Treatment of Nutrients by Stormwater Management

2006 FDOT Design Conference

by

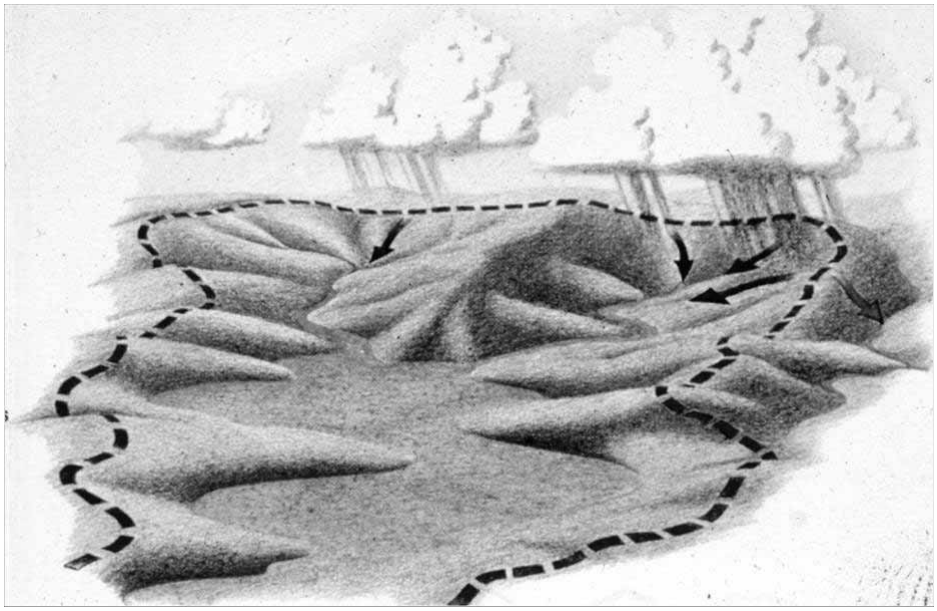
Harvey H. Harper, Ph.D.,PE
Environmental Research & Design Inc.

Areas of Discussion

1. Sources of Nutrients in Stormwater
2. Removal Mechanisms
   A. Structural Techniques
   B. Non-structural Techniques

1. Sources of Nutrients in Stormwater Runoff

Stormwater is Generated within a Watershed



Runoff Entering an Urban Lake

Nutrients

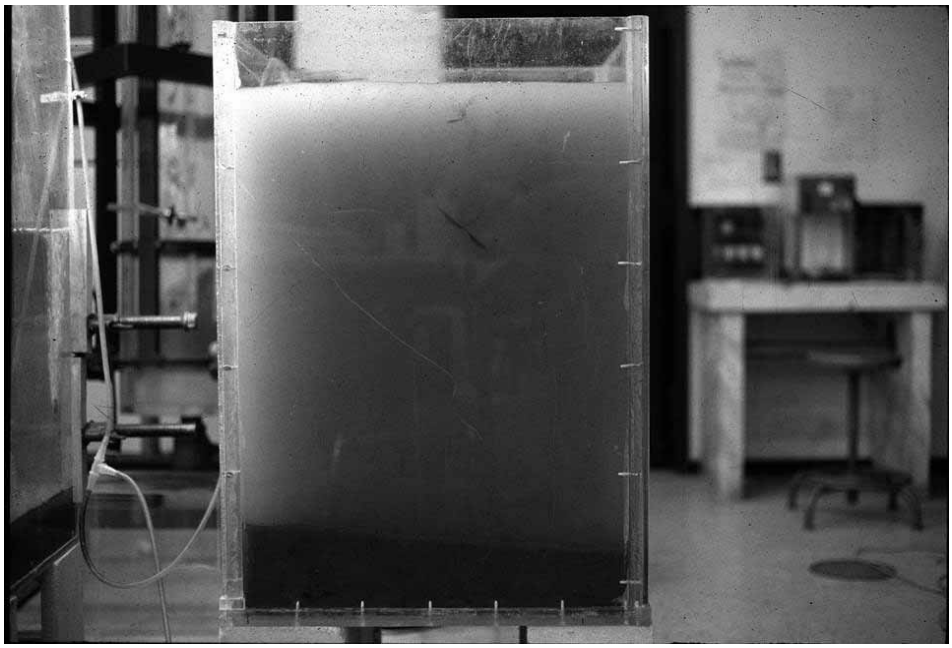
Compounds which stimulate the growth of algae and other plants:

1. Nitrogen – NH_3, NO_X, Organic N, Particulate N
2. Phosphorus – Soluble reactive P (SRP), Organic P, Particulate P

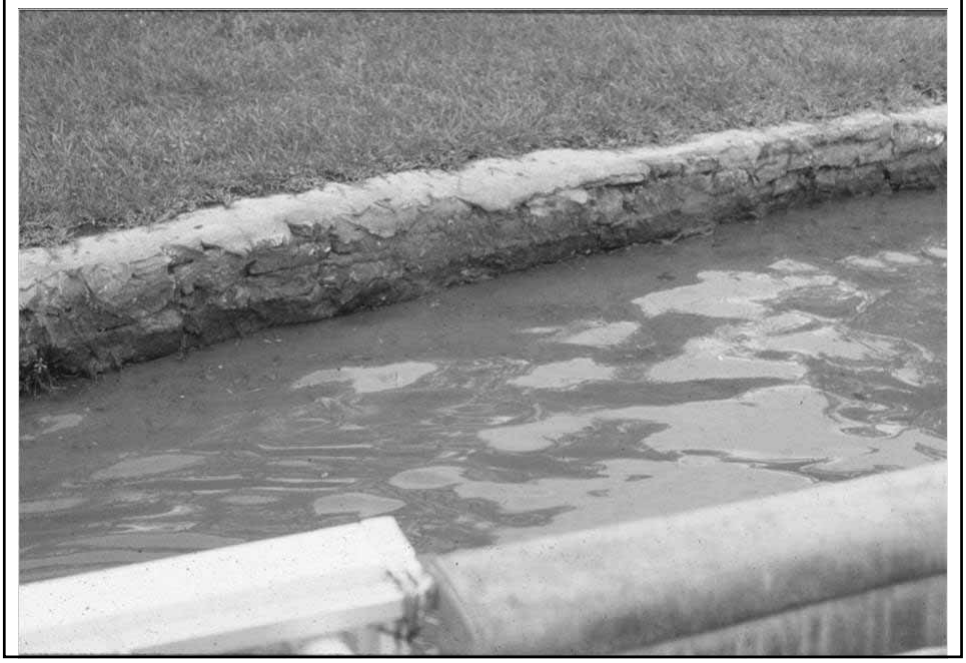
Wash-off from Lawns and Landscaped Areas is a Major Nutrient Source

Suspended Solids and Vegetation Can Be Significant Sources of Nutrients

Nutrients are Also Attached to Colloidal Suspended Solids

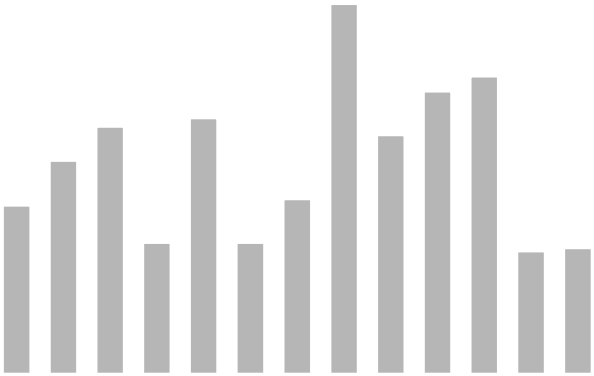


Pelagic Algal Bloom Resulting from Stormwater Runoff



Filamentous Algal Bloom Resulting from Stormwater Runoff

Comparison of Typical Nitrogen Concentrations in Stormwater



Comparison of Typical Phosphorus Concentrations in Stormwater

2. Removal/Control of Runoff Nutrients

a. Structural Techniques

Removal of Stormwater Pollutants

Removal processes depend upon:

