# Lessons Learned About the Steps to Reducing TSS and P Loads in Stormwater

Roger Bannerman

April 10, 2013


# What are we going to cover?

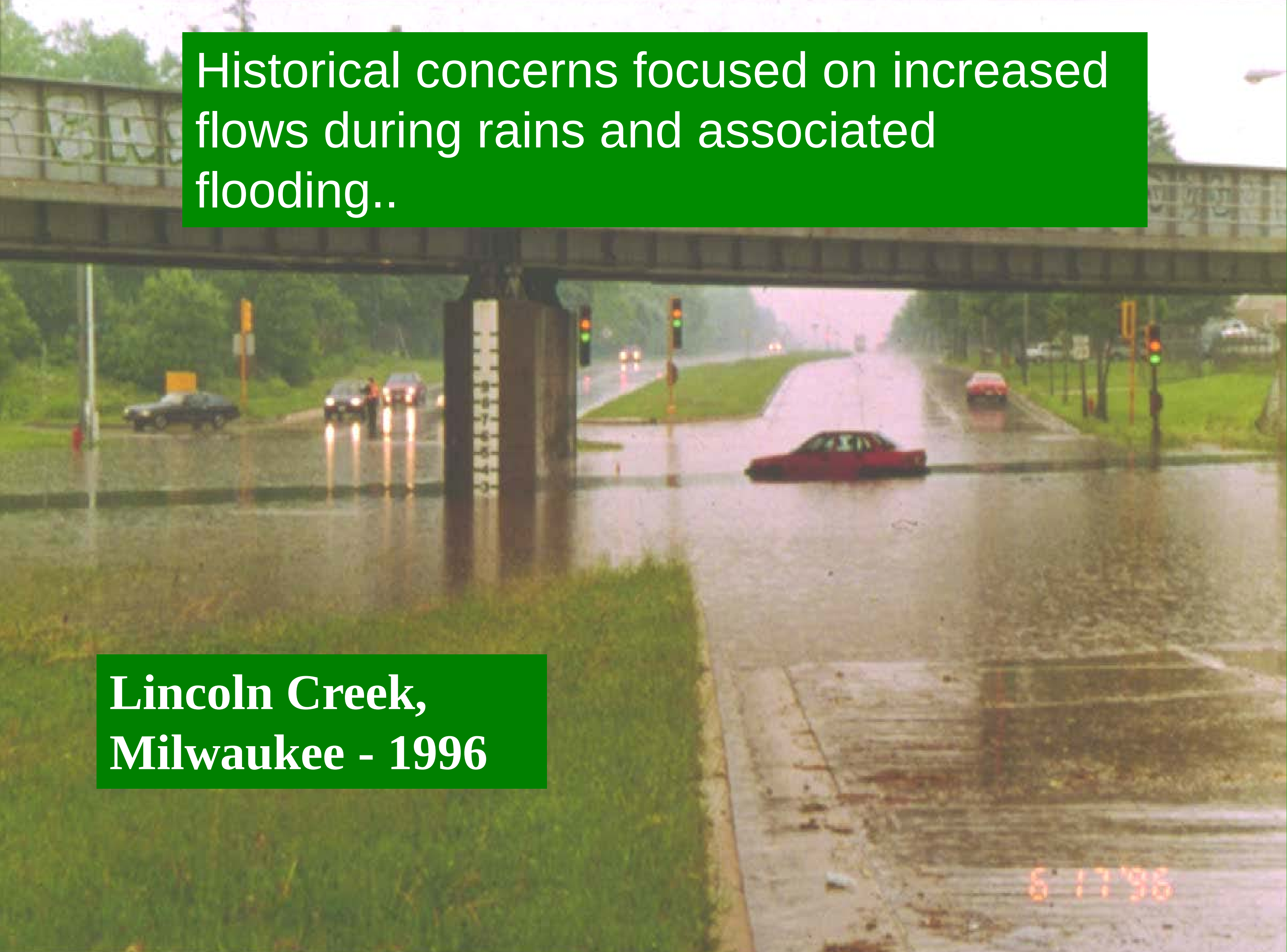
1. Historical Prospective – Steps to Management
2. Sources of TSS and P
3. Potential benefits of Selected Stormwater Control Measures – Technical Standards

Cities in the Mesopotamian Empire during the second millennium BC had practices for flood control, to convey waste, and to store rain water for household and irrigation uses (Manor, 1966)

Cistern Tank: Greece, 7th Century BC

Modern drainage systems came into being shortly after World War II – Rational Method used to design pipes and catch basins to prevent flooding and drainage problems

Historical concerns focused on increased flows during rains and associated flooding..




**Lincoln Creek, Milwaukee - 1996**

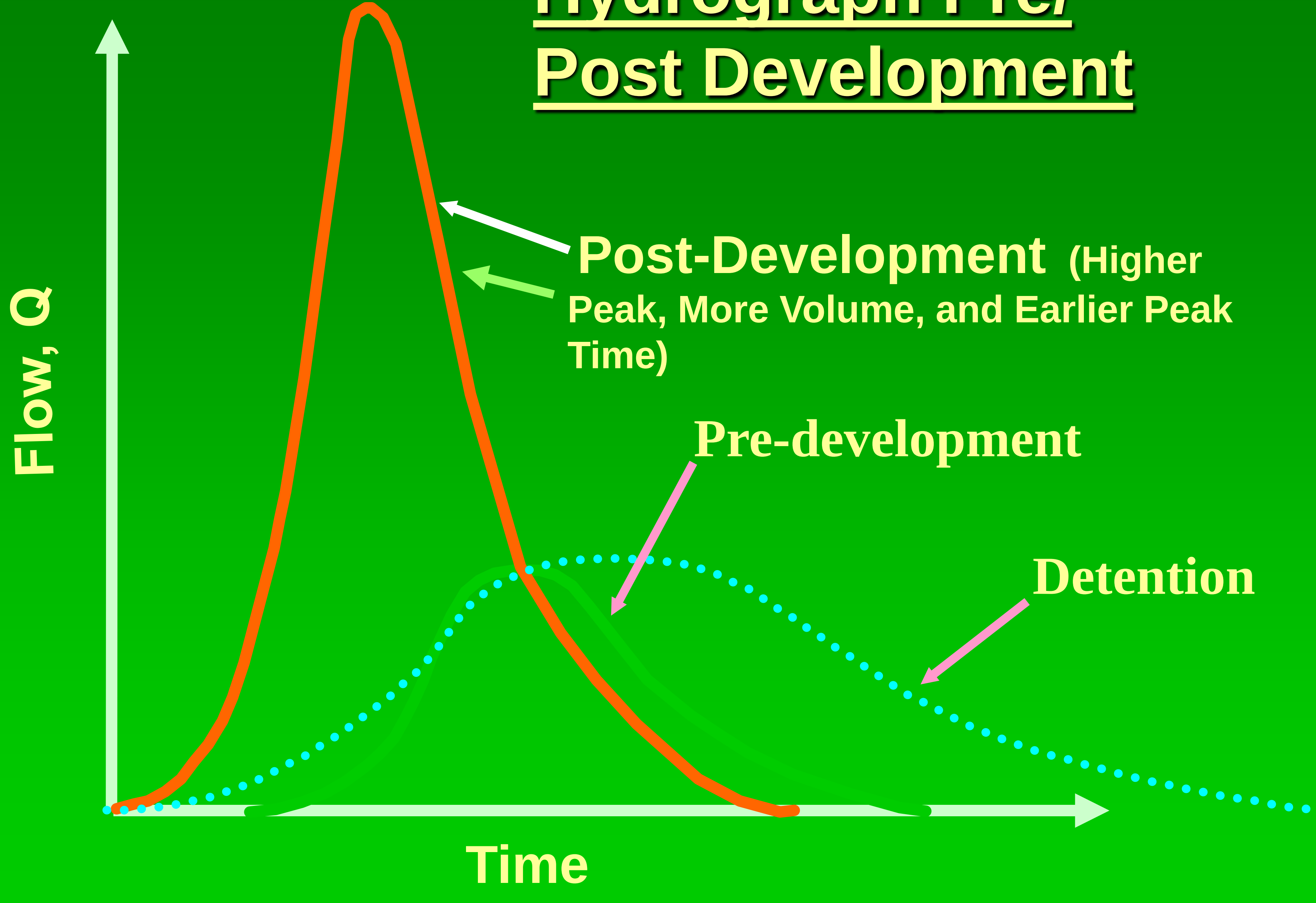
# Impact of Urbanization on Habitat Structure



**Dry Basin for 100 Year Event – Cross Plains, WI**

Ordinances appeared in early 1970s requiring developers to reduce peak flows.

# Hydrograph Pre/ Post Development



# The Runoff Management Rules (NR 151)

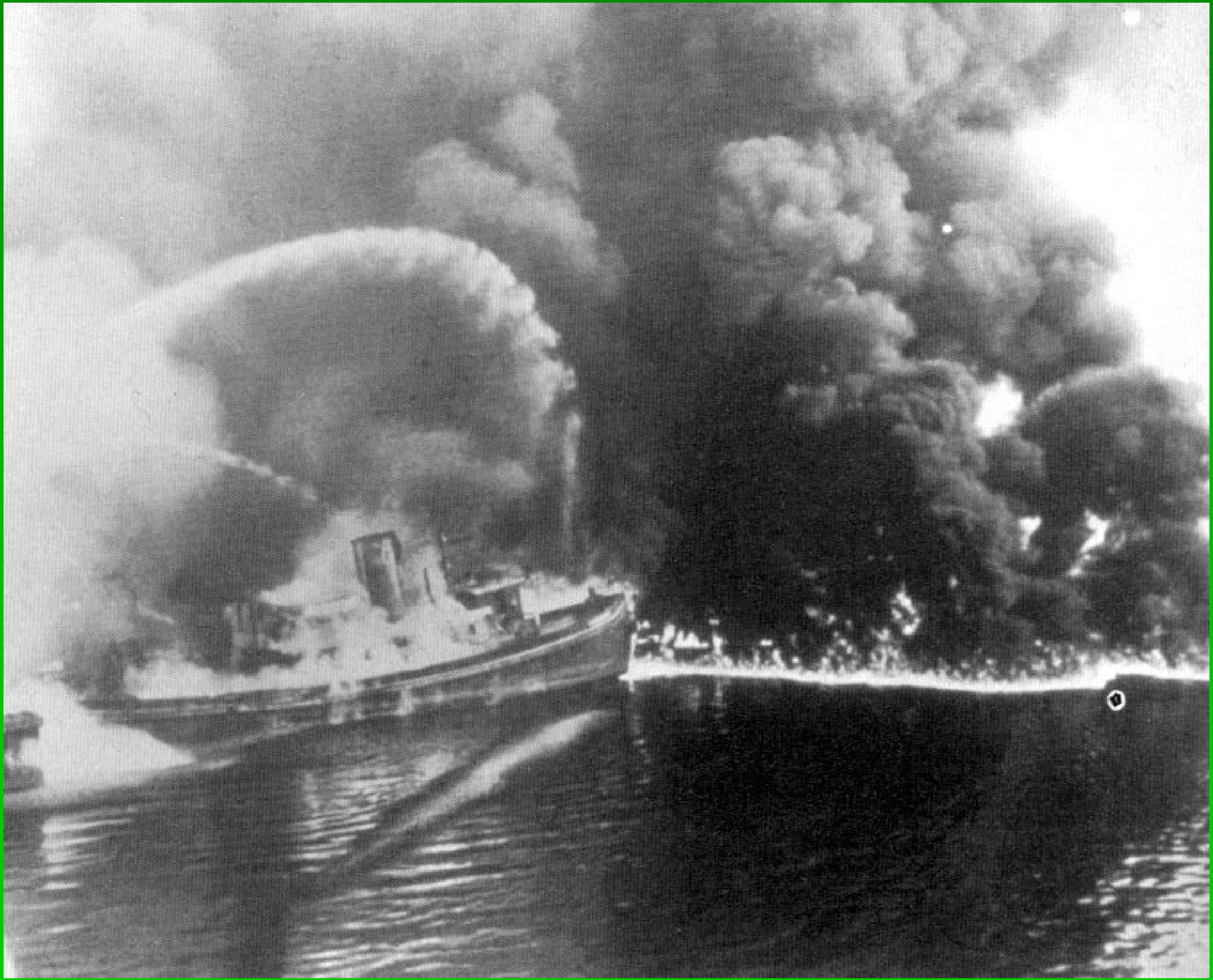
## Runoff Volume Control

# Post Construction Infiltration Performance Standards

By design, infiltrate sufficient runoff volume so that the post-development average annual infiltration volume shall be a portion of pre-development infiltration volume.

| Level of Connected Imperviousness | Standard | Cap |
|---|---|---|
| Up to 40% (Residential) | 90% | 1% |
| Between 40 and 80% (Residential & Non-residential) | 75% | 2% |
| More than 80% (Non-residential) | 60% | 2% |

# Cuyahoga River in Cleveland Often Caught on Fire Between 1952 and 1969 (this lead to the Clean Water Act in 1972)



**Coombs and Boucher**

# Pollution from Land Use Activities Reference Group (PLUARG) Study 1974-1979 - Menomonee River Watershed

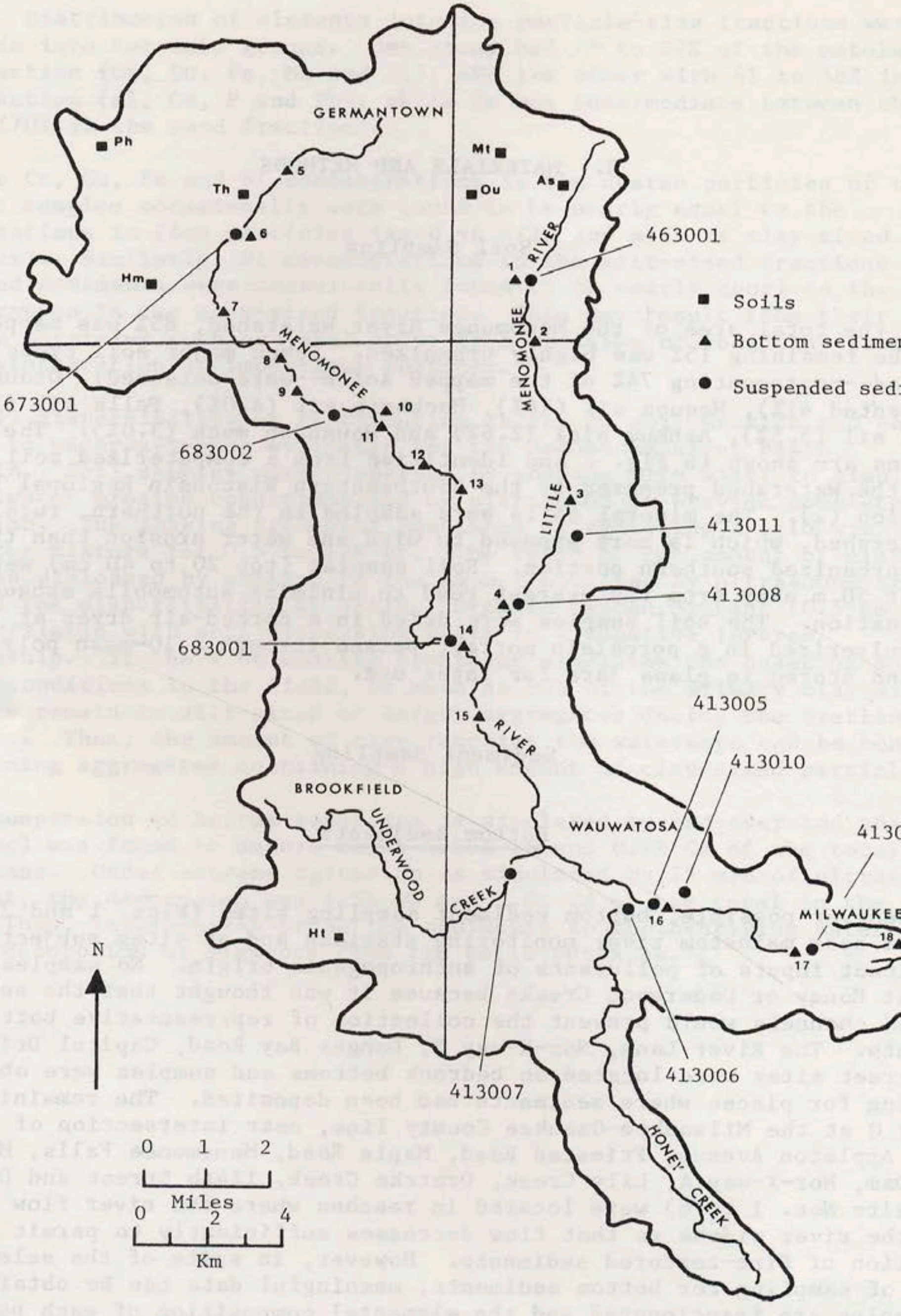
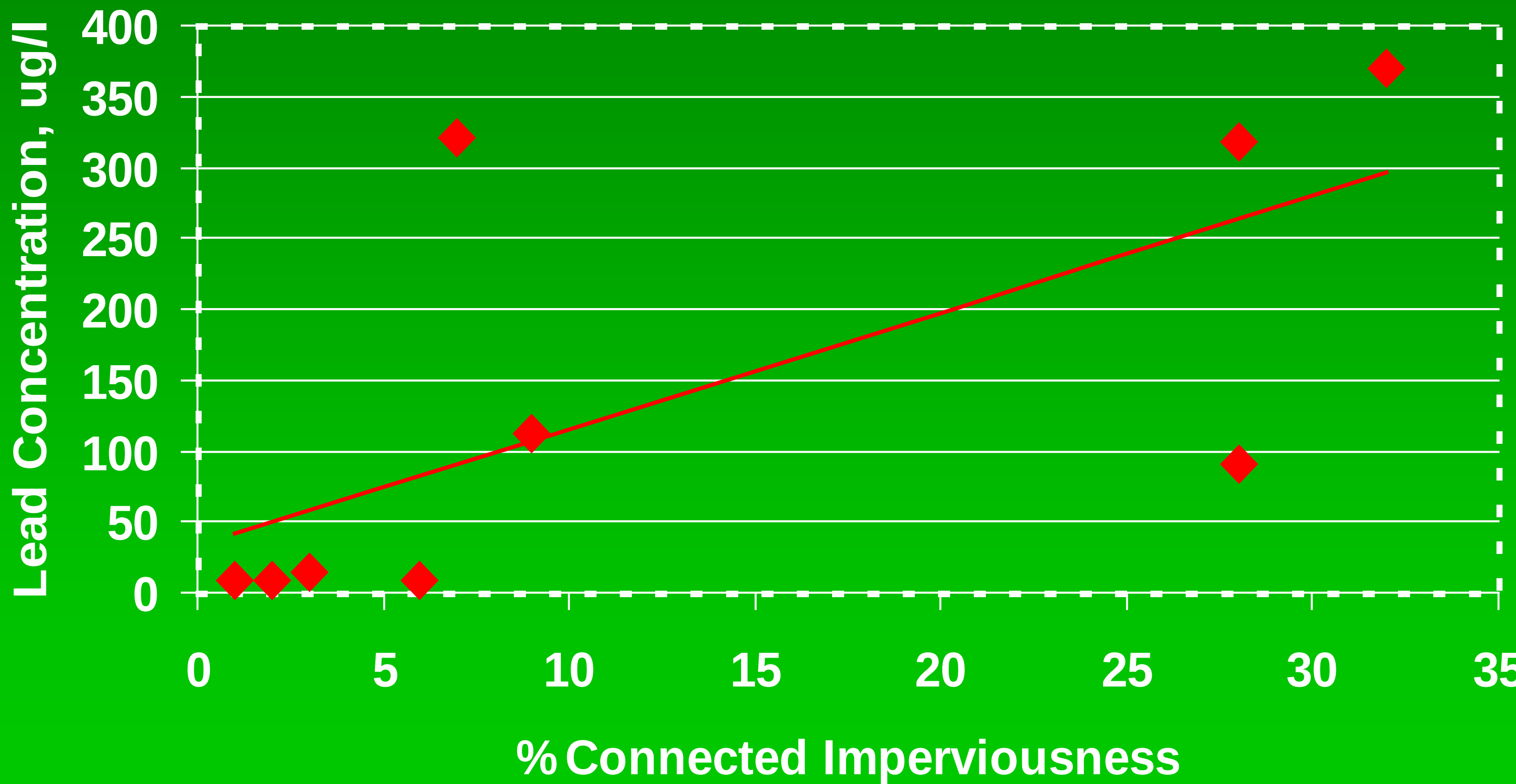


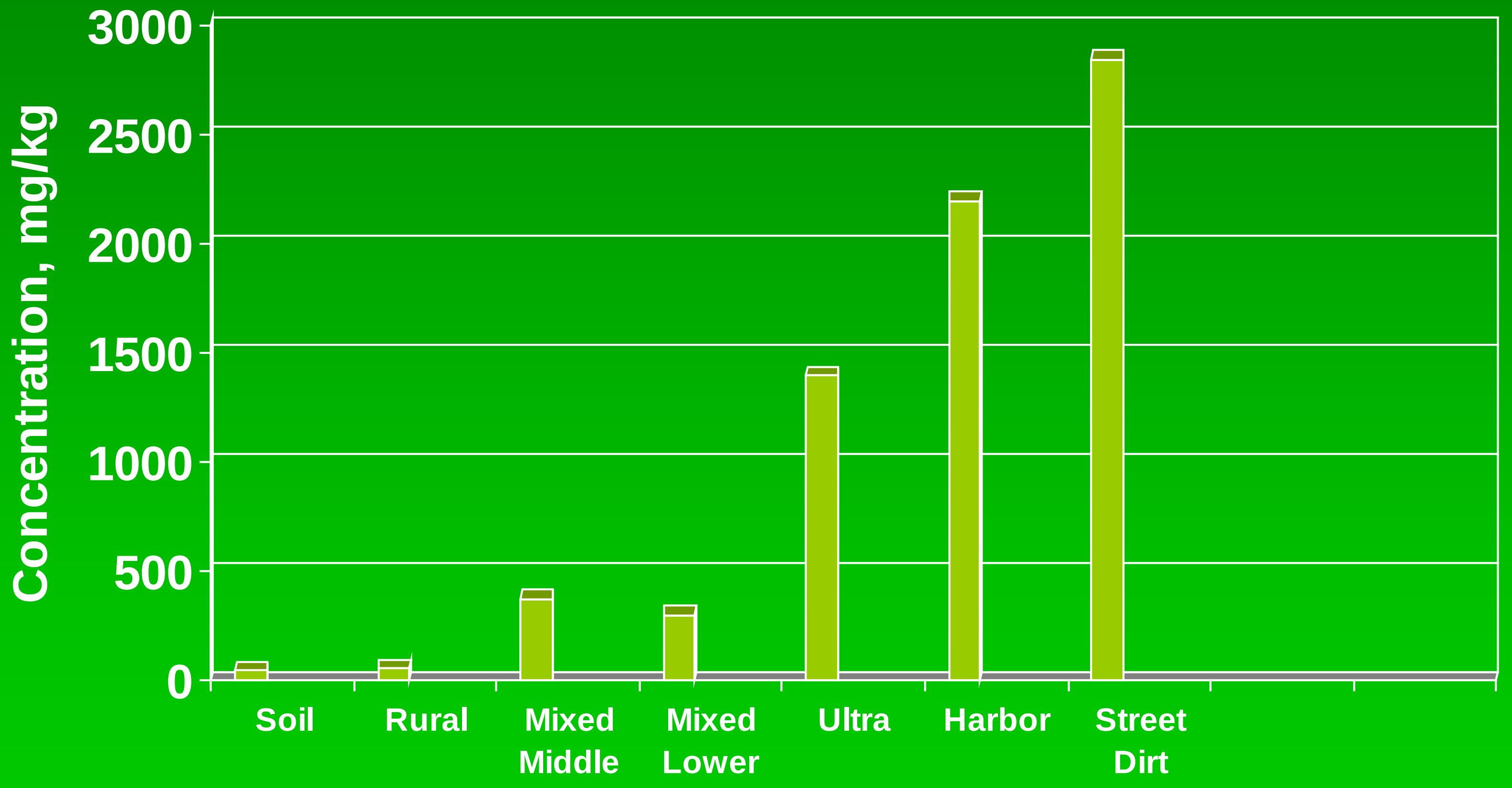

Fig. 1. Sampling sites of soils, bottom sediment and suspended sediment within the Menomonee River Watershed.

# Mean Event Concentrations of Lead for Streams in the Menomonee River Watershed



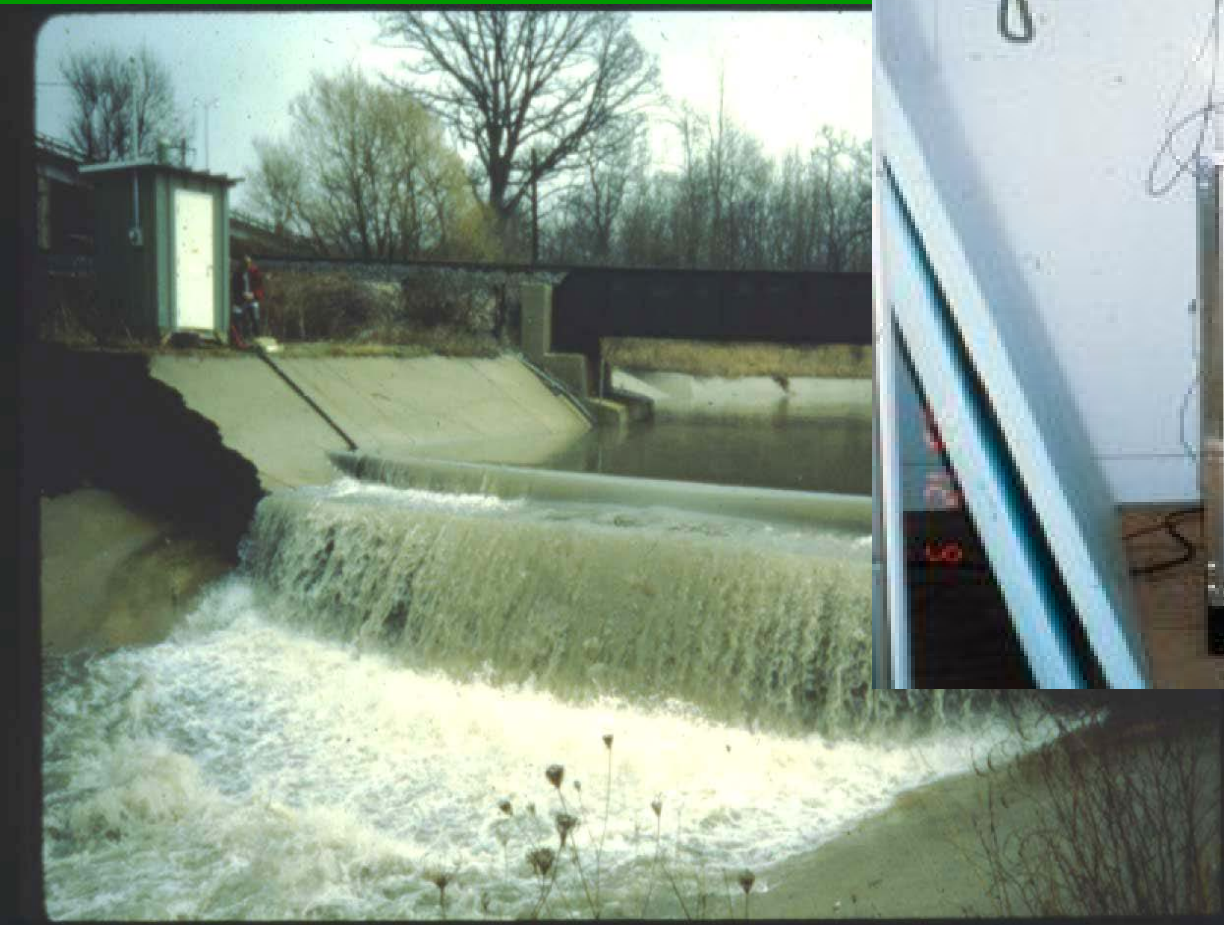

Bannerman, 1979

# Average Lead Levels in Clay Sized Bottom Sediment of the Menomonee River




Dong, 1979

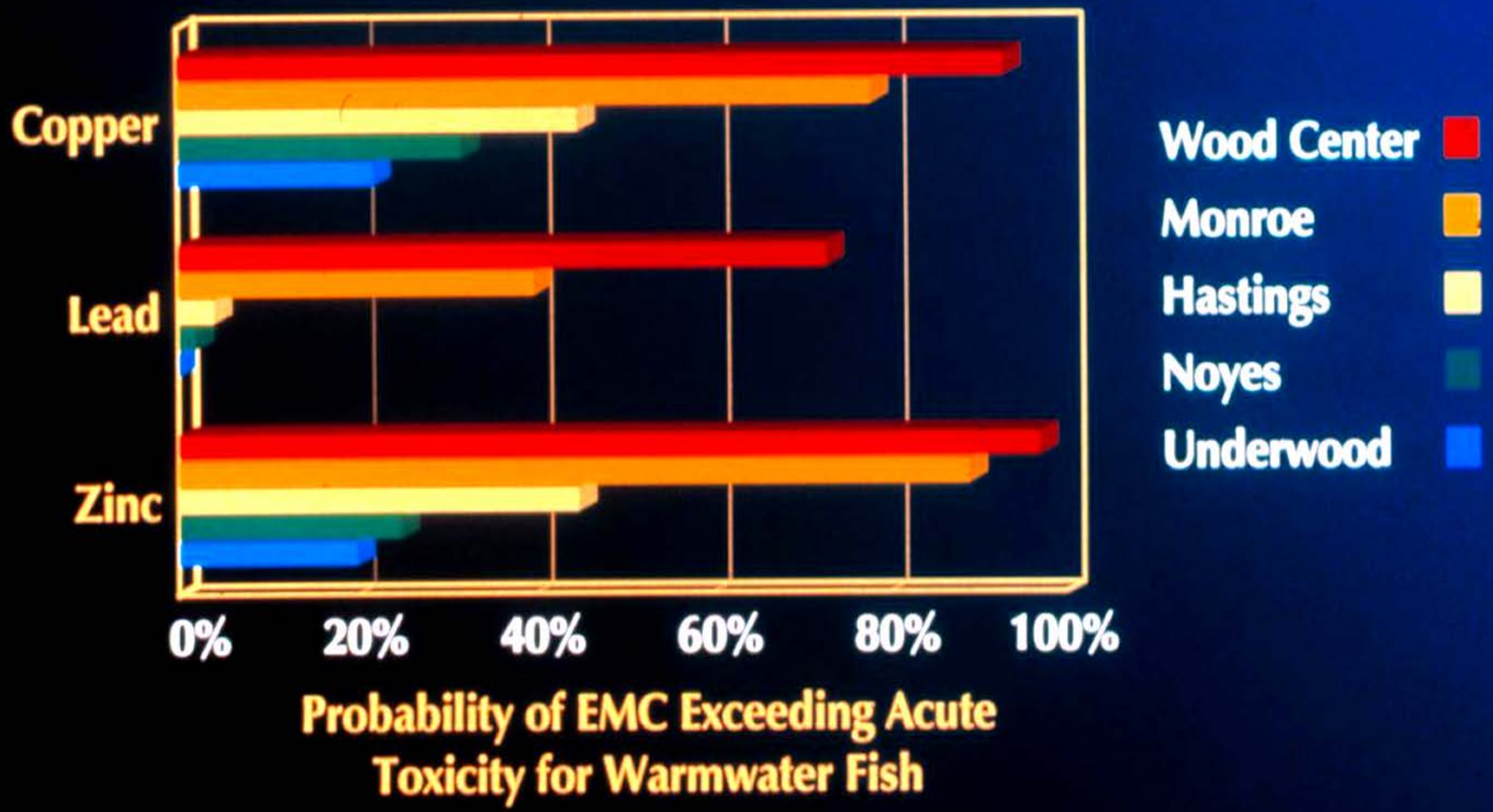
# Nationwide Urban Runoff Project (NURP)



