	0.79	69.7	0.329	28.3	84.0	29.1	0.281
October	0.053	3.94	7.2	0.045	0.40	35.3	0.329	14.3	42.5	14.7	0.281
November	0.039	2.04	3.7	0.045	0.21	18.3	0.329	7.4	22.0	7.6	0.281
December	0.027	2.50	4.6	0.045	0.25	22.4	0.329	9.1	27.0	9.3	0.281
Totals:		52.13	95.7		5.31	467.0		190	563	195	

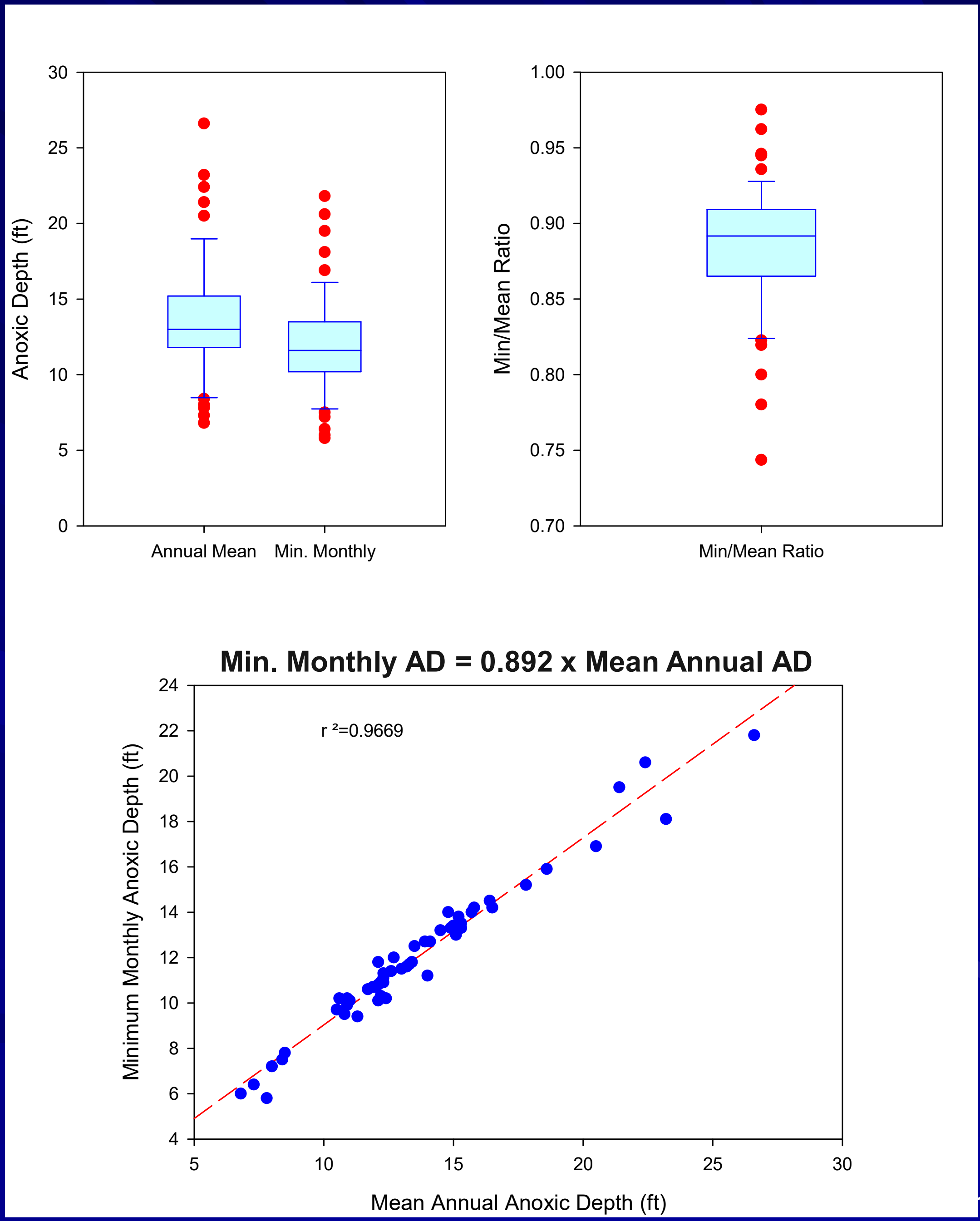
Hydrologic and Mass Losses						Mean Detention Time (days)	P Retention Coeff.	Areal P Loading (g/m^2)	Final Lake P Conc. (mg/l)	Chyl-a Conc. (mg/m^3)	Secchi Disk Depth (m)	Anoxic Zone Depth	
Surface Evaporation		Outfall Losses		Total Losses									
(in)	(ac-ft)	(ac-ft)	(kg P)	(ac-ft)	(kg P)							(m)	(ft)
1.94	3.6	30.9	1.28	34.4	1.28	382	0.855	0.119	0.036	17.5	1.3	3.7	12.1
2.47	4.5	32.3	1.51	36.8	1.51	323	0.841	0.126	0.039	19.2	1.2	3.5	11.4
3.72	6.8	34.0	1.65	40.8	1.65	323	0.840	0.140	0.040	19.2	1.2	3.5	11.4
4.78	8.8	23.3	1.08	32.1	1.08	397	0.859	0.112	0.036	17.3	1.3	3.7	12.2
5.26	9.7	27.0	1.23	36.7	1.23	359	0.850	0.129	0.038	18.5	1.2	3.6	11.7
4.99	9.2	51.2	2.72	60.3	2.72	211	0.803	0.204	0.048	23.6	1.1	3.0	10.0
5.08	9.3	60.6	3.64	69.9	3.64	188	0.793	0.231	0.049	24.3	1.0	3.0	9.8
4.60	8.4	67.7	4.16	76.1	4.16	173	0.786	0.249	0.051	24.9	1.0	2.9	9.6
3.87	7.1	76.9	4.88	84.0	4.88	152	0.775	0.271	0.053	26.0	1.0	2.9	9.4
3.40	6.2	36.3	2.06	42.5	2.06	310	0.837	0.142	0.039	19.2	1.2	3.5	11.4
2.41	4.4	17.6	0.72	22.0	0.72	579	0.893	0.077	0.027	13.0	1.5	4.4	14.5
1.86	3.4	23.6	0.85	27.0	0.85	488	0.877	0.095	0.031	15.0	1.4	4.1	13.3
44.38	81.4	481.2	25.79	563	25.79	324	0.834	0.158	0.041	20.0	1.2	3.5	11.3

Relationships Between Mean Annual Anoxic Depth (AD) and Minimum Monthly Anoxic Depth

-The AD calculation provides an estimate of the mean annual AD

- To impart a conservative bias to the analysis, some of the WMDs require that anoxic conditions not occur during any given month

- A conversion is used to convert the calculated mean annual AD to a minimum monthly value



Calculation of Design Anoxic Depth

- If mean annual water column characteristics are used to calculate the anoxic depth, then the calculated depth represents a mean annual anoxic depth
- However, anoxic depth will vary throughout the year
- The pond design should be based on the minimum anticipated monthly anoxic depth:

Min. Monthly Anoxic Depth = 0.892 x Mean Annual Anoxic Depth

Wet Detention Example

Calculate the wet detention efficiencies for similar developments in Pensacola, Orlando, and Key West

1. Land Use: 90 acres of single-family residential
   5 acres of stormwater management systems
   5 acres of preserved wetlands

2. Ground Cover/Soil Types

   A. Residential areas will be covered with lawns in good condition
   B. Soil types in HSG D

3. Impervious/DCIA Areas

   A. Impervious area =22.50 acres

   DCIA Area = 22.50 acres x 0.75 = 16.88 acres

   % DCIA = (16.88 ac/90.0 ac) x 100 = 18.7% of developed area

Wet Detention Example – cont.

4. Composite non-DCIA curve number: Non-DCIA CN Value = 81.4

5. Wet Detention Pond Design Criteria:

   A. Pond designed to provide an 80% reduction for TP

6. Project Hydrologic and Mass Loading Characteristics:

Location	Annual C Value	Runoff (ac-ft/yr)	TN Loading (kg/yr)	TP Loading (kg/yr)
Pensacola	0.304	149.3	344	55.4
Orlando	0.253	94.8	219	35.2
Key West	0.266	79.8	184	29.6

Wet Detention Example – cont.

7. Calculate required pond detention time (T_d):

Detention time required to achieve 80% TP removal =

$$Eff = 40.13 + 6.372 \ln (t_d) + 0.213 (\ln t_d)^2$$

By iteration, Td = ~ 200 days (79.9%)

Anticipated TN removal for a 200 day detention time =

$$Eff = \frac{(43.75 \times t_d)}{(4.38 + t_d)} = \frac{44.72 \times 200}{5.46 + 200} = \underline{42.6\%}$$

Wet Detention Example – cont.

8. Calculate Permanent Pool Volume (PPV):

For the Pensacola site, the PPV requirement is:

$$\frac{149.3\ \text{ac-ft}}{\text{yr}} \times 200\ \text{days} \times \frac{1\ \text{year}}{365\ \text{days}} = \underline{81.8\ \text{ac-ft}}$$

For the Orlando site, the PPV requirement is:

$$\frac{94.8\ \text{ac-ft}}{\text{yr}} \times 200\ \text{days} \times \frac{1\ \text{year}}{365\ \text{days}} = \underline{51.9\ \text{ac-ft}}$$

For the Key West site, the PPV requirement is:

$$\frac{79.8\ \text{ac-ft}}{\text{yr}} \times 200\ \text{days} \times \frac{1\ \text{year}}{365\ \text{days}} = \underline{43.7\ \text{ac-ft}}$$

Wet Detention Example – cont.

9. Calculate mean annual pond TP concentration (Pensacola):

Annual mass of TP discharged from pond (79.9 % removal)=

$$\frac{55.4\ \text{kg}}{\text{yr}} \times (1 - 0.799) = 11.1\ \text{kg}$$

This mass will be released in discharges from the pond outfall. Assuming that inflow and outflow are equal, outflow volume is 149.3 ac-ft.

Mean pond discharge concentration =

$$\frac{11.1\ \text{kg TP}}{\text{yr}} \times \frac{1\ \text{yr}}{149.3\ \text{ac-ft}} \times \frac{1\ \text{ac}}{43{,}560\ \text{ft}^2} \times \frac{1\ \text{ft}^3}{7.48\ \text{gal}}$$

$$\times \frac{1\ \text{gal}}{3.785\ \text{liter}} \times \frac{10^6\ \text{mg}}{\text{kg}} = 0.060\ \text{mg TP/L} = \underline{60\ \mu\text{g TP/L}}$$

Wet Detention Example – cont.

10. Calculate pond annual chloropyhll-a concentration:

The relationship between TP and chlorophyll-a in a Florida waterbody can be expressed by the following relationship:

$$\ln(\text{chyl-a}) = 1.058 \ln(\text{TP}) - 0.934$$

where: chyl-a = chlorophyll-a concentration (mg/m^3)

TP = total P concentration ($\mu g/l$)

$$\ln(\text{chyl-a}) = 1.058 \ln(60) - 0.934$$

$$\text{chyl-a} = e^{2.94} = 40.4\ mg/m^3$$

Wet Detention Example – cont.

11. Calculate mean annual pond Secchi disk depth:

The relationship between chlorophyll-a and Secchi disk depth in a Florida waterbody can be expressed by the following relationship:

$$SD = \frac{24.2386 + [(0.3041)(\text{chyl-a})]}{(6.0632 + \text{chyl-a})}$$

where: SD = Secchi disk depth (m)

chyl-a = chlorophyll-a concentration (mg/m^3)

$$SD = \frac{24.2386 + [(0.3041)(40.4)]}{(6.0632 + 40.4)} = 0.79 \text{ m} = 2.6 \text{ ft}$$

Wet Detention Example – cont.

12. Calculate mean annual depth of anoxic conditions:

The depth of anoxic conditions (AD) in a wet detention pond can be expressed by the following regression relationship:

$$AD = 3.035 \times Secchi + 0.02164 \times (chly\text{-}a) - 0.004979 \times Total\ P$$

where:

	AD	=	anoxic depth (m)
	Secchi	=	Secchi disk depth (m)
	chly-a	=	chlorophyll-a concentration (mg/m^3)
	Total P	=	total phosphorus concentration ($\mu g/l$)

Wet Detention Example – cont.

12. Calculate mean annual depth of anoxic conditions – cont.

AD = 3.035 (0.79) + 0.02164 (40.4) - 0.004979 (60) = 2.97 m = 9.8 ft

The anoxic depth calculated using this method reflects a mean annual anoxic depth.

The minimum monthly anoxic depth is calculated as:

Min. Monthly AD = 0.892 x mean annual AD

Min. monthly AD = 0.892 x 2.97 m = 2.65 m = 8.7 ft

Modeled Impacts of Additional PPV

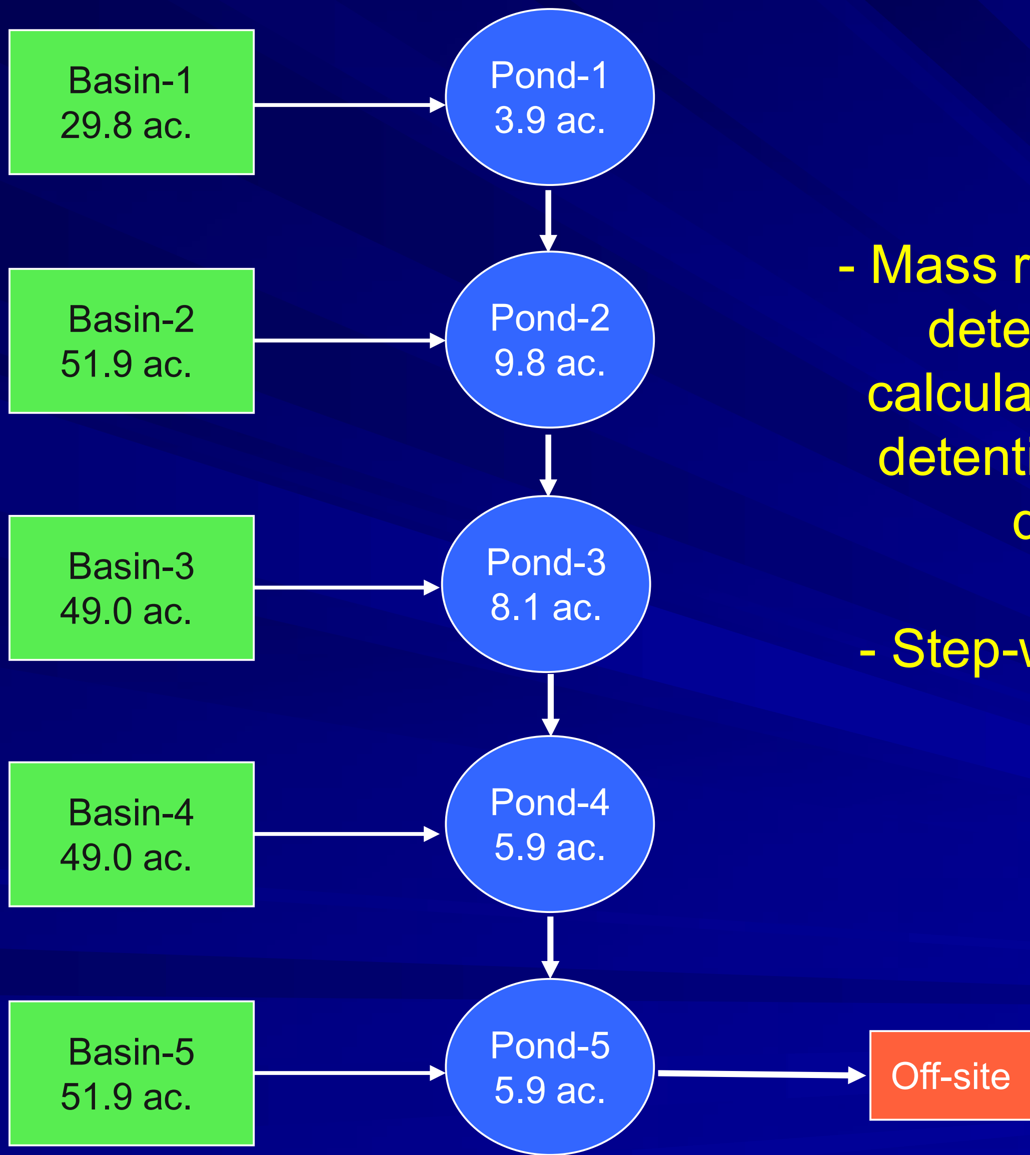
Detention Time (days)[1]	TP Mass Removal (%)	Pond TP Conc. (mg/l)	TP Discharge (kg/yr)
8	68.6	0.094	56.4
11	69.9	0.089	53.9
17	71.3	0.085	51.2
26	72.7	0.080	48.4
39	74.3	0.075	45.4
58	75.9	0.069	42.1
87	77.7	0.063	38.7
130	79.6	0.057	35.0
195	81.6	0.050	31.1
293	83.8	0.042	26.9
440	86.1	0.035	22.3

1. Each detention time increased by 50%

Impacts

1. Increased mass removal
2. Reduced discharge concentrations and mass loadings
3. Increased dilution for slug inputs

Nodal Diagram for a Multi-Pond System



- Mass removal for inputs to a wet detention pond in series is calculated using the cumulative detention time of the pond and downstream ponds

- Step-wise calculations through each pond

Example Calculations for Wet Detention Ponds in Series

Pond	Det. Time (days)	Cumulative Pond Detention time (days)				
		Pond 1	Pond 2	Pond 3	Pond 4	Pond 5
1	315	315				
2	252	567	252			
3	151	718	403	151		
4	123	841	526	274	123	
5	87	928	613	361	210	87

Pond	TP Load (kg/yr)	Incremental TP Removal (kg/yr)				
		Pond 1	Pond 2	Pond 3	Pond 4	Pond 5
1	13.6	11.5				
2	16.2	0.7	13.4			
3	21.2	0.4	0.8	16.7		
4	24.4	0.3	0.5	1.1	18.9	
5	19.5	0.2	0.2	0.4	0.8	14.6

Totals: 94.76

Pond	Det. Time (days)	Cumulative TP Removal (%)				
		Pond 1	Pond 2	Pond 3	Pond 4	Pond 5
1	315	85				
2	252	89	83			
3	151	91	87	79		
4	123	93	89	84	77	
5	87	93	90	86	82	75

Pond	TP Load (kg/yr)	Cumulative TP Remaining (kg/yr)					Pond Load (kg/yr)
		Pond 1	Pond 2	Pond 3	Pond 4	Pond 5	
1	13.6	2.1					2.1
2	16.2	1.3	2.8				4.1
3	21.2	0.9	2.0	4.4			7.3
4	24.4	0.6	1.5	3.3	5.5		10.9
5	19.5	0.5	1.2	2.9	4.7	4.9	14.2

Detention times are cumulative from one pond to another

Concept of Irreducible Concentration

- Irreducible concentrations reflect the limitations of removal pathways for a particular pollutant in a treatment system
  - In wet ponds, the most significant processes are:
    - Sedimentation
    - Biological uptake

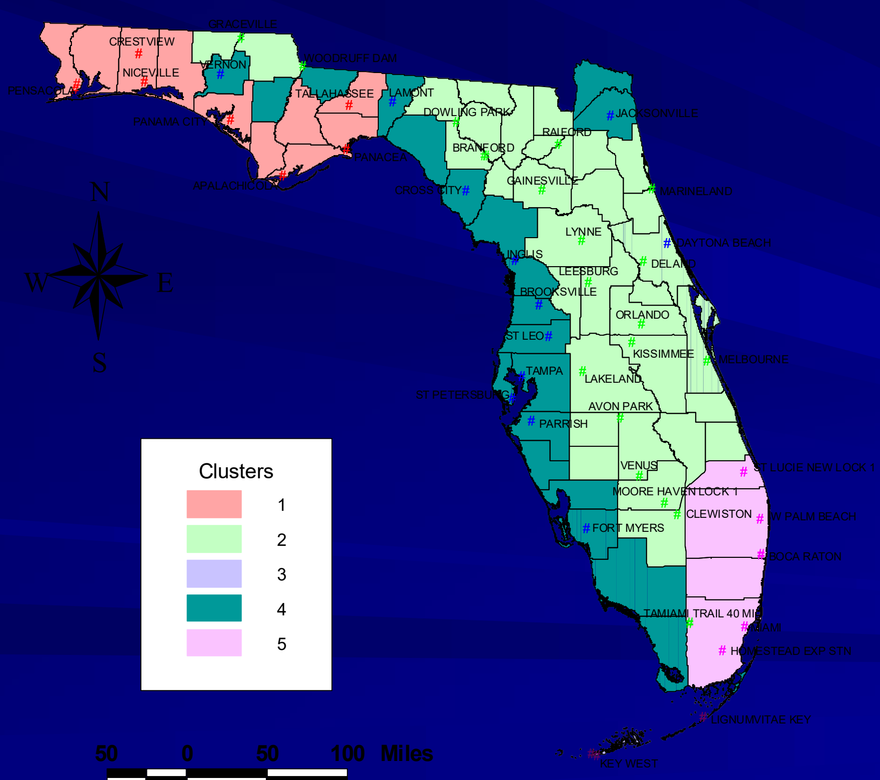
- When the irreducible concentration is reached, no significant additional removal is possible regardless of additional treatment volume or time

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

- Concept is widely used in modeling wastewater treatment wetlands

Comparison of 14 Day Wet Season with Mean Annual Detention Time

- Some of the Water Management Districts base their pond detention time designs on a 14-day wet season detention time
- This Methodology is based on a mean annual detention time



Meteorological Zone	Equivalent Annual Detention Time (days)
1- Panhandle	17.1
2- Central	19.9
3- Keys	21.8
4- West Coastal	20.2
5- Southeast	21.0

Floating Islands

Preparing Mats

Adding plants to mats

Attaching mats

Dragging mats to selected location

Floating Islands – cont.

Inflow monitoring site

Grown plants in mat

Outflow monitoring site

Screens added to restrict birds

Floating Islands – cont.

Root mass under mat at end of study

Root mass at end of study

Root mass at end of study

Root mass at end of study

Wet Detention Pond Enhancement

- Results of field monitoring
  - Pre-monitoring conducted from Jan-April 2011
  - Post monitoring conducted from May 2011-April 2012

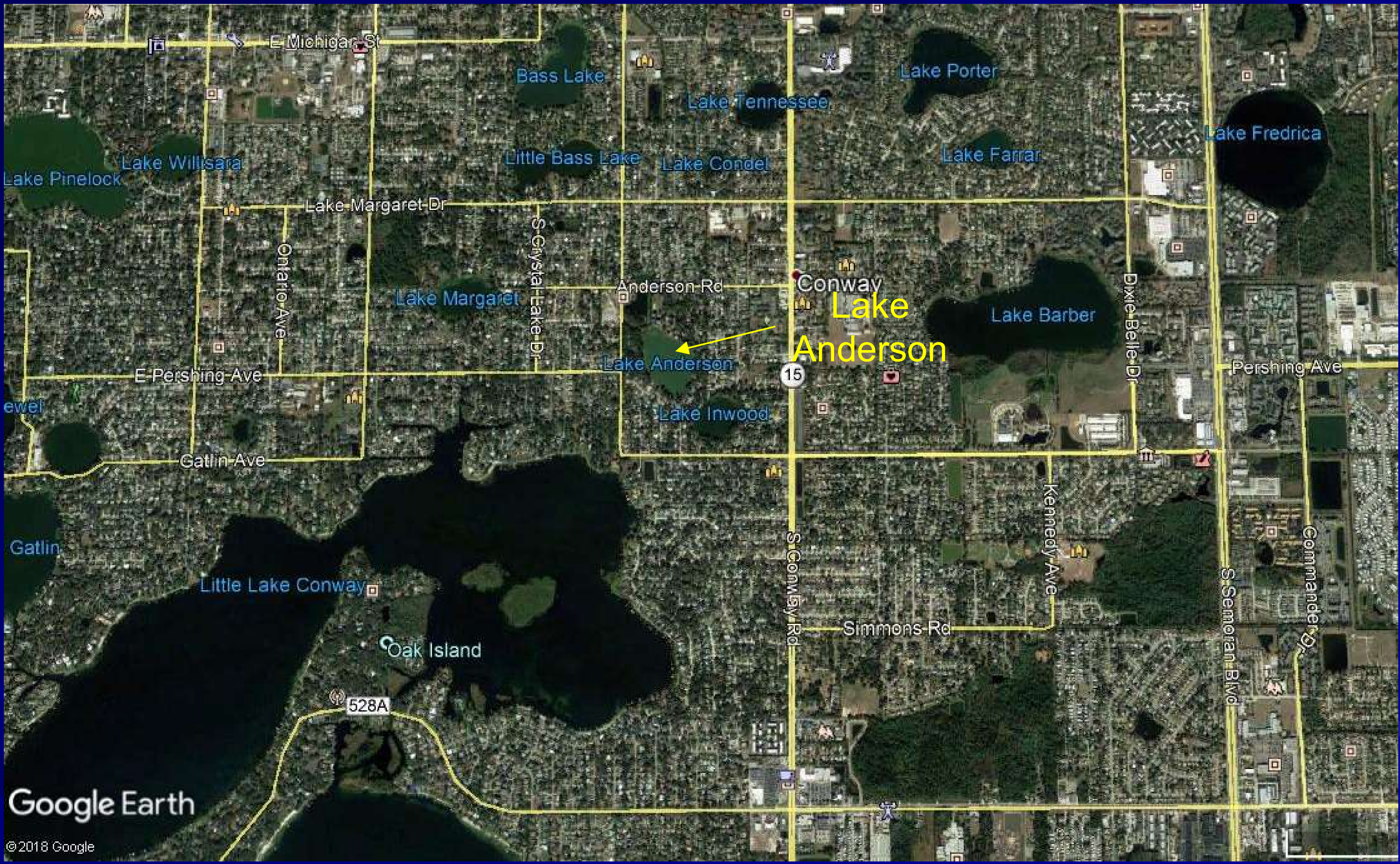
Parameter	Units	Pre-Island			Post Island		
		Inflow	Outflow	% Removal	Inflow	Outflow	% Removal
NH_3	µg/L	80	37	54	25	24	5
NO_X	µg/L	20	8	60	9	7	23
Diss Org N	µg/L	577	597	-4	480	543	-13
Particulate N	µg/L	198	362	-83	148	182	-23
Total N	µg/L	970	1,146	-18	753	842	-12
SRP	µg/L	176	24	87	70	28	59
Diss Org P	µg/L	24	16	36	19	20	-7
Particulate P	µg/L	28	64	-126	30	45	-47
Total P	µg/L	274	133	52	145	128	12
Turbidity	NTU	2.3	5.0	-117	1.9	3.9	-112
TSS	mg/L	3.1	8.0	-155	1.5	3.3	-120

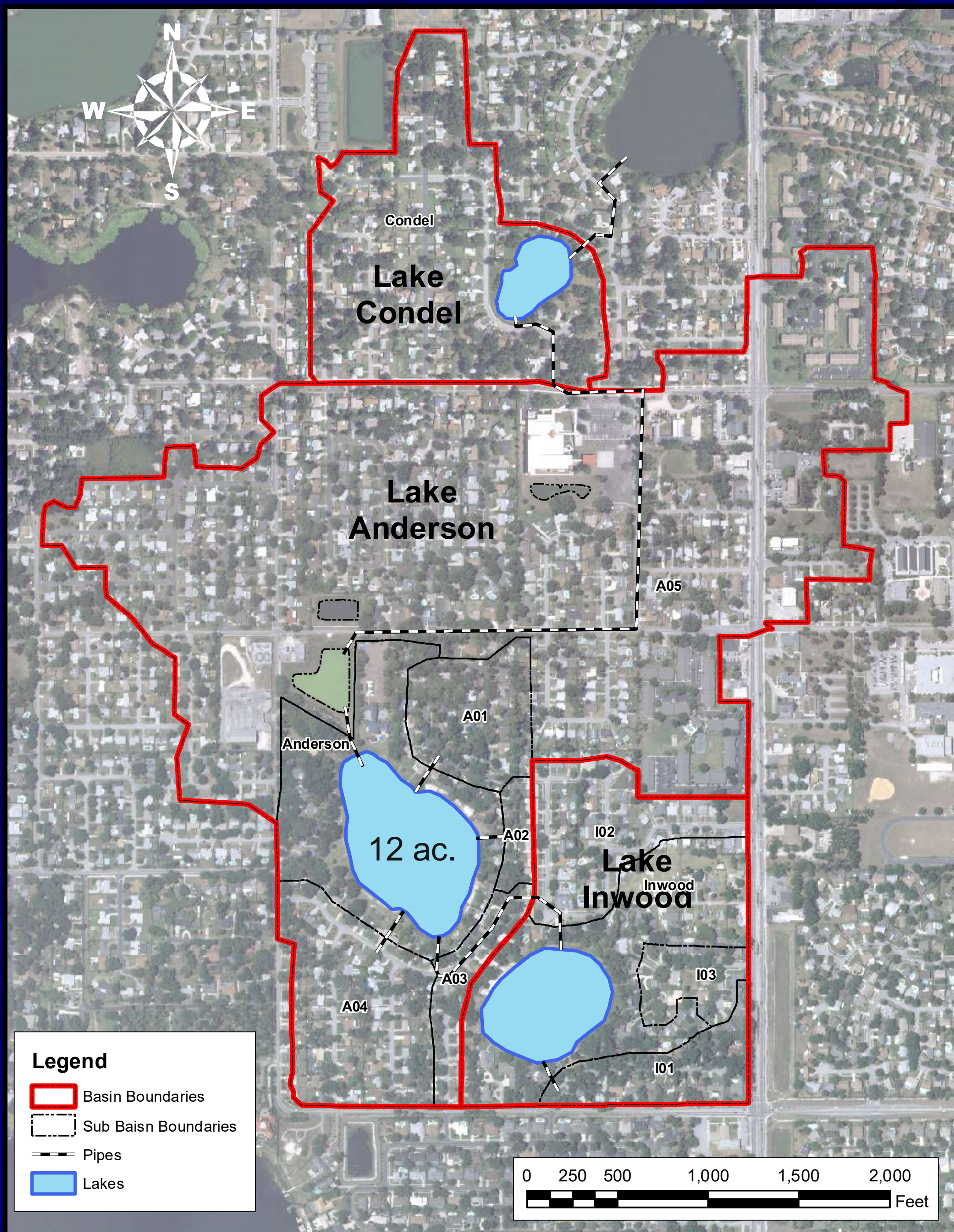
- Efficiency highly impacted by nutrient concentrations in water
- BMPTRAINS uses the following efficiencies
  - Total N – 10%
  - Total P – 10%

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%
- Beneficial bacteria for muck removal
  - Don’t waste your money

Slow Rate Alum Addition
(Lake Anderson)





Watershed Areas Discharging to Lake Anderson

Sub-Basin I.D.	Total (acres)	Percent Of Total
A01	10.6	4.6
A02	2.4	1.0
A03	5.6	2.4
A04	18.9	8.3
A05	173.1	75.2
Overland Flow	19.5	8.5
Totals:	230.0	100

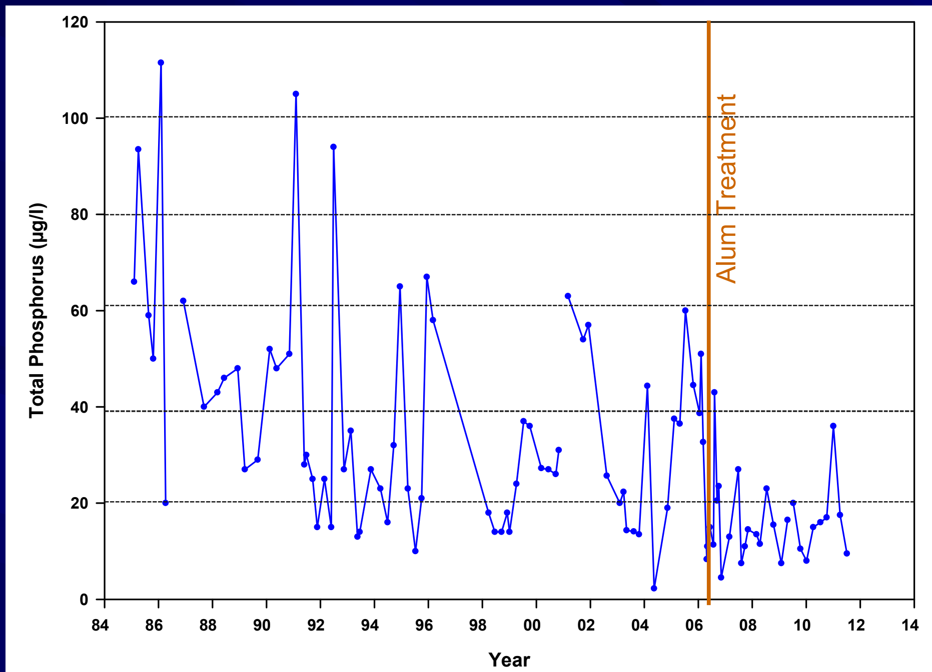
Lake Anderson Pond Overview

Typical wet detention pond removal efficiencies:

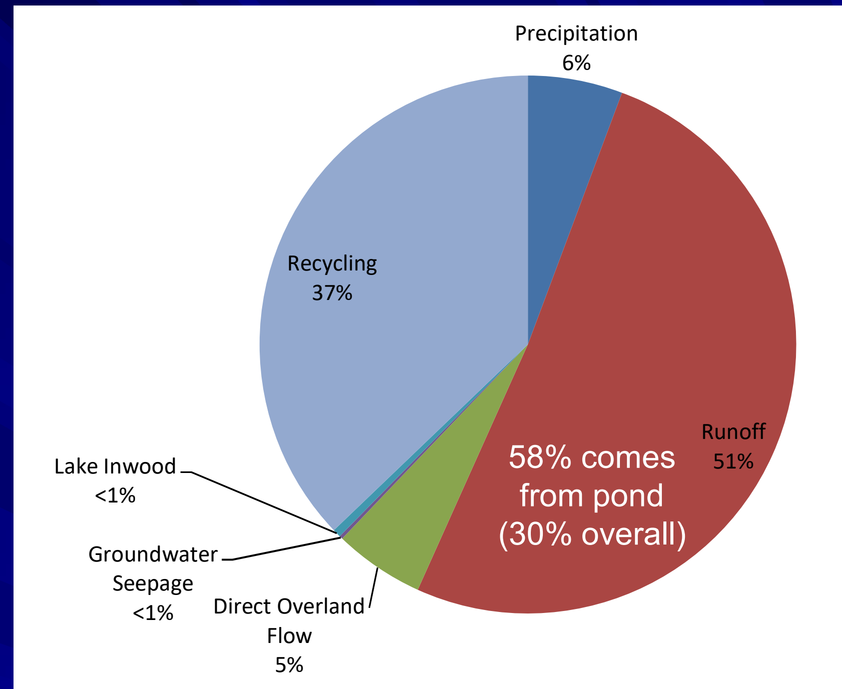
65% for TP
35 % for TN
80% for TSS

Alum addition system recommended to reduce nutrient loadings

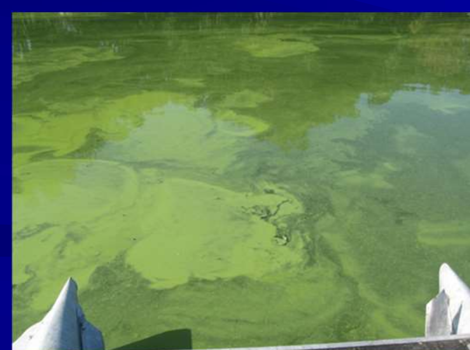
Lake Anderson Management History



TP Conc. From 1986 - 2012



Developed Hydrologic/Nutrient Budget During 2012



Microcystis Bloom Observed on January 20, 2011

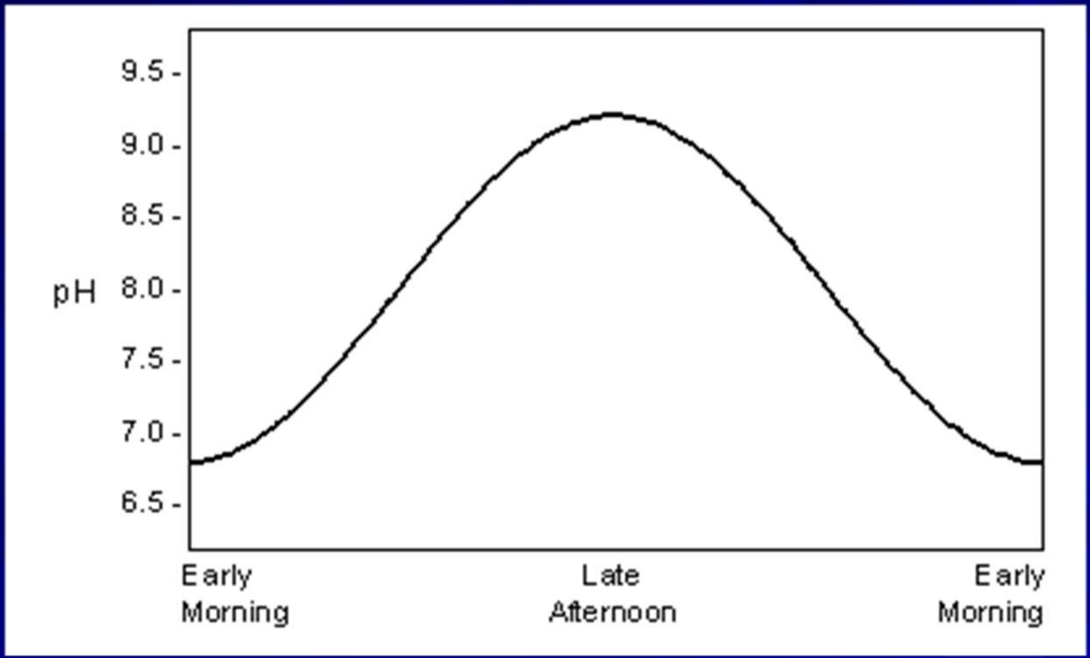
Watershed is heavily built-out with no significant opportunities for BMPs

Lake Anderson Pond Alum Enhancement System

- Traditional alum treatment systems are designed to treat stormwater inflows
  - Inflow discharge is measured
  - Alum is added in proportion to the inflow rate
  - Generated floc is captured in a settling pond or allowed to discharge into the receiving water
- Lake Anderson system is a simplified process that is designed to treat the pond water rather than the runoff inflow
  - Alum addition is based on the water column pH
    - Uses the well known relationship between water pH and algal productivity
    - 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 7 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

Effects of Algal Productivity on pH

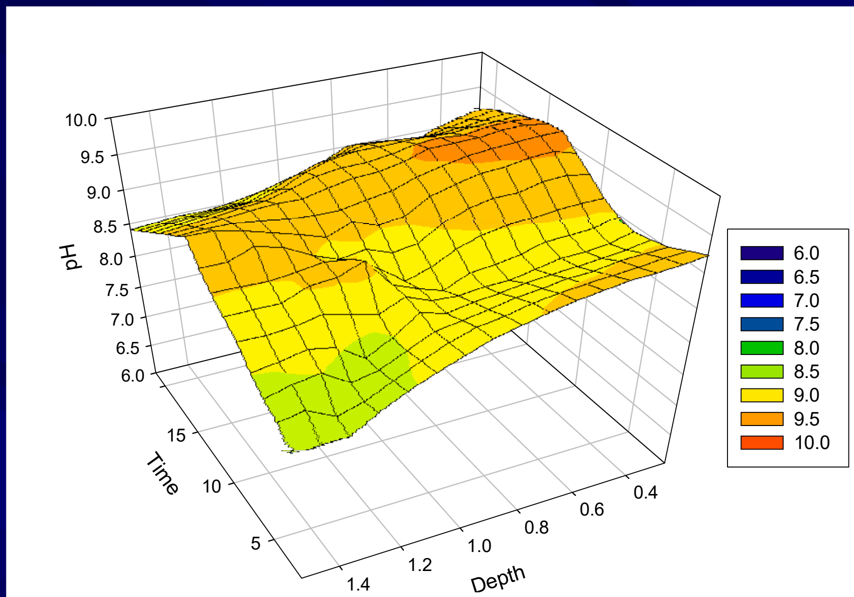
Diurnal pH Fluctuation in Eutrophic Ponds and Lakes



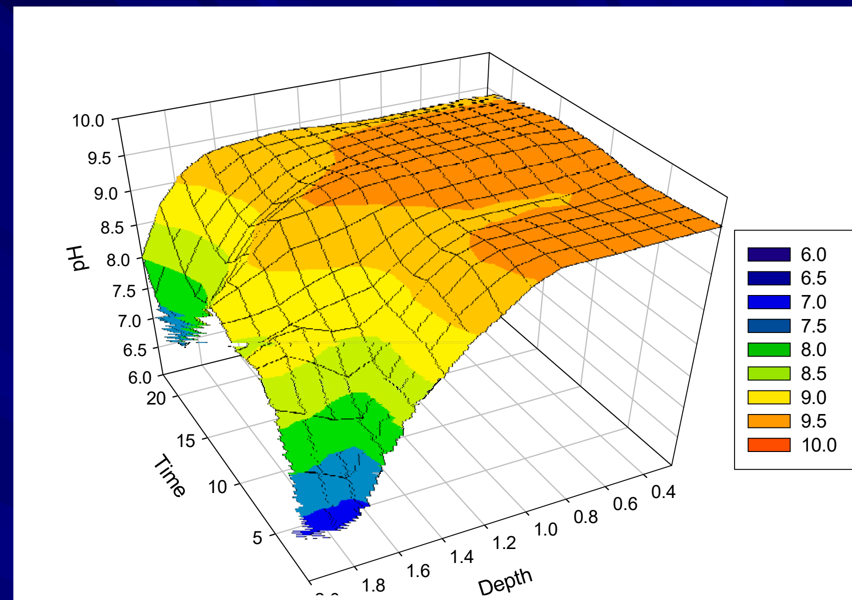
- Algal production causes pH to increase
- Respiration causes pH to decrease
- Magnitude of diurnal pH shift is a function of the rate of production and respiration
- Algal production is fueled by nutrients
- pH can be used as a surrogate for nutrient concentrations