- Type of Pollutant
- Particulate or Ionic Form
- Affinity for Adsorption or Biological Uptake
- Chemical Reactions
- Volatilization

Removal mechanisms can be divided into those responsible for removal of:

- Particulate Forms
- Dissolved Forms

Removal of Particulate Pollutants

- Primary removal mechanism is unhindered gravity settling of discrete particles according to Newton's Law or Stoke's Law
- Removal of suspended solids also removes other pollutants as well
- Removal rate (settling velocity) is a function of:
  - Particle diameter
  - Particle density

Design Techniques to Maximize Removal of Suspended Matter

1. Encourage reduction in flow velocity to allow settling
2. Minimize turbulent conditions
3. Maximize flow length from inlets to outlets
4. Prevent short-circuiting and hydraulic dead zones
5. Include aquatic plants to increase adsorption of solids onto plant surfaces

Removal Processes for Dissolved Nutrients

- Removal occurs primarily through biological processes and adsorption
- Optimize removal by maintaining:
  - Permanent wet pool
  - Diverse biota
  - Well oxygenated water column
  - Soil adsorption

Common Stormwater Treatment Practices

- Infiltration Systems
  - Retention Basins
  - Swales
  - Infiltration Trenches
  - Exfiltration Systems
  - Pervious Pavement
- Detention Systems
  - Dry Detention
  - Wet Detention
- Filter Systems
- Alum Injection
- Gross Pollutant Separators

Infiltration Systems

Description

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

Purpose

- Reduce total runoff volume
- Reduce pollutant loadings

Pollutant Removal

- Percolation, evaporation
- Filtering and adsorption

Infiltration Systems
(Continued)

Limitations on Use:

- Require porous soils
- Not on soils with high clay or silt
- Not where high water tables, bedrock
- Not on fill sites or steep slopes
- Not at sites where hazard materials spill
- Risk of groundwater contamination

Benefits of Infiltration

- Groundwater recharge
- Maintain baseflow
- Maintain pre-development hydrology
- Reduce stormwater pollutant loads
- Reduce total stormwater volume

Dry Retention Basin

DESCRIPTION:

Surface area used to store runoff temporarily until it percolates or evaporates

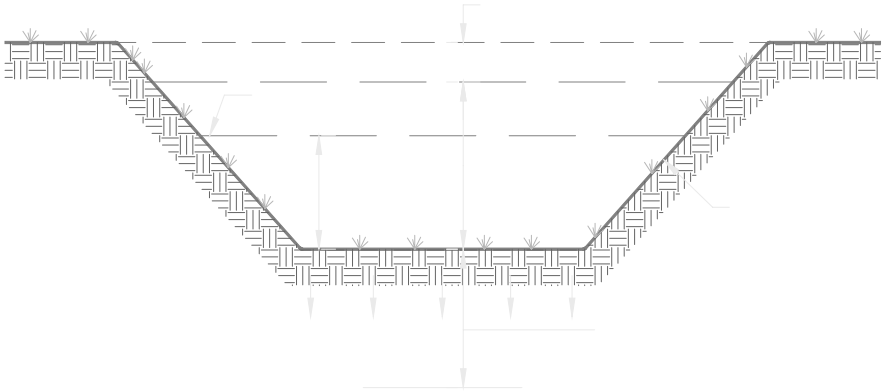
ADVANTAGES:

- Integrate into open space/landscaping
- Use for other purposes between storms
- More easily inspected and maintained

DISADVANTAGES:

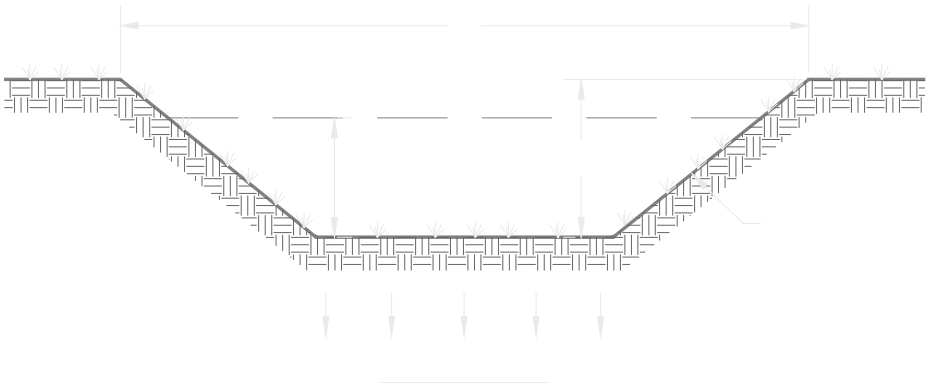
- Land area needed

Dry Retention Pond



Retention Storage Underneath a Commercial Building in Tallahassee

Typical Swale Section



Swale Drainage Along a Collector Road in Orlando

Use of Swales

- Along highways, streets, and rural roads
- Residential subdivisions
- Pre-treatment (BMP Treatment Train)
  - Any land use type, parking lots
  - Before infiltration trenches, wet ponds
- Must be designed for conveyance as well as water quality
- With enhancements
  - Swale blocks
  - Raised inlets
  - Raised driveway culverts

Infiltration Trench

Description

- Shallow excavated trench, backfilled with coarse stone, allowing for temporary storage of runoff

Advantages

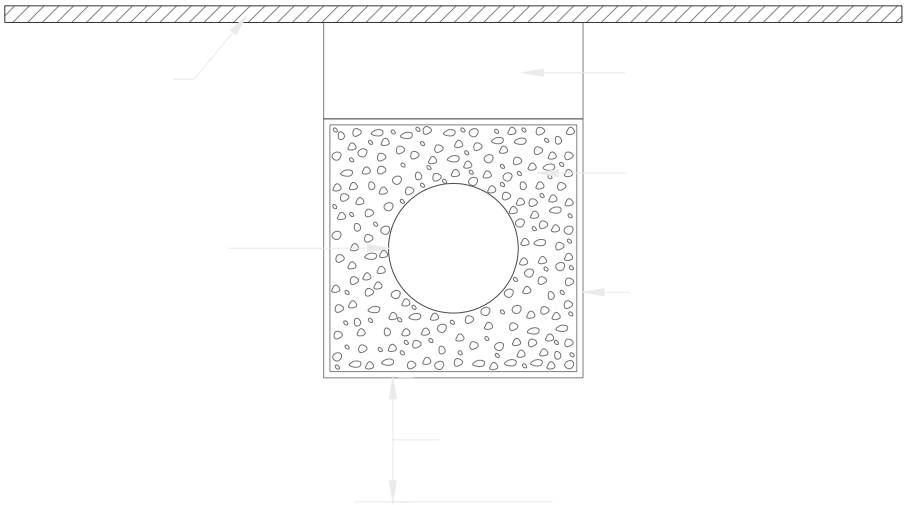
- Require less land
- Can be fit into tight places