Underwood Creek, Milwaukee

## URBAN RUNOFF DATA 1980-82 & 1988-90

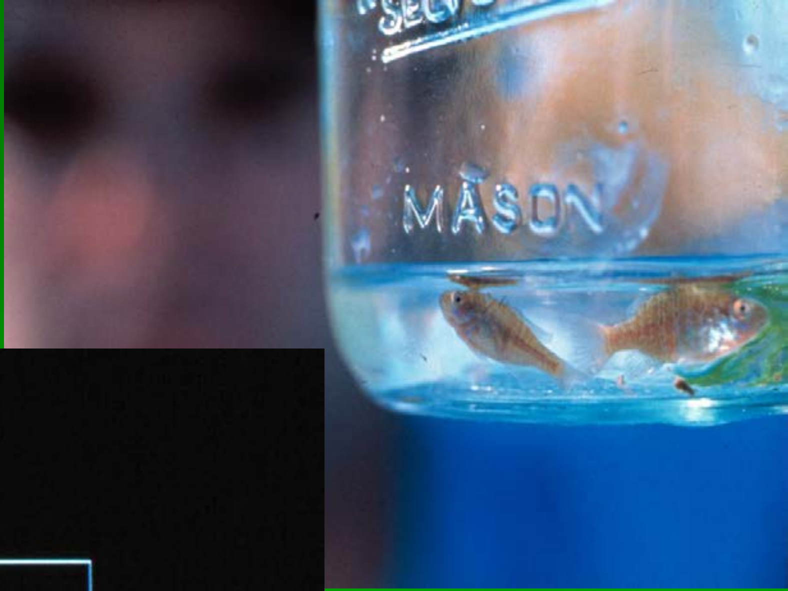
# Metals Exceeding Acute Toxicity

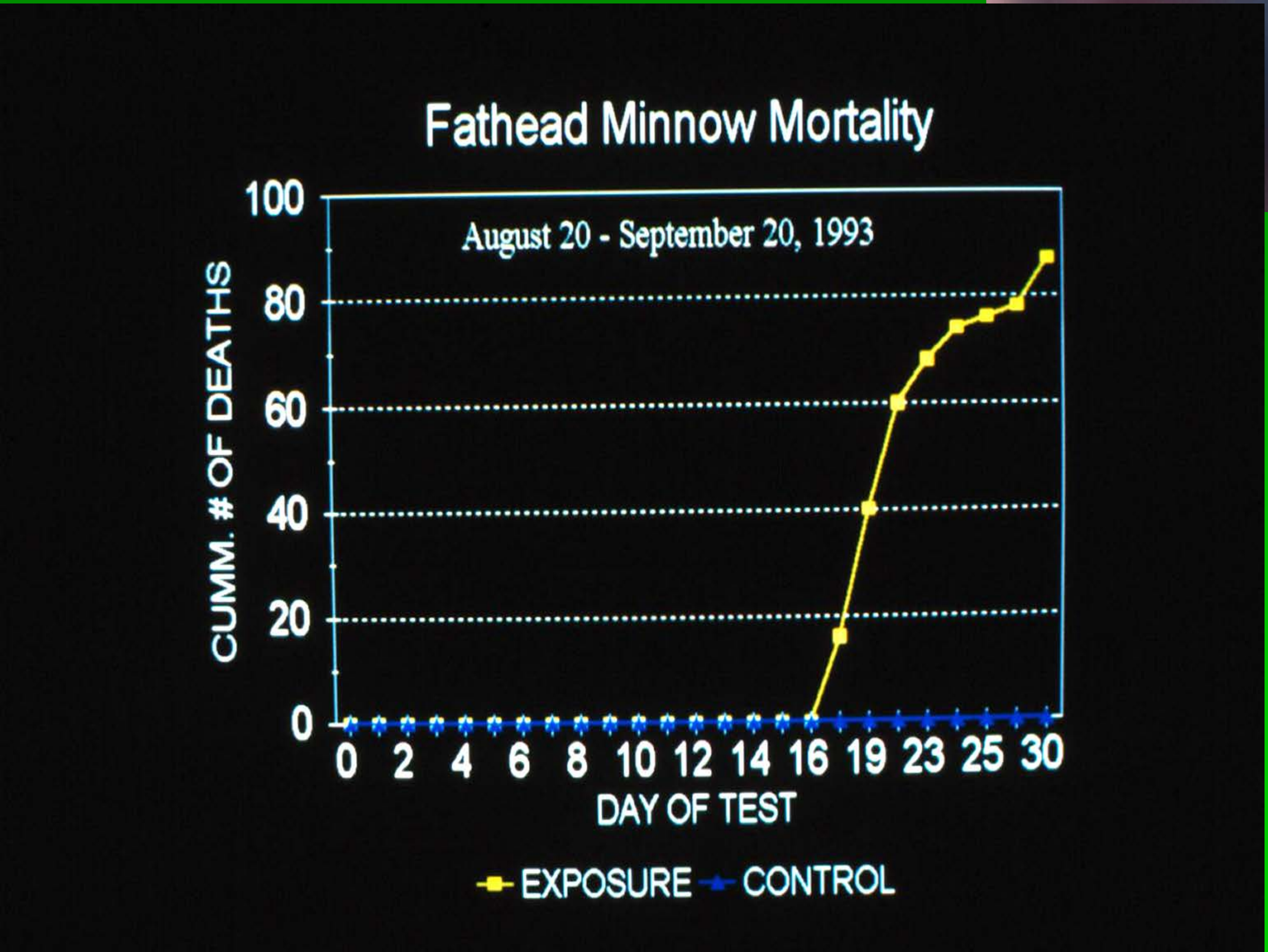


# Bioassay Sampling Station on Lincoln Creek, Milwaukee

**Ron Crunkilton, UW Stevens Point, WDNR, and USGS**

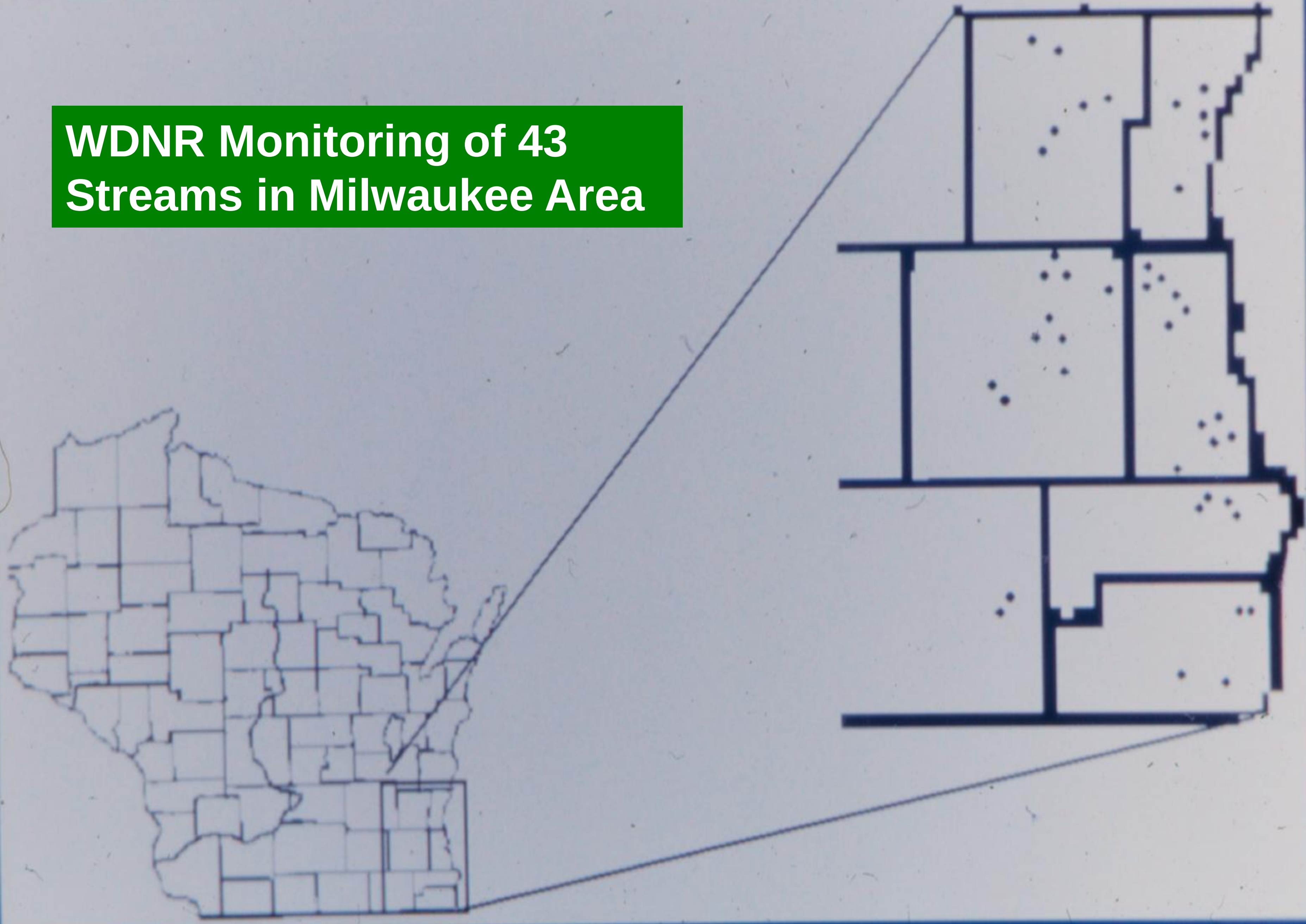
# Chronic Toxicity Discovered in Urban Streams



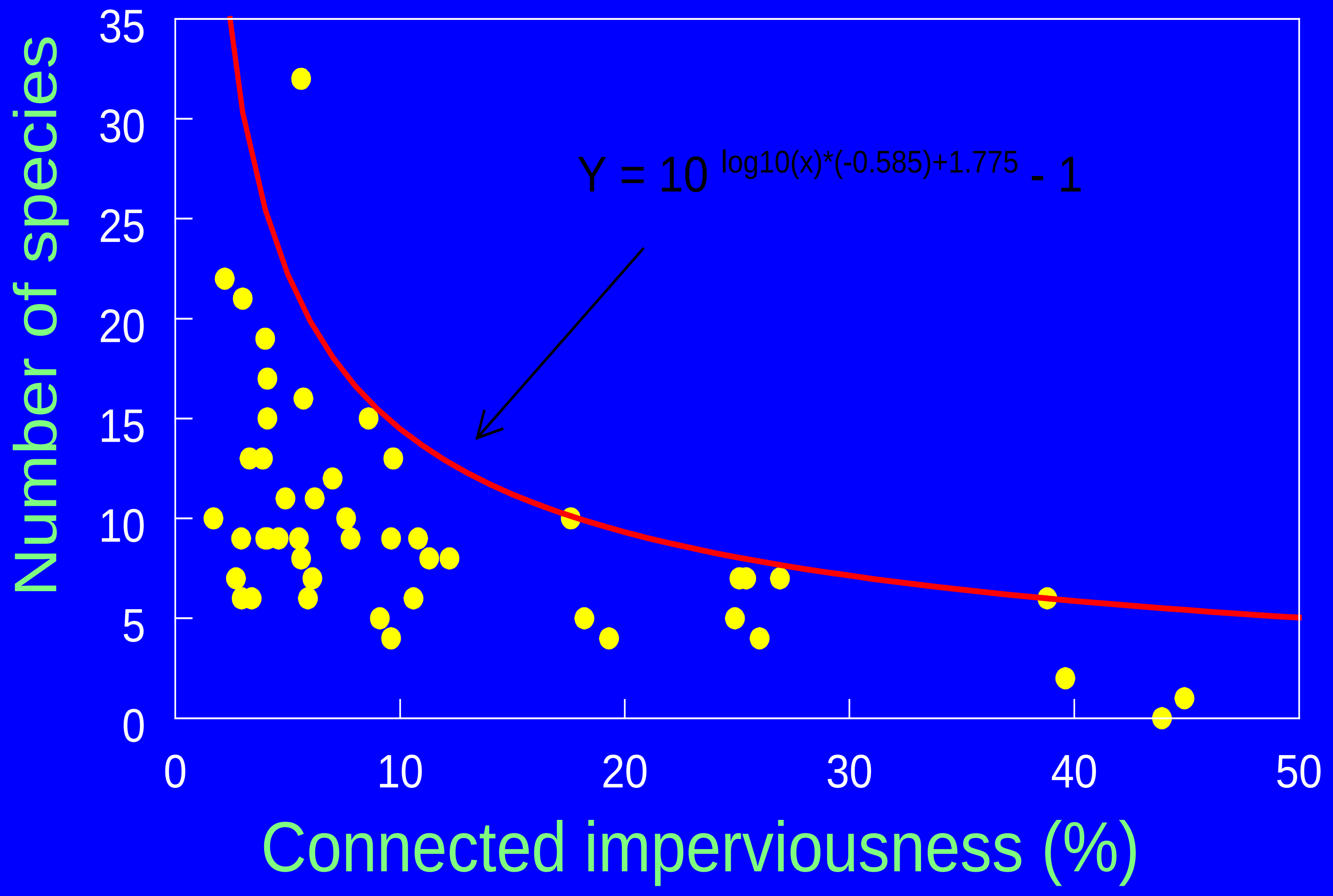



**Crunkilton, 1996 & Ramcheck, 1995**

# WDNR Monitoring of 43 Streams in Milwaukee Area

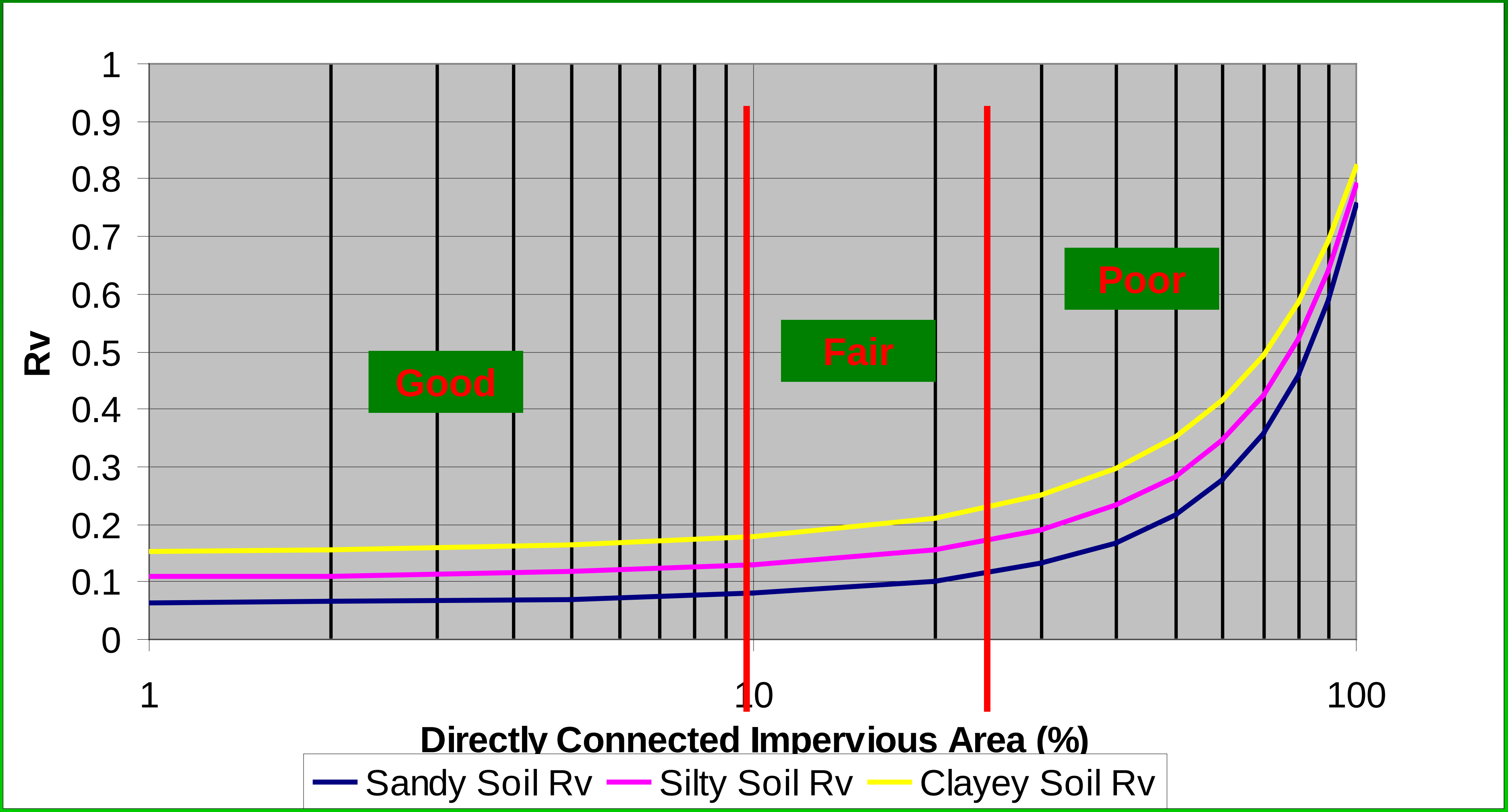


**Wang, 2001**



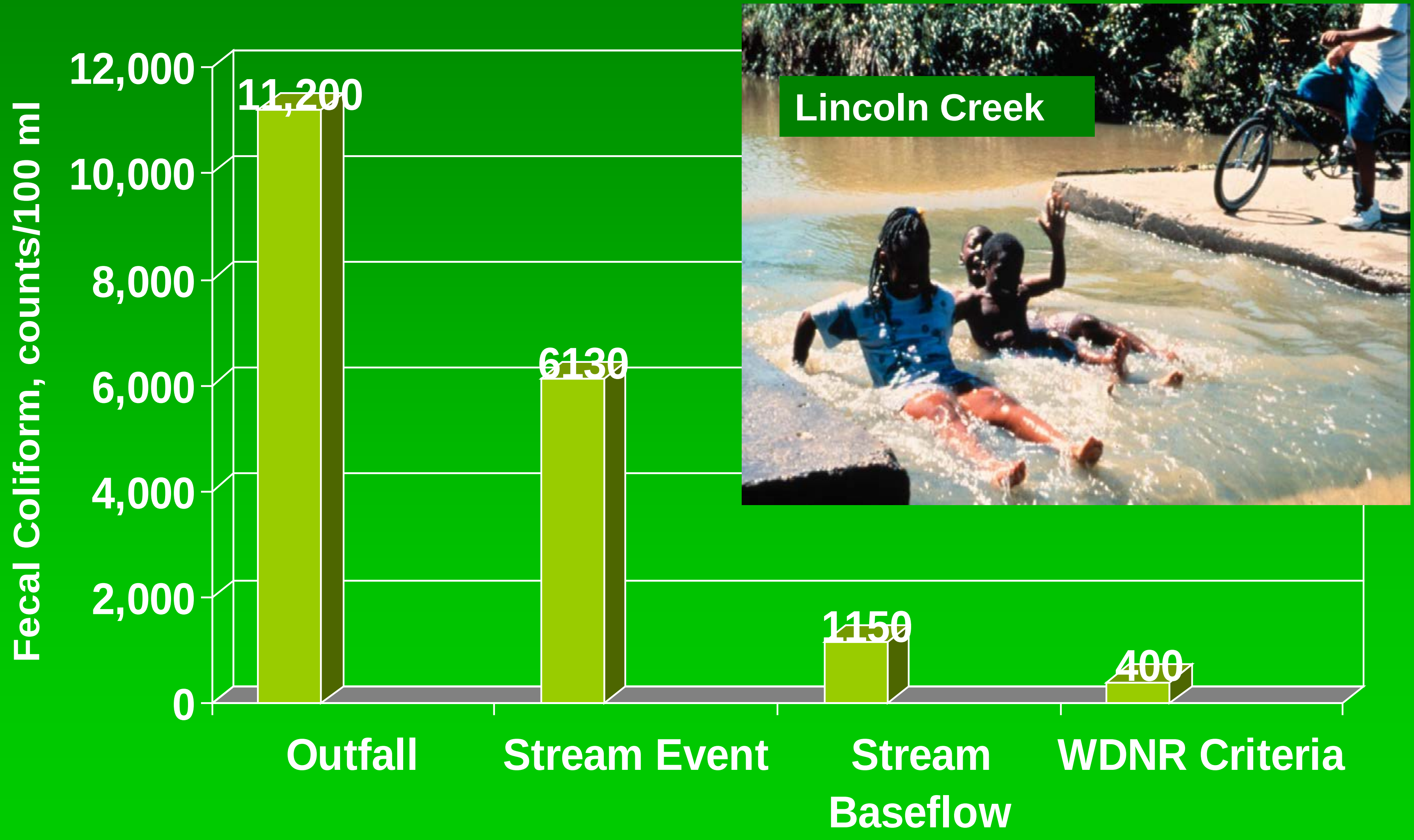
Number of species
35
30
25
20
15
10
5
0
0
10
20
30
40
50
Connected imperviousness (%)
Y = 10 log10(x)*(-0.585)+1.775 - 1

# Relationship between Directly Connected Impervious Areas, Volumetric Runoff Coefficient, and Expected Biological Conditions




Plots based on modeling many actual neighborhoods having various development characteristics and soils

# Bacteria Counts in Water Samples Collected from Lincoln Creek, Milwaukee (Masterson, 1994 & Bannerman, 1983 &1996)



# The Runoff Management Rules (NR 151)

# TMDLs

**Reduce:**
**Phosphorus,**
**Bacteria,**
**Turbidity**

# Stormwater Management Steps

1. Identify beneficial use impairments
2. Identify causes of impairments
3. **Identify sources (magnitude, seasonality, flow phases, etc.) of problem constituents**
4. Identify, select, and design controls suitable for problem pollutants and locations
5. Implement controls, conduct validation monitoring, modify controls as needed

# Contribution of Rain to Total P Loads in Runoff

**Rainfall 0.015 mg/l**

**Dry Deposition 0.05 mg/m2/day (% similar to local soils)**

**NURP Sites – Avg. Rain/Avg. Pipe = 6 to 17%**

**Bannerman et. al., 1983**

- Harper Sewershed 6%
- Monroe Sewershed 0.2
- Mendota Watershed 2%

# Sources of Phophorus to Forest Lake, Fond Du Lac County

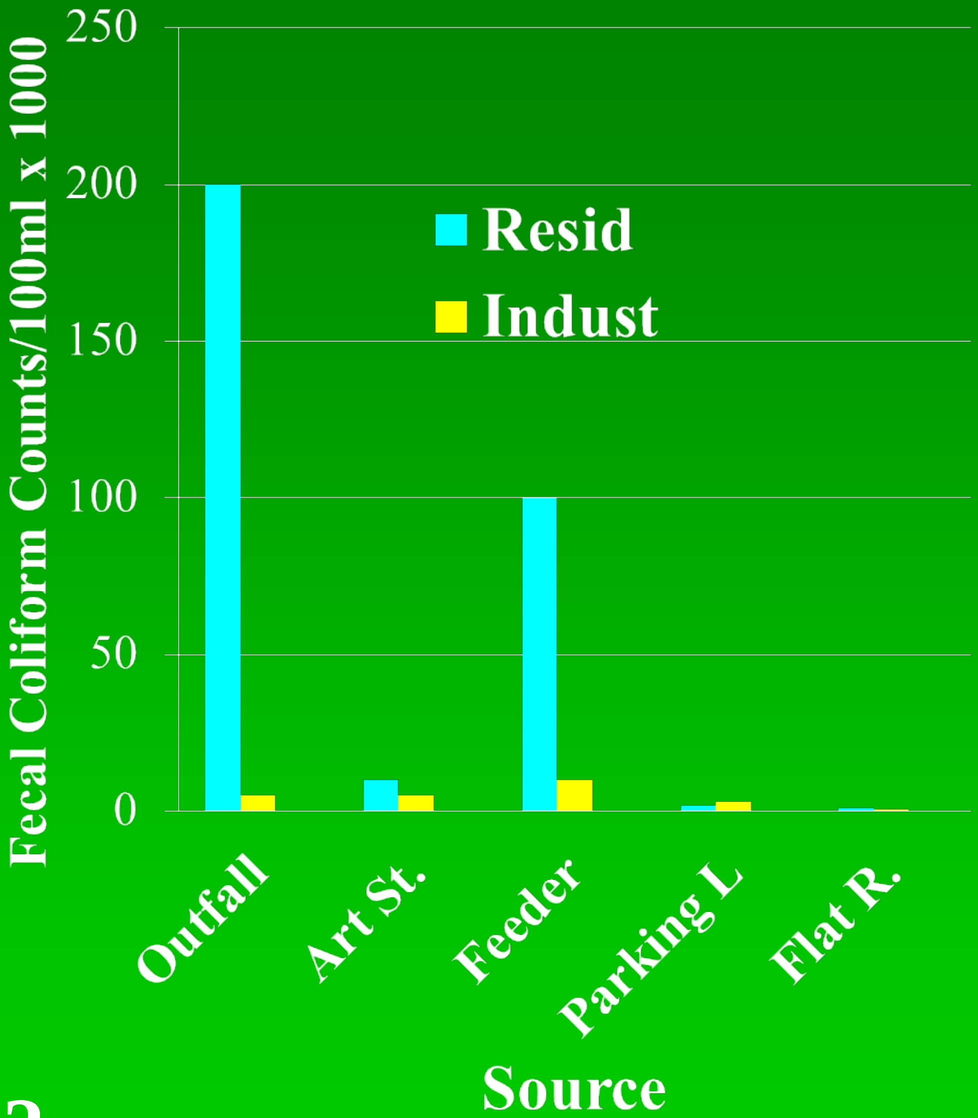
| **Source –**<br>**Total: 45.7 lbs.** | **% of Total** |
|---|---|
| **Medium Residential** | 44 |
| Forest | 1 |
| Septic | 28 |
| Precip. – Wet & Dry | 27 |



