Day 2: Urban Drainage Designs for the Future

Robert Pitt, Ph.D., P.E., BCEE, D.WRE
Emeritus Cudworth Professor of Urban Water Systems
Department of Civil, construction, and Environmental Engineering
University of Alabama
Tuscaloosa, AL 35487

EPA National CSO Control Policy

Minimum Controls/Long-term Control Plan

- Maximization of flow to WWTP
- Select CSO controls that will meet CWA requirements
- Cost/performance considerations to demonstrate reasonable control alternatives
- Maximization of WWF treatment at existing POTW treatment plants

Optimization Strategy

- Maximize use of existing system
- Minimize new construction by:
  - operational & low-cost inline improvements in existing sewerage
  - treatment by settling when storage tanks overflow
  - design capacity function of diminishing returns on control vs cost curve
  - size storage vs treatment based on break-even economics

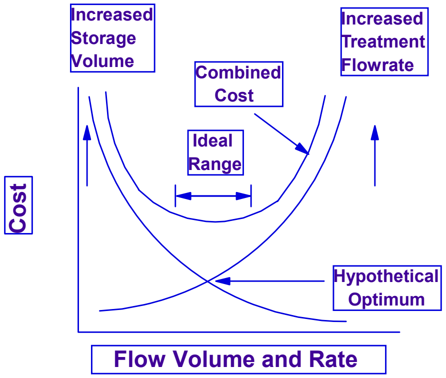
Optimization

- Operational changes to increase existing system use
- Model existing system using long-term continuous approach
- WWTP modifications

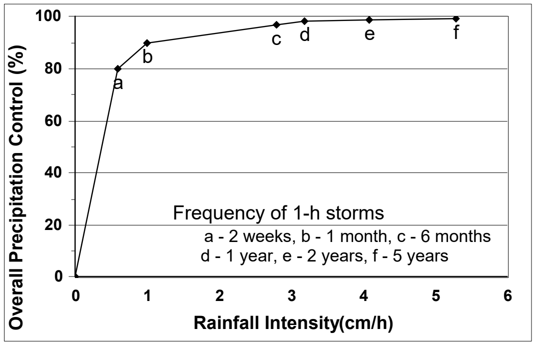
Economic
Optimization Analysis

- Storage-treatment based on:
  - break-even economics
  - point of diminishing returns
  - long-term Q/Q analyses

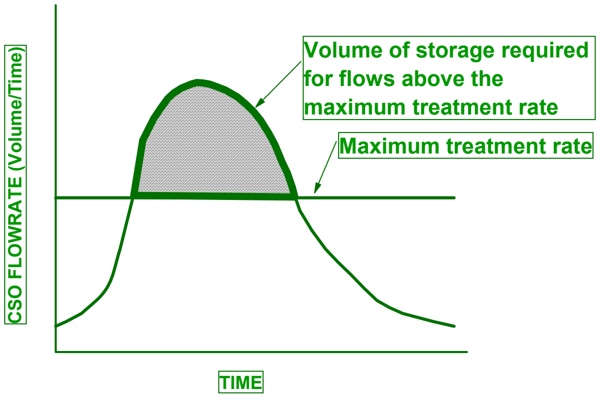
Classical Optimization Curve
(Break-Even Economics)



DIMINISHING RETURNS



Representation of Storage Volume above Treatment Rate



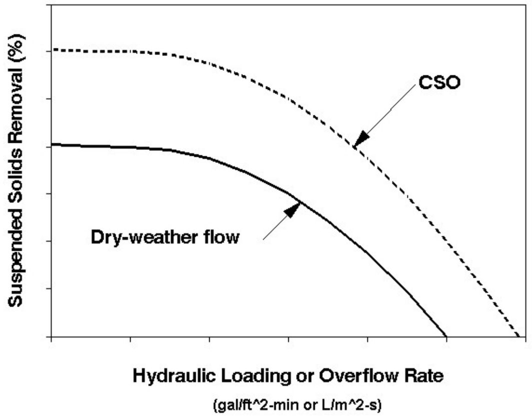
Operational Changes

- Use available storage capacity & routing capability in sewers
- Use abandoned tanks
- Use abandoned treatment plants

Optimize WWTP

- EPA identified maximizing flow to WWTP in combined sewers as one of Nine Minimum Controls (CSO Policy)
  - Stress-testing primary clarifiers
- Retrofitting processes may enable communities to comply with EPA CSO Policy

SS Removal Efficiency



Accounting For Settling In Storage Tank

- Enables smaller sizing for desired CSO load reduction

Optimize CSO Control: Lower-Cost Modifications

- Simple O/F regulator adjustments
- Installation of dynamic regulators with local reactive control
- Global optimal predictive real-time control
- Increase interceptor capacity
  - increase pumping capacity
  - clean out
  - polymer injection
  - parallel interceptor (expensive)

Optimize CSO Control: Higher-Cost Modifications

- Storage tanks
  - basic system component
  - low O&M
  - design based on (mass diagram)
    - hydrology of entire catchment
    - withdrawal rate of WWTP or satellite treatment facility
    - continuous long-term modeling
  - compartmentalization

Optimize CSO Control: Higher-Cost Modifications (Continued)

- Maximize WWTP Capacity by Retrofitting Existing Primary Treatment
  - convert to higher rate DAF
  - install lamella plates
  - install chemical addition facilities
  - install enhanced settling/microcarrier systems

Optimize CSO Control: Higher-Cost Modifications (Continued)

- Maximize WWTP Capacity by Installing Parallel Processes
  - Settling tanks/enhanced settling
  - Hi-rate P/C treatment
    - micro- or fine-mesh screens
    - filters
- Hi-rate treatment at CSO Points … consider last
- Integrate Green & Gray Infrastructure

Optimize CSO Control: Higher-Cost Modifications (Continued)

- Hi-rate Disinfection by Retrofitting Existing or New Parallel Facilities
  - Higher disinfectant dosing
  - More rapid oxidants & stronger disinfectants
  - Slow & hi-speed mixing, by corrugated channels & impellers, respectively
  - 2 stage disinfection

Preliminary Comparison of Present Worth Costs CSO Control for Kansas City, MO

- Deep-Tunnel Storage: $19-27/gallon stored
- Near-Surface Storage: $17-23/gallon stored
- High-Rate Treatment: $15-25/gallon treated
- Green Solutions: $5-10/gallon stored

New Sewerage Systems

- Larger diameter sewers
  - to add storage
- Steeper-sloped sewers/more effective bottom cross-sections/sediment traps
  - to reduce sediment deposition
- WWTP capacity for CSO
- Larger interceptors
- Beneficial use of stormwater
- Blackwater-graywater separation/graywater recycling
- Integrate green & gray infrastructure

What Does EPA Mean by "Green Solutions"?

