# SESWA Regional Seminar
# BMP SELECTION CRITERIA

Doug Beisch - Principal
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# Goals and Objectives

- Design Goals and Objectives
- Multi-Function BMPs
- Innovative Approaches

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# Background Questions:

- How many of you are **designers**?
- How many of you **review and approve plans**?
- How many of you **routinely see “LID” approaches** incorporated into projects?

# BMP Design Goals and Objectives

- Site Drainage
- Erosion and Sediment Control
- Runoff Quality Management
- Receiving Channel Protection
- Flood Control

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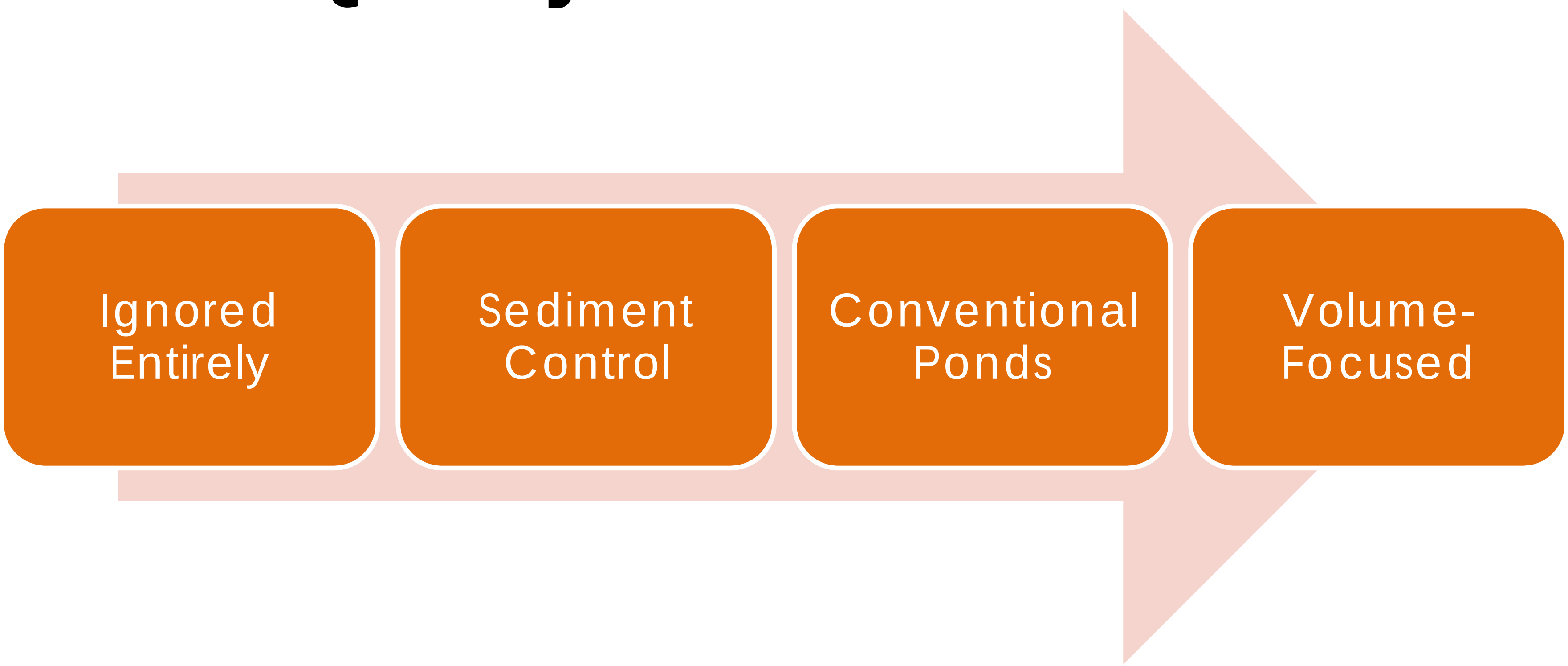
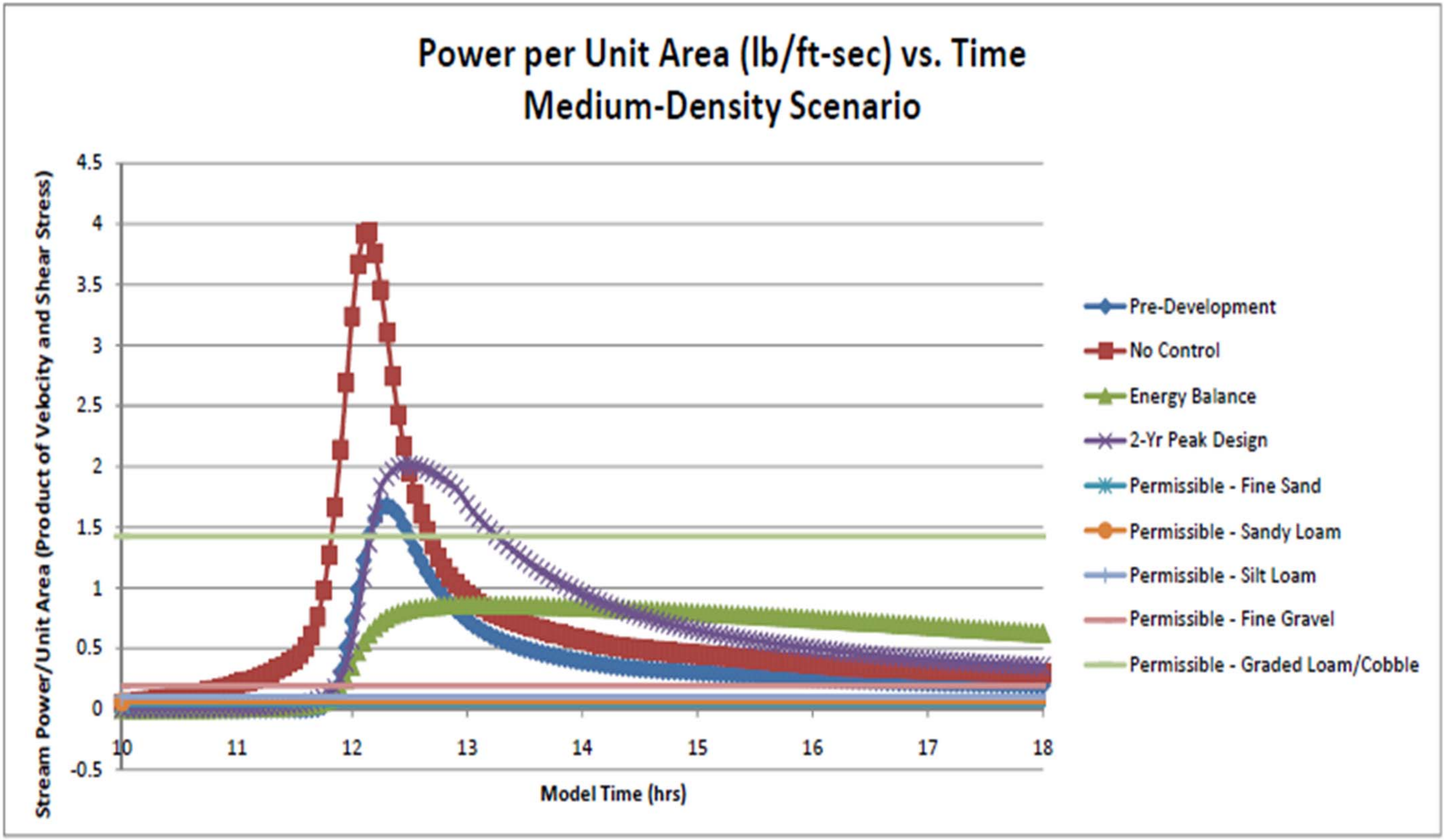
Evolution of Approaches:

# Runoff Quality




USGS, 2012



Power per Unit Area (lb/ft-sec) vs. Time
Medium-Density Scenario
Stream Power/Unit Area (Product of Velocity and Shear Stress)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
10
11
12
13
14
15
16
17
18
Model Time (hrs)
Pre-Development
No Control
Energy Balance
2-Yr Peak Design
Permissible - Fine Sand
Permissible - Sandy Loam
Permissible - Silt Loam
Permissible - Fine Gravel
Permissible - Graded Loam/Cobble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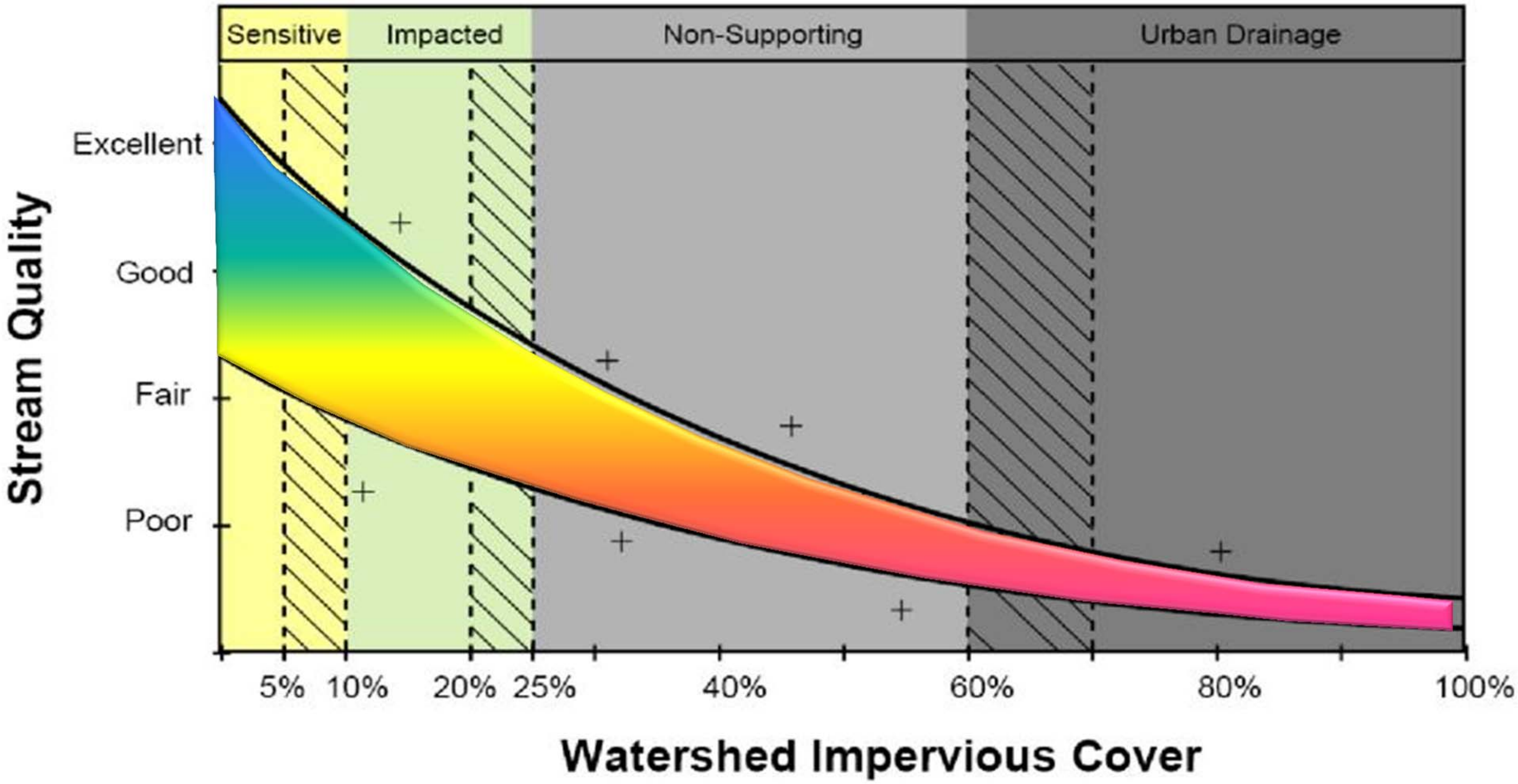
# Impervious Cover Model