# Source Area Sampling

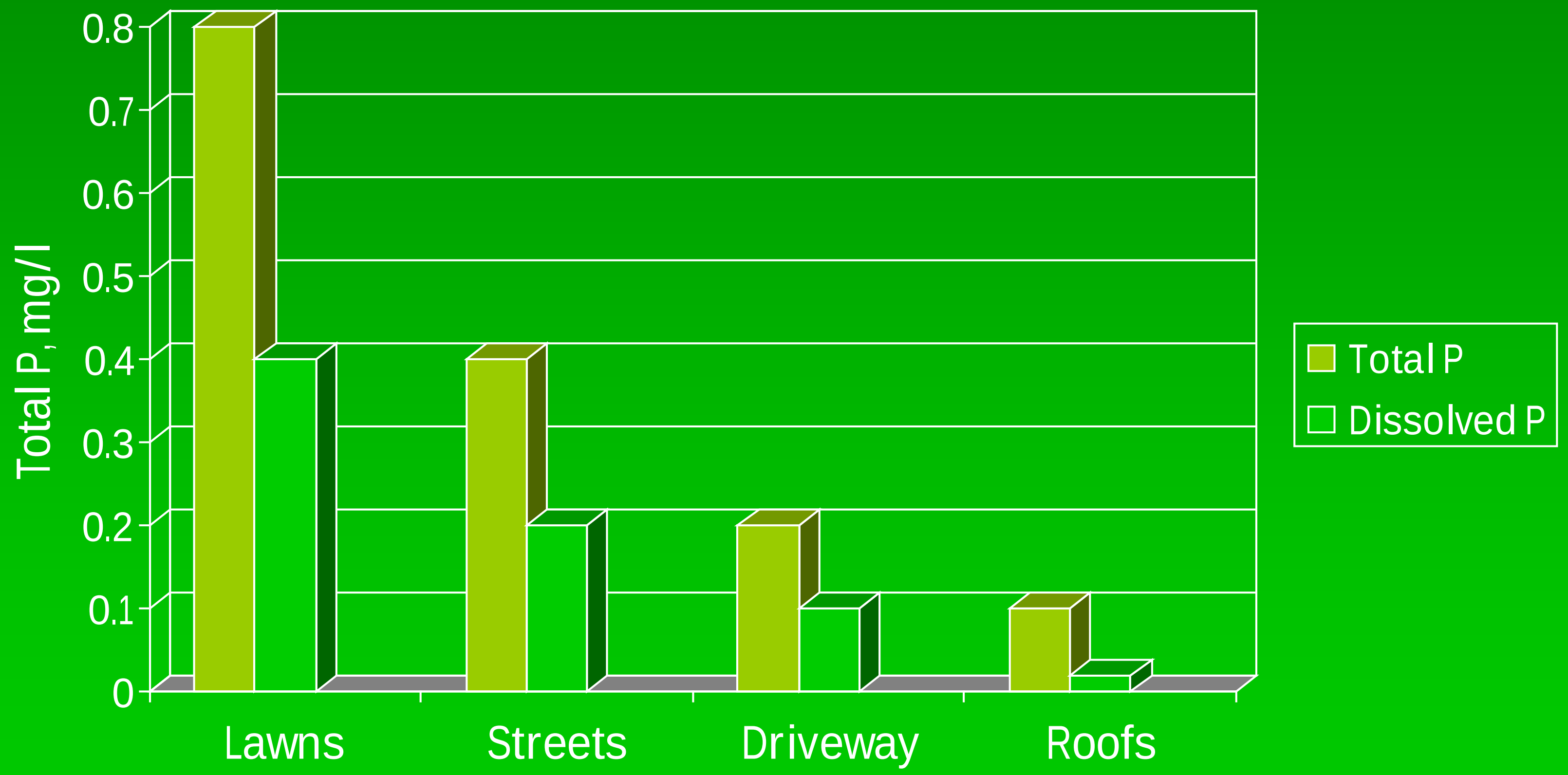


# Comparison Fecal Coliform Counts for Residential and Industrial Source Areas

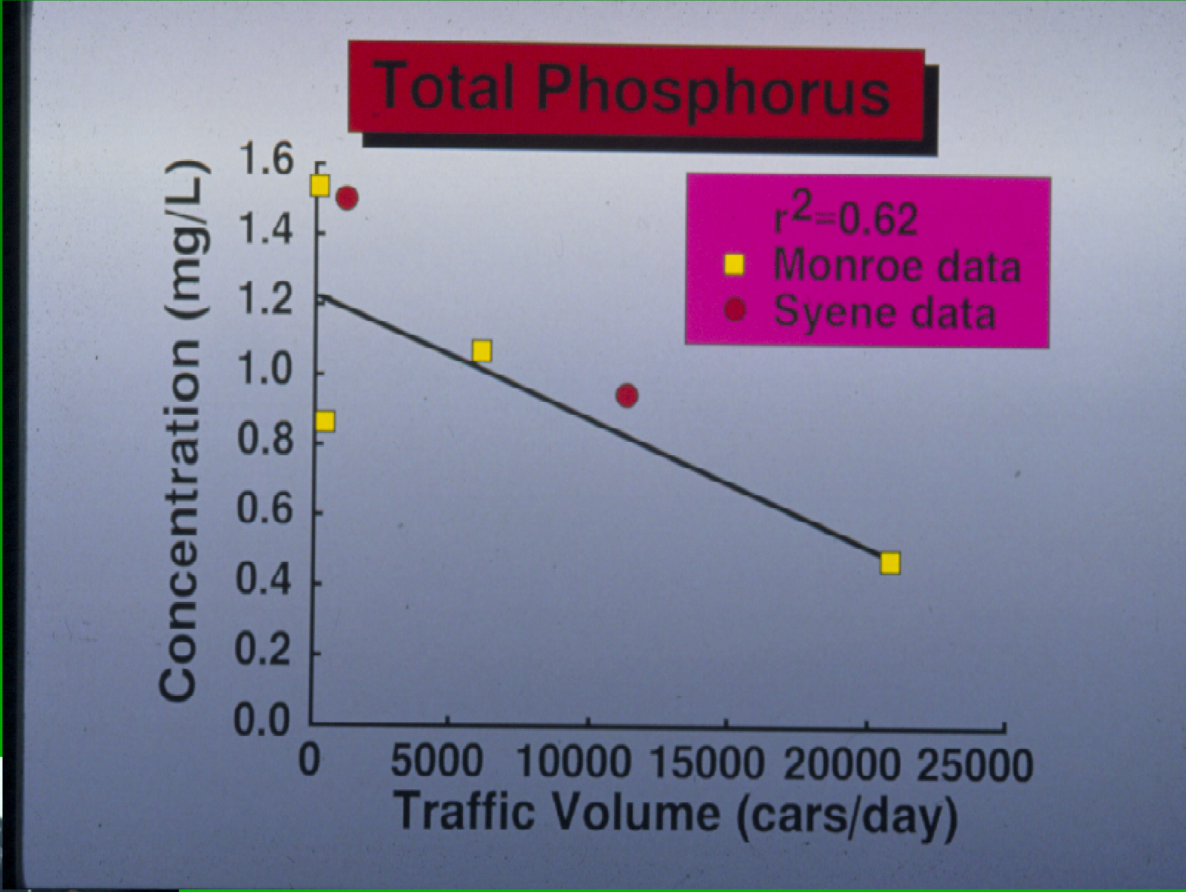



**Burnhart et al, 1992**

# Total and Dissolved P Geometric Means for Different Source Areas in Residential Area - Monroe St.

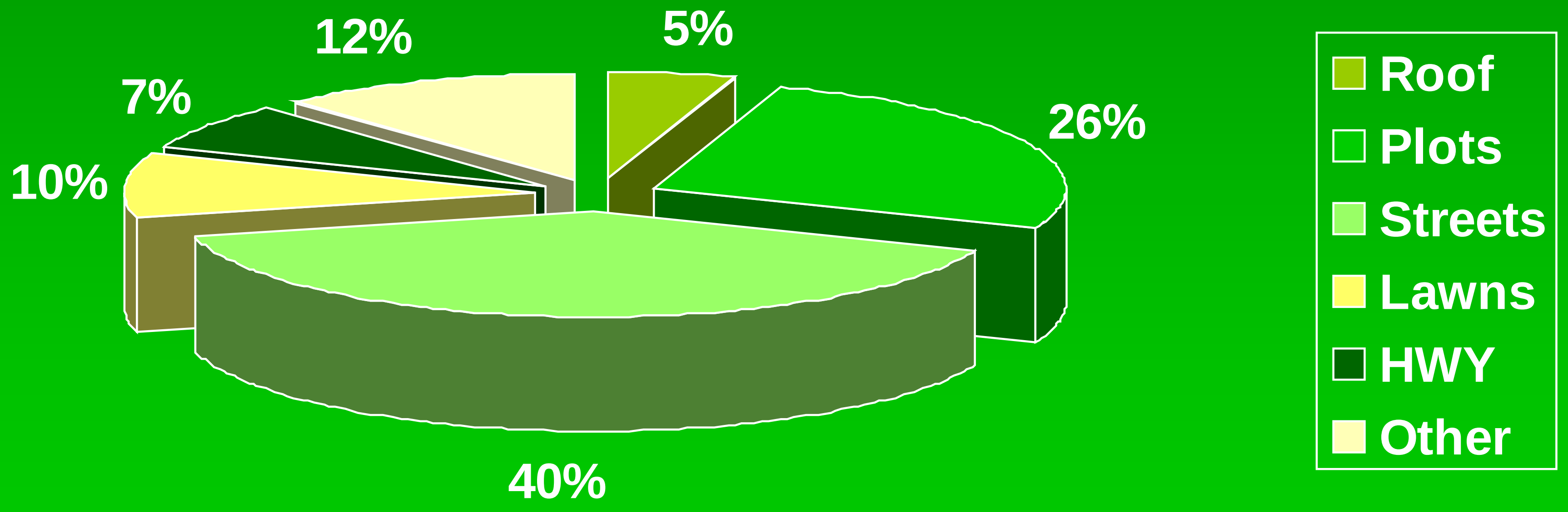


**Streets with Less Traffic Have Higher Total P Concentrations in Runoff - Less Vegetation**

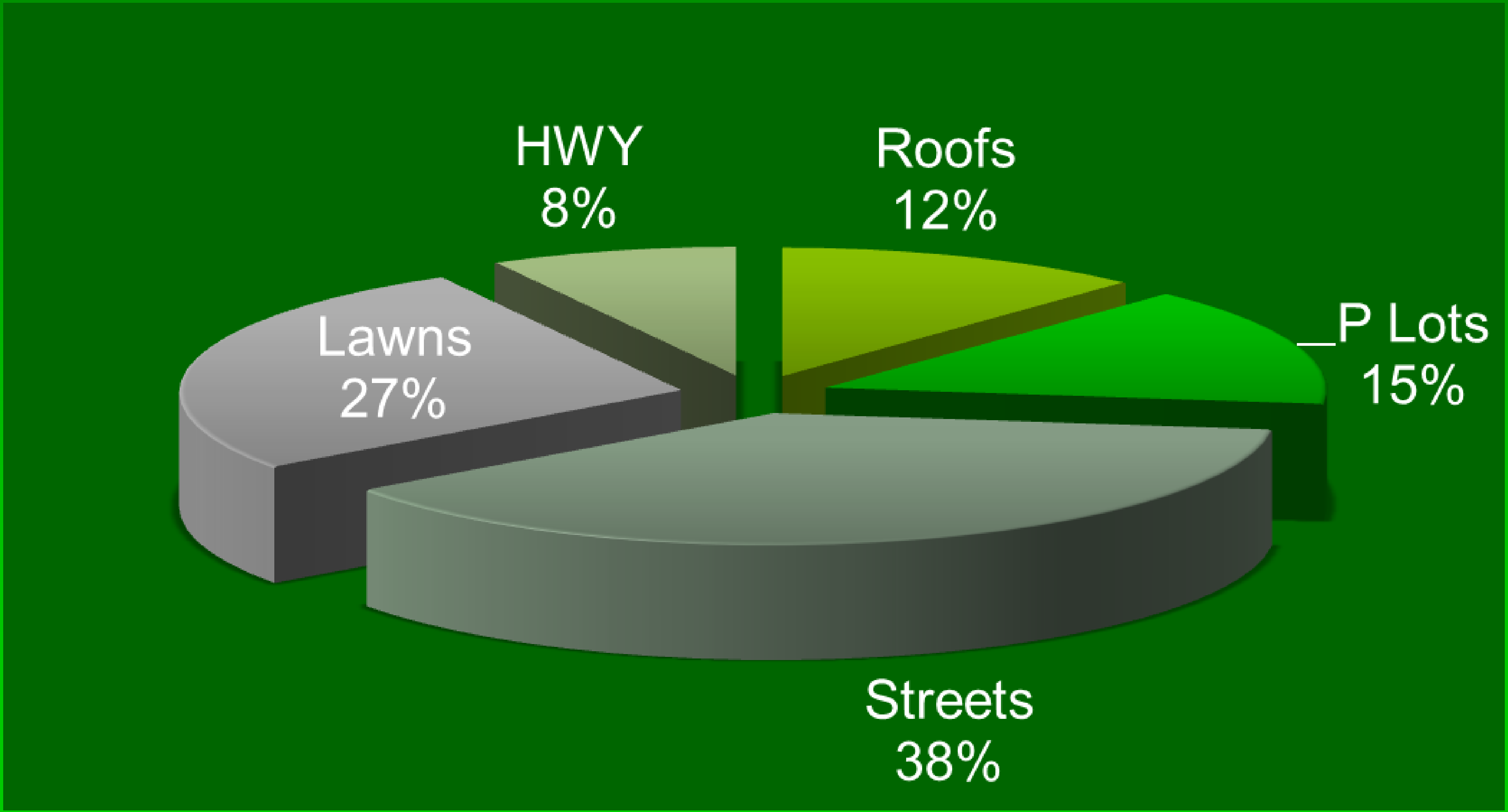



**Monroe Street**

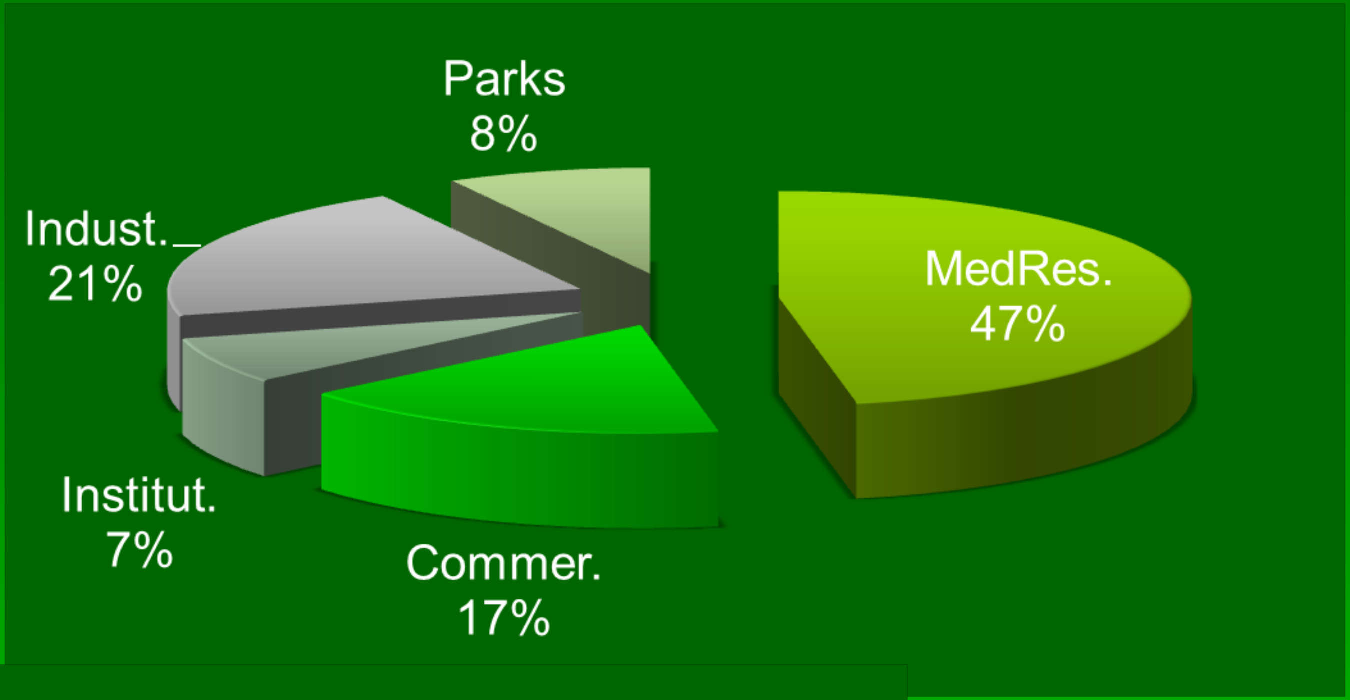
# % Suspended Solids Loads from Source Areas in 4 Subwatersheds

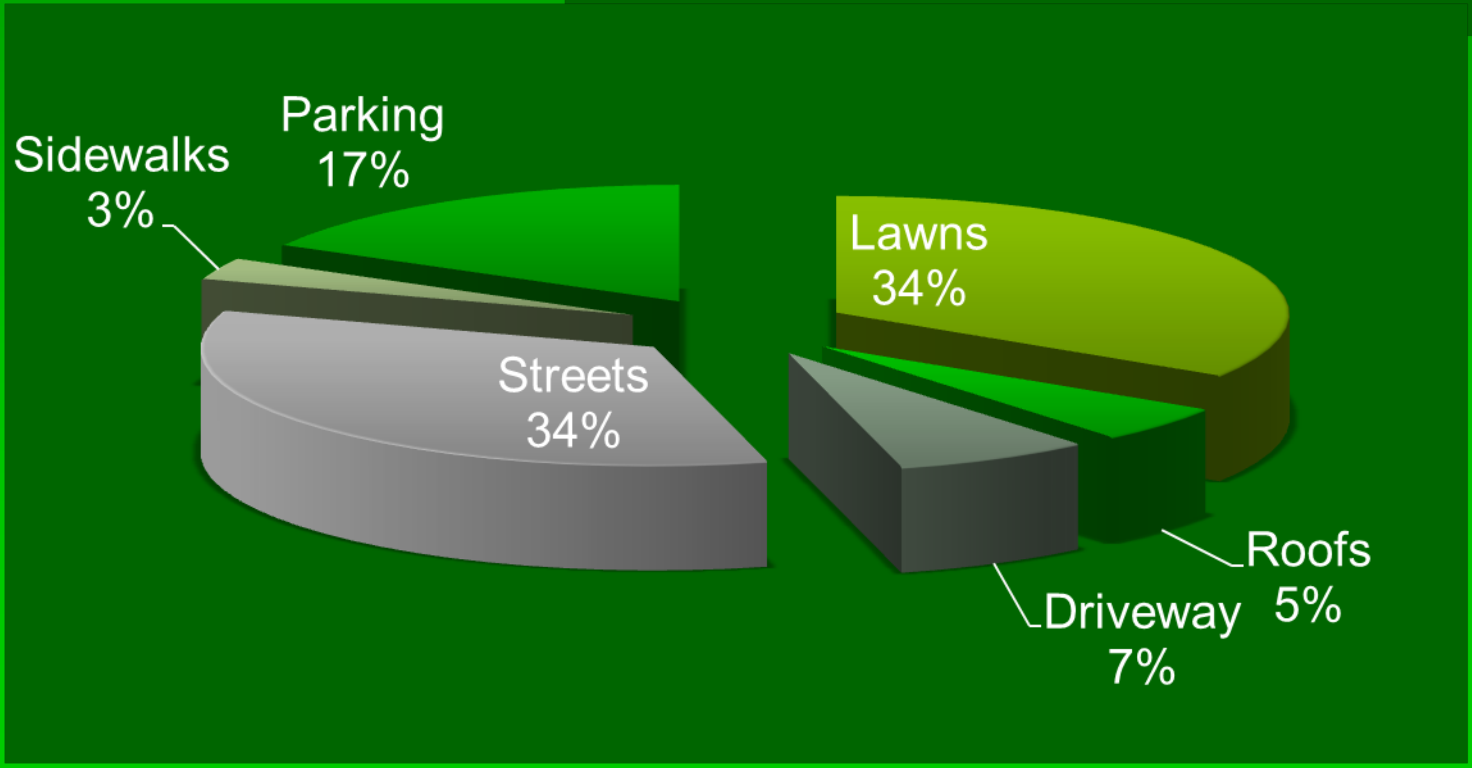


# % Total P Loads for Four Subwatersheds in Lake Wingra Basin



# Madison Annual TP Loads



# Monitoring source areas and land uses with automatic samplers


Shopping Center

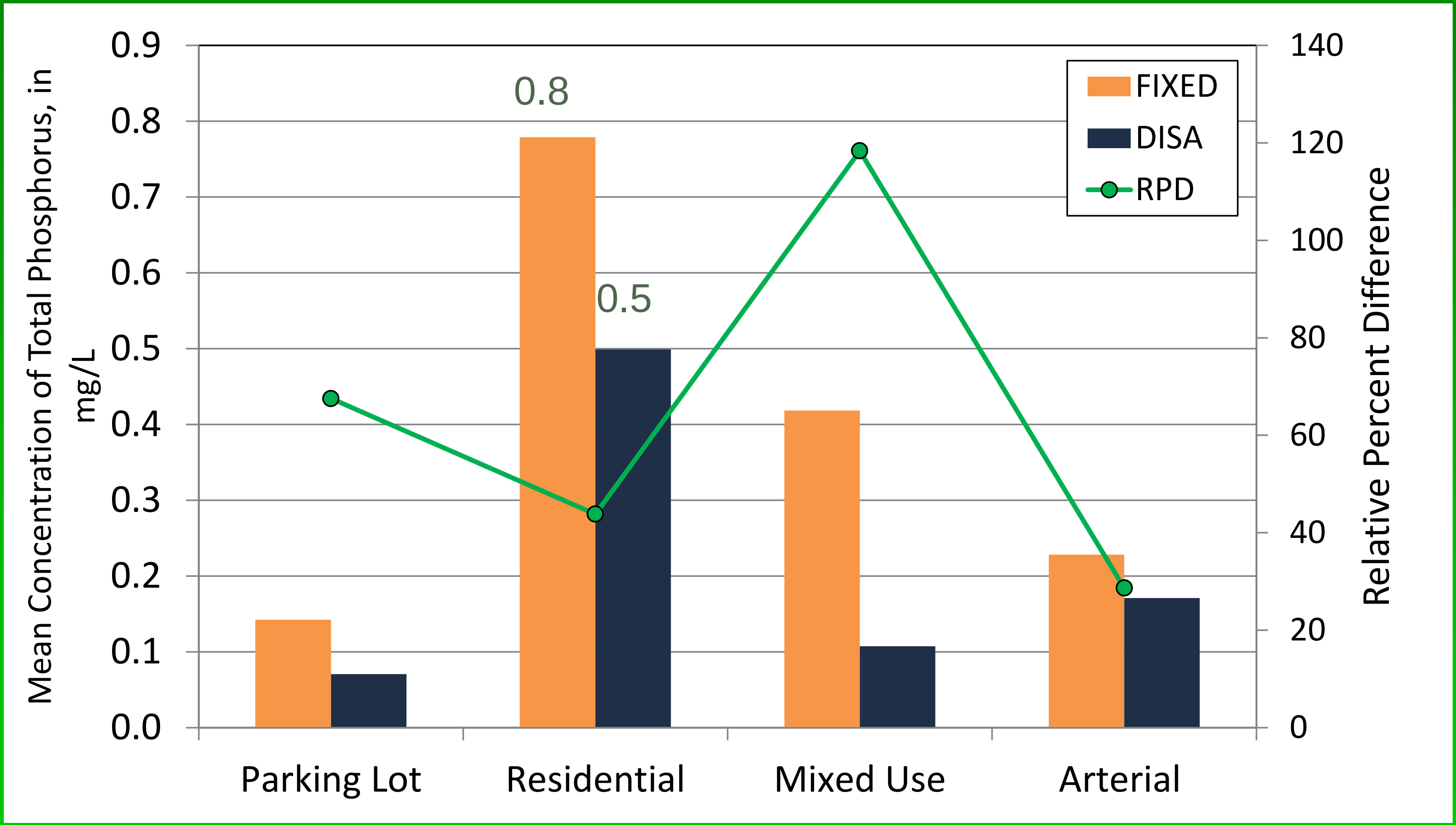

Residential Street

Commercial Street

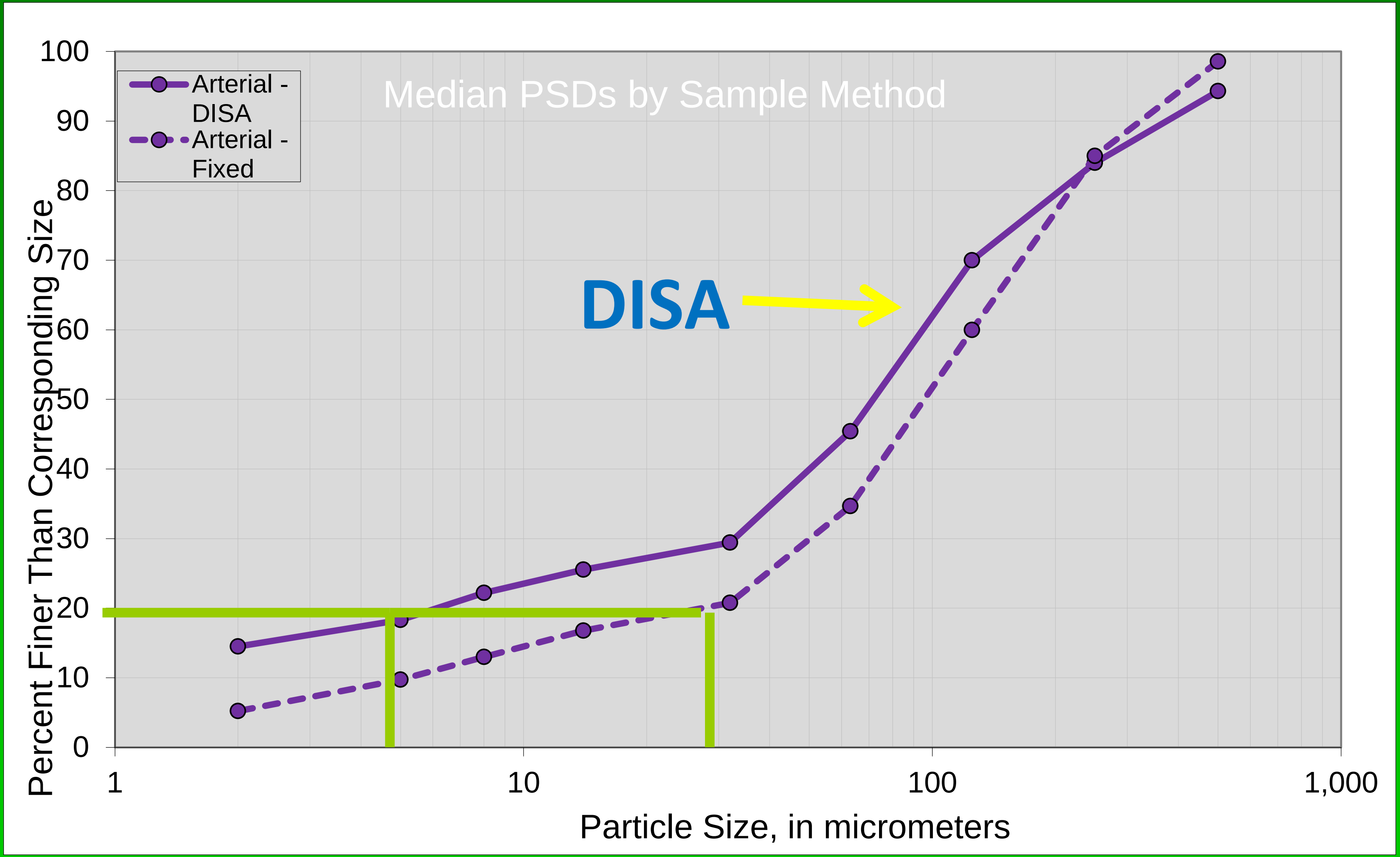

Strip Commercial

# Depth Integrated Sampler (DISA) Reduces Bias and Variability in Concentrations and Distributions Caused by Stratification of Solids

# Field Testing – 30 to 110% Difference Between DISA and Fixed Total P Concentrations



# Field Testing – Median Particle Size Distribution For Arterial Streets Using DISA and Fixed Point Samples



# Standard Land Use Shopping Center (100 acres): Size and Cost of Wet Ponds to Reduce Annual TSS Loads by 80% from Parking Lots.

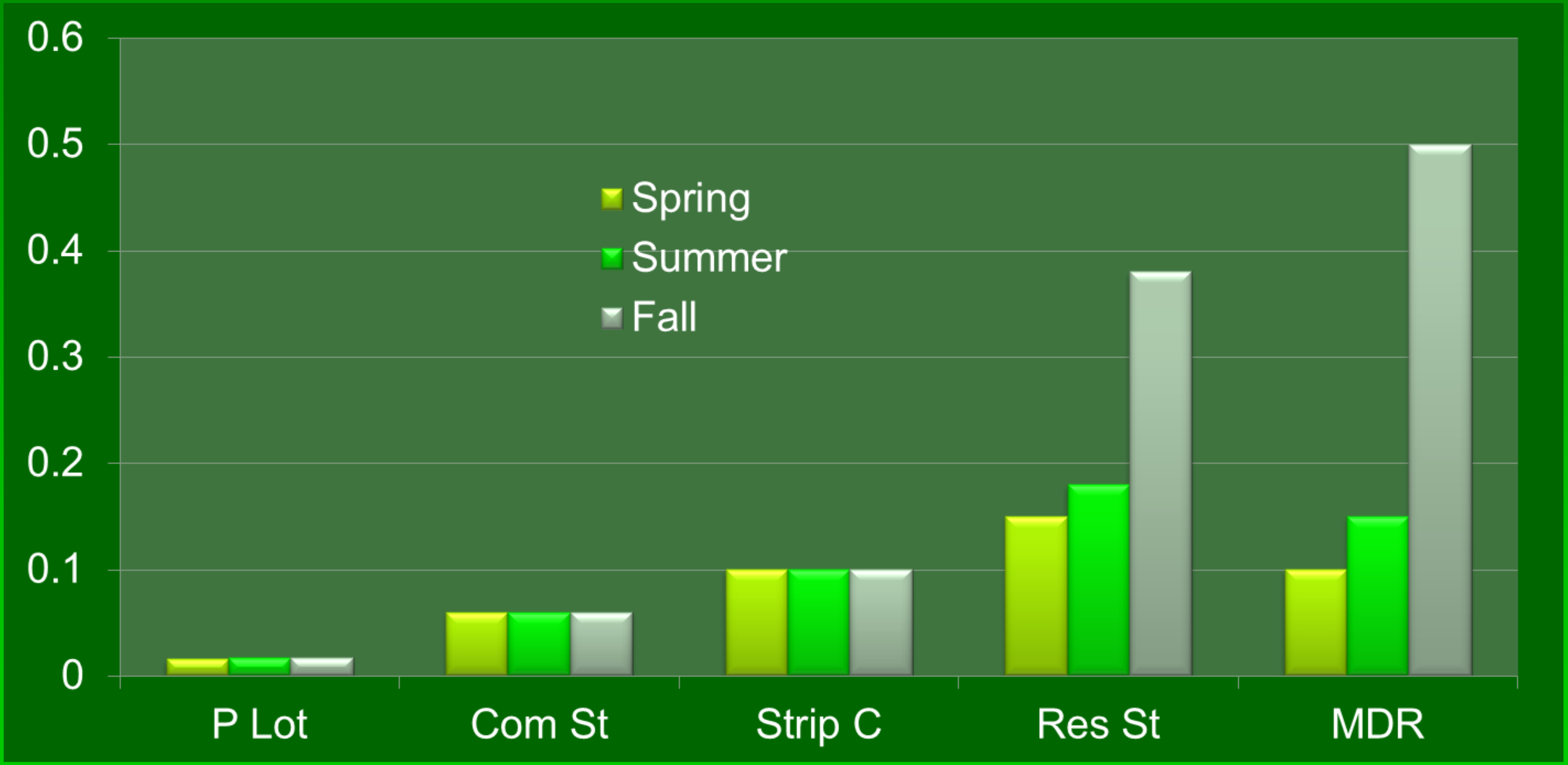

***Size:***

***DISA – 4 acres***
***Fixed – 2 acres***

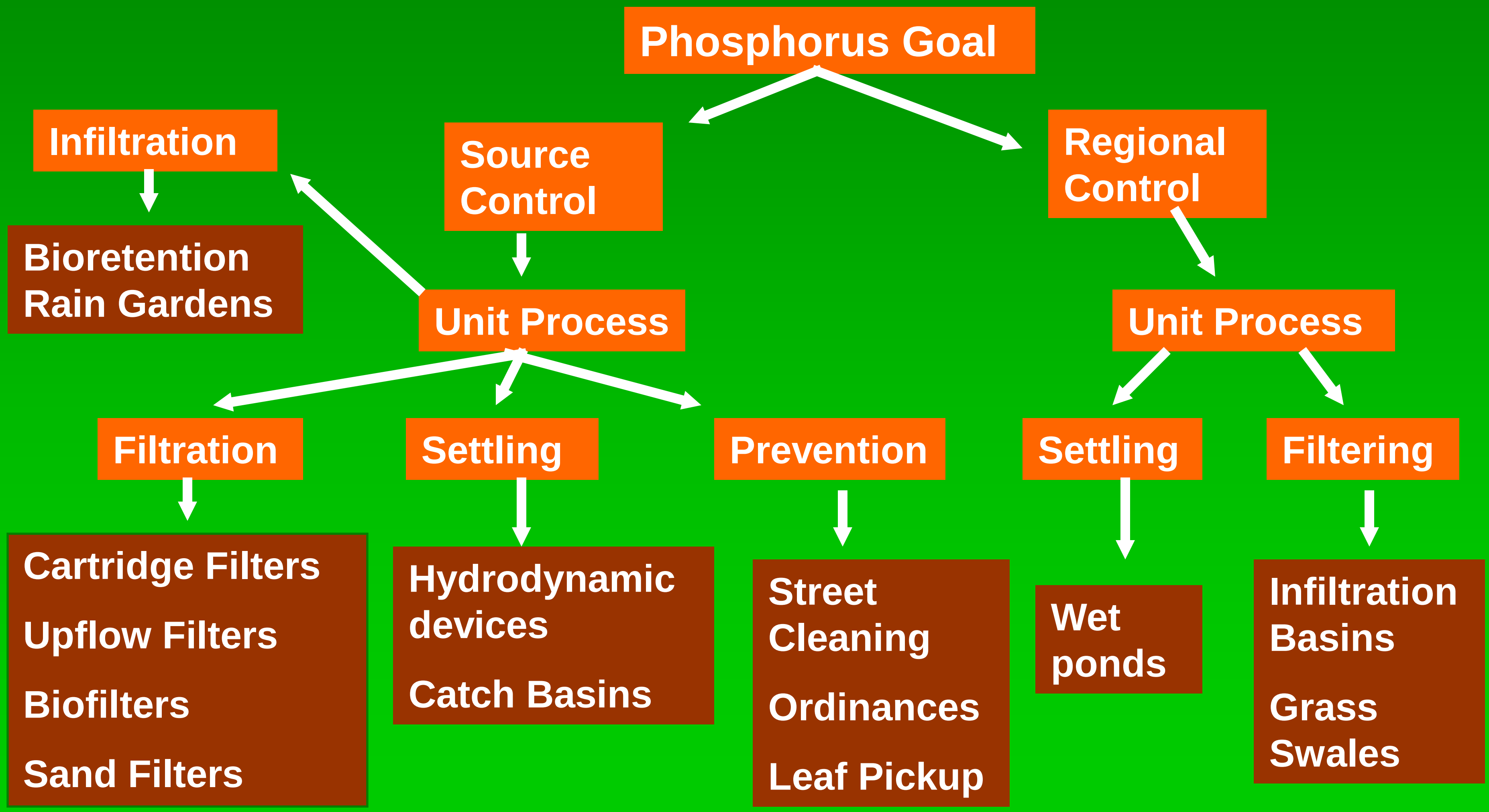
***Capital Cost:***

***DISA - $206,000***
***Fixed - $105,000***

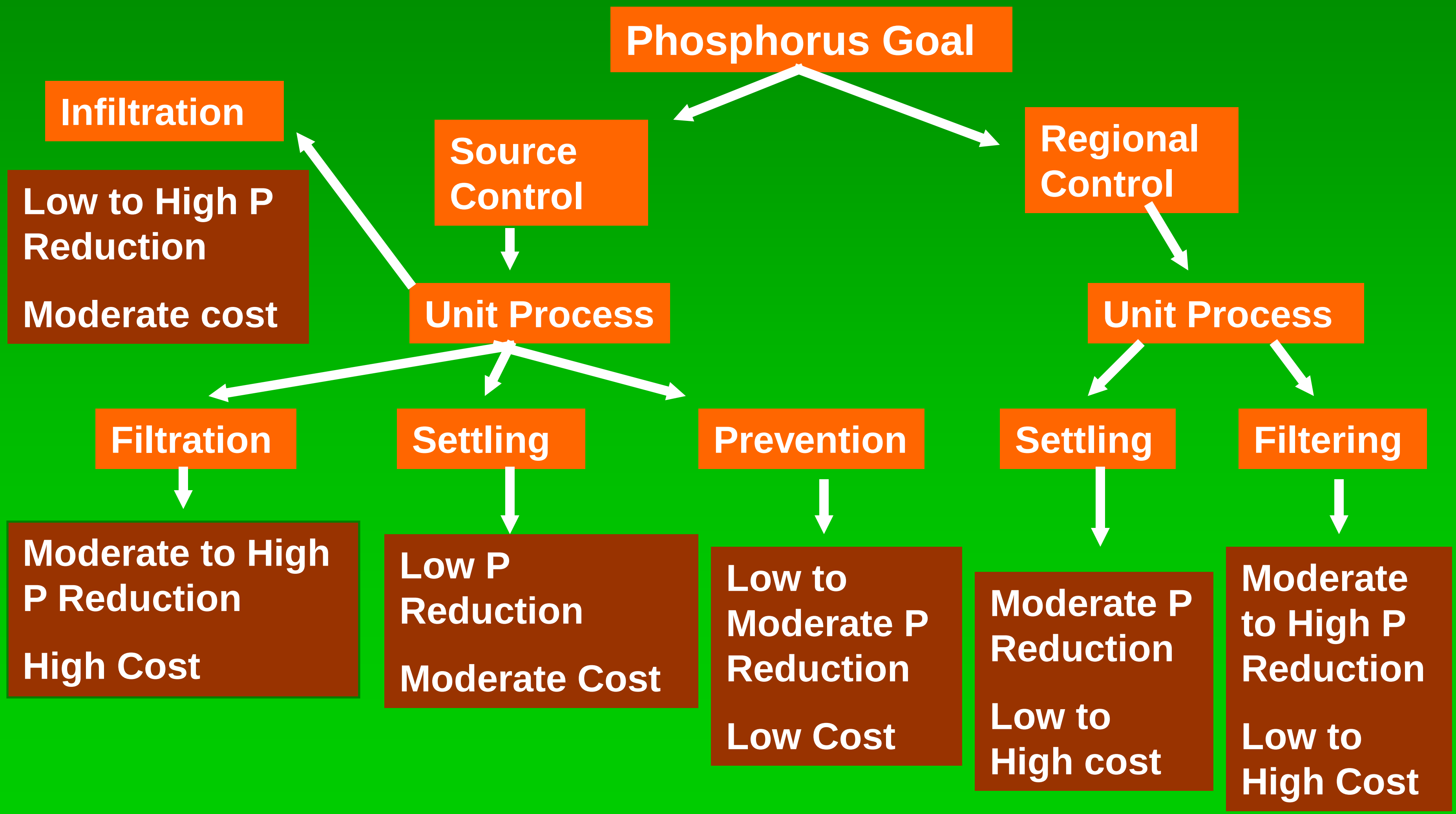
# Seasonal Dissolved P, mg/l, Collected with Automatic Samplers, Selbig, 2012