Disadvantages

- Difficult to monitor performance
- Clog easily and hard to maintain

Schematic of Infiltration Trench with Observation Well

Exfiltration System



Pervious Pavement

Description:

Pavement with traditional strength but designed to allow percolation

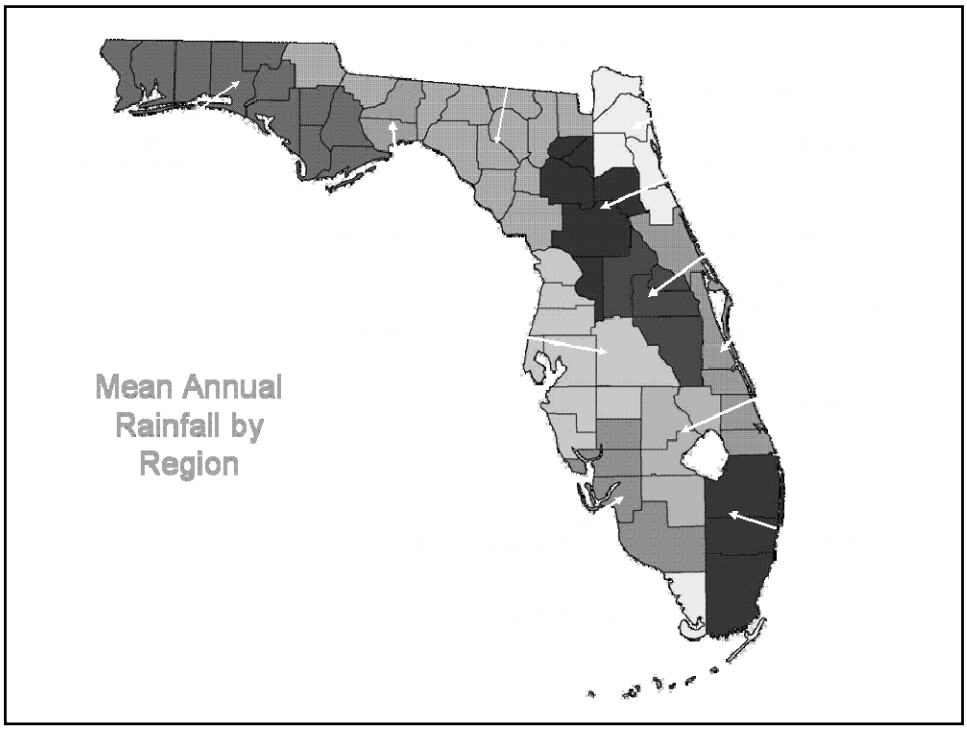
Advantages:

- Reduces site imperviousness
- Reduces hydroplaning by up to 15%
- Pedestrian-friendly, less puddles

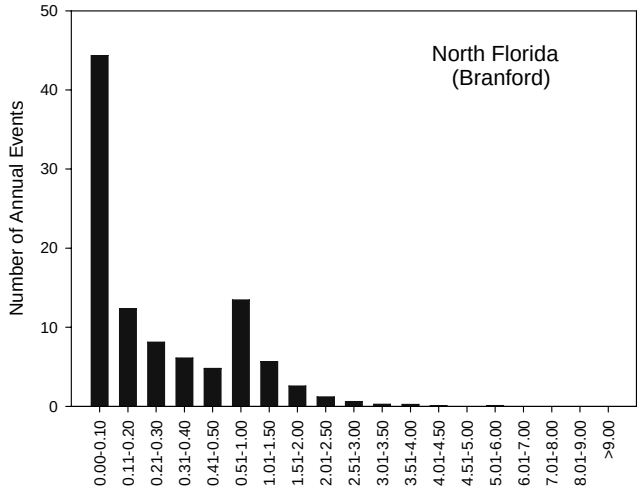
Disadvantages:

- Potential for clogging
- Lack of experienced installers
- Spills may cause groundwater problems
- Anaerobic soils in long duration rain areas

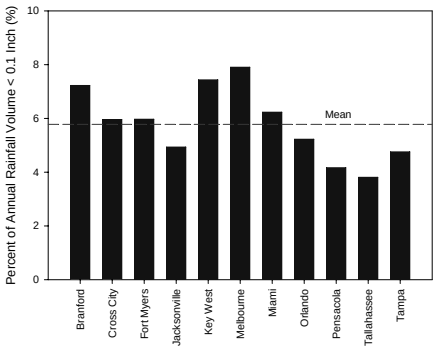
Pervious Pavement in a Shopping Center in Tallahassee