- Green Solutions use natural or engineered systems – e.g., green roofs, bioretention/rain gardens, swales, wetlands, & porous pavement
- These systems mimic natural processes and direct stormwater to areas where it can infiltrate, evapotranspirate, be slowed, & beneficially used
- Green Solutions generally are a subset of sustainable infrastructure
- Green Solutions can provide many environmental benefits

Green Solutions Can Have Multiple Community Benefits

- Water quality
- Flood and hydromodification control
- Rainwater capture and use
- CSO/SSO control
- Increased groundwater recharge and baseflow
- Improved air quality
- Reduced energy consumption

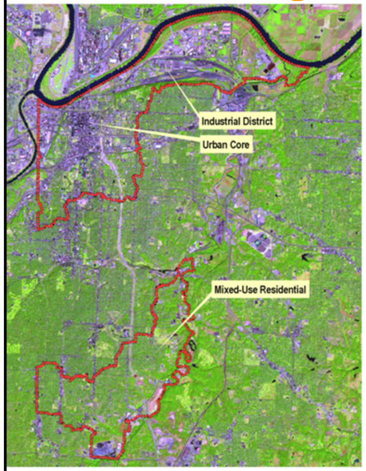
- Cost savings
- Community identity
- Recreational greenspace
- Reduced urban heat island effect
- Wildlife habitat
- Enhanced property values
- Carbon sequestering
- Aesthetics

Retention/Detention Ponds
Kansas City, MO

Rain Gardens
Kansas City, MO

Bioretention at Catchbasins
Kansas City, MO

Locating Green Solutions



- Build a site selection model that will work with varying scales and surface cover
- Evaluate several tiers:
  - City-owned property
  - Vacant private property
  - Catchbasin retrofit
  - Other open spaces

Locating Green Solutions

- Key components of GIS data
  - Topography
    - Digital Elevation Model (DEM) Arc-Hydro model
  - Parcel data
    - Ownership records
  - Remote Sensing/Aerial Imagery
    - Current high quality aerial imagery
    - Natural resources inventory
    - GAP cover analysis
    - Impervious cover

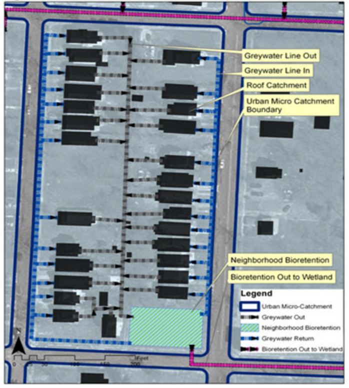
Retrofit of Parks & Lakes
Kansas City, MO

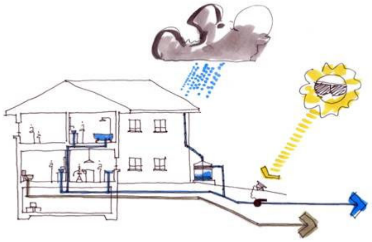
Wetland increases infiltration

Outlet provides CSO control

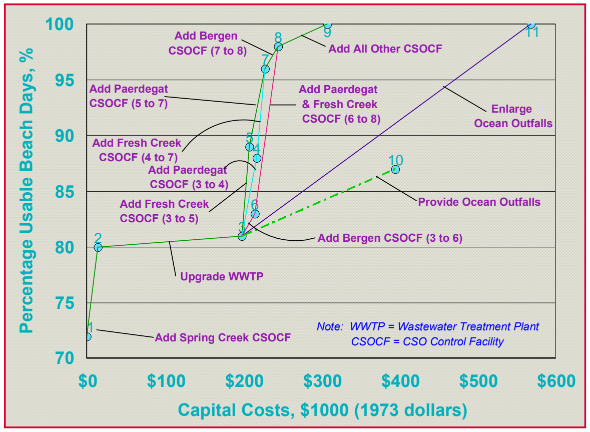
Separate Graywater & Blackwater Systems

Figure 2: The Urban Micro-Catchment (UMC)



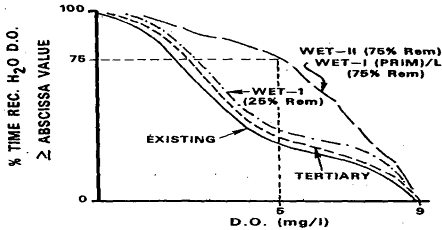


Cost Effectiveness: Usable Beach Days Jamaica Bay, NY



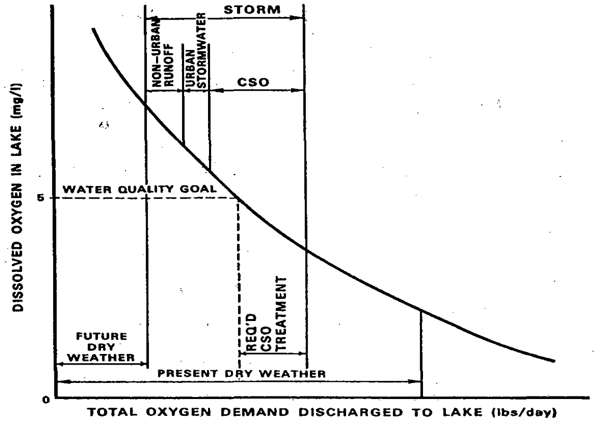
Note: WWTP = Wastewater Treatment Plant
CSOCF = CSO Control Facility

Hypothetical Example Solution Methodology



CONTROL ALTERNATIVES	% BOD REMOVAL		COST ($×10⁶)
	DRY WEATHER	WET WEATHER	
EXISTING	85	0	—
TERTIARY	95	0	6
WET—I (PRIMARY)	85	25	1
WET—II (ADV)	85	75	6
WET—1/LAND MGMT.	85	75	3