Lake Hancock Site 2 – pH

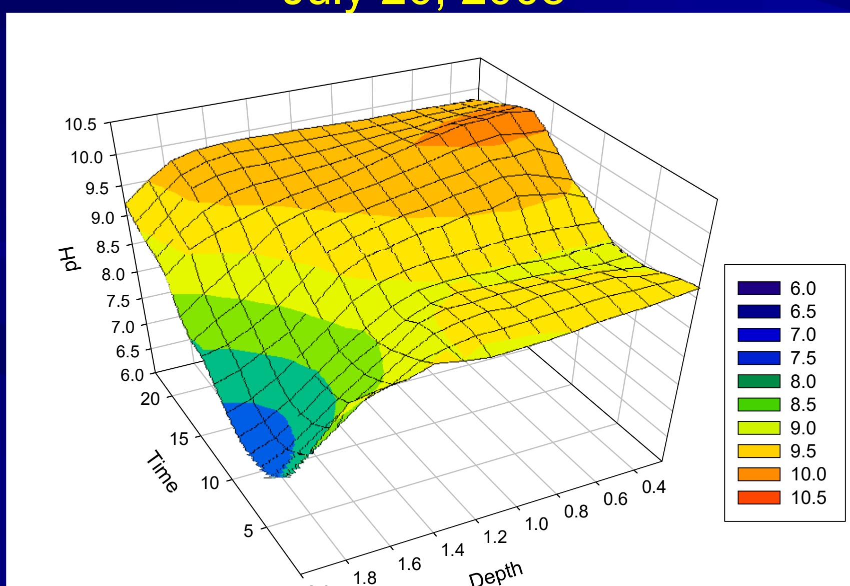
January 31, 205



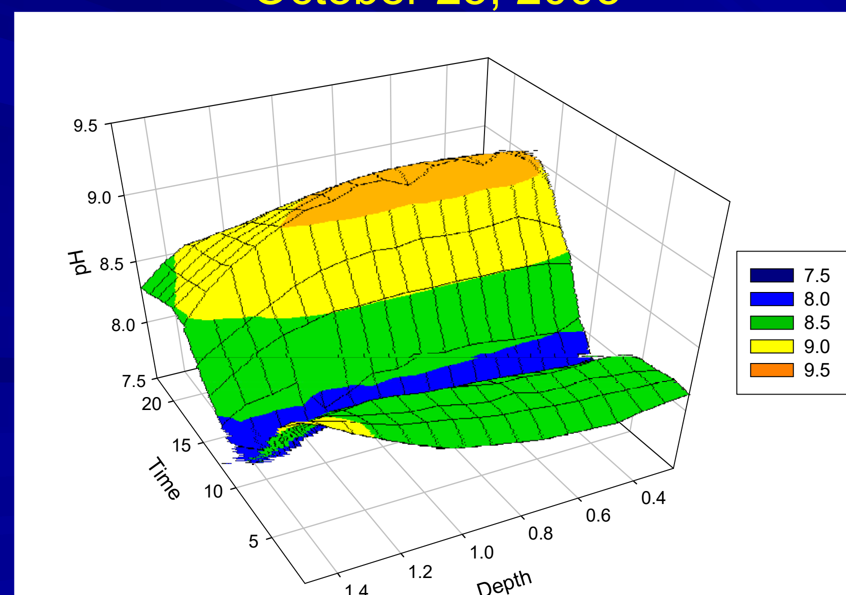
April 15, 2005



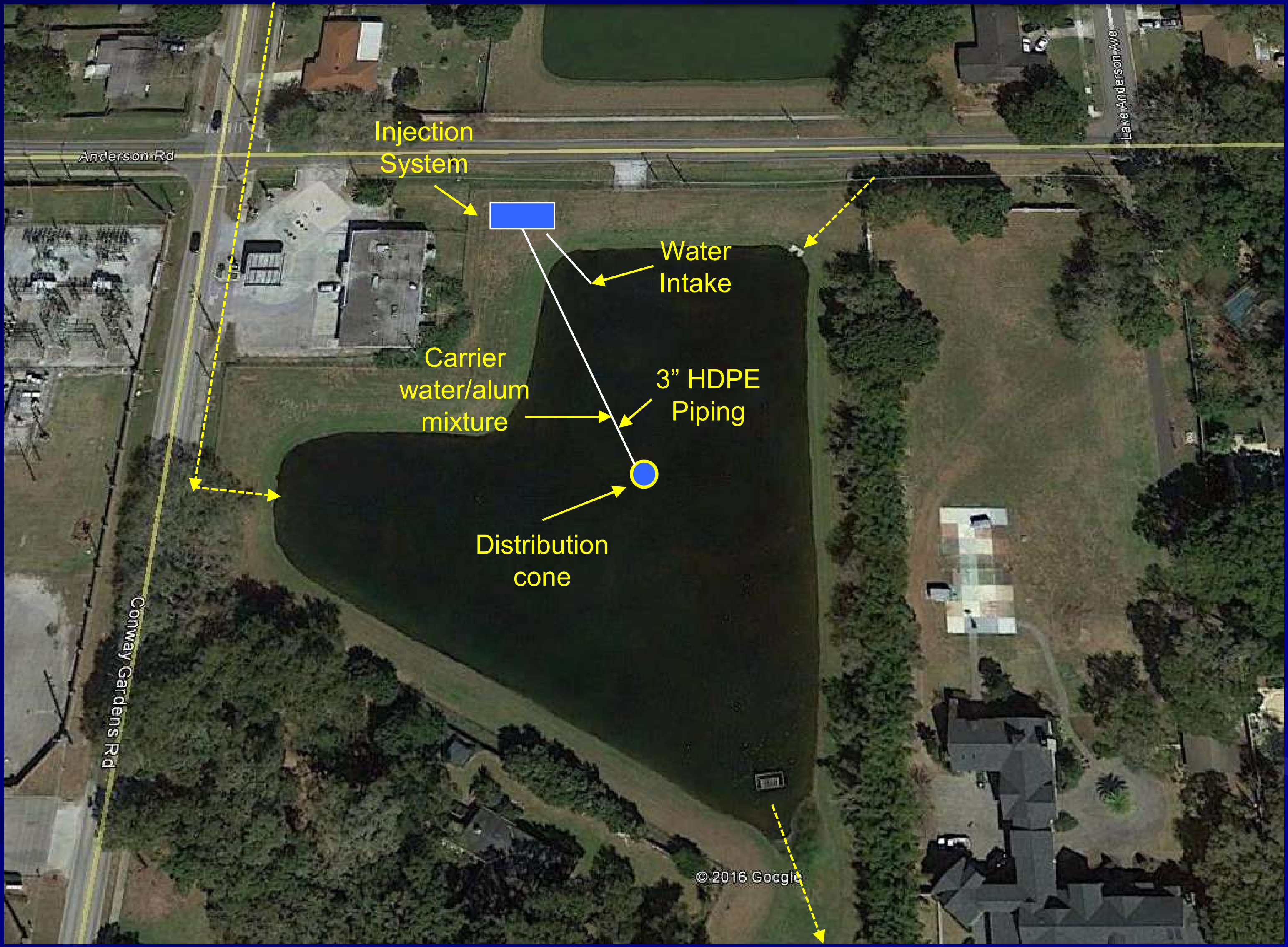
July 20, 2005



October 25, 2005

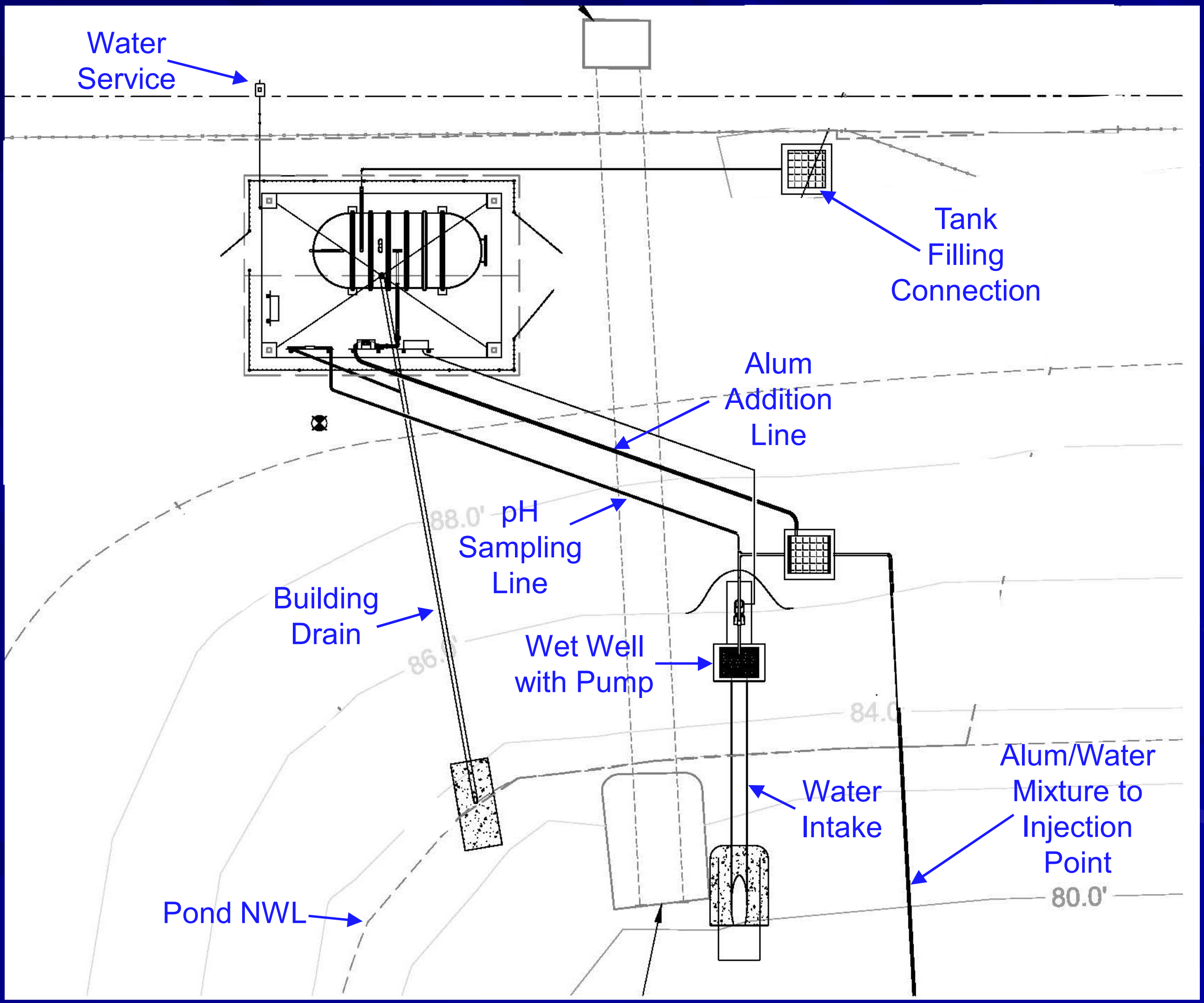


Pond Enhancement System Overview



System Overview

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



Lake Anderson Alum Addition System

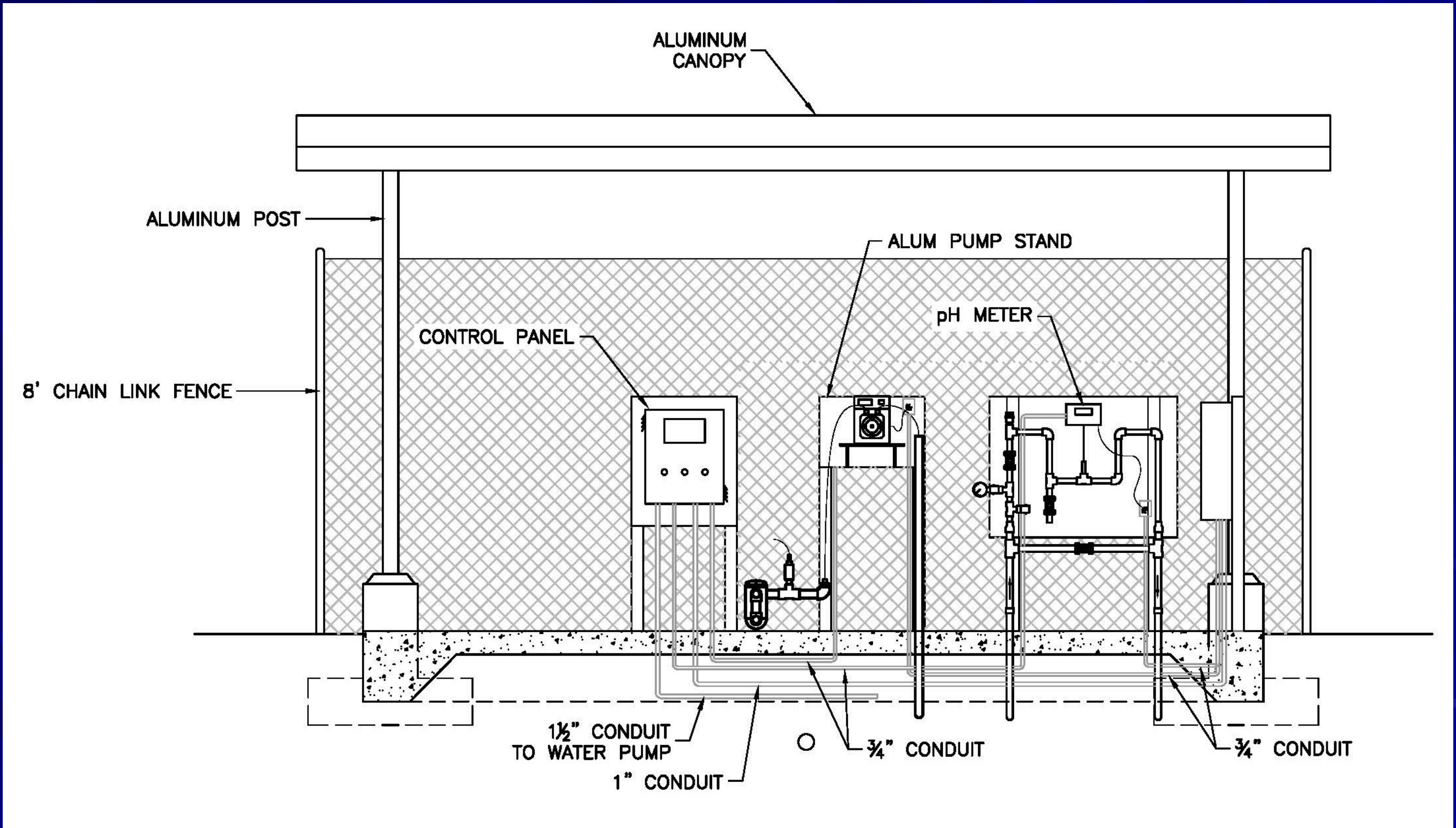
Circulation Pump

Alum Storage Tank

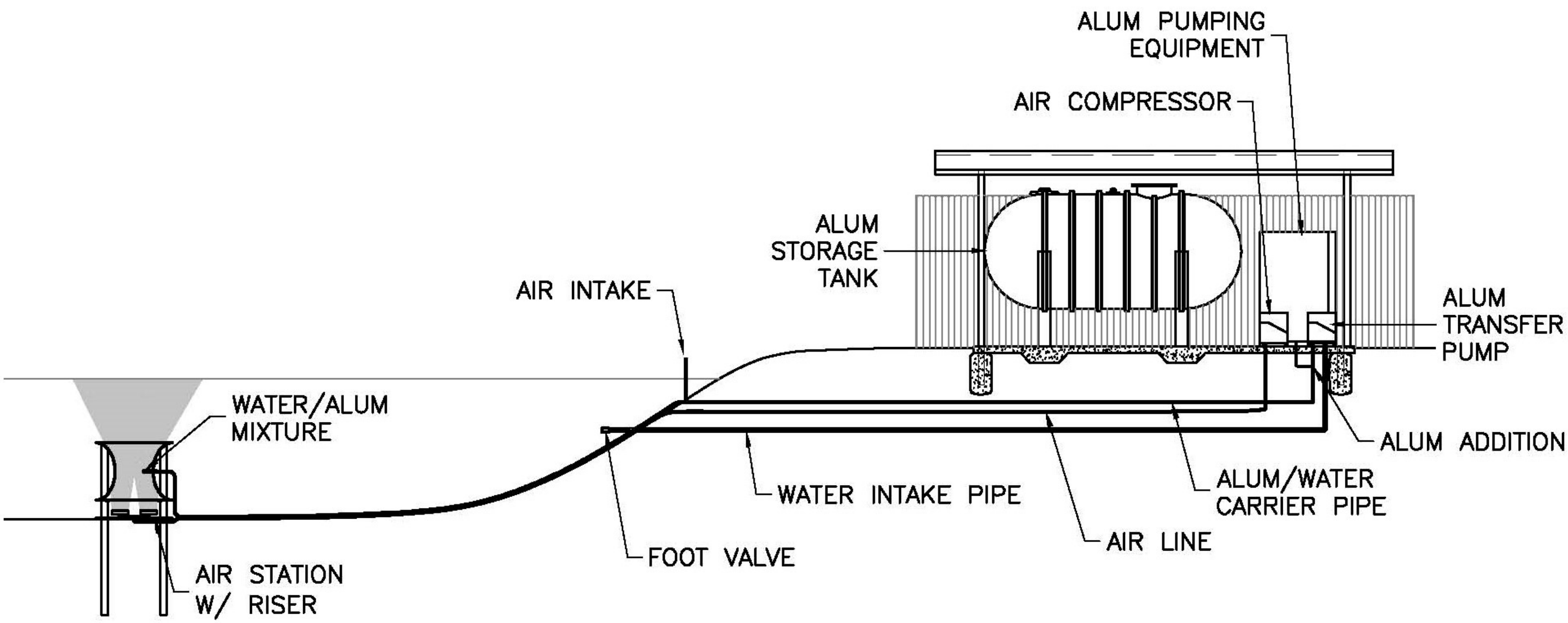
Control System

Venturi for Alum Addition

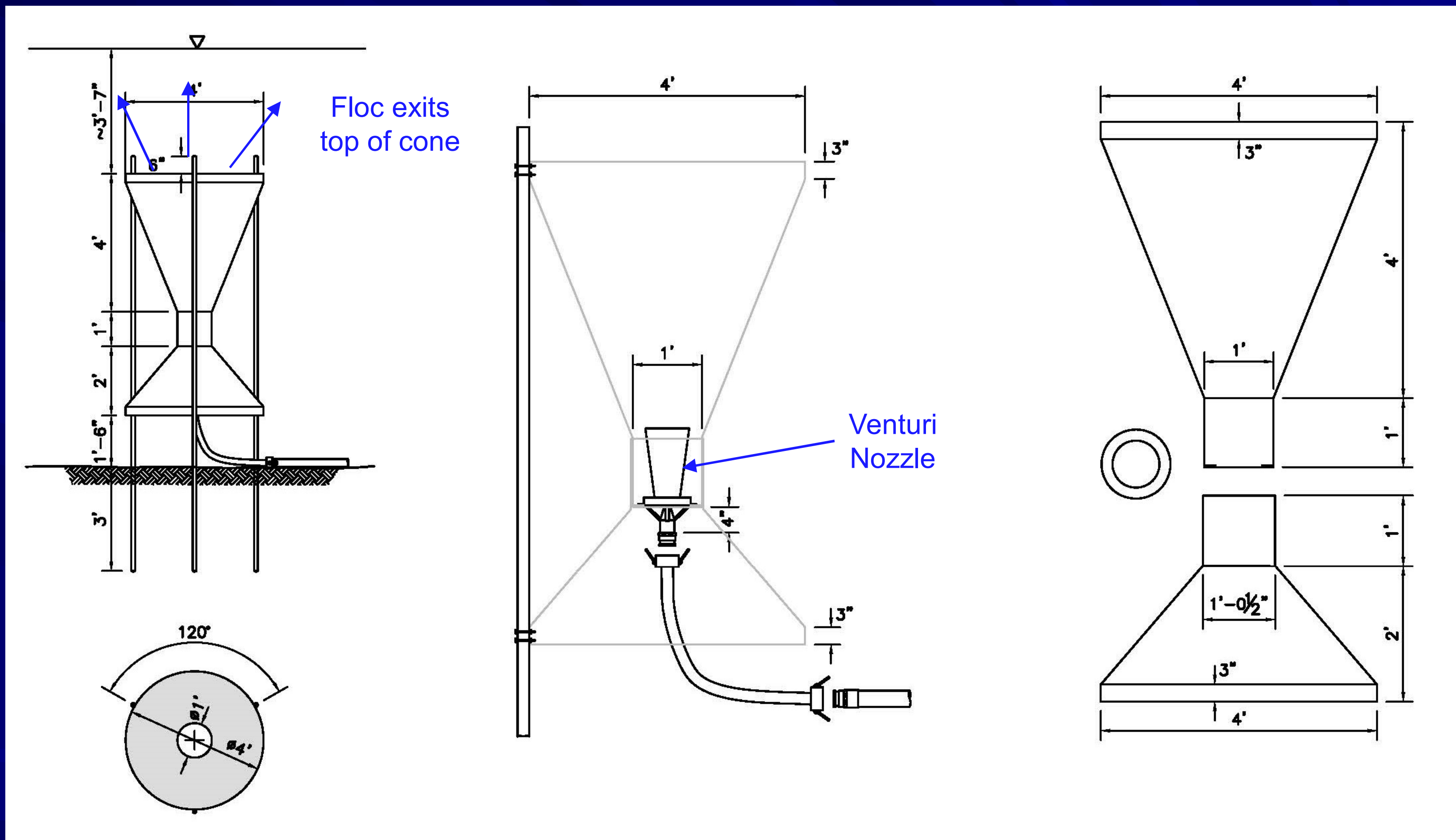
Alum Dosing and pH Monitoring Systems



Schematic of System Components



Distribution Cone



- Venturi nozzle pulls in 3 times as much water as pumped
- Alum floc exits at the surface
- Entrained air keeps floc floating in the water column

Lake Anderson Pond System

Alum metering pump

Water recirculation pump

Distribution cone

Fish bedding along pond bank

Chemical Use and Load Reductions

Parameter	Units	Value
Pond Drainage Basin	acres	175.1
Runoff to Pond	ac-ft/yr	156
Assumed alum dose	mg Al/L	6
Alum Usage	gal/yr	7,500
Alum Cost @ $0.45/gal	$	3,375
Current TP Load	kg/yr	22.6
TP Removal	%	85
	kg/yr	19.2
Construction Cost	$	220,000
Annual O & M	$	8,375
20-year Present Worth	$	345,625
TP Mass Removal Cost	$/kg	900
	$/lb	408

Aluminator!

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

Summary

- Wet detention ponds are man-made lakes designed to treat runoff
- Wet detention ponds provide significant removal efficiencies for nutrients
  - Total N: 35 – 45%
  - Total P: 65 – 80%
- The efficiency of wet detention is a function of detention time
- Wet detention ponds should be designed to maintain aerobic conditions throughout the water column
- Wet detention ponds exhibit irreducible concentrations below which no further reduction is possible
- BMPTRAINS model conducts all calculations for pond design and evaluation

Part 7

Dry Detention

Typical Dry Detention Pond

Dry Detention Efficiency Data

- During 2006-2007, ERD conducted a review of stormwater design criteria in Florida as part of the proposed Statewide Stormwater Rule
  - Included a review of efficiencies for common Florida BMPs:

Summary of Available Dry Detention Efficiency Data

Reference	Location	Study Site/ Land Use	Mean Removal Efficiencies (%)						
			Total N	Total P	TSS	BOD	Total Cu	Total Pb	Total Zn
Bradfordville Study	Leon County	Comm.	80	92	98	93	--	--	--
Harper & Herr (1995)	Orange County	Comm. & Resid.	-136	-86	77	-49	68	93	25

  - ERD study recommended additional evaluations of the performance efficiencies of dry detention systems

Dry Detention Efficiency Study

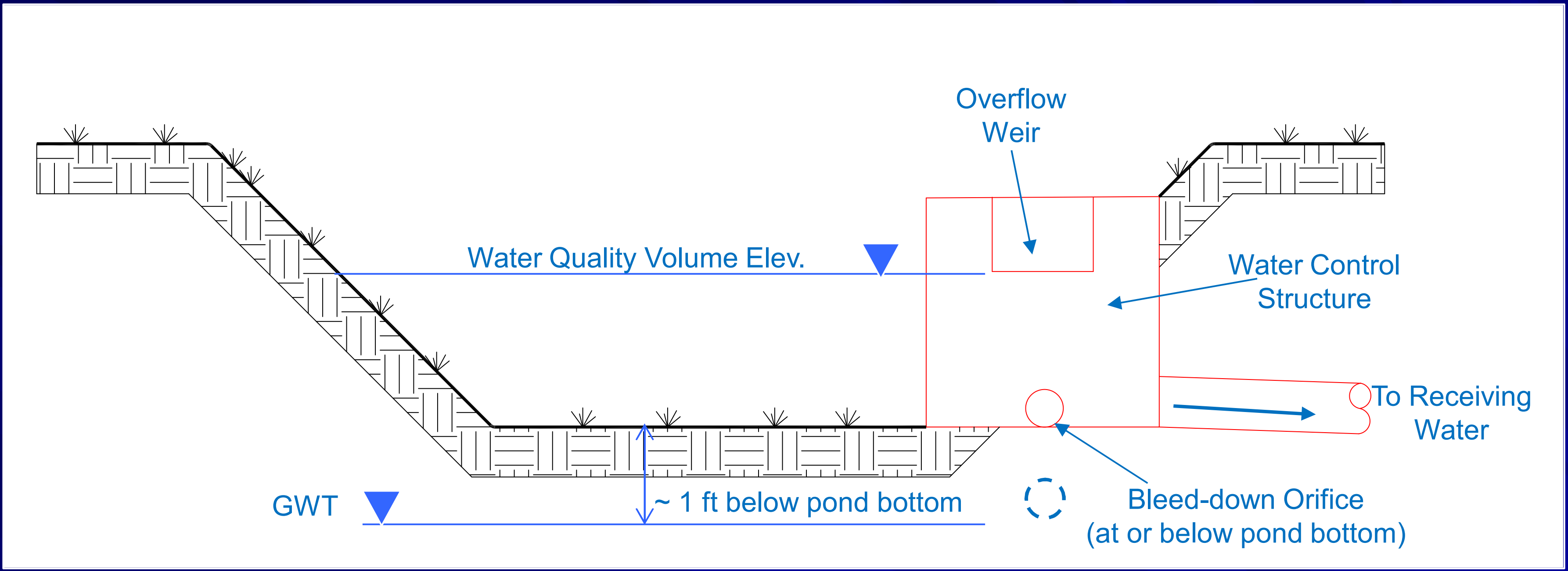
- In 2010 ERD was selected by FDEP to conduct an evaluation of the performance efficiency of dry detention ponds (SFWMD criteria) and underdrain filtration systems (SJRWMD criteria)

- SFWMD and SJRWMD provided lists of project sites with permitted and inspected dry detention and underdrain filtration systems
  - Emphasized low intensity commercial (LIC) land use

- ERD visited each of the sites and evaluated site suitability for:
  - Suitability for monitoring – types of inflows, weirs, tailwater impacts
  - Site security

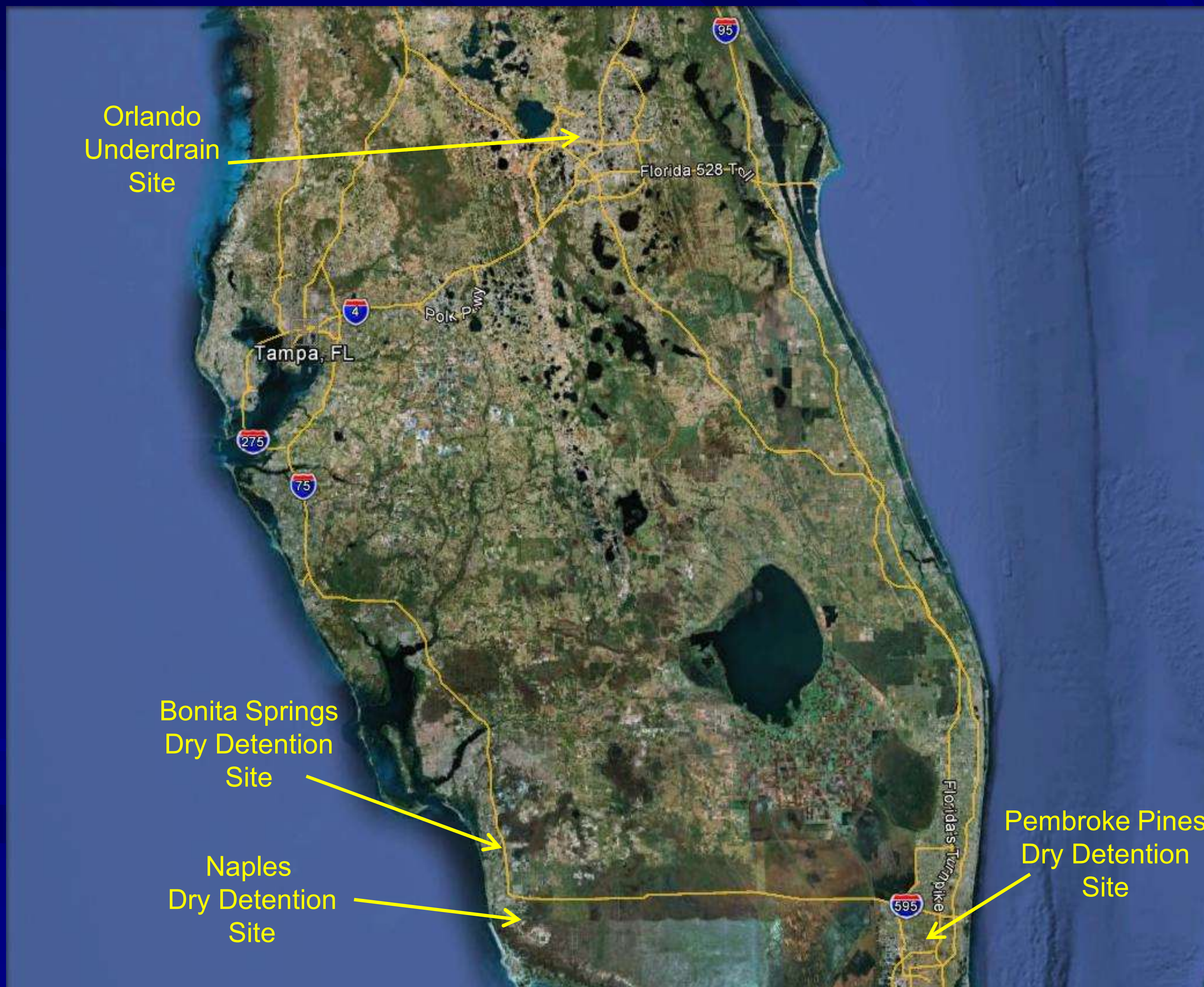
- Developed a “short list” of suitable sites and negotiated access
  - Dry detention – 8 sites
  - Underdrain filtration – 3 sites

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

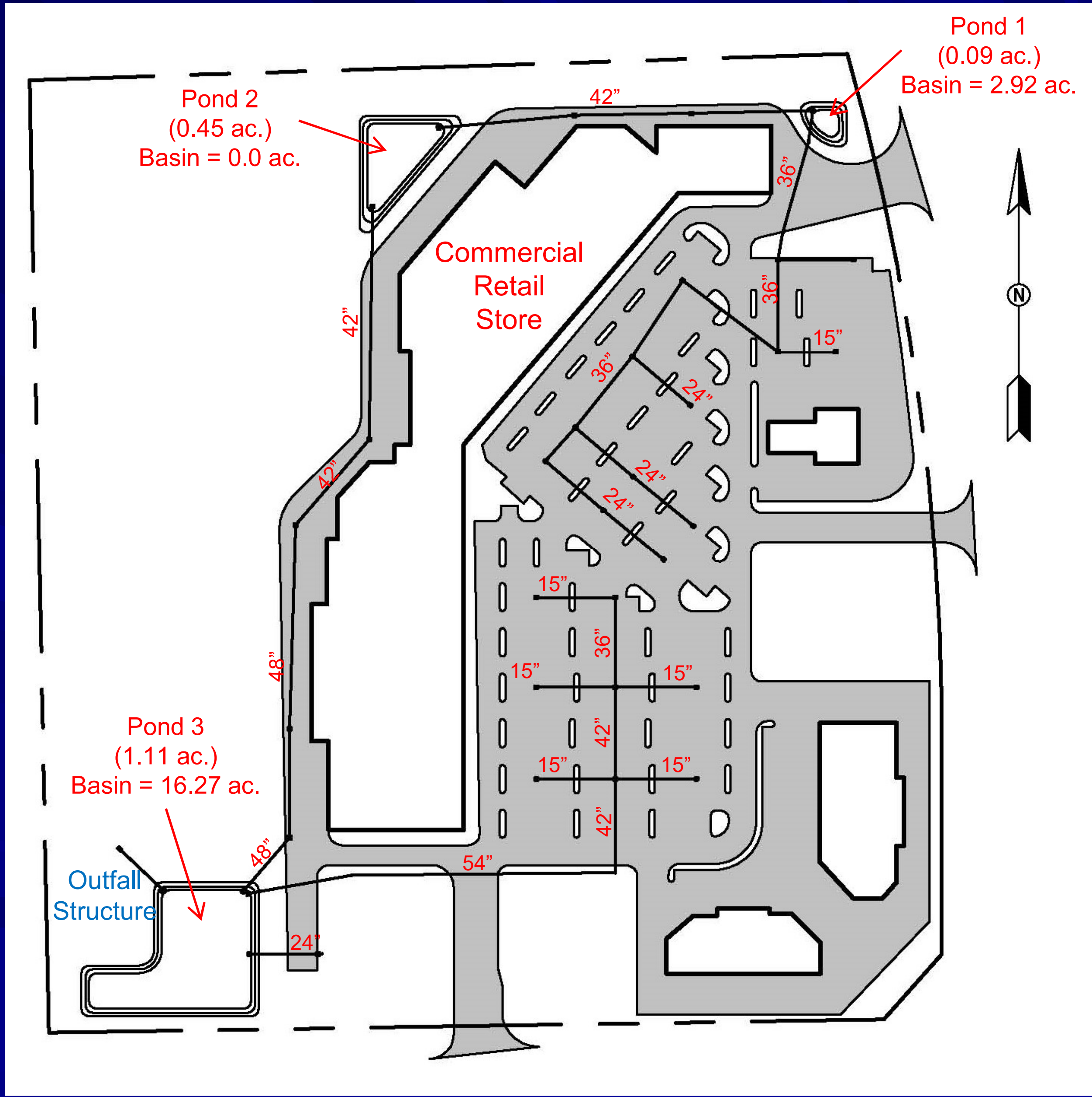
Dry Detention and Underdrain Sites



Bonita Springs Dry Detention Pond Site

Bonita Springs Stormwater System

Parameter	Units	Value
Project Area	acres	22.11
Impervious Area	acres	16.68
DCIA	%	75.4
Stormwater System	acres	1.57
	% of area	7.1
Pervious CN Value	-	63.1
Water Quality Vol.	ac-ft	1.54
Treatment Depth	Inches over basin	0.84
Year Constructed	-	2006