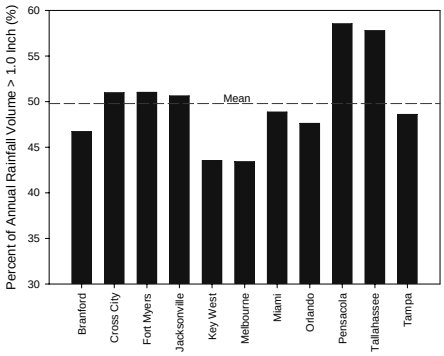


Typical Rainfall Frequency Distribution

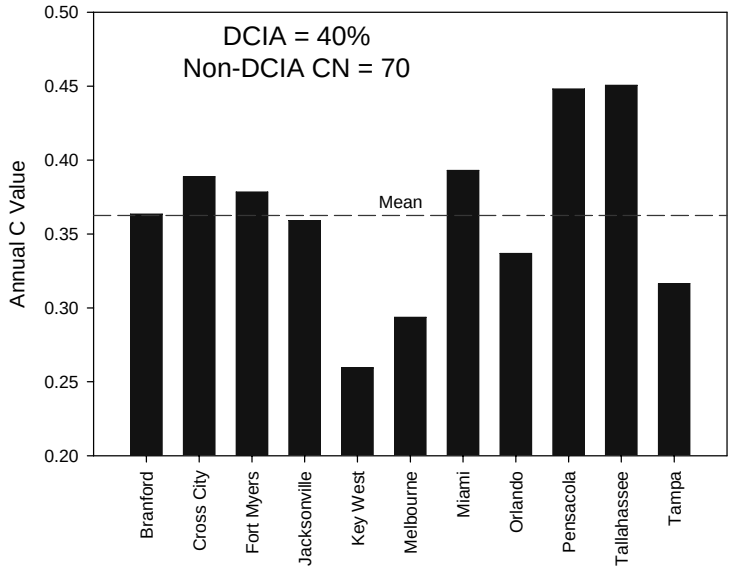


Characteristics of Rainfall Events at the 10 Meteorological Sites

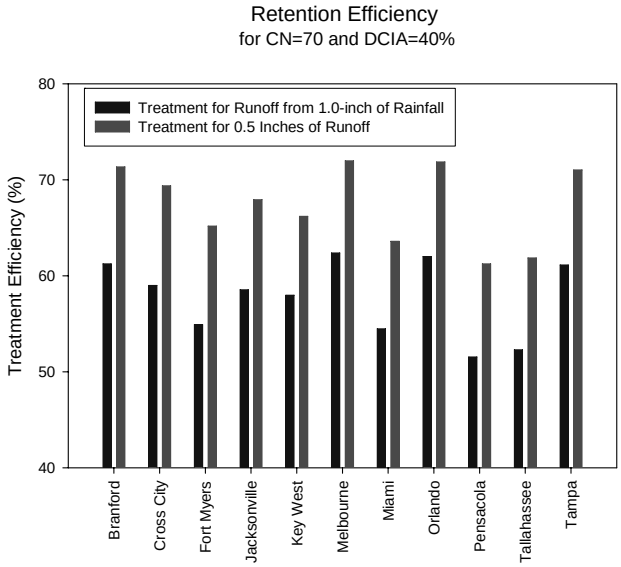




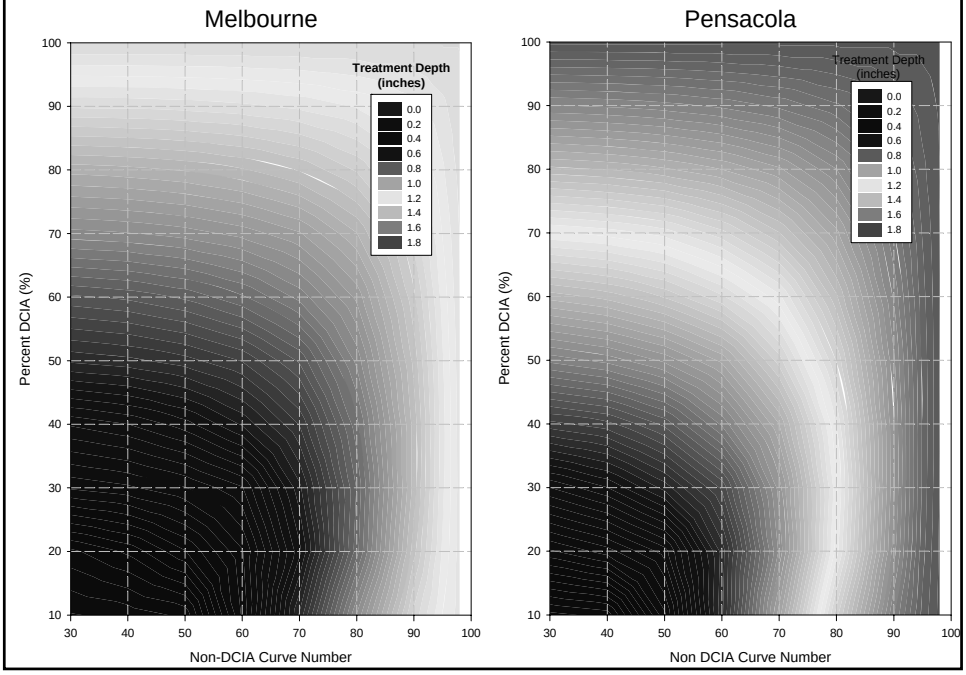
Comparison of State-Wide Annual C Values for A Hypothetical Residential Development



Comparison of Retention Efficiency for 0.5 inch of Runoff and 1 inch of Rainfall



Retention Depth Required for 80% Removal



Detention Practices

DESCRIPTION

- A family of practices which detain runoff and discharge it over a period of days

PURPOSE

- Flood protection
- Water storage
- Pollutant removal

POLLUTANT REMOVAL

- Depends on type of detention BMP

Dry Detention Basin

DESCRIPTION

- Area used to detain runoff for a short time to reduce peak discharge rate

ADVANTAGES

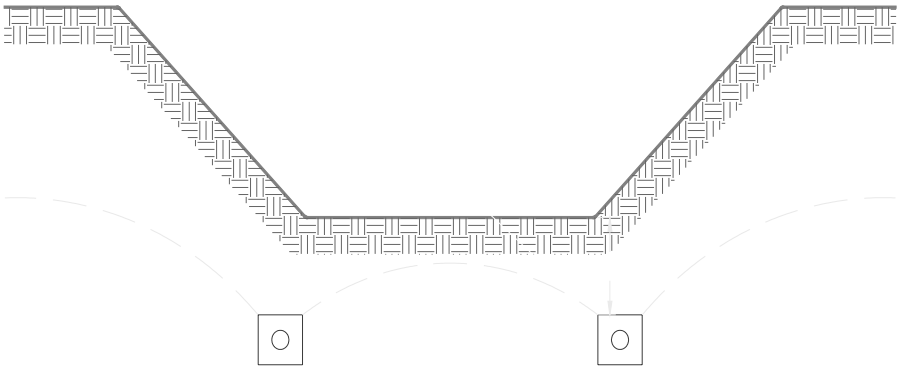
- Use for other purposes between storms

DISADVANTAGES

- Poor stormwater treatment effectiveness
- Considered unattractive nuisances
- Mosquito production

Dry Detention Basin in Orlando

Dry Detention with Filtration



Treatment Efficiencies for Dry Detention with Filtration Systems

Reference	Study Site/ Land Use	Type of Eff. Reported	Mean Removal Efficiencies (%)							
			Total N	SRP	Total P	TSS	BOD	Total Cu	Total Pb	Total Zn
Bradford-ville Study	Leon County/ Comm.	Overall	80	--	92	98	93	--	--	--
Harper & Herr (1995)	Orange County/ Comm. & Resid.	Overall	-136	-229	-86	77	-49	68	93	25
Mean Values			-28	--	3	88	22	--	--	--

Wet Detention Pond

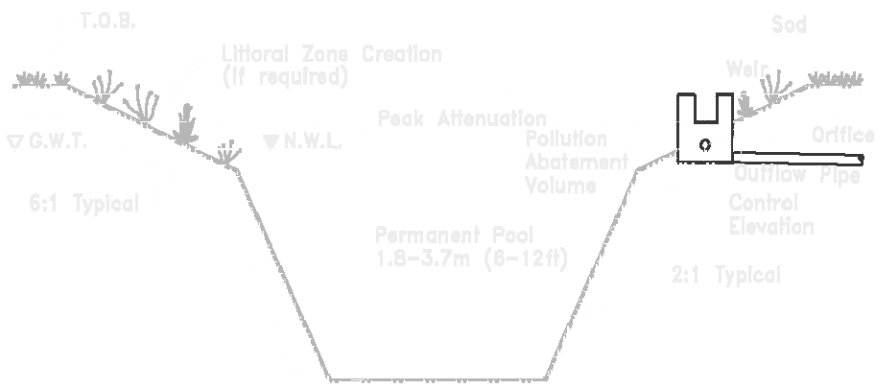
Description

- A detention system with a permanent pool in which runoff is stored temporarily before discharge

Advantages

- High level of flood protection and stormwater treatment
- Used in areas with high water tables, poor soils
- Multiple ancillary benefits
- Relatively low maintenance