# How to Select A Stormwater Control Measure



# How to Select A Stormwater Control Measure



# Technical Standards

- Site Evaluation Standard
- Bioretention Standard
- Infiltration Basin Standard
- Grass Swale Standard
- Rain Garden Standard
- Hydrodynamic Separator Standard
- Wet Detention Pond Standard
- **Permeable Pavement Standard**
- Proprietary Filters

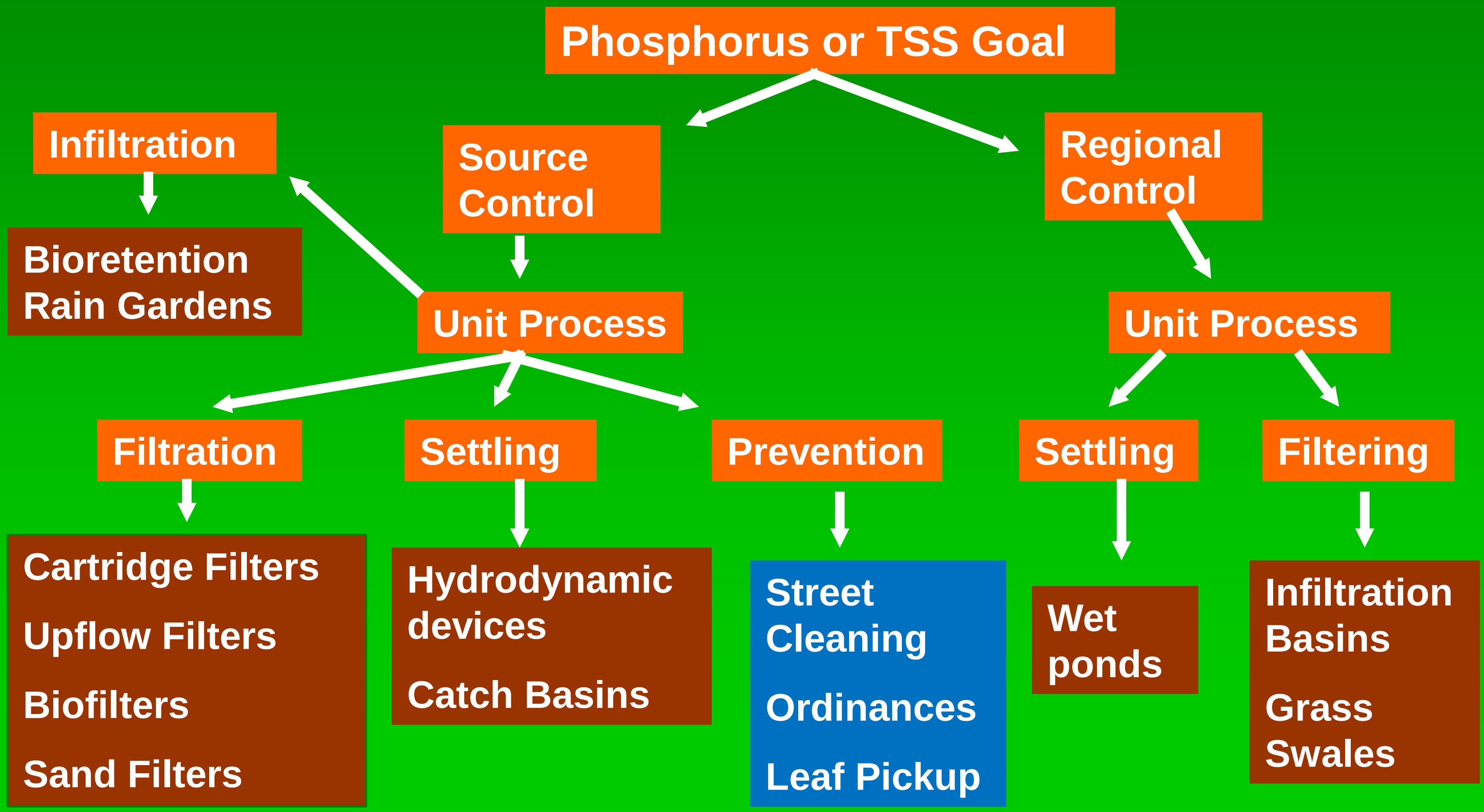
- HTTP://dnr.wi.gov/org/water/wm/nps/stormwater/techstds.htm

# Technical Standards Developed to Support Implementation of Performance Standards in NR 151

**Contents of Technical Std.:**

1. Criteria
2. Considerations
3. Plan or Report
4. Op. and Maintenance

# How to Select A Stormwater Control Measure

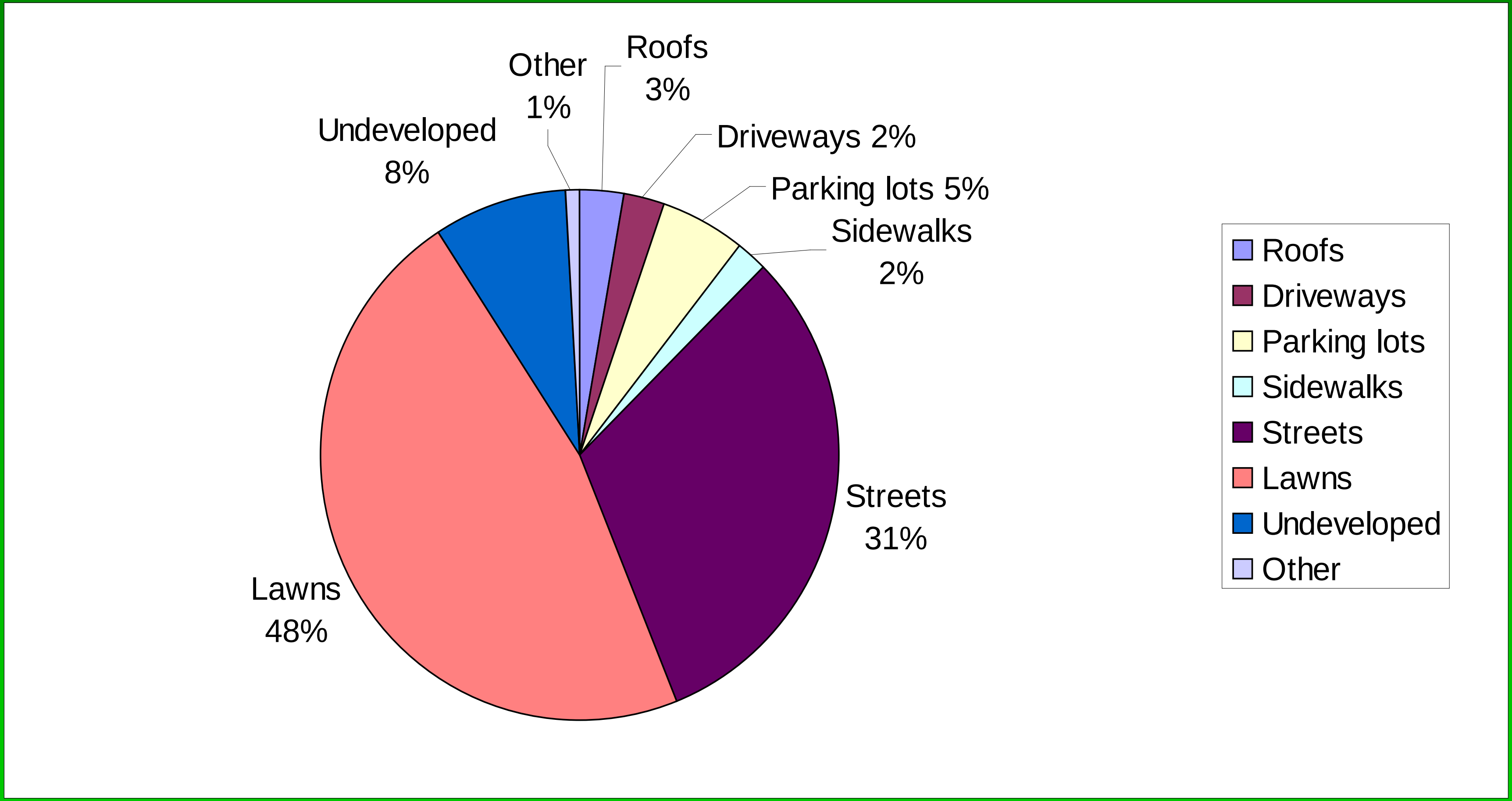


# Reduction in TP Load with P Fertilizer Ban for Lake Wingra Watershed

- Annual TP Load 4000 lbs. (SLAMM)
- 24% of TP Load from Lawns (960 lbs)
- 50% of Homeowners Use Fertilizer (480 lbs)
- 50% Reduction in TP Concentration (240 lbs)
- 240\4000 = 0.06


**6% Reduction in Annual P Load to Lake Wingra**

# Stricker Pond: Allocation of Total Phosphorus load to source areas simulated with SLAMM




**16 % Annual TP Reduction with P Ban**

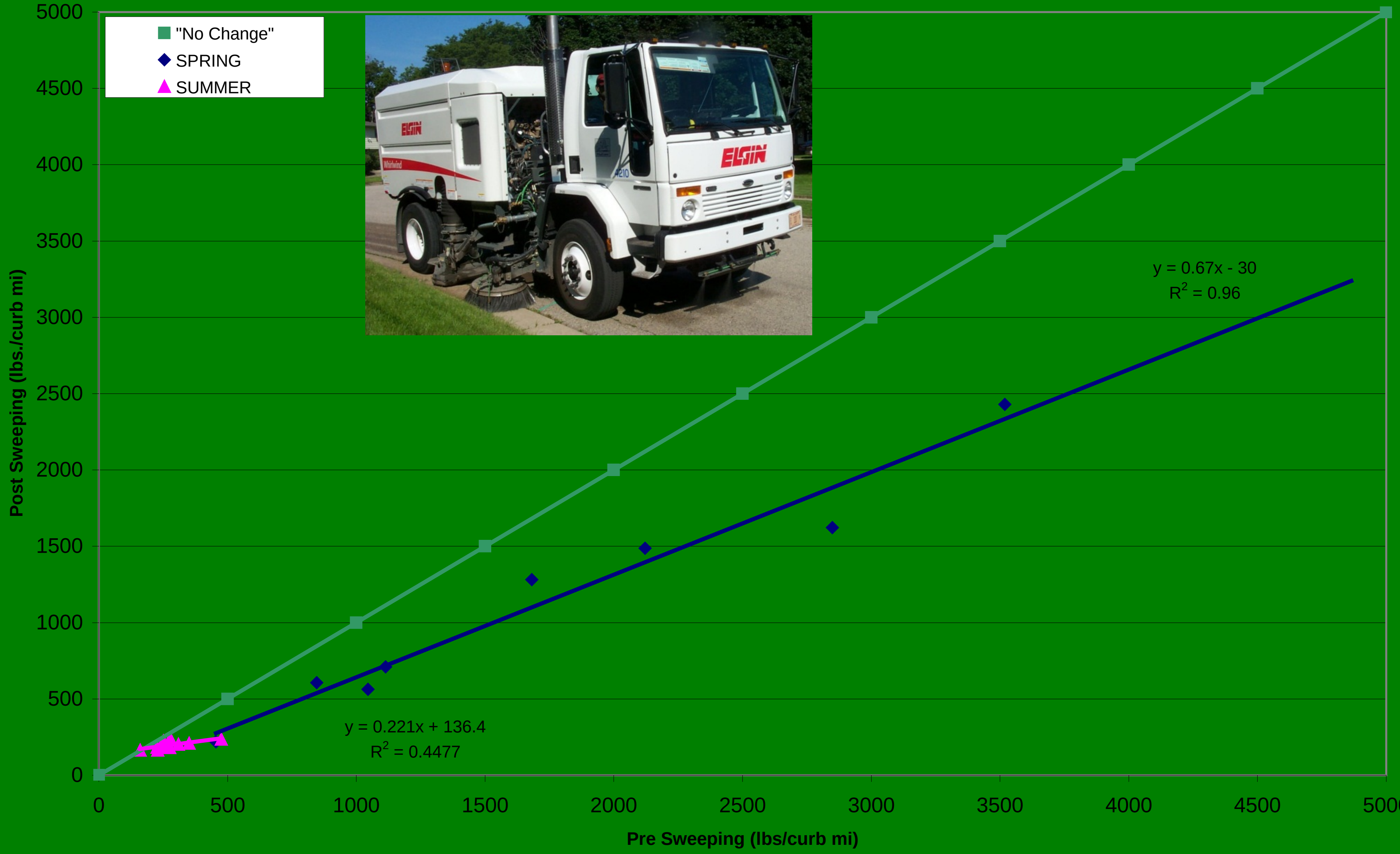
# How Do We Keep Vegetation Out of the Street?


# P Reduction,%, Using Street Cleaning in MDR Assuming No Other Sources of P

| Cleaning Frequency | Vacuum Assisted | | Mechanical Broom | |
|---|---|---|---|---|
| | Multiple Source | Single Source | Multiple Source | Single Source |
| 1/Week | 11% | 30% | 4% | 12% |
| 1/Month | 5% | 14% | 3% | 8% |

Street Loads Measured Before and After Every Cleaning.

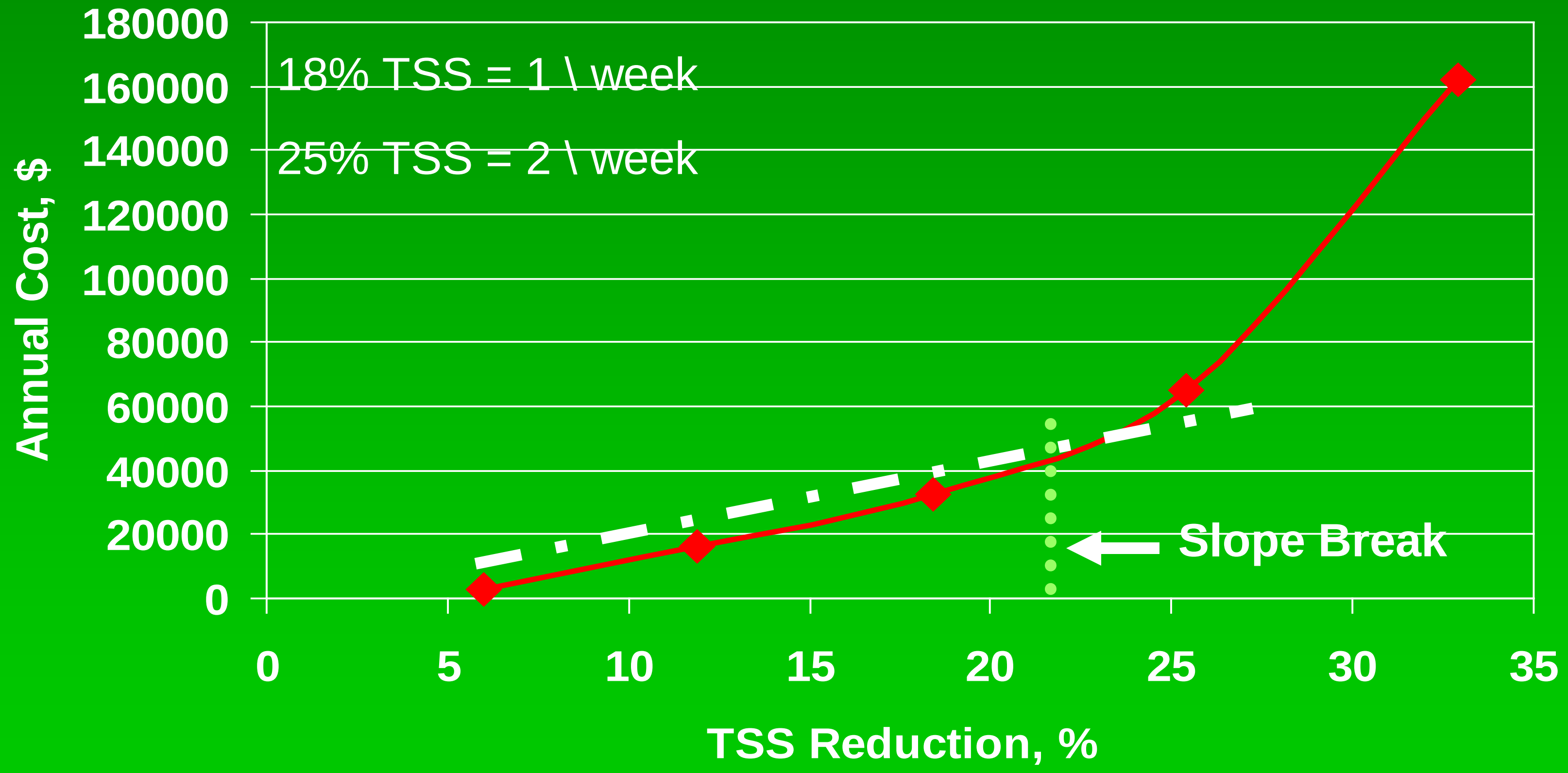
# Vacuum Sweeper



# Annual TSS Reduction, %, for Two Types of Cleaners with Once a Week Frequency, (Total P Reduction)

| Type of Land Use | Parking Density | Broom Street Cleaner | Vacuum Assisted Cleaner |
|---|---|---|---|
| Med. Den. Res. | Light | 7% (6%) | 18% (15%) |
| Strip Comm. | None | 10% (6%) | 20% (11%) |
| Shopping Ctr. | None | 3% | 6% |

# Annual Cost of Vacuum Street Cleaning for Different Cleaning Frequencies in a 100 Acre Medium Density Residential Area




GAS

# Vacuum Assisted Cleaner Productivity Curve for High Traffic Urban

# TSS Reductions for Selected Frequencies on Expanded I-39 with and without large lawn areas – assume clean both curbs

| Street Cleaning Frequency | Percent TSS Reduction Using Vacuum Assisted Machine | | |
|---|---|---|---|
| | No Lawn | 40% Lawn Draining to Freeway | 40% Lawn Not Draining to Freeway |
| 1\week | 70 | 49 | 65 |
| 1\4 weeks | 61 | 42 | 55 |
| 1\8 weeks | 54 | 38 | 49 |


4576



**Street Cleaning After Leaf Collection from Terrace**

# Potential P Reduction with Fall Leaf Collection Program

| Season | Dissolved P, mg/l | Particulate P, mg/Kg | % of Annual Total P Load |
|---|---|---|---|
| Spring-Summer | 0.22 | 2787 | 77% |
| Fall | 0.67 | 4062 | 23% |
| | | | |

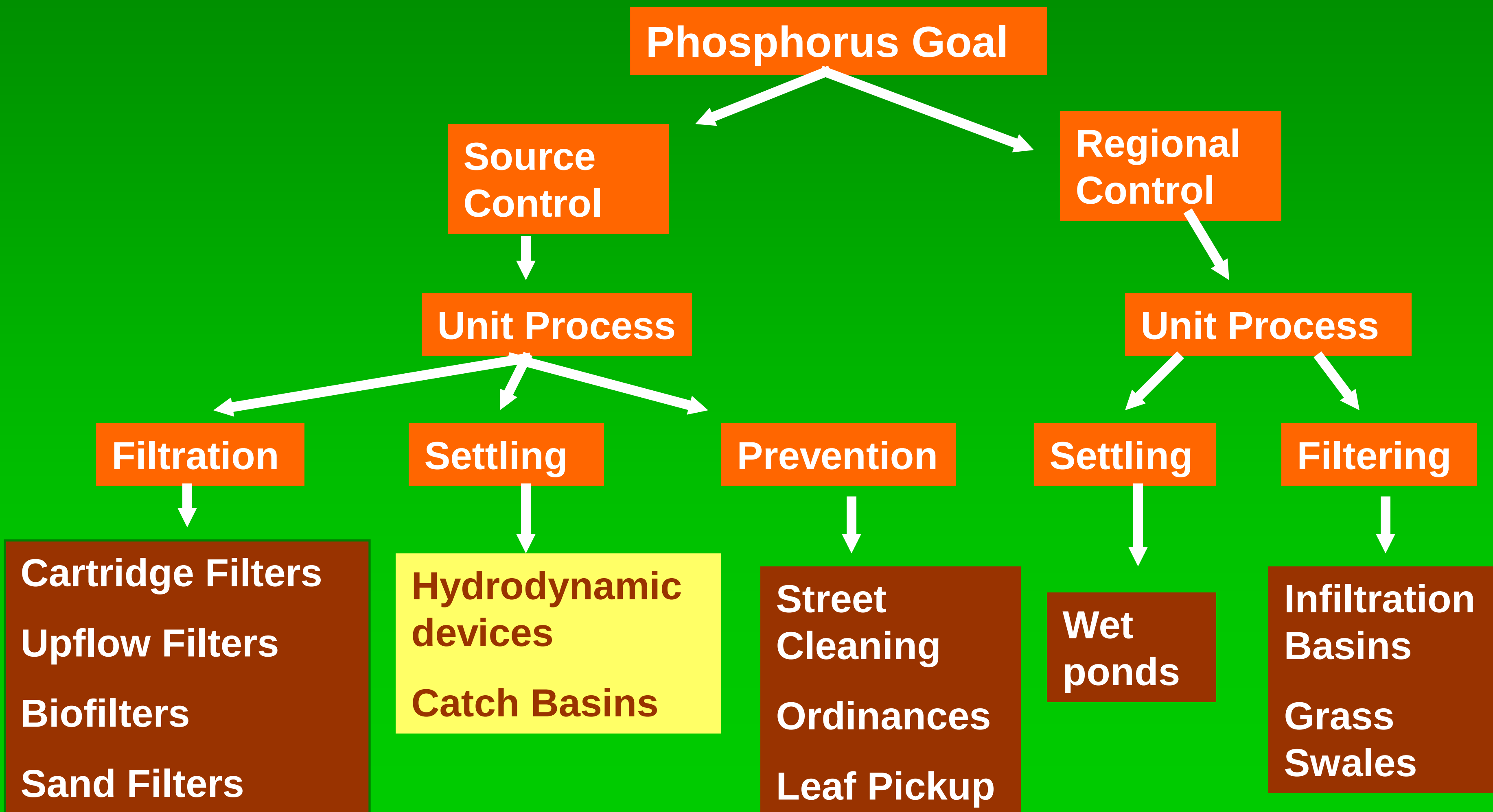
# Leaf Collection Programs to be Evaluated in Study

1. **Base Line: No Street Cleaning in Fall**

2. **Present Program: Street Cleaning 1/month & Clean After Leaf Collection**

3. **Extra Effort: More Frequent Street Cleaning & Put Leaves in Bags.**

# How to Select A Stormwater Control Measure

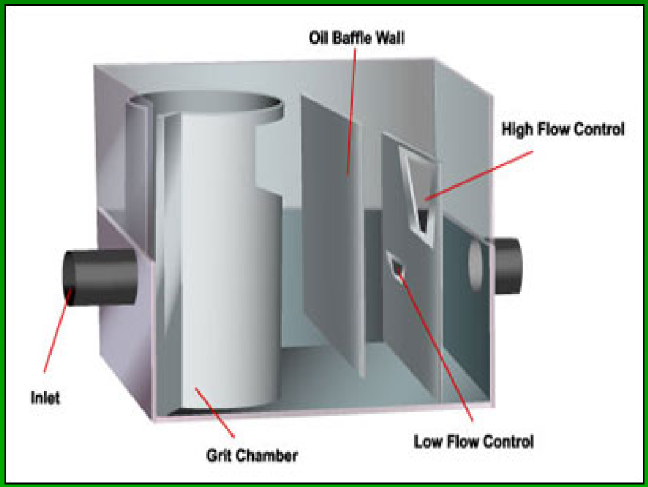


# SOC Technical Standard 106: Predicting Efficiency of Proprietary Sediment Control Devices

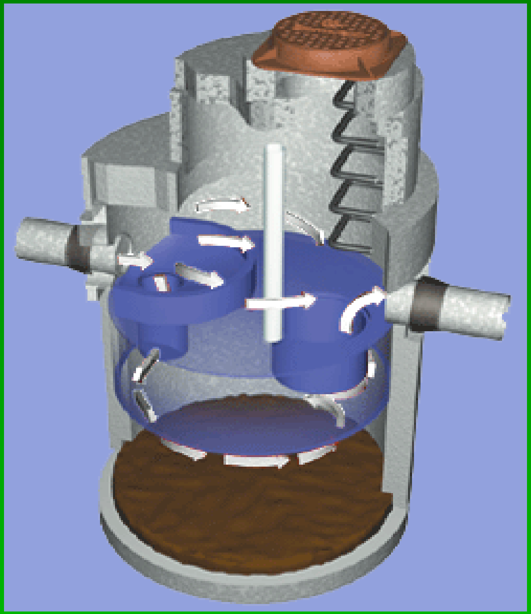
**Joint Custodianship:**

**WI DNR (NR 151) & WI Dept. of Commerce (COMM 82)**

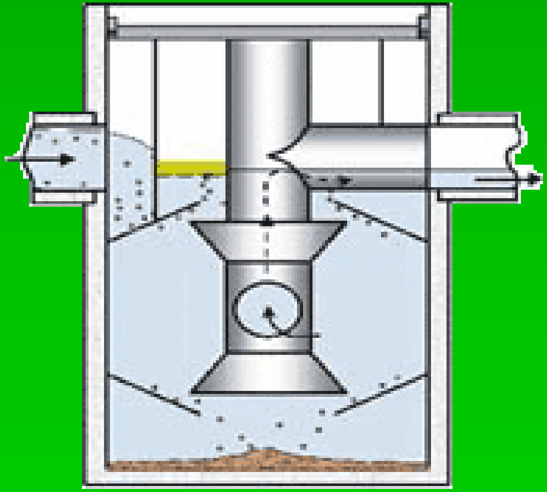
# Examples of Proprietary BMPs Using Settling for Treatment




**Vortechs**



**Stormceptor**

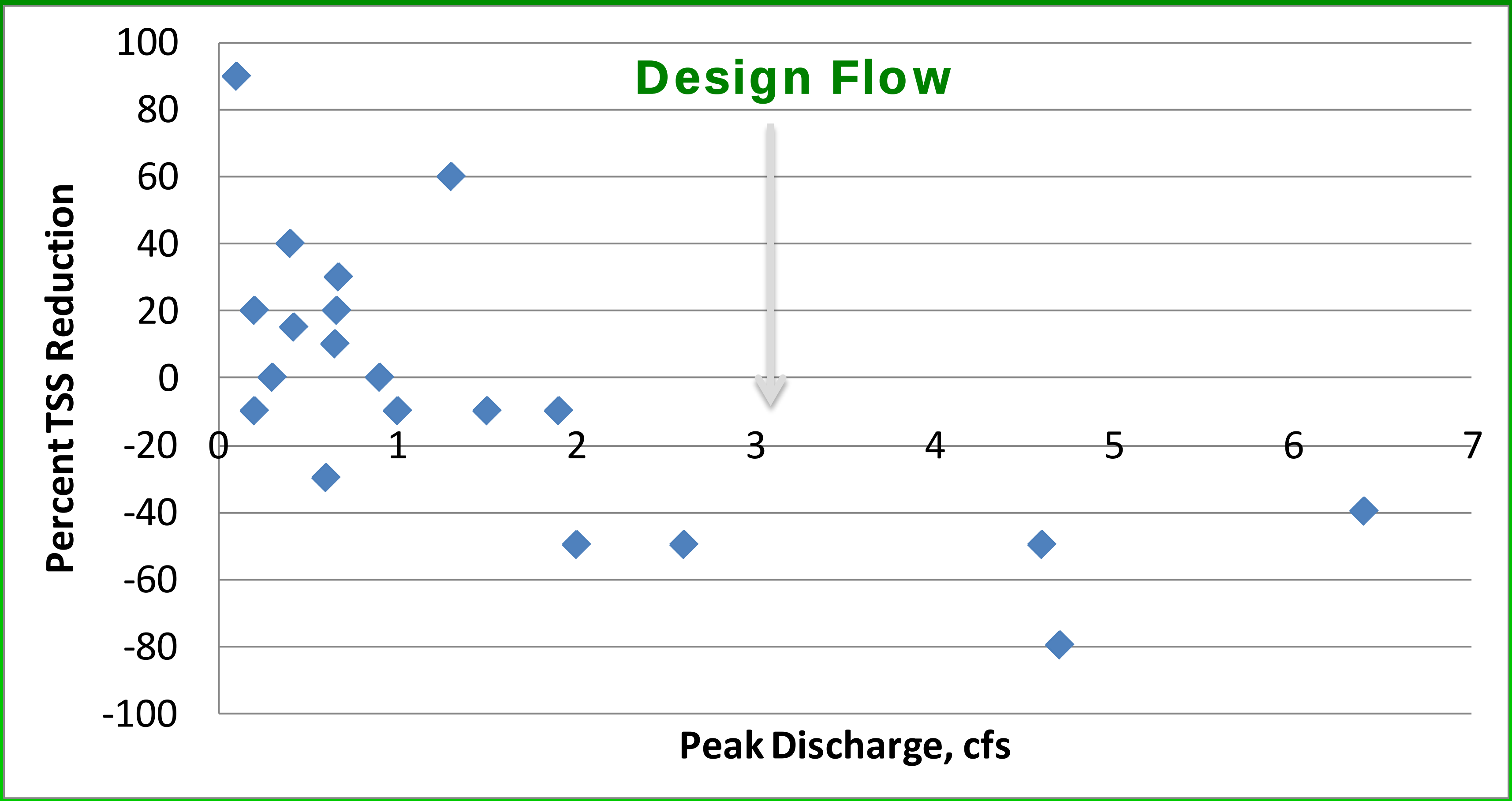


**DownStream Defender**

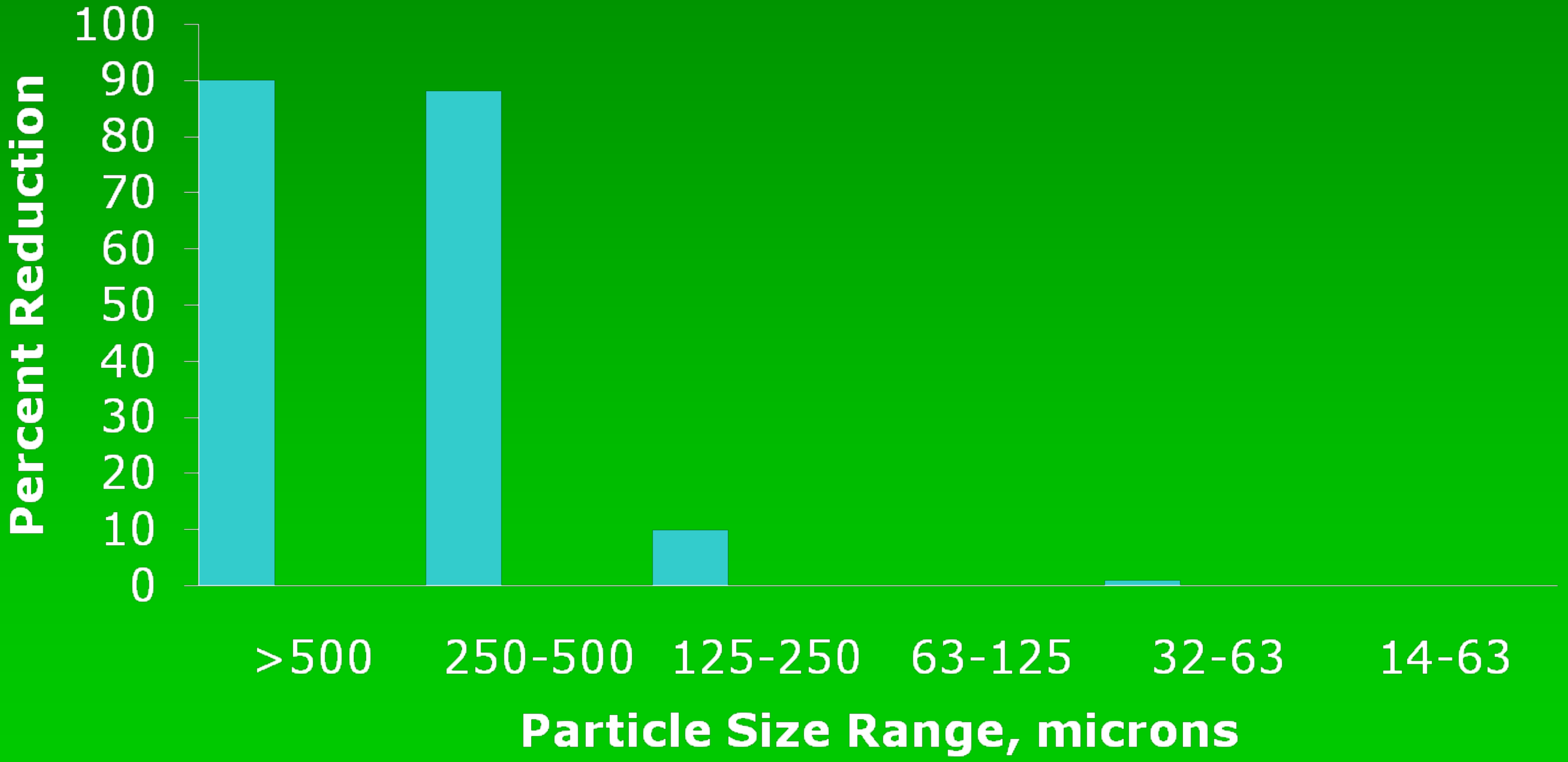
**Criteria:**

1. Method for reducing scour
2. TSS reduction based on WinSLAMM or other approved model

# TSS Reduction as a Function of Peak Discharge



# TSS Sum of the Loads by Particle Size



# Phosphorus Load Reduction for Three Single Chamber Settling Devices

| Type of Load | Dissolved P | Total P | TSS |
|---|---|---|---|
| **Vortechs** (18 events, no bypass) | **0%** | **10** | **25%** |
| **Downstream Defender** | **5%** | **2%** | **22%** |
| **Stormceptor** | **17%** | **17%** | **21%** |