Relating Pollutant Load to Water Quality Response



Watershed-Based CSO Control Planning Approach for a Receiving-Water Segment

Define baseline: Water-Quality Standards, source flows/loads, receiving-water quality

Delineate watershed

Identify and notify stakeholders

Develop water-quality goals

Identify areas of nonattainment and other water-quality concerns

Identify CSO and non-CSO sourcesof pollution causing concerns

Develop corrective action plan and/or Total Maximum Daily Load

Evaluate, select and implement CSO and non-CSO controls

Assess effectiveness

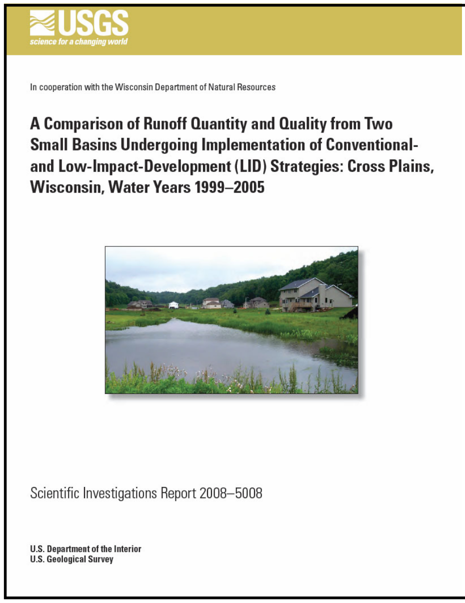
Conclusions

- Storage-treatment concept necessary
- System optimization strategy:
  - maximize existing sewerage capacity
  - include treatment by settling in storage tanks
  - based on continuous long-term hydrology and knee-of-the-curve economics
  - size storage-treatment using break-even analysis
  - mass-flow analysis
- Enhance interceptor & WWTP capacity
- Hi-rate treatment at CSO points
- Integrate green & gray infrastructure
- Beneficial use of stormwater

Elements of Conservation Design for Cedar Hills Development

(near Madison, WI, project conducted by Roger Bannerman, WI DNR and USGS)

- Grass Swales
- Wet Detention Pond
- Infiltration Basin/Wetland
- Reduced Street Width



USGS
science for a changing world

In cooperation with the Wisconsin Department of Natural Resources

A Comparison of Runoff Quantity and Quality from Two Small Basins Undergoing Implementation of Conventional- and Low-Impact-Development (LID) Strategies: Cross Plains, Wisconsin, Water Years 1999–2005

Scientific Investigations Report 2008–5008

U.S. Department of the Interior
U.S. Geological Survey

The most comprehensive full-scale study comparing advanced stormwater controls conducted.

Available at: http://pubs.usgs.gov/sir/2008/5008/pdf/sir_2008-5008.pdf

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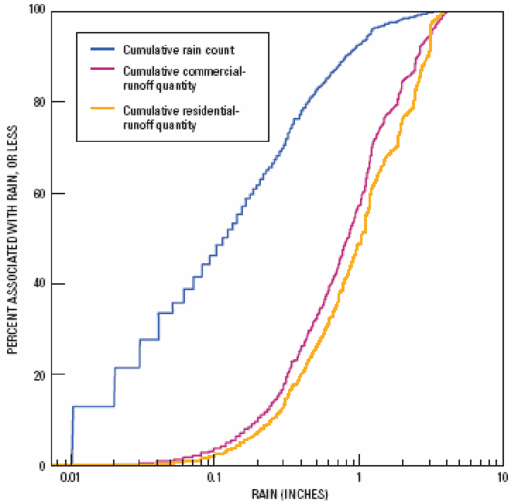
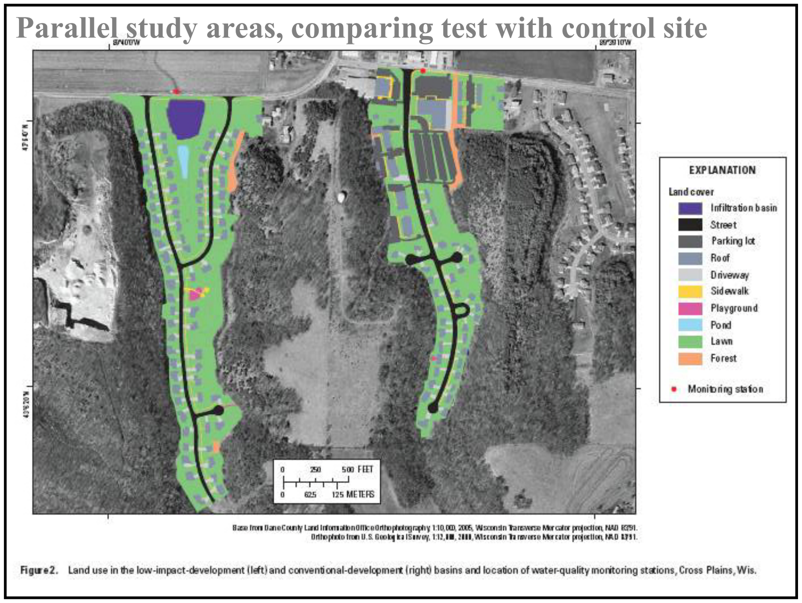


Figure 9. Relation of cumulative-discharge volume to precipitation depth for residential land use in Madison, Wis., based on model predictions (modified from Pitt,1999).

90% of the site runoff is associated with rains between 0.2 and 3 inches in depth. These are the events that need attention when trying to reduce runoff at this site. 50% of the rains, by count, are less than 0.15 inches in depth.