Wet Detention



Wet Detention Lakes Can Be Integral to the Overall Development Plan

Wet Detention Systems

Pollutant Removal Processes

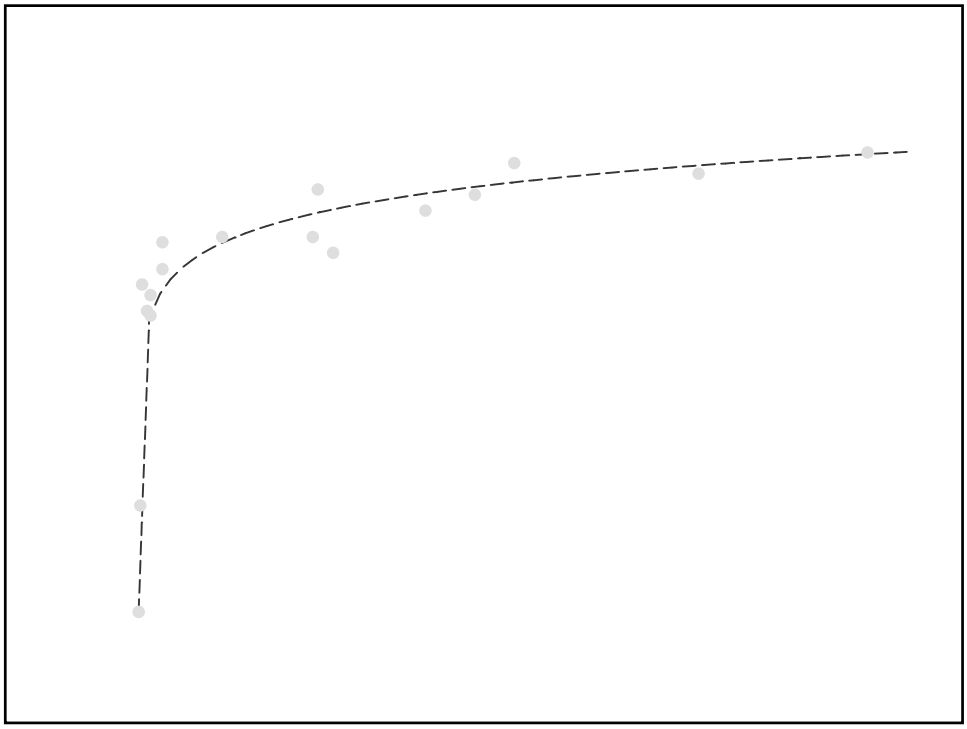
- Occurs during quiescent period between storms
- Permanent pool crucial
  - Reduces energy, promoting settling
  - Habitat for plants and microorganisms
  - Must maintain aerobic bottom conditions
- Gravity settling
  - Pond geometry, volume, residence time, particle size

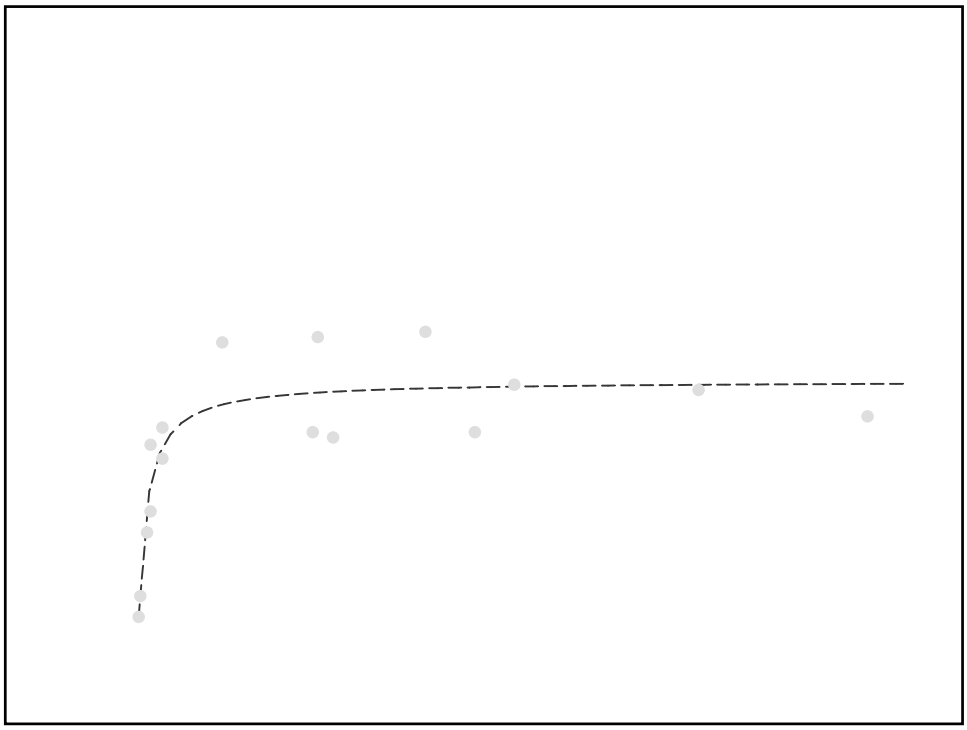
Wet Detention Design Considerations

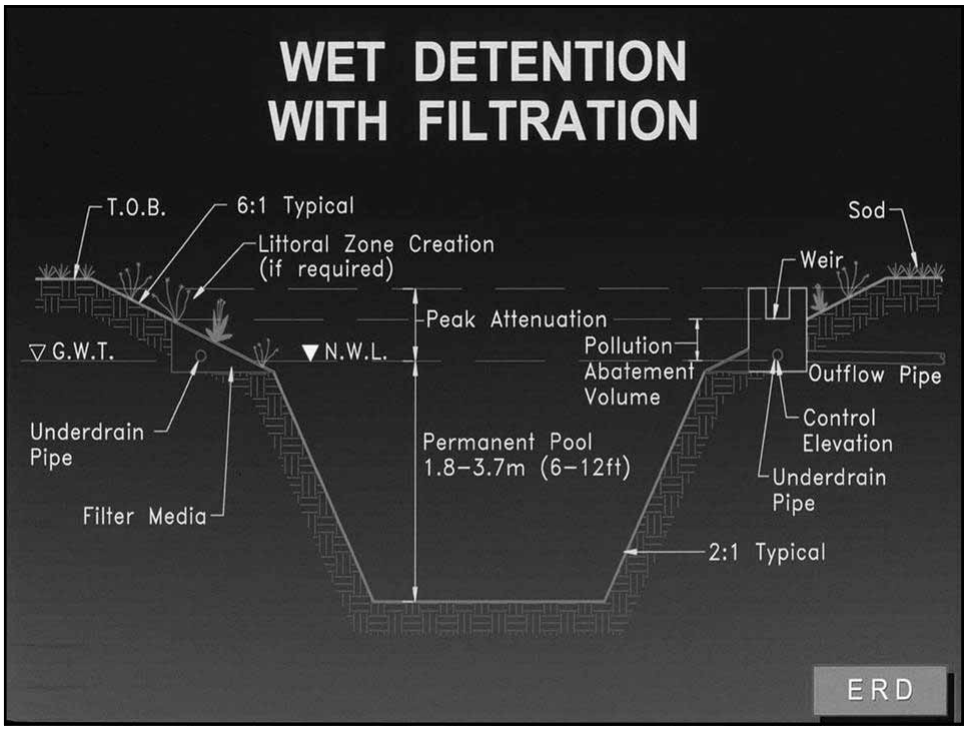
- Permanent pool and residence time
  - Average > 14 days
  - Permanent pool volume calculation:
    - (Annual runoff volume) x (14/365)
- Depth of permanent pool
  - Need mix of deep (> 3 m) and shallow areas (< 1 m)
  - Maximum depth of 6 m (20 ft), maintain aerobic bottom
  - Do not breach confining layers

Wet Detention Design Considerations

- Littoral Zone
  - 30% of surface area, slope gently (6:1 to 10:1), depth < 3 feet
  - Concentrate at outfall or around perimeter
  - Variety of native aquatic plants
- Pond Geometry
  - Length to width ratio at least 3:1, preferably 5:1
  - Separate inlets and outlets, long flow path