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# Managed Turf

- Documented impacts from turf management activities:
  - Fertilization;
  - Pest management;

# Site Runoff Coefficients (Rv)[1]

| Cover | HSG A | HSG B | HSG C | HSG D |
|---|---|---|---|---|
| Forest/Open | **0.02** | **0.03** | **0.04** | **0.05** |
| Managed Turf / Disturbed Soil | **0.15** | **0.20** | **0.22** | **0.25** |
| Impervious Cover | **0.95** | **0.95** | **0.95** | **0.95** |

[1] *Center for Watershed Protection – Technical Memorandum: The Runoff Reduction Method; 4/18/08*

*Pitt et al (2005), Lichter and Lindsey (1994), Schueler (2001a, 2001b, 1987), Legg et al (1996), Pitt et al (1999), and Cappiella et al (2005)*

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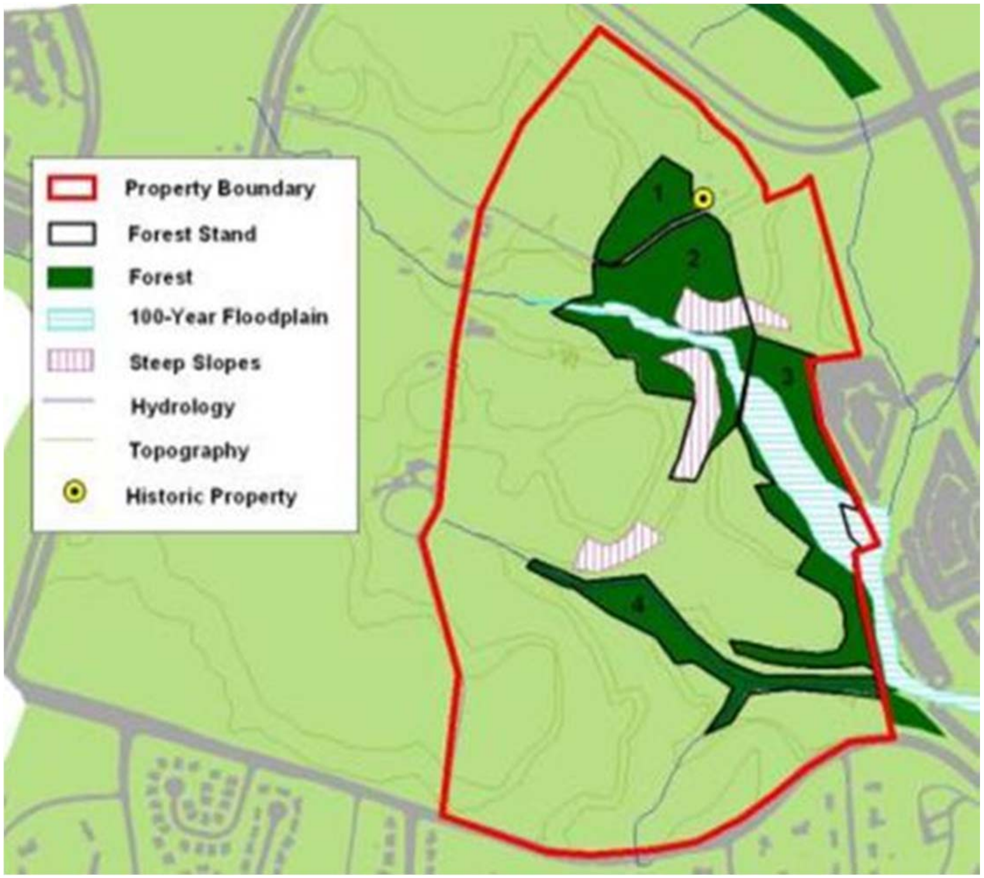
# First Step in BMP Selection
## Environmental Site Inventory & Assessment

- Forest conservation
- Suitable soils
- Steep slopes
- Drainage
- Wetlands
- Zero-order streams
- Buffers
- Sensitive areas
- Limits of disturbance
- Computed nutrient loads & tv

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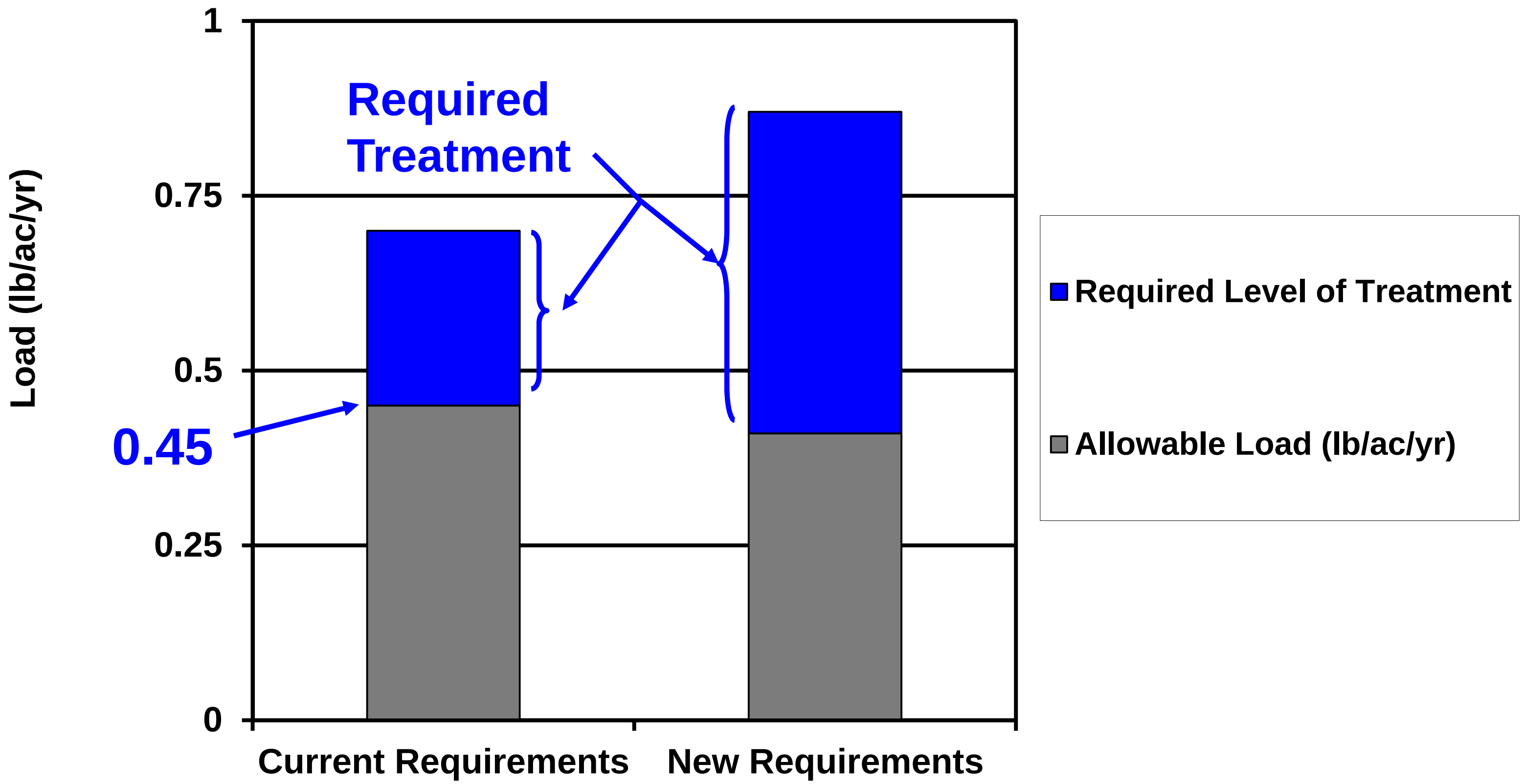
# Water Quality - Treatment

