Operation and Maintenance of Green Infrastructure

Why Must Management Practices be Maintained?

- Aesthetics
- Function
- Safety & Mobility
- Legal requirements
- Investment

2

Long-Term Maintenance

- All stormwater systems require maintenance
- With traditional infrastructure often maintenance only occurs when there is failure because it is 'out of sight and out of mind'
- Most green infrastructure is visible, and considered an aesthetic amenity; it's harder to ignore maintenance needs.
- Small problems are less likely to turn into system failures.

3

Factors to Consider for O&M

- Planning and site characteristics determine how systems are designed
- Design affects how systems need to be maintained
- Construction impacts the performance and therefore the need and type of maintenance
- Completed projects and maintenance provide learning experiences for better designs

4

Key Reasons Why BMP Maintenance Has Historically Been Difficult to Implement

1. Inability to physically locate the management practices
2. Inability to track responsible parties
3. Dedicated staff not assigned to inspection
4. Designs not conducive to easy maintenance
5. Lack of enforcement authority and access
6. Owners are unaware of their responsibilities
7. Proliferation of management practices that require intensive maintenance
8. Insufficient funding sources

WERF 2005, CWP 2004

5

WERF Finding

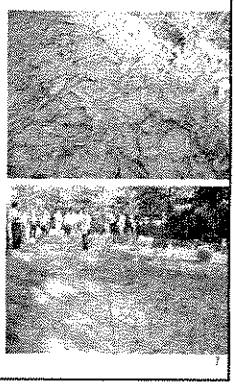
*"Probably **80% of the total man hours spent** in the field in many jurisdictions are **associated with grass mowing**, rather than the issues one might expects such as sediment, debris and trash removal, or structural repair. Of this 80%, **most of the effort has little effect on BMP performance**, but results from the level of service **expectations of residents** living near these facilities. The frequency of maintenance has been found to be dependent on the economic status of the neighborhood and the visibility of the system."*

WERF 2005 Performance and Whole Life Costs of Best Management Practices and Sustainable Urban Drainage Systems

6

Management practices can be damaged by . . .

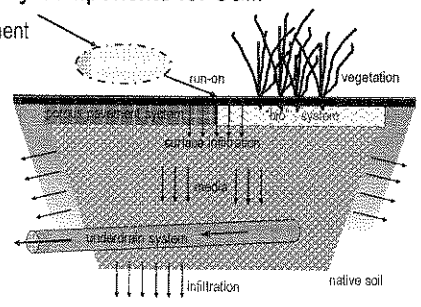
- Excessive sedimentation
- Herbicides (e.g. Roundup)
- Poor vegetation or mulch maintenance
- Excessive mowing or mowing too low
- Compaction
- Clogged inlets/outlets



7

Key Components for O&M

- Inlets (treatment of off-site sources)
- Vegetation
- Surface (infiltration)
- Media
- Native soil
- Outlets
- Other
  - liners
  - filter fabric
  - etc.



8

Factors Affecting Performance of BMPs

	Sediment Buildup	Litter & Debris	Pipe Clogging	Invasive Vegetation
Surface Sand or Soil Filter	50%	30%	10%	0%
Infiltration Basins or Trenches	36%	21%	10%	5%
Wet Ponds	26%*	19%	21%	10%
Underground Sedimentation Devices	58%	21%	11%	0%
Rain Gardens	33%	22%	7%	26%
Filter Strips or Swales	21%	26%	5%	26%

- * PAH's becoming a significant concern for wet pond sediments
- Maintenance Survey of 38 cities and counties in Minnesota and Wisconsin
- Multiple-answers allowed

Erickson, A.J., Gulliver, J.S., Weiss, P.T., and Wilson, C.B. (2009). "Survey of Stormwater BMP Maintenance Practices." Proceedings of the Universities Council on Water Resources/National Institutes for Water Resources Annual Conference. July 7-9, Chicago, IL.

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Agenda

- **Policies and procedures**
- During design and construction
- Maintenance implementation
- Typical maintenance needs
- Cost
- Summary

10

O & M Ordinance

Basic elements commonly include:

- Requirements to inspect and maintain management practices
- Easements or covenants for maintenance
- Identification of party responsible for maintenance
- Authority of City to inspect

Model O&M Ordinance and example maintenance documents available from:

http://www.epa.gov/owow/nps/ordinance/

http://www.stormwatercenter.net/

11

Maintenance Agreements Private Property

Each agreement should contain:

- Routine Maintenance Requirements – Who, What, How
- Maintenance Schedules – When
- Inspection Requirements
- Specifics on Access
- Failure to Maintain Consequences
- Provisions for Recording the Maintenance Agreement