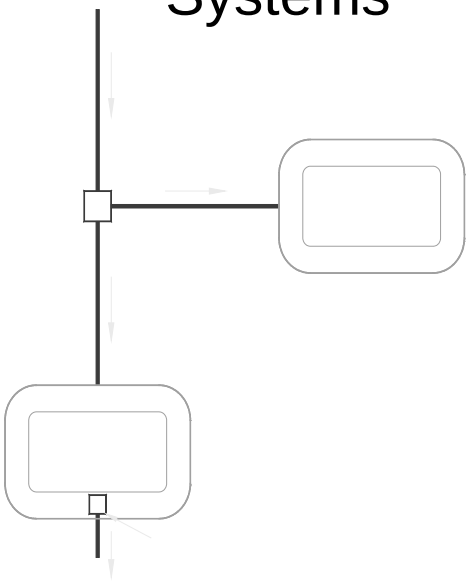




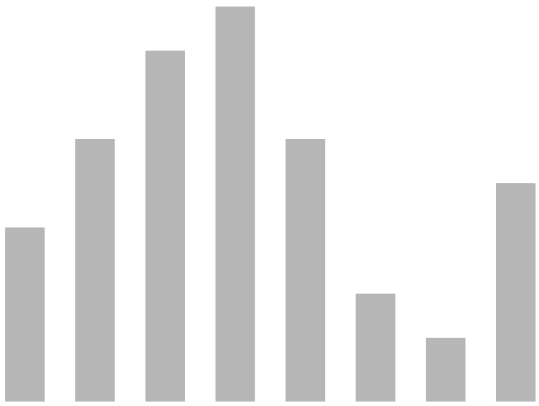


Side Bank Filter with Exposed Filter Fabric

Off-line Retention/Detention Systems



Comparative Removal Efficiencies for Total Nitrogen

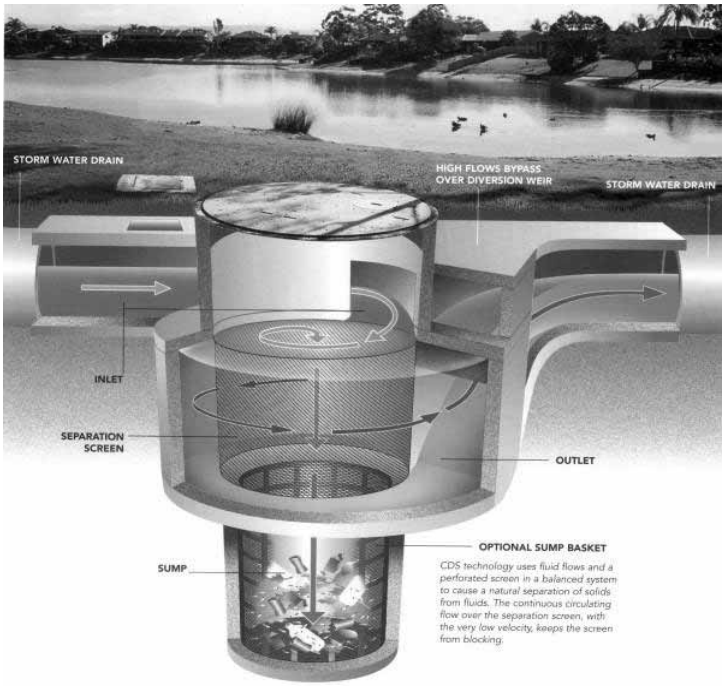


Comparative Removal Efficiencies for Total Phosphorus

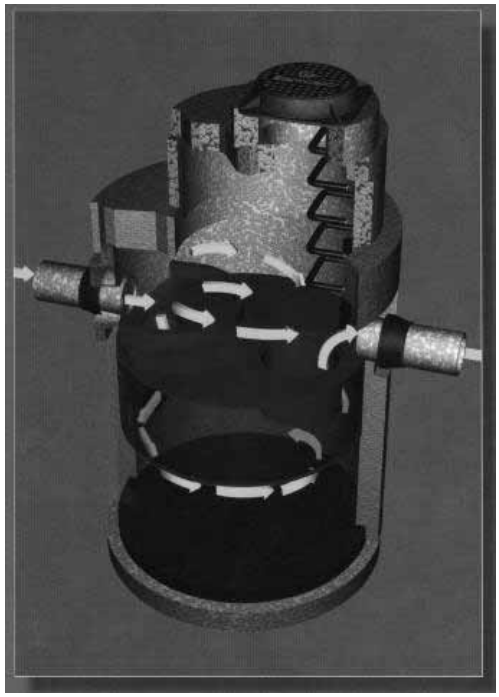
Gross Pollutant Separators

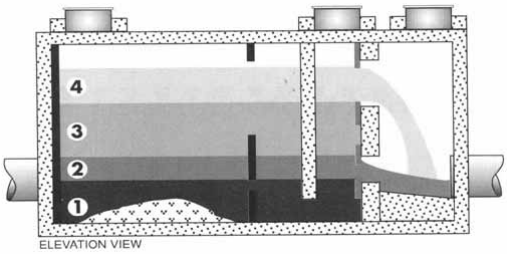
- CDS
- Stormcepter
- Vortechnics
- Baffle Boxes

CDS Unit

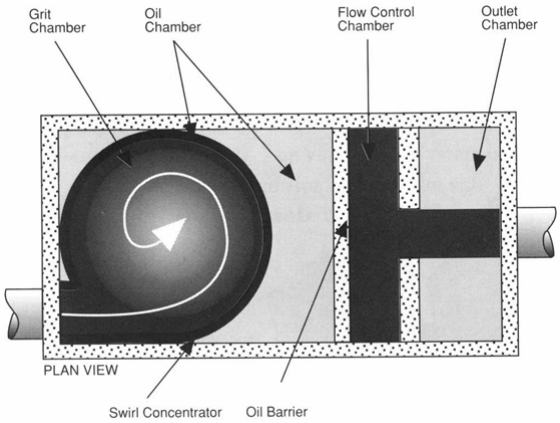


CSR Stormceptor

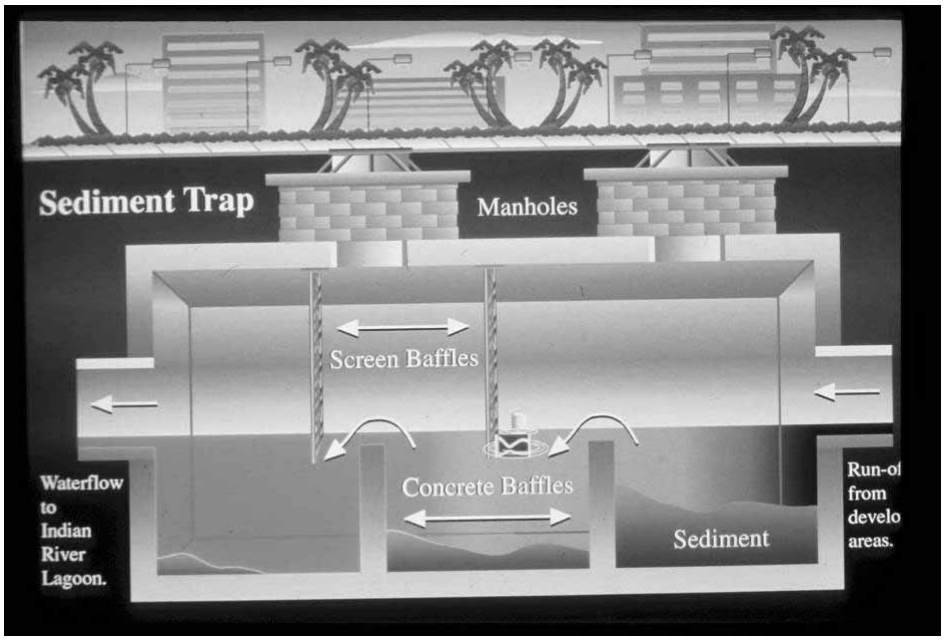




Vortechs Stormwater Treatment System



Typical Baffle Box or Sediment Trap Design



Typical Distribution of Dissolved and Particulate Runoff Fractions for Highway Runoff

Parameter	Typical Distribution[1] (%)	
	Dissolved	Particulate
Total N	65	35
Total P	55	45
TSS	0	100
BOD	65	35
Cadmium	70	30
Chromium	45	55
Copper	50	50
Nickel	80	20
Lead	40	60
Zinc	45	55

1. Harper, H.H. (1988). "Effects of Stormwater Management Systems on Groundwater Quality." Final Report for Project SM 190, submitted to the Florida Department of Environmental Regulation.