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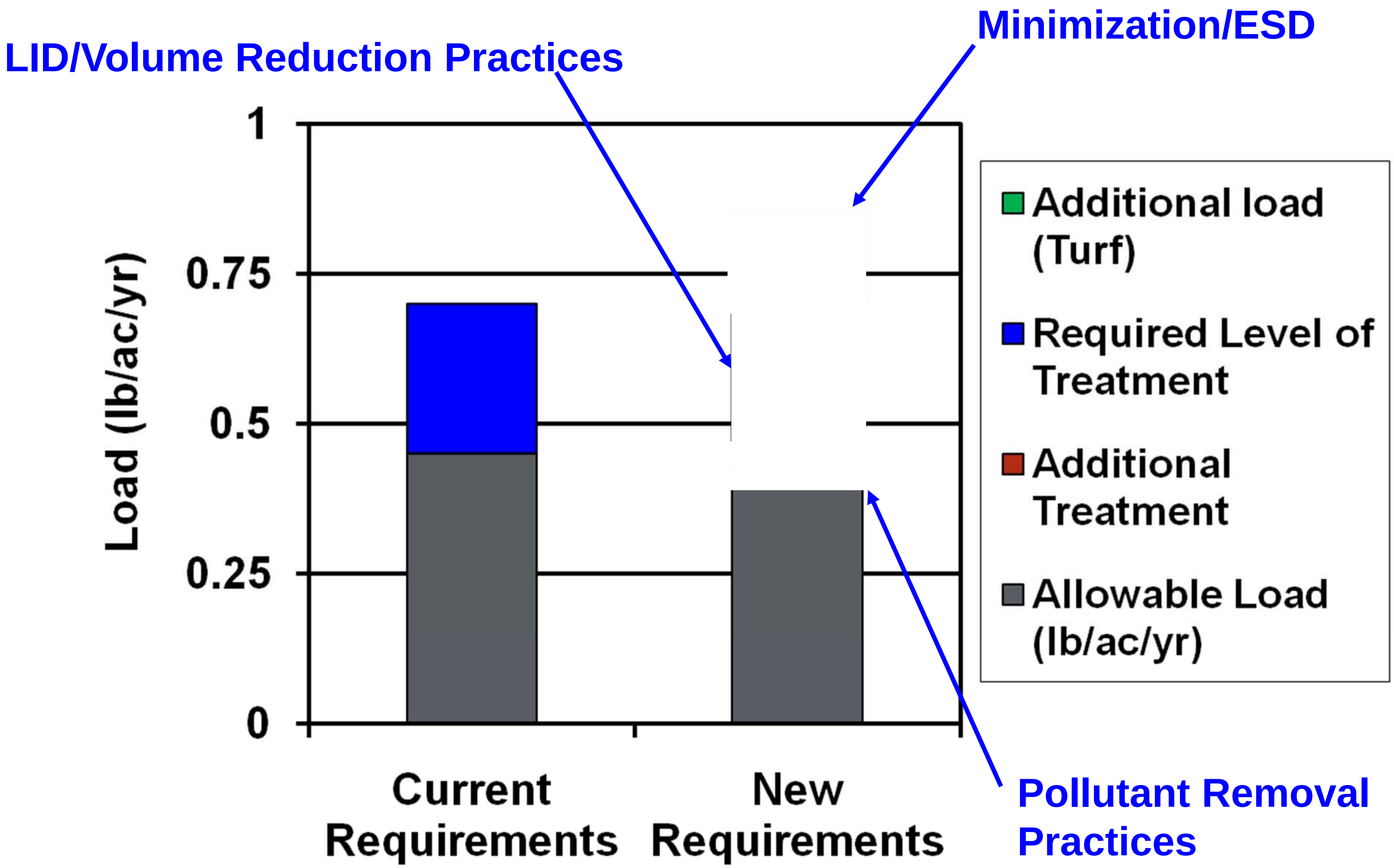
# Treatment Options

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# Traditional Approaches

1,000,000 liters of stormwater (multiple storm events)

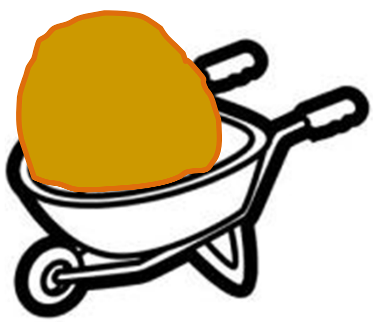
100 mg/L pollutant (average)

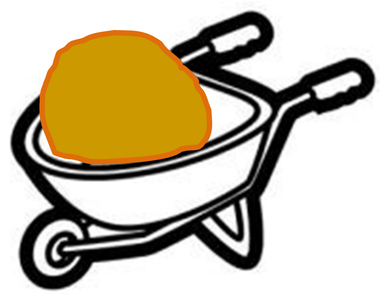
BMP

1,000,000 liters of stormwater (multiple storm events)

50 mg/L of pollutant (average)

**100 kg**
Total pollutant load





**50 kg**
Total pollutant load discharged over time

No volume reduction, only load reduction

SOURCE: VA DEQ, 2013

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# Volume Based Approaches

1,000,000 liters of stormwater (multiple storm events)

100 mg/L of pollutant (average)

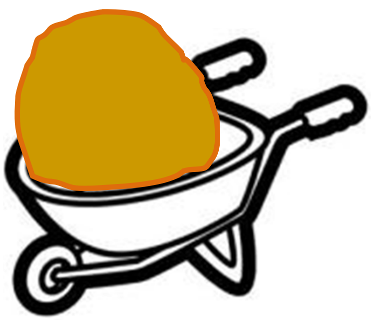
**BMP**

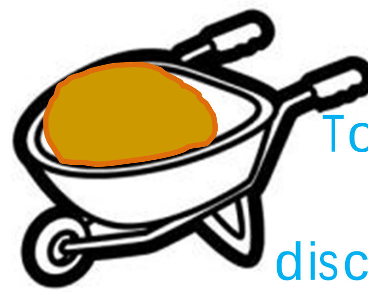
**50% volume reduction**

500,000 liters of stormwater (multiple storm events)

50 mg/L pollutants (average)

**100 kg**
Total load of pollutant





**25 kg**
Total load of pollutant discharged over time

**Volume and load reduction!**

SOURCE: VA DEQ

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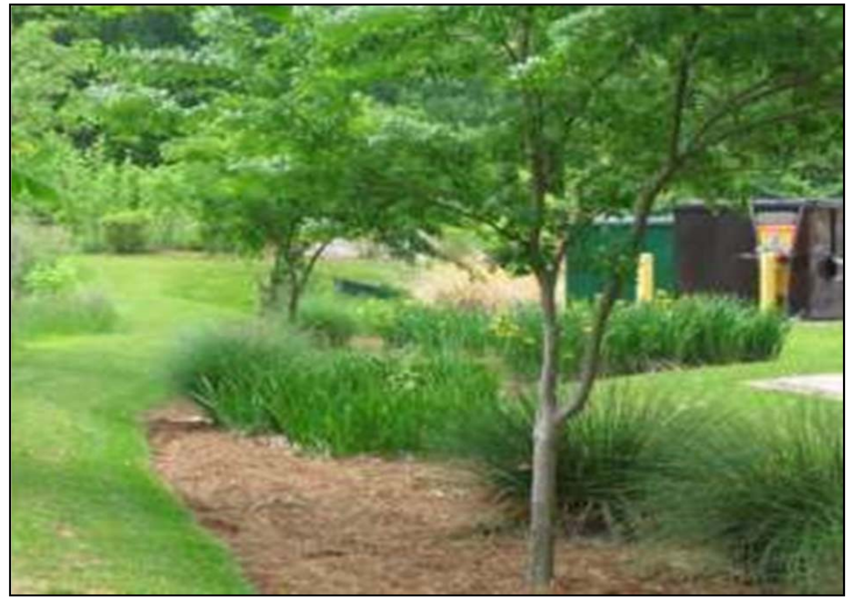
# Stormwater Practices Differ Sharply in Ability to Reduce Runoff Volume

Wet Ponds, ED Ponds and Constructed Wetlands and Filters Reduce Runoff Volumes by zero to 10%



Bioretention, Infiltration, Dry Swales, Soil Amendments, disconnection, and Related Practices Reduce Runoff Volumes by 50 to 90%

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| Practice | Design Level | Runoff Reduction | TN EMC Removal[3] | TN Mass Load Removal | TP EMC Removal | TP Mass Load Removal [6] |
|---|---|---|---|---|---|---|
| Rooftop Disconnect | 1 [2] | 25 to 50 [1] | 0 | 25 to 50 [1] | 0 | 25 to 50 [1] |
| | No Level 2 Design | | | | | |
| Sheet Flow to Veg. Filter or Conserv. Open Space | 1 | 50 | 0 | 50 | 0 | 50 |
| | 2 [5] | 50 to 75 [1] | 0 | 50 to 75 [1] | 0 | 50 to 75 [1] |
| Grass Channels | 1 | 10 to 20 [1] | 20 | 28 to 44 [1] | 15 | 24 to 41 [1] |
| | No Level 2 Design | | | | | |
| Soil Compost Amendment | Can be used to Decrease Runoff Coefficient for Turf Cover at Site. See the design specs for Rooftop Disconnection, Sheet Flow to Vegetated Filter or Conserved Open Space, and Grass Channel | | | | | |
| Vegetated Roof | 1 | 45 | 0 | 45 | 0 | 45 |
| | 2 | 60 | 0 | 60 | 0 | 60 |
| Rainwater Harvesting | 1 | Up to 90 [3, 5] | 0 | Up to 90 [3, 5] | 0 | Up to 90 [3, 5] |
| | No Level 2 Design | | | | | |
| Permeable Pavement | 1 | 45 | 25 | 59 | 25 | 59 |
| | 2 | 75 | 25 | 81 | 25 | 81 |
| Infiltration Practices | 1 | 50 | 15 | 57 | 25 | 63 |
| | 2 | 90 | 15 | 92 | 25 | 93 |
| Bioretention Practices | 1 | 40 | 40 | 64 | 25 | 55 |
| | 2 | 80 | 60 | 90 | 50 | 90 |
| Urban Bioretention | 1 | 40 | 40 | 64 | 25 | 55 |
| | No Level 2 Design | | | | | |
| Dry Swales | 1 | 40 | 25 | 55 | 20 | 52 |
| | 2 | 60 | 35 | 74 | 40 | 76 |
| Wet Swales | 1 | 0 | 25 | 25 | 20 | 20 |
| | 2 | 0 | 35 | 35 | 40 | 40 |
| Filtering Practices | 1 | 0 | 30 | 30 | 60 | 60 |
| | 2 | 0 | 45 | 45 | 65 | 65 |
| Constructed Wetlands | 1 | 0 | 25 | 25 | 50 | 50 |
| | 2 | 0 | 55 | 55 | 75 | 75 |
| Wet Ponds | 1 | 0 | 30 (20) [4] | 30 (20) [4] | 50 (45) [4] | 50 (45) [4] |
| | 2 | 0 | 40 (30) [4] | 40 (30) [4] | 75 (65) [4] | 75 (65) [4] |
| Ext. Det. Ponds | 1 | 0 | 10 | 10 | 15 | 15 |
| | 2 | 15 | 10 | 24 | 15 | 31 |

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# Multi-Function Practices

| | Site Design | Runoff Reduction | Pollutant Removal |
|---|---|---|---|
| 1. Rooftop Disconnection | ✓ | ✓ | |
| 2. Filter Strip | ✓ | ✓ | |
| 3. Grass Channel | | ✓ | ✓ |
| 4. Soil Amendments | ✓* | ✓ | |
| 5. Green Roof | | ✓ | |
| 6. Rain Tanks & Cisterns | | ✓ | |
| 7. Permeable Pavement | | ✓ | ✓ |
| 8. Infiltration | | ✓ | ✓ |
| 9. Bioretention | | ✓ | ✓ |
| 10. Dry Swales | | ✓ | ✓ |
| 12. Filtering Practices | | | ✓ |
| 13. Constructed Wetlands | | | ✓ |
| 14. Wet Ponds | | | ✓ |
| 15. ED Ponds | | ✓ | ✓ |