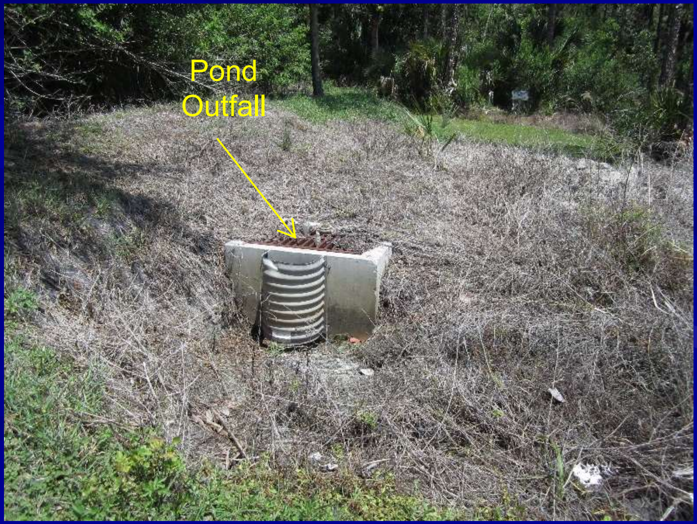


Bonita Springs Dry Detention Ponds

a. Inflow to Pond 1 from parking lot

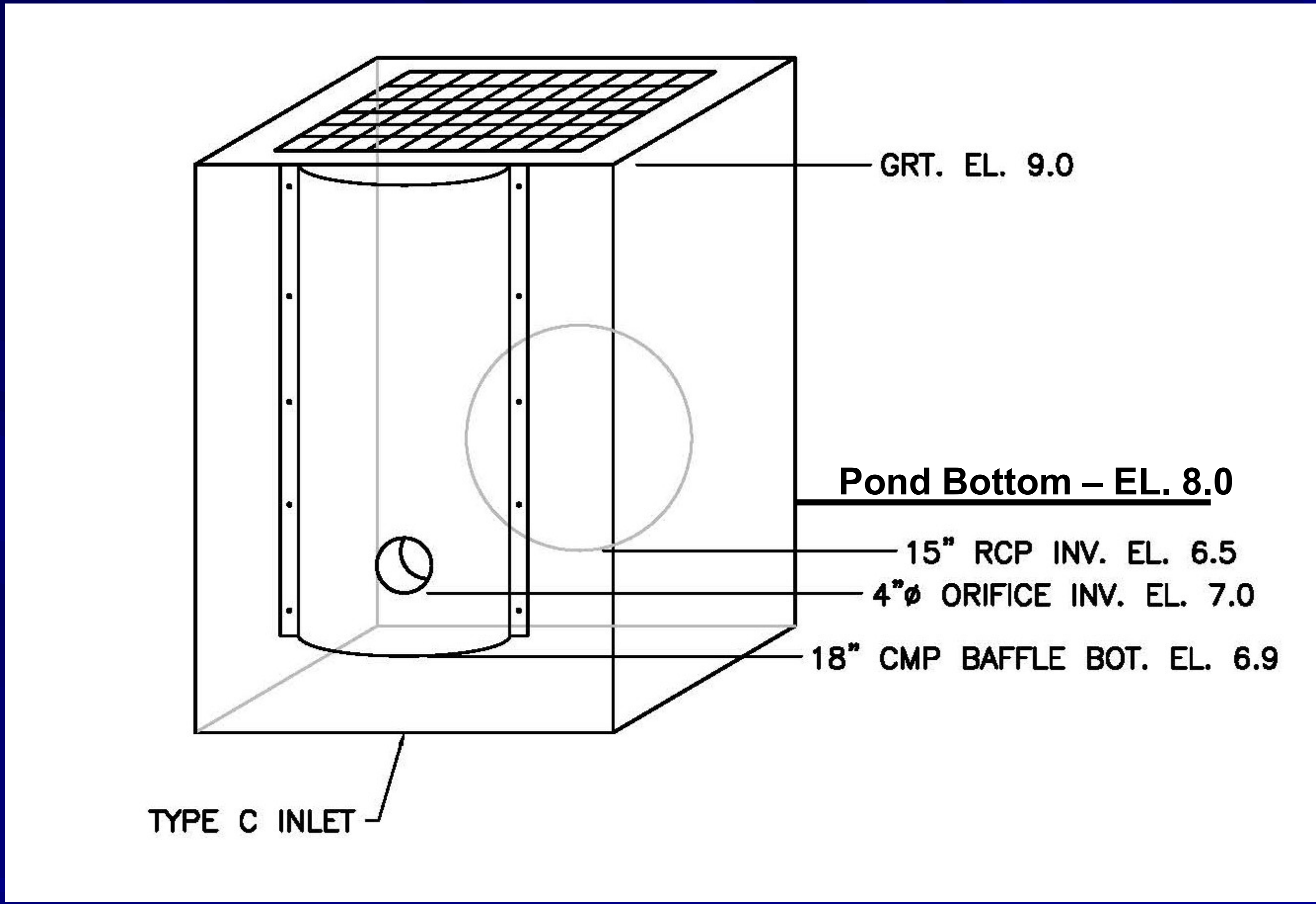
b. Inflows to Pond 3

c. Inflow to Pond 3 from Vacant Out-Parcel

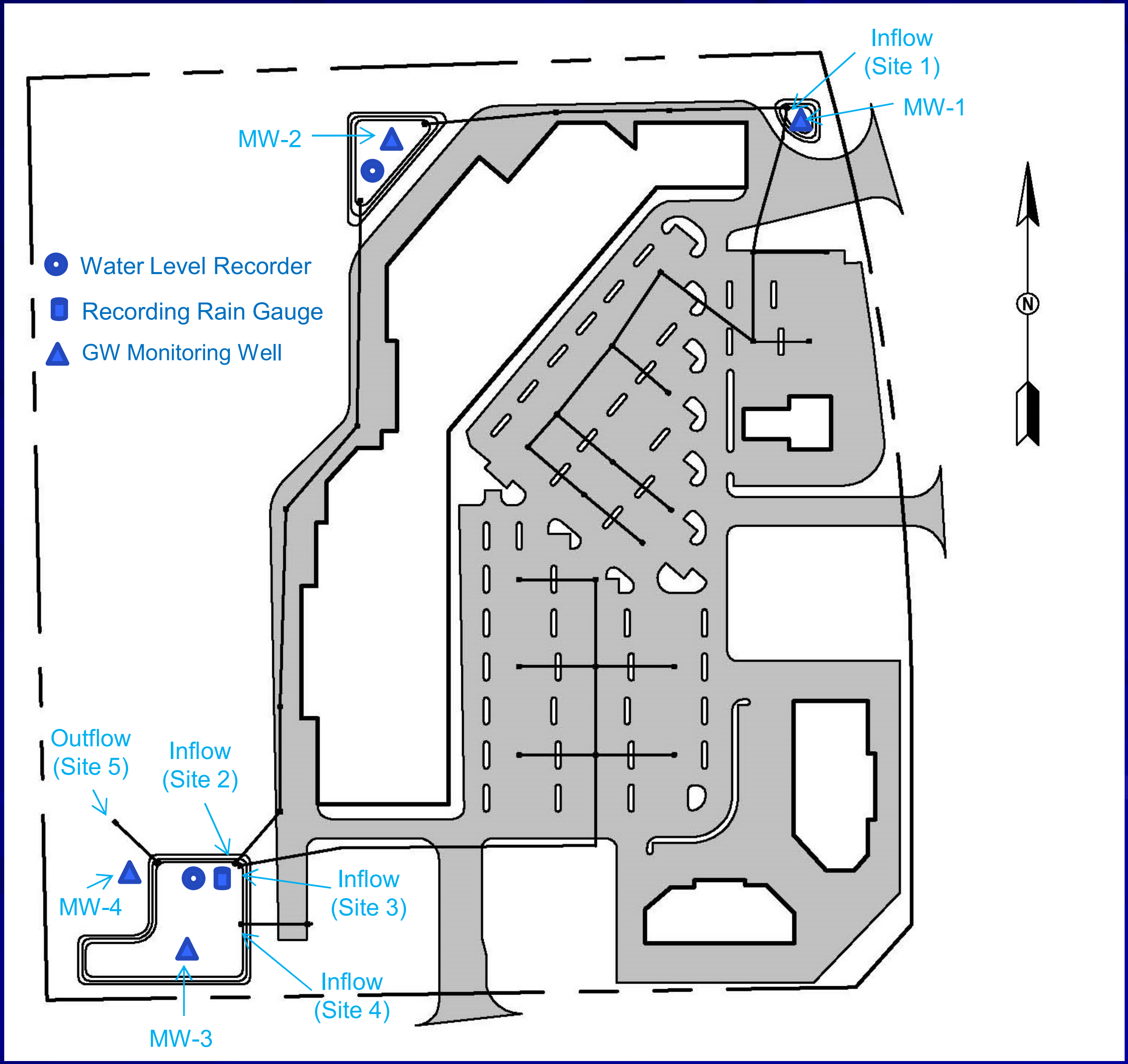


d. Pond 3 Outfall Structure

Bonita Springs Dry Detention Pond Outfall



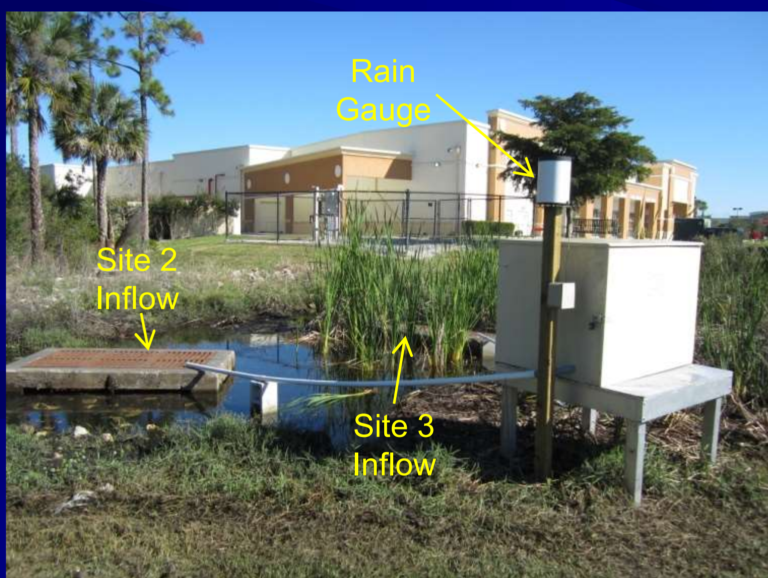
Bonita Springs Monitoring Locations



Bonita Springs Monitoring Sites 1-3

Site 1 – Inflow to Pond 1 from parking lot

Site 1 – Pond 1 inflow monitoring equipment

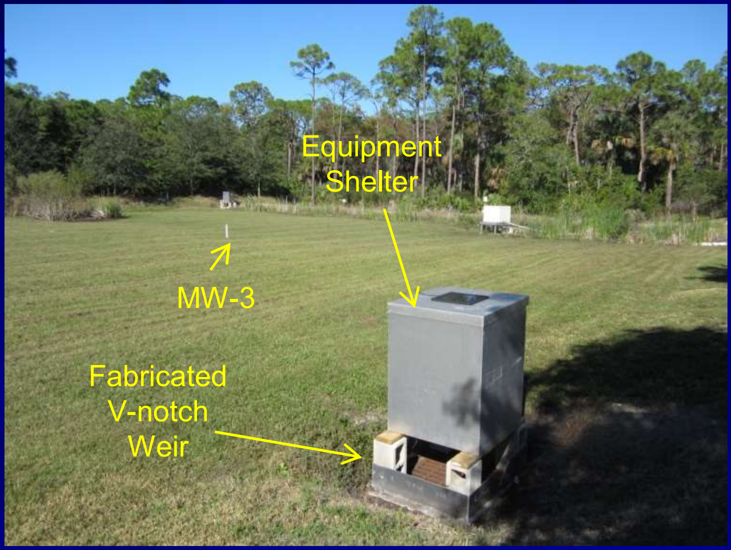


Sites 2 & 3 – Inflows to Pond 3

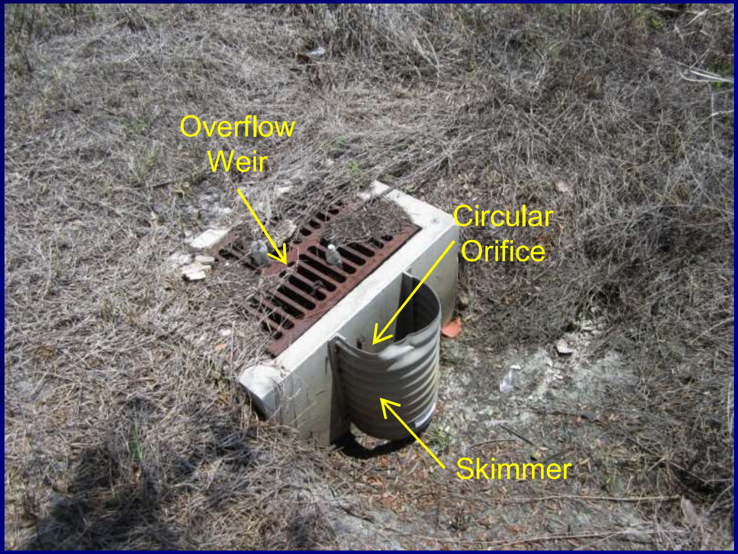
Sites 2 & 3 – Inflows to Pond 3

Bonita Springs Monitoring Sites 4 & 5

Site 4 – Inflow to Pond 3 from Pond 2



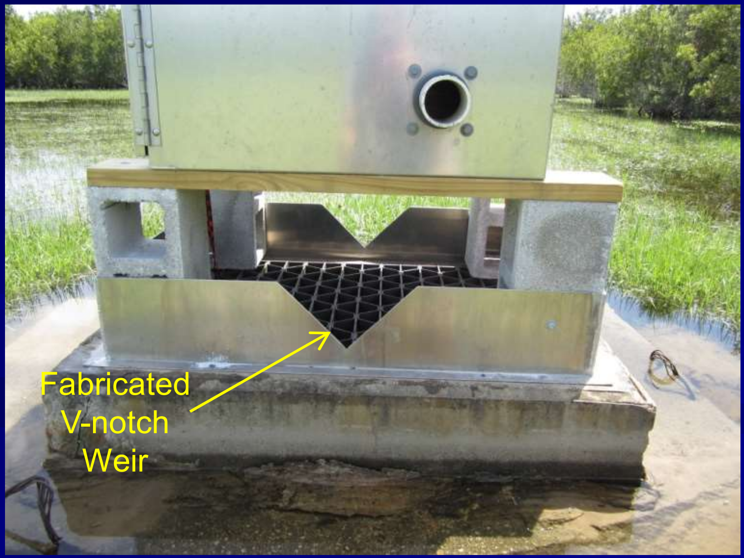
Site 4 – Monitoring equipment

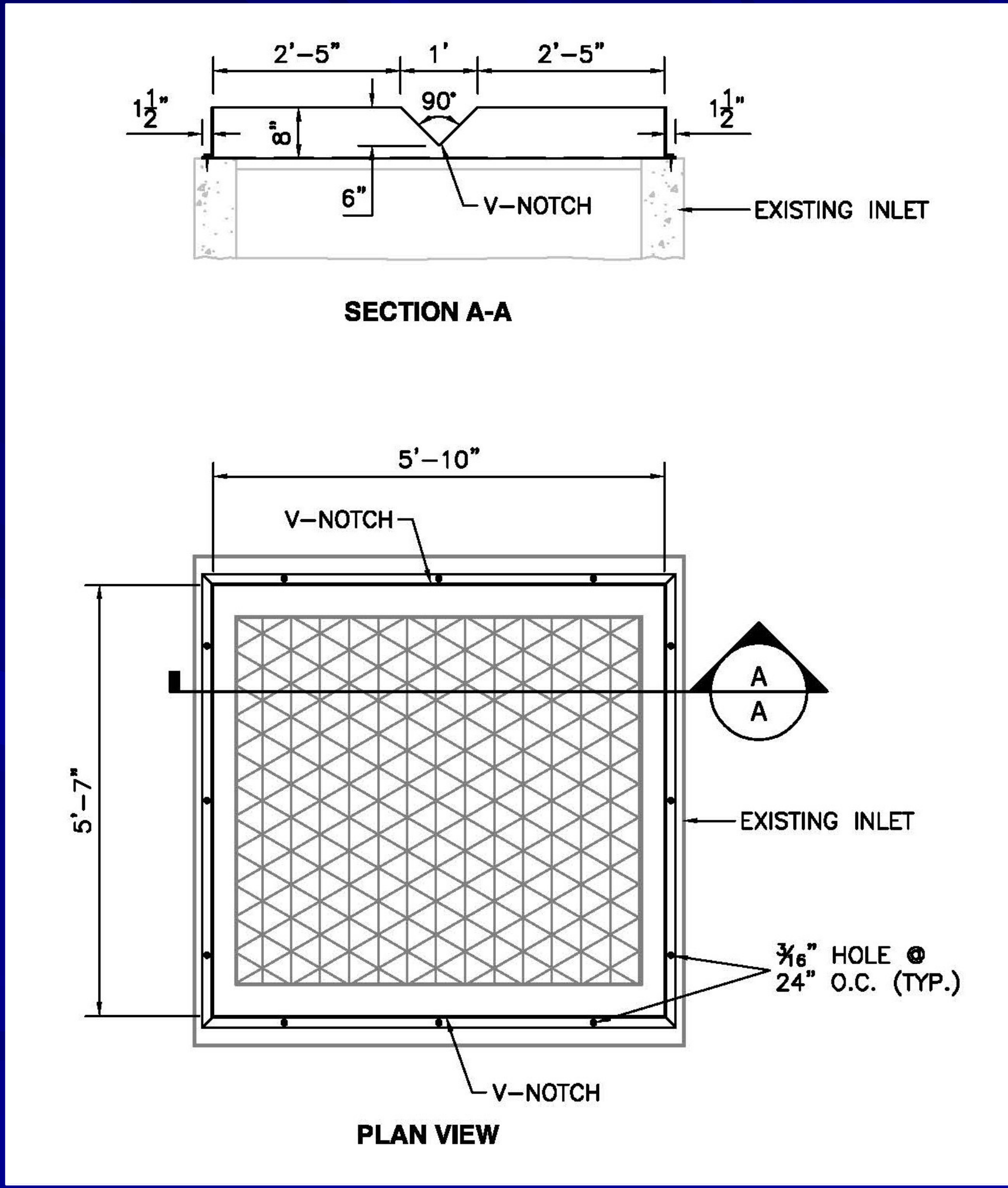


Site 5 – System Outfall to Canal

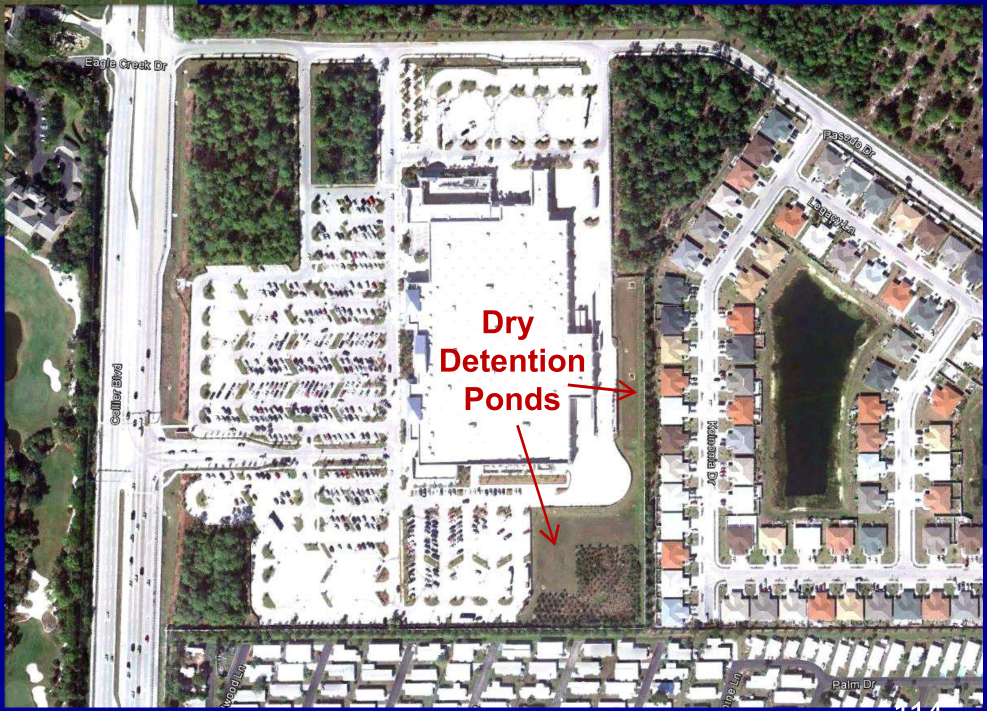
Site 5 – Monitoring Equipment

Schematic of aluminum V-notch structure used to measure pond inflows



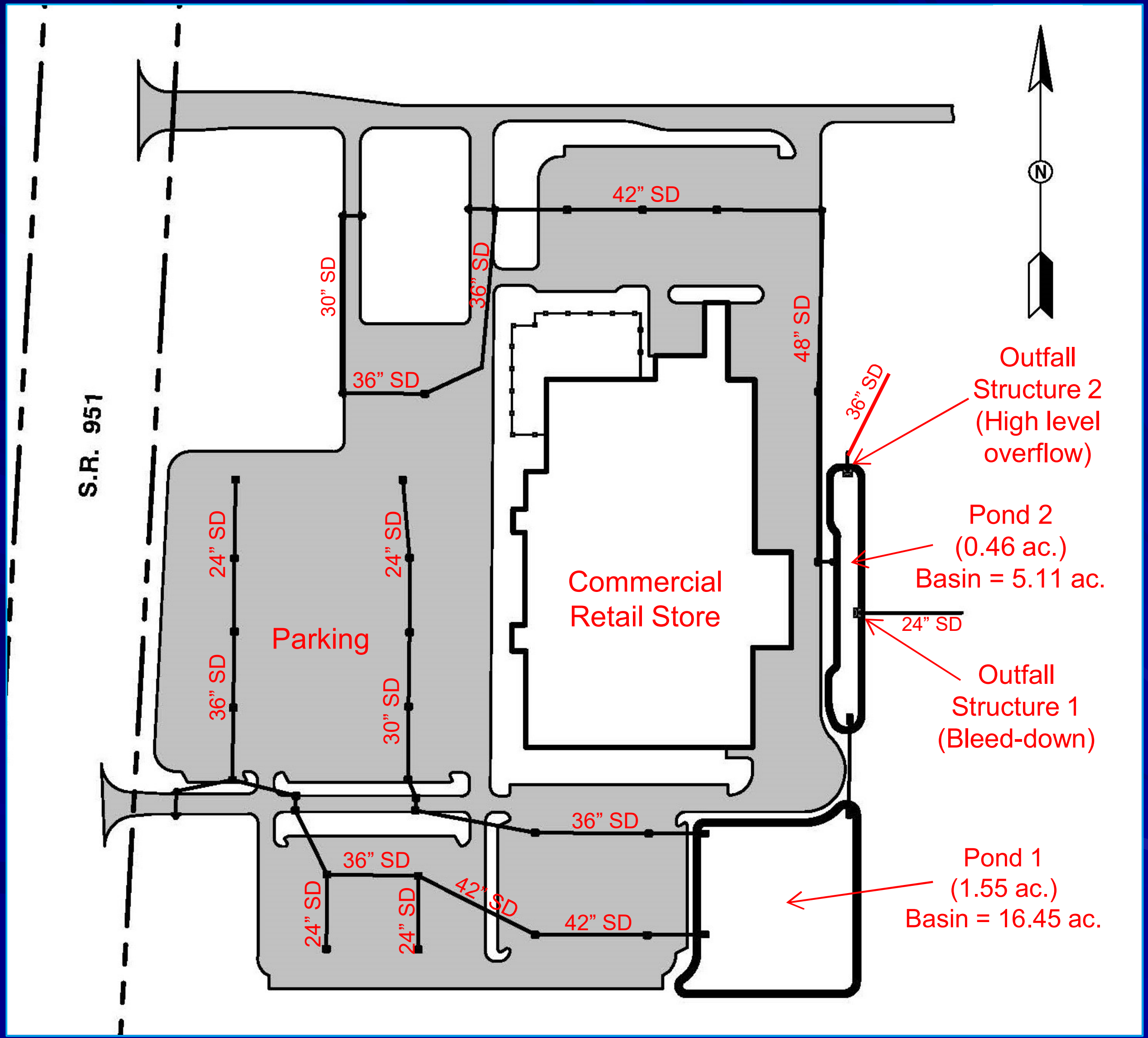


Naples Dry Detention Site Overview

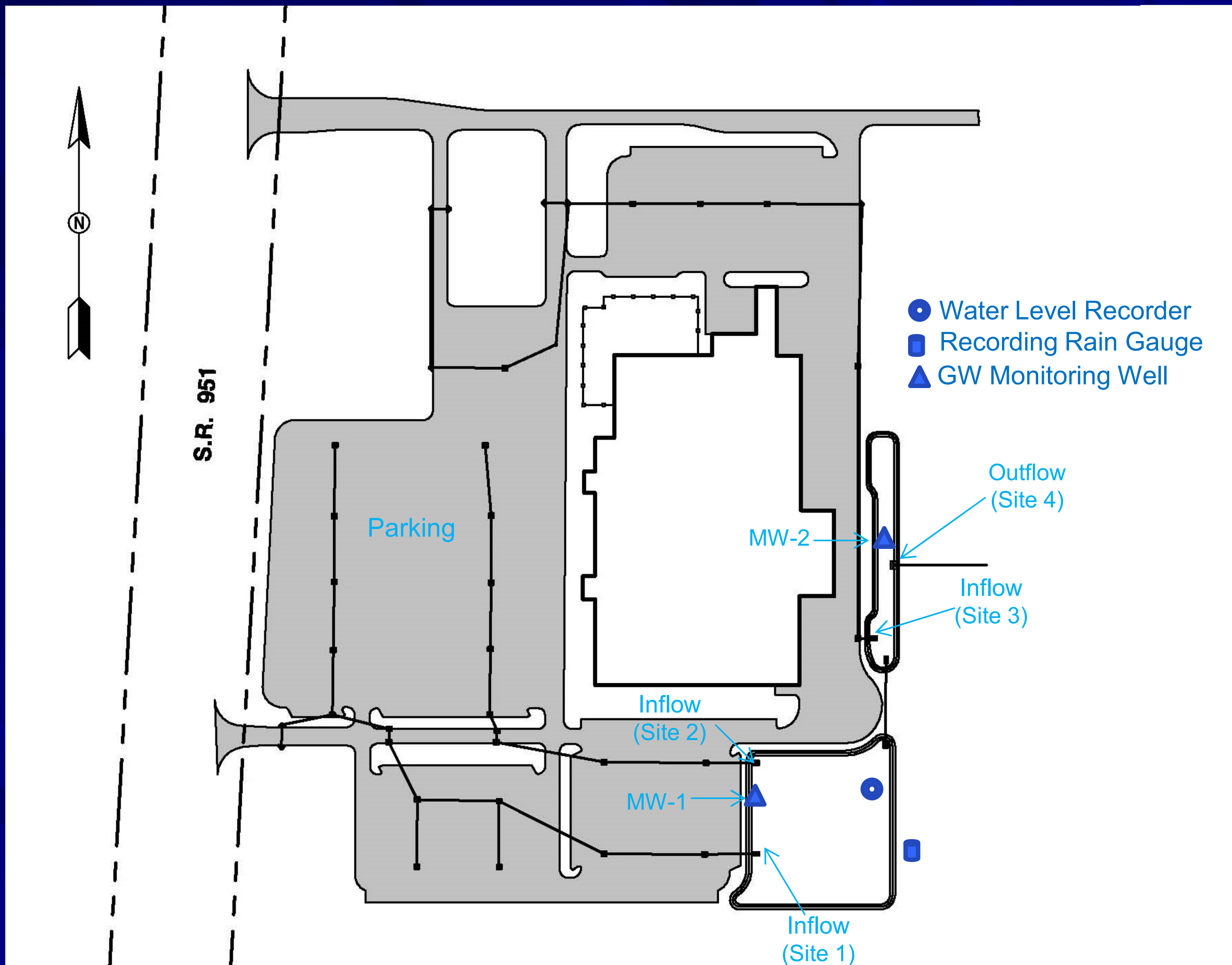


Naples Site Stormwater System

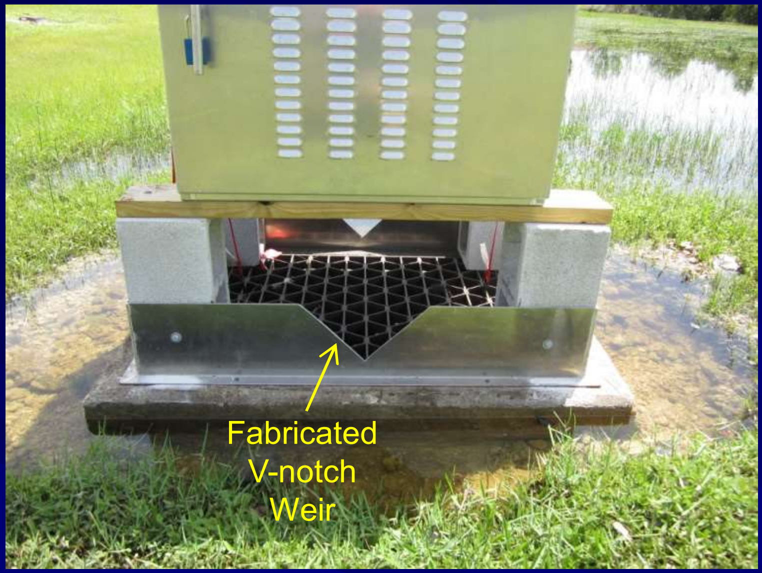
Parameter	Units	Value
Project Area	acres	21.56
Impervious Area	acres	16.84
DCIA	%	78.1
Stormwater System	acres	2.01
	% of area	9.3
Pervious CN Value	-	52.7
Water Quality Vol.	ac-ft	1.77
Treatment Depth	Inches over basin	0.99
Year Constructed	-	2006



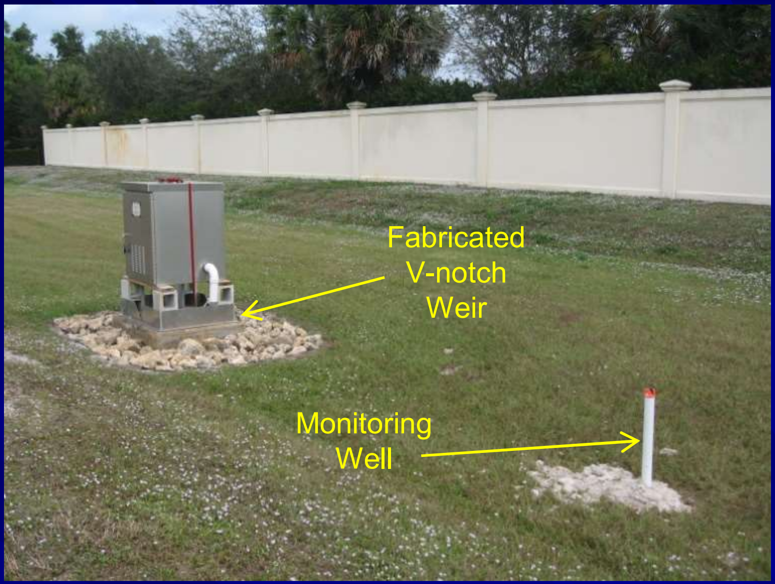
Naples Monitoring Locations



Naples Monitoring Sites 3 & 4

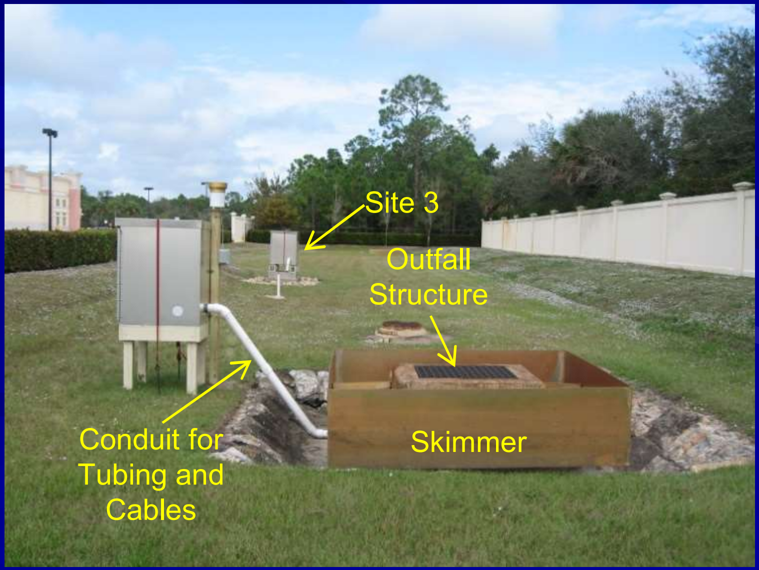


Site 3 – Rear Store Area Inflow Site



Site 3 – Monitoring Equipment

Site 4 – System Outfall

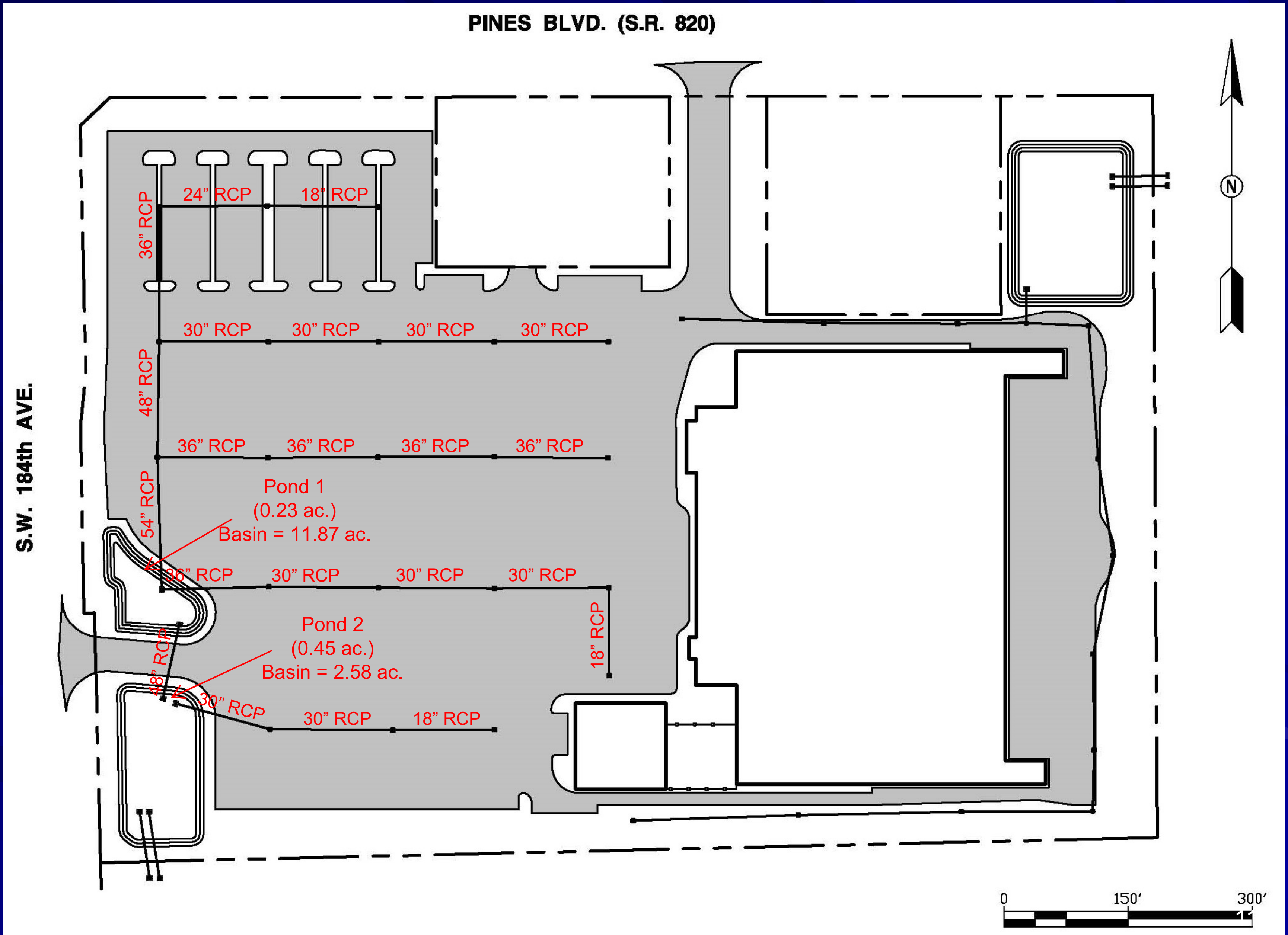


Site 4 – Monitoring equipment at outfall structure

Pembroke Pines Dry Detention Pond Site

Dry Detention
Ponds

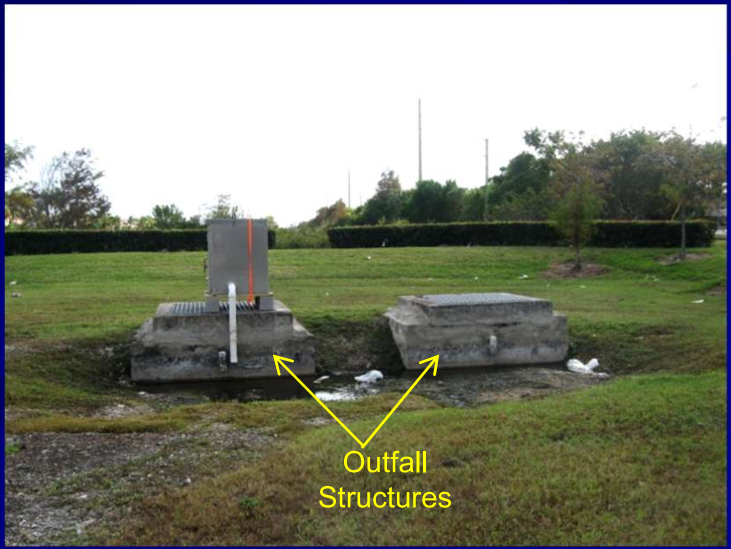
Pembroke Pines Site Stormwater System



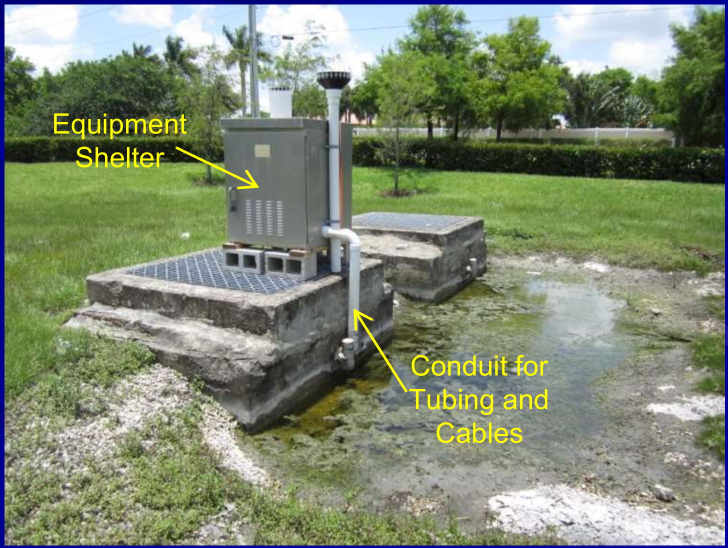
Pembroke Pines Monitoring Sites 2 & 3

Site 2 – Overview of south pond

Site 2 – Monitoring during storm conditions



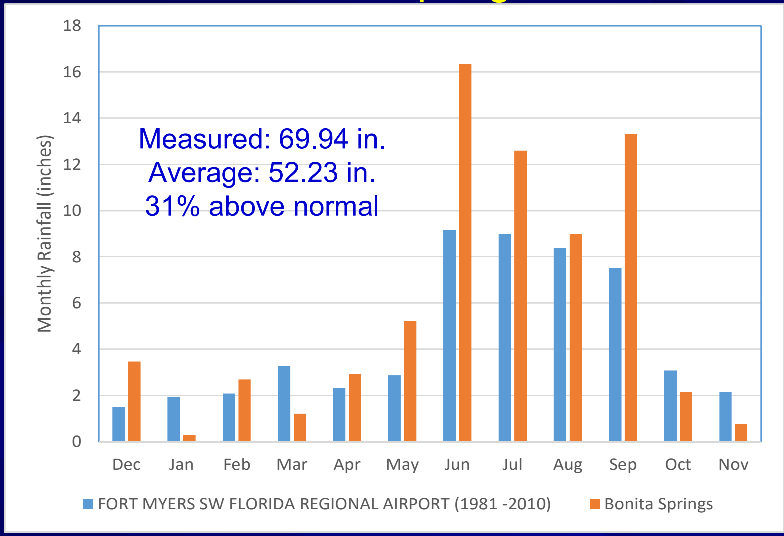
Site 3 – Dual outfall structures



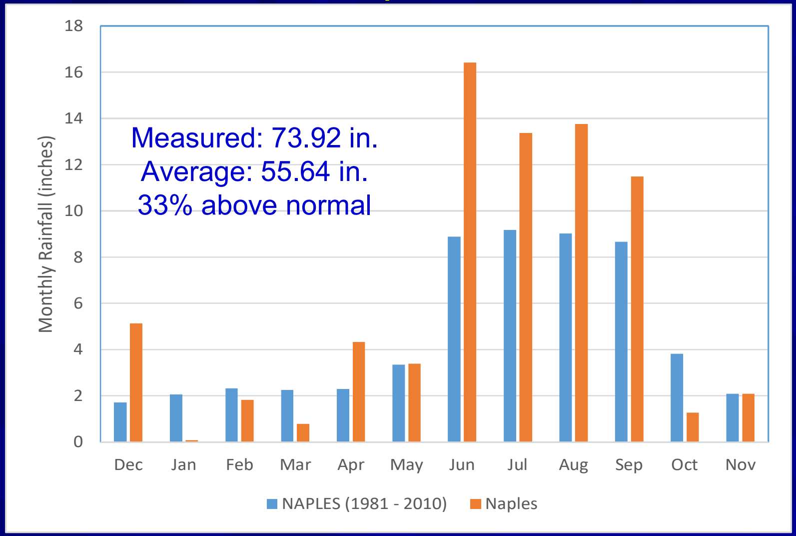
Site 3 – System Outfall and sampling equipment

Comparison of Average and Measured (12/12-11/13) Rainfall at the Monitoring Sites

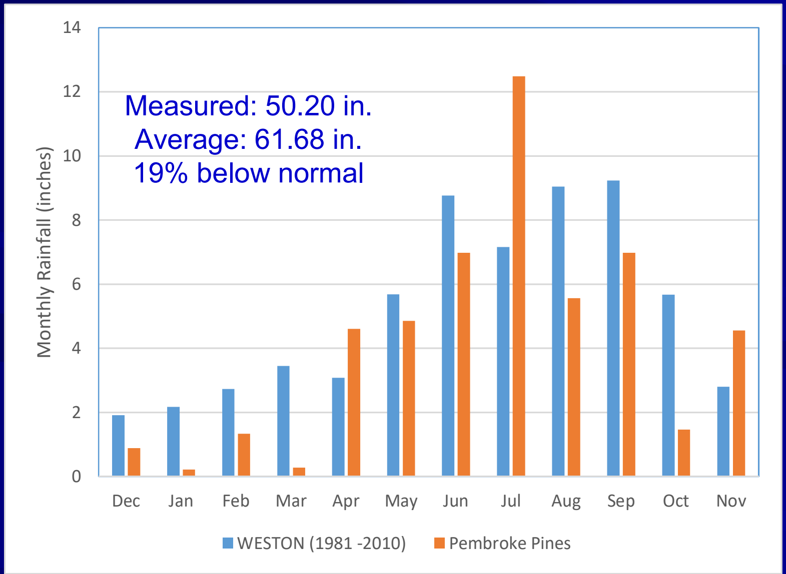
Bonita Springs



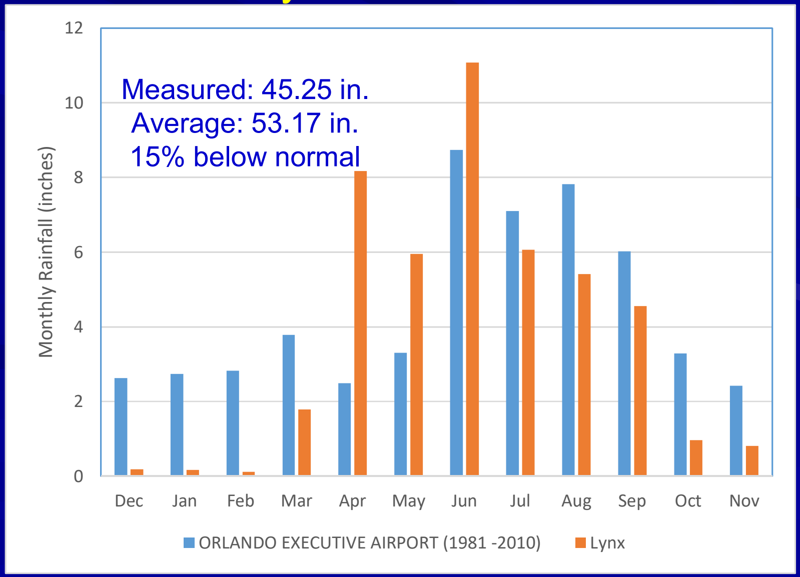
Naples



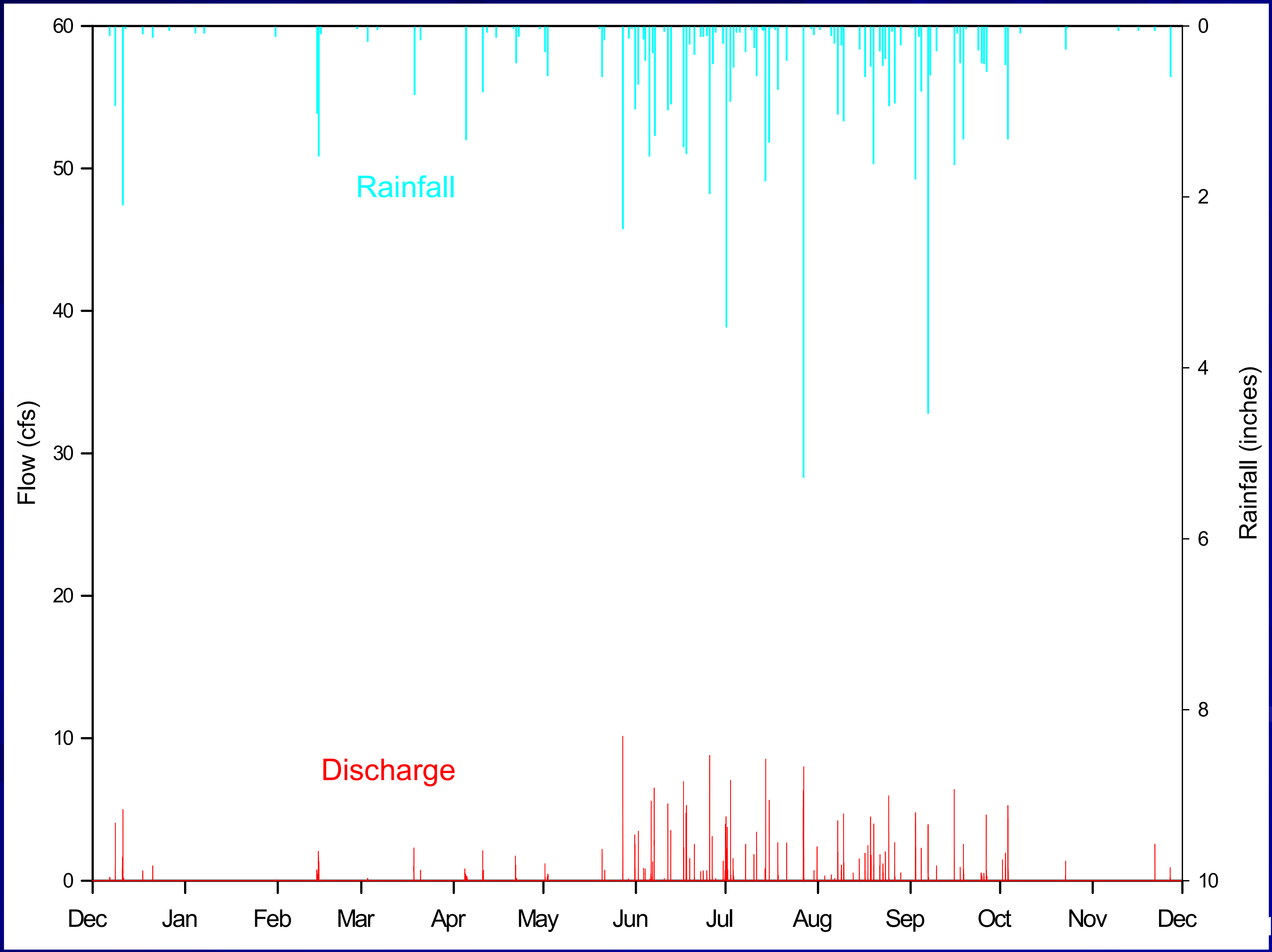
Pembroke Pines



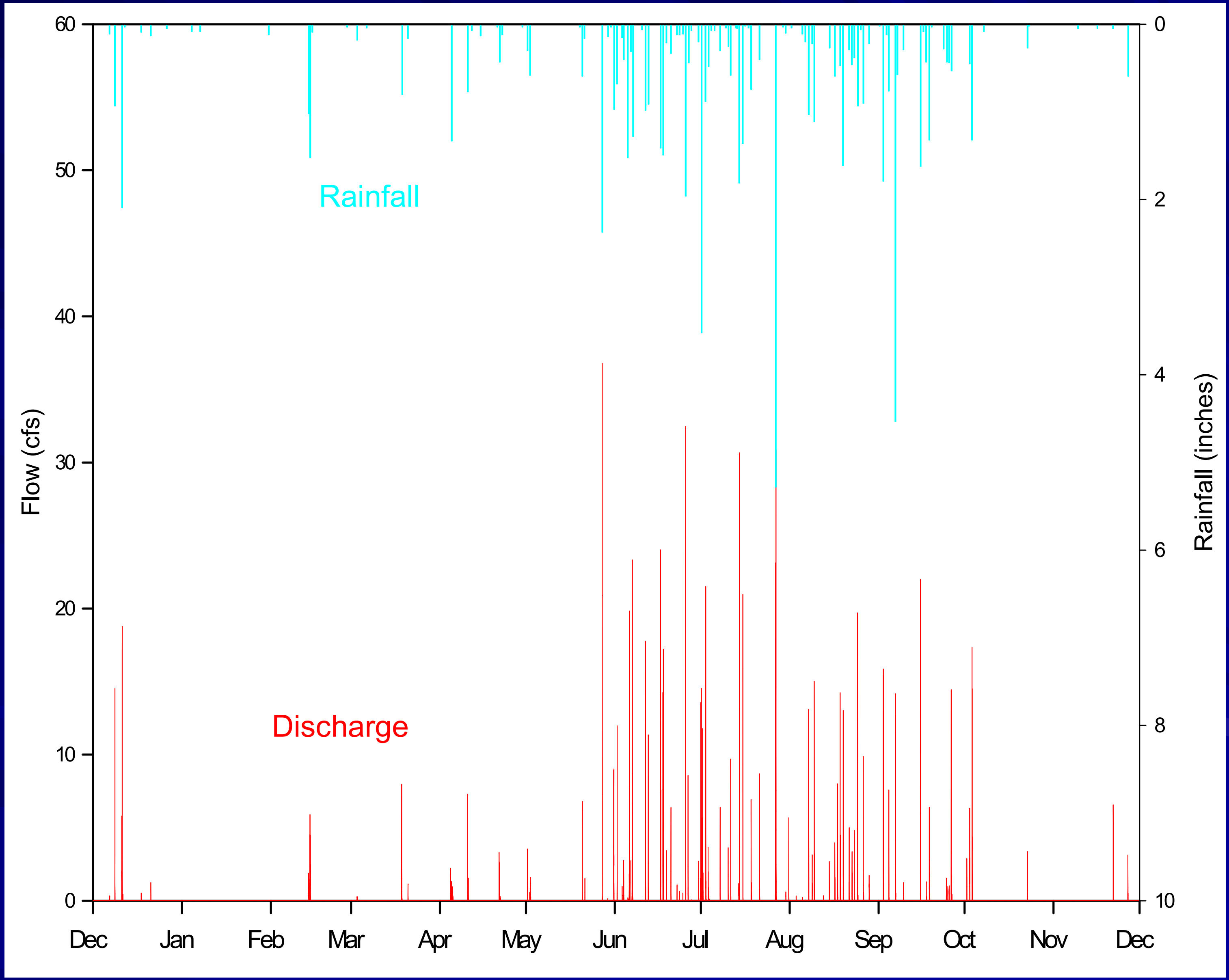
Lynx - Orlando



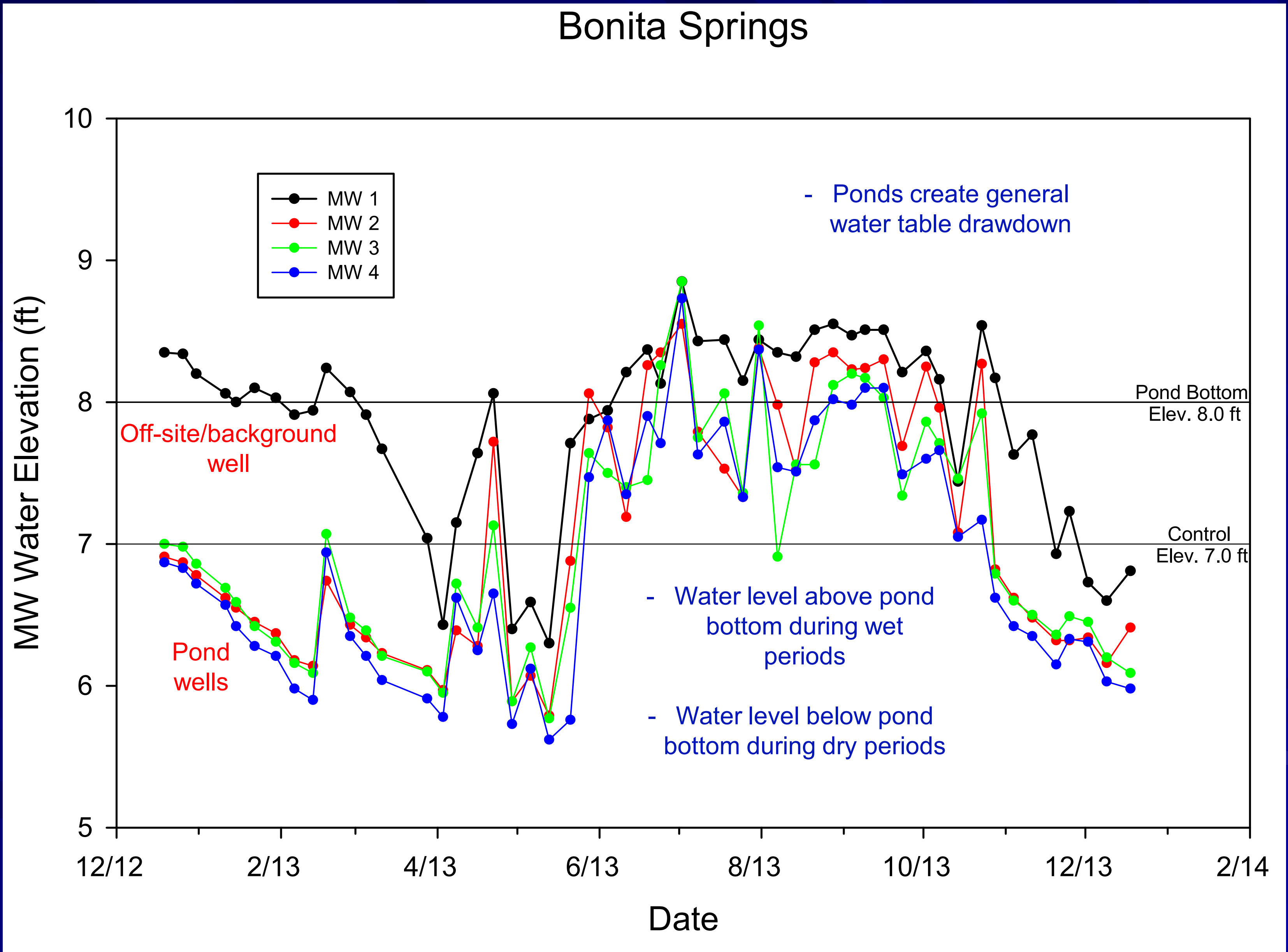
Measured Inflow Hydrographs at Bonita Springs Site 1 (36-inch RCP) from December 2012-November 2013



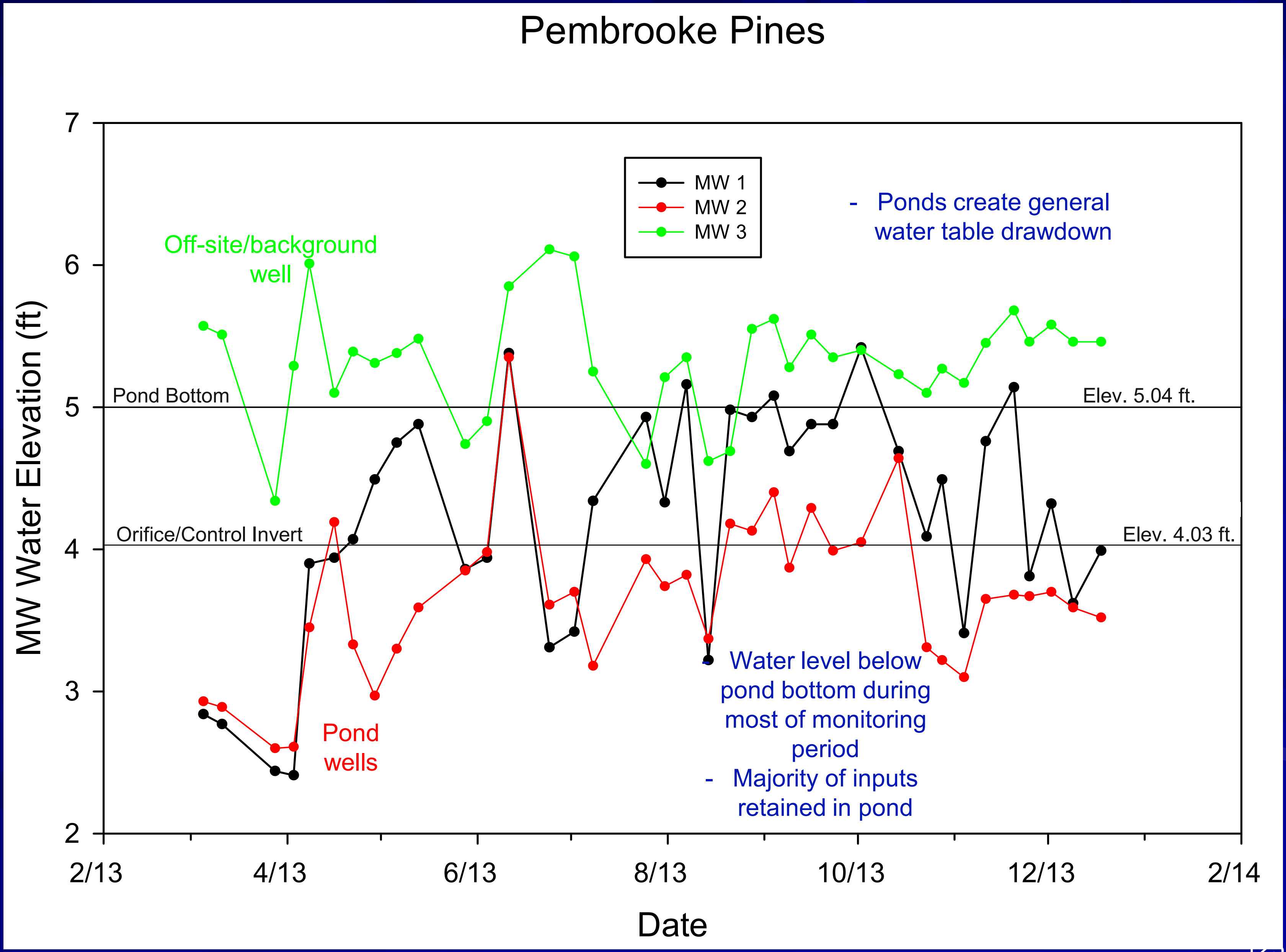
Measured Inflow Hydrographs at Bonita Springs Site 3 (54-inch RCP) from December 2012-November 2013



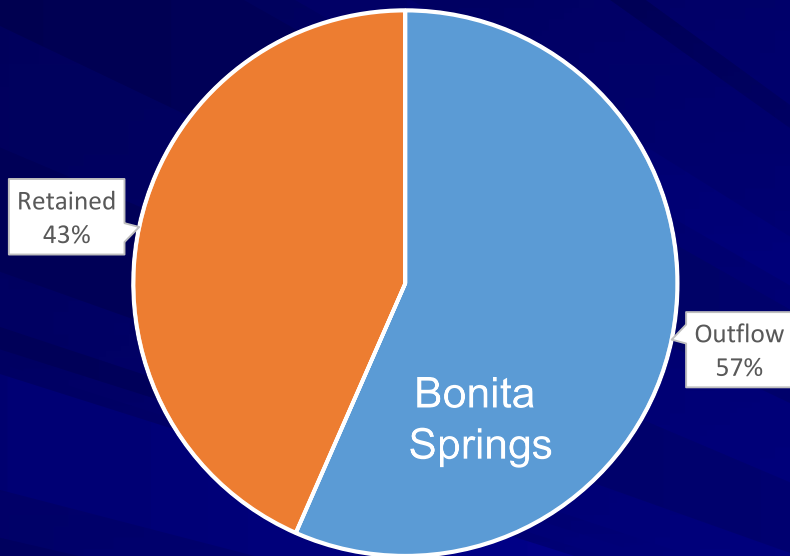
Measured Piezometric Elevations

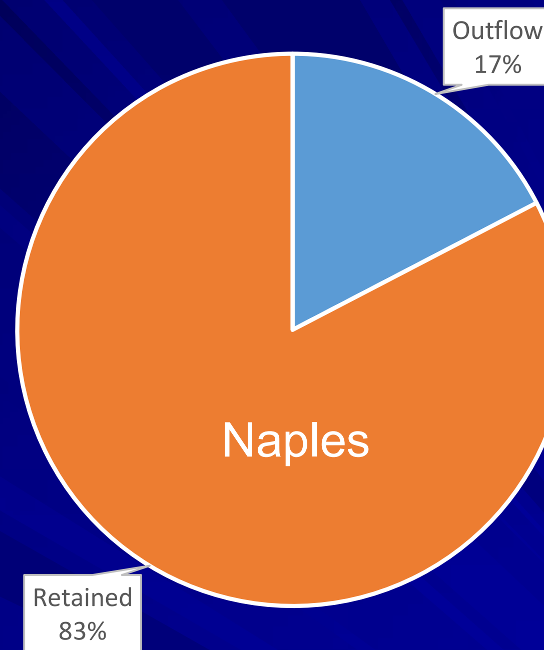


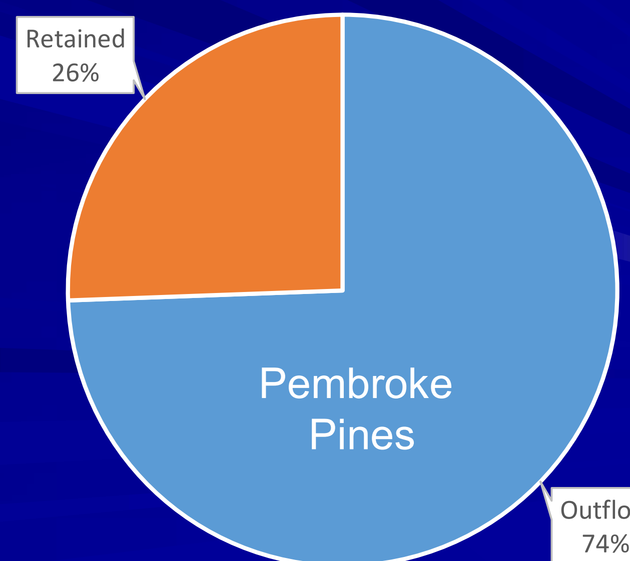
Measured Piezometric Elevations



Measured Hydrologic Losses at the Dry Detention Sites







- Runoff retention in the dry detention ponds ranged from 26 – 83%

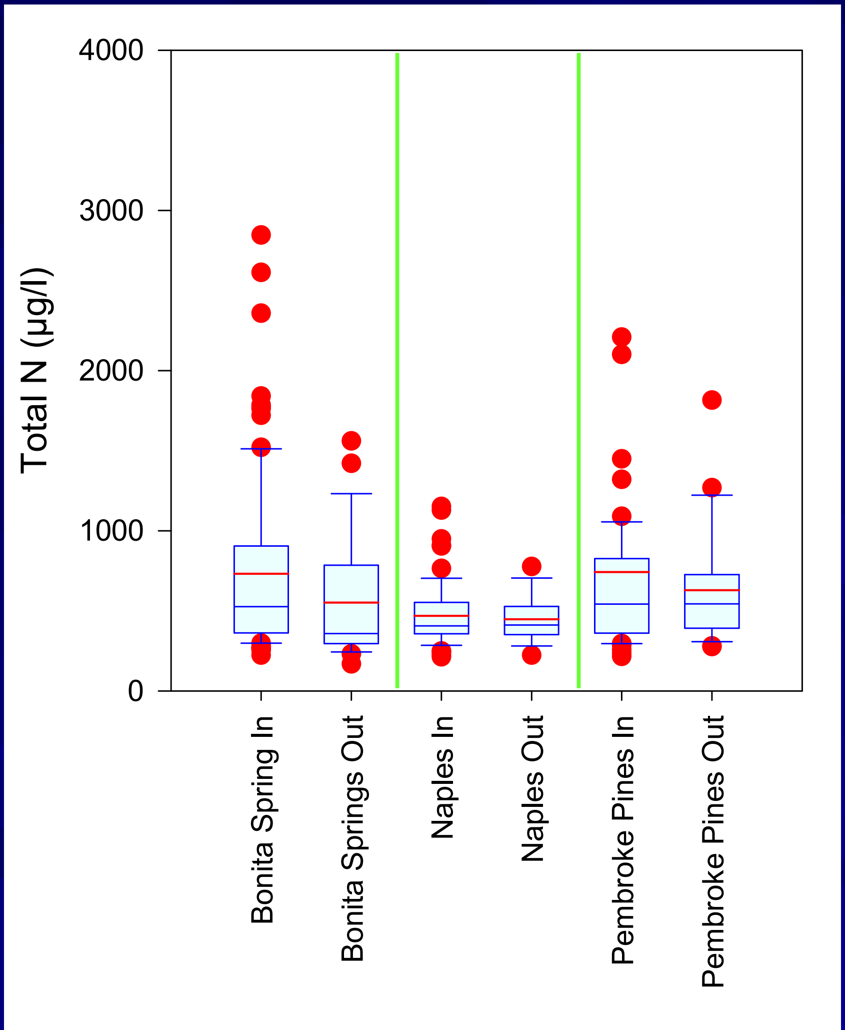
Number of Water Quality Samples Collected at the Dry Detention Monitoring Sites from December 2012-November 2013

Sample Type	Number of Samples Collected/Site			
	Bonita Springs	Naples	Pembroke Pines	Totals
Runoff/Inflows	95	66	63	224
Outflows	26	16	27	69
Bulk Precipitation	25	26	26	77
Groundwater	48	24	36	108
Totals:	194	132	152	478

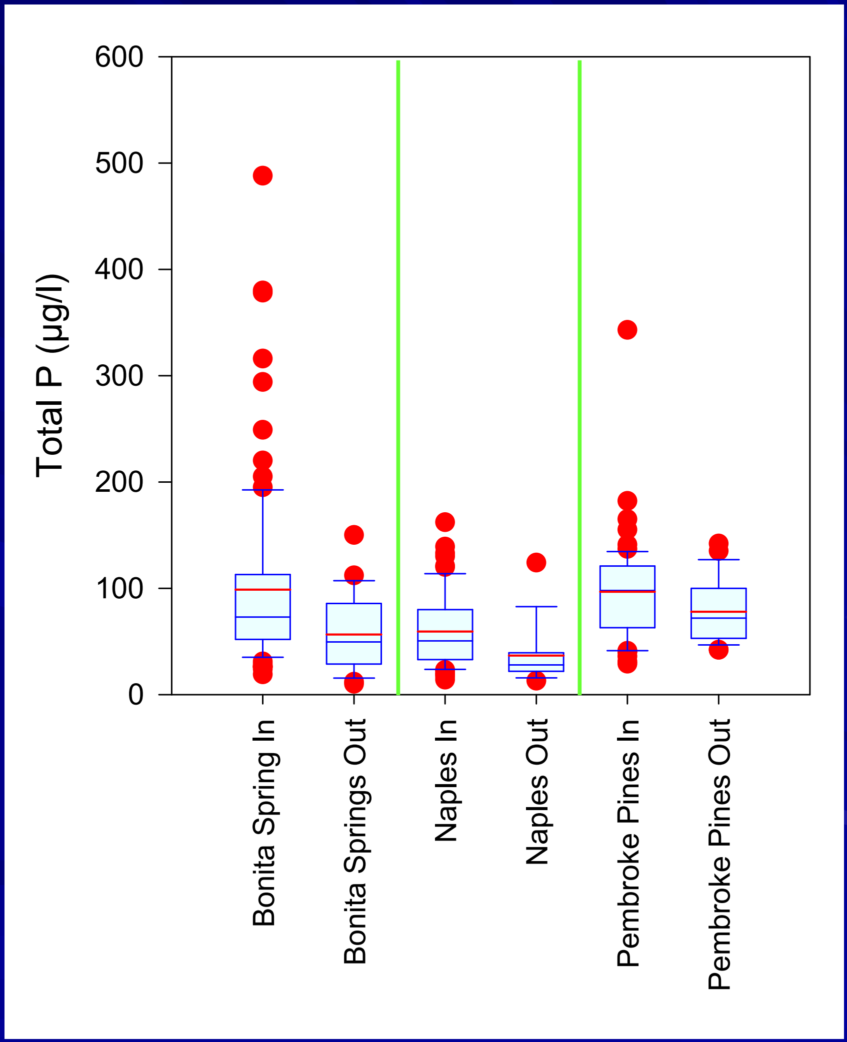
- Each sample analyzed for general parameters, nutrients, and metals (20 parameters)
- Total of 9,560 lab analyses

Comparison of Inflow and Outflow Concentrations of TN and TP at the Dry Detention Sites