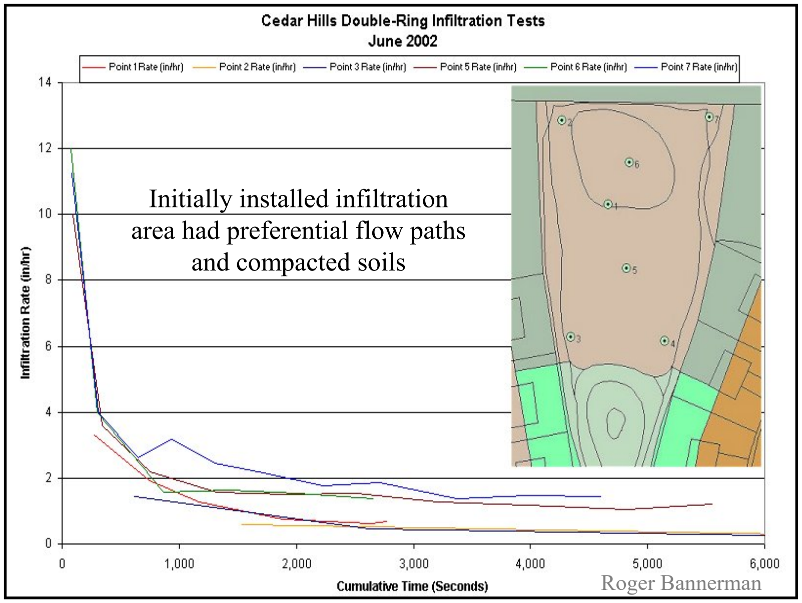


Parallel study areas, comparing test with control site

Base from Dane County Land Information Office Orthophotography 1:10,000, 2005, Wisconsin Transverse Mercator projection, NAD 83/91.
Orthophoto from U.S. Geological Survey, 1:12,000, 2000, Wisconsin Transverse Mercator projection, NAD 83/91.

Figure 2. Land use in the low-impact-development (left) and conventional-development (right) basins and location of water-quality monitoring stations, Cross Plains, Wis.

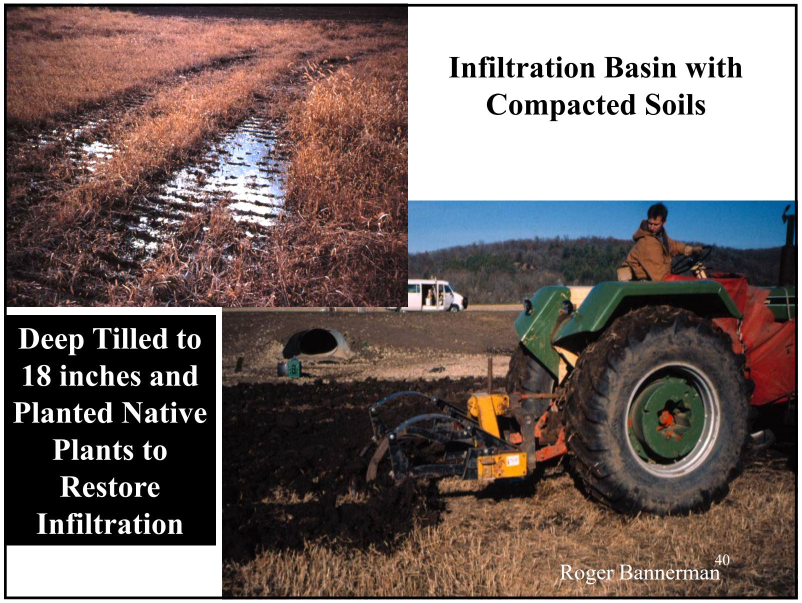
Cedar Hill Site Design, Crossplains WI



Cedar Hills Double-Ring Infiltration Tests June 2002

Initially installed infiltration area had preferential flow paths and compacted soils

Roger Bannerman



Infiltration Basin with Compacted Soils

Deep Tilled to 18 inches and Planted Native Plants to Restore Infiltration

Roger Bannerman

WI DNR photos

Reductions in Runoff Volume for Cedar Hills (calculated using WinSLAMM and verified by site monitoring)

Type of Control	Runoff Volume, inches	Expected Change (being monitored)
Pre-development	1.3	
No Controls	6.7	515% increase
Swales + Pond/wetland + Infiltration Basin	1.5	78% decrease, compared to no controls 15% increase over pre-development

Monitored Performance of Controls at Cross Plains Conservation Design Development

Water Year	Construction Phase	Rainfall (inches)	Volume Leaving Basin (inches)	Percent of Volume Retained (%)
1999	Pre-construction	33.3	0.46	99%
2000	Active construction	33.9	4.27	87%
2001	Active construction	38.3	3.68	90%
2002	Active construction (site is approximately 75% built-out)	29.4	0.96	97%

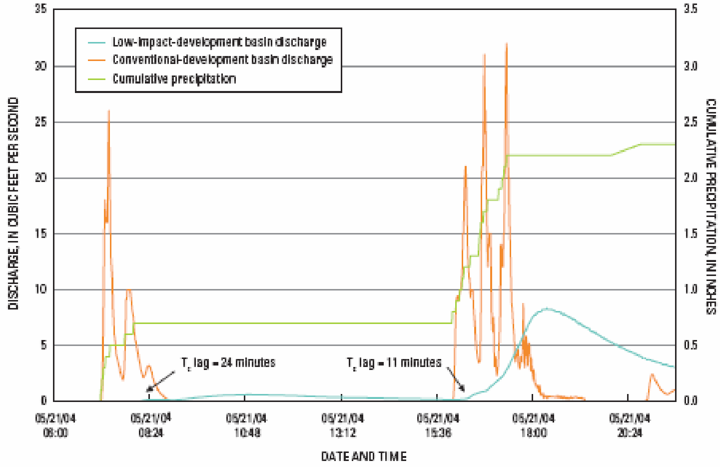


Figure 10. Hydrologic response of low-impact-development (LID) and conventional-development basins to two consecutive precipitation events, Cross Plains, Wis. [T_c, time of concentration]

NORTH HUNTSVILLE CONSERVATION DESIGN INDUSTRIAL PARK

Aerial Photo of Site under Construction (Google Earth)

Conservation Design Elements for North Huntsville, AL, Industrial Park

- Grass filtering and swale drainages
- Modified soils to protect groundwater
- Wet detention ponds
- Bioretention and site infiltration devices
- Critical source area controls at loading docks, etc.
- Pollution prevention through material selection (no exposed galvanized metal, for example) and no exposure of materials and products.
- Trail system throughout area.

A new industrial site in Huntsville, AL, has 52 approximately two acre individual building sites. Each of the sites will be served with a grass-lined bioretention channel that will carry site water to a larger swale system. The slopes of the channels vary from about 1 to 6.5%. The peak flow from each construction site was calculated to be about 16 ft^3/sec (corresponding to the Huntsville, AL, 25 yr design storm of 6.3 inches for 24 hours). The on-site swales will also have modified soils to increase the CEC and organic matter content to protect groundwater resources.