Alum Treatment

Alum is a viscous clear liquid with a greenish to tan color

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:

$$Al^{+3} + H_nPO_4^{n-3} \longleftrightarrow AlPO_{4(s)} + nH^{+}$$

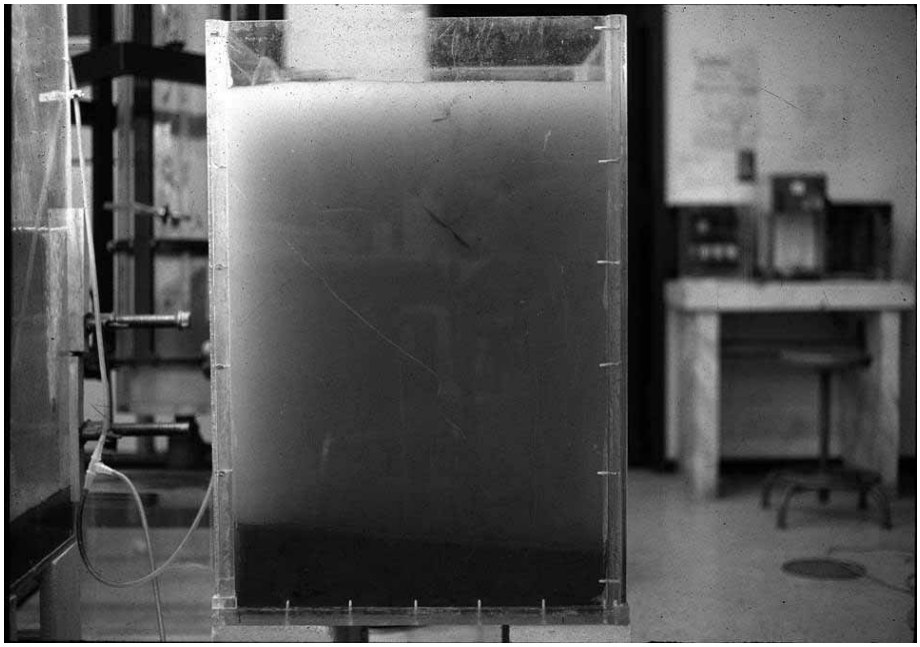
Aluminum Coagulants

Aluminum Sulfate (alum)

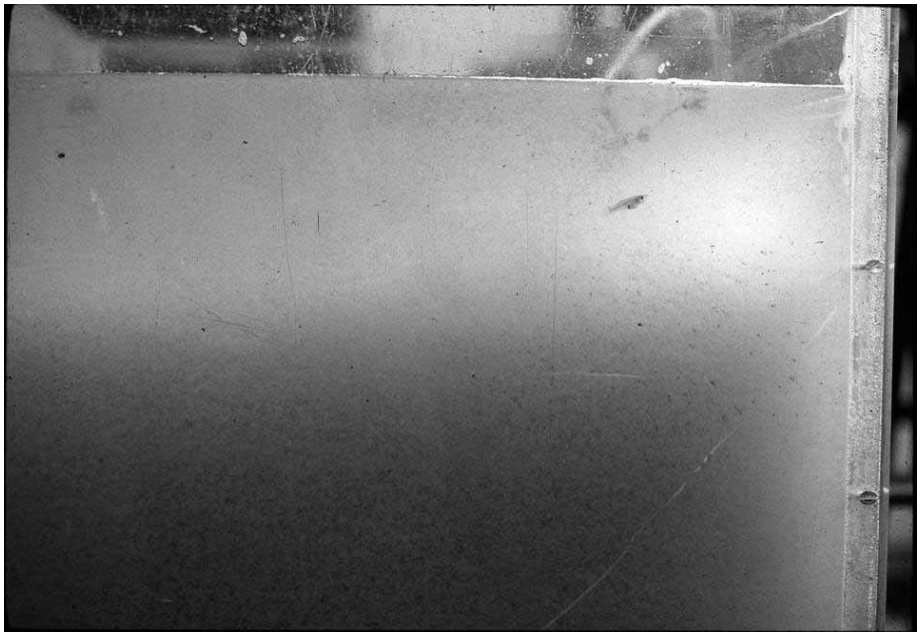
Aluminum Chloride

Poly Aluminum Hydroxychloride

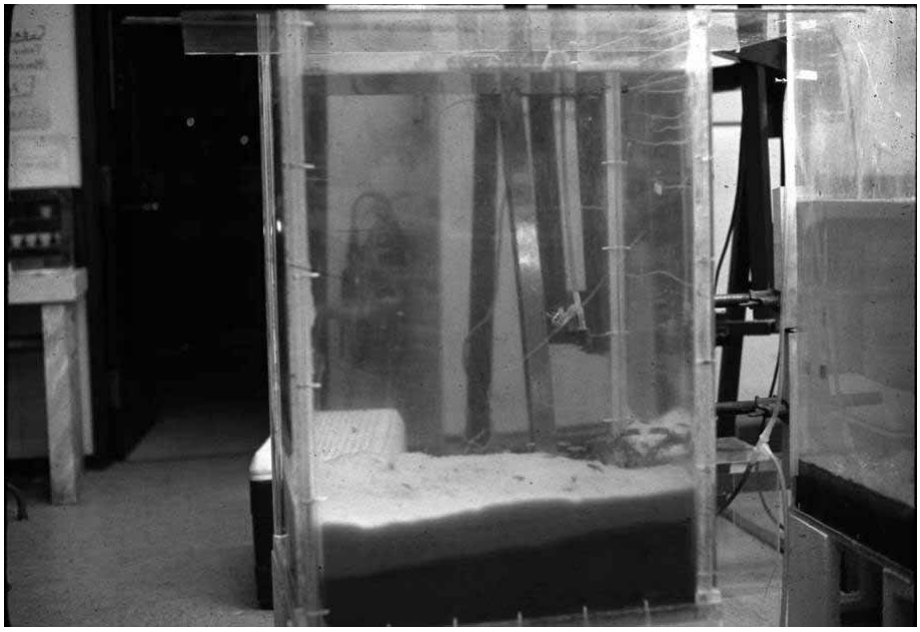
Alum/Polymer Blends (floc logs)