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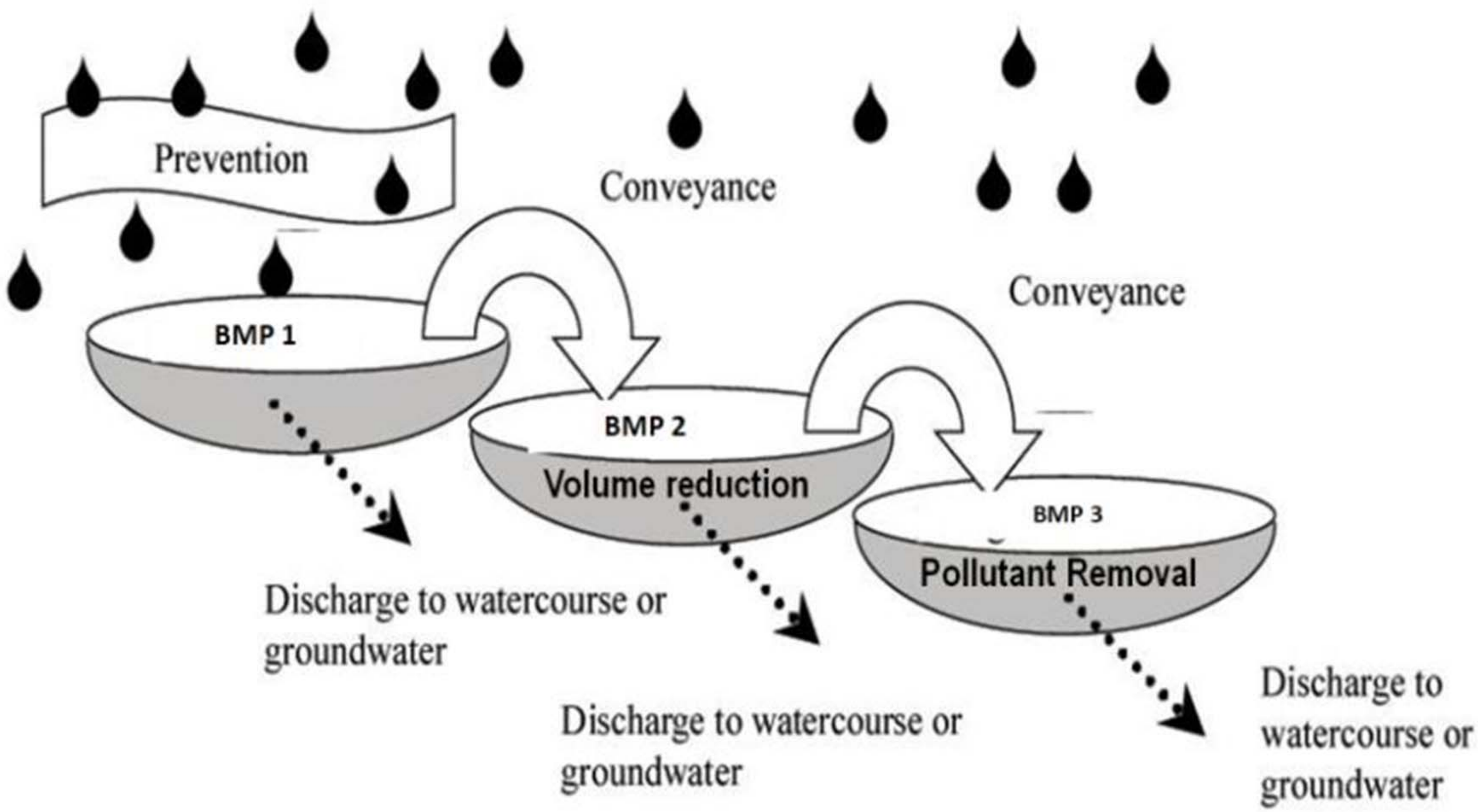
# BMP Treatment Train

Consider guidance to standardize *Process Diagrams* to track volume and load through complex treatment trains



# Tools in the Toolbox

1. Impervious Disconnection
2. Sheetflow to Conservation Area/Filter Strip
3. Grass Channels
4. Soils Compost Amendments
5. Vegetated Roofs
6. Rainwater Harvesting
7. Permeable Pavement
8. Infiltration
9. Bioretention (including Urban Bioretention)
10. Dry Swales
11. Wet Swales
12. Filtering Practices
13. Constructed Wetlands
14. Wet Ponds
15. Dry Extended Detention Ponds

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# Rooftop/Impervious Area Disconnection

Simple Disconnection

Rainwater Harvesting & Cisterns;

Micro-Infiltration (dry wells);

Rain Gardens Urban Planter

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# Sheet Flow to a Vegetated Filter Strip or Conserved Open Space

## Filter Strip & Open Space Design Criteria

| Design Issue | Conserved Open Space | Vegetated Filter Strip |
|---|---|---|
| Soil and Vegetative Cover (Sections 6.1 and 6.2) | Undisturbed soils and native vegetation | Amended soils and dense turf cover or landscaped with herbaceous cover, shrubs, and trees |
| Overall Slope and length (parallel to the flow) (Section 5) | 0.5% to 3% Slope – Minimum 35 ft length<br>3% to 6% Slope – Minimum 50 ft length<br>The first 10 ft. of filter must be 2% or less in all cases [2] | 1% [1] to 4% Slope – Minimum 35 ft. length<br>4% to 6% Slope – Minimum 50 ft. length<br>6% to 8% Slope – Minimum 65 ft. length<br>The first 10 ft. of filter must be 2% or less in all cases |
| Contributing Area of Sheet Flow (Section 5) | Maximum flow length of 150 ft. from adjacent pervious areas; Maximum flow length of 75 ft. from adjacent impervious areas | |
| Level Spreader for dispersing Concentrated Flow (Section 6.3) | Length of ELS [6] Lip = 13 lin. ft. per each 1 cfs of inflow if area has 90% Cover [3]<br>Length = 40 lin. ft. per 1 cfs for forested or re-forested Areas [4]<br>(ELS [6] length = 13 lin.ft. min; 130 lin.ft. max.) | Length of ELS [6] Lip = 13 lin.ft. per each 1 cfs of inflow (13 lin.ft. min; 130 lin.ft. max.) |
| Construction Stage (Section 8) | Located outside the limits of disturbance and protected by ESC controls | Prevent soil compaction by heavy equipment |
| Typical Applications (Section 5) | Adjacent to stream or wetland buffer or forest conservation area | Treat small areas of IC (e.g., 5,000 sf) and/or turf-intensive land uses (sports fields, golf courses) close to source |
| Compost Amendments (Section 6.1) | No | Yes (B, C, and D soils) [5] |
| Boundary Spreader (Section 6.3) | GD [6] at top of filter | GD [6] at top of filter<br>PB [6] at toe of filter |

[1] A minimum of 1% is recommended to ensure positive drainage.
[2] For Conservation Areas with a varying slope, a pro-rated length may be computed only if the first 10 ft. is 2% or less.
[3] Vegetative cover is described in **Section 6.2**.
[4] Where the conserved open space is a mixture of native grasses, herbaceous cover and forest (or re-forested area), the length of the ELS [6] Lip can be established by computing a weighted average of the lengths required for each vegetation type. Refer to **Section 6.3** for design criteria
[5] The plan approving authority may waive the requirement for compost amended soils for filter strips on B soils under certain conditions (see **Section 6.1**).
[6] ELS = Engineered Level Spreader; GD = Gravel Diaphragm; PB = Permeable Berm.

# Soil Amendments

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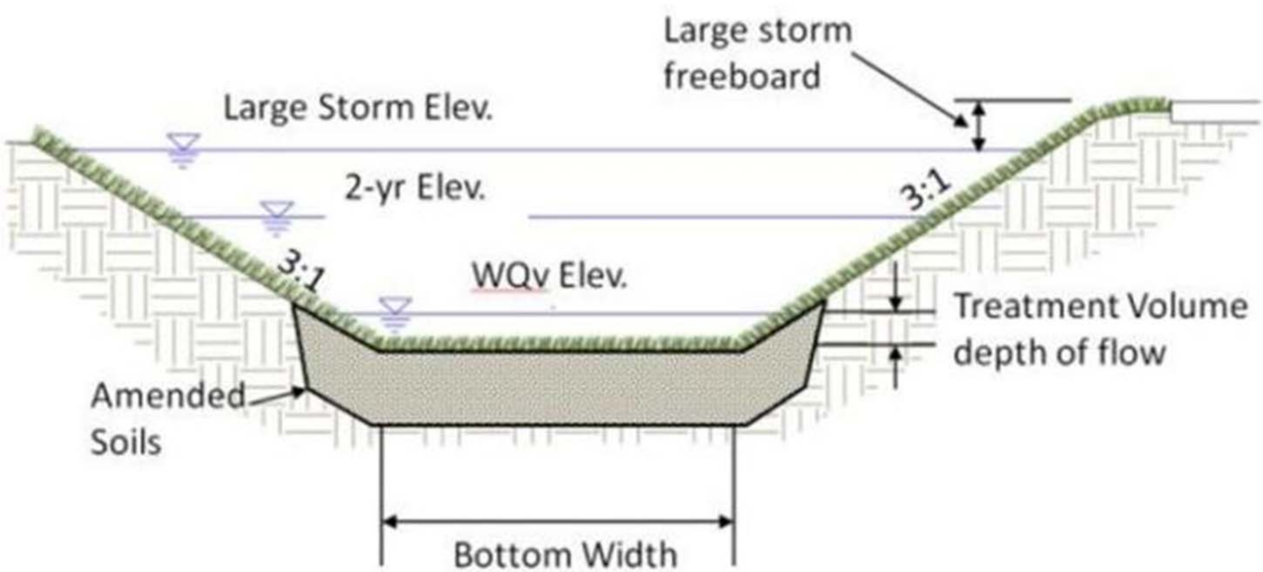
# Grass Channels

## Key Design Consideration: Soils

- Infiltration is greatest in HSG A soils;
- Infiltration gradually decreases in HSG B, C and D soils;
- HSG C and D soils lining the bottom of the Grass Channel can be amended to improve performance

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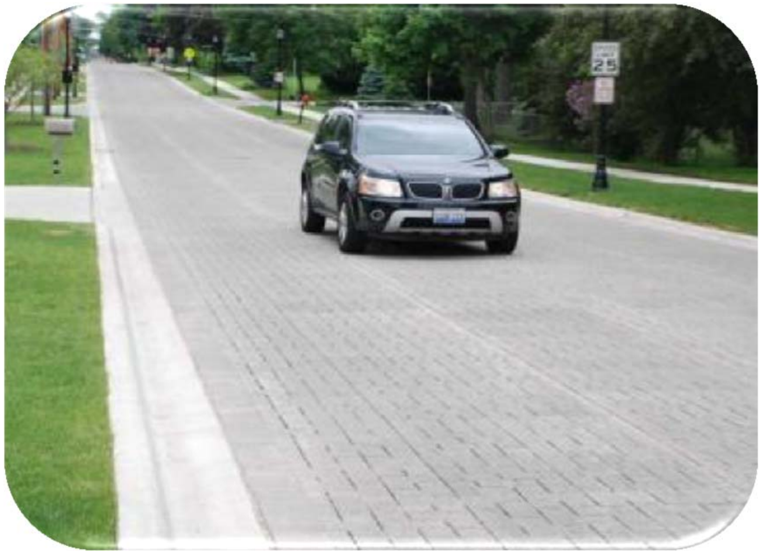
# Permeable Pavement




| Stormwater Function | Level 1 Design | Level 2 Design |
|---|---|---|
| Annual Runoff Volume Reduction (RR) | 45% | 75% |
| Total Phosphorus (TP) EMC Reduction[1] by BMP Treatment Process | 25% | 25% |
| Total Phosphorus (TP) Mass Load Removal | 59% | 81% |
| Total Nitrogen (TN) EMC Reduction[1] | 25% | 25% |
| Total Nitrogen (TN) Mass Load Removal | 59% | 81% |
| Channel Protection | • Use VRRM Compliance spreadsheet to calculate a Curve Number (CN) adjustment[2]; ***OR*** <br> • Design extra storage in the stone underdrain layer and peak rate control structure (optional, as needed) to accommodate detention of larger storm volumes. | |
| Flood Mitigation | Partial. May be able to design additional storage into the reservoir layer by adding perforated storage pipe or chambers. | |

[1] Change in event mean concentration (EMC) through the practice. Actual nutrient mass load removed is the product of the removal rate and the runoff reduction rate (see Table 1 in the *Introduction to the New Virginia Stormwater Design Specifications*).