The bare swale soil has an allowable shear stress of about 0.05 lb/ft^2. The calculated values for unprotected conditions are all much larger. Therefore, a North American Green S75 mat was selected, having an allowable shear stress of 1.55 lb/ft^2 and a life of 12 months. Check dams are needed when slopes are >5% due to high velocities.

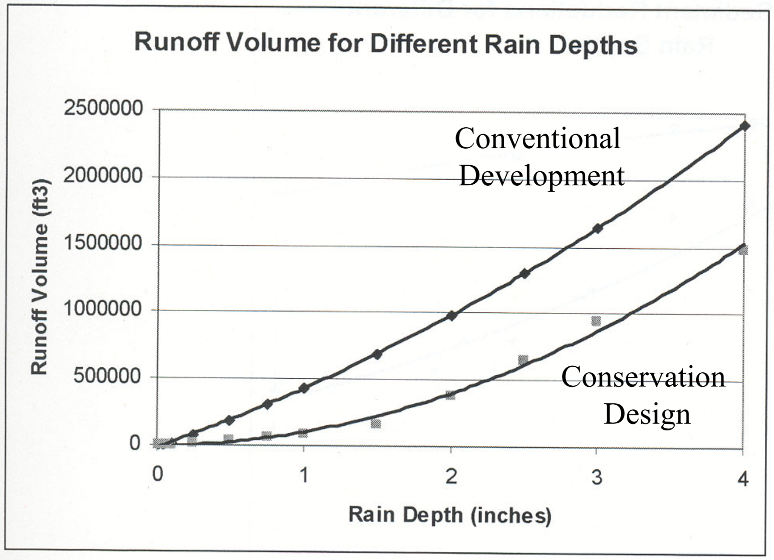
Slope	**Bare soil shear stress (lb/ft^2)**	**Unvegetated mat shear stress, effect on soil (lb/ft^2)**	**Safety factor (allowable shear stress of 0.05 lb/ft^2)**	**Maximum velocity with mature vegetation (ft/sec)**
1%	**0.14**	**0.012**	**4.2**	**3.1**
3%	**0.28**	**0.023**	**2.2**	**4.8**
5%	**0.42**	**0.035**	**1.4**	**5.5**
6.5%	**0.46**	**0.039**	**1.3**	**6.4**

Different site subareas have different combinations of controls. Base conditions are for conventional development.

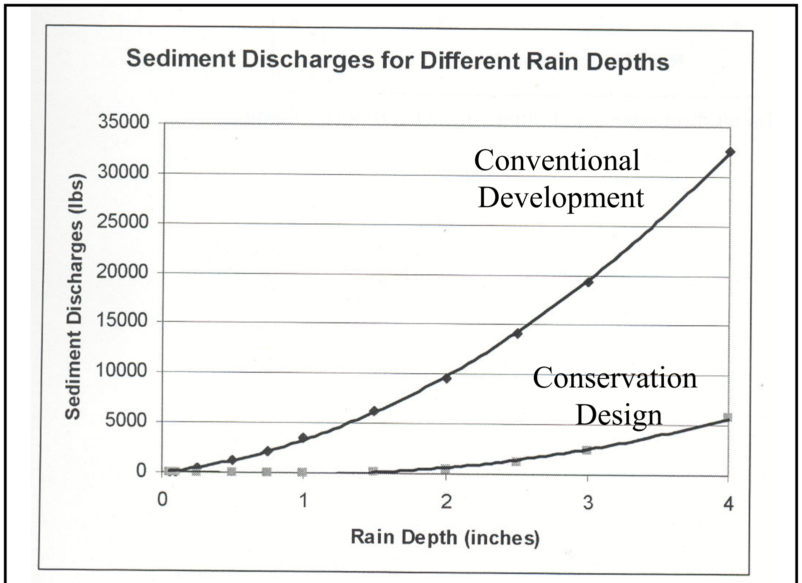
		Annual Runoff Volume (ft^3/year)	
Drainage Area	**Proposed Stormwater Components**	**Base Conditions**	**With Controls**
A	Pond, swale, and site bioretention	6.3×10^6	2.5×10^6 (61%)
B	Small pond and swale	5.4×10^6	1.7×10^6 (69%)
C	Pond and swale	2.5×10^6	0.83×10^6 (68%)
D (including off-site area)	Off-site pond, swale, and site bioretention	11×10^6	5.8×10^6 (50%)

Calculated using WinSLAMM and 40 years of rain records

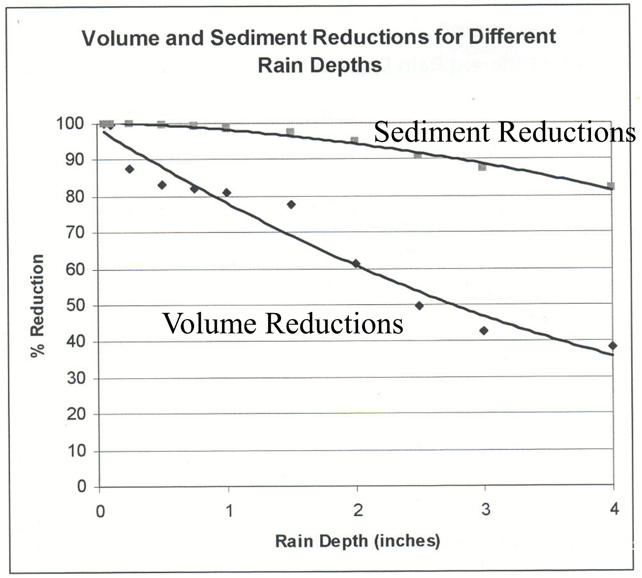
		Annual Particulate Solids Discharges (lb/year)	
Drainage Area	**Proposed Stormwater Components**	**Base Conditions**	**With Controls**
A	Pond, swale, and site bioretention	98,000	4,400 (96%)
B	Small pond and swale	54,000	3,800 (93%)
C	Pond and swale	19,000	1,200 (94%)
D (including off site area)	Off-site pond, swale, and site bioretention	120,000	9,250 (92%)