Total N

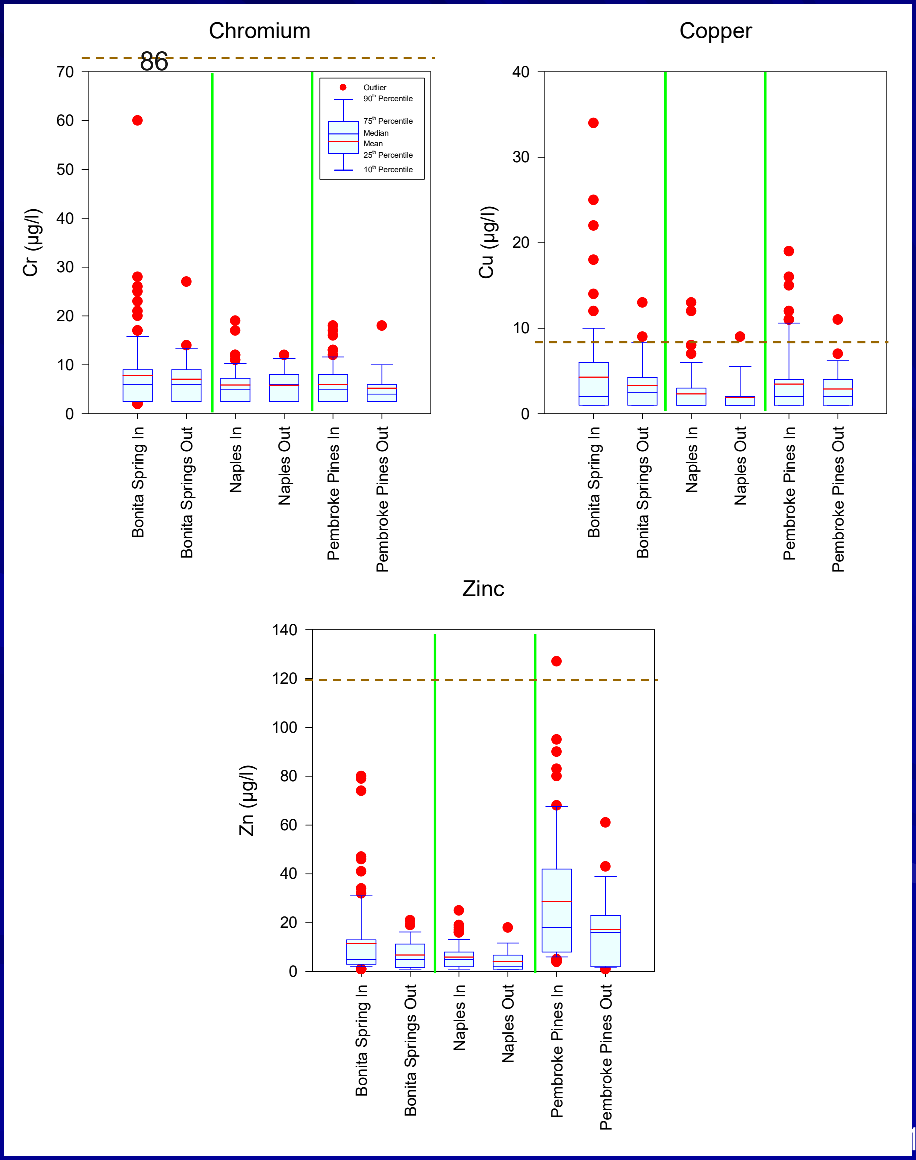


Total P



Comparison of Inflow and Outflow Concentrations of Metals at the Dry Detention Sites

- In general, metal concentrations were low in value
- Dry detention had no significant impact on metal concentrations at any site



Summary of Changes in Inflow / Outflow Concentrations at the Dry Detention Monitoring Sites

Parameter	Concentration Change (%)			Mean Change (%)
	Bonita Springs	Naples	Pembroke Pines	
pH	3	5	6	5
Alkalinity	25	19	29	24
Conductivity	21	16	9	15
Ammonia	-3	-66	-54	-41
NO_x	-47	-73	-78	-66
Dissolved Organic N	-12	21	51	20
Particulate N	-21	69	90	46
Total N	-23	0	3	-7
SRP	-75	-40	-24	-46
Dissolved Organic P	-19	-22	5	-12
Particulate P	-38	-25	-45	-36
Total P	-44	-30	-16	-30
Turbidity	-29	-29	-3	-20
Color	1	98	127	75
TSS	-50	-34	-29	-38
Chromium	-11	2	-13	-7
Copper	-28	-16	-3	-16
Zinc	-11	-48	-37	-32

Overall Mass Removal Efficiencies for the Dry Detention Monitoring Sites from December 2012-November 2013

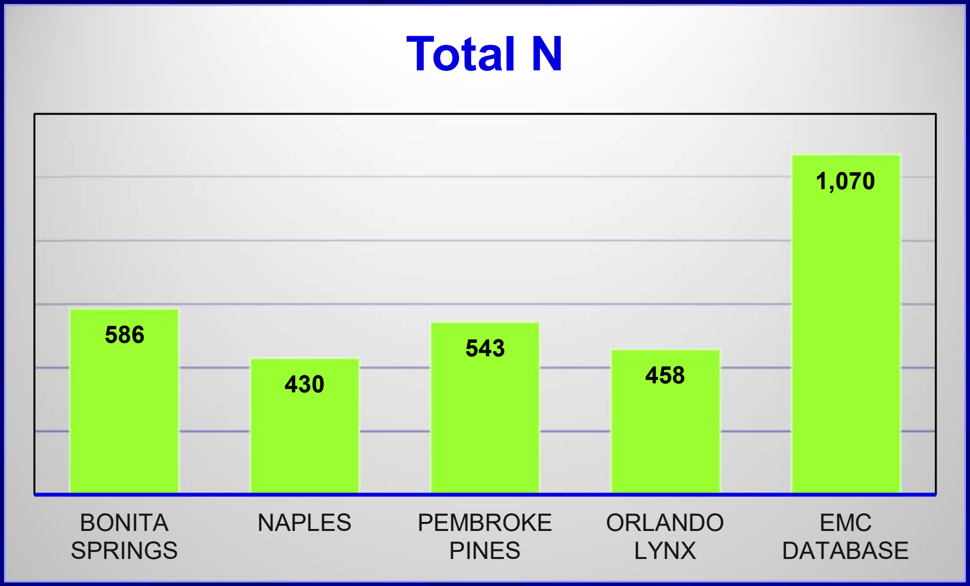
Parameter	Mass Removal (%)			Mean Removal (%)
	Bonita Springs	Naples	Pembroke Pines	
Ammonia	47	87	69	67
NO_x	64	89	85	79
Dissolved Organic N	53	53	14	40
Particulate N	57	71	46	58
Total N	59	69	50	59
SRP	73	84	59	72
Dissolved Organic P	60	82	51	64
Particulate P	63	72	63	66
Total P	66	80	52	66
TSS	78	68	73	73
Chromium	48	71	51	57
Copper	47	67	50	54
Lead	44	56	45	48
Zinc	59	68	48	58
Volume	43	83	26	51

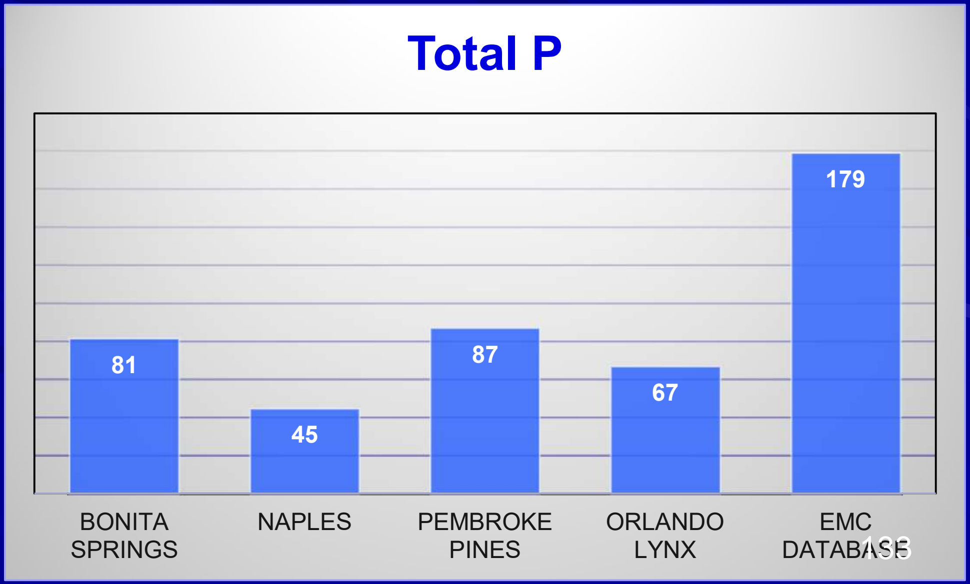
Pond Modifications

- Pond area used as recreational field
- Channel dug from inflow to outflow to keep bottom dry

Comparison of Low Intensity Commercial (LIC) Runoff Characteristics

- Sites selected to provide additional runoff emc data from LIC sites
- Each of the study sites conducted vacuum sweeping 2-3 times per week on parking areas
  - Conducted primarily for removal of trash
  - Not part of any water quality related permit
- Runoff emc values at the commercial sites were ~ 50% of emc database value





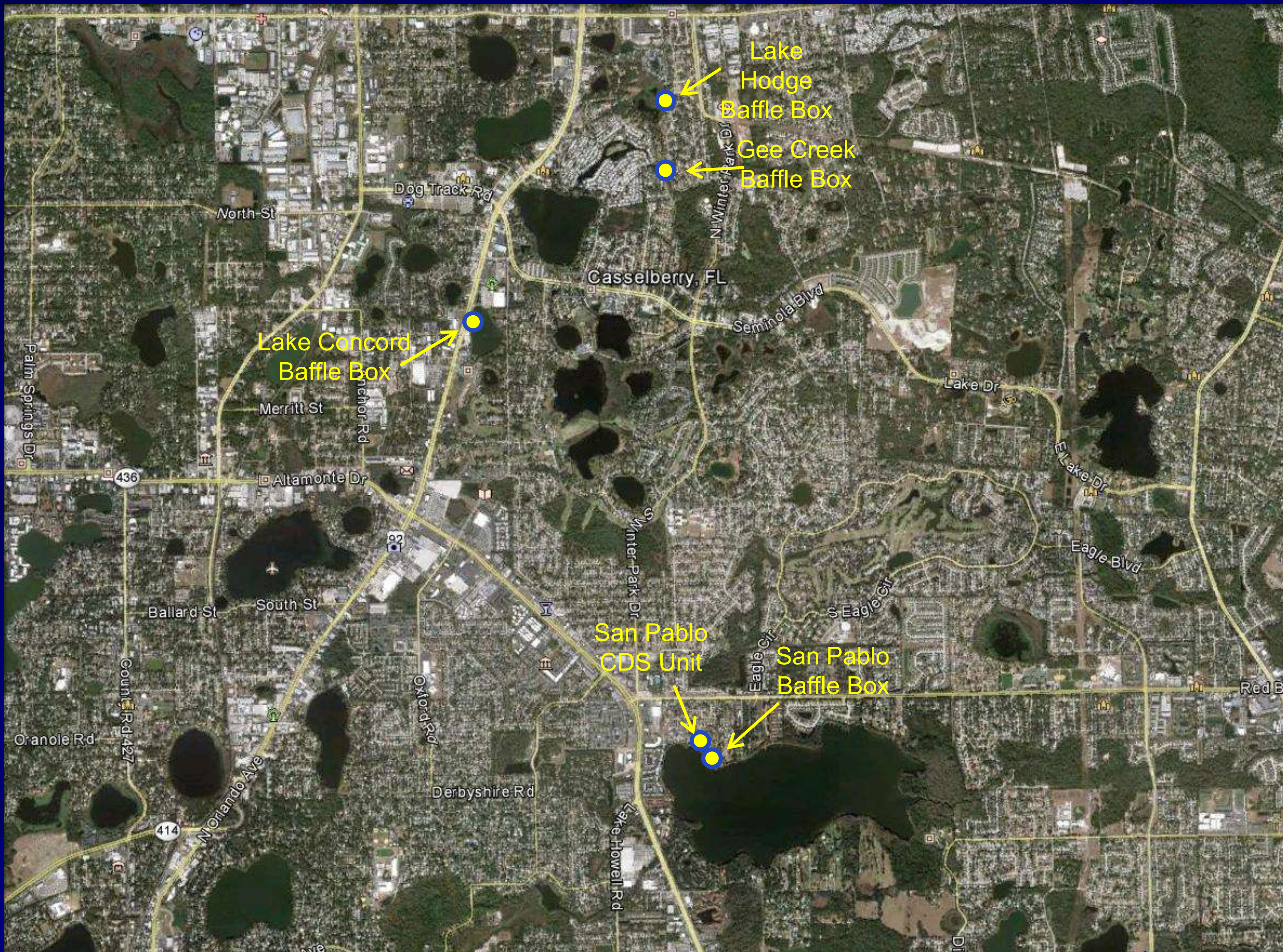
Conclusions

- Dry detention ponds provide highly variable and generally low removal efficiencies for runoff constituents
  - Fall far short of the 80% load reduction goal outlined in “Water Resource Implementation Rule”
    - Total N: 7% removal
    - Total P: 30% removal
    - TSS: 38% removal
    - Metals: 0 – 32% removal
- Significant mass removal efficiencies can only be achieved when a large portion of the runoff infiltrates into the ground
  - When infiltration is included, mass removals increase to:
    - Total N: 50-69% - average = 59%
    - Total P: 52-80% - average = 66%
    - TSS: 68-78% - average = 73%
    - Metals: 48-58%
  - Highly variable removal efficiencies which fall far short of the 80% load reduction goal, even with significant infiltration losses
  - With significant infiltration, removals are similar to wet detention

Part 8

Gross Pollutant Separators

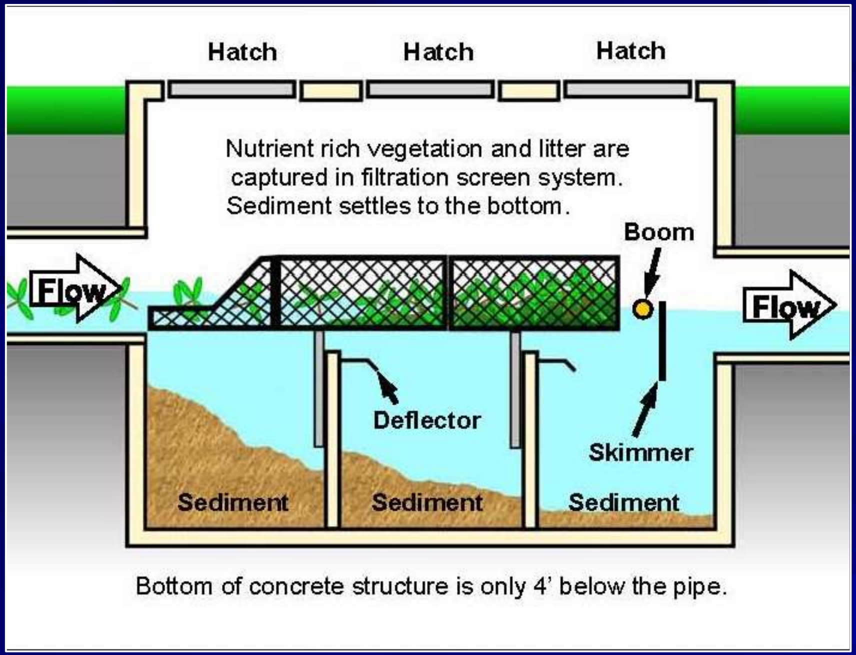
Location Map for GPS Study Sites



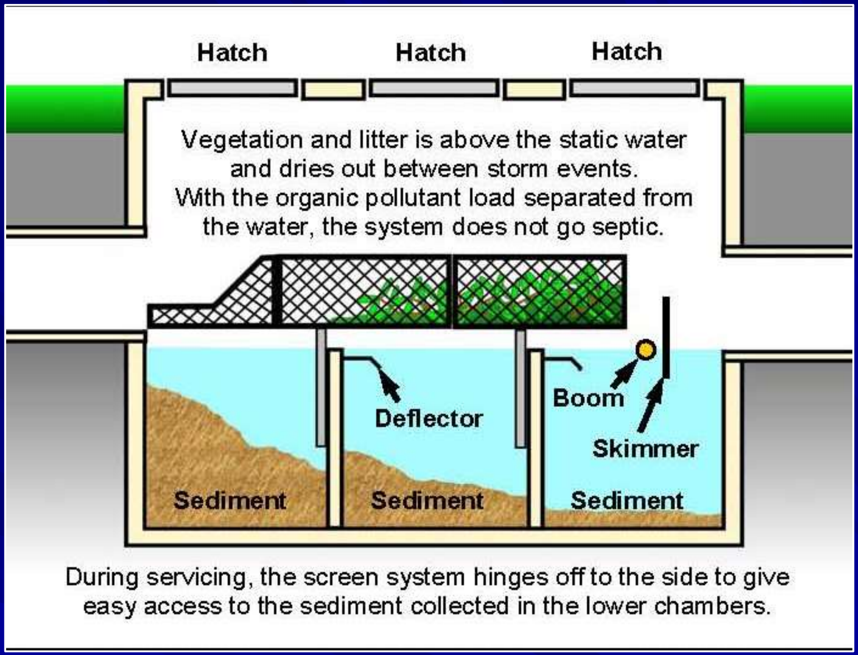
Evaluated BMPs

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

Suntree Nutrient Separating Baffle Box

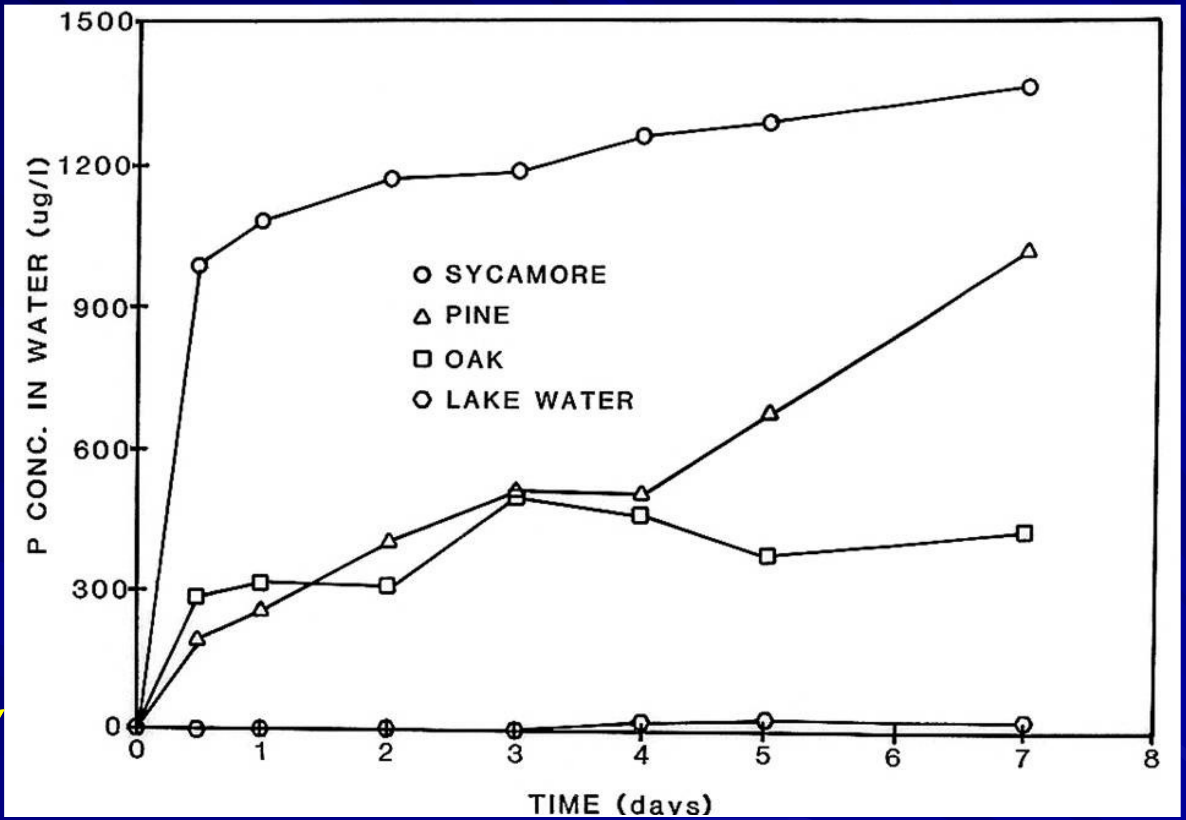


a. During storm event conditions



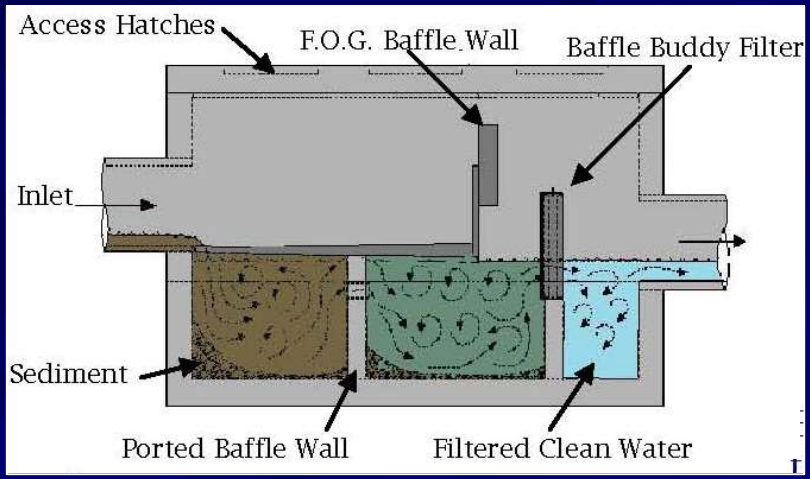
b. Following storm event

Release of Phosphorus from Saturated Leaves



- After entering water, leaves and vegetation exhibit a rapid nutrient release
- Frequent maintenance and removal is essential
- Nutrient release is much less when the solids are stored in a dry condition

EcoVault Unit

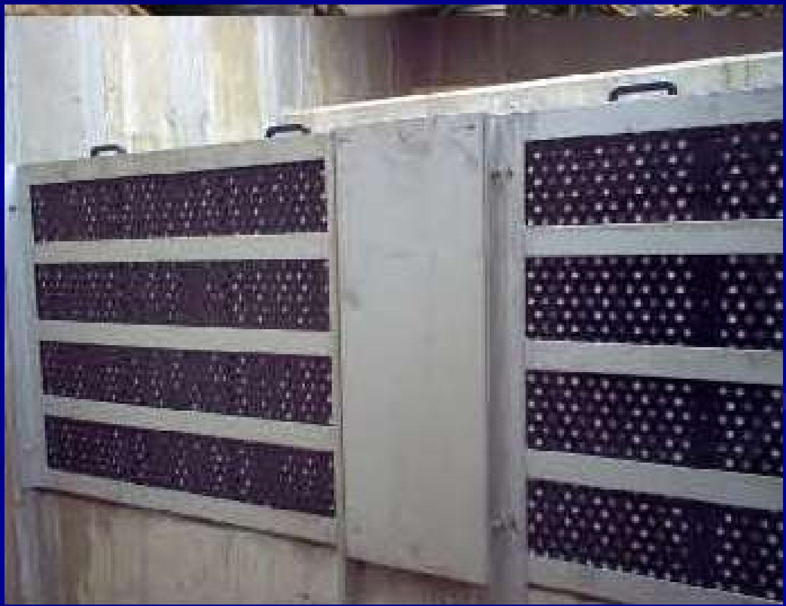


a. Schematic flow patterns in the EcoVault Unit

b. Bottom solids screens

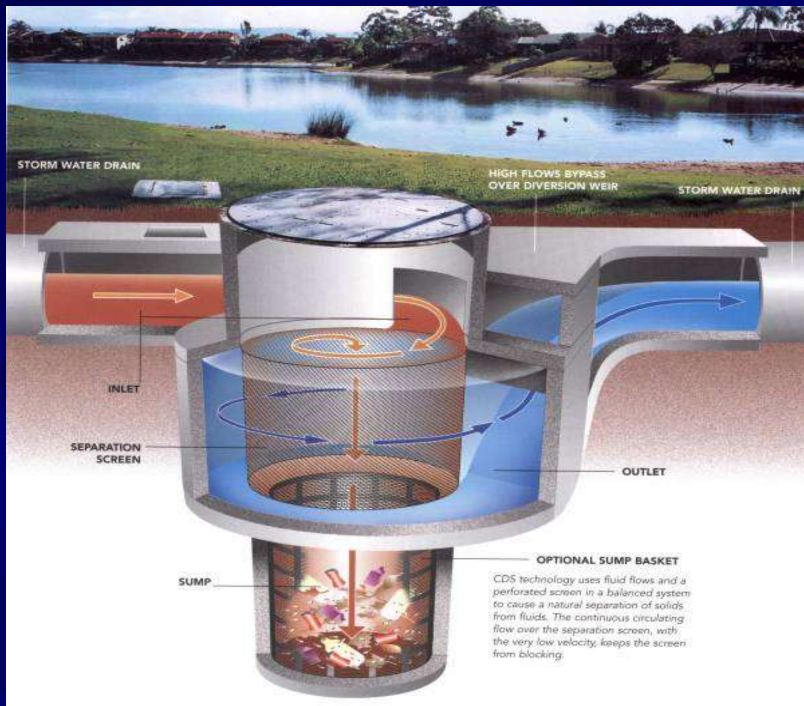
c. Vault-Ox equipment

d. Bottom screens opened for cleaning

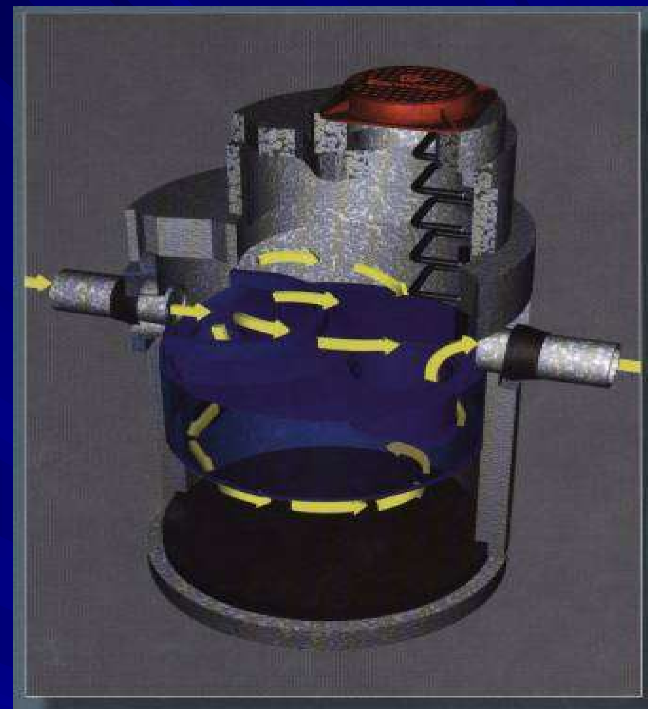


e. Outlet filter containing aluminum silicate

Swirl Separators



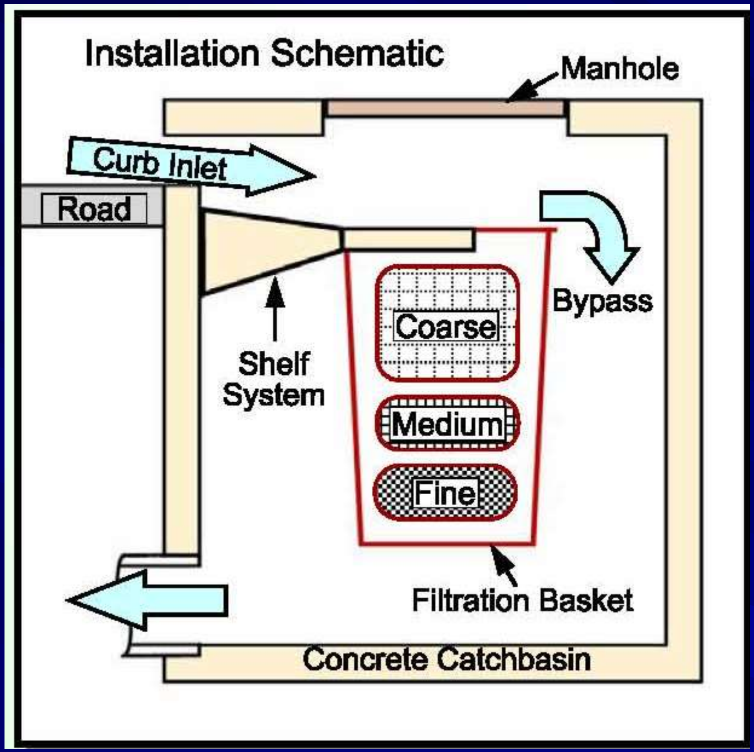
CDS Unit



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

Inlet Baskets



a. Schematic of the Suntree high capacity curb inlet basket

b. Basket filled with collected solids

Drainage Basins Discharging to the Ecosense Baffle Box Sites

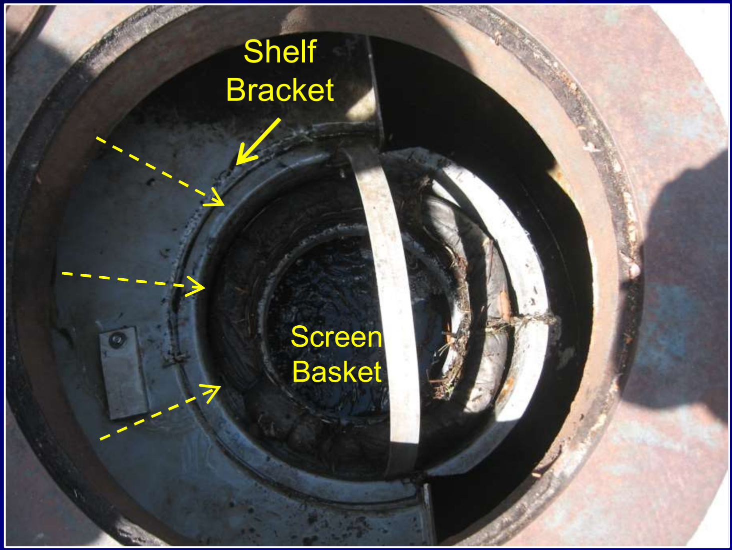
- Sub-basin G-1 has curb and gutter drainage
  - No runoff pre-treatment

- Sub-basin G-s has roadside swale drainage
  - Runoff pre-treatment in swales

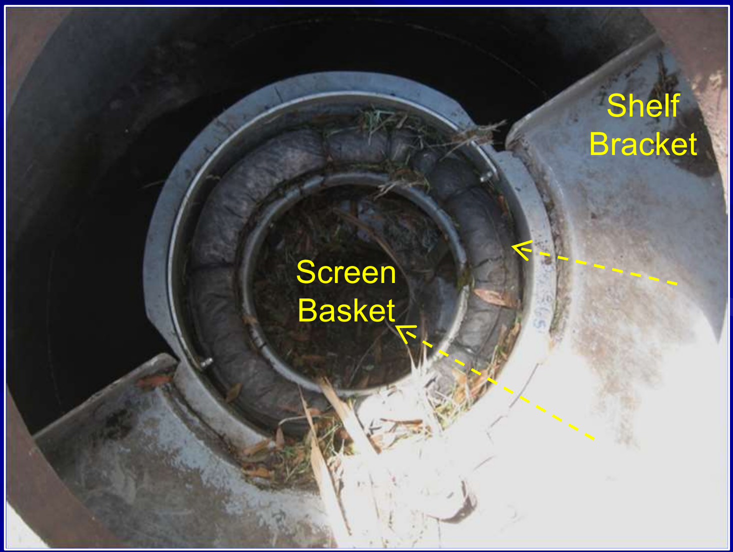
Drainage Basins Discharging to the Ecosense Baffle Box, CDS Unit, and Inlet Insert Sites

- Sub-basin H-3 has curb and gutter drainage
  - No runoff pre-treatment
- Sub-basin H-4 has curb and gutter drainage
  - No runoff pre-treatment
- Sub-basin H-5 has curb and gutter drainage
  - No runoff pre-treatment

Curb Inlet Basket Sites



a. Interior of the 668 San Pablo inlet basket



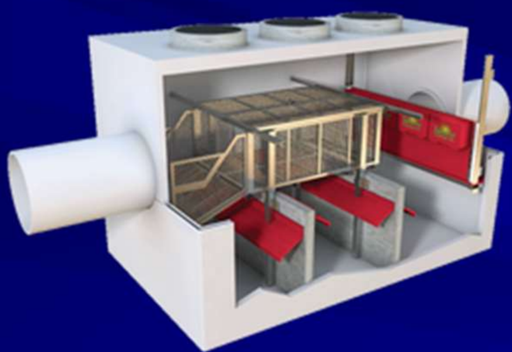
b. Interior of the 669 San Pablo inlet basket

Drainage Basins Discharging to the Suntree Baffle Box Site

- Sub-basin G-3 has curb and gutter drainage

- No runoff pre-treatment

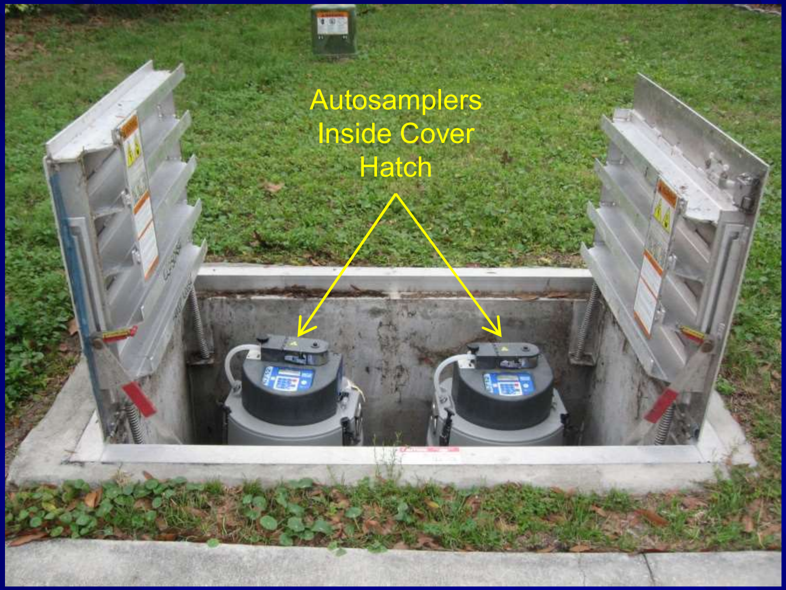
Suntree Baffle Box Monitoring Site



Internal View of Suntree Baffle Box

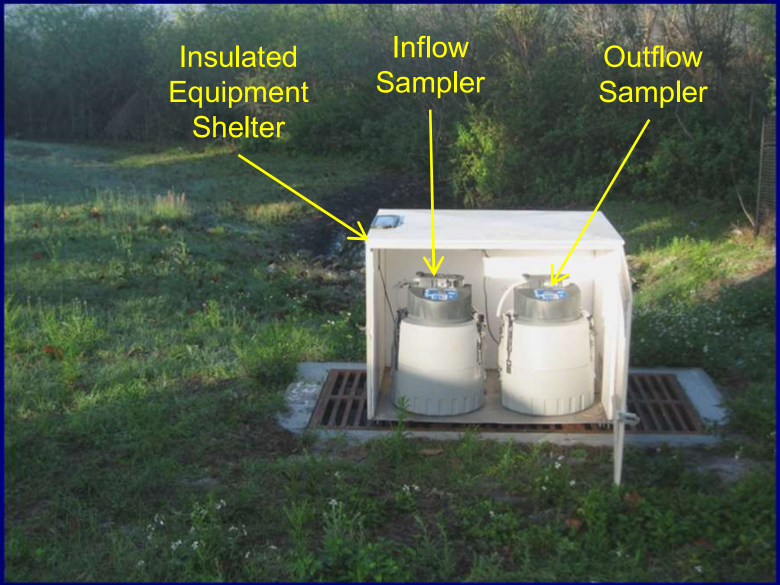
Exterior of the Lake Concord Suntree Baffle Box

Gee Creek EcoVault Unit Monitoring Equipment



- Outlet filter with aluminum silicate media designed to remove dissolved P

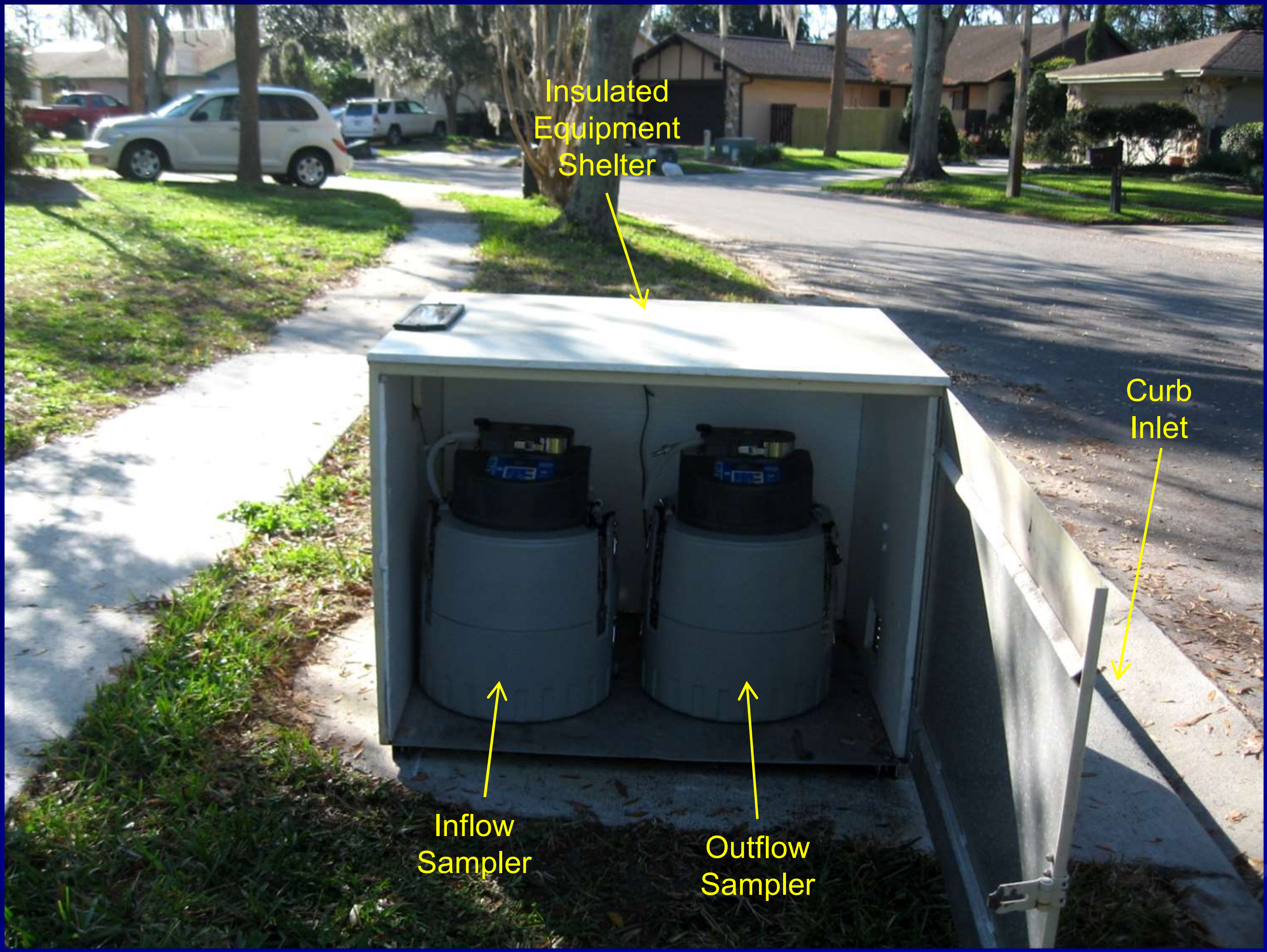
Lake Hodge EcoVault Unit Monitoring Equipment



- Unit contained leaf/debris screen and outlet filter with aluminum silicate media

Lake Howell Ecosense Baffle Box Monitoring Site

- Unit contained leaf/debris screen only



Lake Hodge Baffle Box Cleanout

a. Captured vegetation on the screen

b. Water pumped from sump area

c. Solids removed using Vactor truck

d. Screen following cleaning

Gee Creek Baffle Box Cleanout

a. Accumulated vegetation on the screens

b. Standing water is pumped from the sump area

c. Solids removed from screen using Vactor truck

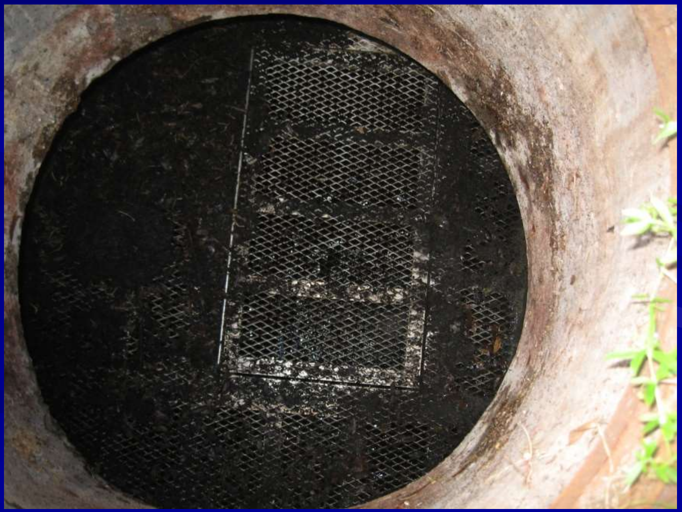
d. Screening following cleaning

Lake Howell Baffle Box Cleanout

a. Cleanout operations

b. Standing water pumped from bottom chambers

c. Solids vacuumed from chambers



d. Screens following cleaning

CDS Unit Cleanout

a. Interior of CDS unit prior to cleaning

b. Standing water is pumped from the unit

c. Sump area cleaned using a Vactor truck

d. Sump area following cleaning

Suntree Unit Cleanout

a. Accumulated solids and debris

b. Vegetation screen prior to cleaning

c. Solids removed from screen using Vactor truck

d. Baffle box unit following cleaning

Solids Collected from Evaluated Units

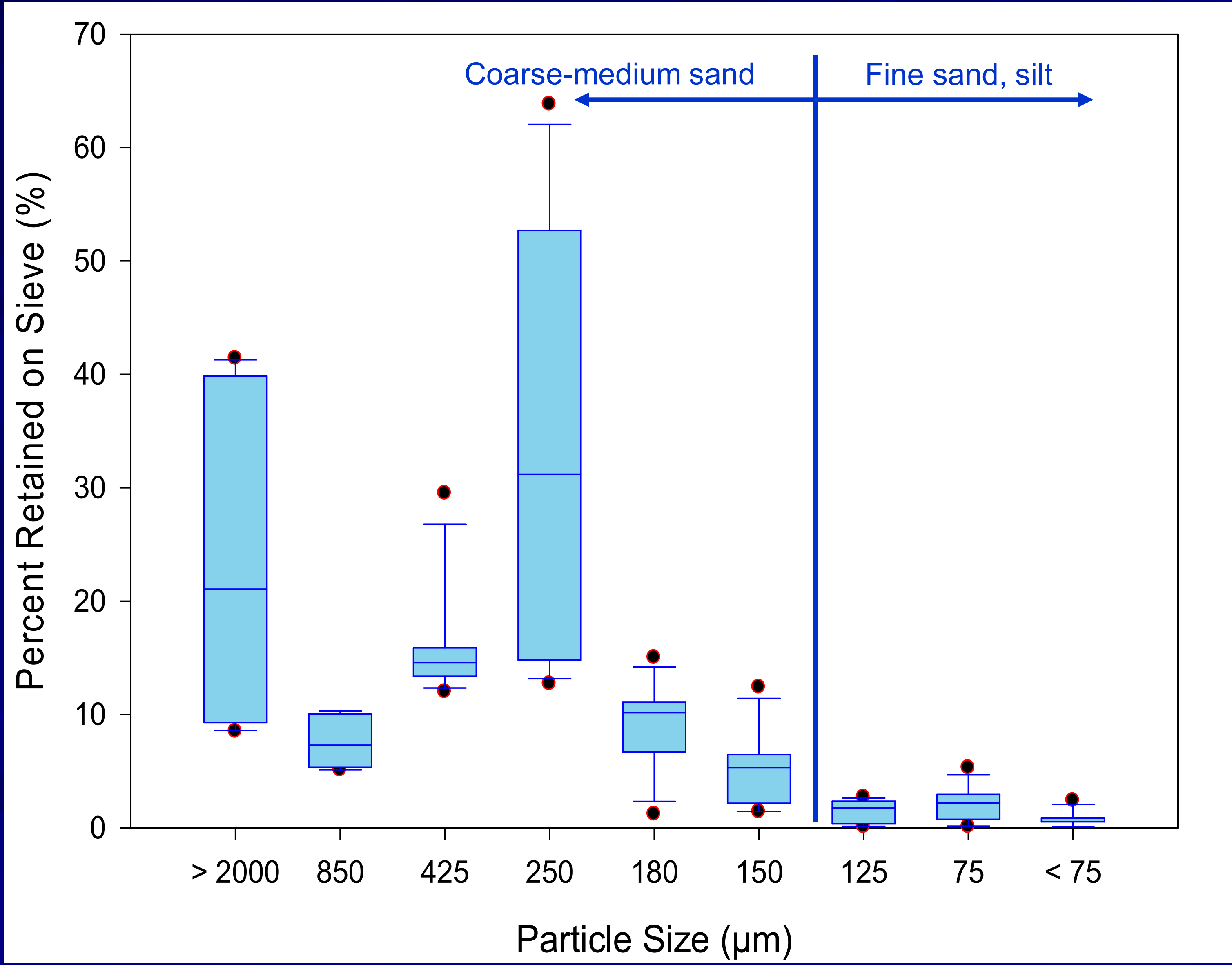
a. Material removed from the Lake Hodge B/B

b. Material removed from the Gee Creek B/B

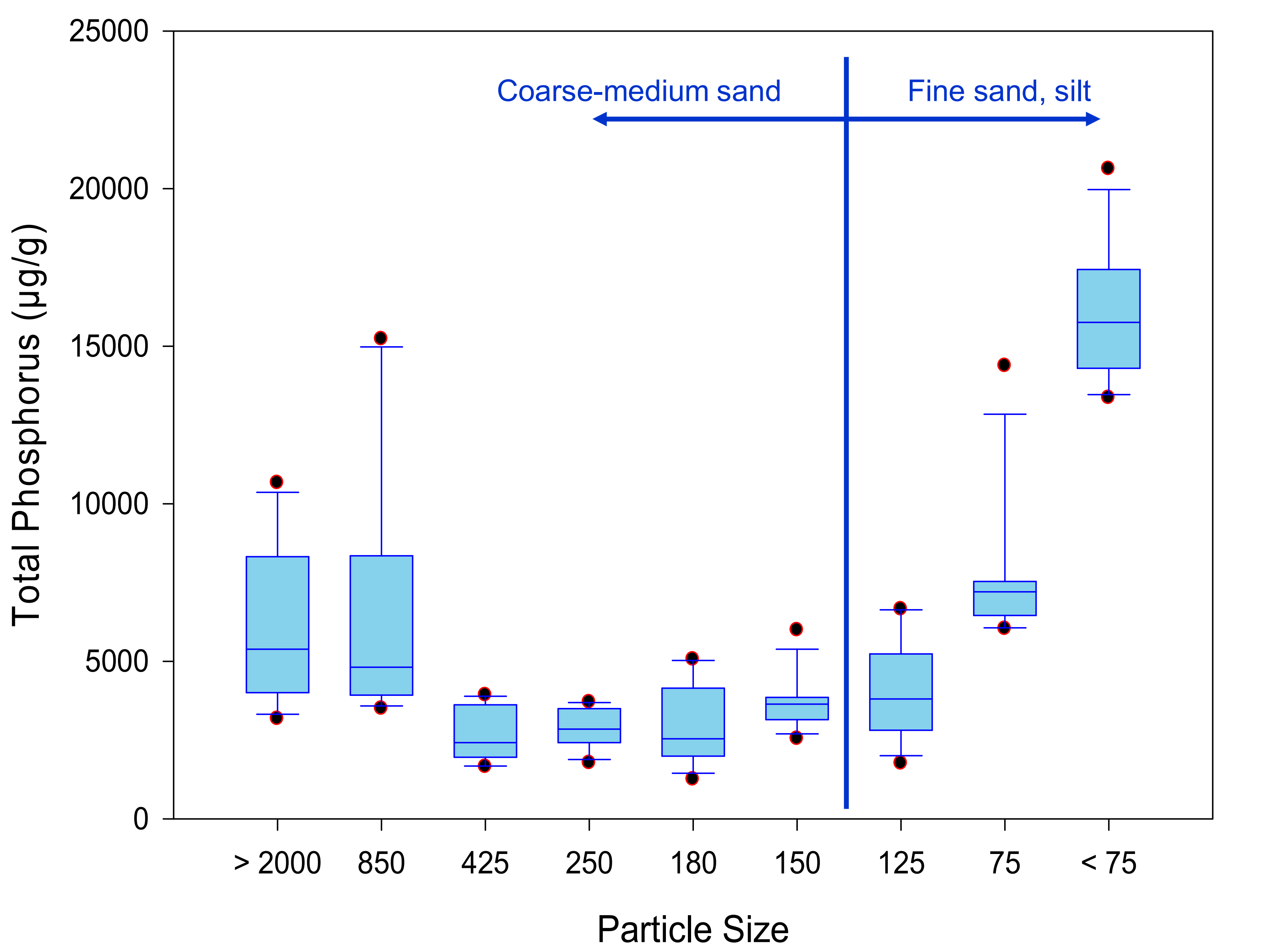
c. Material removed from the San Pablo B/B

d. Material removed from the Lake Concord B/B

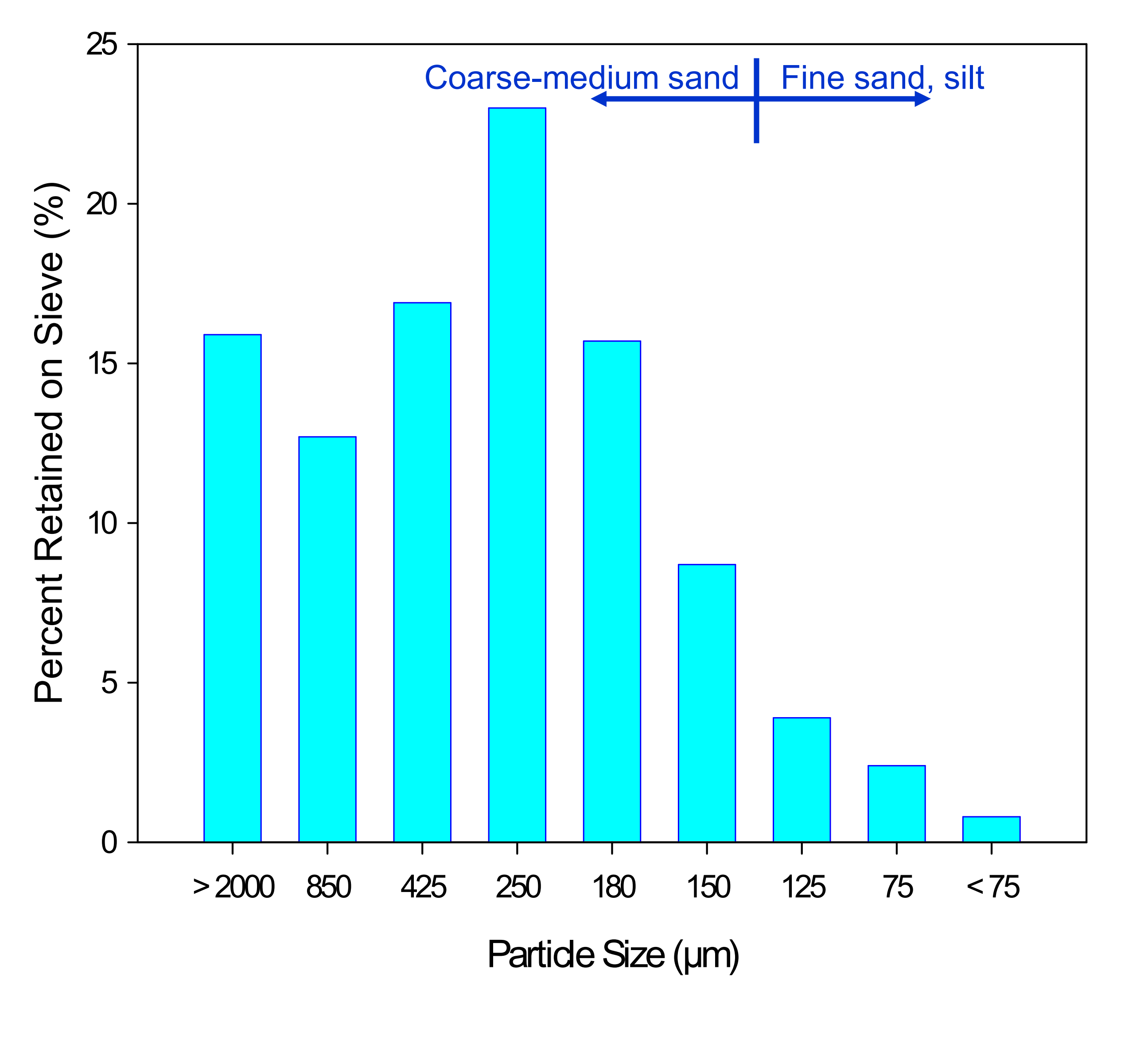
Distribution of Particle Sizes in Residential Roadway Solids