[2] NRCS TR-55 Runoff Equations 2-1 thru 2-5 and Figure 2-1 can be used to compute a curve number adjustment for larger storm events based on the retention storage provided by the practice(s).

**Sources:** CWP and CSN (2008) and CWP (2007)

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# Bioretention

## Summary of Stormwater Functions [1]

| Stormwater Function | Level 1 Design | Level 2 Design |
|---|---|---|
| **Annual Runoff Volume Reduction (RR)** | 40% | 80% |
| **Total Phosphorus (TP) EMC Reduction[1] by BMP Treatment Process** | 25% | 50% |
| **Total Phosphorus (TP) Mass Load Removal** | 55% | 90% |
| **Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process** | 40% | 60% |
| **Total Nitrogen (TN) Mass Load Removal** | 64% | 90% |
| **Channel and Flood Protection** | • Use the Virginia Runoff Reduction Method (VRRM) Compliance Spreadsheet to calculate the Curve Number (CN) Adjustment<br>***OR***<br>• Design extra storage (optional; as needed) on the surface, in the engineered soil matrix, and in the stone/underdrain layer to accommodate a larger storm, and use NRCS TR-55 Runoff Equations[2] to compute the CN Adjustment. | |

[1] Change in event mean concentration (EMC) through the practice. Actual nutrient mass load removed is the product of the removal rate and the runoff reduction rate(see Table 1 in the *Introduction to the New Virginia Stormwater Design Specifications*).
[2] NRCS TR-55 Runoff Equations 2-1 thru 2-5 and Figure 2-1 can be used to compute a curve number adjustment for larger storm events based on the retention storage provided by the practice(s).

Sources: CWP and CSN (2008) and CWP (2007)

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# Stormwater Quantity Analysis Considering Volume

# Treatment Volume & BMP Sizing

$$Tv_{BMP} = \frac{(P \times Rv_{composite} \times A)}{12}$$

Where:

$Tv_{BMP}$ = Design Treatment Volume from the contributing drainage area to the stormwater practice (does not include remaining runoff from upstream practices)

***P*** **= 90th Percentile rainfall depth = 1"**

$Rv_{composite}$ = Composite runoff coefficient

*A* = Contributing drainage area to the stormwater practice.

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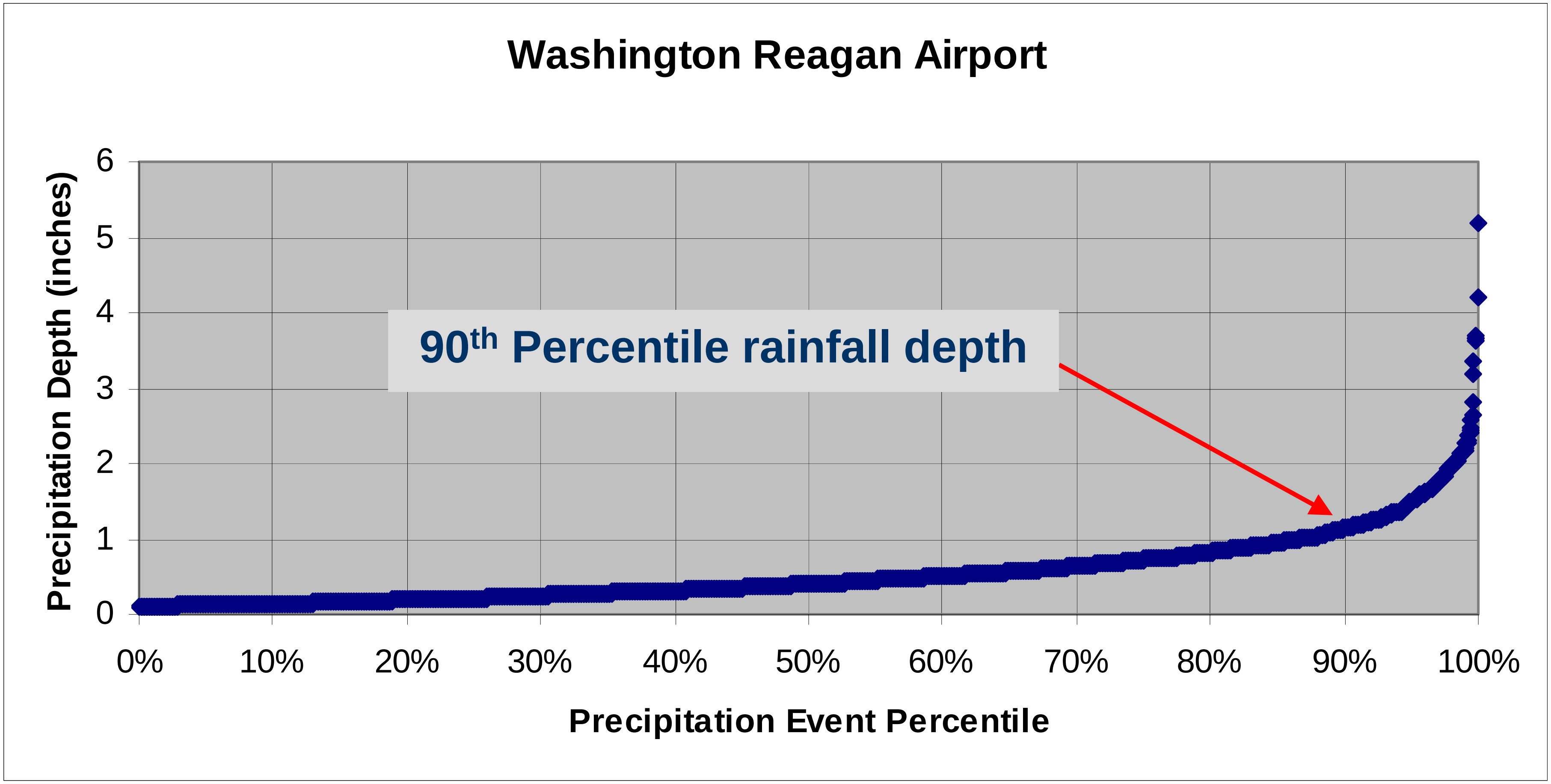
# Design Rainfall = 90th percentile rainfall depth = 1”




1” annual average: Washington Reagan Airport, Richmond Airport, Harrisonburg, Lynchburg, Bristol

# Small Storm Hydrology

- Volume Management focused on small storms
- Focus is on minimizing increases in stream power and energy
- Replicating depressional storage and abstraction from natural watersheds