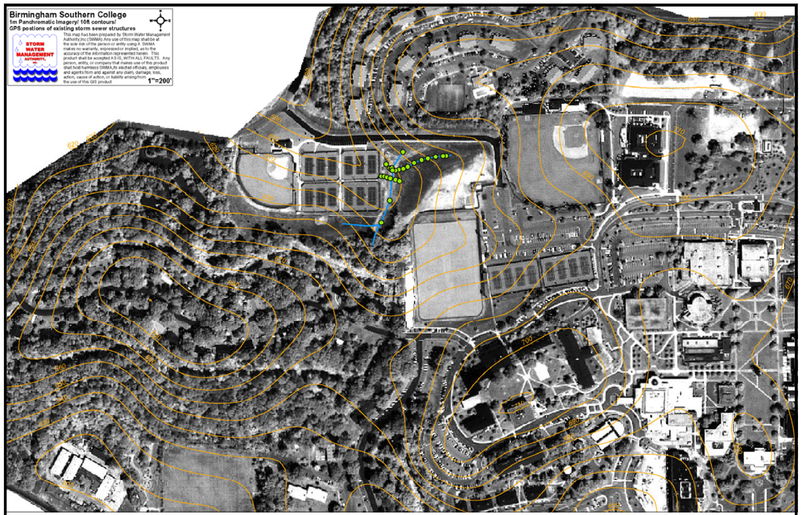
Runoff Volume for Different Rain Depths



Sediment Discharges for Different Rain Depths



Volume and Sediment Reductions for Different Rain Depths



Birmingham Southern College Campus

(map by Jefferson County Stormwater Management Authority)

Birmingham Southern College Fraternity Row (new construction at existing site)

	Acres	% of Total
Roadways	0.24	6.6%
Parking	0.89	24.5
Walks	0.25	6.9
Roofs	0.58	16.0
Landscaping	1.67	46.0
Total:	3.63	100.0

Supplemental Irrigation

	Inches per month (example)	Average Use for 1/2 acre (gal/day)
Late Fall and Winter (Nov-March)	1 to 1-1/2	230 - 340
Spring (April-May)	2 to 3	460 - 680
Summer (June-August)	4	910
Fall (Sept-Oct)	2 to 3	460 - 680
Total:	28 (added to 54 inches of rain)	

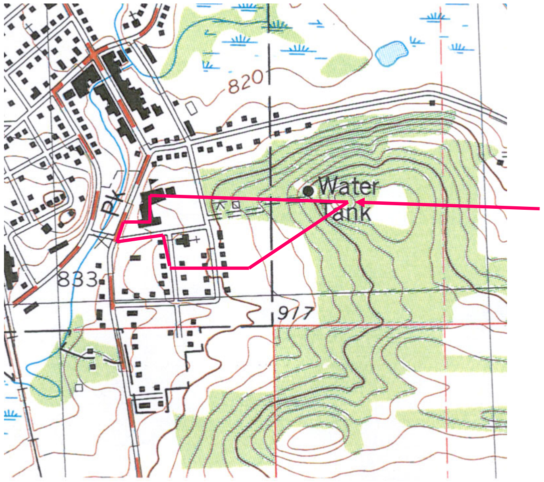
Capture and Reuse of Roof Runoff for Supplemental Irrigation

Tankage Volume (ft^3) per 4,000 ft^2 Building	Percentage of Annual Roof Runoff used for Irrigation
1,000	56%
2,000	56
4,000	74
8,000	90
16,000	98

Combinations of Controls to Reduce Runoff Volume

	Total Annual Runoff (ft^3/year)	Increase Compared to Undeveloped Conditions
Undeveloped	46,000	--
Conventional development	380,000	8.3X
Grass swales and walkway porous pavers	260,000	5.7
Grass swales and walkway porous pavers, plus roof runoff disconnections	170,000	3.7
Grass swales and walkway porous pavers, plus bioretention for roof and parking area runoff	66,000	1.4

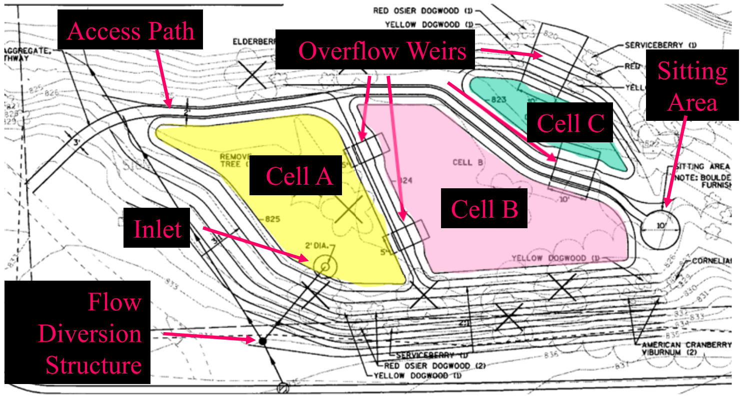
Lodi, Wisconsin, Transportation Area Rain Garden