Concentrations of Total Phosphorus by Particle Size in Residential Roadway Solids



Typical Distribution of Solids Removed from Gross Pollutant Separators



CDS Unit

Baffle Box Unit

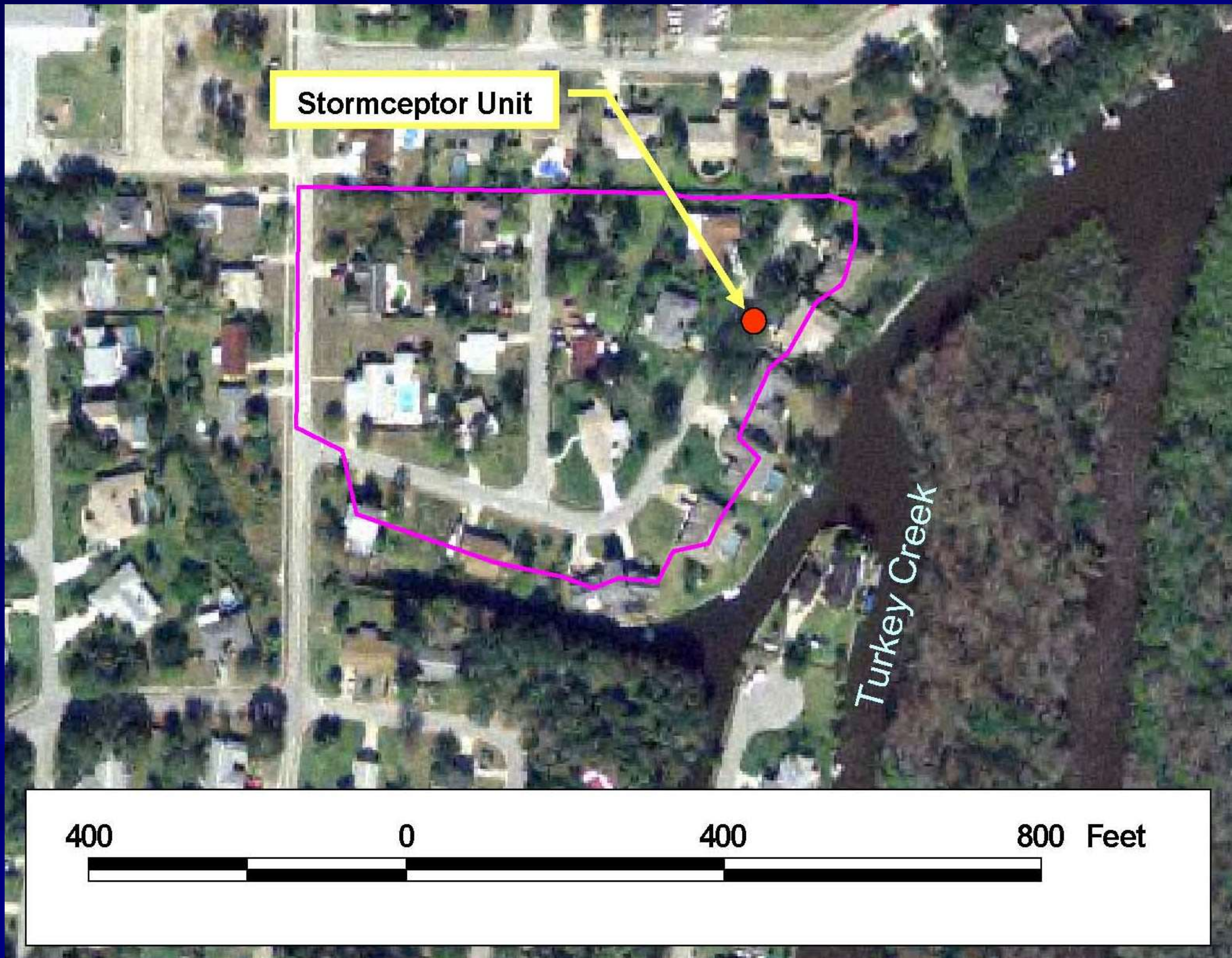
Baffle Box and CDS Removal Efficiencies and Costs

Site/Unit	Mass Removal (%)			Present Worth Removal Cost ($/kg) (20-yr, i = 2.5%)		
	Total N	Total P	TSS	Total N	Total P	TSS
Concord Suntree Baffle Box	2	7	73	6,110	15,928	11.20
San Pablo CDS Unit	5	12	94	5,699	23,252	43.32

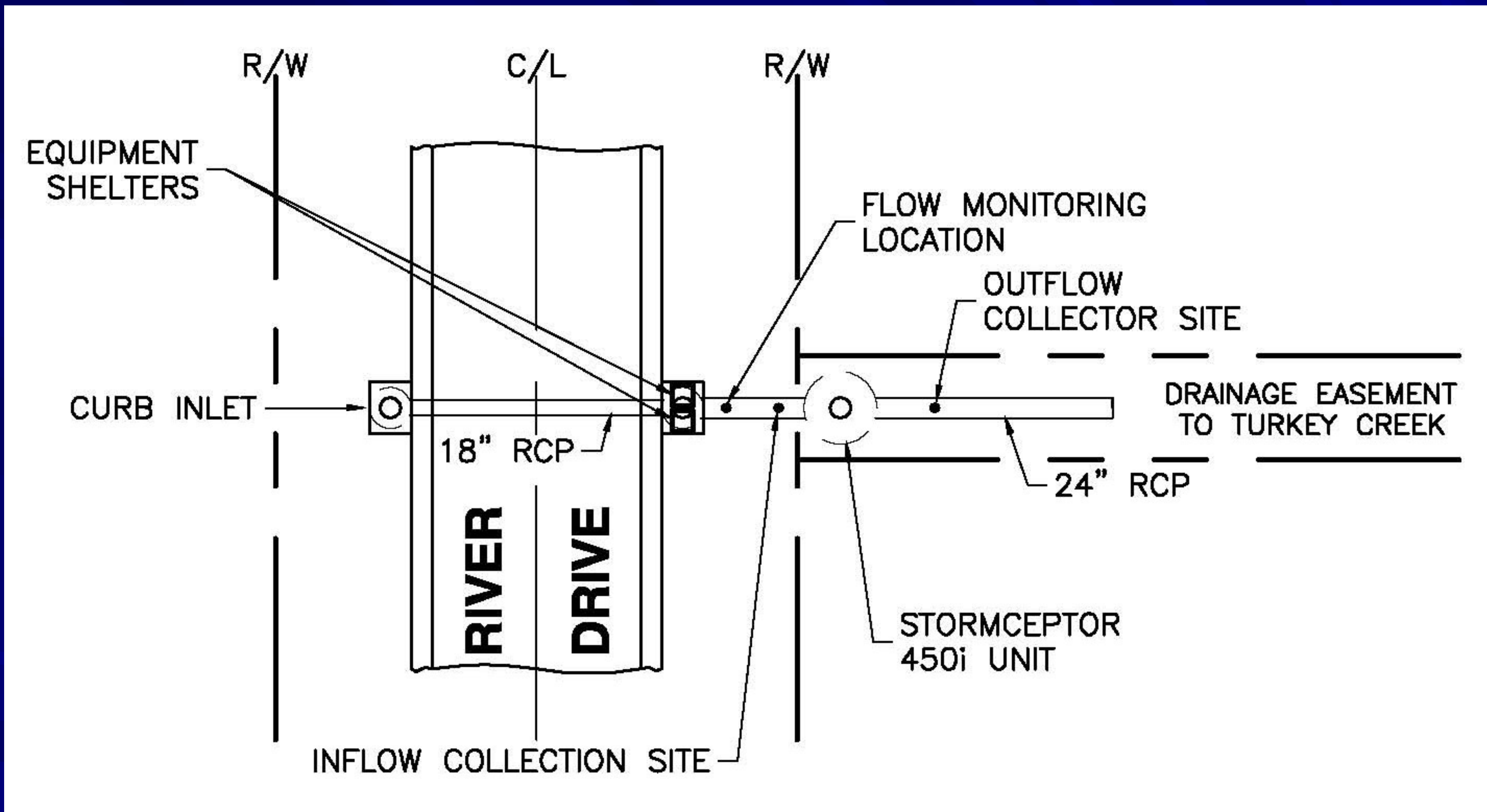
EcoVault Removal Efficiencies and Costs

Site/Unit	Mass Removal (%)			Present Worth Removal Cost ($/kg) (20-yr, i = 2.5%)		
	Total N	Total P	TSS	Total N	Total P	TSS
Lake Hodge EcoVault	14	57	90	3,433	1,755	4.89
Gee Creek EcoVault	2	41	78	34,377	10,188	14.05
San Pablo EcoVault	14	11	89	3,393	25,582	14.49

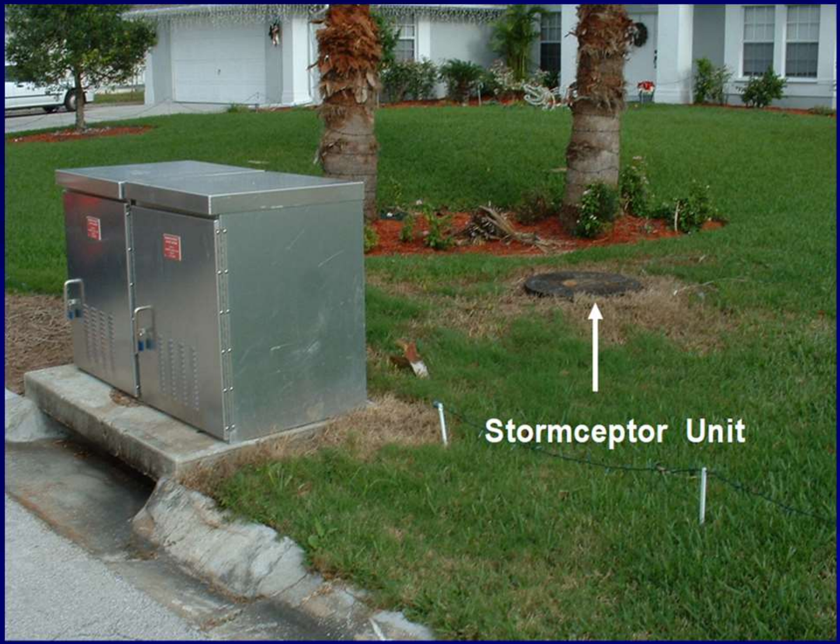
Contributing Watershed for the Stormceptor Unit



Schematic of the Stormceptor Monitoring Locations



Monitoring Equipment for the Stormceptor Unit

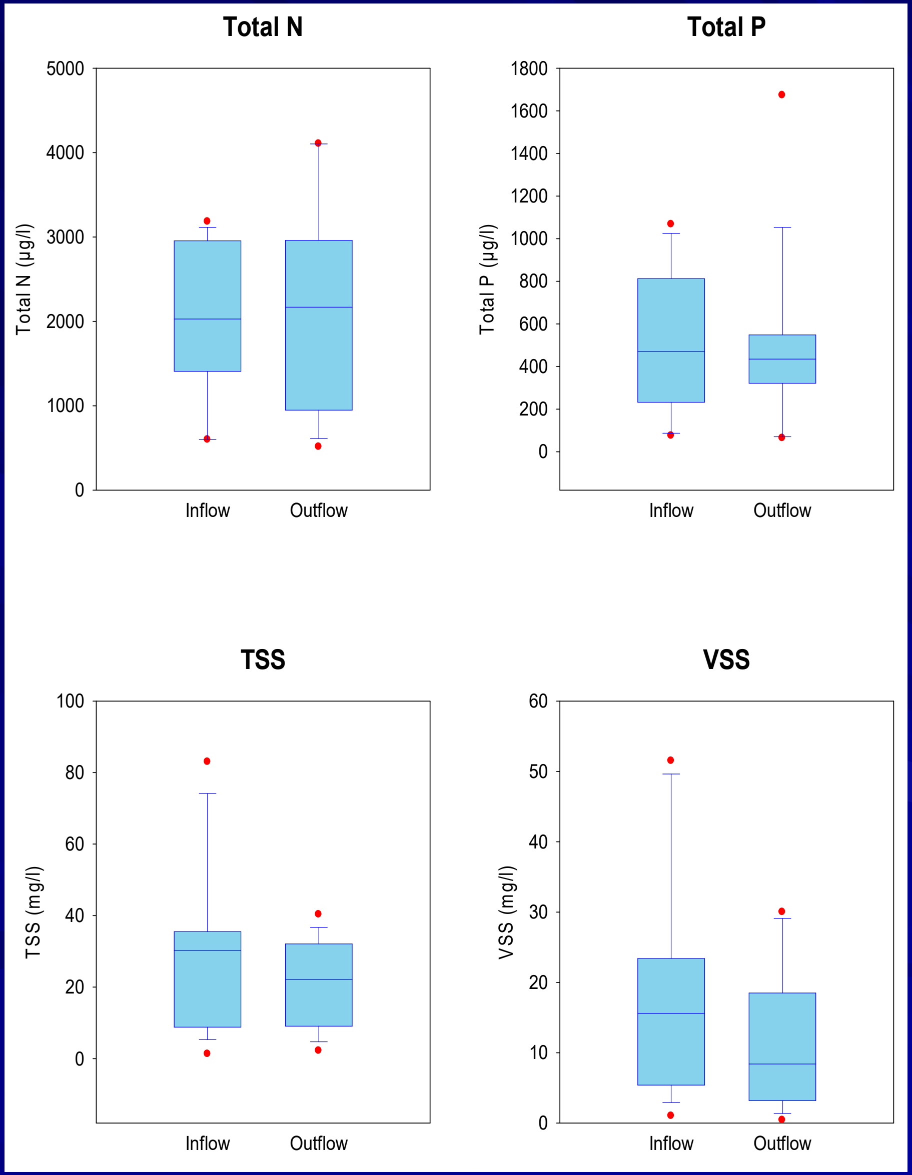


Inflow and Outflow Equipment Shelters

Inflow and Outflow Autosamplers

Sump Pump-Out Activities for the Stormceptor Unit

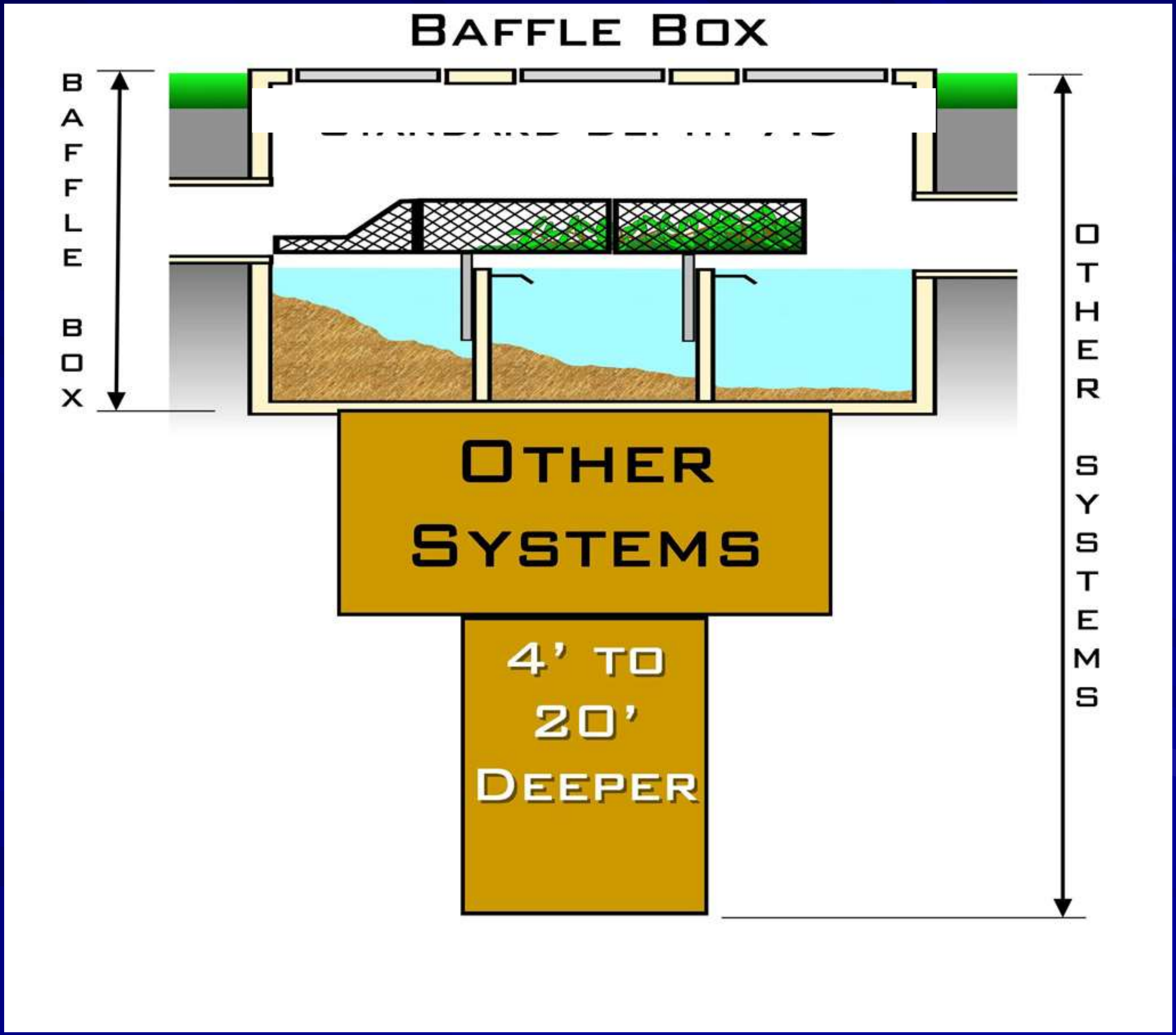
Statistical Comparison of Inflow and Outflow Characteristics for the Stormceptor Site



Overall Mass Removal Efficiency for the Stormceptor Unit from September 1, 2005 - February 17, 2006

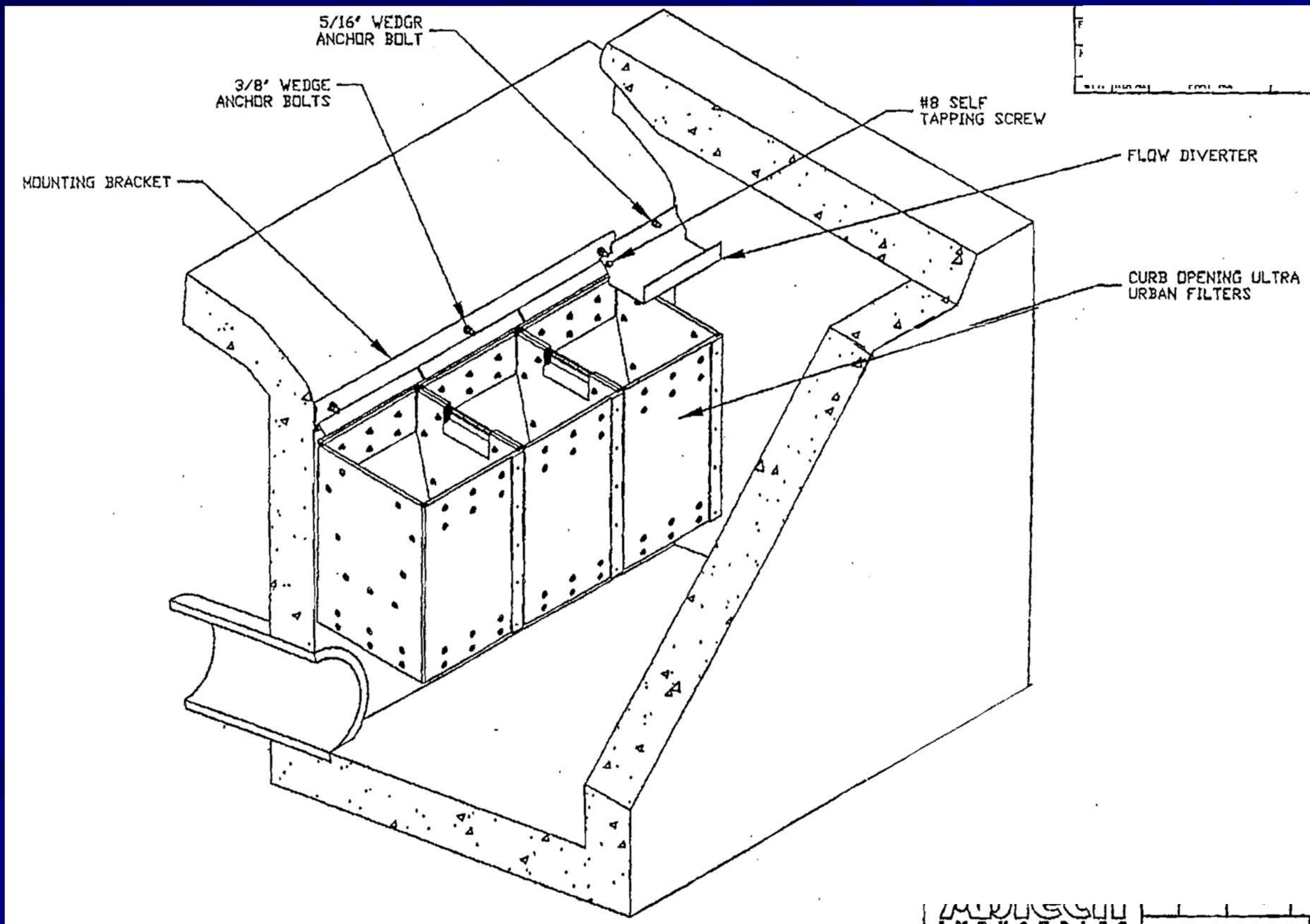
Parameter	Total Mass Inflow (kg)	Total Mass Outflow (kg)	Mass Removal (%)
TSS	56.6	40.8	28
VSS	34.6	26.3	24
Total N	3.67	4.32	-18
Total P	0.92	0.89	3

Excavation Requirements for GPS Units



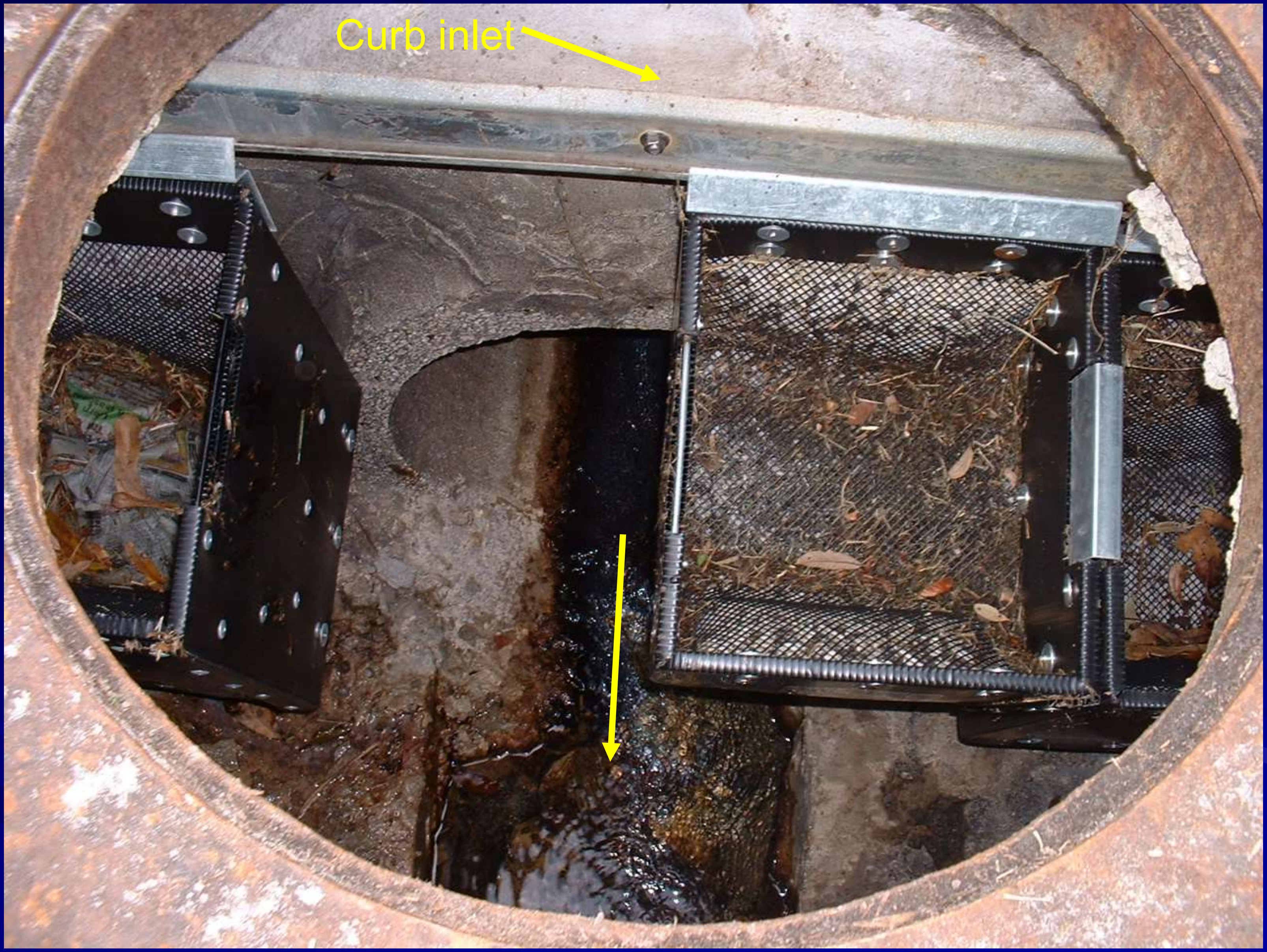
Hydro-Kleen and Ultra-Urban Units

Schematic of the Turkey Creek Subdivision Ultra-Urban Filter Unit

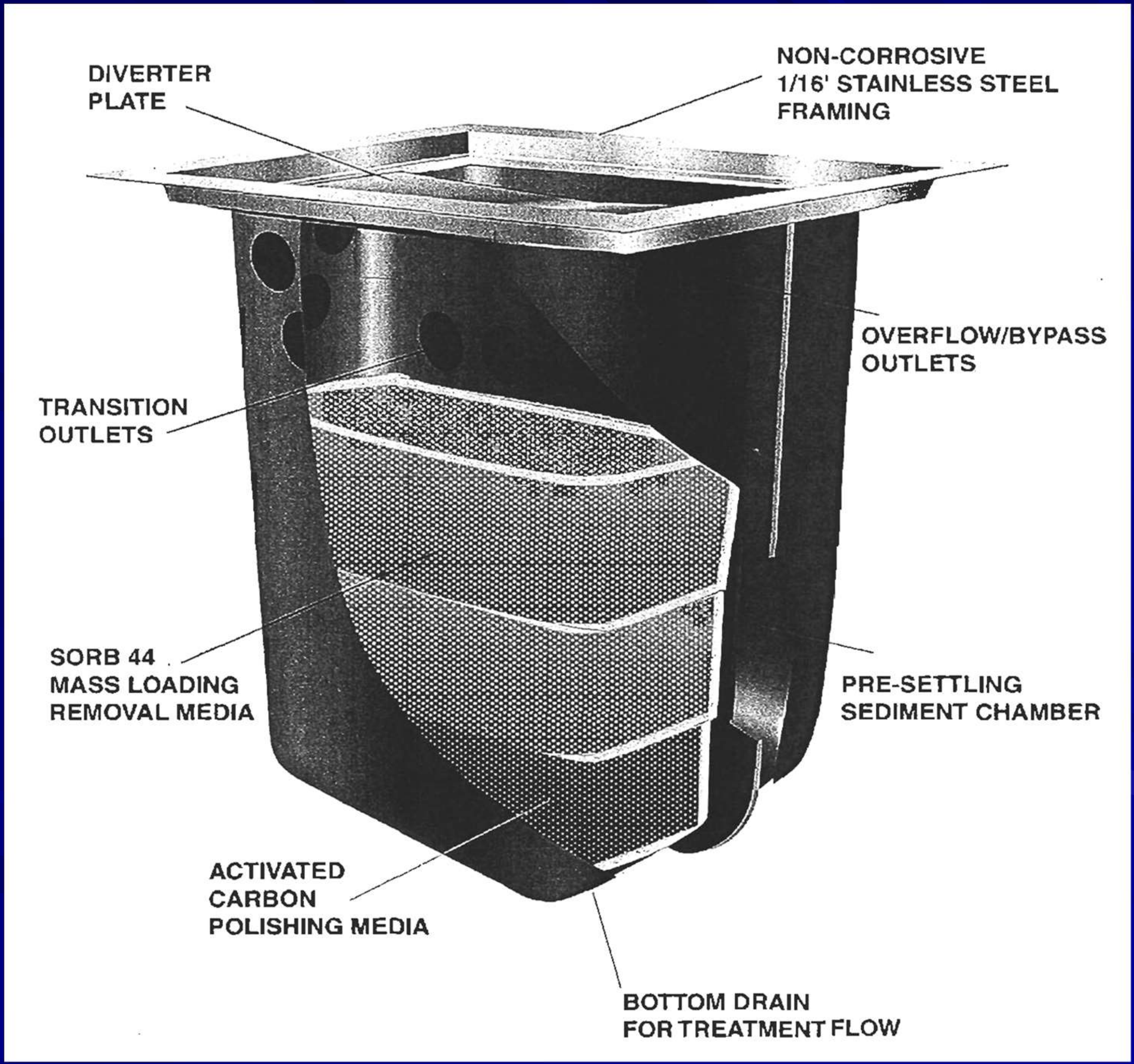


Ultra-Urban Filter Unit from the City of Palm Bay Installation

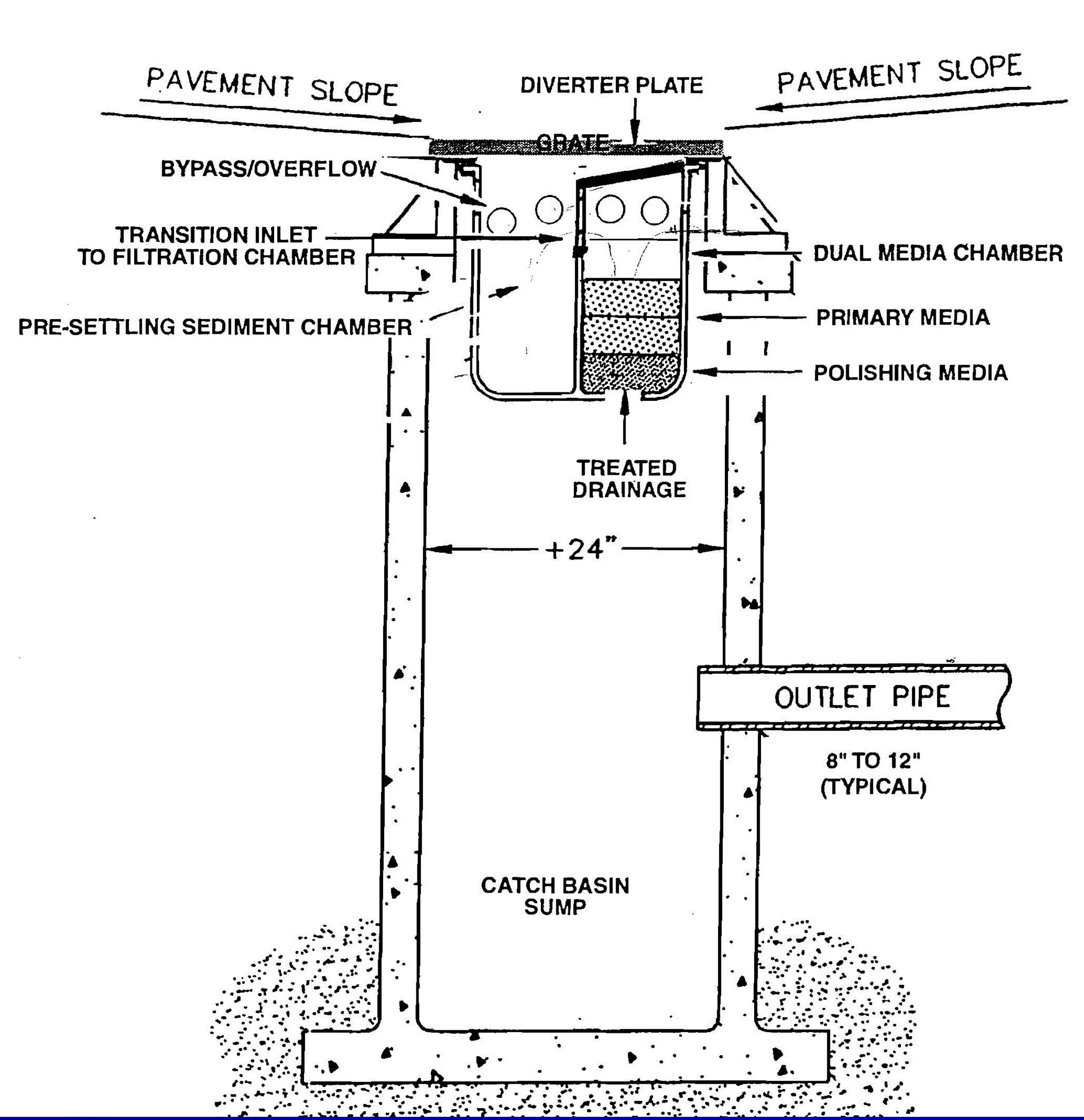
Ultra-Urban Filters Installed in Curb Inlet Structure



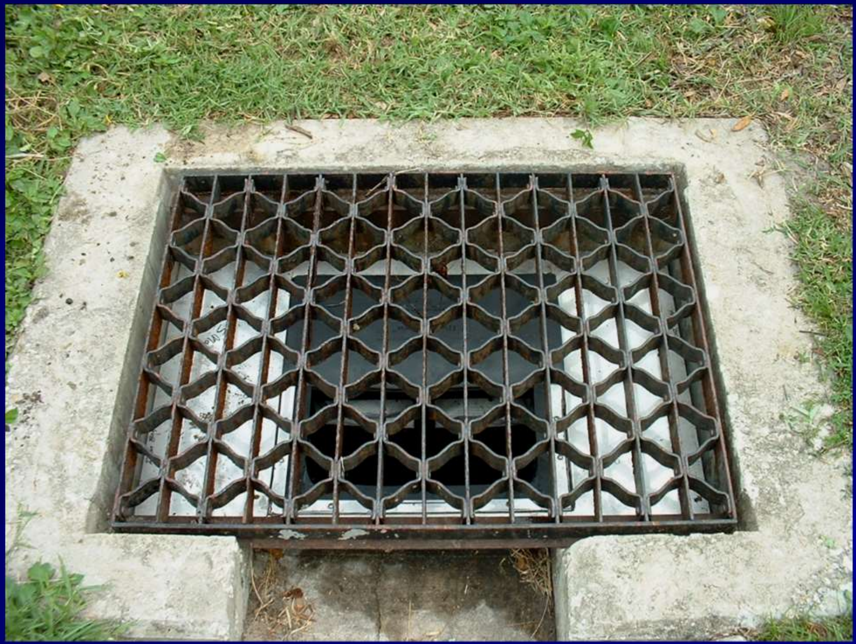
Schematic of the Hydro-Kleen Filtration System



Typical Hydro-Kleen Installation



Photos of Hydro-Kleen Installation at the Turkey Creek Subdivision



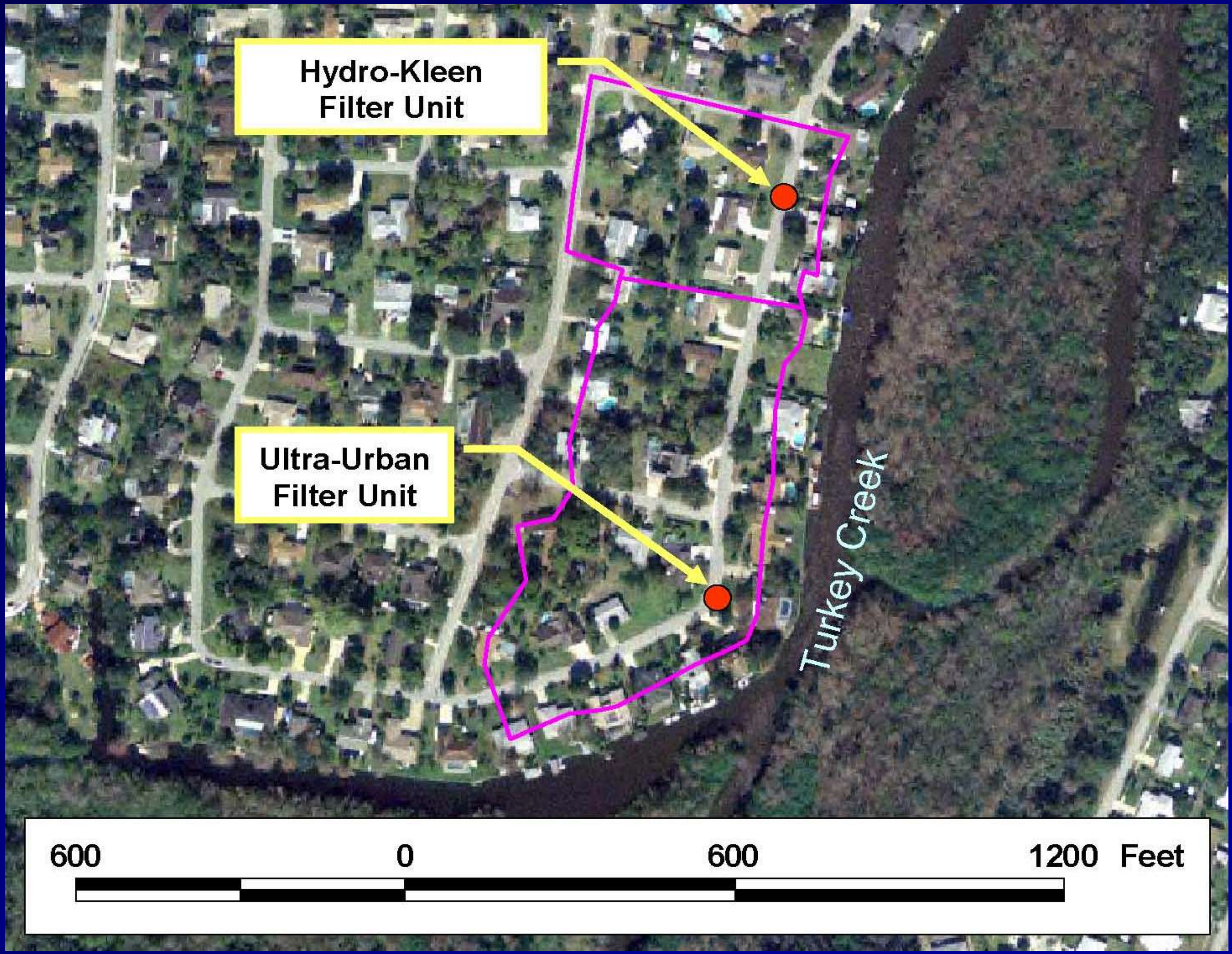
Hydro-Kleen Unit

Inside Inlet Box

Hydro-Kleen Unit

with Grate Removed

Contributing Watershed for the Hydro-Kleen and Ultra-Urban Filter Units



Pilot Testing Apparatus for the Hydro-Kleen and Ultra-Urban Filters

Solids Collection Activities

Hydraulic Performance Testing Using the Ultra-Urban Filter

Pilot Testing with the Filters

Ultra-Urban Filter

Hydro-Kleen Filter

Collection of Outflow Samples for the Ultra-Urban Filter

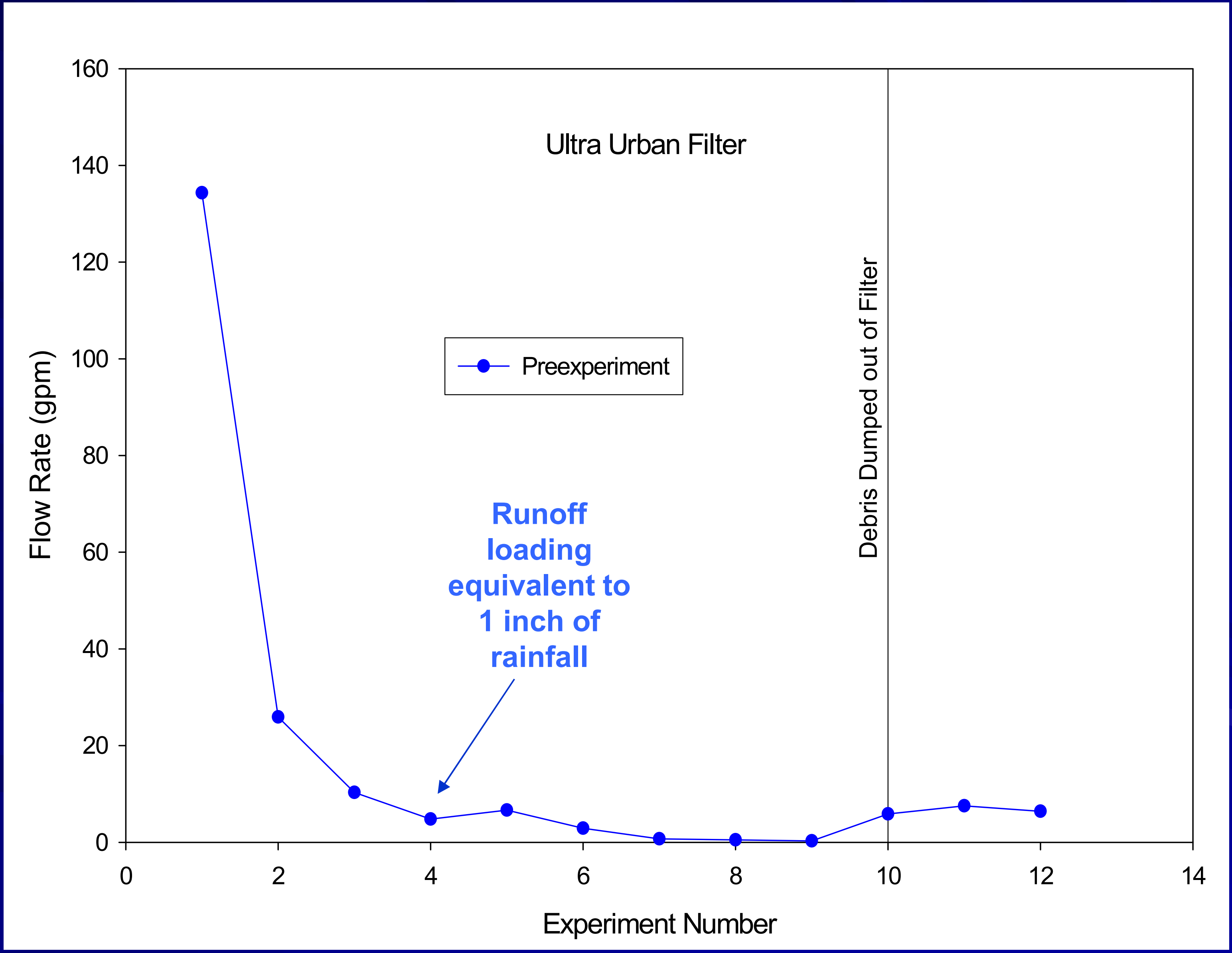
Loss of Leaves During Overflow of the Ultra-Urban Filter Unit

Summary of Residential Solids Used in Pilot Testing for the Ultra-Urban Filter Unit

Experiment No.	Mass of Dry Solids Used (g)	Equivalent Runoff TSS Concentration[1] (mg/l)
1	2969.41	83.4
2	3043.28	85.5
3	3980.78	112
4	927.03	26.0
5	823.48	23.1
6	756.69	21.3
7	329.95	9.3
8	280.06	7.9
9	371.60	10.4
10	293.69	8.3
11	290.30	8.1
12	329.91	9.3
TOTAL:	14,396.18	

1. Based on a watershed area of 6.93 acres for the Ultra-Urban Filter, a rainfall of 0.25 inches, and a runoff coefficient of 0.200

Hydraulic Performance of the Ultra-Urban Filter Unit During Pilot Testing

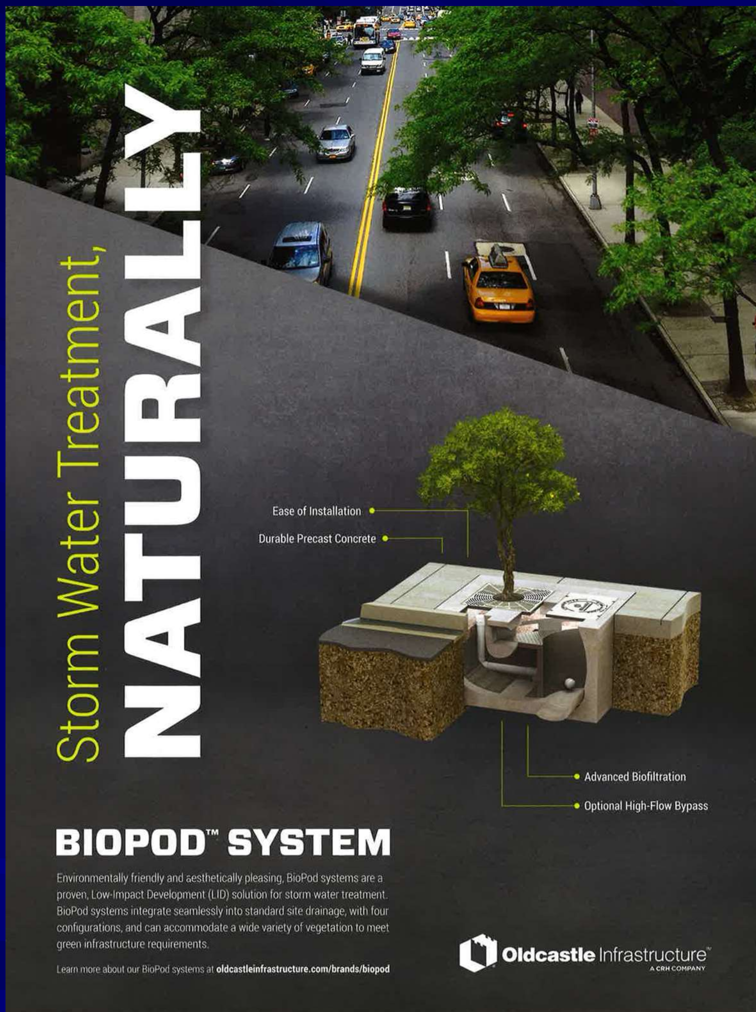


Mass Removal Efficiency of the Ultra-Urban Unit

-The Ultra-Urban unit removed ~99% of the TSS, particulate N, and particulate P in water which flowed through the filter

- However, the unit clogged after the equivalent of runoff from <1 inch of rainfall entered the unit

Limitations of LID Systems



- 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
- Limits effectiveness of the system
  - Manufacturers efficiencies will over-estimate achieved efficiencies

Limitations of LID Systems – con't.