Total Basin Area: 0 acres

1. Area served by catchbasins (acres): 0.00

2a. Catchbasin density (cb/ac):

2b. Number of Catchbasins:

3. Average sump depth below catchbasin outlet invert (ft): 0.00

4. Depth of sediment in catchbasin sump at beginning of study period (ft): 0.00

5. Typical outlet pipe diameter (ft): 1.00

6. Typical outlet pipe Manning's n: 0.013

7. Typical outlet pipe slope (ft/ft): 0.020

8. Typical catchbasin sump surface area (sf): 0.0

9. Catchbasin Depth from Sump Bottom to street level (ft): 0.0

10. Inflow Hydrograph Peak to Average Flow Ratio 3.8

11. Leakage rate through sump bottom (in/hr) 0.00

12. Select Critical Particle Size file name:

Typical Catchbasin Densities

- Low density residential (0.25 inlets/acre)
- Medium density residential (0.5 inlets/acre)
- High density residential (1 inlet/acre)
- Strip commercial (1.2 inlets/acre)
- Shopping center (1.2 inlets/acre)
- Industry (0.8 inlets/acre)
- Freeways (1 inlet/acre)

---

Catchbasin Cleaning Dates

| Catchbasin Cleaning No. | Catchbasin Cleaning Date (mm/dd/yy) |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |

**Select**

OR

Catchbasin Cleaning Frequency

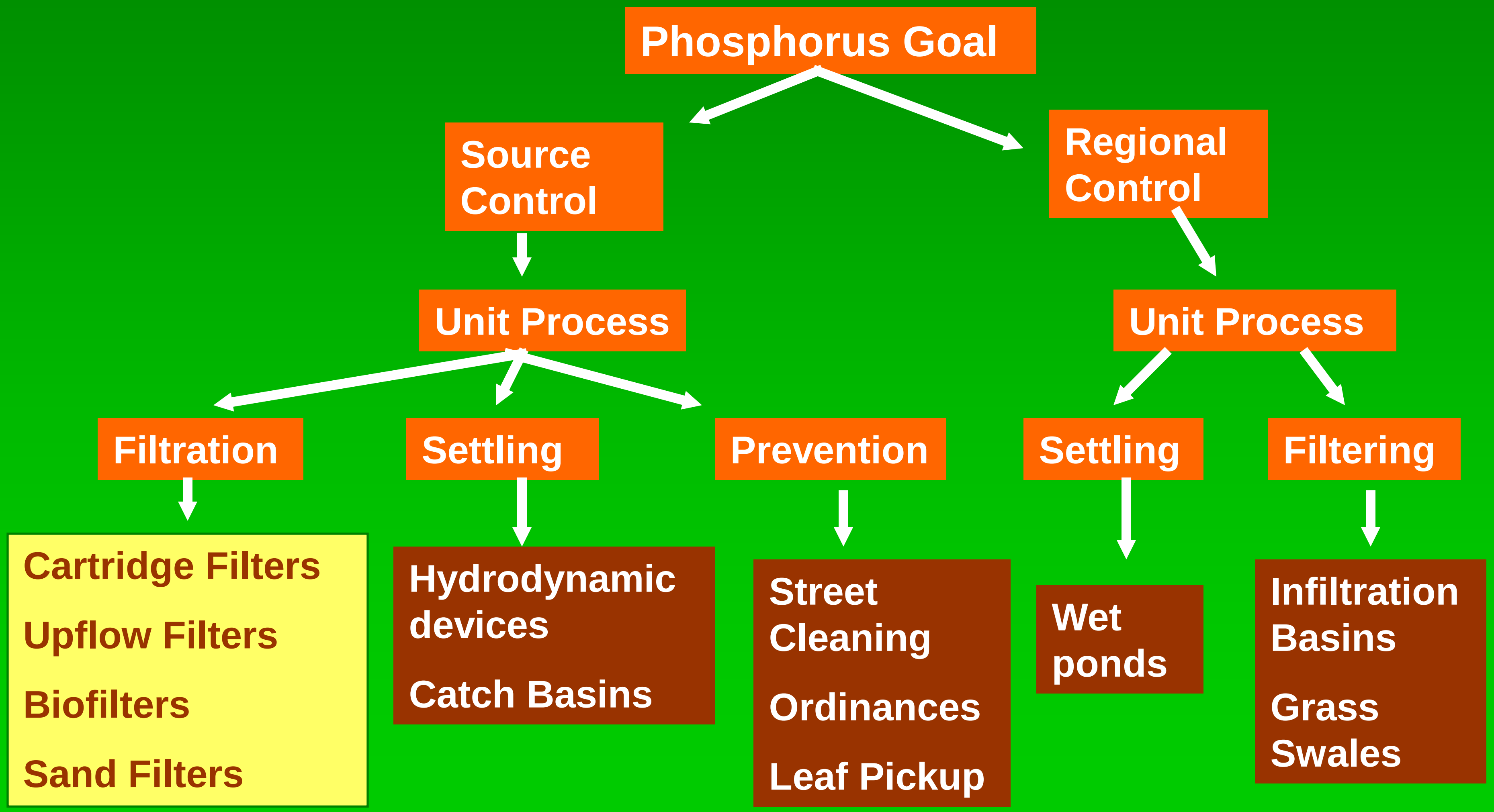
- Monthly
- Three Times per Year
- Semi-Annually
- Annually
- Every Two Years
- Every Three Years
- Every Four Years
- Every Five Years

Inflow Bypass Data

Continue | Clear | Cancel | Delete Control


CASE

# How to Select A Stormwater Control Measure



# Technical Standards

- Site Evaluation Standard
- **Bioretention Standard**
- Infiltration Basin Standard
- Grass Swale Standard
- Rain Garden Standard
- Hydrodynamic Separator Standard
- Wet Detention Pond Standard
- Permeable Pavement Standard
- Proprietary Filters

- HTTP://dnr.wi.gov/org/water/wm/nps/stormwater/techstds.htm

# What are Criteria in Technical Standard 1004 and Why

Depth Of Surface Pond: < 12 inches

Design drawdown rate: < 24 hours

Total device drawdown: < 72 hours

**Justifications:**

1. Limit submergence of plants
2. Prevent compaction
3. Minimize clogging
4. Design for frequent WQ events
5. Safety

# Soil Mixing

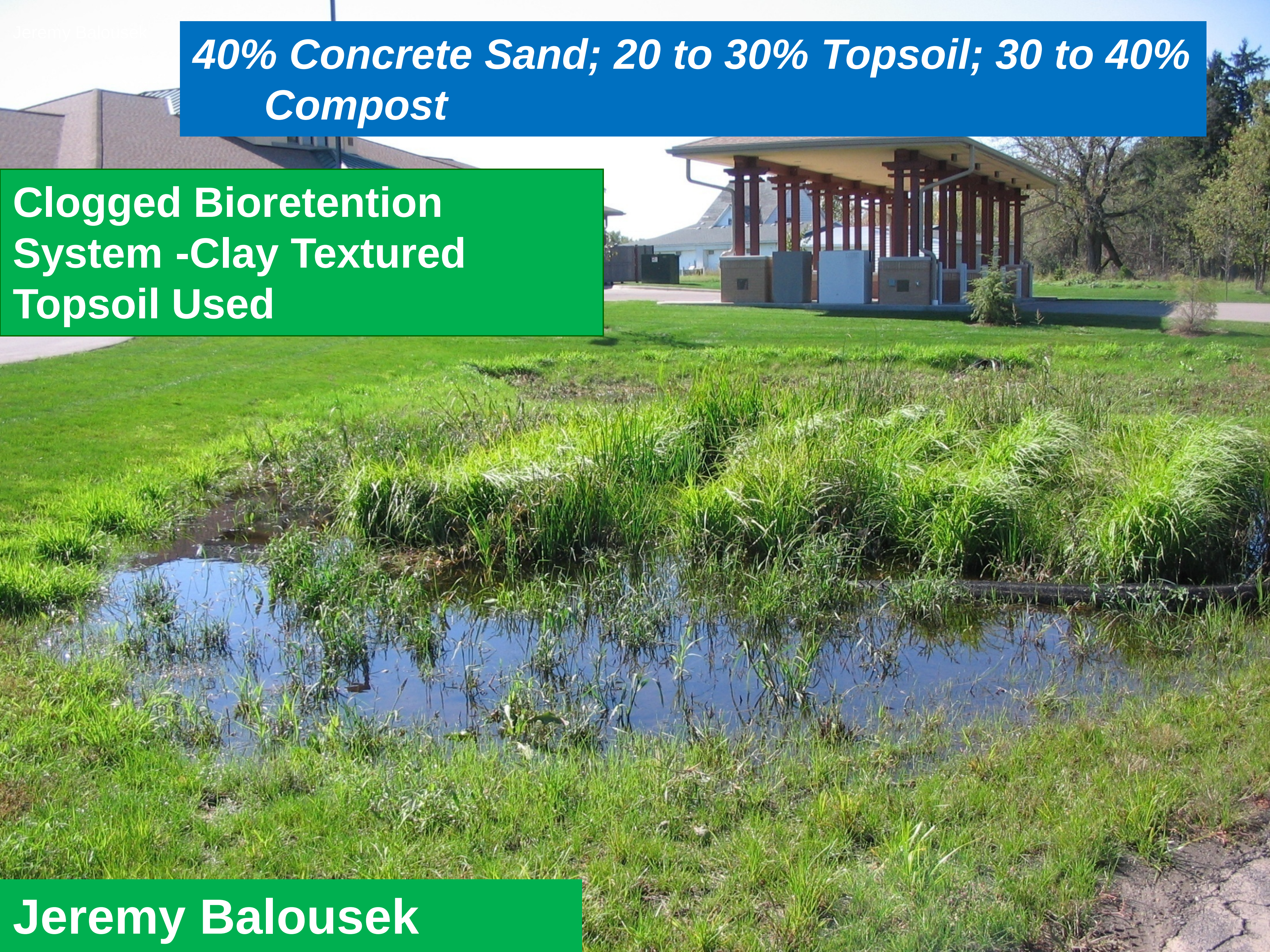
Technical Standard 1004 trying to achieve a balance between:

**1. Adequate infiltration rate**
**2. Reducing pollutant concentration**
**3. Supporting plant growth**
**4. Sodium Adsorption Ratio (SAR)**
**5. Cost**

# Criteria for Bioretention Engineered Soil Mix – Technical Standard 1004

Jeremy Balousek

1. ***40% Concrete Sand; 20 to 30%Topsoil; 30 to 40% Compost***
2. ***50% sand/50% compost***
3. ***70 to 85% Sand/15 to 30% Compost***
4. ***85% Sand, 10% fines, 5% Bark***
5. **86% Sand; 11% Peat Moss; 3% SorbtiveMedia (Imbrium)**


40% Concrete Sand; 20 to 30% Topsoil; 30 to 40% Compost
Clogged Bioretention System -Clay Textured Topsoil Used
Jeremy Balousek

**Modify Technical Standard 1004:**
**50% Concrete Sand (ASTM C33)**
**50% Compost**

Linda and Mark Piotrowski
28020 El Dorado Place, Lathrup Village

# Location of Biofilter Study – City of Neenah, WI

# Evaluate Effect of Engineered Soil Depth on Pollutant Removal


**Three Depths:**
- **1 foot**
- **2 feet**
- **3 feet**

McMAHON ENGINEERS ARCHITECTS

USGS science for a changing world

# Neenah Biofilters – Clay Soils and High Bedrock

## Geosynthetic Fabric and Perforated Drain Pipe

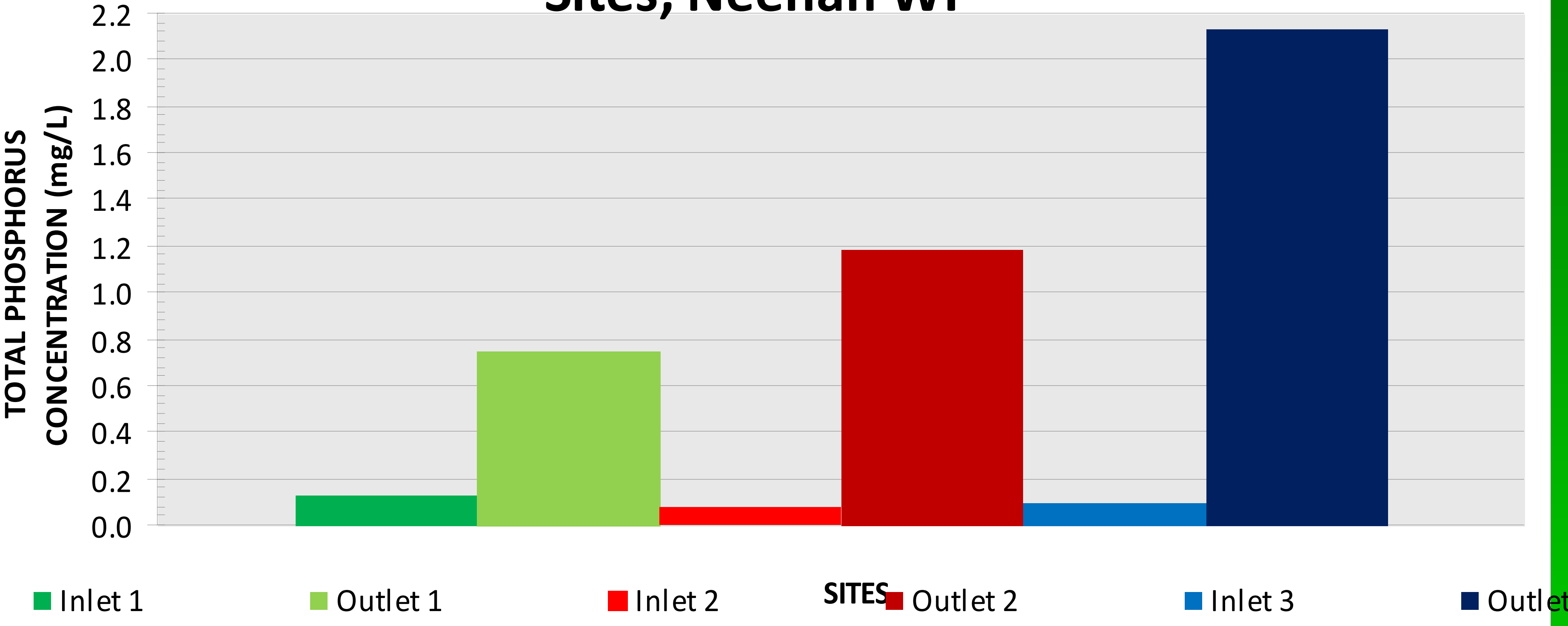
Perforated Drain Pipe & Filter Sock

# Efficiency Ratios for TSS:

Eff Ratio = 1- ( avg. outlet conc./avg. inlet conc.)

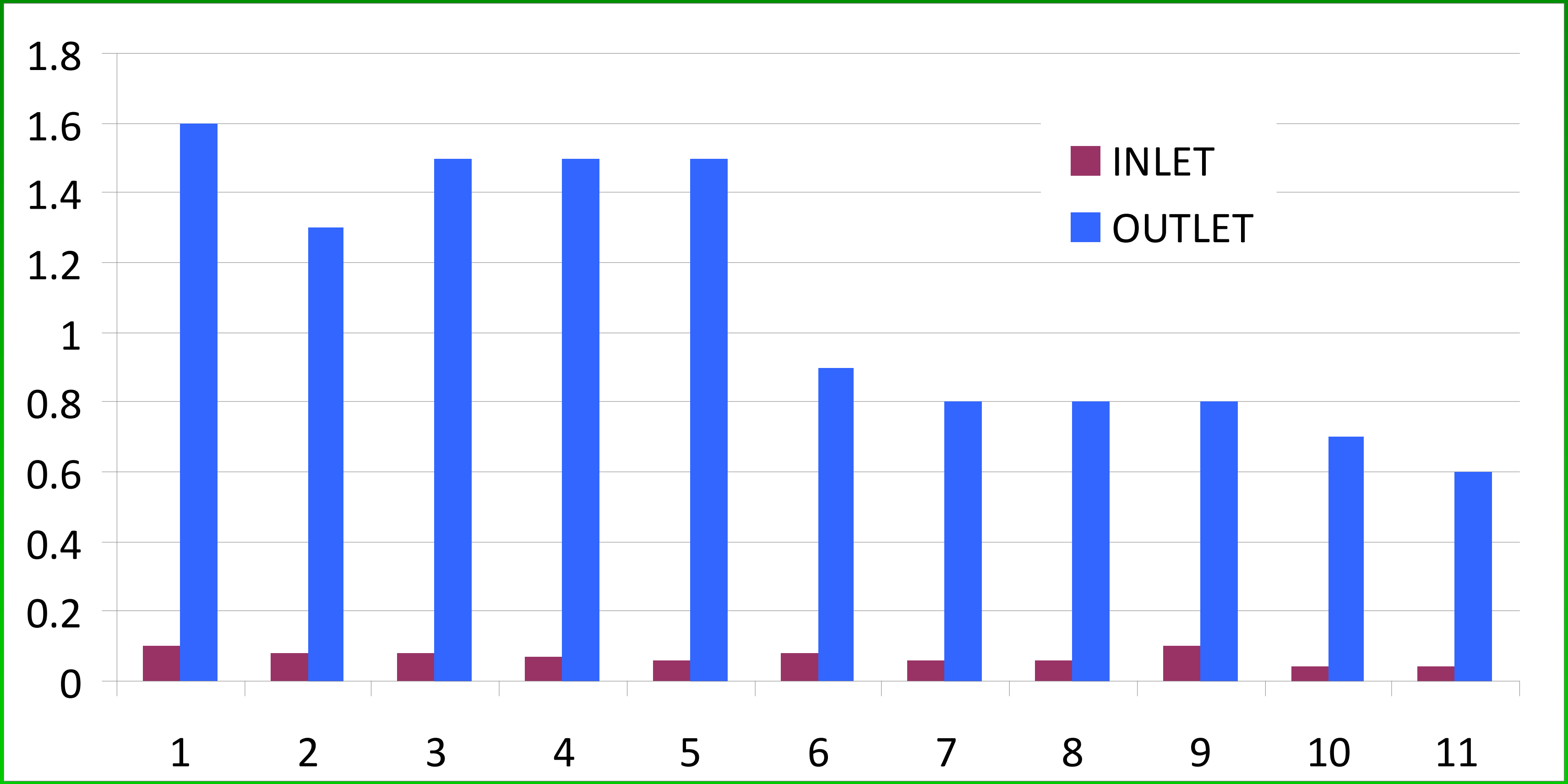
| Site | Inlet TSS, mg/l | Outlet TSS, mg/l | Efficiency Ratio TSS, % |
|---|---|---|---|
| Cell 1 (11) | 144 | 23 | 84 |
| Cell 2 (13) | 31 | 7 | 77 |
| Cell 3 (13) | 28 | 8 | 68 |

## Comparing Average Inlet and Outlet Total Phosphorus Concentration for Three Bioretention Sites, Neenah WI




| | | |
|---|---|---|
| Cell 1 | 0.75 mg/l | -494% |
| Cell 2 | 1.2 mg/. | -1463% |
| Cell 3 | 2.1 mg/l | -2091% |

# Total Phosphorus Concentrations, mg/l, at the Inlet and Outlet of 2 Foot Depth Media



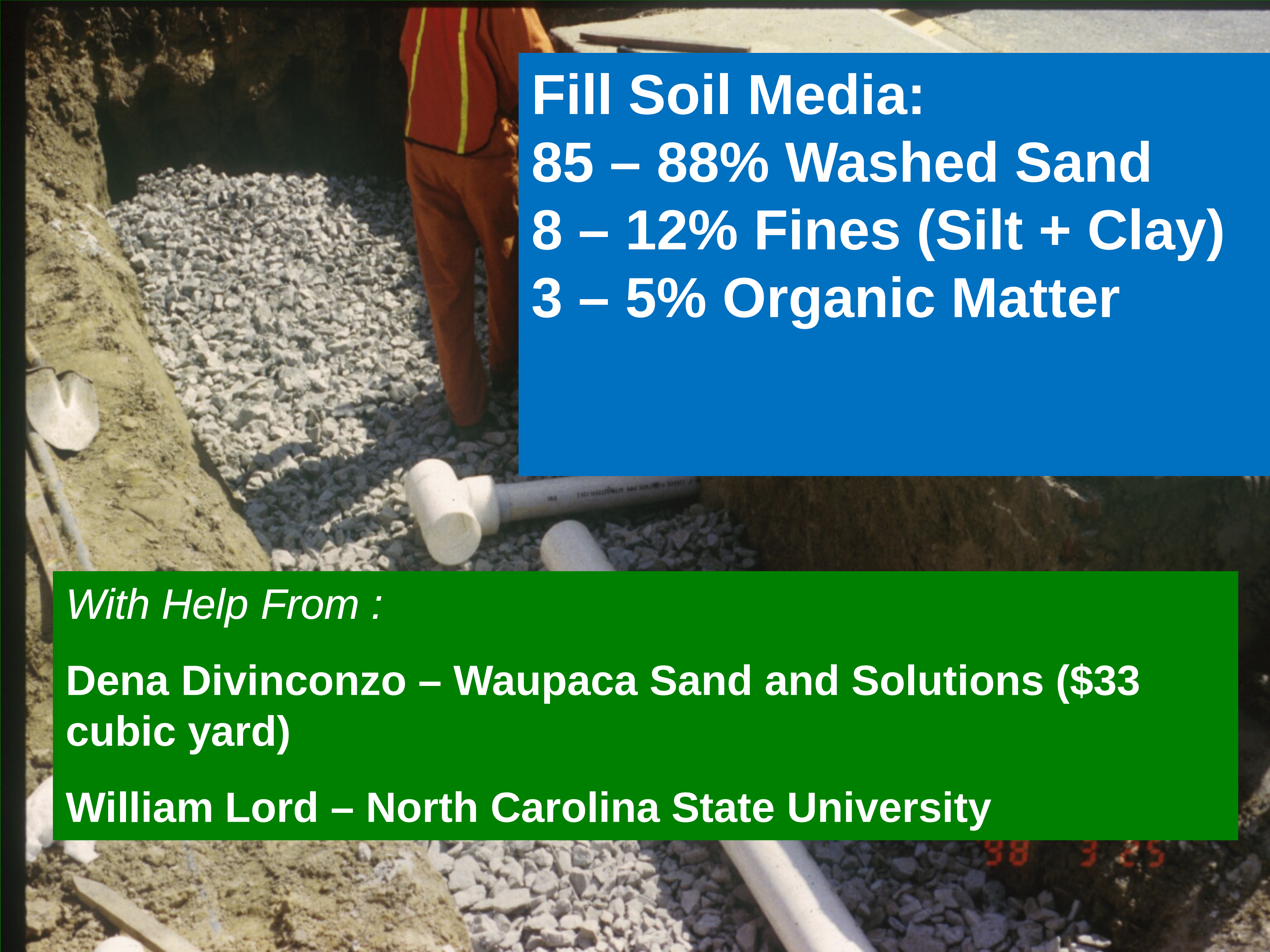
# Simulating Event with City Water to Detemine Mobility of Media Particles

| Type of Value | 2 Foot Depth Media | 3 Foot Depth Media |
|---|---|---|
| City Water - Inlet TSS | < 2 mg/l | < 2 mg/l |
| City Water - Outlet TSS | 3 | 3 |
| Media Outlet TSS | 3 | 7 |
| City Water – Outlet TP | 0.6 | 0.9 |
| Media Outlet TP | 0.6 | 0.9 |
| Particle Size - Outlet | < 63 microns | < 63 microns |

# Immediate Change to Bioretention Engineered Soil Mix – Technical Standard 1004


**The planting mix shall consist of 70 to 85% sand and 15 to 30% compost**

# Adam St. Inlets to Rain Gardens



# Fill Soil Media:

**85 – 88% Washed Sand**

**8 – 12% Fines (Silt + Clay)**

**3 – 5% Organic Matter**

*With Help From :*

**Dena Divinconzo – Waupaca Sand and Solutions ($33 cubic yard)**

**William Lord – North Carolina State University**

# Performance – Austin Filter – 18 to 24 inches

| | Univ. of New Hampshire | % Reduction-CALTRAN |
|---|---|---|
| TSS | 80 | 90 |
| Total P | 30 | 39 |
| Diss. P | | 24 |
| Total Zn | 95 | 80 |


# New Mix at USGS Parking Lot – Special Focus SAR Effect

# What About Removing Dissolved Phosphorus & SAR Effect ?


1. **Conduct Leaching Tests on Old and NCSU Mix**
2. **Determine Best Additive to Enhance P Sorption.**

**Mauricio Avila and Philip Barack- University Soils and Plant Lab. & Soils Dept.**

# Choices of Additives to Reduce Dissolved P

# New Media for Three Tests Systems in Neenah – Technical Standard 1004

Jeremy Balousek

86% Sand; 11% Peat Moss; 3% SorbtiveMedia (Imbrium) –

No SAR Effect & Dissolved P Reduction

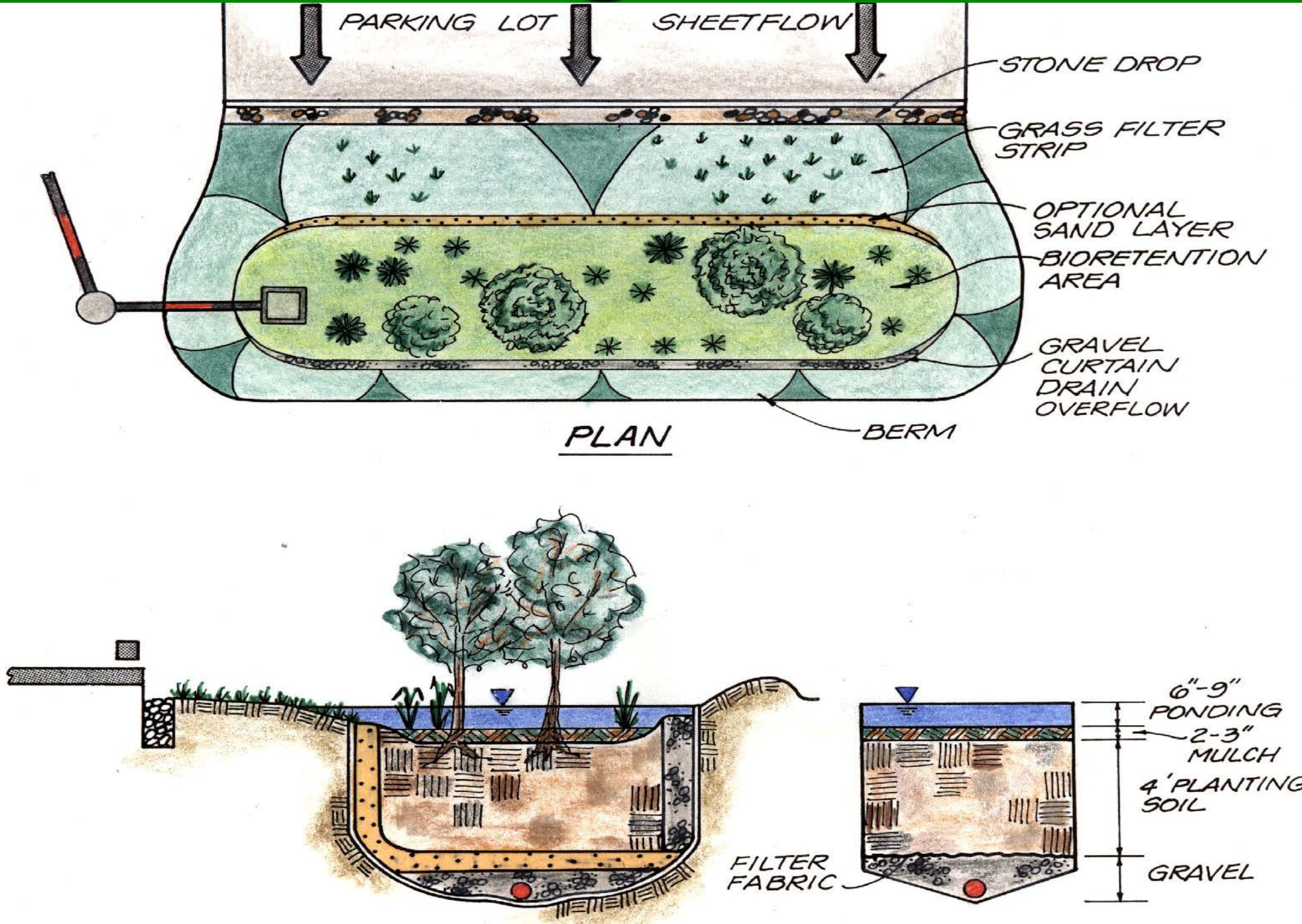




# Replacing Media at Neenah Sites

New Media (McMahon) 2 feet deep; 86% Concrete Sand, 11% Peat Moss, and 3% SorbtiveMedia

# Bioretention Facility Diagram



# Groundwater Contamination Potential for Sandy Loam (0.1%TOC)

| *Compound* | *Contamination Potential* |
|---|---|
| Nutrients (Nitrates) | Low/Moderate |
| Pesticides | Low/Moderate |
| Other Organics | Low/Moderate |
| Pathogens | Moderate/High |
| Heavy Metals | Low |
| Salts | High |

# Examples of Stormwater Contaminating Groundwater

*Pesticides:*

Fresno,CA Diazinon

Florida Diazinon, 2.4-D, etc.

*Organics:*

Florida Phthalates

Long Island Phthalates, toulene, etc.

*Pathogens:*

Long Island viruses

*Heavy Metals:*

Maryland chromium lead, cadmium

*Salts:*

Maryland chloride

# Site Characteristics Effecting Risk of Groundwater Contamination

- Landuse
- Soil Texture
- Total Organic Carbon Content of Soils
- Depth to Groundwater
- Thickness of soil layer
- Amount of Rainfall

# Technical Standards

- Site Evaluation Standard
- Bioretention Standard
- Infiltration Basin Standard
- Grass Swale Standard
- Rain Garden Standard
- Hydrodynamic Separator Standard
- Wet Detention Pond Standard
- Permeable Pavement Standard
- **Proprietary Filters**

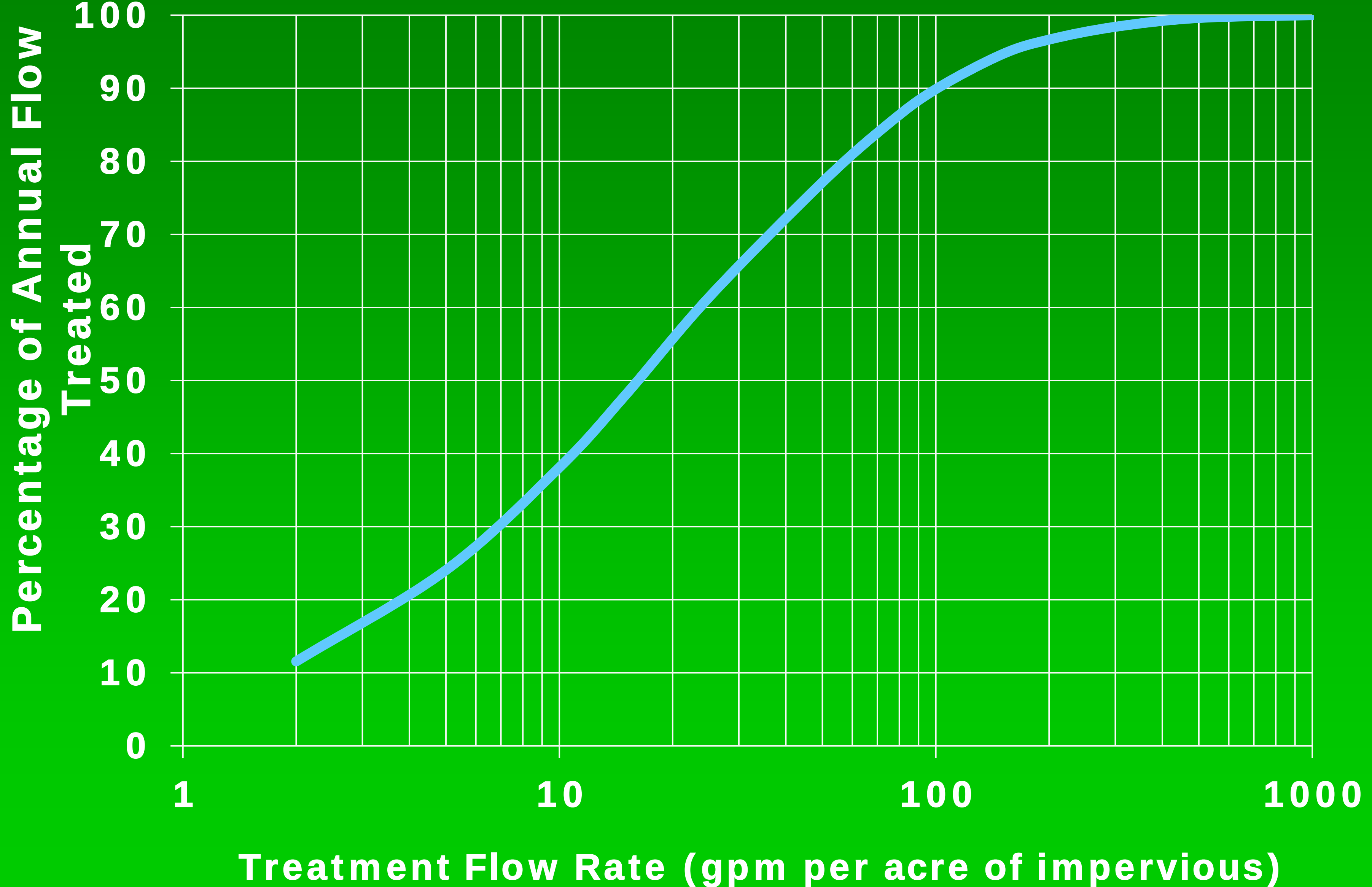
- HTTP://dnr.wi.gov/org/water/wm/nps/stormwater/techstds.htm

# Method for Estimating TSS Reduction

1. Determine treatment flow rate and apply constant % reduction.
2. Develop particulate solids performance data for the different particle sizes and flow rates for each media type.