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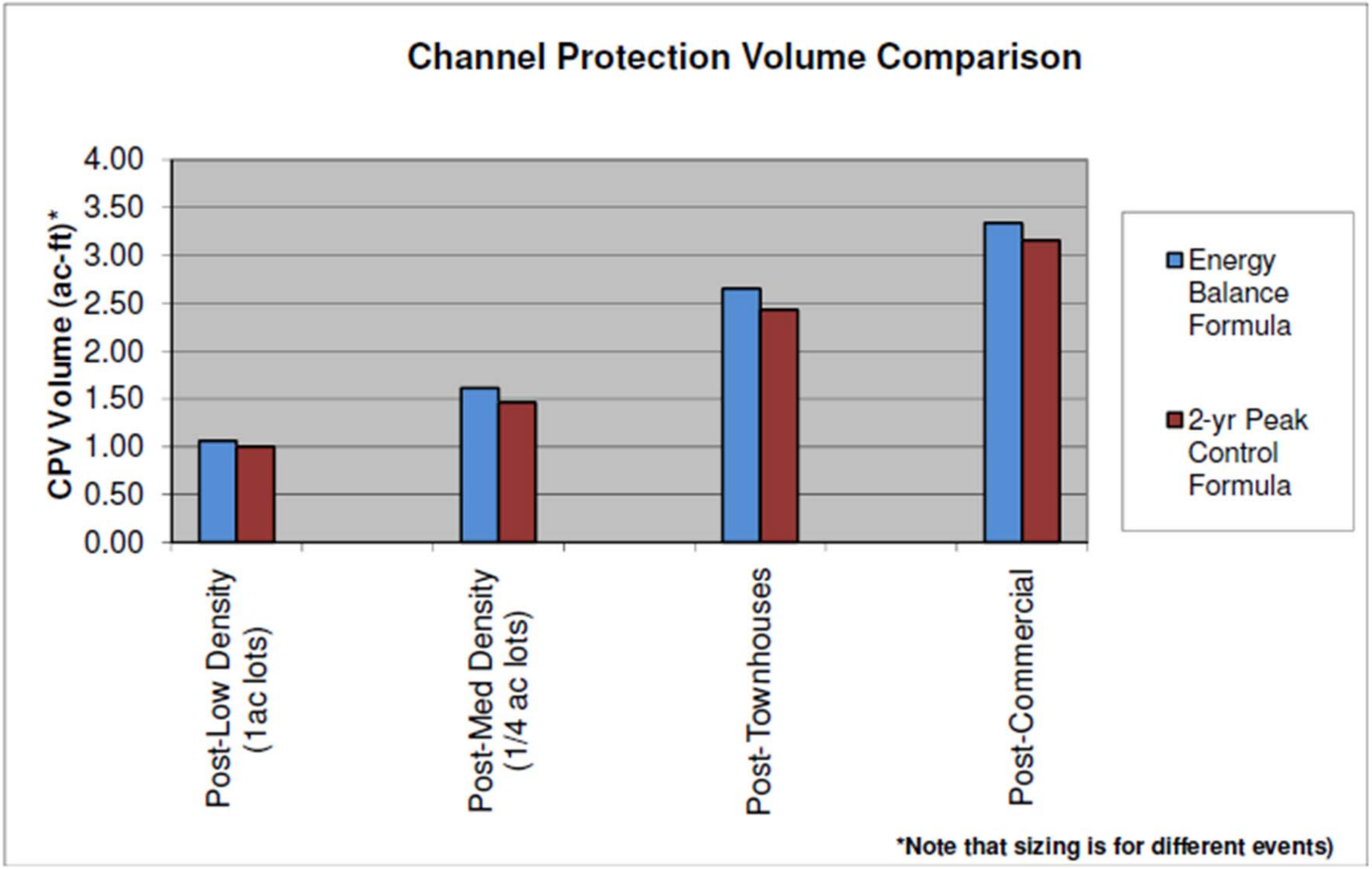
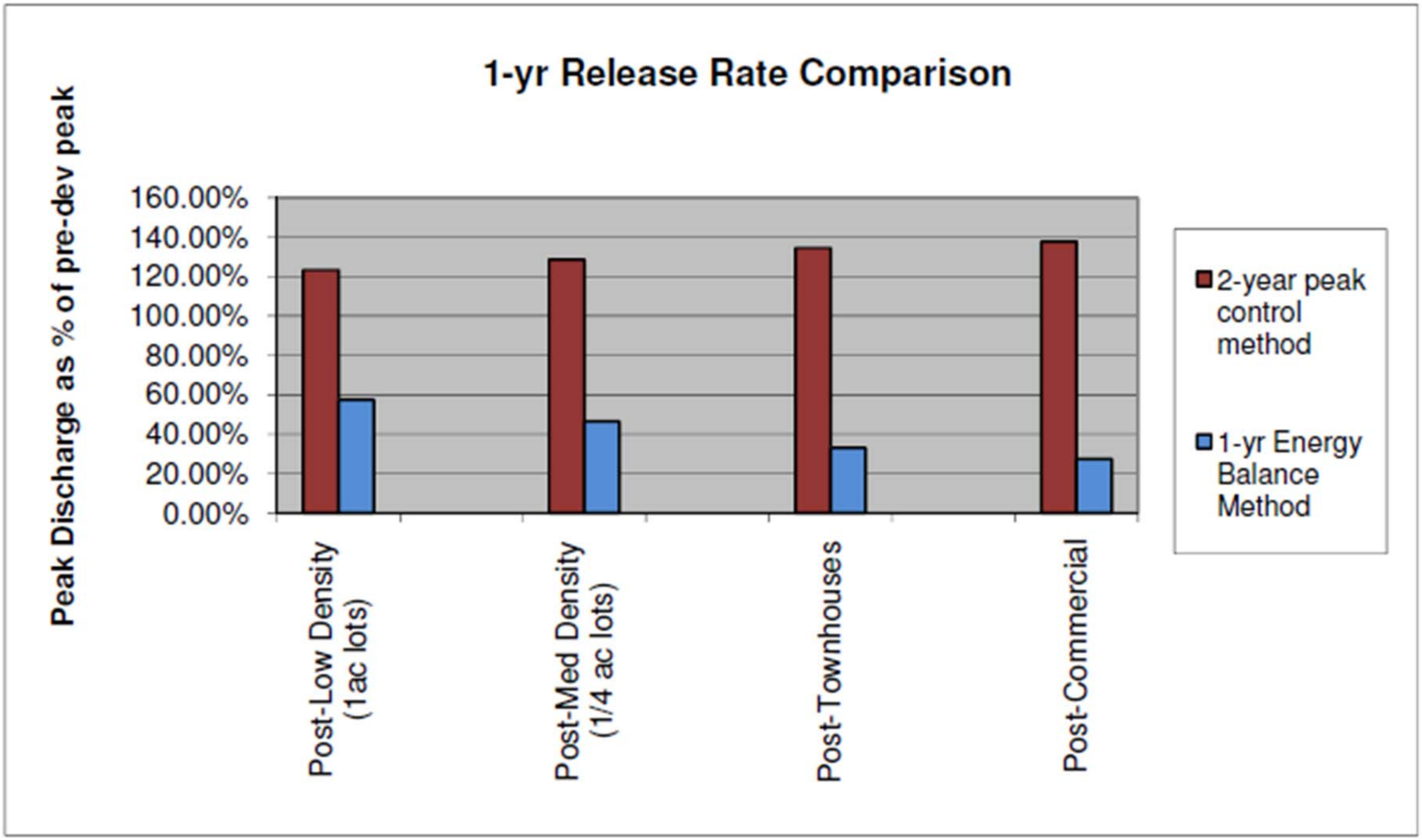
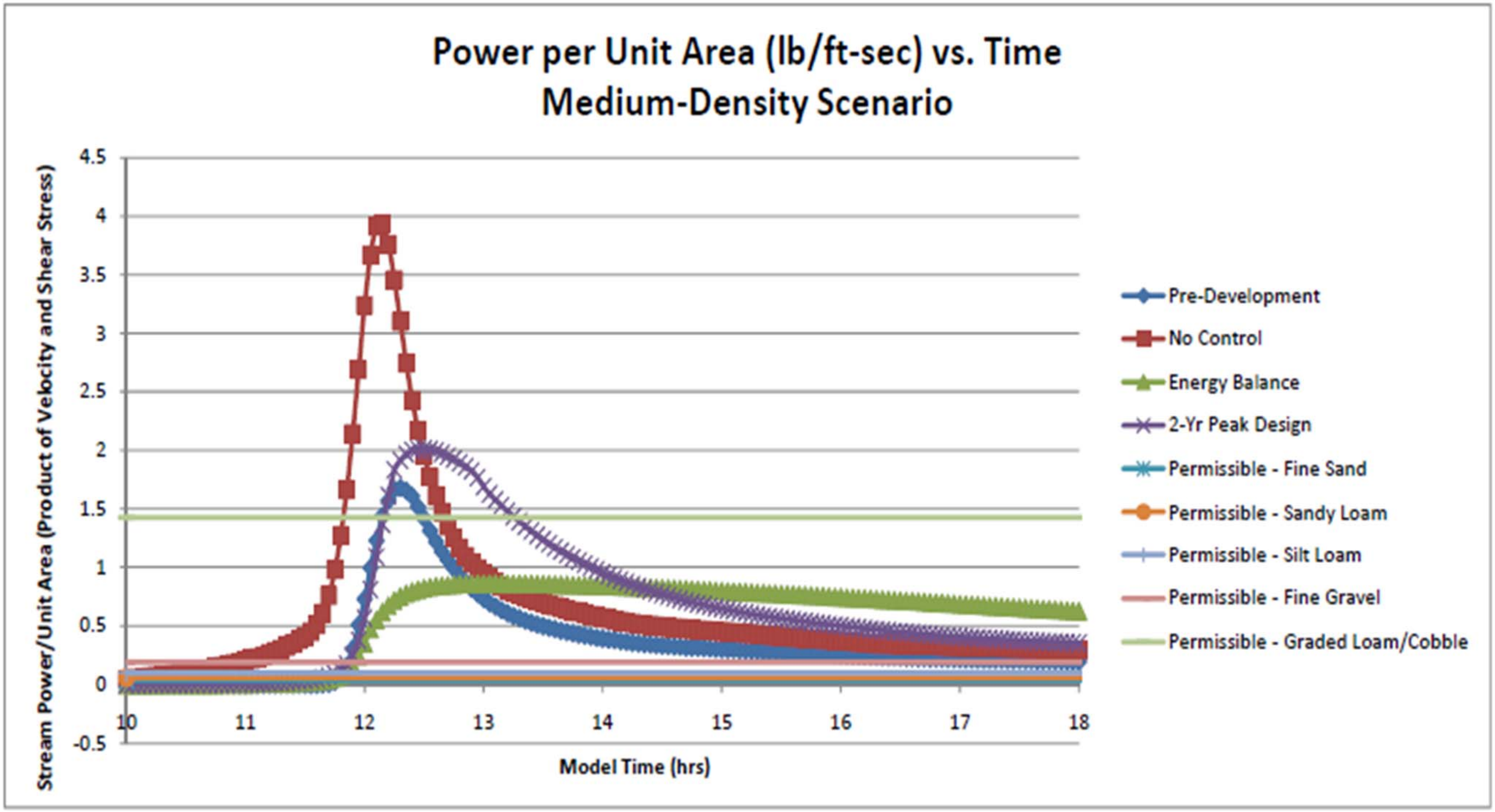
# Sizing Comparison *(+ 5-10%)*



# Release Rate Comparison



# Stream Power Comparison



# Challenge

- Provide quantity “credit” for distributed retention practices
- Avoid Complex routing/modeling
- Allow designers to target volume as a primary metric (quantity and quality)
- Various methods explored

**Table 4. Review of Recent Research on Volumetric Runoff Reduction by LID Practices**

| LID Practice | **% Runoff Reduction** | Reference |
|---|---|---|
| Bioretention | 99 | Dietz and Clausen (2006) |
| Bioretention | 58 | Seters et al (2006) |
| Bioretention | 98 | Rushton (2002) |
| Bioretention | 50 | Hunt et al (2006) |
| Bioretention | 40 to 60 | Smith and Hunt (2007) |
| Bioretention | 75 | Ballestro et al (2006) |
| Bioretention | 80 | Traver et al (2006) |
| Bioretention | 73 | Lloyd et al (2002) |
| Biofiltration Swale | 98 | Horner et al (2003) |
| Biofiltration Swale | 94 | Jefferies (2004) |
| Bioflitration Swale | 46 to 54 | Stagge (2006) |
| Permeable Pavement | 75 | Rushton (2002) |
| Permeable Pavement | 99 | Seters et al (2006) |
| Permeable Pavement | 95 to 97 | Traver et al (2006) |
| Permeable Pavement | 60 to 90 | Hunt and Lord (2006) |
| Permeable Pavement | 50 | Jefferies (2004) |
| Rainwater Harvesting | 60 to 90 | Coombes et al (2004) |

# Volume Reduction: Hydrograph Modification

Objective: Account for hydrologic effect of distributed retention storage;

Simplifying Assumptions:

- Assume retention is uniformly distributed if considering multiple features or sub-areas;
- Assume negligible discharge from under-drains (if any)

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# Volume Reduction: Hydrograph Modification

Methods Considered:

1. Hydrograph Truncation
2. Hydrograph Scalar Multiplication
3. Precipitation Adjustment
4. Runoff Adjustment
5. Curve Number Adjustment

Excerpted from work by Paul R. Koch, Ph.D., P.E.