- Devices such as these are intended for small catchments
- A typical Florida afternoon storm would quickly exceed the capacity of the system

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: 30-60% 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

Part 9

Street Sweeping

Pavement Cleaning

Practices designed to clean and remove sediment, debris, and other pollutants from impervious surfaces

- used to reduce pollutant transport to receiving waters

- often used as aesthetic practices

- used most often in urban areas

- removes pollutants before they become solubilized, reducing need for stormwater treatment

Types of Street Sweepers

Mechanical Sweepers

- Most common type of sweeper – requires hard curb
- Uses rotating brooms to sweep solids onto a conveyor and into a hopper
- Water may be sprayed for dust control
- Mostly remove leaves, debris and larger solids
- May cause dust release

Types of Street Sweepers – cont.

Mechanical Sweepers – cont.

- Capable of removing only coarse particles (>400 μm)
- National Urban Runoff Program (NURP) studies indicated that mechanical sweeping is not a viable water quality management practice
- Bender and Terstriep (1984) evaluated mechanical sweeping in Champaign, Il.
  - Bi-weekly sweeping achieved 42% reduction of street solids
  - No removal of particles <10 μm
  - No significant difference between pre and post runoff nutrient concentrations

Mechanical Sweepers

Mechanical sweepers grind up roadway solids and leave a homogenized “paste” on the roadway surface

Mechanical sweepers perform poorly in areas with accumulated leaves

Types of Street Sweepers – cont.

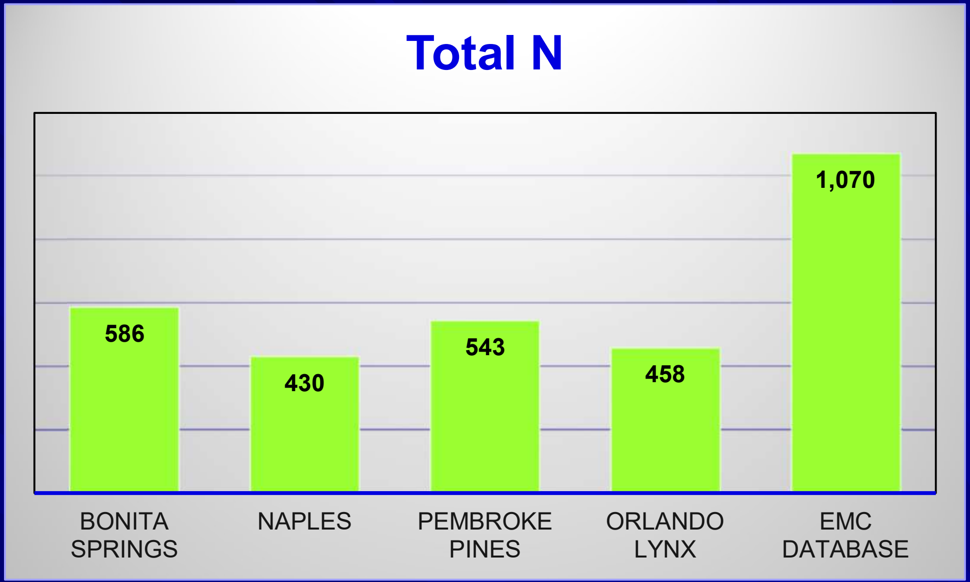
- Regenerative Air
  - Air is forced down onto the pavement, to suspend particles
  - Particles are captured by a high powered vacuum
  - Air is filtered and recycled
  - Large particles may not receive sufficient agitation to become air-entrained
  - Efficiency ~ 30% for particles < 10 µm

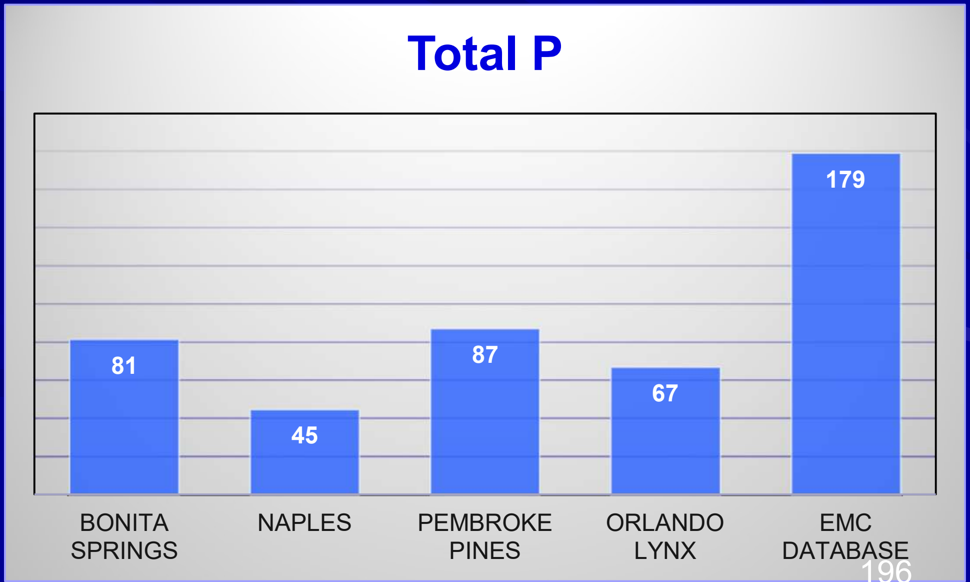
Types of Street Sweepers – cont.

- <u>Vacuum Assisted</u>
  - Provides air vacuum over entire path
  - Does not require a hard curb
  - May have mechanical brush assist
  - May or may not use sprayed water
  - Best removal of all street sweeper

Impacts of Vacuum Sweeping on Runoff Characteristics

- Each of the study sites conducted vacuum sweeping 2-3 times per week on parking areas
  - Conducted primarily for removal of trash
  - Not part of any water quality related permit
- Runoff emc values at the commercial sites were ~ 50% of emc database value





Efficiency of street sweeping is a function of:

- Sweeper type – vacuum sweepers are more effective than mechanical
- Particle size – smaller particles are more difficult to remove than larger particles
- Frequency of sweeping – Efficiency increases with frequency of sweeping. Studies indicate that the optimum frequency is every 1-2 weeks.
- Number of passes - Efficiency increases as the number of passes increases
- Equipment speed - Efficiency decreases as speed of operation increases
- Pavement conditions - Deteriorated pavement contains irregularities which trap solids and are difficult to clean
- Operator skill - Experienced operators can operate more effectively

Estimated TSS Reduction from Street Sweeping (%)

(Residential Area)

Sweeper Type	Frequency of Sweeping			
	Monthly	Twice Monthly	Weekly	Twice Weekly
New Type Vacuum	51	63	79	87
Regenerative Air	43	53	65	71
Mechanical Brush Type	17	23	29	33

Source: U.S. EPA

Relationships Between Particle Size and Sweeper Efficiency

(Mechanical Sweeper; Ref. USEPA)

Particle Size (microns)	Sweeper Efficiency (%)
>2000	76
840 – 2000	66
246 – 840	60
104 – 246	48
43 – 104	20
<43	15
Overall	50

Roadway Particulate Removal Efficiencies (<10 μm) for Various Sweepers

(Ref. USEPA)

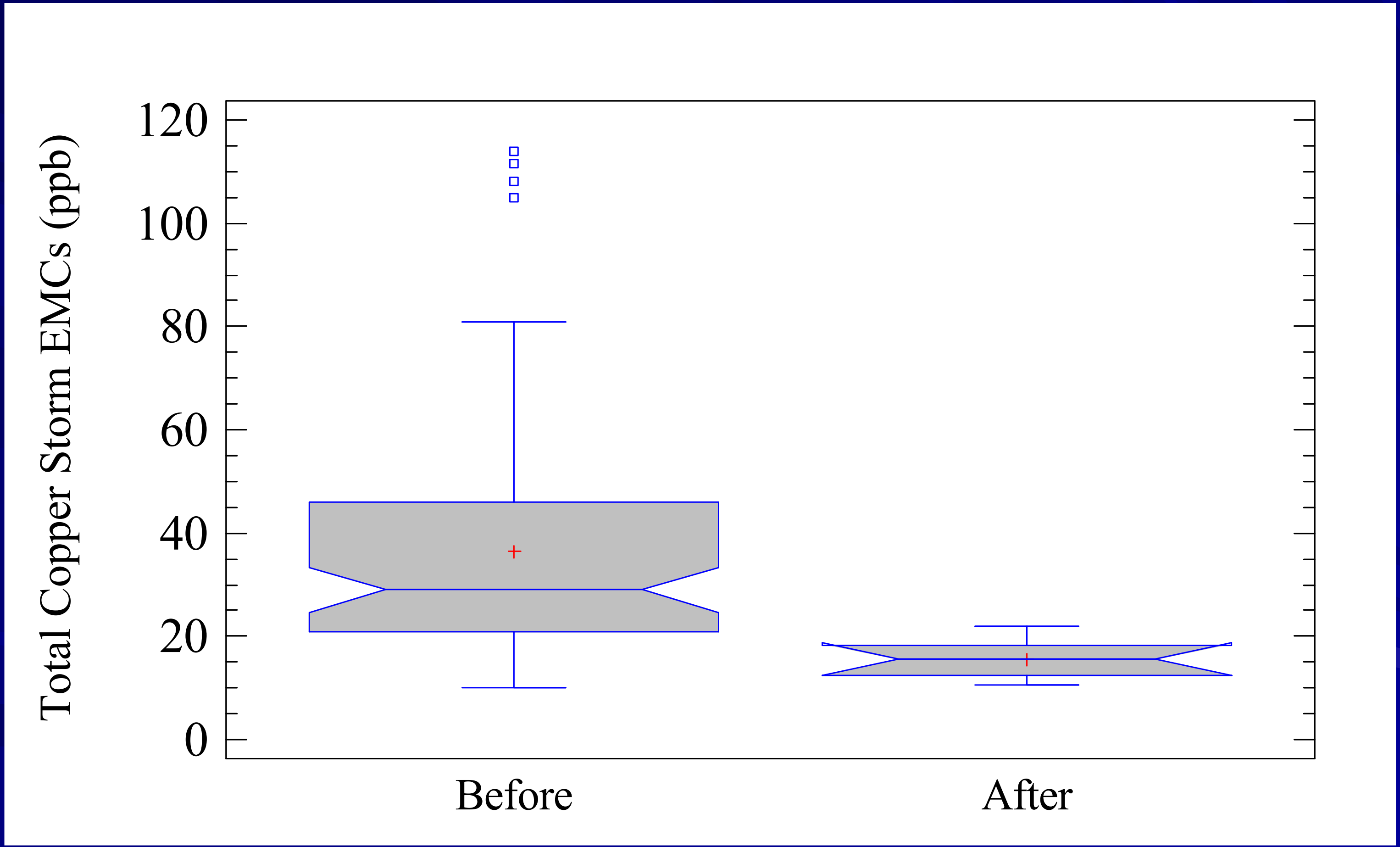
Sweeper Type	Removal Efficiency (%)
Mechanical – Model 1	-6.7
Mechanical – Model 2	8.6
Regenerative Air	31
Vacuum Assisted – Wet – Model 1	40
Vacuum Assisted – Wet – Model 2	82
Vacuum Assisted – Dry	99.6

Hamilton, Ohio Watershed

Every second and fourth Wednesday of the month, streets are swept in the pilot study area using mechanical sweepers.

Hamilton Watershed Stormwater EMCs Before & After Street Sweeping Began

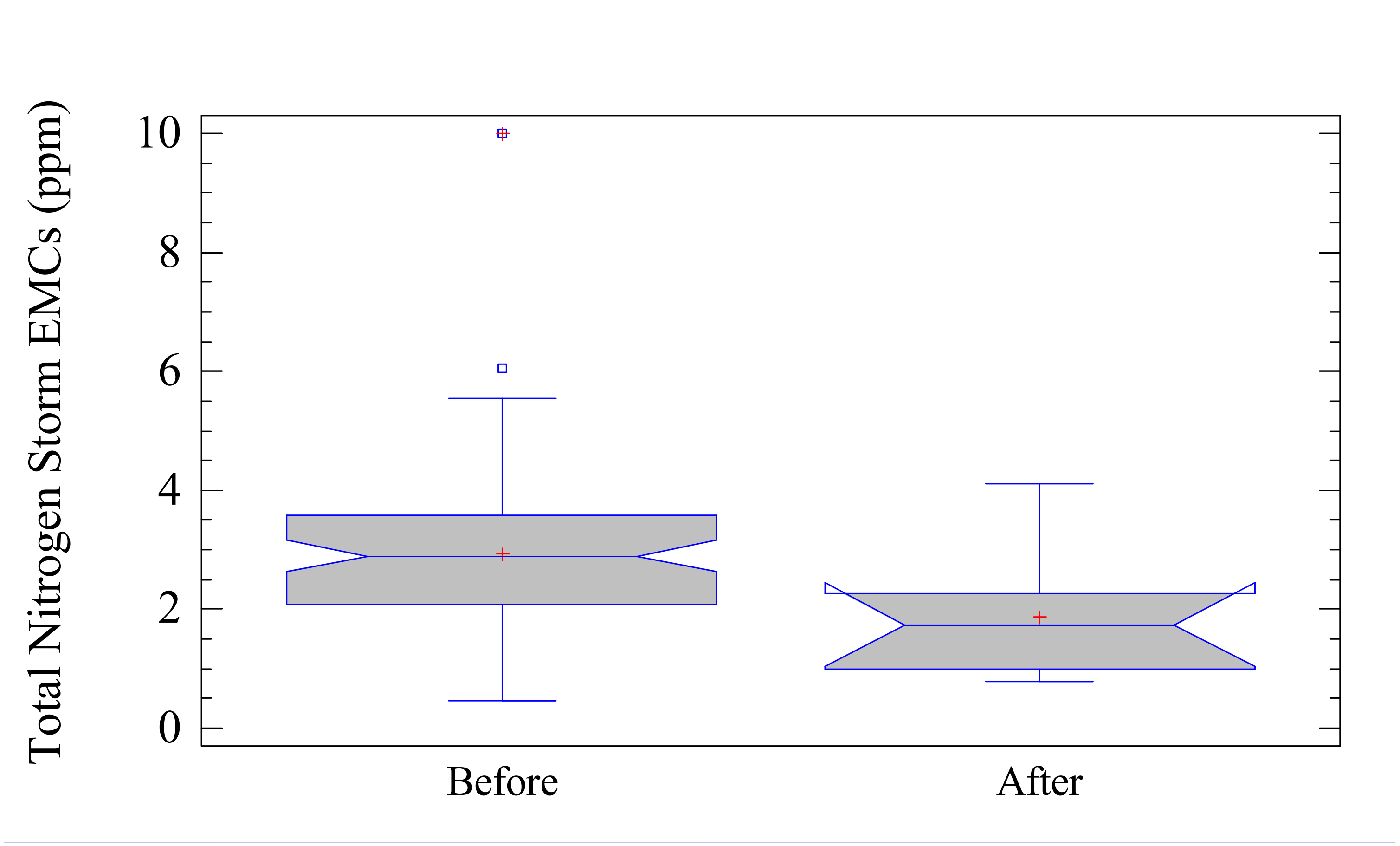
Total Copper



Significant decline in total copper

Hamilton Watershed Stormwater EMCs Before & After Street Sweeping Began

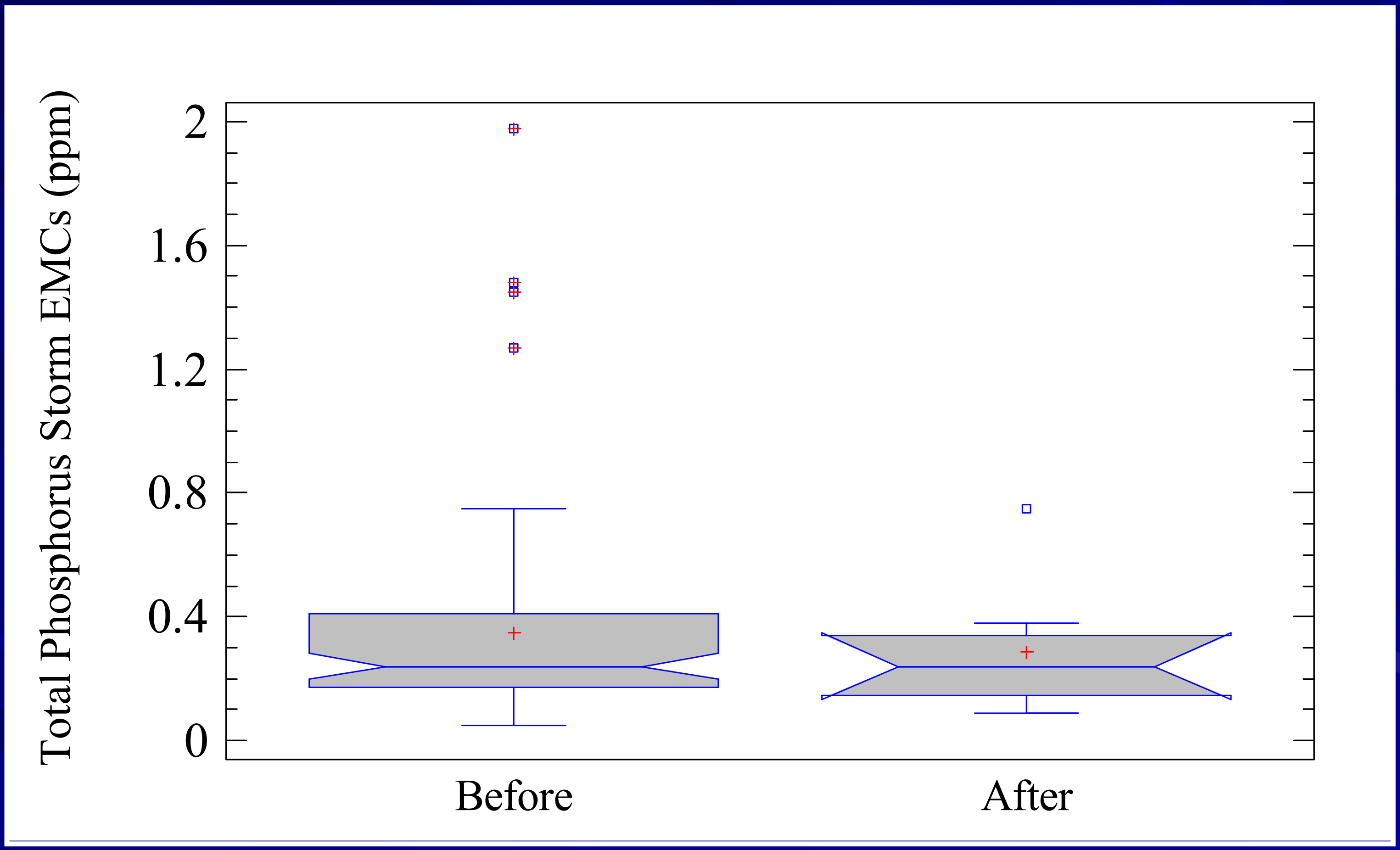
Total Nitrogen



Significant decline in total nitrogen

Hamilton Watershed Stormwater EMCs Before & After Street Sweeping Began

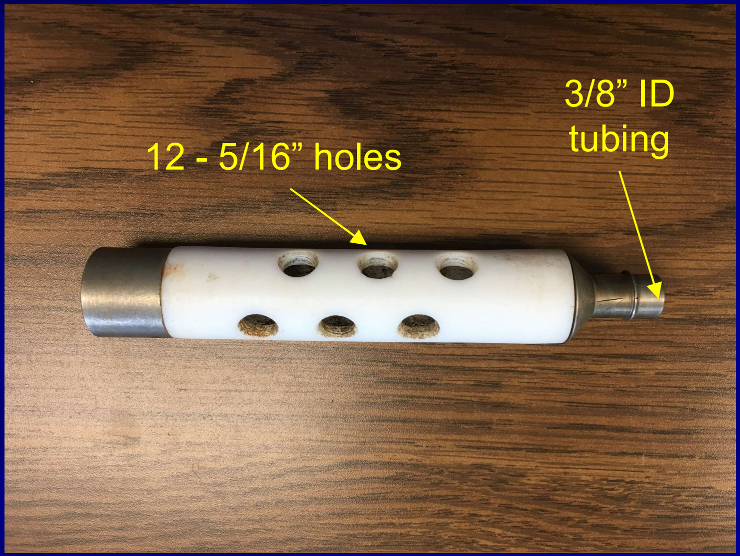
Total Phosphorus



No change in total phosphorus

Field Monitoring for Runoff

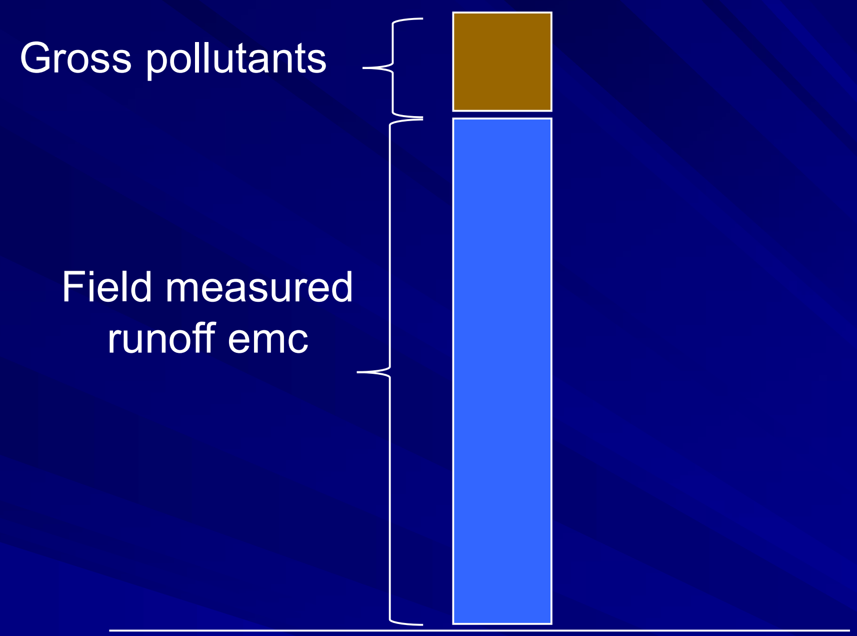
- Auto-samplers do an extremely poor job of collecting representative sample of runoff solids
- Manufacturers claim that water moves through the suction tubing at a rate of 2 fps
  - Minimum velocity required to transport most solids
- Velocities through strainer holes are much lower
  - ~ 0.24 fps (12%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

Part 10

Alum Treatment

Characteristics of Alum

-Clear, light green to yellow solution, depending on Fe content

-Liquid is 48.5% solid aluminum sulfate

-Specific gravity = 1.34

-11.1 lbs/gallon

-Freezing point = -15° C

-Delivered in tanker loads of 4500 gallons each

Significant Alum Removal Processes

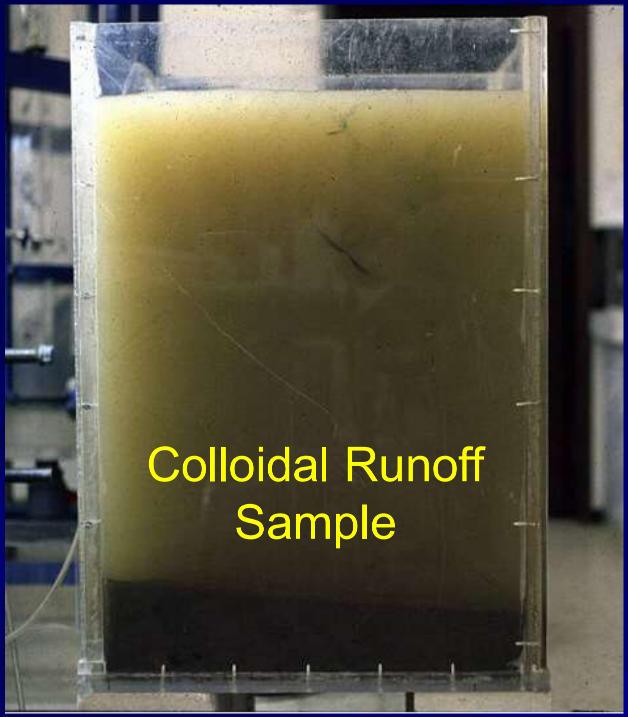
1. Removal of suspended solids, algae, phosphorus, heavy metals and bacteria:

$$Al^{+3} + 6H_2O \longrightarrow Al(OH)_{3(s)} + 3H_3O^+$$

2. Removal of dissolved phosphorus:

$$Al^{+3} + H_nPO^{n-3} \longleftrightarrow AlPO_{4(s)} + nH^+$$

Initial Experiments (1980)



Initial testing evaluated salts of:
- Aluminum
- Iron
- Calcium

Alum was most effective

Alum Reacts Quickly to Remove Both Particulate and Dissolved Pollutants

How Alum Treatment Works

BEFORE	DURING	AFTER
Untreated stormwater entering a waterbody contains many pollutants, such as phosphorus and nitrogen (nutrients), suspended solids, and heavy metals (toxins). These chemicals are harmful to aquatic ecosystems.	During treatment, the mixture of aluminum sulfate (alum) and stormwater forms particles called floc which attract and capture pollutants as they float through the water column.	Once sufficiently heavy, the floc particles settle harmlessly to the bottom of the lake where they accumulate for later removal. What remains is clean lake water and a benefit for all downstream ecosystems.

Alum Treatment

Advantages

- Rapid, efficient removal of solids, phosphorus, and bacteria
- Inexpensive and cost efficient
- Relatively easy to handle and feed
- Does not deteriorate under long-term storage
- Floc is inert and is immune to fluctuations in pH and redox potential
- Floc binds heavy metals in sediments, reducing sediment toxicity
- Rapid clarification of water column
- Does not harm biological life

History of Alum Usage

Drinking water - Roman Times

Wastewater - 1800s

Lake surface treatments - 1970

Stormwater treatment - 1986

Typical Percent Removal Efficiencies for Alum Treated Stormwater Runoff

Parameter	Settled Without Alum (24 hrs)	Alum Dose (mg Al/liter)		
		5	7.5	10
Diss. Organic N	20	51	62	65
Particulate N	57	88	94	96
Total N	20*	65*	71*	73*
Diss. Ortho-P	17	96	98	98
Particulate P	61	82	94	95
Total P	45	86	94	96
Turbidity	82	98	99	99
TSS	70	95	97	98
Total Coliform	37	80	94	99
Fecal Coliform	61	96	99	99

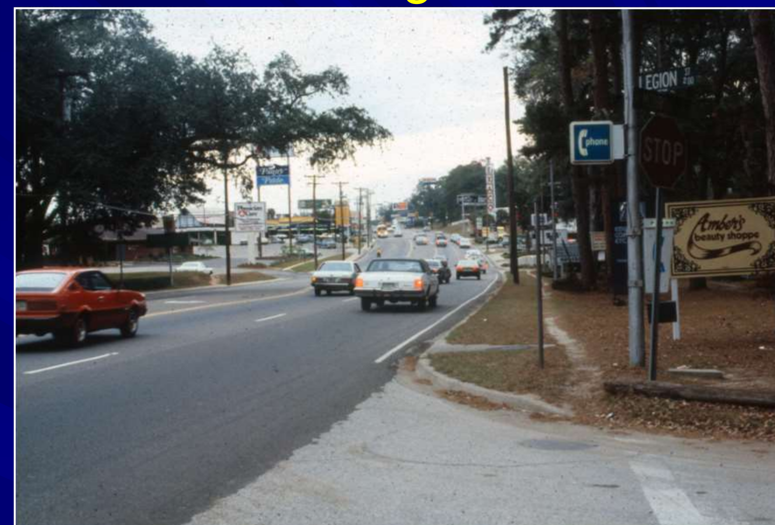
* Depending on the type of nitrogen species present

Lake Ella – Tallahassee

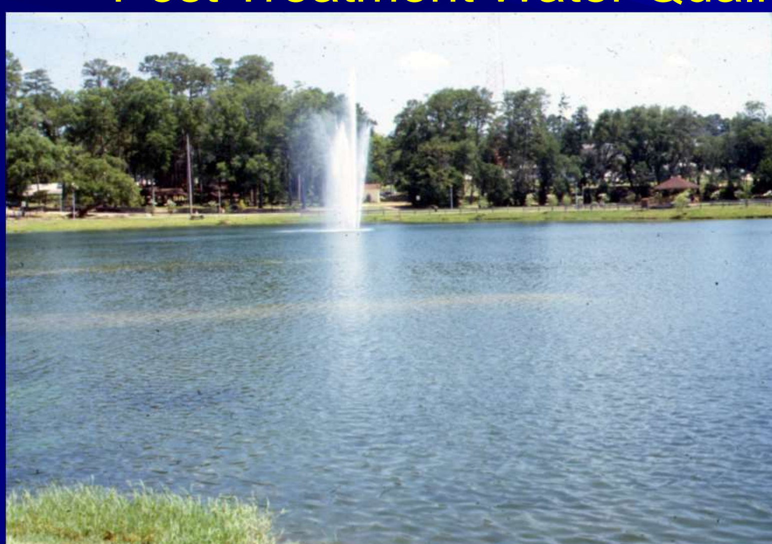
13 ac. Lake Receiving Runoff from 170 ac. Urban Watershed

Pre-treatment Water Quality

Drainage Basin



Post Treatment Water Quality



Shoreline Vegetation

Lake Dot – Orlando

5 ac. Lake Receiving Runoff from 305 ac. Urban Watershed

Pre-treatment Water Quality

108 inch Stormsewer

Post Treatment Water Quality

Newspaper Cartoon

Lake Howard Alum Injection System

Equipment Building

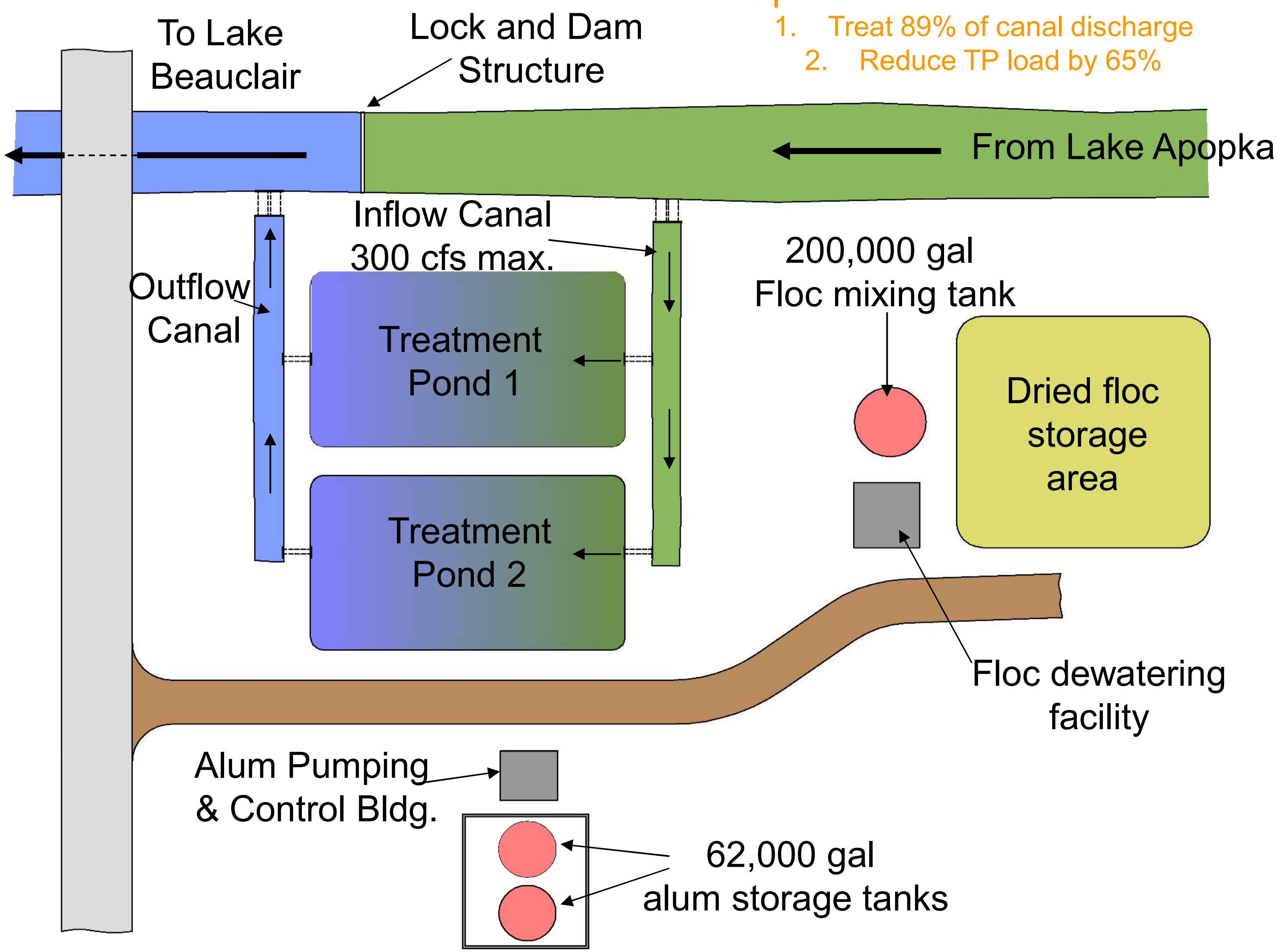
Underground Alum Storage Tank

Alum Injection Equipment

LCWA Nutrient Reduction Facility (NuRF)

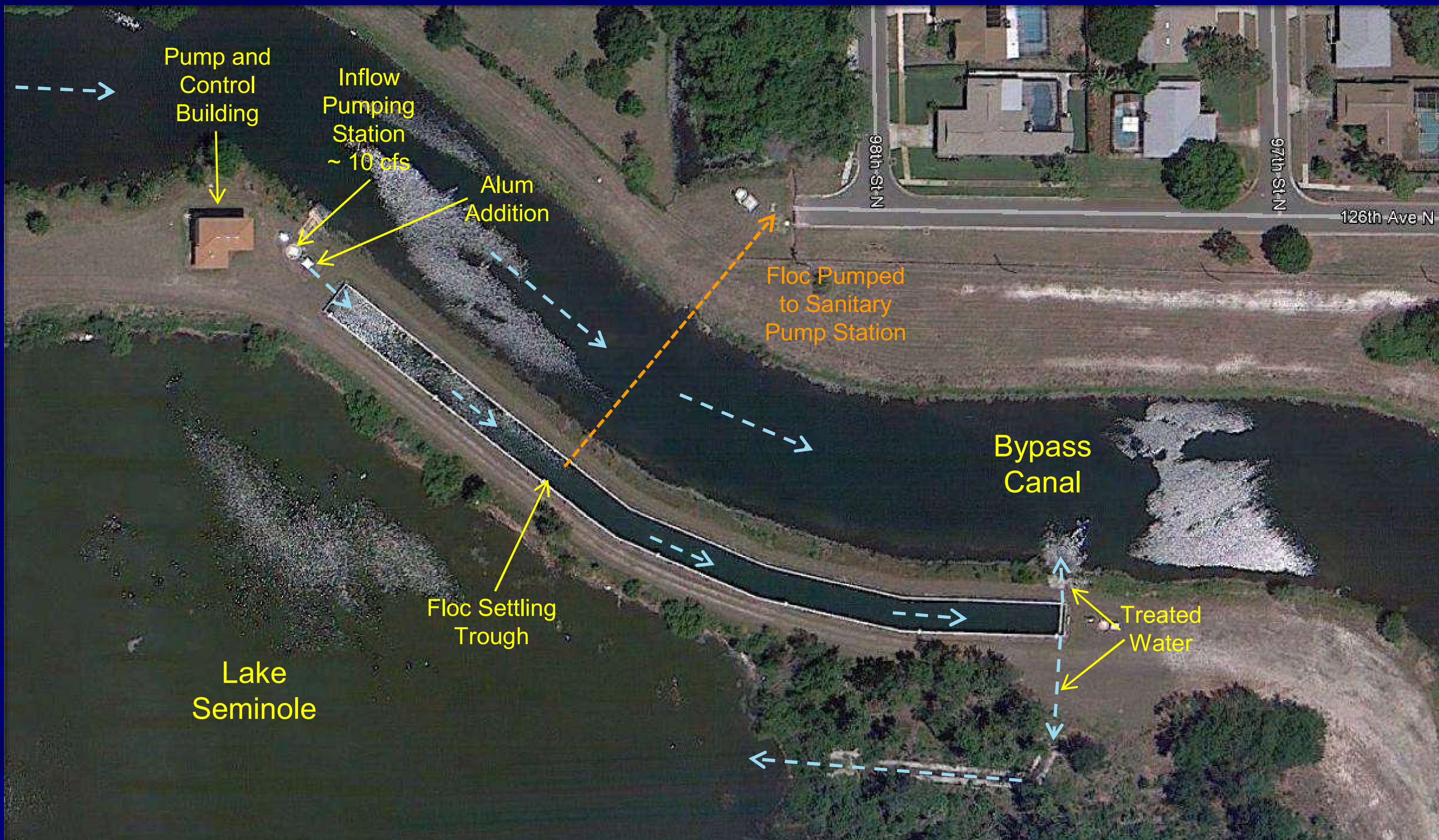
Operational Characteristics

1. Treat 89% of canal discharge
2. Reduce TP load by 65%

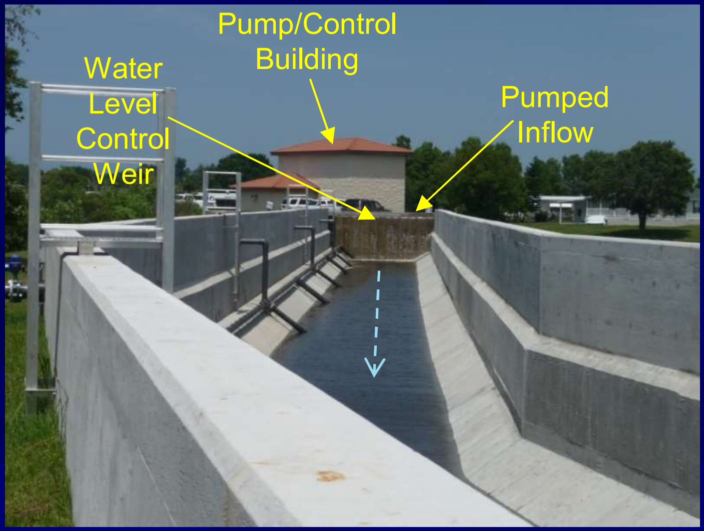


Overview of NuRF Project

Lake Seminole Bypass Canal Alum Treatment System



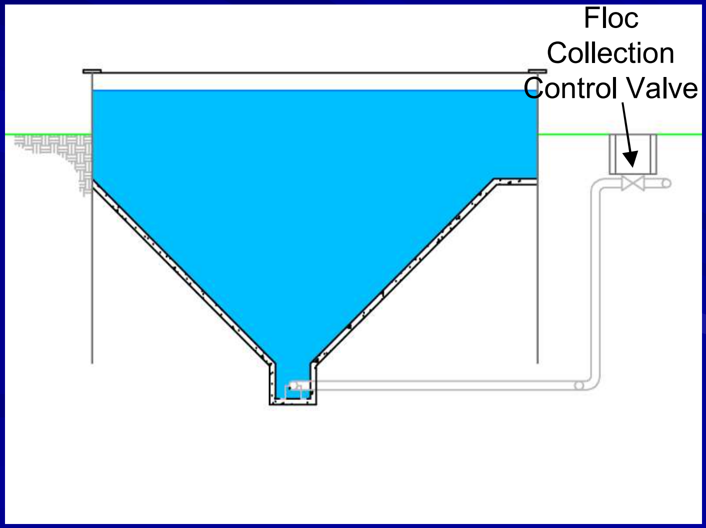
Bypass Canal Floc Collection Trough



Inflow Portion of Floc Collection Trough

Floc Collection System

PLC Pump and System Controller



Floc Collection System Schematic

Comparative Aluminum Concentrations

- Class I, II or III Water: No Standard

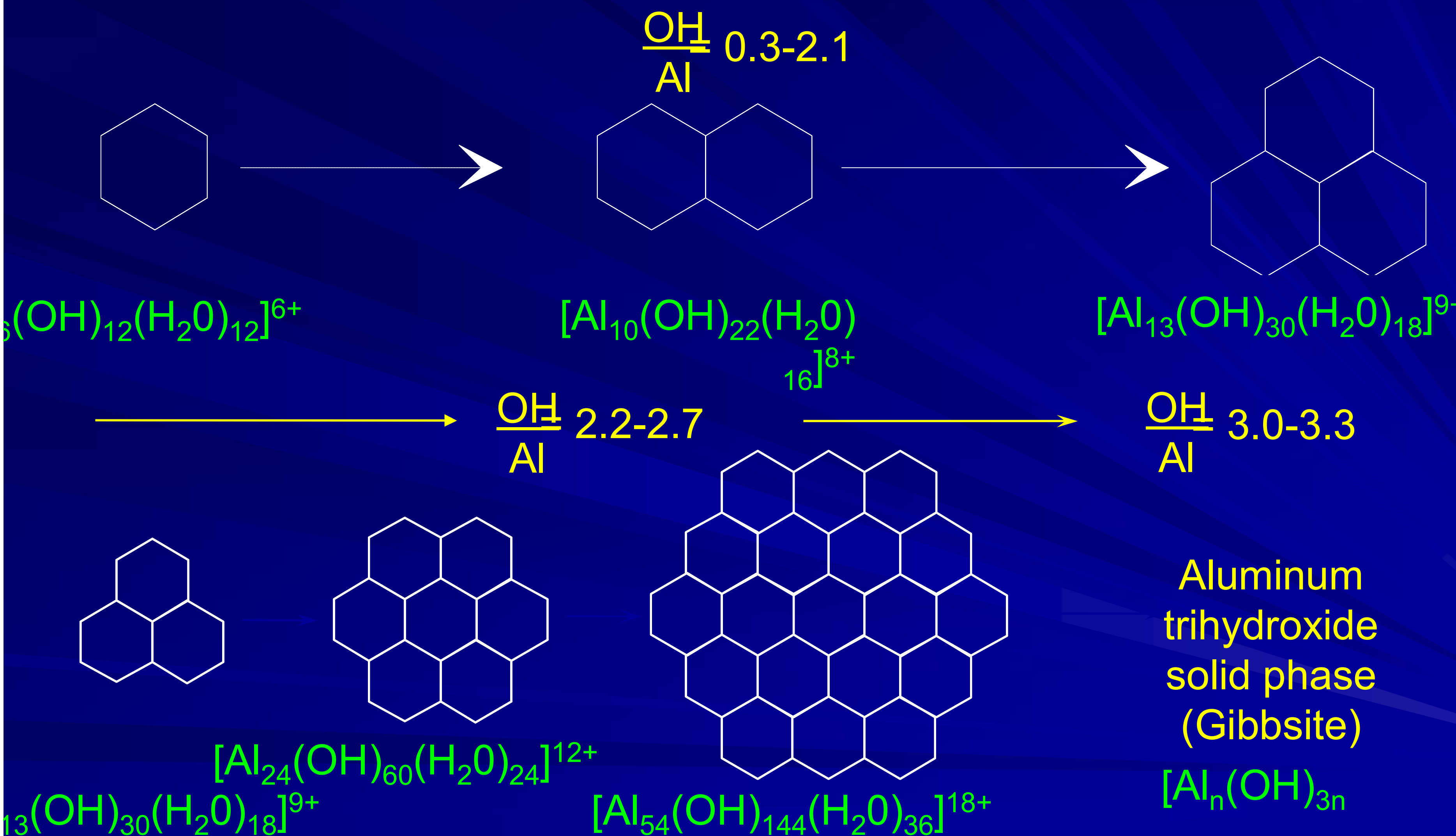
- Most Stringent EPA Recommendation: 87 μg/l
  - Designed to protect most sensitive species in U.S.
  - Cold water trout species in Washington State

- Drinking Water: 200 μg/l

- Milk: 700 μg/l

- Steeped Tea: 4600 μg/l

Aging Process for Alum Sludge



Conclusions: 1. Aged alum floc is exceptionally stable under a wide range of pH and redox conditions

2. Constituents bound into the floc are inert and have virtually no release potential

Alum Treatment Design Guidelines

- Only guidelines are provided in Section 19 of the Draft Statewide Stormwater Rule (March 2010)

- Issues that must be addressed in an application:
  - Range of flow rates to be treated by system
  - Recommended optimum coagulant dose
  - Chemical pumping rates
  - Provisions to ensure adequate turbulence for chemical mixing and a minimum 60 second mixing time
  - Sizes and types of chemical metering pumps - must include flow totalizer for alum injected
  - Requirements for additional chemicals to buffer for pH neutralization, if any
  - Post-treatment water quality characteristics
  - Percentage of annual runoff flow treated by chemical system

Alum Treatment Design Guidelines

- Issues that must be addressed in an application – con't.
    - Method of flow measurement – must include flow totalizer
    - Floc formation and settling characteristics
    - Floc accumulation rates
    - Recommended design settling time
    - Annual chemical costs
    - Chemical storage requirements
    - Proposed maintenance procedures
- Floc collection required when using as stormwater treatment for new development
- Floc can discharge into receiving water for retrofit projects if receiving water is impaired and floc will benefit internal recycling

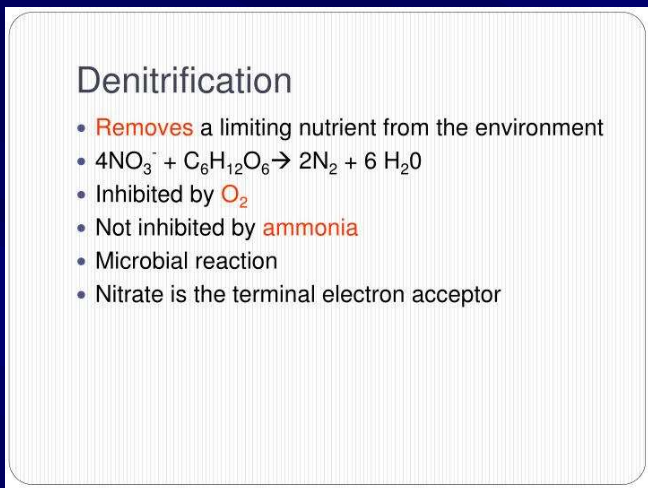
Alum Treatment Summary

- Alum stormwater treatment is a highly effective and low cost BMP for large watersheds or retrofit projects
- Capital cost is largely independent of the watershed size
- Lowest mass removal cost for TN, TP, and TSS of any BMP
- Mass removal costs decrease as TP loading increases
- Excellent removal for metals and bacteria
- On-going O&M costs

Part 11

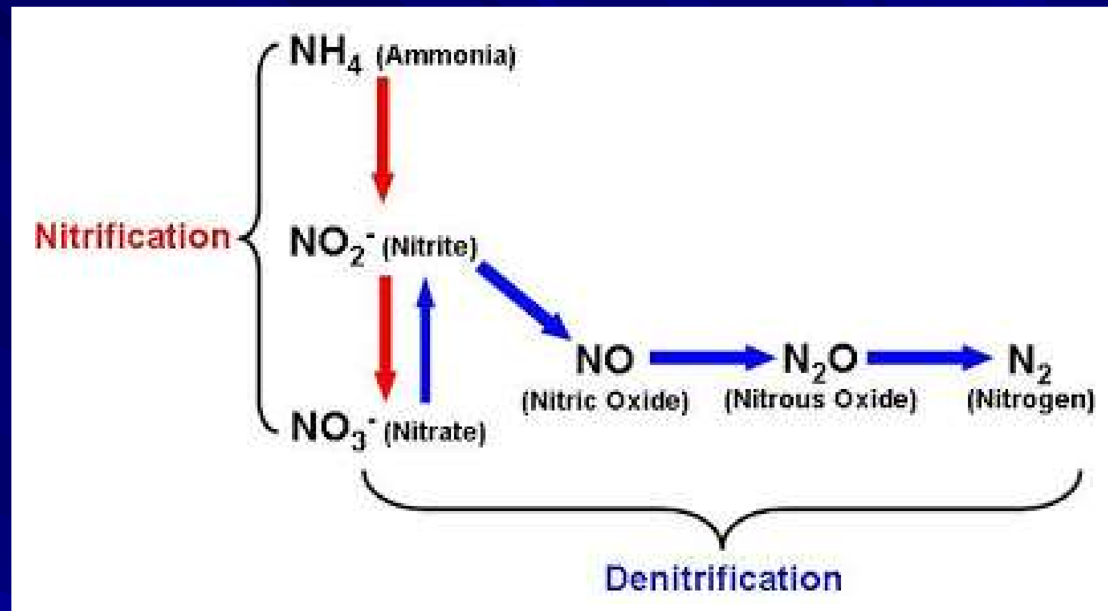
Denitrification

Denitrification



Denitrification

- Removes a limiting nutrient from the environment
- $4NO_3^- + C_6H_{12}O_6 \rightarrow 2N_2 + 6\ H_20$
- Inhibited by O_2
- Not inhibited by ammonia
- Microbial reaction
- Nitrate is the terminal electron acceptor

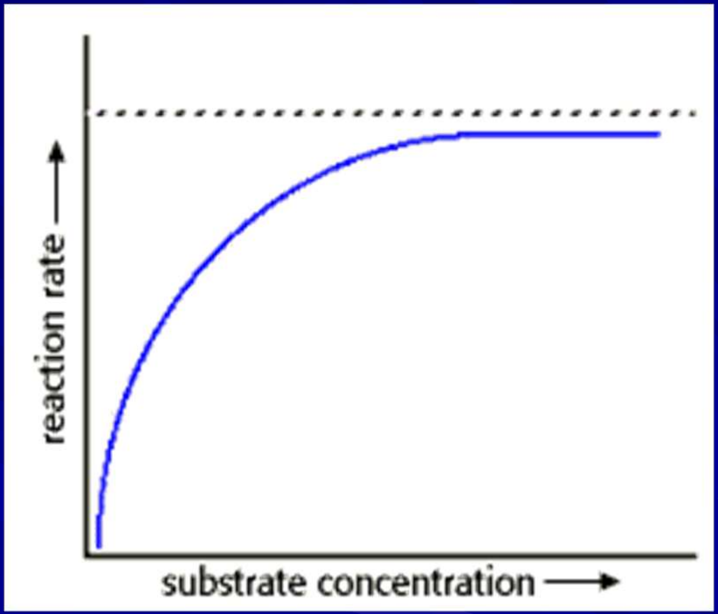


- Biologically mediated process conducted by facultative, heterotrophic bacteria
  - Facultative bacteria –
    - Organism capable of both aerobic and anaerobic respiration
    - Obtain oxygen either by removing dissolved oxygen from water or by removing bound oxygen from inorganic ions, ex. NO_3^-
  - 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

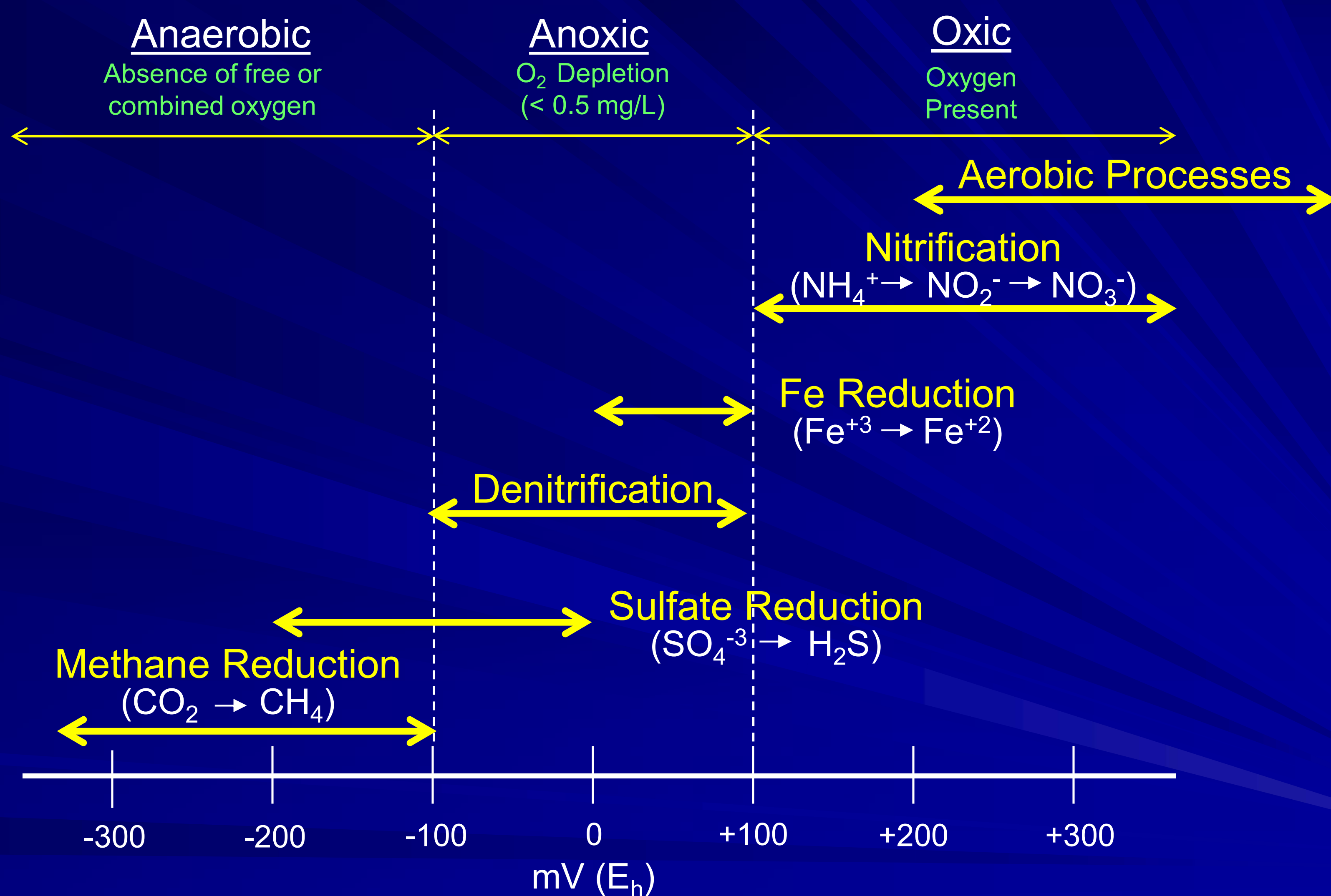
All are common in nature



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
- Reduced anoxic environment
  - Minimum redox potential (Eh) of -100 to -200
- Significant nitrate source
  - Urban runoff may not contain sufficient nitrate
- Proper environmental conditions
  - pH
    - Optimum range: 7.0 – 8.5
  - Temperature
    - Optimum range: 5 - 30ºC
  - Water-based environment
- Contraindicated conditions
  - High color water with low pH
  - Sources with low nitrate concentrations

Common Redox Processes



- All processes are microbial
- Microbially mediated processes can produce redox potentials of -300 mV or less

Part 12

BMP Selection Summary and Removal Costs

Treatment Efficiencies for Typical Stormwater Management Systems

Type of System	Estimated Removal Efficiencies (%)		
	Total N	Total P	TSS
Dry Retention	Varies with hydrologic characteristics and treatment volume Generally 50-75% for typical design criteria		
Dry Detention	Highly variable – depends on pond bottom/GWT relationship		
Wet Detention	25	65	85
Gross Pollutant Separators	0 -20	0 - 10	10 - 80
Alum Treatment	50	90	90

Mass Removal Costs for Common Stormwater Management Systems

Type of System	20-Year Present Worth (PW) Mass Removal Costs ($/kg)[1]		
	Total N	Total P	TSS
Dry Retention	800 – 3,000	2,000 – 5,000	20 - 50
Dry Detention	Highly variable		
Wet Detention	150 - 300	350 – 750	2 - 3
Gross Pollutant Separators	15,000 – 25,000	10,000 – 20,000	5 - 10
Alum Treatment	15 - 75	100 - 250	1 - 4

1. PW costs include construction costs plus annual O & M costs.

Considerations in BMP Selection

- Watershed Area
  - Large areas – wet ponds, alum treatment
  - Small areas – infiltration, filtration, biofiltration
- Area Requirements
  - Adequate area must be available for the selected BMP
  - Many BMPs are land intensive
  - Some systems can be placed underground
    - Infiltration
    - Alum treatment
- Stormwater Pollutants
  - Most BMPs remove particulates
  - Removal of dissolved pollutants is highly variable between BMPs
  - Select BMP which maximizes removal for target pollutant(s)

Considerations in BMP Selection – cont.