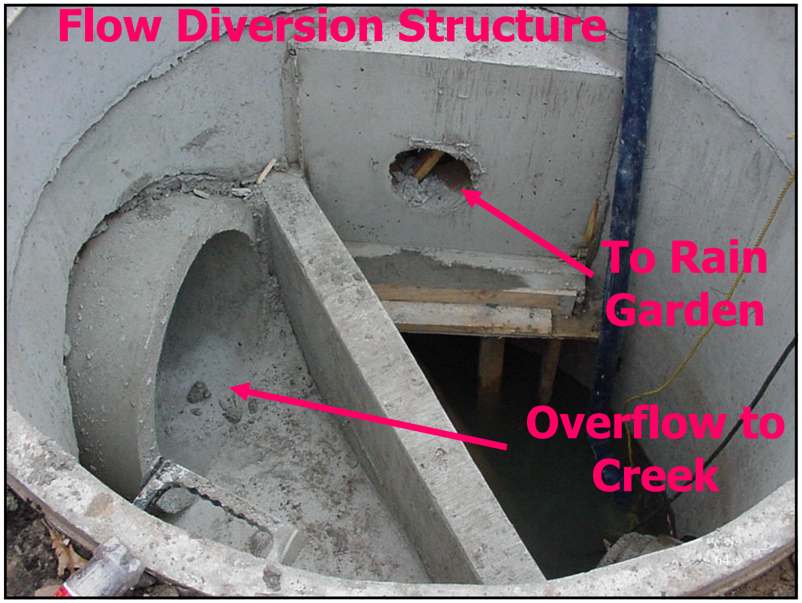


Drainage Basin Area = 16 acres

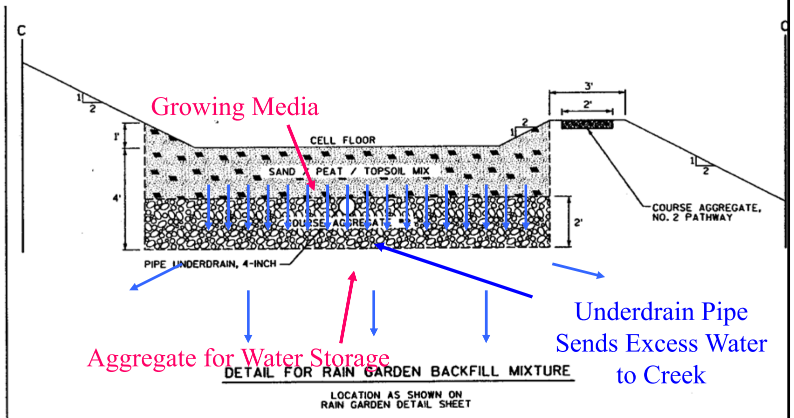
City of Lodi, Columbia County

Lodi Rain Garden Features





Rain Garden Backfill Material



DETAIL FOR RAIN GARDEN BACKFILL MIXTURE

LOCATION AS SHOWN ON
RAIN GARDEN DETAIL SHEET

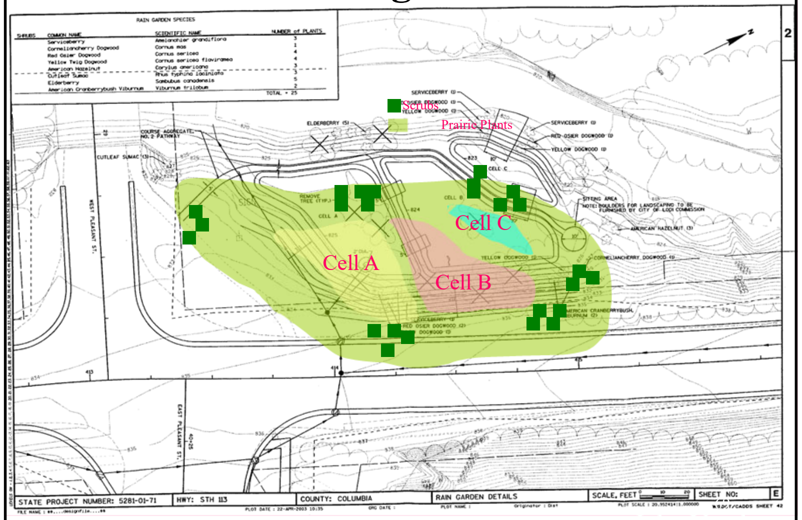
Soil/Peat/Sand Mixing

John Voorhees

John Voorhees

John Voorhees

Planting Plan



RAIN GARDEN SPECIES

SHRUBS	COMMON NAME	SCIENTIFIC NAME	NUMBER of PLANTS
	Serviceberry	Amelanchier grandiflora	3
	Cornelian cherry Dogwood	Cornus mas	1
	Red Osier Dogwood	Cornus sericea	4
	Yellow Twig Dogwood	Cornus sericea flaviramea	4
	American Hazelnut	Corylus americana	3
	Cutleaf Sumac	Rhus typhina laciniata	3
	Elderberry	Sambubus canadensis	5
	American Cranberrybush Viburnum	Viburnum trilobum	2
		TOTAL = 25	


Fall 2004

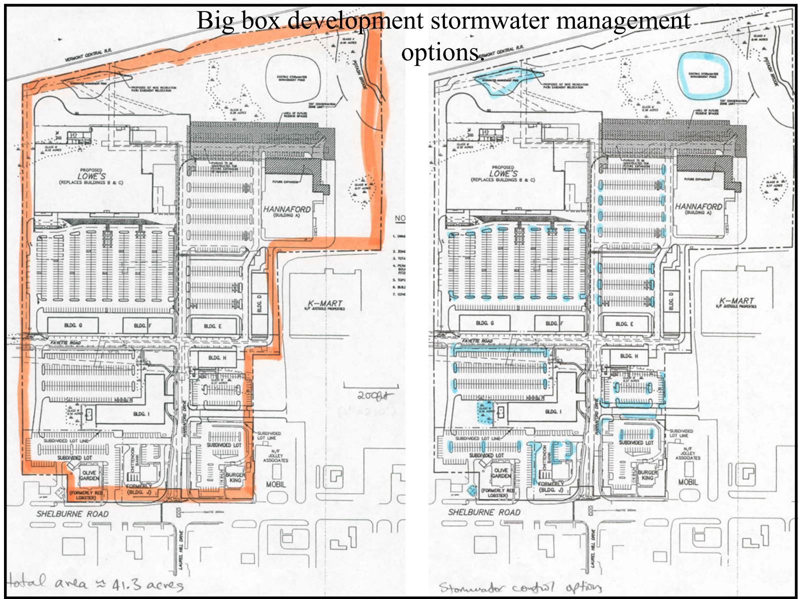
Spring 2005

Summer 2005

Lodi, WI, Rain Garden Costs

Pipe Underdrain and Endwalls		$700
Flow Regulation Structure		$3,000
Plants		$2,200
Shrubs		$450
Backfill		$11,600
Excavation		$2,200
Select Crushed Material/Riprap		$3,850
Storm Sewer and Manholes		$3,500
Total	$4.70/sf	$27,500

Big box development stormwater management options



Summary of Measured Areas

- Totally connected impervious areas: 25.9 acres
  - parking 15.3 acres
  - roofs (flat) 8.2 acres
  - streets (1.2 curb-miles and 33 ft wide) 2.4 acres

- Landscaped/open space 15.4 acres

- Total Area 41.3 acres

Stormwater Controls

- Biofiltration areas (parking lot islands)
  - 52 units of 40 ft by 8 ft
  - Surface area: 320 ft^2
  - Bottom area: 300 ft^2
  - Depth: 1 ft
  - Vertical stand pipe: 0.5 ft. dia. 0.75 ft high
  - Broad-crested weir overflow: 8 ft long, 0.25 ft wide and 0.9 ft high
  - Amended soil: sandy loam