Both approaches require performance data for each type of filter and media

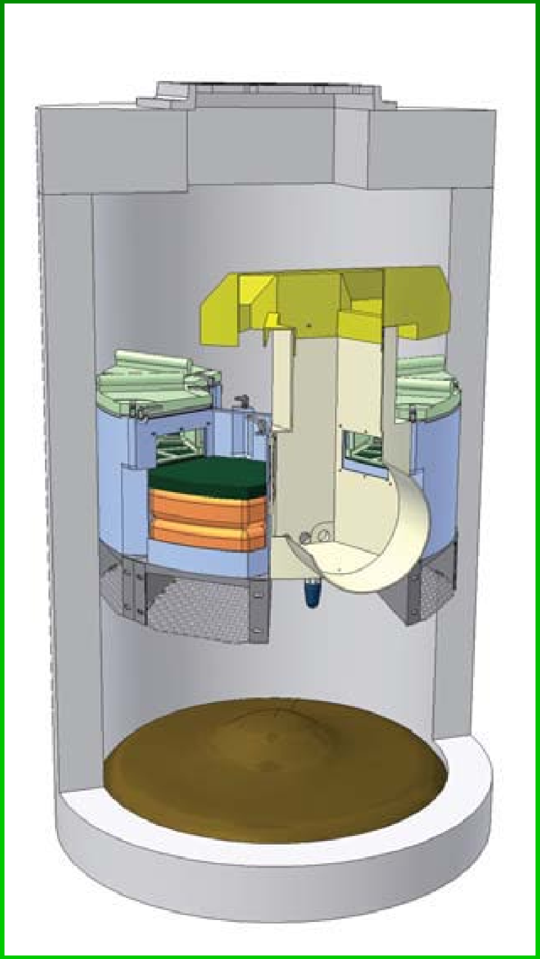
# Percentage of Annual Flows Treated for Different Treatment Flow Rates (Pitt, 2010)



# 80% SSC Load Reductions (95% annual flow treated at 85% reductions)(Pitt, 2010)

| Control Option | Storage Volume, $ft^3$\acre | Treatment Flow Rate, gpm/acre | Costs/acre of imp. |
|---|---|---|---|
| 1 | 0 | 160 | $63,000 |
| 2 | 228 | 160 | $63,000 |
| 3 | 1240 | 130 | $62,000 |
| 4 | 2310 | 100 | $71,000 |

# TSS Reduction with Sil-Co-Sil 106 – 20% Sand & 80% Silt



Upflow Filter (Hydro)

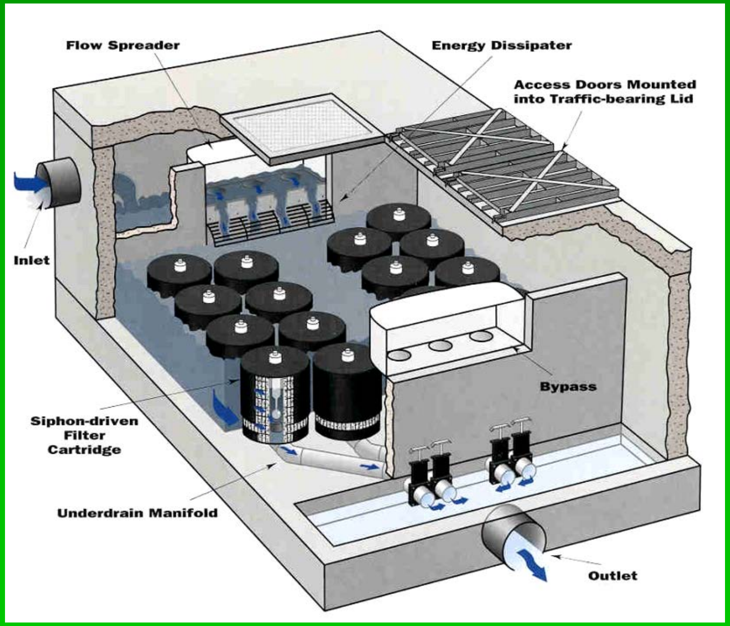
Most tested at NJCAT Laboratory with 106 (median size of 20 microns):

TSS = 80 to 90% Reduction

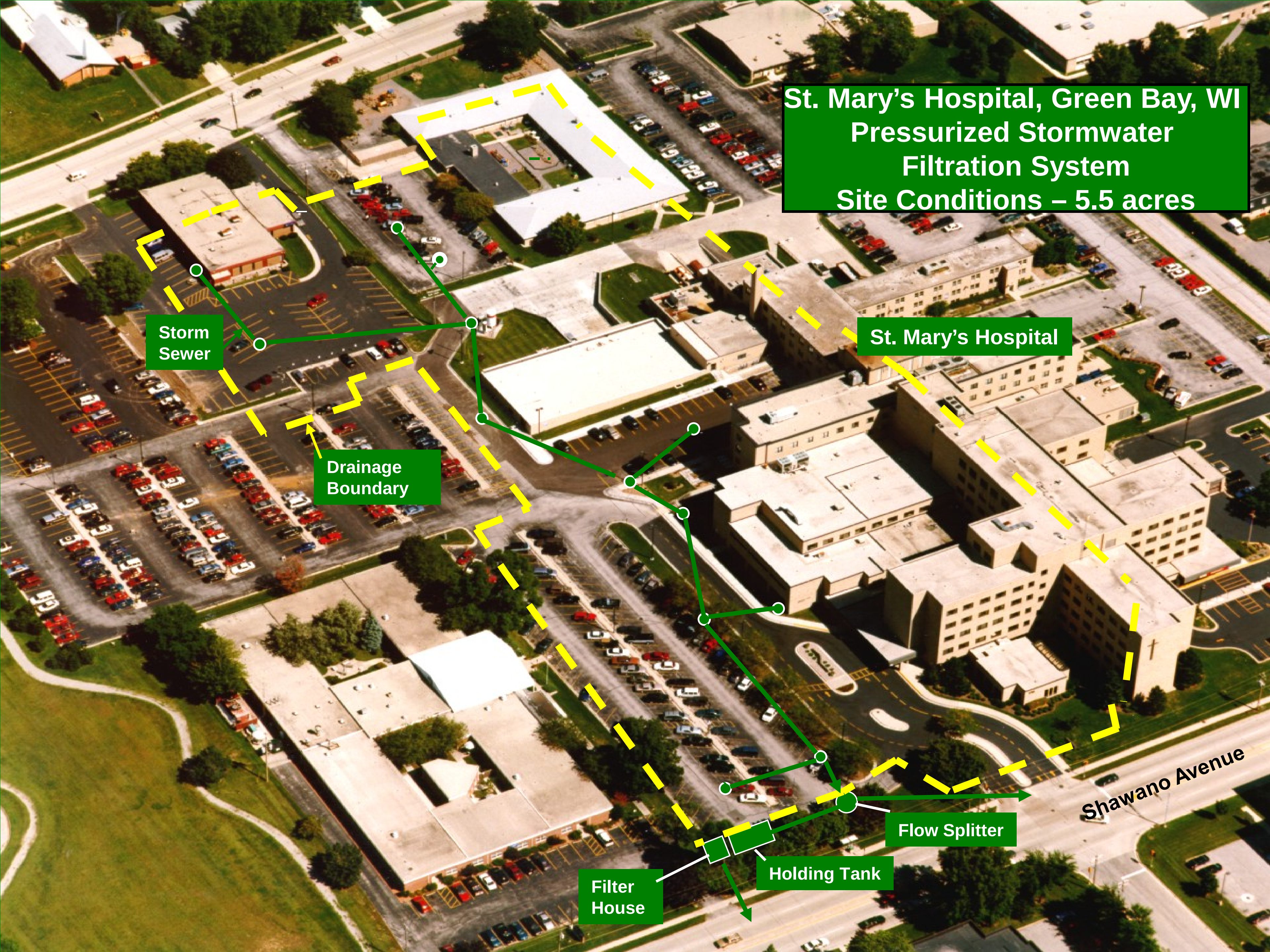
(Control about 7 micron)

# Proprietary Filters We Have Studied – Green Bay, Milwaukee, & Madison (USGS)

Arkal Pressurized Sand Filter




Stormfilter


St. Mary's Hospital, Green Bay, WI
Pressurized Stormwater
Filtration System
Site Conditions – 5.5 acres
Storm Sewer
St. Mary's Hospital
Drainage Boundary
Shawano Avenue
Flow Splitter
Holding Tank
Filter House

# Percent Reduction Using Sum of the Loads for Arkal Filter (Horwatich, 2004)

| *Constituent* | *% Reduction* | *EMC Inlet, mg/l* | *EMC Outlet, mg/l* |
|---|---|---|---|
| TSS | 83 | 72 | 15 |
| Suspended Sediment | 81 | 82 | 14 |
| Total Rec. Zinc | 62 | 68 ug/l | 26 ug/l |
| Total Phosphorus | 54 | 0.107 | 0.050 |
| Dissolved P | 9 | 0.031 | 0.027 |


Elevated Deck – I 794
(40,000 ADT)
StormFilter ETV Site

# Sum of the Loads for Stormfilter at Milwaukee Site (Horwatich, 2010)

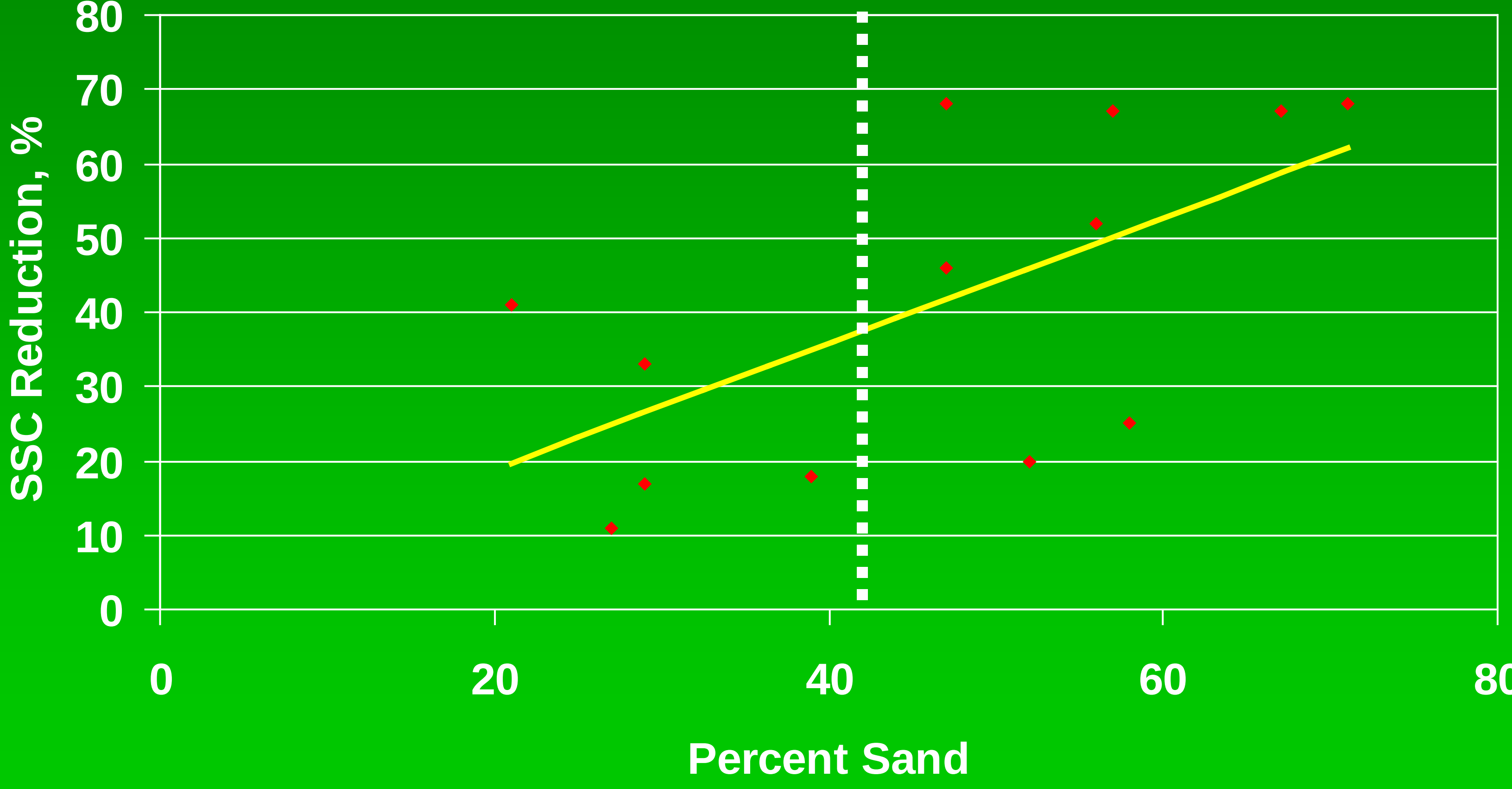
| *Constituent* | *% Reduction* | *EMC Inlet, mg/l* | *EMC Outlet, mg/l* |
|---|---|---|---|
| TSS | 50 | 60 | 36 |
| Suspended Sediment | 89 | 389 | 34 |
| Total Rec. Zinc | 68 | 226 ug/l | 91 ug/l |
| Total Phosphorus | 38 | 0.152 | 0.098 |
| Dissolved Zinc | 20 | 59 ug/l | 45 ug/l |
| Dissolved P | 5 | 0.041 | 0.037 |


Installation:
$50,000
StormFilter Unit:
$55,000
Engineering:
$15,000
Total:
$120,000
StormFilter – 0.92
Acre MG&E
Parking Lot

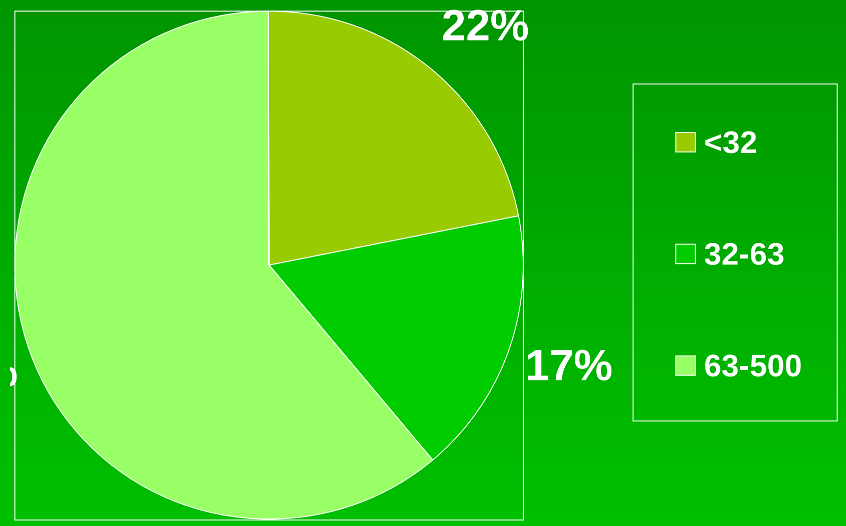
# Sum of Loads and Mean EMCs for MG&E Site (Horwatich, 2008)

| Constituent | EMC Inlet, mg/l | EMC Outlet, mg/l | Sum of Loads |
|---|---|---|---|
| SSC | 24 | 14 | 39% |
| TSS | 23 | 16 | 25% |
| VSS | 10 | 7 | 25% |
| Diss. P | 0.034 | 0.029 | 18% |
| Total P | 0.12 | 0.054 | 36% |
| Total Copper | 5 ug/l | 4 ug/l | 22% |

# SSC Reduction as a Function of Percent Sand in Inlet Water



# Distribution of SSC Trapped by Stormfilter at MG&E




| Particle Size, um | lbs | % |
|---|---|---|
| <32 | 6.3 | 22% |
| 32 – 63 | 4.7 | 17% |
| 63 - 500 | 17.3 | 61% |
| Total | 28.3 | 100% |

# Percent Load Reductions for StormFilter

| Constituent | CALTRAN | WI - Madison | WI – Milw. |
|---|---|---|---|
| TSS | 40 | 25 | 50 |
| SSC | NA | 39 | 89 |
| Total P | 17 | 36 | 38 |
| Diss. P | 9 | 18 | 5 |
| Total Zinc | 51 | NA | 68 |
| Diss. Zinc | 18 | NA | 20 |

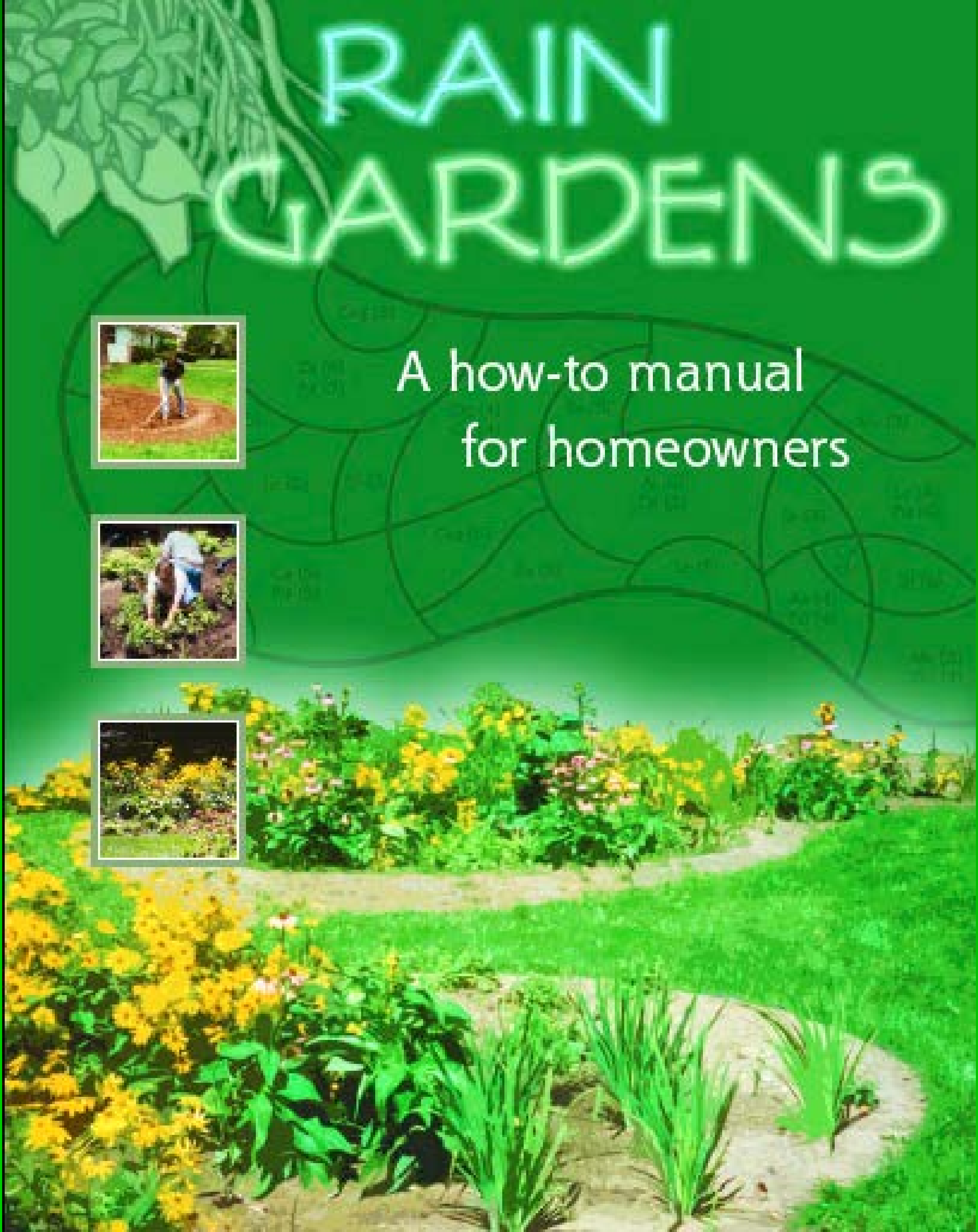
# Technical Standards

- Site Evaluation Standard
- Bioretention Standard
- Infiltration Basin Standard
- Grass Swale Standard
- **Rain Garden Standard**
- Hydrodynamic Separator Standard
- Wet Detention Pond Standard
- Permeable Pavement Standard
- Proprietary Filters

- HTTP://dnr.wi.gov/org/water/wm/nps/stormwater/techstds.htm

# Rain Garden Manual on WDNR Web Site

http://dnr.wi.gov/topic/shorelandzoning/documents/rgmanual.pdf




Evapotranspiration
Datalogger
Soil Moisture
Volume In
Pond Depth
Volume Out
11/3/2003

# Recharge

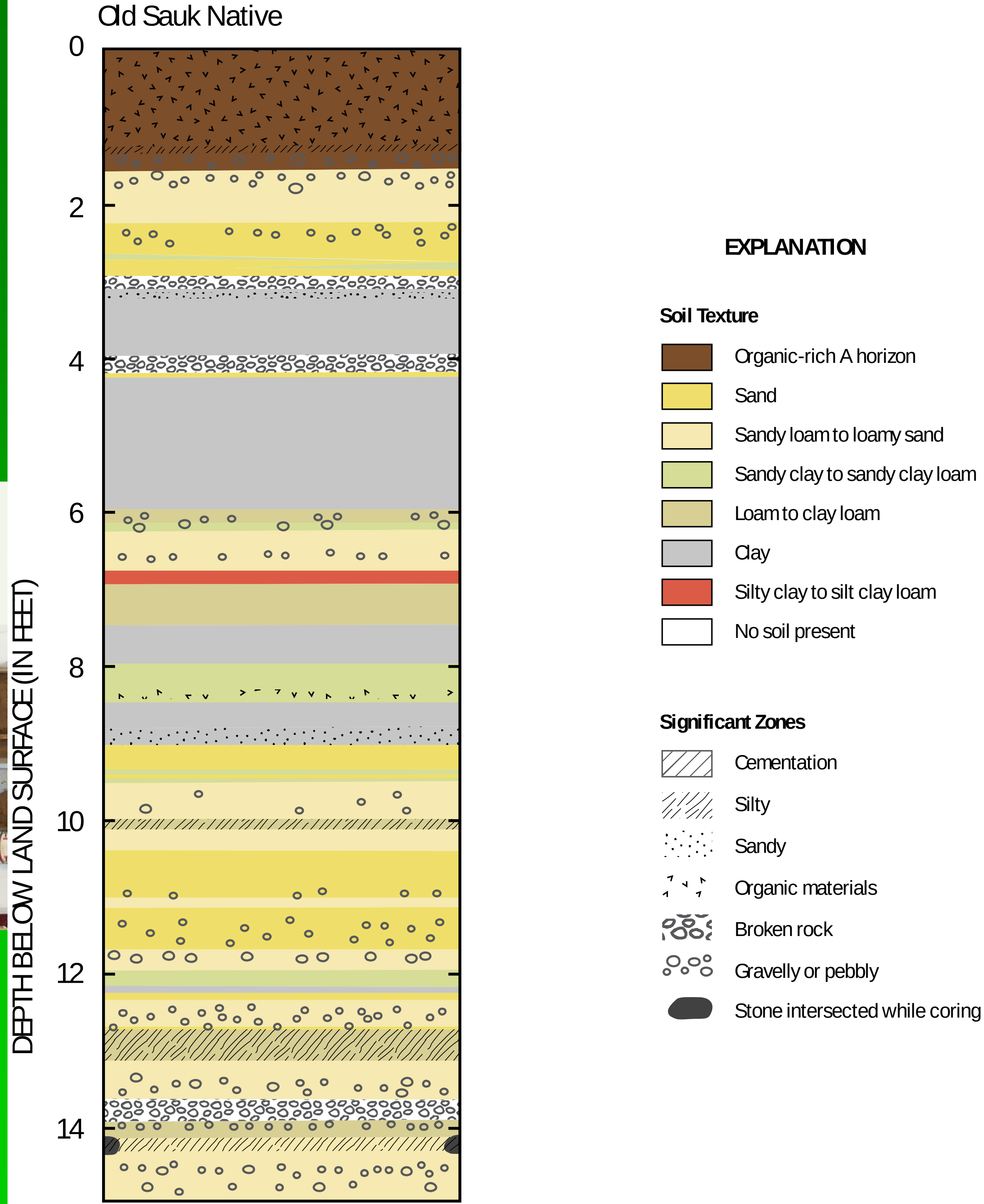
**Evapotranspiration:**

- Using modified Penman-Monteith equation
- Parameters:
  - Solar radiation
  - Wind speed
  - Precipitation depth
  - Humidity
  - Air Temperature
- Applies correction factor for vegetation type

# Water Balance in Prairie and Turf Clay Rain Gardens

| Water Year | Precip. , inches | Influent, inches | Effluent, inches | Evapo, inches | Recharge, inches |
|---|---|---|---|---|---|
| 2007 (Prairie) | 42 | 132 | 0 | 5 (3%) | 169 (97%) |
| 2007 (Turf) | 42 | 176 | 0 | 23 (11%) | 194 (89%) |

# Silt/Clay rain garden soil core reveals sand down to approximately 3 feet then turns to clay

# Capacity of Prairie Clay Rain Gardens

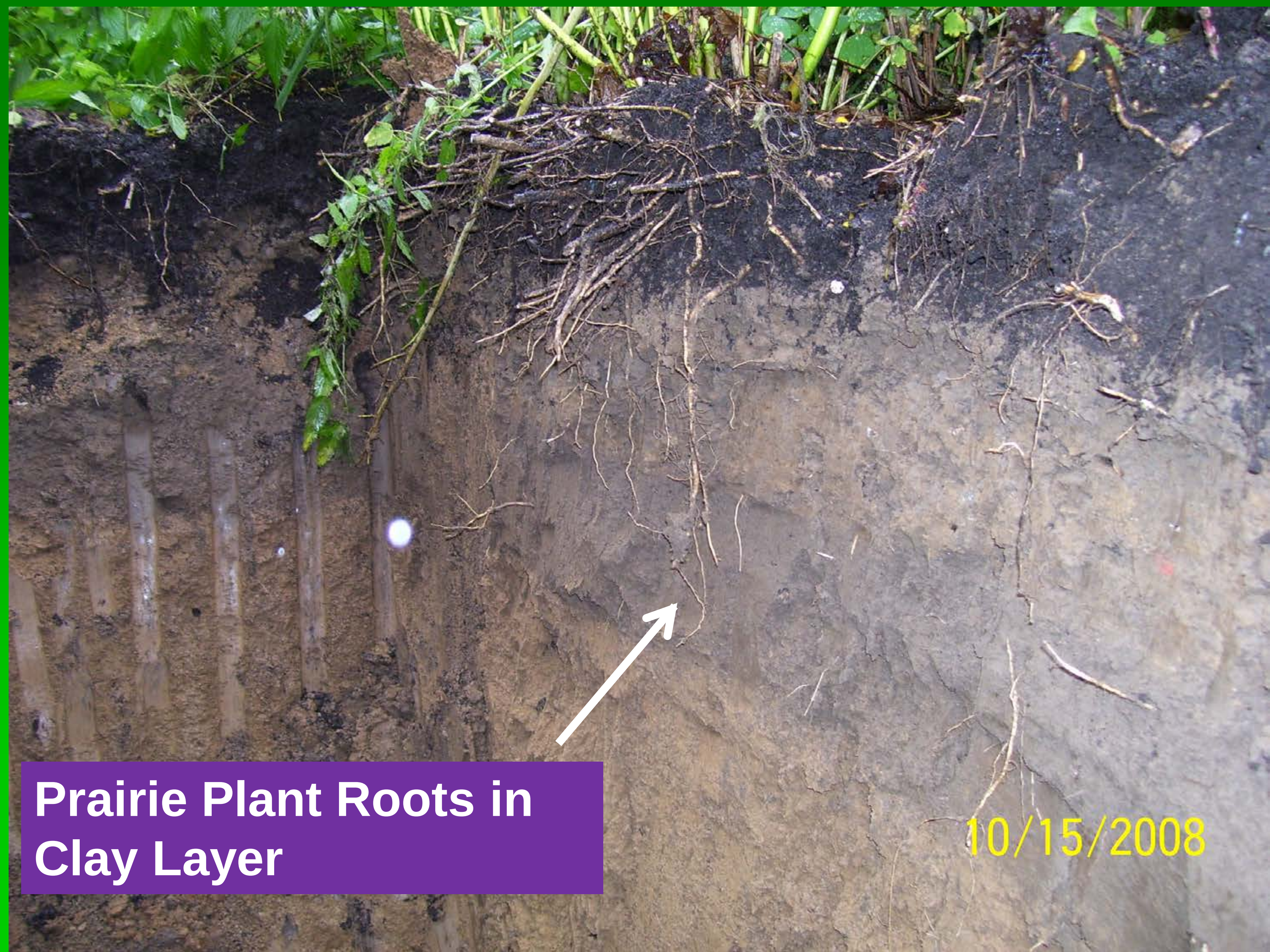
Storage Volume = 200 cubic feet

Equal Roof Runoff = 1.56 inches (90% of Events)

Void Space Above Clay = 200 cubic feet

Equal Roof Runoff = 1.56 inches

Total Capacity = 3.12 inches of rain


Prairie Plant Roots in Clay Layer
10/15/2008

# 30 Events Over Four Years in January, February, and March – Zero Discharge From Prairie Clay Garden

# Roof Gardens

# Technical Standards

- Site Evaluation Standard
- Bioretention Standard
- Infiltration Basin Standard
- Grass Swale Standard
- Rain Garden Standard
- Hydrodynamic Separator Standard
- Wet Detention Pond Standard
- **Permeable Pavement Standard**
- Proprietary Filters