- Sediment Loading
  - Many BMPs are sensitive to clogging
  - Heavy sediment loading may require pre-treatment
- Soil Types
  - Affects BMP selection and effectiveness
  - Also affects runoff characteristics
- Slope
  - Steep slopes restrict use of some BMPs
- Water Table Elevation
  - Critical factor in design
  - Need low water table for exfiltration or infiltration systems
  - Need high water table for wet ponds
- Bedrock or Hardpan
  - Restrictive soil layers can impede infiltration
  - Can make excavation difficult and expensive

Considerations in BMP Selection – cont.

- Karst Geology
  - Possibility of channels which transport infiltrated water directly into deeper aquifers
- Proximity to Septic Tanks and Wells
  - Do not locate close to septic tanks or wells
  - Possibility of groundwater pollution
- Receiving Water
  - Must consider quality, type, and designation of receiving warer
- Side Effects and Ancillary Benefits
  - Mosquito breeding
  - Groundwater contamination
  - Passive recreation/wildlife
- Public Acceptance

Summary of Recommended BMPs for Target Pollutants

Pollutant	Recommended BMP
1. Nutrients	a. Infiltration b. Wet detention c. Alum treatment d. Street Sweeping
2. Suspended solids, leaves, litter	a. Gross pollutant separators b. Street sweeping c. Wet or dry detention d. Inlet devices
3. Heavy metals	a. Infiltration b. Wet detention c. Alum treatment d. Street sweeping
4. Bacteria	a. Source reduction b. Infiltration c. Wet detention d. Alum treatment

Part 13

BMPs in Series

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

Example Stormwater Treatment Train Concept

Source: Minnesota Stormwater Manual

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

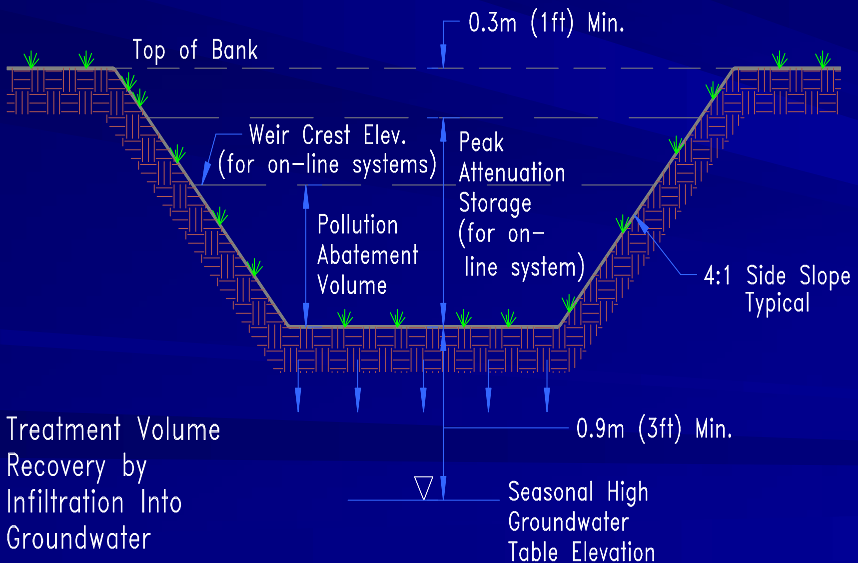
Eff_3 = efficiency of third treatment system

Assumptions:

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

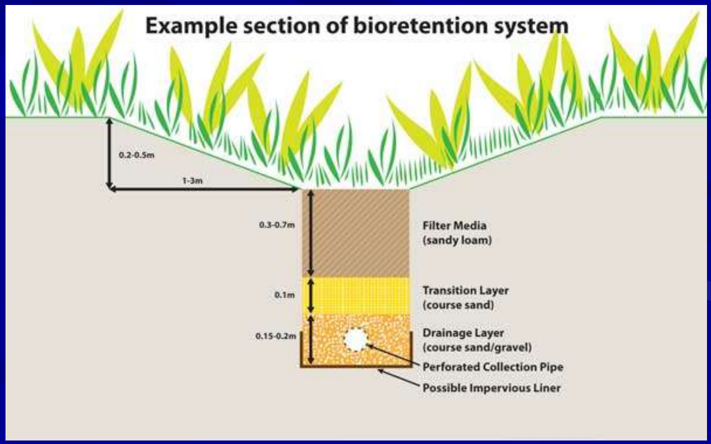
Stormwater Load Reduction Techniques

- Volume reduction
  - Infiltration techniques
    - Retention ponds
    - Underground exfiltration
    - Stormwater harvesting (reuse)



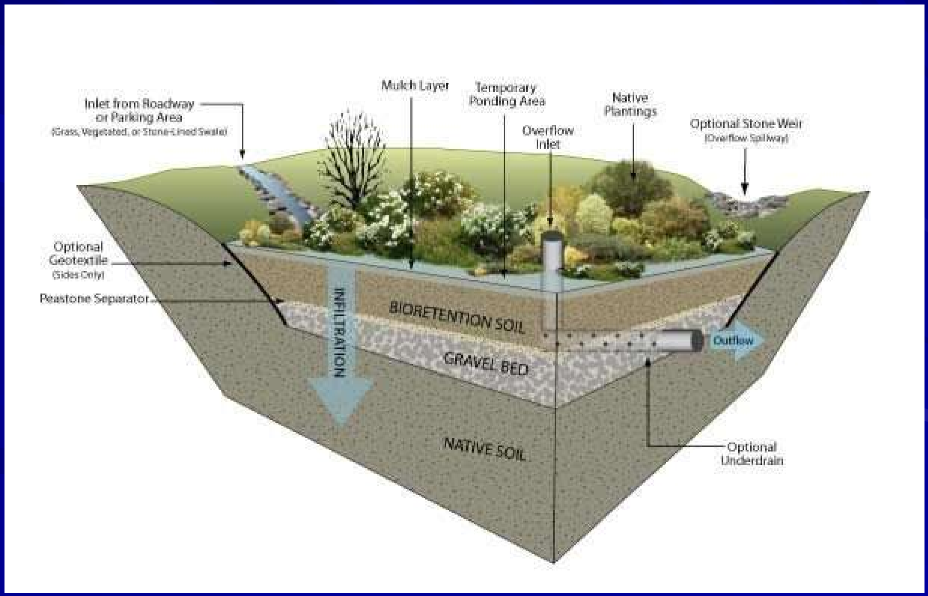
Stormwater Load Reduction Techniques

- Concentration reduction
  - Techniques which involve biological or chemical processes
    - Wet detention
    - Media filtration
    - Floating wetlands
    - Alum treatment



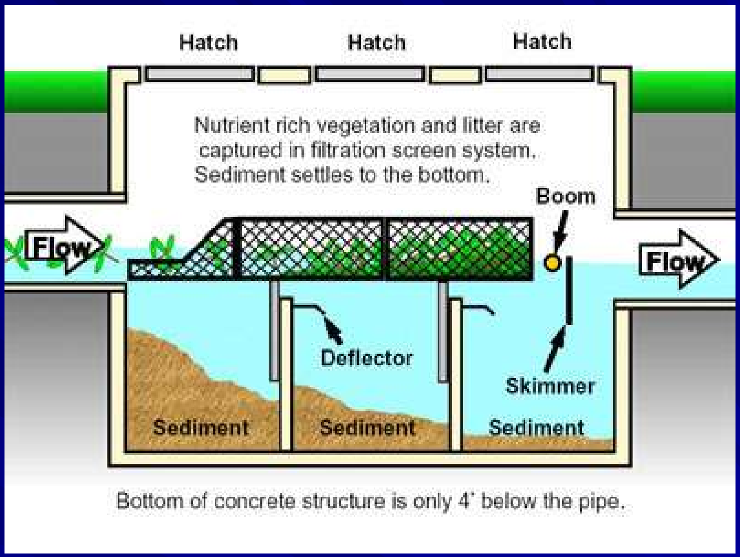
Stormwater Load Reduction Techniques
(Continued)

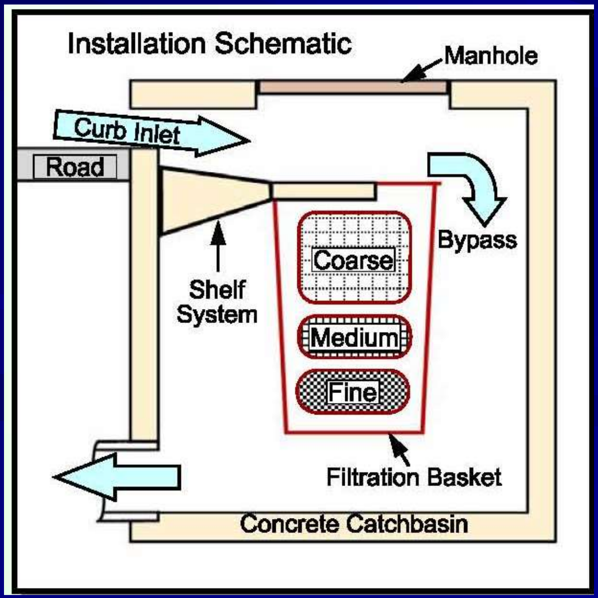
- Both volume and concentration
  - Techniques which include parts of each
    - Dry detention
    - Rain gardens



Stormwater Load Reduction Techniques
(Continued)

- Solids removal
  - Techniques that capture solids, leaves, and debris
    - Gross pollutant separators
    - Inlet baskets/filters
    - Street sweeping





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

Treatment Train Example No. 1

Vacuum Street Sweeping

Removes solids, leaves, and debris

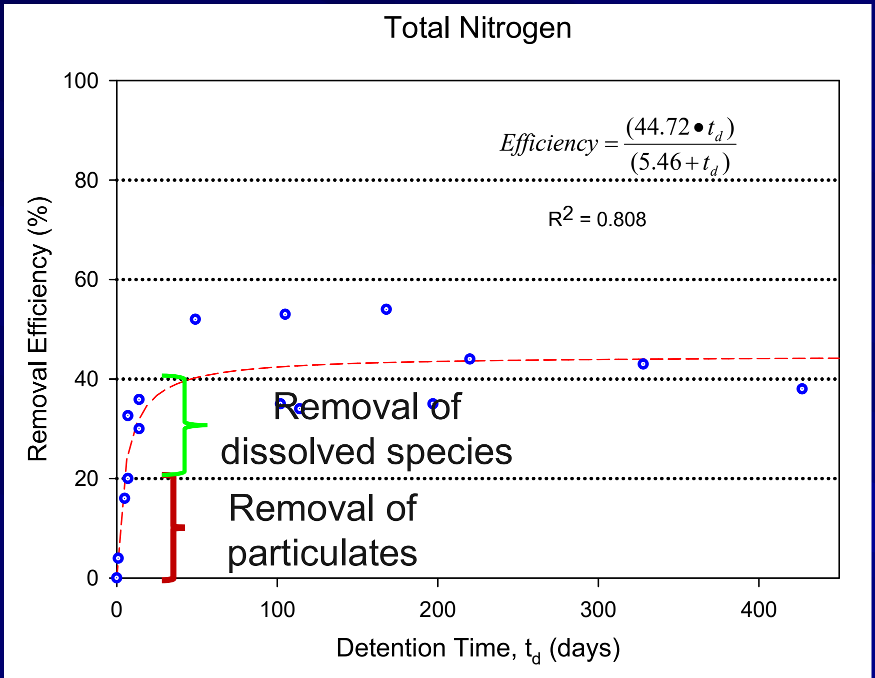
Wet Detention

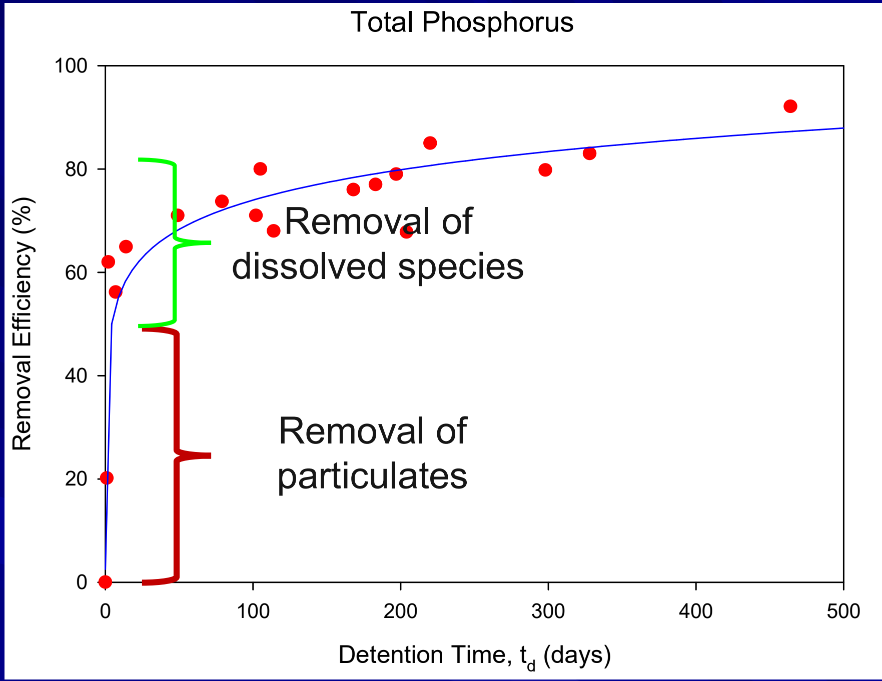
Removes solids and dissolved nutrients

- Sweeping will remove particulate pollutants
- Particulate pollutants would also be removed in wet detention

Treatment Train Example No. 1
(Continued)

Nutrient Removal Relationships for Wet Ponds



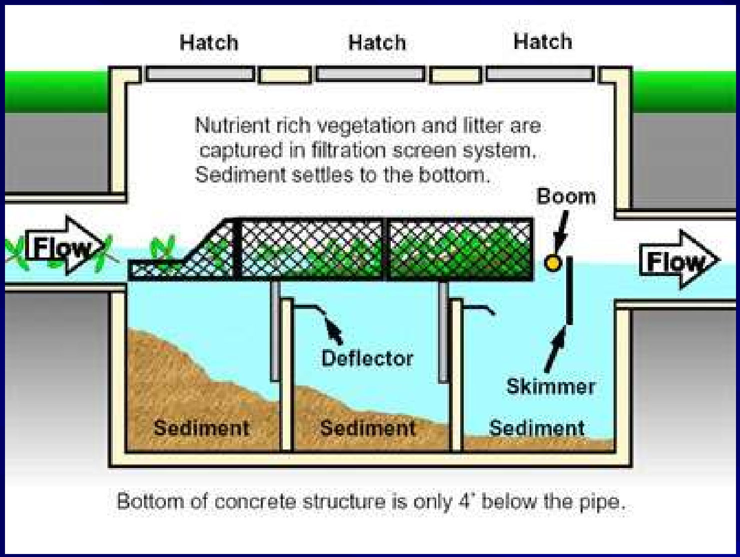


No enhancement in efficiency

Est. TT Eff.: 35% for TN; 65% for TP

Treatment Train Example No. 2

Baffle Box



Removes solids, leaves, and debris

Wet Detention

Removes solids and dissolved nutrients

- Baffle box will remove particulate pollutants
- Particulate pollutants would also be removed in wet detention
- Baffle box <u>may</u> reduce pond maintenance interval

No enhancement in efficiency

Est. TT Eff.: 35% for TN; 65% for TP

Treatment Train Example No. 3

Off-Line Exfiltration System

Reduces runoff volume

Wet Detention

Removes solids and dissolved nutrients

- Exfiltration will reduce runoff volume
- Runoff bypass will discharge to wet detention for treatment
- Wet detention size may be reduced because of runoff volume reduction

Efficiency enhancement from loss of runoff volume

TN Eff. = 60% (exfilt.) + 40% · 0.35 (wet det.) = 74%

TP Eff. = 60% (exfilt.) + 40% · 0.65 (wet det.) = 88%

Treatment Train Example No. 4

Dry Detention

Reduces runoff volume and removes solids

Wet Detention

Removes solids and dissolved nutrients

- Dry detention will remove particulates and runoff volume, minimal change in concentration
- Lack of particulates will reduce the efficiency of the wet pond

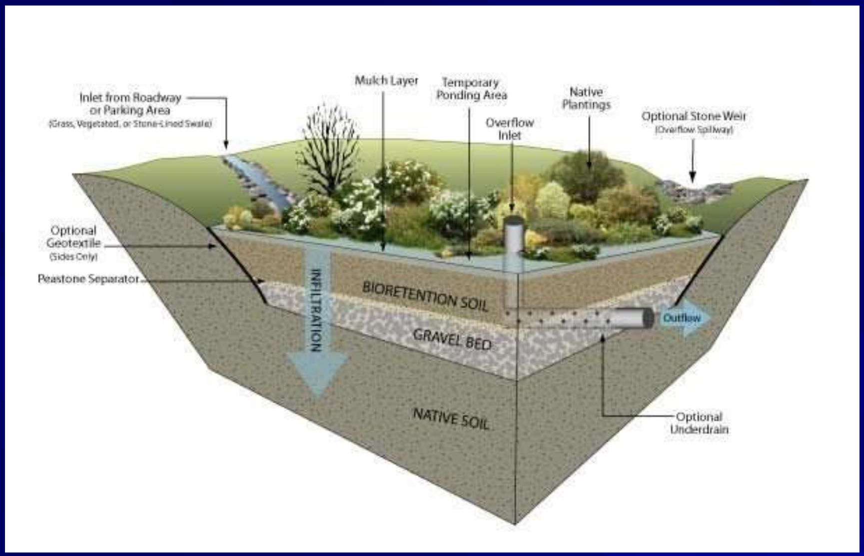
Efficiency enhancement from loss of runoff volume

TN Eff. = 30% (exfilt.) + 70% · 0.35 (wet det.) = 55%

TP Eff. = 30% (exfilt.) + 70% · 0.65 (wet det.) = 75%

Treatment Train Example No. 5

Rain Garden



Runoff volume loss, solids removal, concentration reduction

Off-Line Exfiltration

Reduces runoff volume

- Rain garden will remove particulates and runoff volume, minimal change in concentration
- Lack of particulates will increase longevity of exfiltration system

TT efficiency will be close to the sum of the two BMPs

Treatment Train Example No. 6

Roadside Swale → **Wet Detention**

Runoff volume loss, solids removal, small concentration reduction

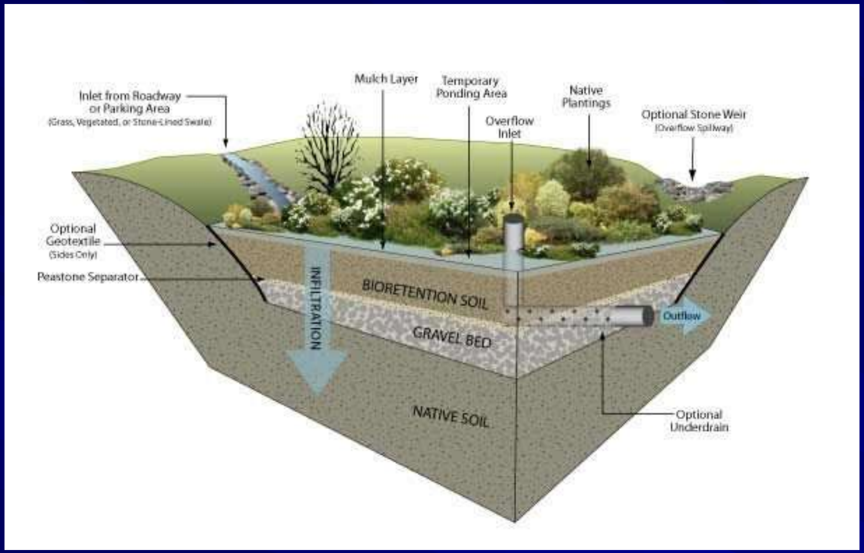
Removes solids and dissolved nutrients

- Roadside swale will remove particulates and runoff volume, reduce runoff concentrations
- Solids would be removed in the wet detention
- Concentration reduction in swale will reduce efficiency of wet detention

Efficiency enhancement equal to runoff volume lost in swale

Treatment Train Example No. 7

Rain Garden



Runoff volume loss, solids removal, concentration reduction

Wet Detention

Removes solids and dissolved nutrients

- Rain garden will remove particulates and runoff volume, reduce runoff concentrations
- Concentration reduction in rain garden will reduce efficiency of wet detention

Efficiency enhancement equal to runoff volume lost in rain garden

Treatment Train Example No. 8

Wet Detention

Removes solids and dissolved nutrients

Reuse Irrigation

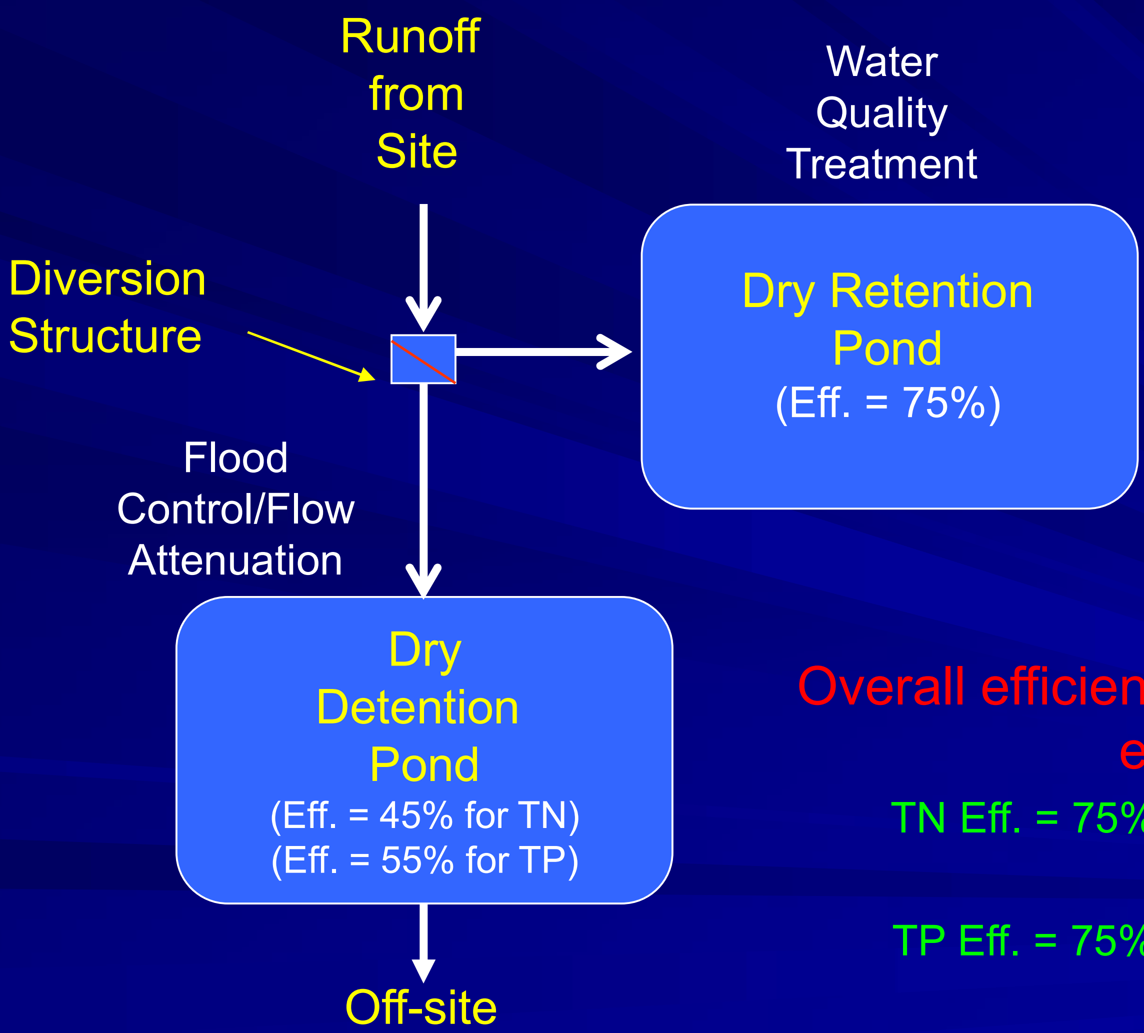
Runoff volume loss

- Wet detention will provide pre-treatment for the irrigation
- Reuse irrigation will provide loss of runoff volume

Wet detention efficiency will be enhanced by the mass of pollutants removed by irrigation

Treatment Train Example No. 9

Off-line Retention/Detention Systems



- Efficiency of dry retention is equal to runoff volume removed
- Dry detention will provide additional volume reduction and concentration reduction

Overall efficiency is the sum of the two efficiencies

TN Eff. = 75% + 25% · (0.45) = 86.2%

TP Eff. = 75% + 25% · (0.55) = 88.8%

Treatment Train Example No. 10

Wet Detention

Removes solids and dissolved nutrients

→

Hardwood Wetland

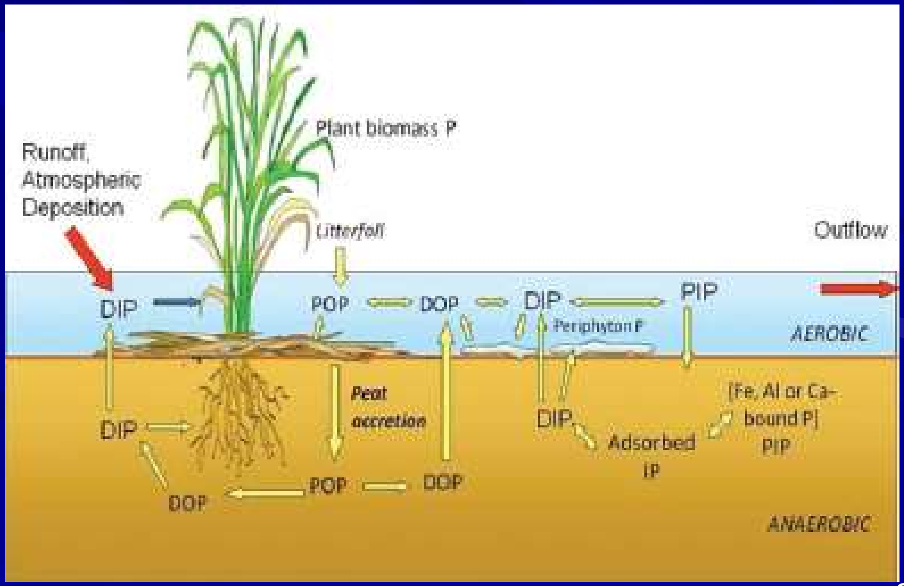
Little uptake by vegetation; water reaches equilibrium with soils

- Efficiency of initial pond is calculated using the removal curves
- Wetland will likely add nutrients to treated pond effluent

Wet detention efficiency will be reduced by substantial amount

Shallow Hardwood Wetlands

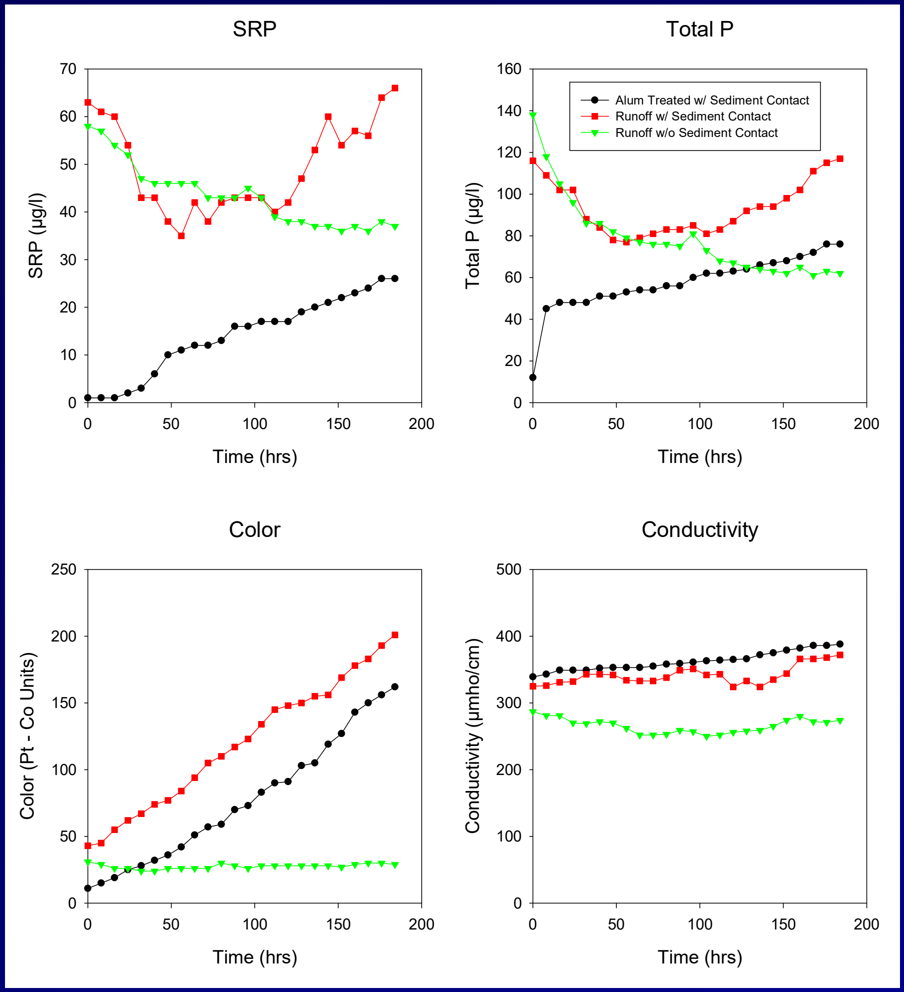
- Shallow waterbody with nutrient rich, acidic, and typically anoxic soils
- Water quality of wetland discharges is based primarily on an equilibrium between the soils and the water column
  - First-order reaction rate based on concentration
  - Equilibrium reached in 3-4 days
  - High concentrations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

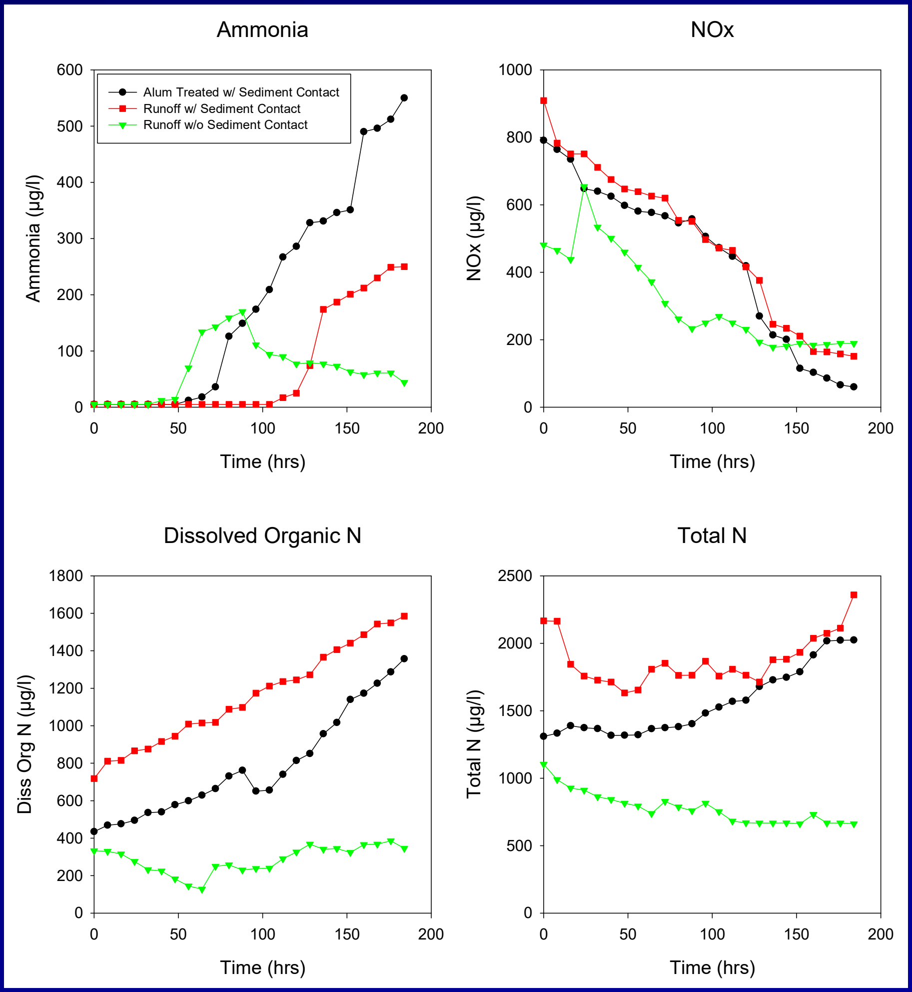


Nutrient Equilibrium in Hardwood Wetlands

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

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

Treatment Train Example No. 12

Wet Detention

Removes solids and dissolved nutrients

→

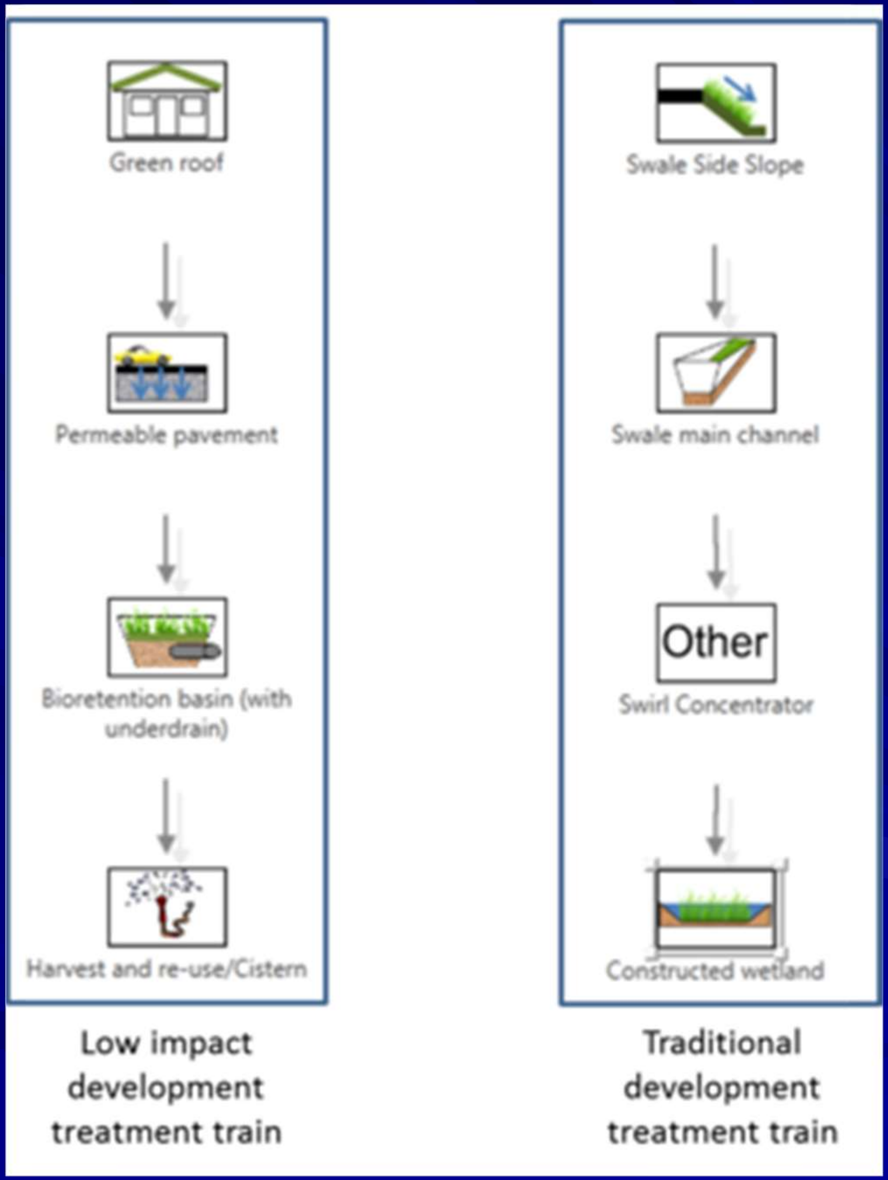
Vegetated Wetland

Significant uptake by vegetation and biology attached to plant stalks

- Efficiency of initial pond is calculated using the removal curves
- Wetland will remove additional nutrients from treated pond effluent

Wet detention efficiency will be increased

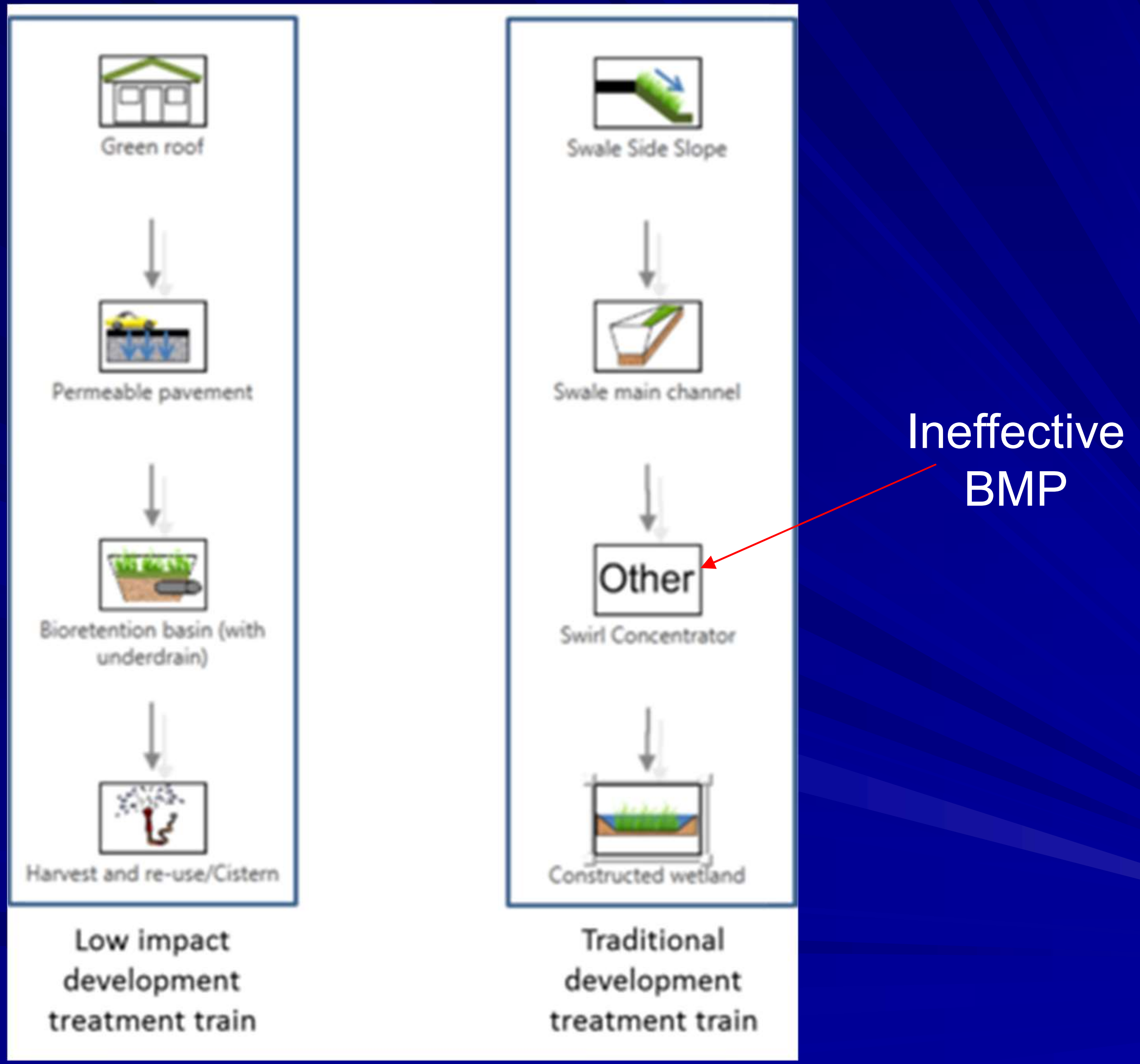
Stormwater Treatment Train Concept



Source: Minnesota Stormwater Manual

Stormwater Treatment Train Concept

Even official manuals sometimes reference ineffective BMPs



Source: Minnesota Stormwater Manual

Conclusions

- Effectiveness of volume reduction BMPs are a direct function of the runoff volume removed
  - BMP train efficiencies are cumulative
- Designs of BMP treatment trains should consider the types of pollutants removed in each portion of the train and impacts on downstream treatment processes
  - Selection of incorrect BMPs may reduce effectiveness of the BMP train
- Maximum effectiveness of a BMP train occurs when using complimentary BMPs

Part 14

Common Mistakes in BMP Selection and Implementation

Introduction

- Implementation of retrofit stormwater BMPs has accelerated in recent years to reduce loadings to receiving waters
- Potential BMP projects are often identified through TMDL evaluations and watershed studies
- Projects involving certain grant funding sources require post construction monitoring to evaluate BMP performance
- These studies have revealed common pitfalls within the BMP evaluation, selection, and design process which have the potential to affect the success of the project

Common Pitfalls in BMP Selection

1. Inaccurate modeling of pollutant loadings
2. Consideration of the type and form of the target pollutant
3. Consideration of baseflow loadings
4. Improper BMP selection
5. Failure to identify and fund maintenance activities
6. Failure to consider pollutant removal costs

1. Inaccurate Modeling of Pollutant Loadings

- Watershed studies and TMDL evaluations provide *estimates* of pollutant loadings based on a multitude of assumptions
- Some models and methods are better than others, but they all produce *estimates*
- Most models tend to over-estimate actual pollutant loadings due to:
  - Over-estimation of raw runoff volume
  - Failure to consider volume and pollutant attenuation within the basin
- The model results may lead to incorrect conclusions concerning the significance of a particular sub-basin with respect to loadings or water quality impacts
- Inaccurate pollutant loadings can also impact:
  - Identification of target pollutants
  - Ranking of sub-basins
  - Order of BMP implementation

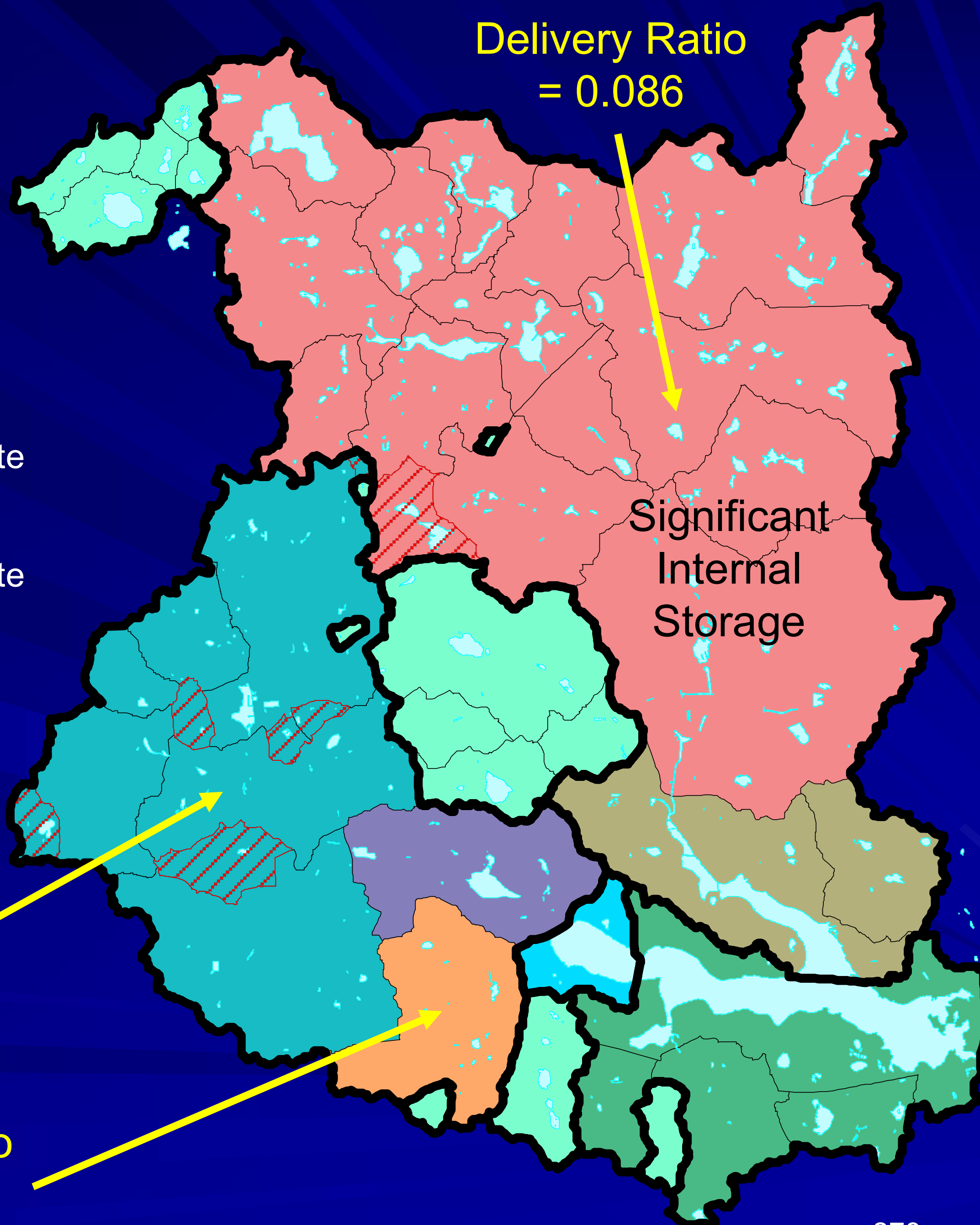
1. Inaccurate Modeling of Pollutant Loadings – cont.