Colloidal Runoff Sample Settled for 45 Days



Immediately Following Alum Addition



Treated Sample 4 Hours After Alum Addition

Alum Coagulation

Advantages

- Rapid, efficient removal of solids, phosphorus, and bacteria
- Inexpensive – approximately $0.65/gallon
- Relatively easy to handle and feed
- Does not deteriorate under long-term storage
- Floc is inert and is immune to normal fluctuations in pH and redox potential
- Floc also binds heavy metals in sediments, reducing sediment toxicity

Disadvantage

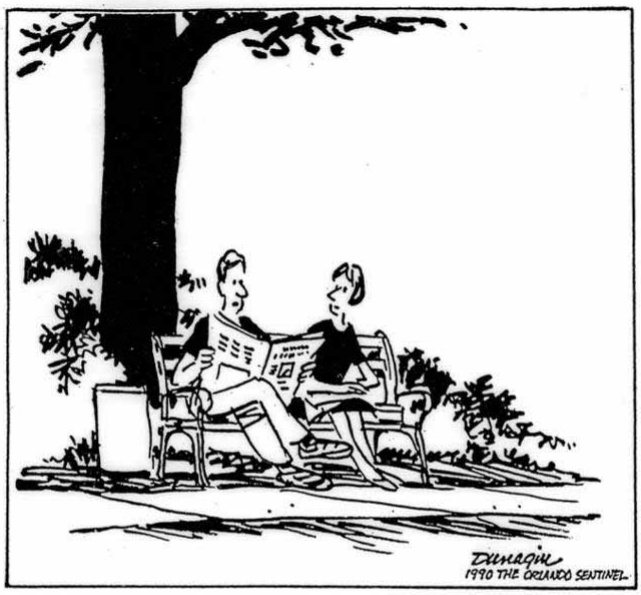
- May result in lowered pH and elevated levels of Al^{+3} if improperly applied

Typical Percent Removal Efficiencies for Alum Treated Stormwater Runoff

PARAMETER	SETTLED WITHOUT ALUM (24 hrs)	ALUM DOSE (Dose in mg Al/liter)		
		5	7.5	10
Diss. Organic N	20	51	62	65
Particulate N	57	88	94	96
Total N	25	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
BOD	30	61	63	64
Total Coliform	37	80	94	99
Fecal Coliform	61	96	99	99

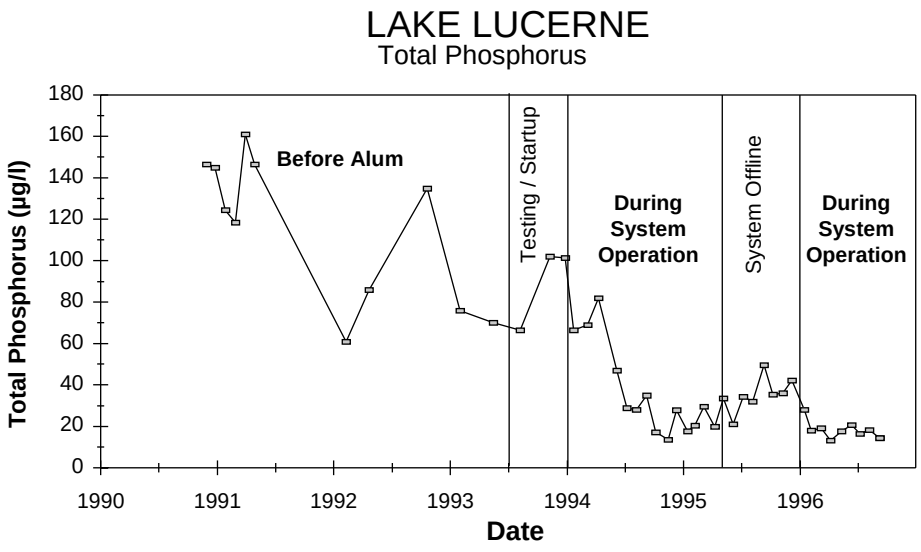
Lake Dot – Post Treatment

Cartoon in
Orlando Sentinel
After Completion
Of the Lake Dot
Alum Stormwater
Treatment
System



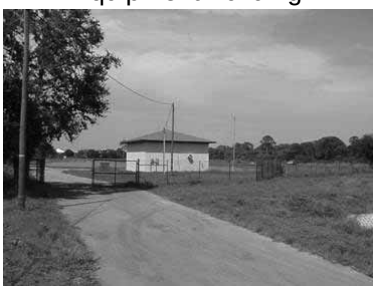
"THAT STRANGE SUBSTANCE IN LAKE DOT HAS BEEN IDENTIFIED AS CLEAN WATER."

Lake Lucerne – Post Treatment



Merritt Ridge Alum Injection System

Equipment Building



In-line Floc Settling Pond

Alum Injection Equipment

pH Control Equipment

Construction and O&M Costs for Existing Alum Treatment Systems

Parameter	Area Treated (acres)	Construction Cost ($)	Annual O&M Costs	Construction Cost/Area Treated ($/acre)
Minimum	64	75,000	6,500	139
Maximum	538	400,000	26,298	3,769
Average	310	276,800	18,580	1,233

2. Removal/Control of Nutrients

b. Non-structural Techniques

Street Sweeping

- Most applicable for paved streets having curbs and gutters, but can be used on any impervious surface
- Particularly applicable to urban built-out areas where space for conventional stormwater treatment is unavailable or too expensive

Types of Street Sweepers

- Mechanical Sweepers
  - Most common type of sweeper
  - Uses brooms to sweep solids into a hopper
  - Water is sprayed for dust control
  - Efficiency is a function of:
    - Particle size
    - Frequency of sweeping
    - Number of passes
    - Equipment speed
    - Pavement conditions

Types of Street Sweepers

- Vacuum (plus mechanical)
  - Provides air vacuum over entire path with mechanical broom assist
  - Some particles do not receive sufficient agitation to become air-entrained
- Regenerative Air
  - Air is forced down onto the pavement, suspending particles, which are then picked up by the vacuum

Estimated TSS Reduction from Street Sweeping (%)

(Major Arterial Highway)

Sweeper Type	Frequency of Sweeping			
	Monthly	Twice Monthly	Weekly	Twice Weekly
New Type Vacuum	49	62	76	85
Air Sweeper	15	17	22	24
Mechanical Brush Type	3	4	5	7

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

Removal of Other Pollutants by Street Sweeping

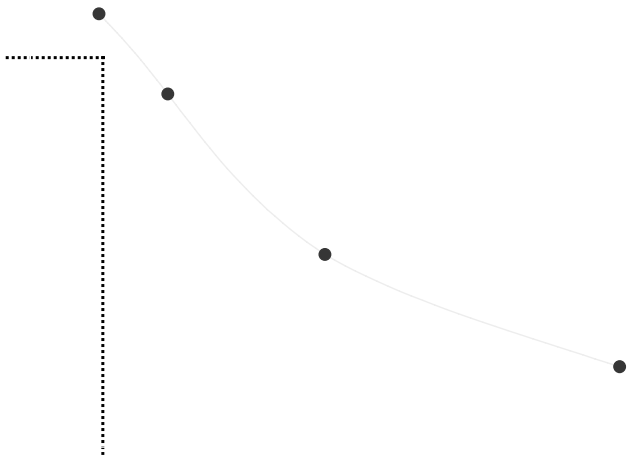
(Based on a 60% TSS Removal)

Total Metals – 45% - 55%

Phosphorus – 25% - 35%

BOD – 35% - 45%

High Efficiency Street Sweeping Equipment



Questions?