- HTTP://dnr.wi.gov/org/water/wm/nps/stormwater/techstds.htm

Porous Pavement Control Device

**First Source Area Control Practice** **Porous Pavement Number 1**

**Land Use: Institutional 1**

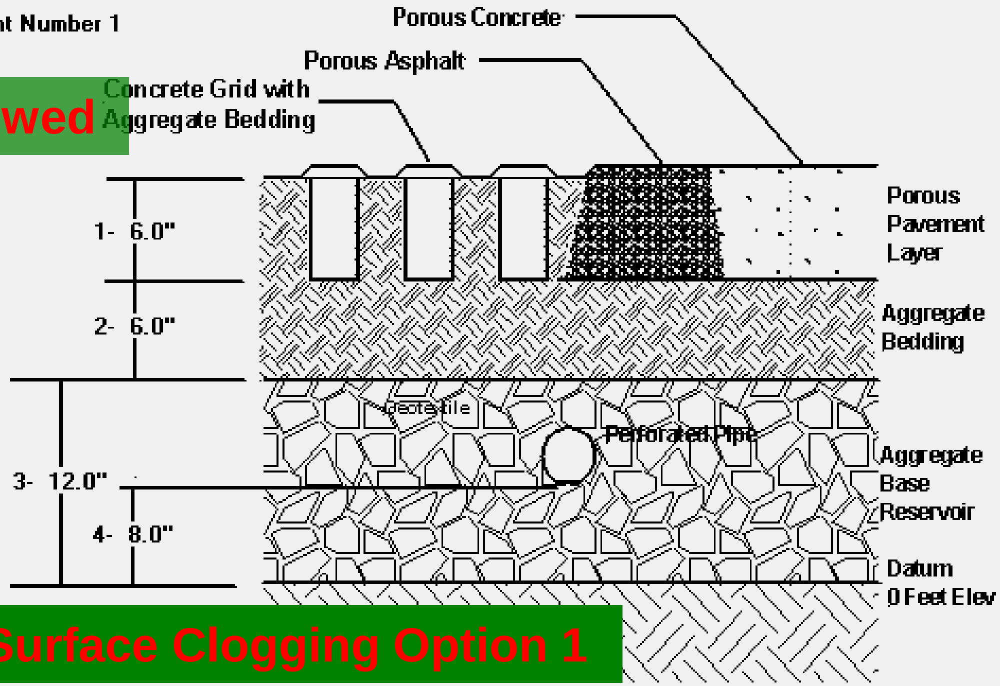
**Source Area: Paved Parking 4**

**Total Area: 23.000**

# Run-on Allowed

**Porous pavement area (acres):** 15.000

**Inflow Hydrograph Peak to Average Flow Ratio** 3.8




# Surface Clogging Option 1

### Pavement Geometry and Properties

| | |
|---|---|
| 1 - Pavement Thickness (in) | 6.0 |
| Pavement Porosity (0-1) | 0.35 |
| 2 - Aggregate Bedding Thickness (in) | 6.0 |
| Aggregate Bedding Porosity (0-1) | 0.35 |
| 3 - Aggregate Base Reservoir Thickness (in) | 12.0 |
| Aggregate Base Reservoir Porosity (0-1) | 0.40 |

### Outlet/Discharge Options

| | |
|---|---|
| Perforated Pipe Underdrain Diameter, if used (inches) | 3.00 |
| 4 - Perforated Pipe Underdrain Outlet Invert Elevation (inches above Datum) | 8.0 |
| Number of Perforated Pipe Underdrains | 10 |
| Subgrade Seepage Rate (in/hr) - select below or enter | 0.100 |
| Use Random Number Generation to Account for Uncertainty in Seepage Rate | ☐ |
| Subgrade Seepage Rate COV | 0.00 |

### Select Subgrade Seepage Rate

- ○ Sand - 8 in/hr
- ○ Loamy sand - 2.5 in/hr
- ○ Sandy loam - 1.0 in/hr
- ○ Loam - 0.5 in/hr
- ○ Silt loam - 0.3 in/hr
- ○ Sandy silt loam - 0.2 in/hr
- ○ Clay loam - 0.1 in/hr
- ○ Silty clay loam - 0.05 in/hr
- ○ Sandy clay - 0.05 in/hr
- ○ Silty clay - 0.04 in/hr
- ○ Clay - 0.02 in/hr

### Surface Pavement Layer Infiltration Rate Data

| | |
|---|---|
| Initial Infiltration Rate (in/hr) | 30.00 |
| Percent of Infiltration Rate After 3 Years (0-100) | 0.0 |
| Percent of Infiltration Rate After 5 Years (0-100) | 0.0 |
| Time Period Until Complete Clogging Occurs (yrs) | 0.0 |
| Percent of Original Infiltration Rate Upon Cleaning (0-100) | 90.0 |
| Surface Clogging Load (lb/sf) | 5.1 |

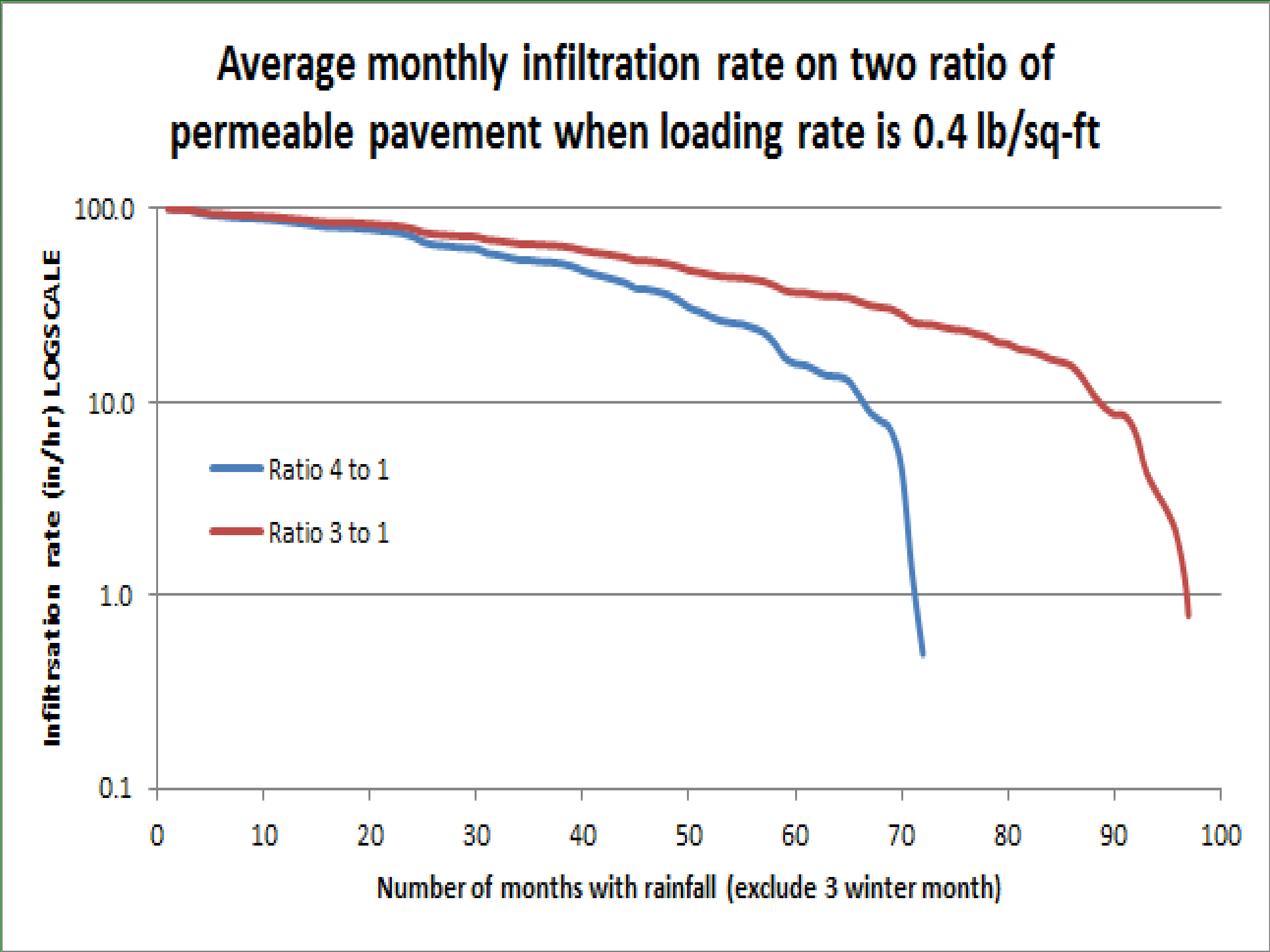
Enter values in either rows 2-4 or row 6. You cannot enter values in both sets of rows.

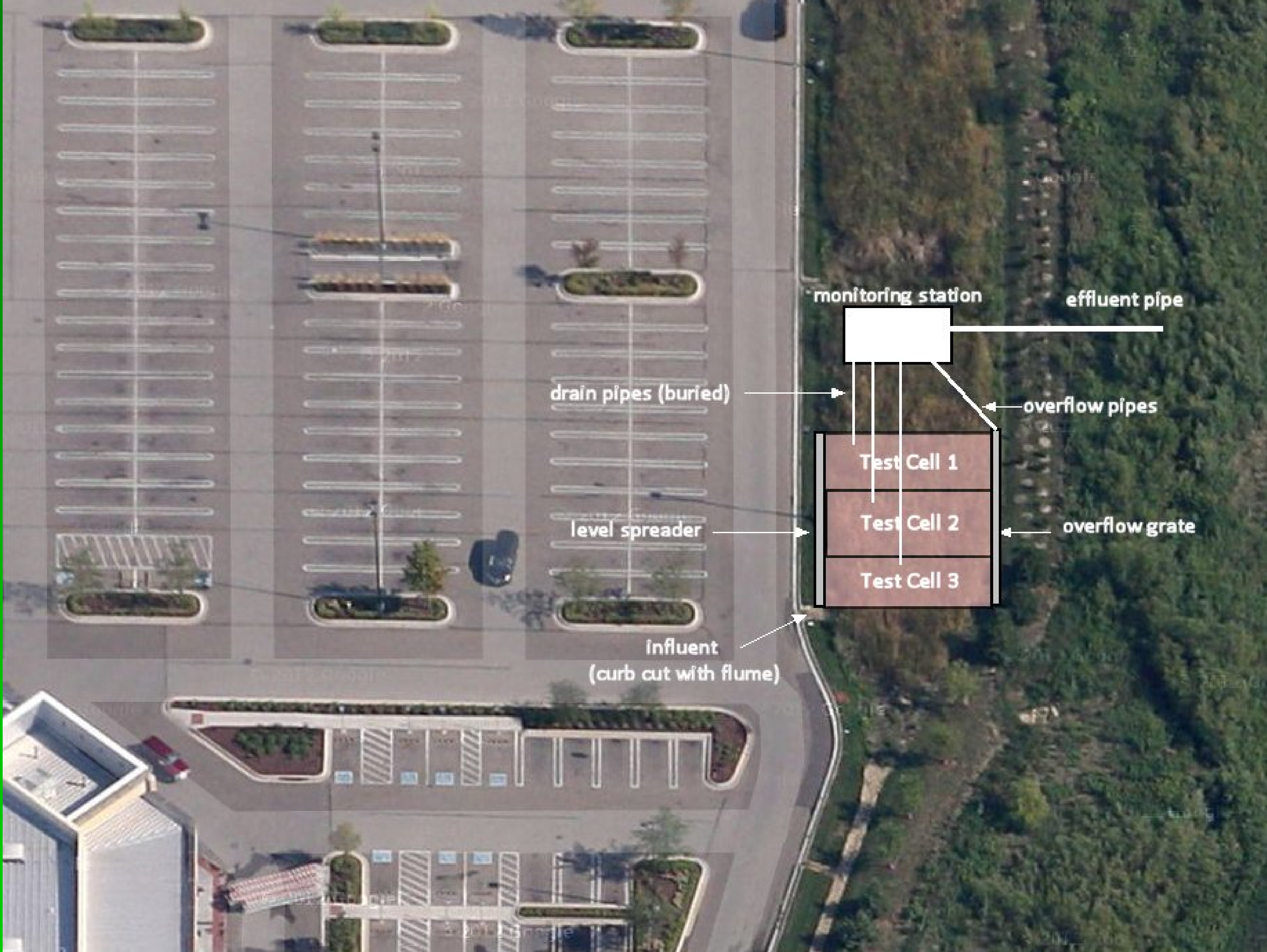
### Restorative Cleaning Frequency

- ○ Never Cleaned
- ○ Three Times per Year
- ○ Semi-Annually
- ○ Annually
- ● Every Two Years
- ○ Every Three Years
- ○ Every Four Years
- ○ Every Five Years
- ○ Every Seven Years
- ○ Every Ten Years

[Copy Porous Pavement Data] [Paste Porous Pavement Data] [Cancel] [Delete Control] [Continue]

Control Practice # : 4 | Land Use # : 1 | Source Area # : 16


Average monthly infiltration rate on two ratio of permeable pavement when loading rate is 0.4 lb/sq-ft
Infiltration rate (in/hr) LOGSCALE
100.0
10.0
1.0
0.1
Ratio 4 to 1
Ratio 3 to 1
0
10
20
30
40
50
60
70
80
90
100
Number of months with rainfall (exclude 3 winter month)

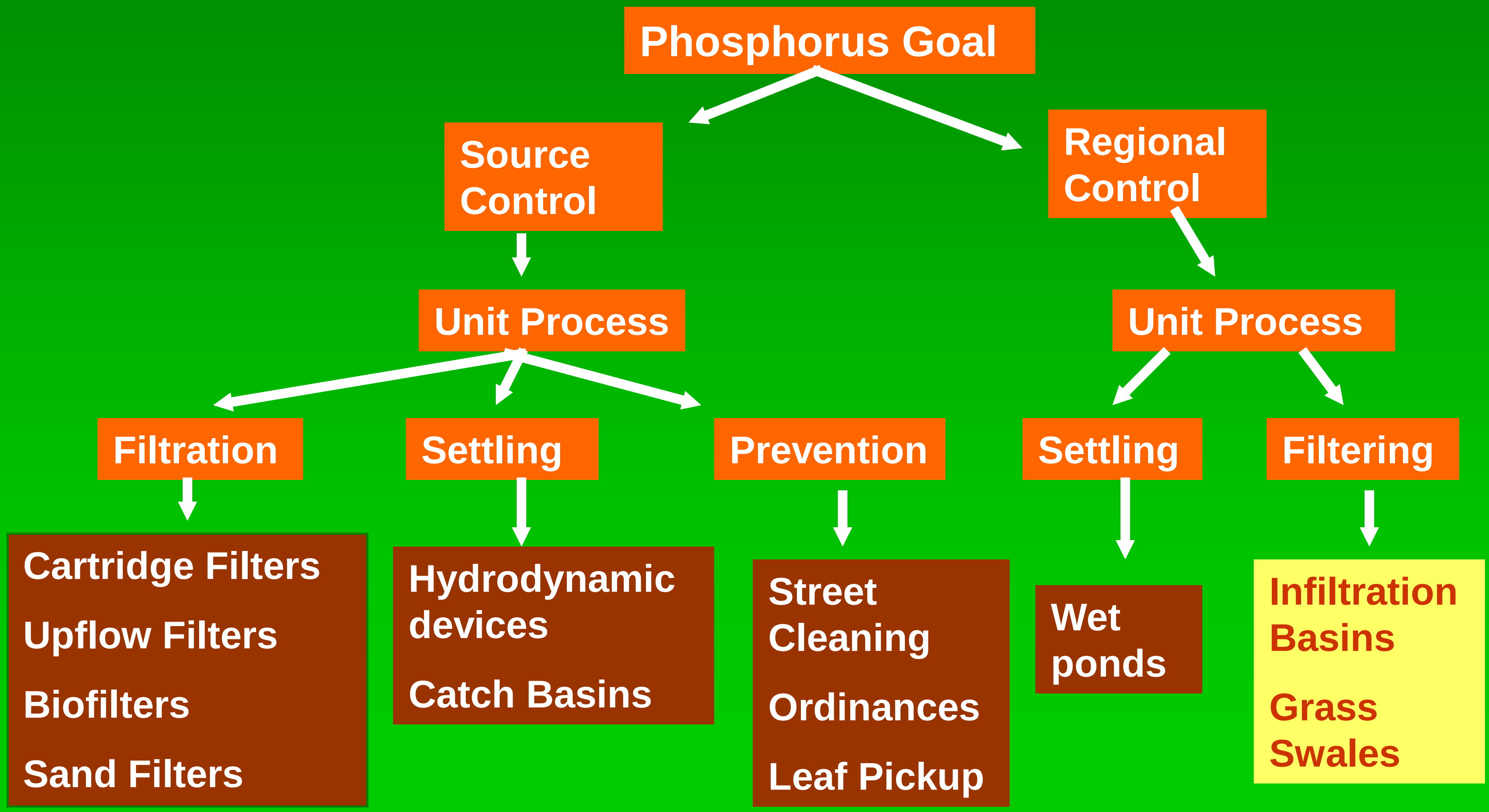

monitoring station
effluent pipe
drain pipes (buried)
overflow pipes
Test Cell 1
Test Cell 2
Test Cell 3
level spreader
overflow grate
influent
(curb cut with flume)

# Snow and Ice Cover - Porous Asphalt Versus Regular Asphalt


Lots one-hour after plowing, -4*C (11AM on 2/3/07)

Robert Roseen, 2011

# How to Select A Stormwater Control Measure



# Technical Standards

- Site Evaluation Standard
- Bioretention Standard
- **Infiltration Basin Standard**
- Grass Swale Standard
- Rain Garden Standard
- Hydrodynamic Separator Standard
- Wet Detention Pond Standard
- Permeable Pavement Standard
- Proprietary Filters

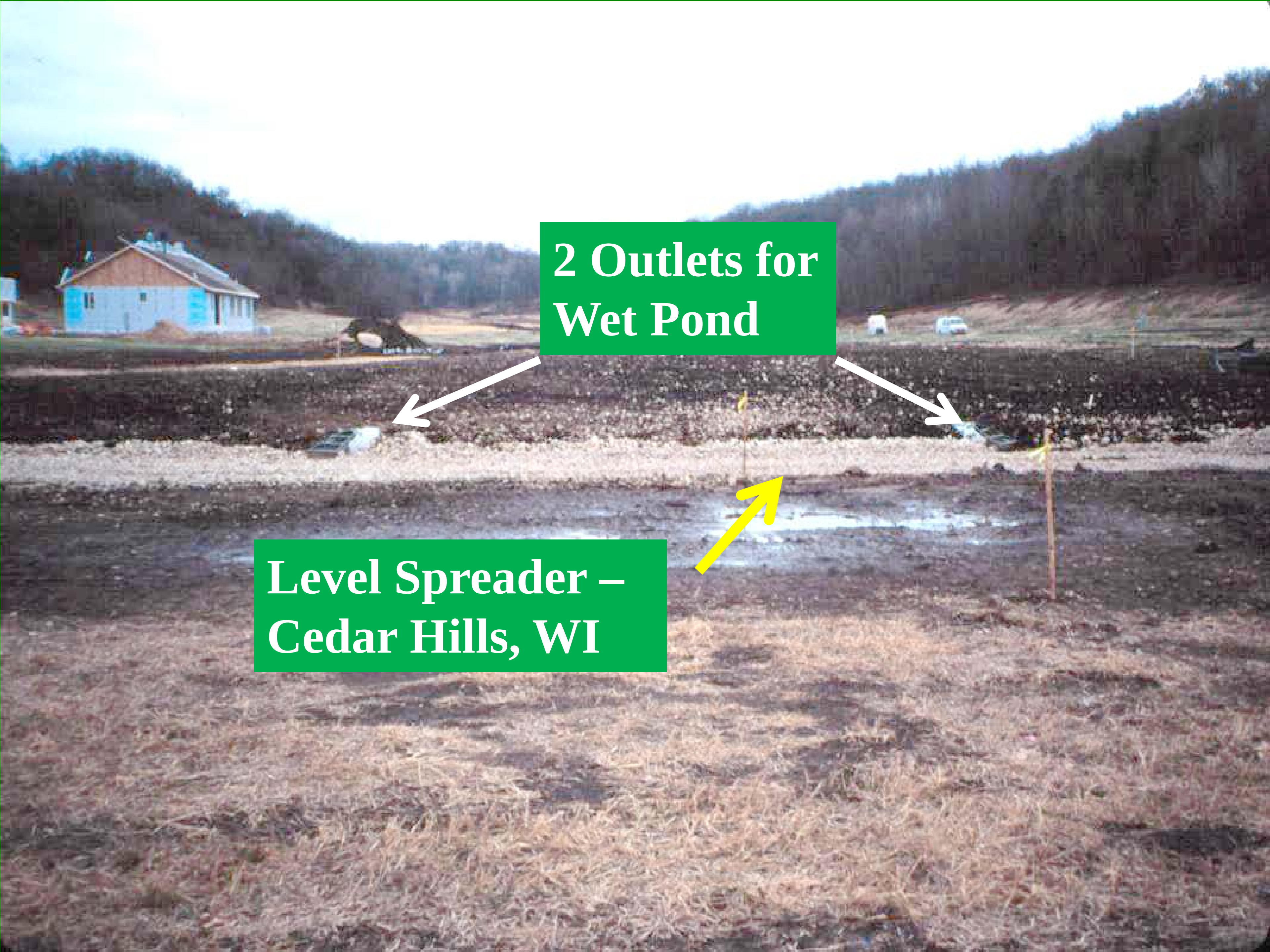
- HTTP://dnr.wi.gov/org/water/wm/nps/stormwater/techstds.htm

# BMPs used to control runoff quantity and quality

**Wet Detention Pond – Pretreatment for Cedar Hills, WI**

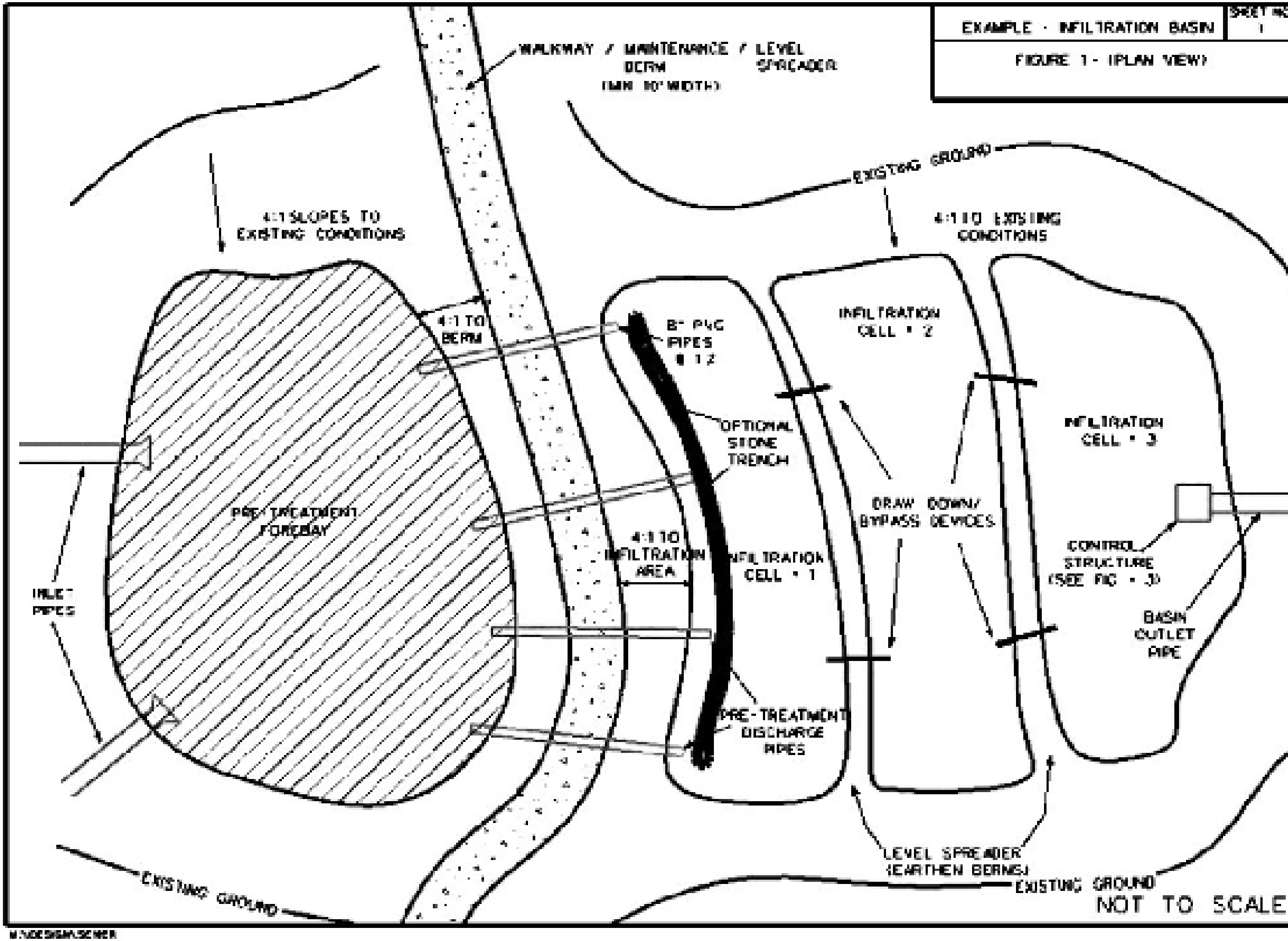

Infiltration Basin – Cross Plains, WI


8/5/2000 15:40


2 Outlets for
Wet Pond
Level Spreader –
Cedar Hills, WI

# Diminished Effective Infiltration Area – Only 50% of Flow Reaching Basin is Controlled.

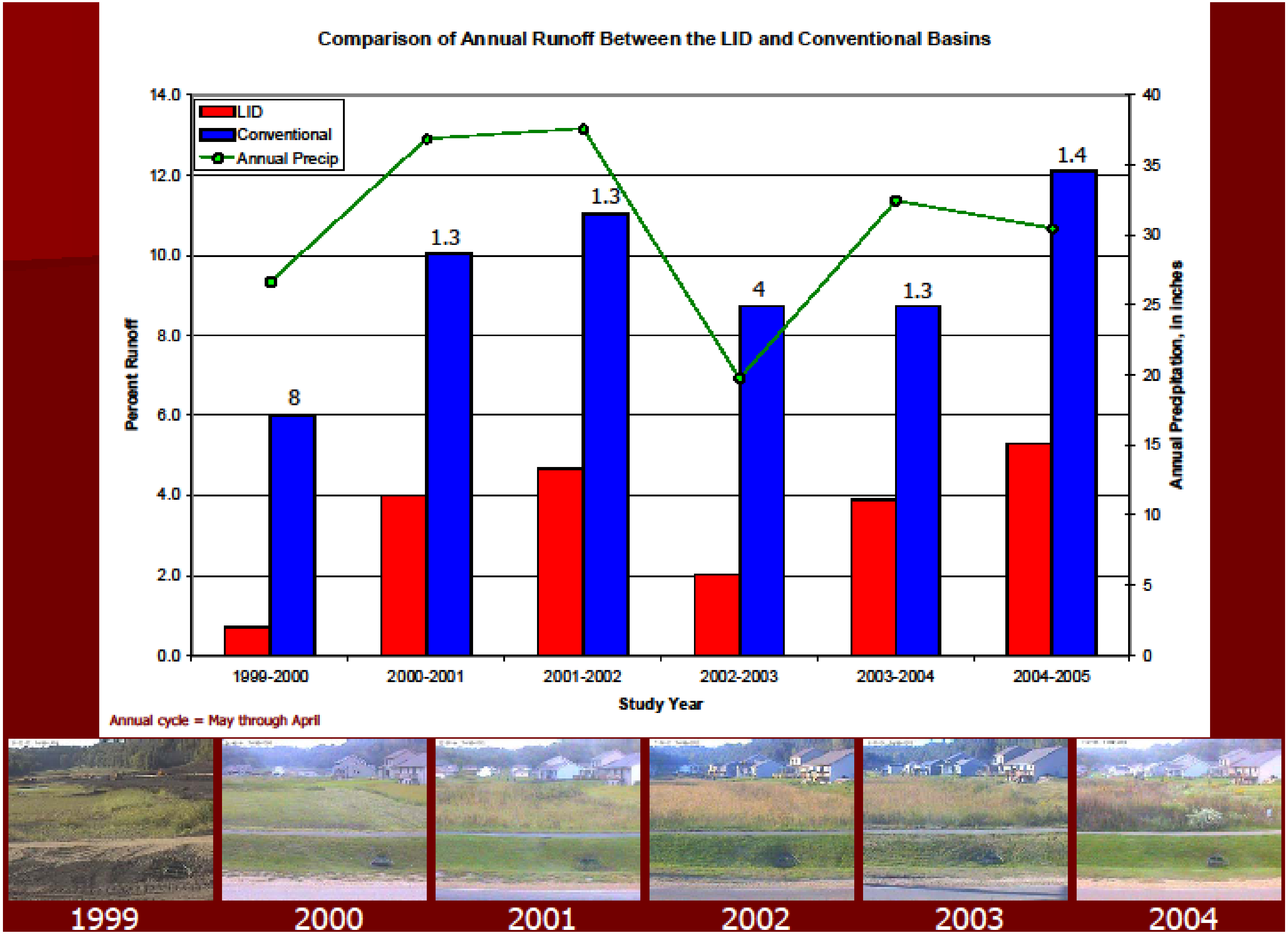

**Infiltration Standard Requires Breaking Effective Infiltration Area into Cells.**



EXAMPLE - INFILTRATION BASIN
SHEET NO. 1
FIGURE 1 - (PLAN VIEW)
WALKWAY / MAINTENANCE / LEVEL SPREADER BERM (MIN 10' WIDTH)
EXISTING GROUND
4:1 SLOPES TO EXISTING CONDITIONS
4:1 TO EXISTING CONDITIONS
4:1 TO BERM
8" PVC PIPES @ 1%
INFILTRATION CELL # 2
INFILTRATION CELL # 3
OPTIONAL STONE TRENCH
PRE-TREATMENT FOREBAY
DRAW DOWN/ BYPASS DEVICES
4:1 TO INFILTRATION AREA
INFILTRATION CELL # 1
CONTROL STRUCTURE (SEE FIG # 3)
INLET PIPES
BASIN OUTLET PIPE
PRE-TREATMENT DISCHARGE PIPES
LEVEL SPREADER (EARTHEN BERMS)
EXISTING GROUND
EXISTING GROUND
NOT TO SCALE

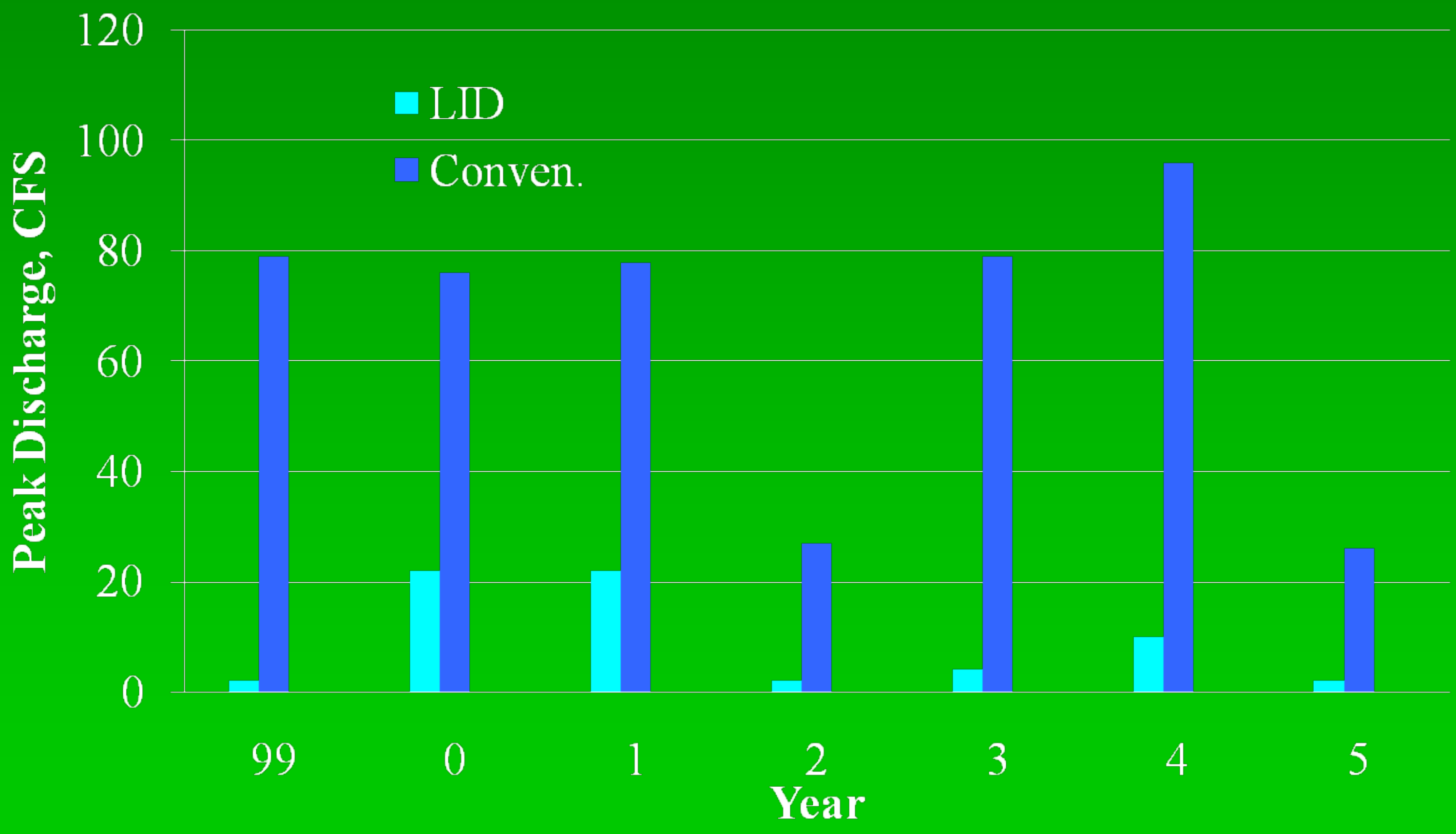
# Infiltration Basin with Compacted Soils