A. Modeling Runoff Volume

- Runoff models calculate the runoff volume generated within the modeled area
- However, this does not represent the volume of runoff which may actually reach the ultimate receiving water body
- The delivery ratio (fraction of generated runoff which reaches the waterbody) varies widely
  - Values can range from 0.0 – 1.0
- Delivery ratios are a function of:
  - Depressional storage
    - Large amount of depressional storage decreases delivery ratio
  - Internal waterbodies
    - Provides internal storage which reduces delivery ratio
  - Watershed size
    - Large watersheds have smaller delivery ratios
- Few models incorporate the concept of delivery ratios
- Lack of consideration of delivery ratio combined with initial overestimation of runoff volume results in significant errors in runoff volume estimation

Major Drainage Areas in the Lake Lafayette Basin

- Weems Pond Tributary
- Lafayette Creek
- Direct Runoff to Upper Lake Lafayette
- Direct Runoff to Piney Z
- Direct Runoff to Lower Lake Lafayette
- Direct Runoff to Alford Arm
- Closed Basins
- Alford Arm Tributary
- Partially Closed Basins



Calculated Delivery System Reduction Factors for Verification Sub-Basins in Tallahassee Urban Watershed Study

Sub-Basin	Area (ac)	Delivery Ratio
John Knox Road	80	0.453
Franklin Blvd.	423	0.450
Betton Road	333	0.545
Dorset Way	458	0.272
Mean	324	0.430

1. Inaccurate Modeling of Pollutant Loadings – cont.

B. Land Use Considerations

- Land use information for loading models are typically derived from GIS-based coverages

- Many of these coverages are based on zoning which indicate allowable potential coverage which may or may not exist

- Ex. – Residential homes in Village of Wellington
  - Constructed on 1-5 acre lots
  - Most have equestrian uses which significantly impacts loading estimates
  - However, land use in GIS is indicated as rural residential which carries a low loading rate

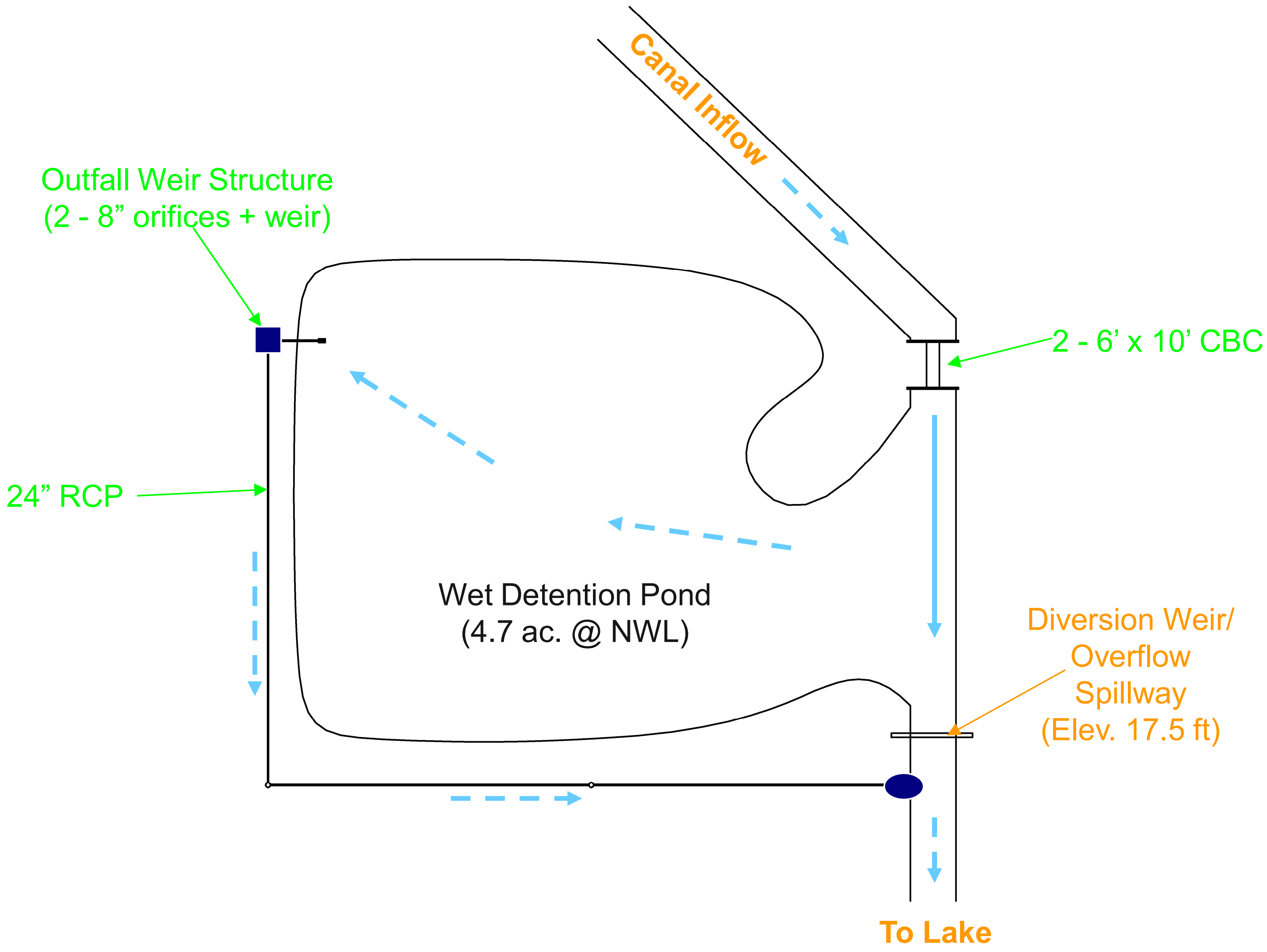
- Ex. – Indian Trails Improvement District
  - Entire area divided into 1+ acre rural residential lots
  - GIS coverage lists all lots as single family even though less than half have been developed

1. Inaccurate Modeling of Pollutant Loadings – cont.

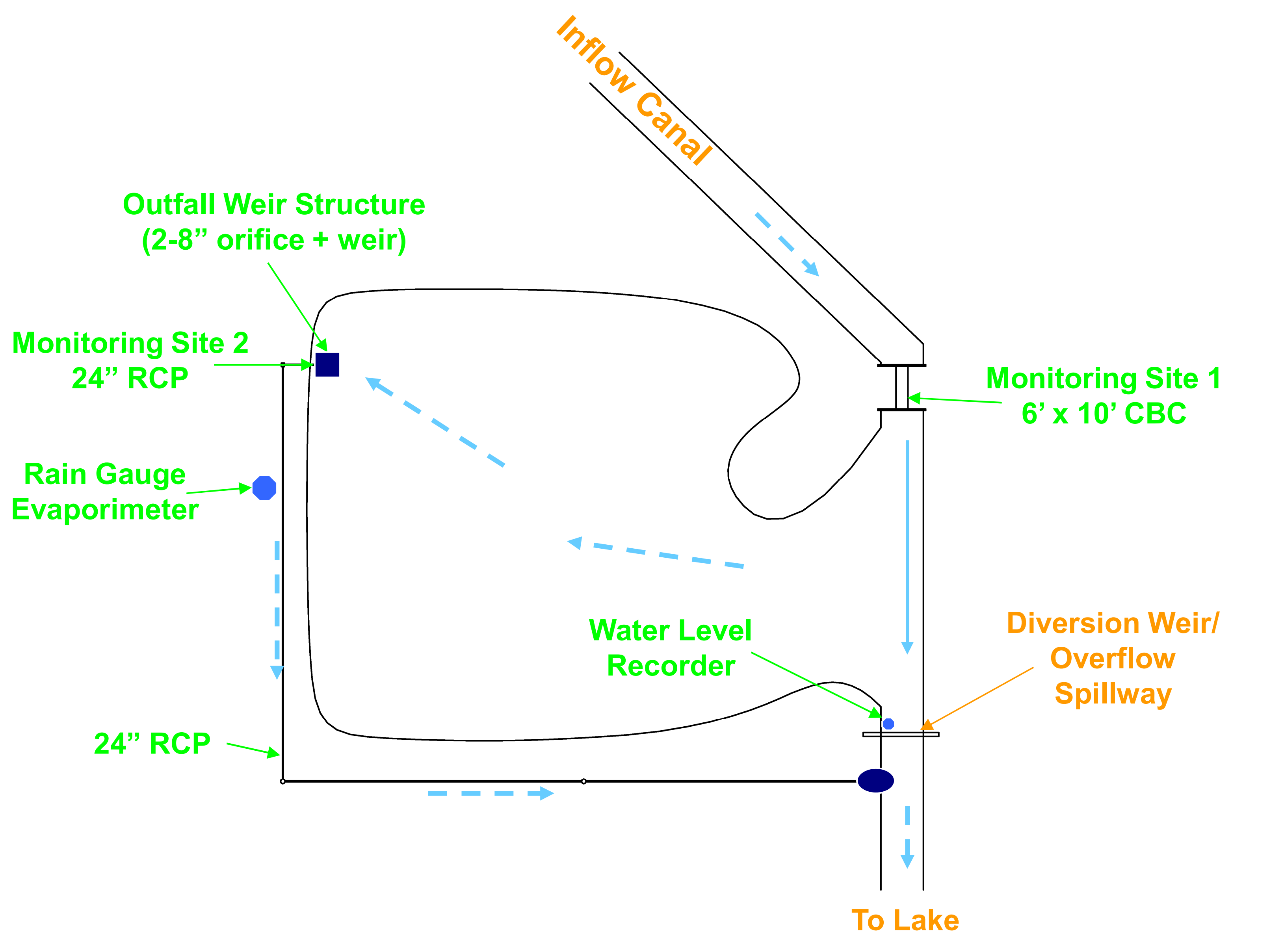
C. Consequences of Bad Loading Estimates

- Under worst case conditions, inaccurate loading estimates can:
  - Falsely identify insignificant sub-basins or pollutants as significant
  - Result in construction of an unnecessary BMP project
- In most cases insufficient information exists at the TMDL level to properly characterize pollutants and select appropriate BMPs
- Example
  - Wet detention pond recommended as a retrofit project for an 820 acre watershed which discharges to an impaired water
  - Loading model estimates indicate that the canal contributes 215 kg/yr of TP and the project will remove approximately 129 kg/yr of TP from the receiving water
  - Pond was constructed based on the recommendations
  - Unique partnership between private and governmental entities
  - Governmental agency applied for and received a 319 Grant for construction of the facility
  - BMP monitoring was conducted for a period of 12 months as directed by the 319 Grant

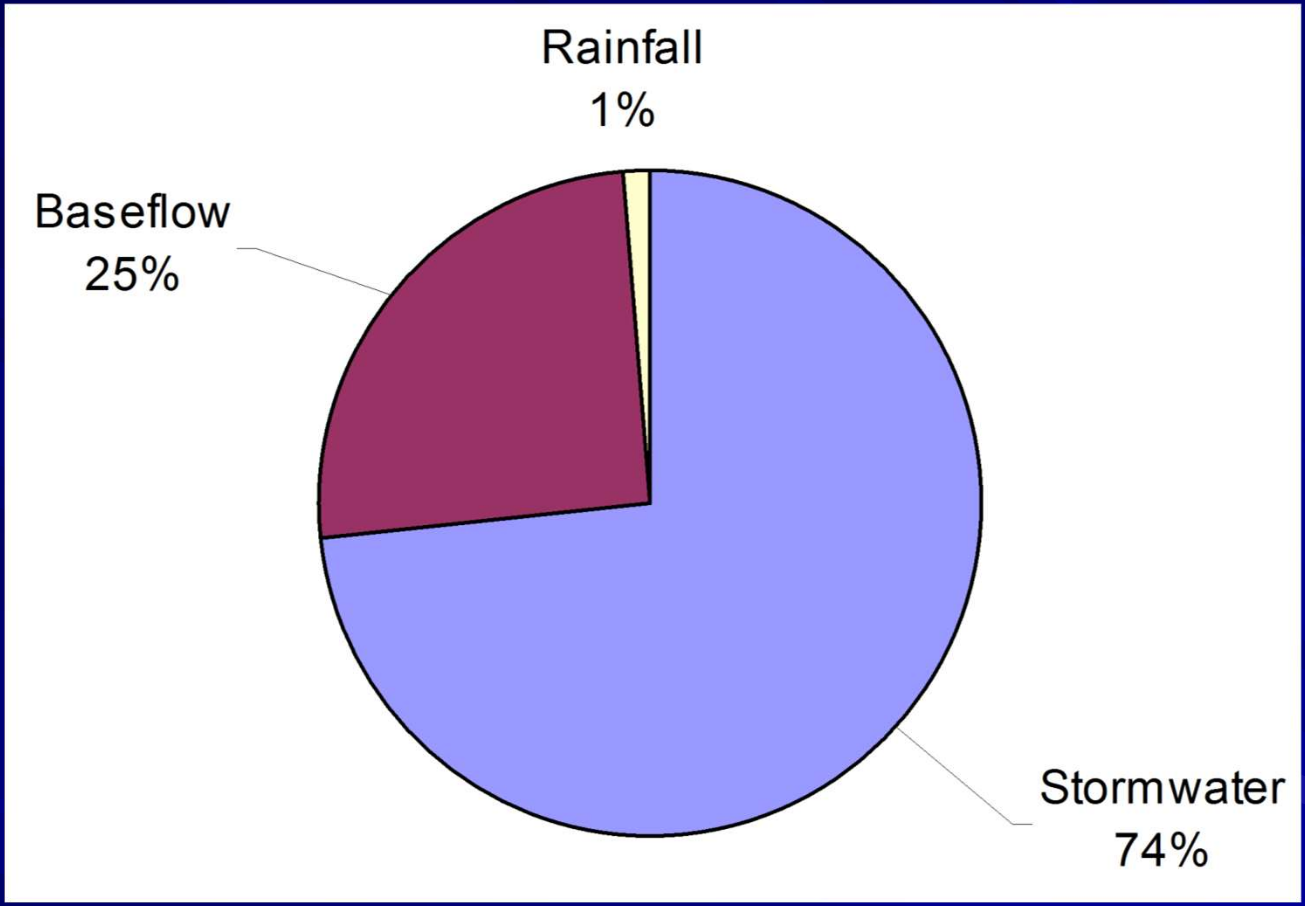
Characteristics of the Stormwater Treatment Facility



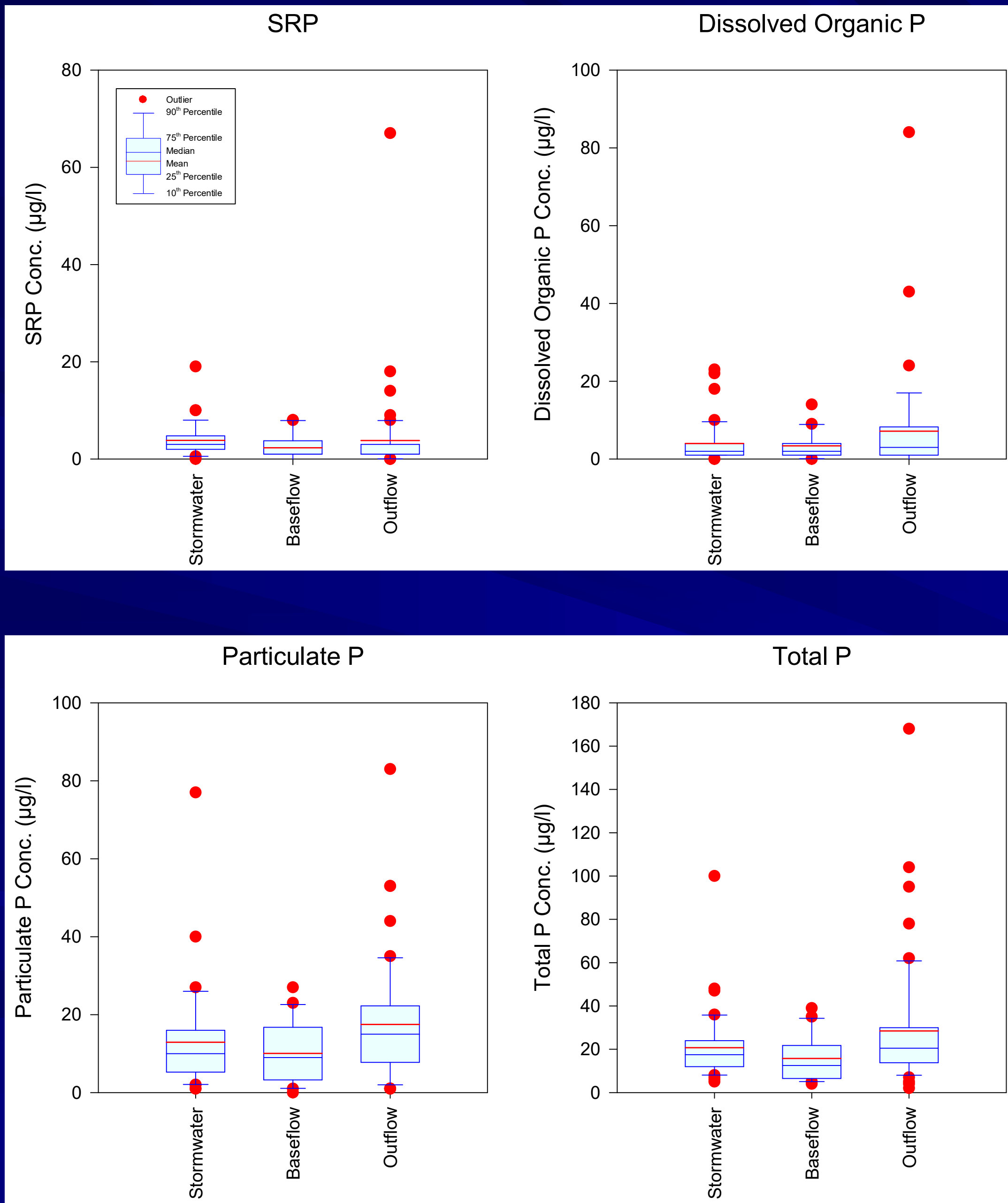
Locations for Monitoring Equipment



Measured Hydrologic Inputs to the Pond



Inputs



Statistical Comparison of Phosphorus Species Measured in Stormwater, Baseflow, and Outflow at the Pond Site

- No measurable change in phosphorus concentrations within pond

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

1. Inaccurate Modeling of Pollutant Loadings – cont.

D. Verify Loading Conditions Prior to Design

- Since pollutant loadings are only estimates, loading conditions should be verified as part of the Preliminary Design phase of any BMP project
- This step is particularly important for projects involving land purchases and significant expenditures of public funds
- Limited field monitoring should be conducted to verify the anticipated concentrations of the target pollutant(s)
- Conditions can be easily verified by monitoring 3-5 storm events and analyzing for pollutants of concern
- An inexpensive field verification monitoring program prior to design is a sound investment toward a successful BMP project

2. Consideration of the Type, Form, and Concentration of the Target Pollutant

- Untreated stormwater runoff contains a variety of pollutants
  - Particulates
    - Suspended solids
    - Nutrients
    - Heavy metals
  - Dissolved species
    - Nutrients
    - Heavy metals
- Particulate and dissolved pollutants are removed by different types of mechanisms
  - Type and form of pollutant must be considered in selecting BMPs
- Most BMP system designs and stated removal efficiencies are based on characteristics of <u>untreated raw runoff</u>

2. Consideration of the Type, Form, and Concentration of the Target Pollutant – cont.

A. Impacts of Pre-Treatment Processes

- Runoff characterization data used in models reflect "end-of-pipe" characteristics prior to treatment in stormwater management systems or attenuation in conveyance systems such as swales and canals

- If the runoff experiences significant pretreatment processes prior to reaching the point of treatment, then the runoff characteristics may change considerably and impact BMP selection
  - May result in selection of a different BMP
  - May affect the effectiveness of the selected BMP

2. Consideration of the Type, Form, and Concentration of the Target Pollutant – cont.

A. Impacts of Pre-Treatment Processes – cont.

- Ex. - Runoff discharging over grassed or vegetated swales, ditches, or canals may have much of the particulate matter removed
  - Amount of removal depends on particle size and velocity of flow
  - Since much of the particulate matter has been removed, a primarily biological process would be required to remove the remaining dissolved nutrients
- Ex. - Runoff which passes through water bodies prior to reaching the point of treatment may have much of the particulate and dissolved matter already removed
  - This substantially changes the ability to achieve additional reductions and will impact BMP selection

3. Failure to Consider Baseflow Loadings

- Most pollutant loading models do not consider impacts from dry weather baseflow
- Baseflow represents drawdown of the water table, ponds, and wetland areas within the basin between storm events
- Baseflow can be particularly significant in basins with channelized conveyance systems, such as canals and creeks
- In basins with permeable soils, baseflow often reflects infiltrated rainfall which migrates toward the conveyance system
  - This baseflow can significantly increase the observed C-value for a basin compared with model estimates
- In some instances, baseflow loadings can equal or exceed runoff volumes and loadings

4. Improper BMP Selection

- Stormwater runoff contains a variety of pollutants:
  - Suspended solids
  - Nutrients
  - Heavy metals
  - Oil and Grease
  - Oxygen demanding substances
  - Pathogens
- Each of these pollutants are removed by different mechanisms
- The selected BMP should maximize opportunities for appropriate removal mechanisms for target pollutants

Removal Processes and BMP Types for Common Runoff Pollutants

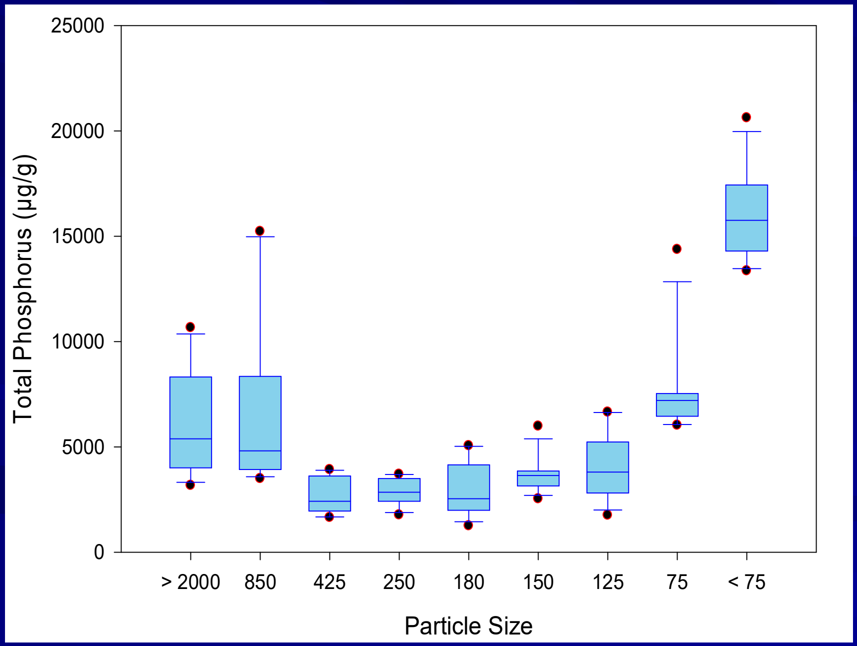
Pollutant	Removal Processes	Appropriate BMPs
1. Suspended solids	Physical – settling, filtration	Wet/dry ponds Gross pollutant separators
2. Nutrients	Physical – settling, adsorption Biological – biological uptake Chemical - coagulation	Infiltration systems Wet ponds, plants Alum treatment
3. Heavy metals	Physical – settling, adsorption Biological – biological uptake Chemical - coagulation	Infiltration systems Wet ponds Alum treatment
4. Oil & grease	Physical – settling, adsorption, volatilization	Wet pond with skimmer
5. Oxygen demanding substances	Biological – biological degradation Chemical - coagulation	Wet pond w/extended Td Alum treatment
6. Pathogens	Physical – filtration, UV exposure Biological – biological predation Chemical - coagulation	Infiltration systems Wet ponds Alum treatment

4. Improper BMP Selection– cont.

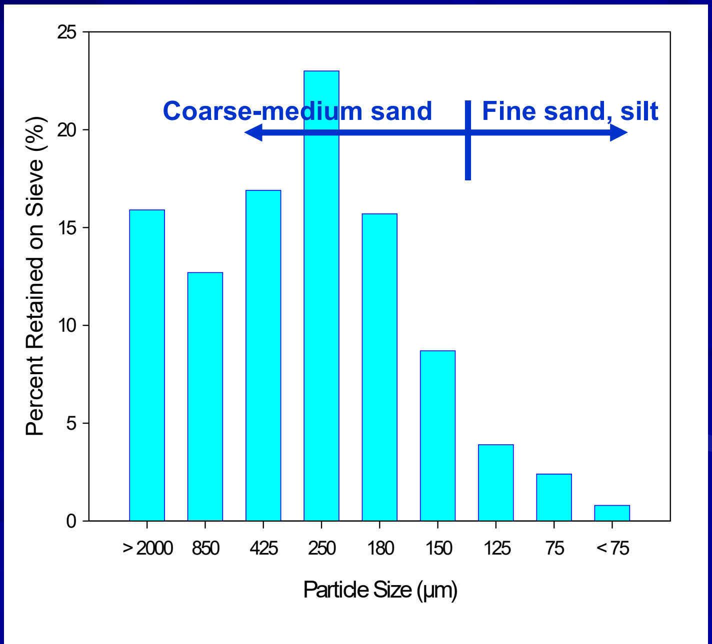
A. Common Errors in BMP Selection

- Use of gross pollutant separators for nutrient removal

Distribution of TP in Residential Solids



Distribution of Solids in Sump



4. Improper BMP Selection– cont.

A. Common Errors in BMP Selection – cont.

- Use of wetlands for “polishing”
  - Implies that all wetlands have ability to reduce input concentrations, regardless of what the inflow concentration may be
  - Most wetlands can easily reduce elevated concentrations of nutrients such as present in wastewater
  - Wetlands have a limit on their ability to reduce concentrations
  - Generally involves an equilibrium between the wetland soils and the water column
  - If input concentrations are low in comparison to the wetland equilibrium, outflow concentrations may actually increase

5. Failure to Identify and Fund Maintenance Activities

- All BMPs require at least some type of maintenance
- It is important to plan and fund maintenance activities early in the planning stage
- Failure to provide maintenance activities can reduce the effectiveness of the BMP, and in extreme cases, may lead to failure of the BMP altogether
- Potential maintenance activities and costs should be clearly identified prior to implementation
- In general, more innovative and specialized BMPs require more maintenance activities than traditional BMPs

Typical Maintenance Activities for Common and Traditional BMPs

BMP Type	Required Maintenance	Relative Costs
1. Infiltration a. Dry Ponds b. Exfiltration c. Pervious pavement	a. Mowing, trash removal, verify infilt. rate b. Monitor observation well, verify infilt. c. Vacuum sweeping, verify infilt. rate	a. Low b. Low c. Moderate/high
2. Wet Ponds	Mowing, trash removal, nuisance vegetation control, check outlet structure	Low
3. Filter/Sorption Systems	Monitor flow rates, trash removal, replace media/cartridges as necessary	Moderate to high
4. Vegetated Removal	Monitor vegetation, control nuisance species, remove vegetation as necessary	Low to moderate
5. Solids Removal Systems a. Curb/gutter inlet baskets b. GPS/Baffle boxes c. Street sweeping	a. Remove debris, quantification, disposal b. Remove debris, quantification, disposal c. Remove debris, quantification, disposal	a. Moderate b. Moderate c. Moderate/High
6. Chemical Treatment	Periodic inspection/maintenance, resupply chemicals	Moderate/high

6. Failure to Consider Pollutant Removal Costs

- Calculation of pollutant removal costs is an important part of the BMP design process
  - Essentially a cost/benefit ratio
  - Calculated as the ratio of present worth (PW) cost to mass of pollutant removed
  - PW is generally calculated over a period of 20-50 years and includes construction and O&M costs

PW = (Construction cost + annual O&M x analysis period)

  - The time value of money is often included in the analysis
  - Pollutant removal costs are calculated by:

= PW / kg of pollutant removed over analysis period

- Decisions between treatment options should consider pollutant removal costs
- Failure to consider pollutant removal costs may lead to a poor BMP decision

Comparison of Pollutant Removal Costs for the Evaluated Treatment Options

Parameter	Bear Gully Creek		Garden Lake Inflow
	Wetland System	Diversion/ Rehydration	
Current P Load	32.9 kg/yr	32.9 kg/yr	27.0 kg/yr
Assumed P Removal	40%	30%	60%
Annual P Removal	13.1 kg/yr	9.9 kg/yr	16.2 kg/yr
Construction Cost	$135,702	$35,145	$47,500
Annual O&M	$5,000	$2,000	$7,395
20-yr PW Cost	$235,702	$75,145	$195,400
P Removal Cost	$900/kg	$380/kg	$603/kg

Part 15

Pre vs. Post Design Example

Example

Stormwater Treatment to Meet the Post ≤ Pre Pollutant Reduction Goal

Determine the water quality treatment requirements for proposed 100-acre single-family residential sites located in Pensacola (Zone 1), Orlando (Zone 2), and Key West (Zone 3).

Pre-Development Conditions

1. Project Area: 100 acres
2. Land Use: Wet flatwoods
3. Ground Cover/Soil Types: HSG D
4. Impervious Areas: 0% impervious
   0% DCIA

Post ≤ Pre Example – cont.

5. Pre-Development Runoff Volumes: The total project site covers 100 acres and existing land use is assumed to be wet flatwoods.

   (A) Wet Flatwoods: From TR-55, the CN for wooded areas (poor condition) in HSG D soils is 83

   From Appendix C (Harper and Baker, 2007), the annual runoff coefficient for DCIA = 0 and CN = 83 can be estimated by interpolation:

City	Zone	Annual C Value
Pensacola	1	0.197
Orlando	2	0.140
Key West	3	0.159

   From Appendix A.3, the annual rainfall depths for the 3 sites are:

City	Zone	Annual Rainfall	Runoff Volume (ac-ft/yr)
Pensacola	1	65.5	107.5
Orlando	2	50.0	58.3
Key West	3	40.0	53.0

Post ≤ Pre Example – cont.

6. Pre-Development Nitrogen Loadings

Wet Flatwoods: TN concentration for wet flatwoods = 1.032 mg/l

Pensacola: Annual TN Load =

$$\frac{107.5 \text{ ac-ft}}{\text{year}} \times \frac{43{,}560 \text{ ft}^2}{\text{acre}} \times \frac{7.48 \text{ gal}}{\text{ft}^3} \times \frac{3.785 \text{ liter}}{\text{gallon}} \times \frac{1.032 \text{ mg N}}{\text{liter}} \times \frac{1 \text{ kg}}{10^6 \text{ mg}} = 136.8 \text{ kg TN/yr}$$

Orlando: Annual TN Load =

$$\frac{58.3 \text{ ac-ft}}{\text{year}} \times \frac{43{,}560 \text{ ft}^2}{\text{acre}} \times \frac{7.48 \text{ gal}}{\text{ft}^3} \times \frac{3.785 \text{ liter}}{\text{gallon}} \times \frac{1.032 \text{ mg N}}{\text{liter}} \times \frac{1 \text{ kg}}{10^6 \text{ mg}} = 74.2 \text{ kg TN/yr}$$

Key West: Annual TN Load =

$$\frac{53.0 \text{ ac-ft}}{\text{year}} \times \frac{43{,}560 \text{ ft}^2}{\text{acre}} \times \frac{7.48 \text{ gal}}{\text{ft}^3} \times \frac{3.785 \text{ liter}}{\text{gallon}} \times \frac{1.032 \text{ mg N}}{\text{liter}} \times \frac{1 \text{ kg}}{10^6 \text{ mg}} = 67.5 \text{ kg TN/yr}$$

Post ≤ Pre Example – cont.

7. Total Phosphorus Loadings:

Wet Flatwoods: The typical TP concentration for wet flatwoods = 0.011 mg/l

Pensacola: Annual TP Load =

$$\frac{107.5 \text{ ac-ft}}{\text{yr}} \times \frac{43{,}560 \text{ ft}^2}{\text{ac}} \times \frac{7.48 \text{ gal}}{\text{ft}^3} \times \frac{3.785 \text{ liter}}{\text{gal}} \times \frac{0.011 \text{ mg TP}}{\text{Liter}} \times \frac{1 \text{ kg}}{10^6 \text{ mg}} = \underline{1.46 \text{ kg TP/yr}}$$

Orlando: Annual TP Load =

$$\frac{58.3 \text{ ac-ft}}{\text{yr}} \times \frac{43{,}560 \text{ ft}^2}{\text{ac}} \times \frac{7.48 \text{ gal}}{\text{ft}^3} \times \frac{3.785 \text{ liter}}{\text{gal}} \times \frac{0.011 \text{ mg TP}}{\text{Liter}} \times \frac{1 \text{ kg}}{10^6 \text{ mg}} = \underline{0.79 \text{ kg TP/yr}}$$

Key West: Annual TP Load =

$$\frac{53.0 \text{ ac-ft}}{\text{yr}} \times \frac{43{,}560 \text{ ft}^2}{\text{ac}} \times \frac{7.48 \text{ gal}}{\text{ft}^3} \times \frac{3.785 \text{ liter}}{\text{gal}} \times \frac{0.011 \text{ mg TP}}{\text{liter}} \times \frac{1 \text{ kg}}{10^6 \text{ mg}} = \underline{0.72 \text{ kg TP/yr}}$$

Post ≤ Pre Example – cont.

Post Development Conditions

1. Land Use: 95 acres of single-family residential
   5 acres of stormwater management systems

2. Ground Cover/Soil Types

   A. Residential areas will be covered with lawns in good condition
   B. Soil types in HSG D

3. Impervious/DCIA Areas

   A. Residential areas will be 25% impervious, 75% of which will be DCIA

   Impervious Area = 25% of developed site = 95 ac x 0.25 = 23.75 acres

   DCIA Area = 23.75 acres x 0.75 = 17.81 acres

   DCIA Percentage = (17.81 ac/95.0 ac) x 100 = 18.7% of developed area

Post ≤ Pre Example – cont.

4. Calculate composite non-DCIA curve number from TR-55:

Curve number for lawns in good condition in HSG D = 80

Areas of lawns = 95 acres total – 23.75 ac impervious area = 71.25 acres of pervious area

Impervious area which is not DCIA = 23.75 ac – 17.81 ac = 5.94 ac

Assume a curve number of 98 for impervious areas

$$\text{Non-DCIA curve number} = \frac{71.25\ ac\ (80) + 5.94\ ac\ (98)}{71.25\ ac + 5.94\ ac} = 81.4$$

Post ≤ Pre Example – cont.

5. Calculate annual runoff volume for developed area:
   - Proposed developed area for the project is 95 ac.
   - The 5-acre stormwater management area is not included in runoff calculations since runoff generated in these areas is incorporated into the performance efficiency estimates for the stormwater system.

   a. Pensacola (Zone 1) Project: From the tables included in Appendix C (Zone 1), the annual runoff coefficient is estimated for a project site with 18.75% DCIA and non-DCIA CN = 81.4

      Annual C value = 0.304

      The annual rainfall for the Pensacola area = 65.5 inches (Appendix A.3)

      Annual generated runoff volume =
      95 ac x 65.5 in/yr x 1 ft/12 in x 0.304 = 157.6 ac-ft/yr

Post ≤ Pre Example – cont.

b. Orlando (Zone 2) Project: From the tables included in Appendix C (Zone 2), the annual runoff coefficient is estimated for a project site with 18.75% DCIA and non-DCIA CN = 81.4

Annual C value = 0.253

The annual rainfall for the Orlando area = 50.0 inches

Annual generated runoff volume =
95 ac x 50.0 in/yr x 1 ft/12 in x 0.253 = 100.2 ac-ft/yr

c. Key West (Zone 3) Project: From the tables included in Appendix C (Zone 3), the annual runoff coefficient is estimated for a project site with 18.75% DCIA and non-DCIA CN = 81.4

Annual C value = 0.266

The annual rainfall for the Key West area = 40.0 inches

Annual generated runoff volume =
95 ac x 40.0 in/yr x 1 ft/12 in x 0.266 = 84.2 ac-ft/yr

Post ≤ Pre Example – cont.

6. Calculate post-development loading prior to stormwater treatment:

   Under post-development conditions, nutrient loadings will be generated from the 95-acre developed single-family area.

   Stormwater management systems are not included in estimates of post-development loadings since incidental mass inputs of pollutants to these systems are included in the estimation of removal effectiveness.

   From Table 4-17, mean emc values for total nitrogen and total phosphorus in single-family residential runoff are:

   TN = 2.07 mg/l   TP = 0.327 mg/l

Post ≤ Pre Example – cont.

Post Development Nitrogen Loadings

Single Family Residential: TN concentration = 2.07 mg/l

Pensacola: Annual TN Load =

$$\frac{157.6\text{ ac-ft}}{\text{year}} \times \frac{43{,}560\text{ ft}^2}{\text{acre}} \times \frac{7.48\text{ gal}}{\text{ft}^3} \times \frac{3.785\text{ liter}}{\text{gallon}} \times \frac{1.032\text{ mg N}}{\text{liter}} \times \frac{1\text{ kg}}{10^6\text{ mg}} = \underline{402\text{ kg TN/yr}}$$

Orlando: Annual TN Load =

$$\frac{100.2\text{ ac-ft}}{\text{year}} \times \frac{43{,}560\text{ ft}^2}{\text{acre}} \times \frac{7.48\text{ gal}}{\text{ft}^3} \times \frac{3.785\text{ liter}}{\text{gallon}} \times \frac{1.032\text{ mg N}}{\text{liter}} \times \frac{1\text{ kg}}{10^6\text{ mg}} = \underline{256\text{ kg TN/yr}}$$

Key West: Annual TN Load =

$$\frac{84.2\text{ ac-ft}}{\text{year}} \times \frac{43{,}560\text{ ft}^2}{\text{acre}} \times \frac{7.48\text{ gal}}{\text{ft}^3} \times \frac{3.785\text{ liter}}{\text{gallon}} \times \frac{1.032\text{ mg N}}{\text{liter}} \times \frac{1\text{ kg}}{10^6\text{ mg}} = \underline{215\text{ kg TN/yr}}$$

Post ≤ Pre Example – cont.

Post Development Phosphorus Loadings

Single Family Residential: TP concentration = 0.327 mg/l

Pensacola: Annual TN Load =

$$\frac{157.6\text{ ac-ft}}{\text{year}} \times \frac{43{,}560\text{ ft}^2}{\text{acre}} \times \frac{7.48\text{ gal}}{\text{ft}^3} \times \frac{3.785\text{ liter}}{\text{gallon}} \times \frac{0.327\text{ mg P}}{\text{liter}} \times \frac{1\text{ kg}}{10^6\text{ mg}} = 63.6\text{ kg TP/yr}$$

Orlando: Annual TN Load =

$$\frac{100.2\text{ ac-ft}}{\text{year}} \times \frac{43{,}560\text{ ft}^2}{\text{acre}} \times \frac{7.48\text{ gal}}{\text{ft}^3} \times \frac{3.785\text{ liter}}{\text{gallon}} \times \frac{0.327\text{ mg P}}{\text{liter}} \times \frac{1\text{ kg}}{10^6\text{ mg}} = 40.4\text{ kg TP/yr}$$

Key West: Annual TN Load =

$$\frac{84.2\text{ ac-ft}}{\text{year}} \times \frac{43{,}560\text{ ft}^2}{\text{acre}} \times \frac{7.48\text{ gal}}{\text{ft}^3} \times \frac{3.785\text{ liter}}{\text{gallon}} \times \frac{0.327\text{ mg P}}{\text{liter}} \times \frac{1\text{ kg}}{10^6\text{ mg}} = 34.0\text{ kg TP/yr}$$

Post ≤ Pre Example – cont.

7. Calculate required removal efficiencies to achieve post- less than or equal to pre-loadings for TN and TP:

A summary of pre- and post-loadings and required removal efficiencies is given in the following table:

Project : Location	Total N			Total P		
	Pre-Load (kg/yr)	Post-Load (kg/yr)	Required Removal (%)	Pre-Load (kg/yr)	Post-Load (kg/yr)	Required Removal (%)
Pensacola (Zone 1)	136.8	402	66.0	1.46	63.6	97.7
Orlando (Zone 2)	74.2	256	71.0	0.79	40.4	98.0
Key West (Zone 3)	67.5	215	68.6	0.72	34.0	97.9

Only two traditional BMPs are capable of approaching the required pollutant reduction goals

- Dry retention
- Wet detention

Post ≤ Pre Example – cont.

1. Dry Retention

   Removal efficiencies for TN and TP in a dry retention pond are identical since the efficiency is based on the portion of the annual runoff volume infiltrated.

   A. Pensacola Project: The annual load reduction is 66.0% for TN and 97.7% for TP. The design criteria is based on the largest required removal of 97.7%. The required retention depth to achieve an annual removal efficiency of 97.7% in the Pensacola area is determined for Zone 1 based on project characteristics:

   % DCIA = 18.75% of developed area
   Non-DCIA CN = 81.4

   From Appendix D (Zone 1), a dry retention treatment volume equivalent to 4 inches of runoff will achieve an annual load reduction of 95.8%. The required removal efficiency of 97.7% will require a dry retention runoff depth in excess of 4 inches. WMDs generally cap the design retention volume at 4 inches of runoff over the project area.

Post ≤ Pre Example – cont.

B. Orlando Project: For the Orlando area, the load reduction is 71.0% for TN and 98.0% for TP. The design criteria is based on the largest required removal which is 98.0%. The required retention depth is obtained from Appendix D (Zone 2) by interpolation:

By iterating between 3.75 inches (97.95%) and 4.00 inches (98.25%), the dry retention depth required to achieve 98.0% removal is 3.80 inches.

C. Key West Project: For the Key West area, the annual load reduction is 68.6% for TN and 97.9% for TP. The design criteria is based on the largest required removal which is 97.9%. The required retention depth is obtained from Appendix D (Zone 3) by iterating between DCIA percentages of 10 and 20, and for non-DCIA CN values between 80 and 90.

From Appendix D (Zone 3), a dry retention treatment volume of 4 inches of runoff will achieve an annual load reduction of 98.25%. The removal efficiency of 98.25% will require a dry retention treatment volume in excess of 4.0 inches. Therefore, the design retention volume will be 4 inches of runoff over the project area.

Post ≤ Pre Example – cont.

2. Wet Detention/dry retention treatment train

Removal efficiencies for TN and TP in a wet detention pond are based on the mean annual detention time in the pond. Removal in wet detention is limited to ~ 40% for TN and 80% for TP. To achieve higher removals, a treatment train approach is required. Assume initial dry retention followed by wet detention with t_d = 150 days.

A. Calculate removal in wet detention:

1. Nitrogen removal:

$$\text{TN Removal} = \frac{(43.75 \times t_d)}{(4.38 + t_d)} = \frac{44.72 \times 150}{5.46 + 150} = \underline{42.5\%}$$

2. Phosphorus removal:

$$Eff = 40.13 + 6.372 \ln (t_d) + 0.213 (\ln t_d)^2 = 40.13 + 6.372 \ln (150) + 0.213 (\ln 150)^2 = \underline{77.4\%}$$

Post ≤ Pre Example – cont.

B. Calculate required dry retention removal:

The required efficiency for the dry retention is calculated by:

$$\textit{Treatment Train Efficiency} = Eff_1 + (1 - Eff_1) \times Eff_2$$

where: Eff_1 = required efficiency of dry retention

Eff_2 = efficiency of wet detention (TN - 42.5%; TP - 77.4%)

Pensacola Site

For Total N:

Overall Eff. = $0.66 = Eff_1 + (1 - Eff_1) \times 0.425$

$Eff_1 = 0.409 =$ 40.9%

For Total P:

Overall Eff. = $0.977 = Eff_1 + (1 - Eff_1) \times 0.774$

$Eff_1 = 0.898 =$ 89.8%

The required treatment train will consist of:

2.54 inches dry retention (89.8%), followed by
Wet detention pond with a 150-day mean residence time

Post ≤ Pre Example – cont.

Orlando Site

For Total N:

$$\text{Overall Eff.} = 0.71 = \text{Eff}_1 + (1 - \text{Eff}_1) \times 0.425$$

$$\text{Eff}_1 = 0.496 = \underline{49.6\%}$$

For Total P:

$$\text{Overall Eff.} = 0.980 = \text{Eff}_1 + (1 - \text{Eff}_1) \times 0.774$$

$$\text{Eff}_1 = 0.912 = \underline{91.2\%}$$

The dry retention treatment volume is dictated by the required removal for TP.

The required treatment train will consist of:

1.74 inches dry retention (91.2%), followed by
Wet detention pond with a 150-day mean residence time

Post ≤ Pre Example – cont.

Key West Site

For Total N:

$$\text{Overall Eff.} = 0.686 = \text{Eff}_1 + (1 - \text{Eff}_1) \times 0.425$$

$$\text{Eff}_1 = 0.454 = 45.4\%$$

For Total P:

$$\text{Overall Eff.} = 0.979 = \text{Eff}_1 + (1 - \text{Eff}_1) \times 0.774$$

$$\text{Eff}_1 = 0.907 = 90.7\%$$

The dry retention treatment volume is dictated by the required removal for TP.

The required treatment train will consist of:

3.14 inches dry retention (90.7%), followed by
Wet detention pond with a 150-day mean residence time

Post ≤ Pre Example – cont.

Potential for Meeting Required Retention Volume by Reuse

Assumptions:
1. 75% of the pervious areas are irrigated
2. irrigated at a rate of 0.50 inch/application
3. two applications per week.

Based on previous analyses, the annual post-development runoff volume for the Key West area is 84.2 ac-ft.

$$53.44 \text{ acres pervious} \times \frac{0.50 \text{ inch}}{\text{application}} \times \frac{2 \text{ applications}}{\text{week}} \times \frac{52 \text{ weeks}}{\text{year}} \times \frac{1 \text{ ft}}{12 \text{ inches}} = 232 \text{ ac-ft/yr}$$

A reuse irrigation system could easily consume the required annual retention volume, eliminating the need for dry retention to meet the pre- vs. post- requirements.

Questions?

Treatment Train Example No. 5

Vacuum Street Sweeping

Removes solids, leaves, and debris

Dry Detention

Reduces runoff volume and removes solids

- Sweeping will remove particulate pollutants
- Particulate pollutants would also be removed in dry detention

No enhancement in efficiency