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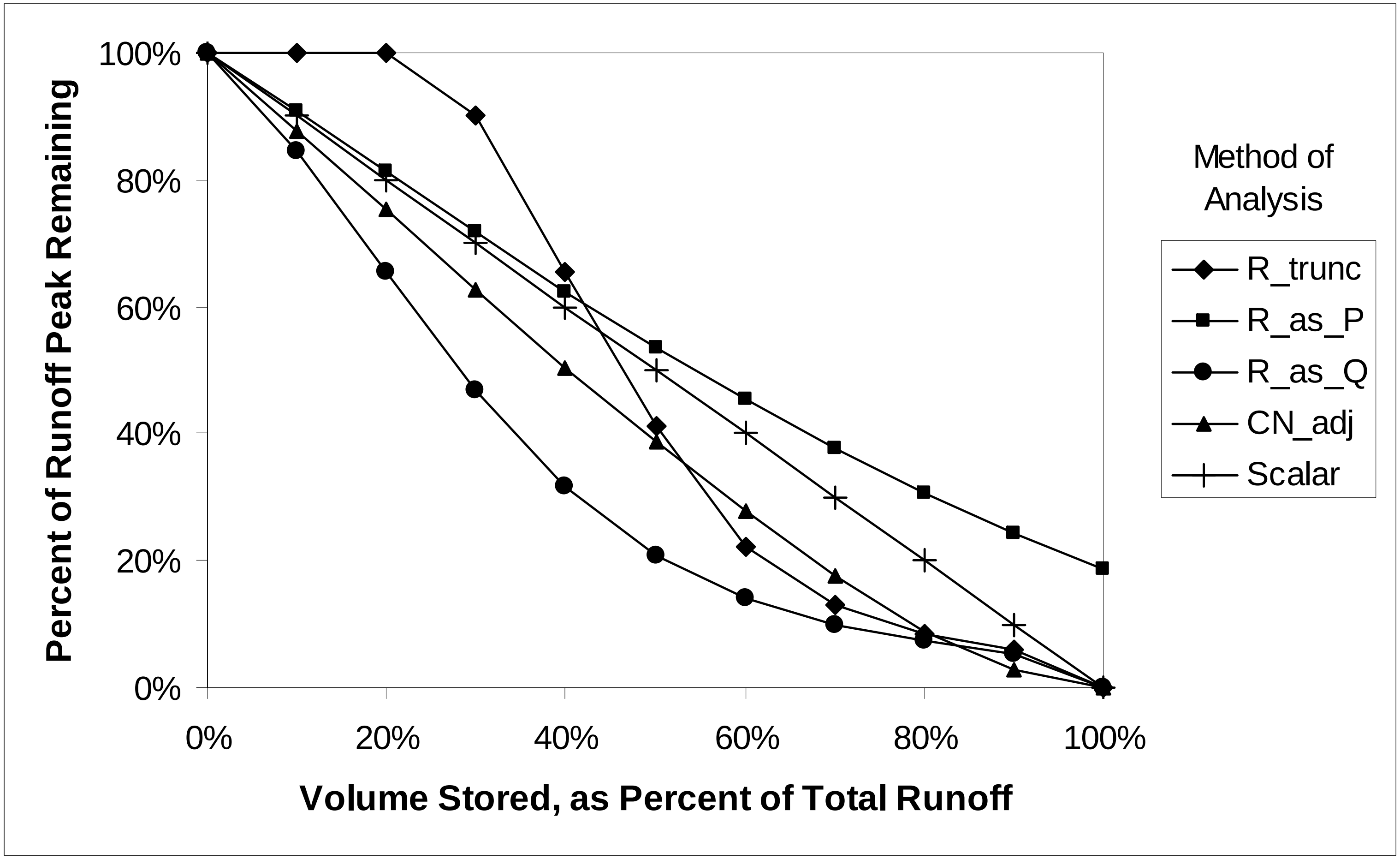
# 5 Methods




Excerpted from work by Paul R. Koch, Ph.D., P.E.

# Volume Reduction: Hydrograph Modification

## Runoff Depth Equations (TR-55):

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

Where:

$Q$ = runoff depth (in)

$P$ = precipitation depth (in)

$S$ = potential maximum retention after runoff begins

$I_a$ = initial abstraction, volume that must be filled before runoff begins.

Additionally:

$$\mathrm{I_a} = 0.2\mathrm{S}$$

$$S = \frac{1000}{CN} - 10$$

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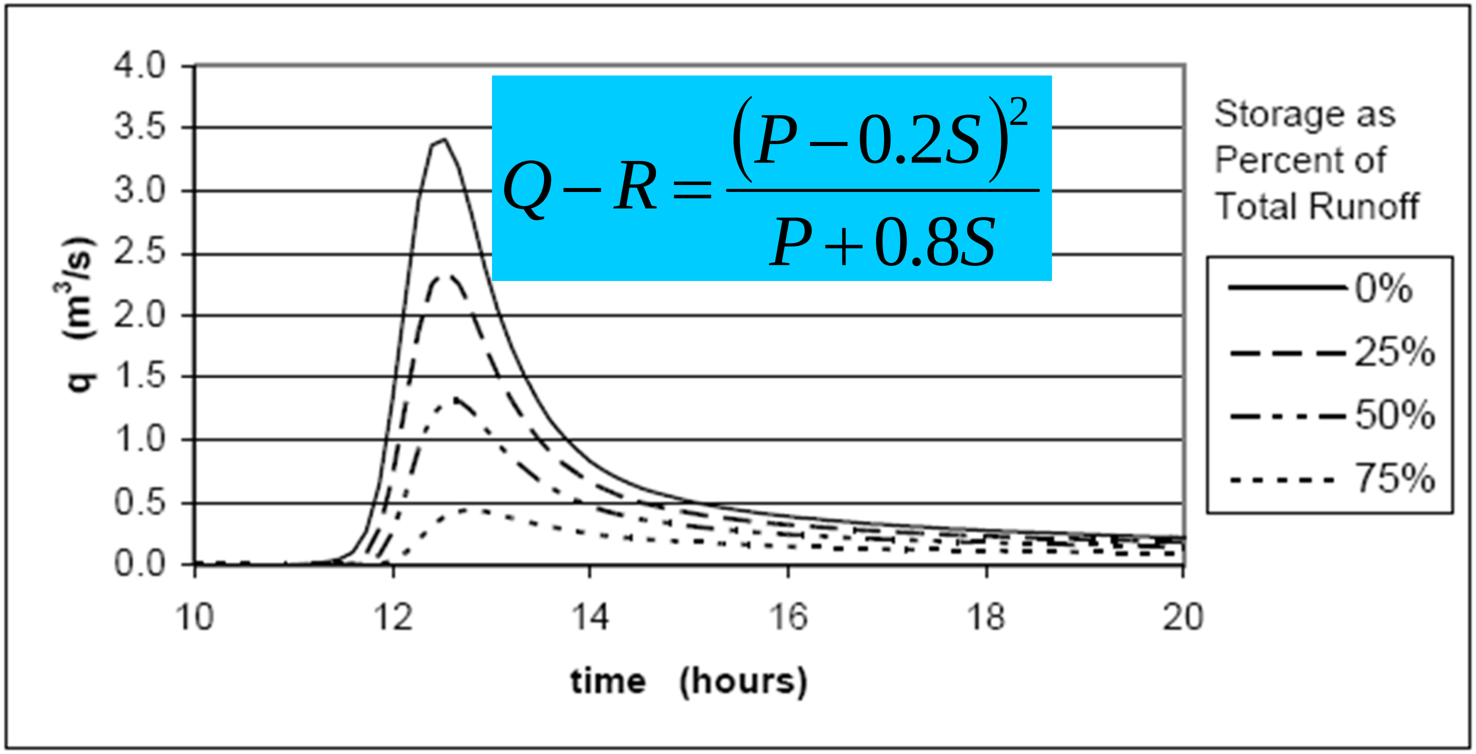
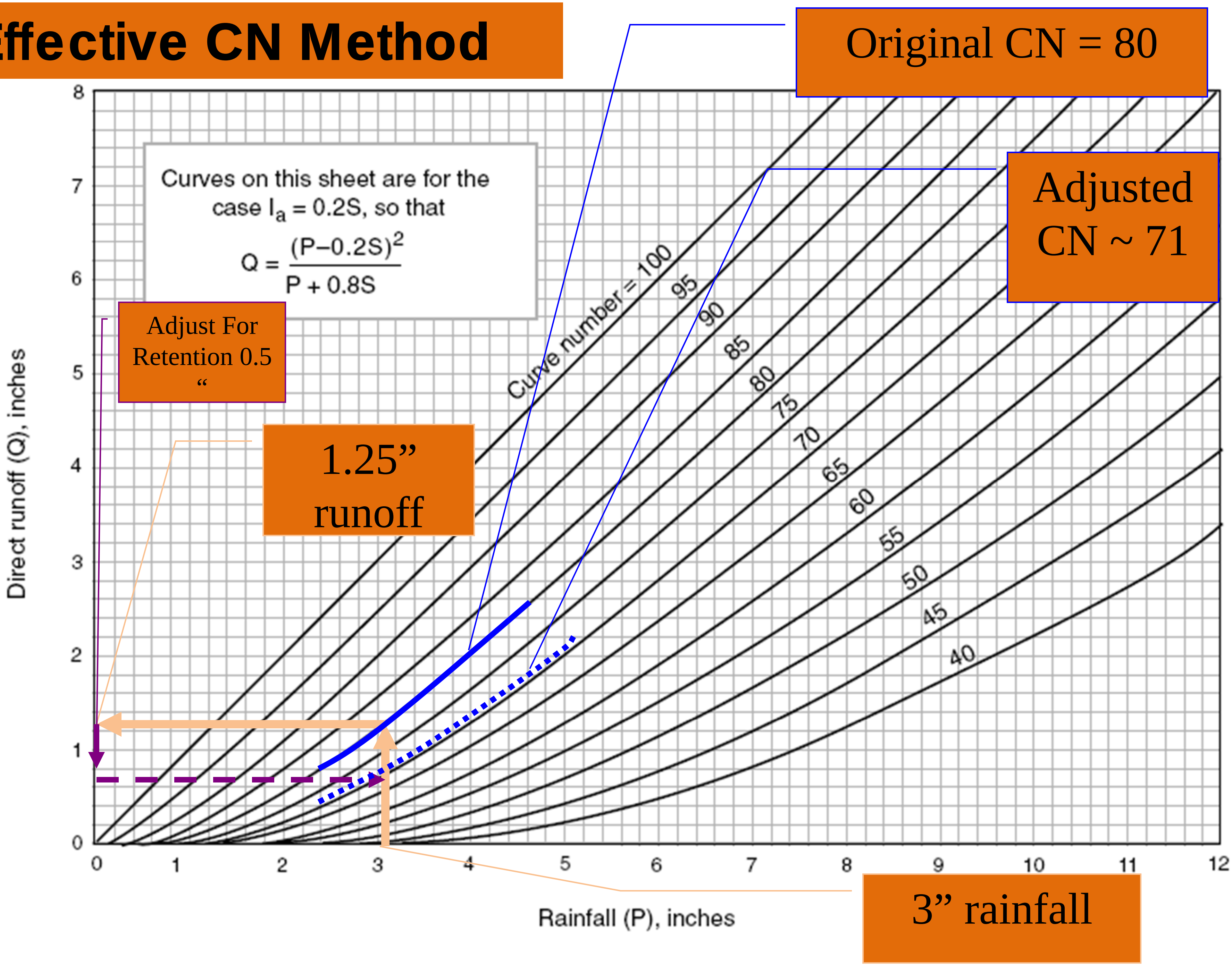
# Volume Reduction: Hydrograph Modification




$$Q - R = \frac{(P - 0.2S)^2}{P + 0.8S}$$

NRCS Runoff depth formula solved for a new value of *S*, and then a revised *CN* value can be calculated from the revised *S*. No delay in the Tc is reflected, and the reduction is distributed across the entire storm, resulting in a conservative estimate of the peak discharge.