**Standard requires adding compost and chisel plowing**



Comparison of Annual Runoff Between the LID and Conventional Basins
LID
Conventional
Annual Precip
Percent Runoff
Annual Precipitation, in Inches
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
0
5
10
15
20
25
30
35
40
8
1.3
1.3
4
1.3
1.4
1999-2000
2000-2001
2001-2002
2002-2003
2003-2004
2004-2005
Study Year
Annual cycle = May through April
1999
2000
2001
2002
2003
2004

# Maximum Peak Discharge for Each Year, CFS



# Infiltration Basin Performance

*Overall Reduction in Runoff Volume for Infil. Basin = 51%*

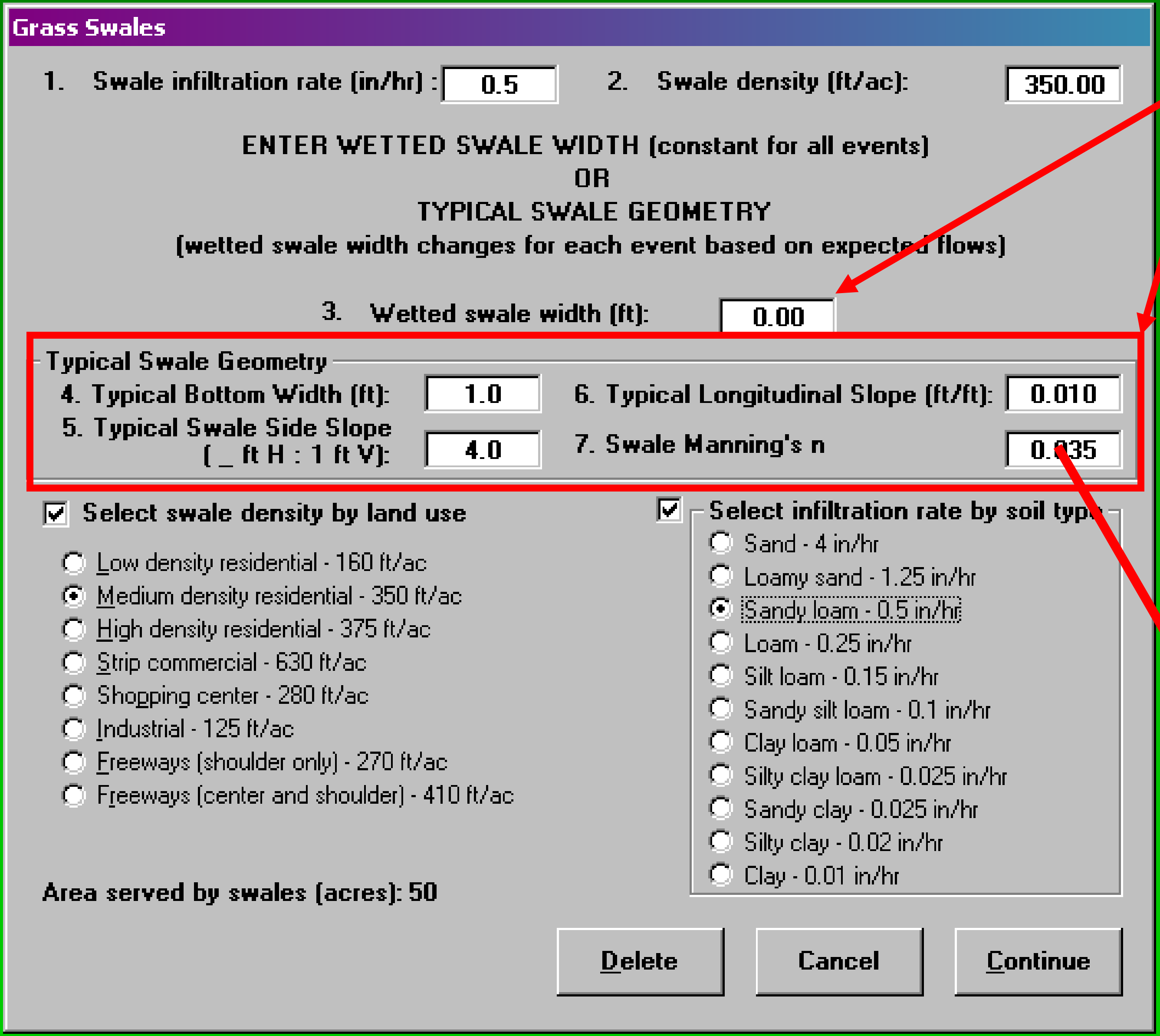
| | Percent Reduction | | |
|---|---|---|---|
| | Precipitation Intensity (inches/hour) | | |
| Statistic | 0 - 0.5 | 0.5 - 1.0 | > 1.0 |
| Mean | 69 | 43 | 32 |
| Median | 71 | 44 | 43 |

# Technical Standards

- Site Evaluation Standard
- Bioretention Standard
- Infiltration Basin Standard
- **Grass Swale Standard**
- Rain Garden Standard
- Hydrodynamic Separator Standard
- Wet Detention Pond Standard
- Permeable Pavement Standard
- Proprietary Filters

- HTTP://dnr.wi.gov/org/water/wm/nps/stormwater/techstds.htm

# Modeling Swales SLAMM



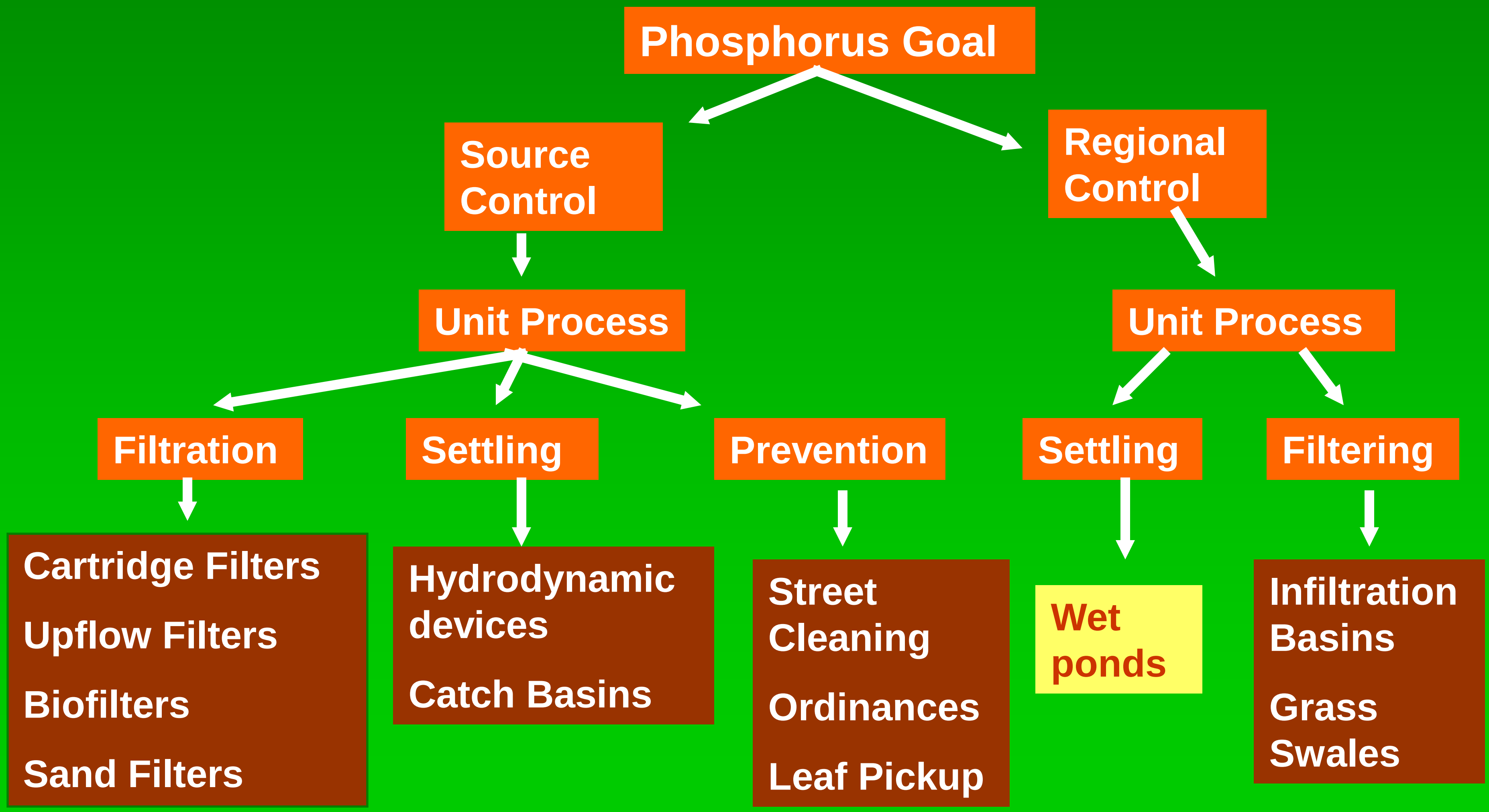

**Swale Geometry**

**Select either a static or a dynamic wetted width. If use static width, width based on 1-inch depth of flow.**

**Recommend default design value for Manning's n of 0.30 for turf.**

# WI DOT Grass Swale Study, Madison: TSS Reduction, Dynamic Infiltration Rate, Filter Strip.

# How to Select A Stormwater Control Measure

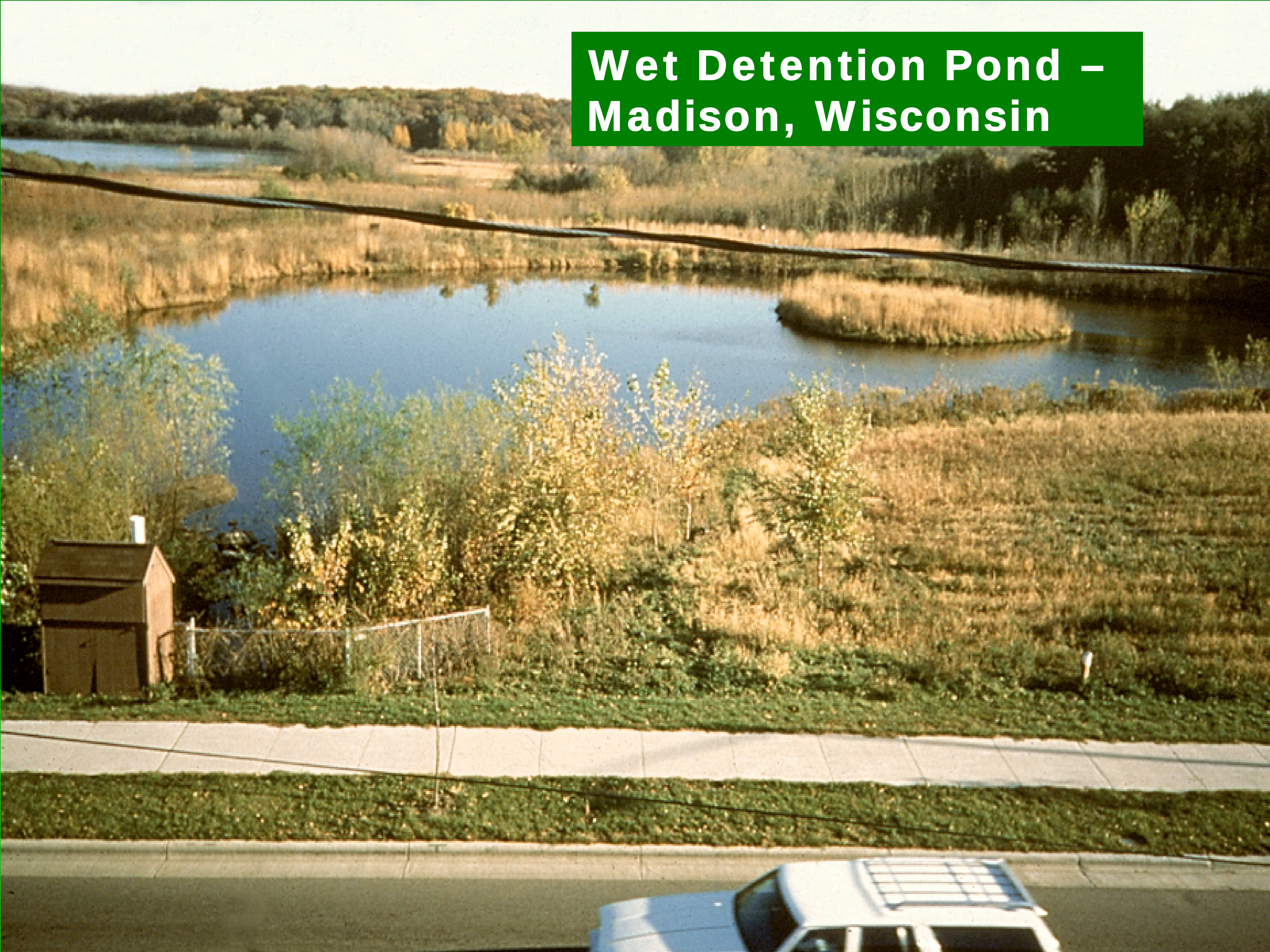


# Technical Standards

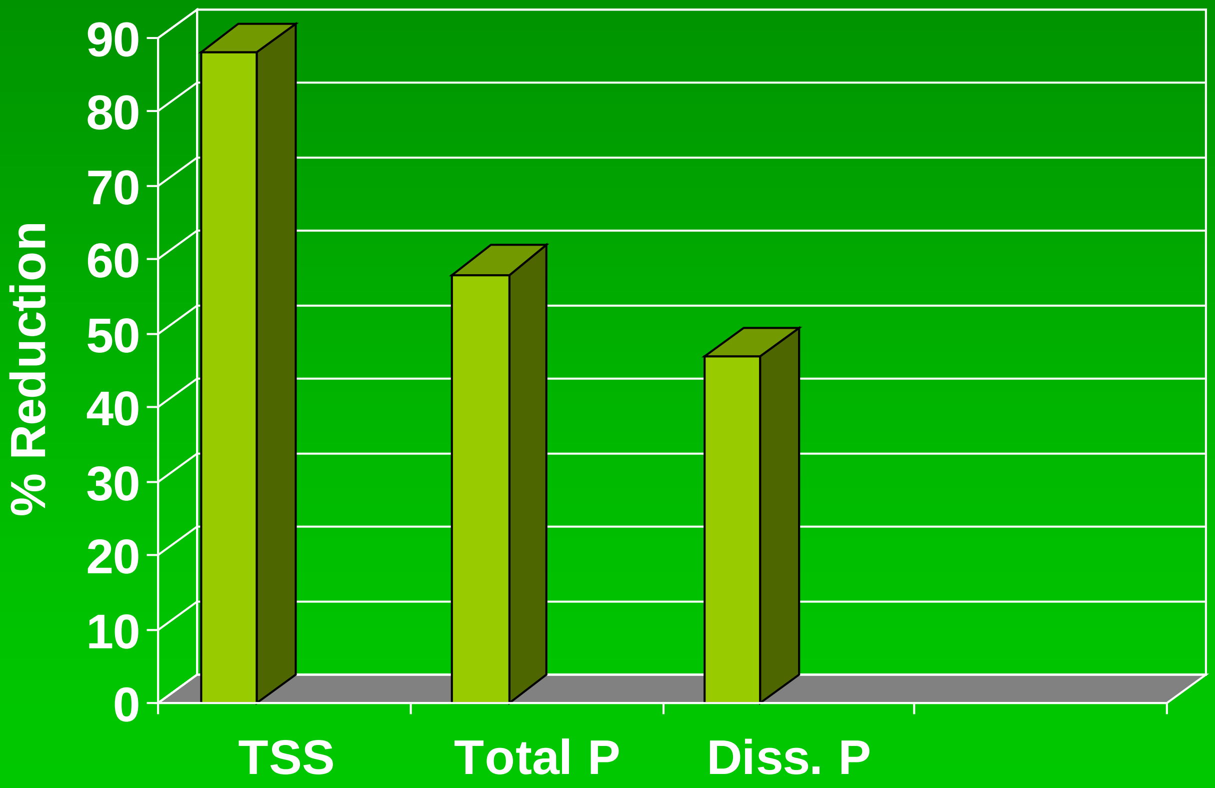
- Site Evaluation Standard
- Bioretention Standard
- Infiltration Basin Standard
- Grass Swale Standard
- Rain Garden Standard
- Hydrodynamic Separator Standard
- **Wet Detention Pond Standard**
- Permeable Pavement Standard
- Proprietary Filters

- HTTP://dnr.wi.gov/org/water/wm/nps/stormwater/techstds.htm

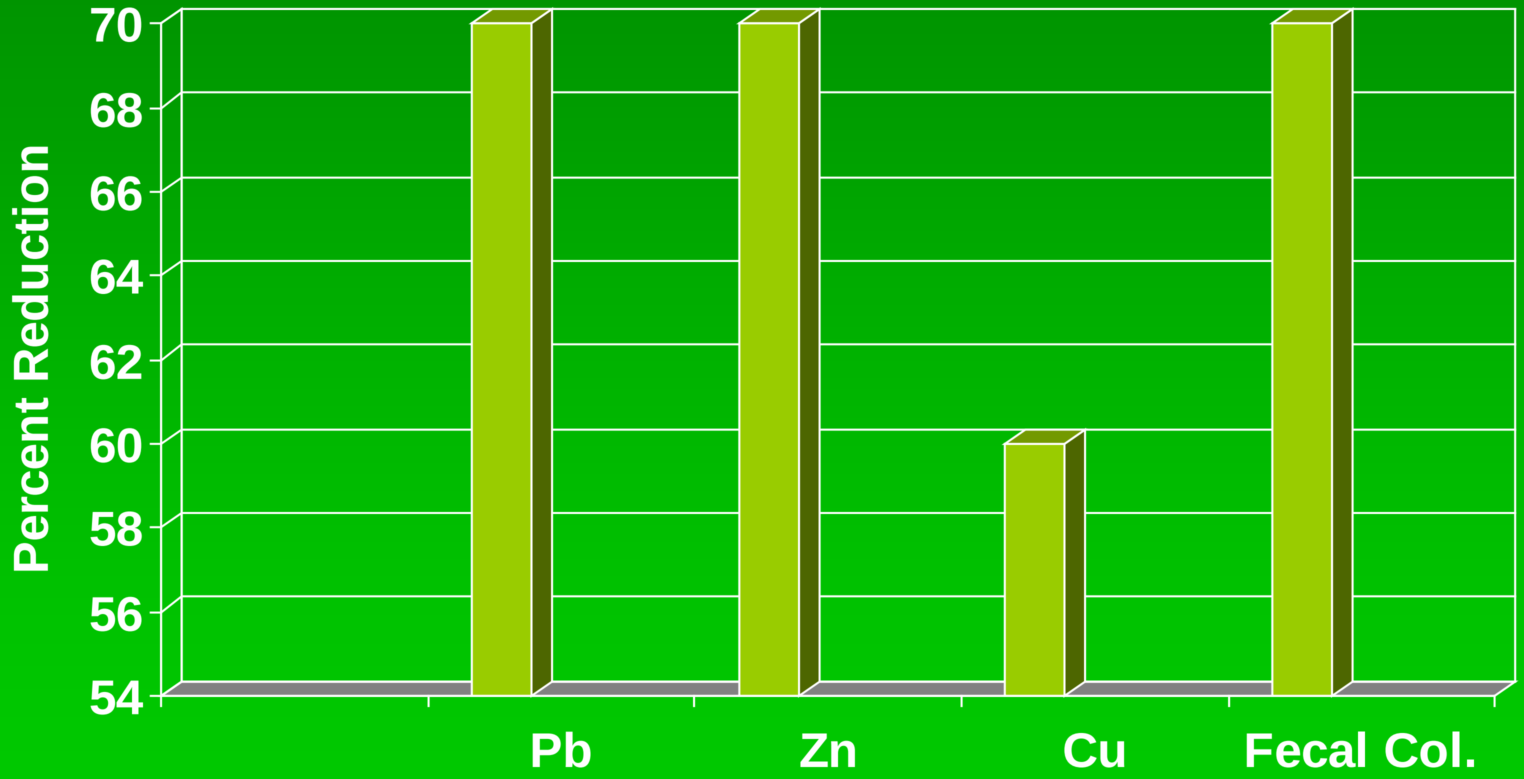
# Wet Detention Pond – Madison, Wisconsin



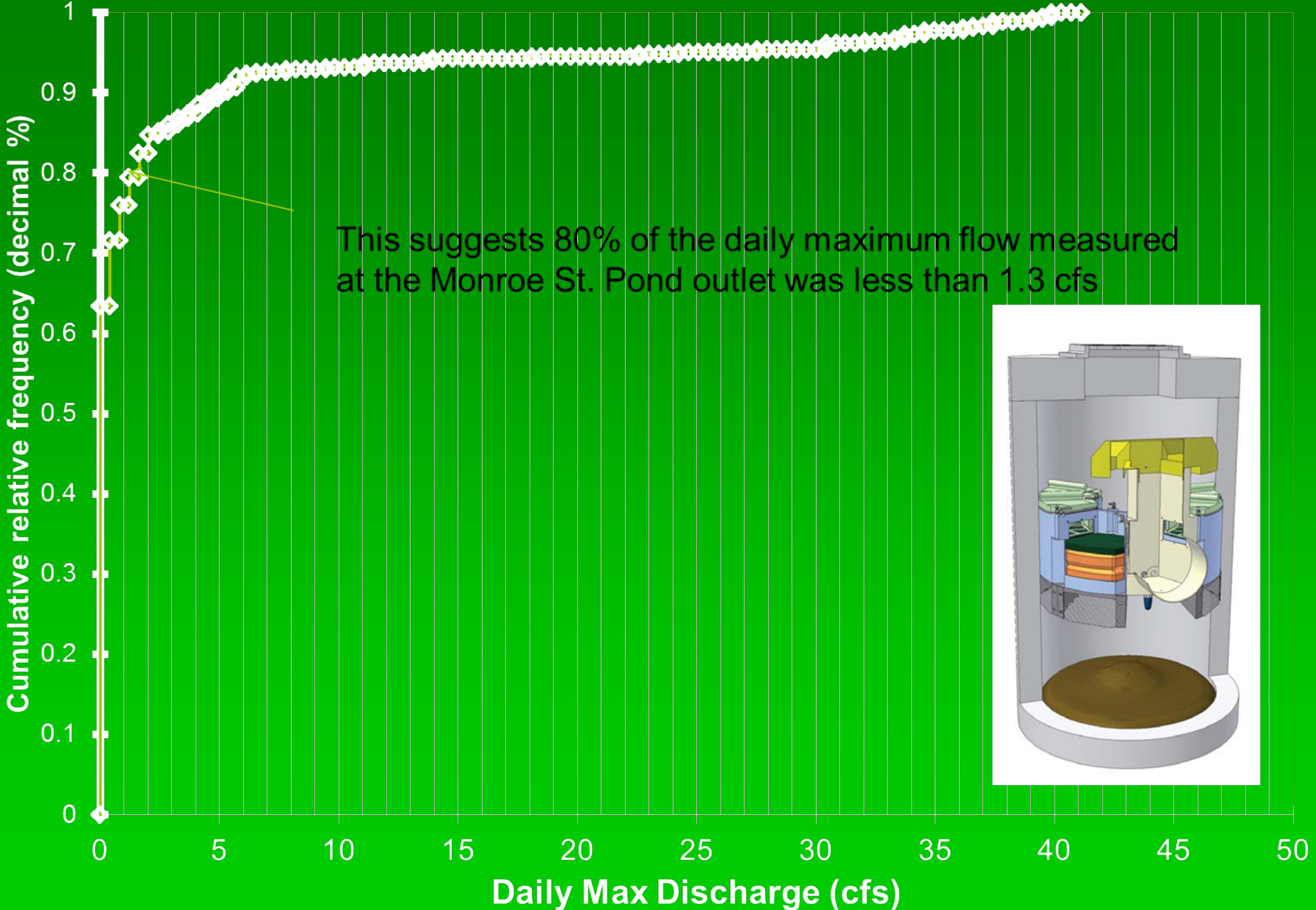
# Total Load Reduction Achieved by Monroe Pond



# Monroe St. Pond Efficiency – Reduction in Avg. Conc.



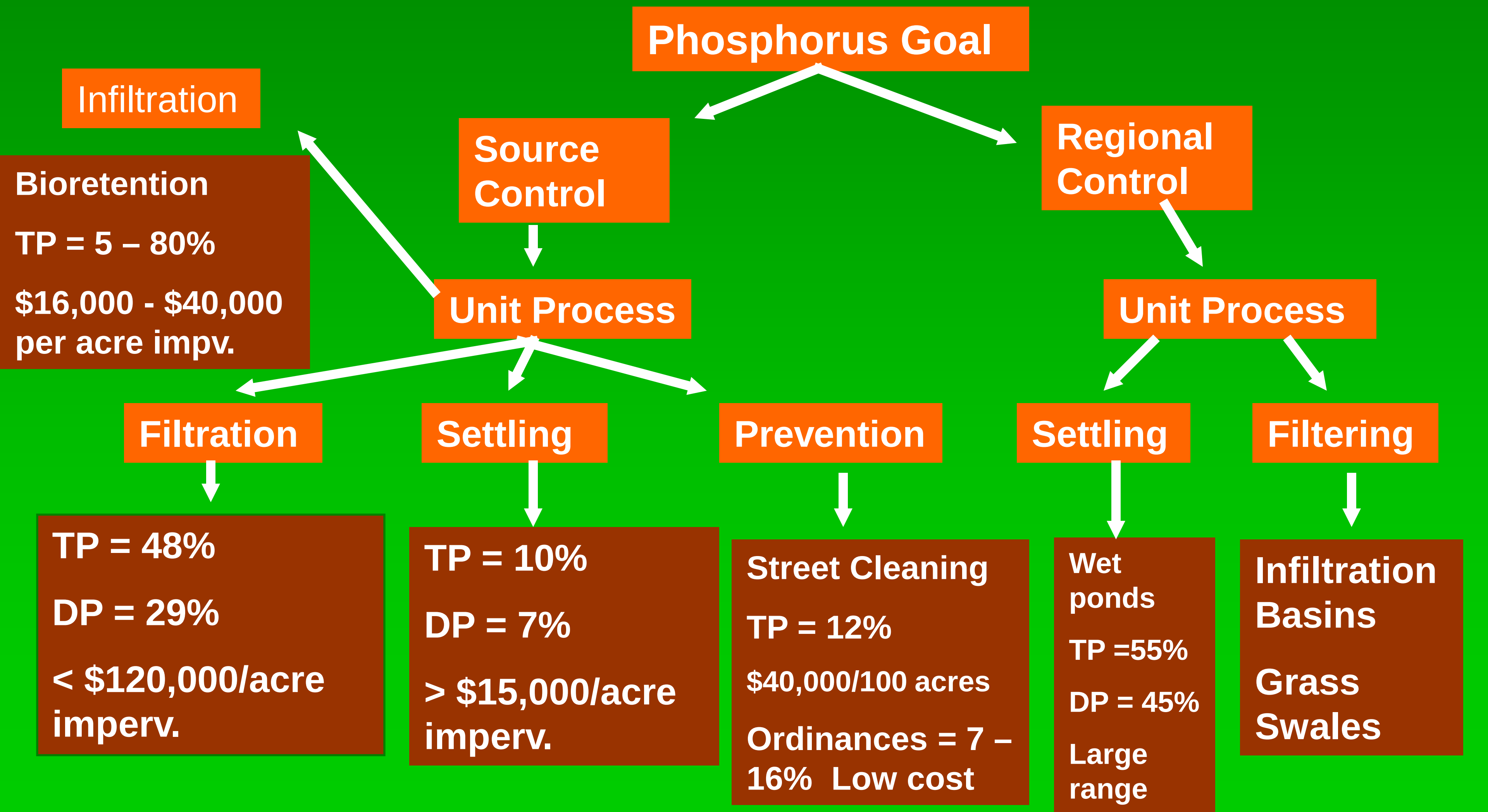
## Monroe Street Pond Outlet ( 1991 - 1995 )



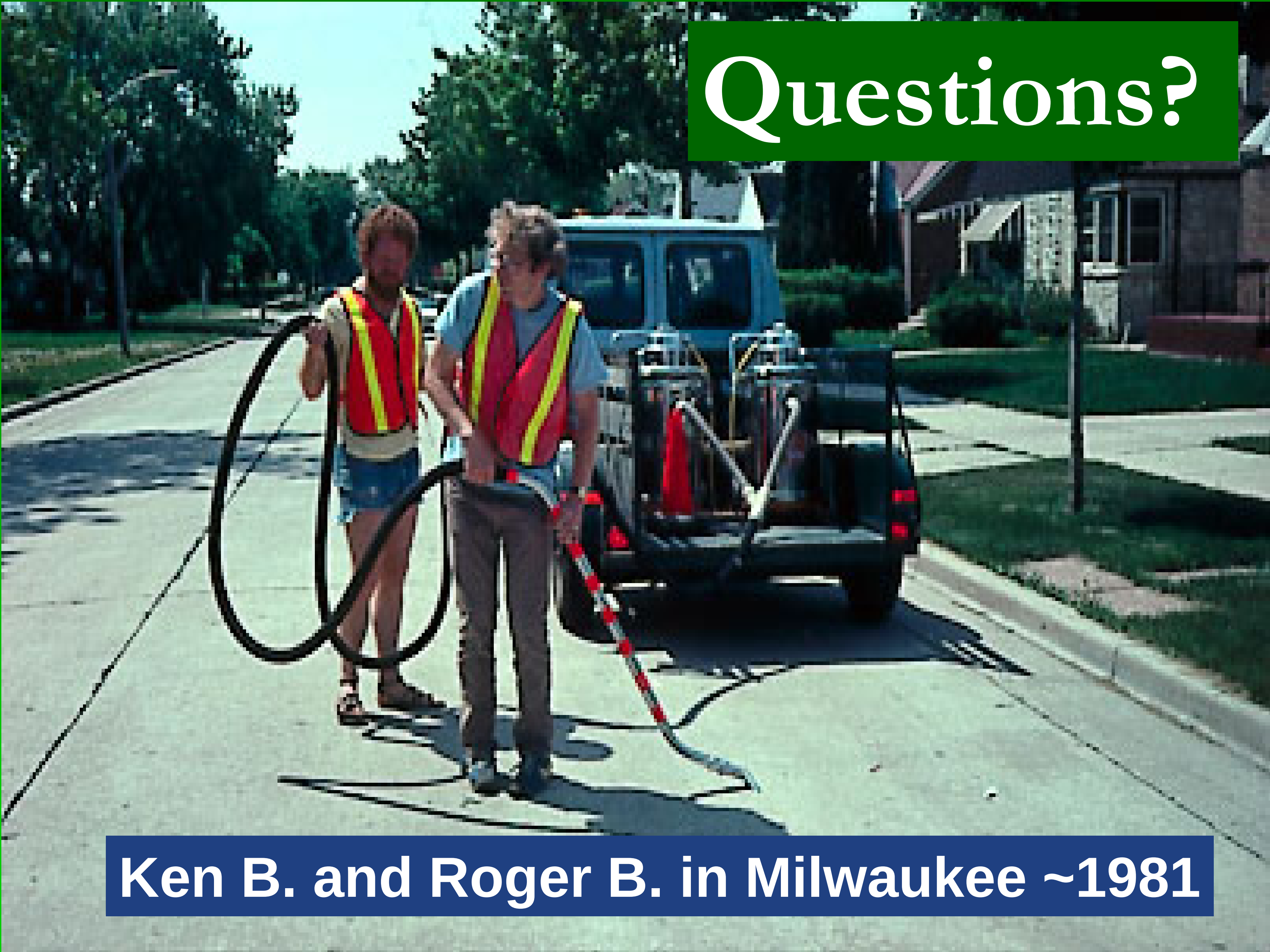
# Stormwater Management Steps

1. Identify beneficial use impairments
2. Identify causes of impairments
3. Identify sources (magnitude, seasonality, flow phases, etc.) of problem constituents
4. Identify, select, and design controls suitable for problem pollutants and locations
5. Implement controls, conduct validation monitoring, modify controls as needed

# How to Select A Stormwater Control Measure



# Questions?



Ken B. and Roger B. in Milwaukee ~1981