- Also examined wet detention ponds

Runoff Volume Changes

	Base conditions	**With biofiltration**
Runoff volume (10^6 ft^3/yr)	**2.85**	**1.67**
Average Rv	**0.59**	**0.35**
% reduction in volume	**n/a**	**41%**

Using Graywater and Stormwater to Enhance Local Water Supplies: An Assessment of Risks, Costs, and Benefits

National Resources Council, 2016

Original Analysis of Potential Savings

- Analysis of residential stormwater and graywater use:
  - 100 acres, 12 persons per acre
  - Site-specific data: LA, Seattle, Madison, Lincoln, Newark, & Birmingham
  - 1995-1999 rainfall, long-term ET to estimate monthly irrigation needs
  - Graywater assumed U.S. average graywater daily supply
- Scenarios considered:
  - Graywater: whole house and laundry to landscape (irrigation only)
  - Stormwater: roof runoff in 2 rain barrels (70 gal total) or 2,200 gal tank
- Calculated potential savings for:
  - Conservation irrigation (barely meet ET) for turfgrass
  - Toilet flushing
  - Irrigation and toilet flushing

Water Availability

Stormwater:

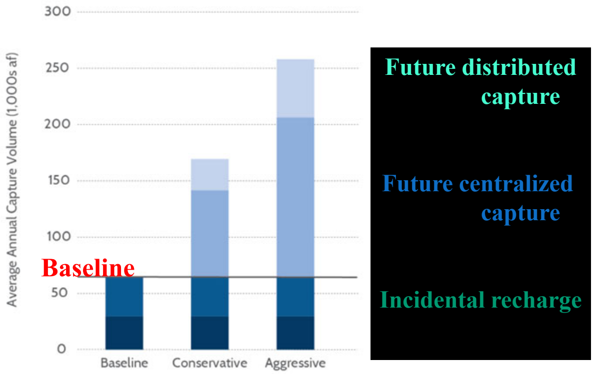
- Dependent on tank size and amount/timing of precipitation relative to demand
- Neighborhood and regional-scale projects can contribute significantly to urban water supplies

Graywater:

- Substantial potential savings, particularly useful in arid regions

If water conservation is the objective, strategies to reduce outdoor water use should first be examined.

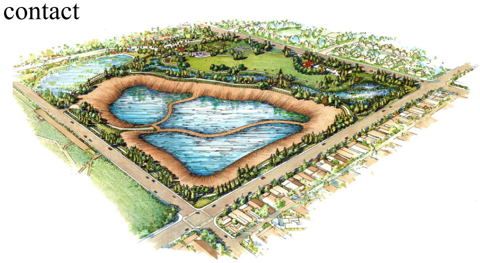
Urban Stormwater Capture & Recharge



LA's stormwater capture master plan --- an aggressive path *this century* could add nearly 200,000 afy from today's baseline (SWCMP, 2015)

Water Quality

- Stormwater :
  - Highly variable over space and time, although related to land use
  - Little is known regarding human pathogens and organic chemicals in stormwater, additional research is needed
- Graywater:
  - Pathogens & organic matter necessitate treatment for uses with human contact



Risk

- Risk assessment provides a means to determine “fit-for-purpose” criteria or treatment needs based on exposures
- Pathogens: the most significant acute risks
  - Extremely limited data, which precludes a full assessment of risk, particularly for roof runoff.
- Stormwater recharge poses risks of groundwater contamination and necessitates careful design to minimize those risks

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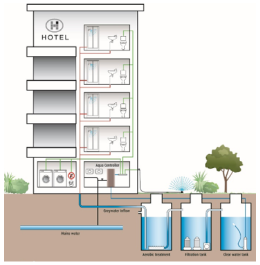
State of Practice: Graywater



- Irrigation at the household scale can be achieved with simple systems
- Reuse for toilet flushing are most appropriate in multi-residential buildings
- Many state graywater treatment standards for toilet flushing are not risk-based or fit-for-purpose
- New developments provide opportunities for rethinking the use of water and waste streams for saving money, energy, & water

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State of Practice: Stormwater

- The state of practice for cost-effective, safe roof-runoff capture systems are hindered by the lack of data on human pathogens.

- Stormwater infiltration for aquifer recharge is commonly practiced, but designs and regulations in the United States may not be adequately protective of groundwater quality for new systems in urban areas.

State of Practice: Operations

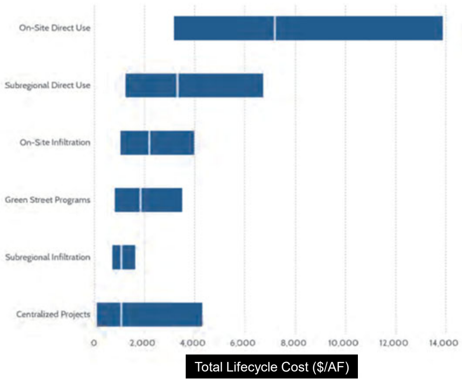
- Operations and maintenance of household and neighborhood graywater and stormwater use systems is not well guided or monitored.
- Many states require that systems meet water quality targets, but ongoing monitoring is not required.
- Online monitoring of surrogate parameters (e.g., on-line residual chlorine, turbidity) should be considered.

Costs and Benefits

It is important to recognize the full suite of benefits—as well as the full costs—of graywater and stormwater projects, although it may be challenging to do so.

- Financial cost data are extremely limited
- Social & environmental costs and benefits rarely monetized
- Energy savings are possible, but data for a sound assessment are lacking.

Costs and Benefits



- Simple systems can offer reasonable financial payback periods under certain scenarios/climates.
  - However, behavioral factors on water use are poorly understood
- Economies of scale are evident

Summary

- Graywater and stormwater capture and use can expand local water availability while providing additional benefits.
- Treatment can help address contaminants in the water, but a lack of risk-based treatment guidelines hinders the broader use of stormwater and graywater.
- There is no single best way to use graywater or stormwater to address local water needs
  - many important considerations—including legal and regulatory constraints, potential applications, climate, and source water availability—vary widely with local conditions.
- Research on information about costs, benefits, risks, treatment needs, and behavioral factors would enhance decision making.