# Effective CN Method



## Site Parameters:~39 Ac, Pre-CN=70, Post-CN=80, Lag time = 20 min(pre/post)

| Design Approach | Original CN | Adjusted $CN_{(1\text{-year})}$ | Runoff (in) | Add'l Detention Storage Req'd ($ft^3$) | Treatment Approach |
|---|---|---|---|---|---|
| Conventional Design | 80 | 80 | 1.25 | 73000 | Treat with 2 acre wet pond |
| LID Practices | 80 | 75 | 0.95 | 37000 | Bioretention, Grassed Channels w/ soil amendments |
| Better Site Design with LID | 80 | 73 | 0.85 | 28000 | Reduce Impervious Cover, Reduce Turf Acreage + above |
| Pre-Development | 70 | N/A | 0.71 | N/A | N/A |

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| | Recurrence Interval | | |
|---|---|---|---|
| | 1-yr | 2-yr | 10-yr |
| Total Rainfall (in) | 2.6 | 3.5 | 5.6 |
| Pre-dev CN | 70 | 70 | 70 |
| Pre-Dev Runoff (in) | 0.50 | 1.01 | 2.49 |
| Post-Dev CN | 80 | 80 | 80 |
| Runoff (in.) | 0.96 | 1.64 | 3.43 |
| Runoff Reduction Vol. (in.) | 0.27 | 0.27 | 0.27 |
| Net Runoff (w/ RRM, in) | 0.69 | 1.37 | 3.16 |
| CN Adjusted for RRM | 75 | 76 | 77 |
| % Redux In Runoff Volume | 28.0% | 16.4% | 7.9% |

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# Innovative/Emerging Approaches

# Issues in Urbanized Areas

- Historical/Legacy Urbanization
- Minimal Stream Functions and Values
- Surface Practices Cost Prohibitive/Innefectual
- Forces Watershed-based Approaches

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# Stream Restoration

- Reduces Nutrients and Sediments
- Protect Property and Infrastructure
- Improves Ecology
- Non-land Consumptive


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- Nutrient and Sediment Loadings are dramatically affected by urban stream restoration
- Stream and Shoreline Restoration can affect multiple objectives:
  - Protect Property & Infrastructure
  - Improve Flood Conveyance
  - Ecological Functions & Values
  - Compatible with Park/Trail systems
  - Not (as) Land-Consumptive
  - Enhance Aesthetics

# Stream Restoration/Stabilization

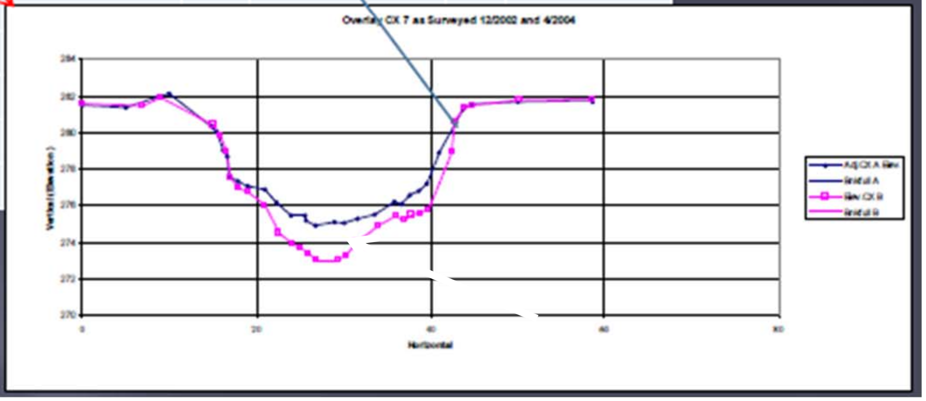
- Treatment Mechanisms:
  - “Pass through” physical, chemical, and biological treatment of the improved natural system
    - *Research ongoing, not covered herein*
  - Reduction in bank erosion = reduction in nutrients associated with the bank sediment
    - *Standard Methodologies under development*

# Stream Restoration/Stabilization Nutrient Reduction

- Detailed Studies:
  - Sediment Transport Modeling
  - Physical Sampling
- Simpler, more practical methods
  - BANCS Method (Rosgen)
  - Maryland Guidance
  - City of Baltimore Dept. of Public Works
  - “Sediment Wedge” Calculations
    - Measured Historical Bank Erosion Rates
    - Predictive Geomorphology (Channel Evolution Model)
    - Stable Channel Hydraulic Analysis

# Data for local curve for Stony Run

| Stream Bank No. | NBSS Rating | Avg. Erosion Rate | NBSS Rating | BEHI Rating |
|---|---|---|---|---|
| 1-1L | 2 | 0.1 | Moderate | High |
| 1-1U | 4 | 0.156 | Very High | Moderate |
| 1-2U | 5 | 0.343 | Extreme | High |
| 3-1U | 4 | 0.182 | Very High | High |
| 4-1U | 4 | 0.515 | Very High | High |
| 4-2U | 5 | 0.206 | Extreme | Moderate |
| 5-1U | 4 | 0.171 | Very High | High |
| 3-1L | 0.01 | 0.01 | Very Low | Moderate |
| 4-1L | 4 | 0.48 | Very High | High |
| 5-1L | 5 | | | |
| 5-2L | 4 | | | |
| 5-3L | 4 | | | |
| 6-2L | 4 | | | |
| 7-1L | 5 | | | |




Source: CWP: Urban Stream Restoration Expert Panel, 2012

# Stream Erosion

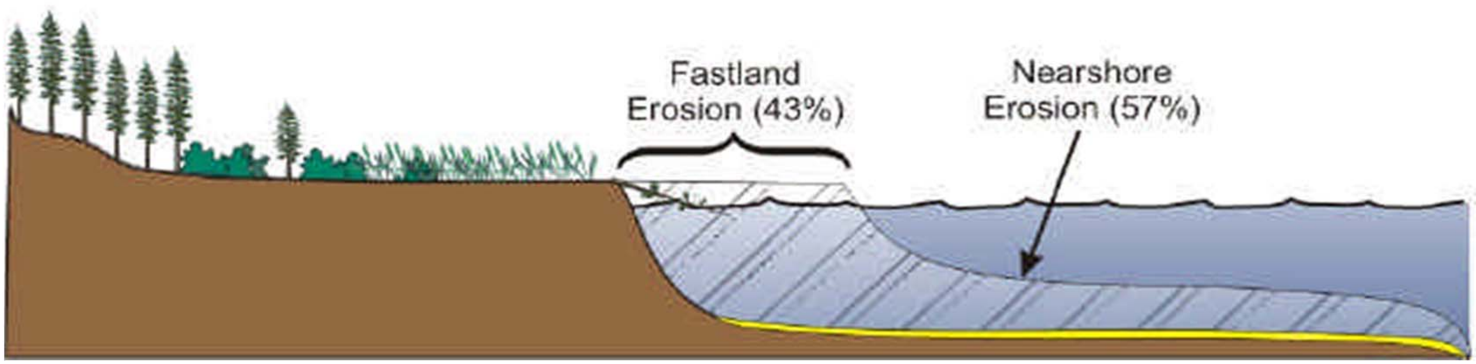
- Typical Bank-line Sediment Conc. btw: 100-200 mg/kg TP
- Scale of the problem can be staggering (1000s of tons of sediment/yr from degraded urban stream channels)

Pre-Restoration

CBWM reflects up to 600 lb/ac of sediment generated by the most urbanized watersheds

# Shoreline Nutrient Reductions

- Similar to Stream Restoration
- Shoreline Erosion = Sediment Load = Nutrient Load
  - Sediment from Bank and Nearshore Material
  - Nutrients Attached to Sediment
    - Nitrogen
    - Phosphorus
- Shoreline Stabilization Stops the Erosion
- Sediment & Nutrient "Removal" Credit




*Source: Maryland Geological Survey/Chesapeake Bay Program (modified from USACE,1990)*

# Examples of Shoreline Stabilization Practices

Conventional
- – Bulkheads
- – Seawalls
- – Ripraps Revetments

➢ Living Shorelines
- ▪ Marsh Sills
- ▪ Nearshore Breakwaters with Beach Nourishment

**No one solution is appropriate for all cases – site specific**

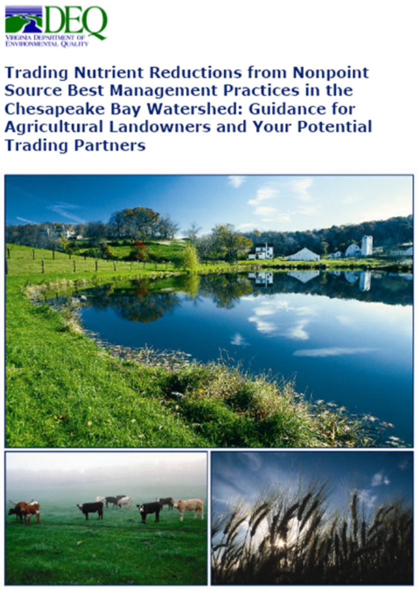
*Source: Google Imagery ([www.googlemaps.com](http://www.googlemaps.com))*

# Shoreline Nutrient Reductions: Past Research

- Numerous Studies from 1970s – Present
  - USACE
  - Virginia Institute of Marine Science (VIMS)
  - Virginia Dept. of Conservation and Recreation (DCR)
  - Chesapeake Bay Program
  - Maryland Dept. of the Environment

# Agricultural  Nutrient Offsets

- Significant Federal Support at EPA/USDA
- Agricultural Trading Guidance and Support Available
- Offset Credit Generation generally constrained to Land Conversion
- Service area defined (similar to mitigation banking)



# Non-traditional Surface Water Quality Offsets

- Land/Mine Reclamation
- Pollution Abatement
- Nutrient Management
- Large scale ecological improvements (constructed/ created wetlands)

# Questions?

**Doug Beisch** - Principal
Doug.Beisch@Stantec.com
757-810-2687

Special Thanks to the **Center for Watershed Protection** for helping to organize training materials for Stantec and the Virginia DEQ. Most figures/images sourced from Virginia DEQ training materials compiled by Stantec and CWP.

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