12

O & M Plan

- Identify general maintenance requirements and schedule for each type of management practice
- May be included with design manual or as a separate document
- Involve and list all responsible departments
- Focus on specific activities
- Focus on maintenance of controls
- Consider seasonal variations
- Update as appropriate
- Reflect staff input and ideas

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Agenda

- Policies and procedures
- **During design and construction**
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Design Elements for Reduced Maintenance

- Accessibility (ROW, easements, vehicle access, cleanouts)
- Design documentation (remove sediment when?)
- Communicate presence, function, use and specialized maintenance needs (signage, manuals, etc.)
- Help from neighbors
- Involve maintenance staff on selection and design
- Pretreatment (sediment traps, vegetative buffer, etc.)
- Anti-clogging devices (inlet/outlet)
- Infiltration tests
- Vegetation (suitable selection)

15

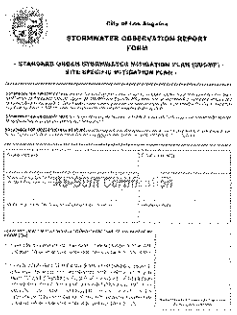
Field Practices for Reduced Maintenance

- Keep sediment out of planting area
- Certify soils/materials
- Inspect all plants prior to planting
- Stabilization is critical
- Have management practices in good shape before assuming responsibility for them

Construction Inspection Checklists

Common design elements requiring inspection during construction:

- Storage volume
- Inlets, outlets, overflows structures
- Pipes (material, joints, alignment, compaction, etc.), if relevant
- Elevations
- Porous pavement installation
- Sedimentation
- Vegetation


STORMWATER OBSERVATION REPORT FORM

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Agenda

- Policies and procedures
- During design and construction
- **Maintenance implementation**
- Typical maintenance needs
- Costs
- Summary

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Maintenance Guidance

- Develop standard operating procedures for maintenance
  - Who
  - What
  - How often, or triggers
- Training
  - Municipal Employees
  - Private entities

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Training for Municipal Staff

- General awareness training for all city employees
- Regular and targeted training for employees based on the activities they perform
- Provide materials for easy, frequent refreshers
- Teach employees that their actions have an impact on water quality and they are examples for the community

20

Example Program

NCSU BMP Inspection and Maintenance Certification

Overview/Main Certification Description Upcoming Classes and Registration Information
Typical Agenda Sample Powerpoint Meet the Instructors List of Certified Professionals

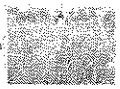
Why is Stormwater BMP Inspection and Maintenance Needed?

Communities across the State of North Carolina must manage rainfall that runs off roofs, streets and parking lots. This runoff is called stormwater. To manage stormwater, man-made devices called BMPs have been built. These devices include wet detention ponds, bioretention areas, stormwater wetlands, permeable pavement, and level spreaders. BMPs must have annual and sometimes more frequent maintenance to perform as intended. Maintenance includes hydrologic and water quality functions, aesthetics, and human health concerns. Some communities are currently having contractors do this work, but it is a specialized area, making substantial and lasting impacts before you might. As a result of not having your wet

- Understand stormwater basics & effects water quality, and regulations associated with it
- Understand stormwater management devices used in North Carolina and how they function
- Understand inspection and maintenance requirements of each stormwater practice

About the Training

This workshop offers 7 PDHs professional development hours for professional engineers and surveyors, as authorized by the NC Board of Examiners for Engineers and Surveyors. Other professionals may apply to their respective boards to obtain professional education credits. All participants who pass an examination at the end of the course will be certified by NC State Cooperative Extension. Certificates of Completion will be given to all attendees upon the passing of Exam Repairs.



www.bae.ncsu.edu/topic/bmp-im

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Tracking System

- Provide an inventory of existing practices
- Track maintenance and inspection
- Streamline the inspection & maintenance process
- Provide documentation for legal action
- Relate design to actual performance
- Use as a tool to develop program cost estimates
- Identify future retrofit opportunities



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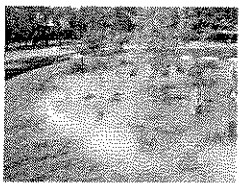
Inspections

- When
  - At regular intervals
  - After significant rainfall events
- Use a checklist
- Focus on preventative measures to avoid costly corrective repairs



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Inspections

- Inspect each component (tributary area, inlet, primary storage, outlet or overflow, downstream of outlet)
- Vegetation management issues
  - Too much or too little vegetation
  - Invasive species
- Water storage management
  - Infiltration/filtration capacity
  - Standing water
  - Water harvesting devices
- Trash and debris
- Sediment accumulation

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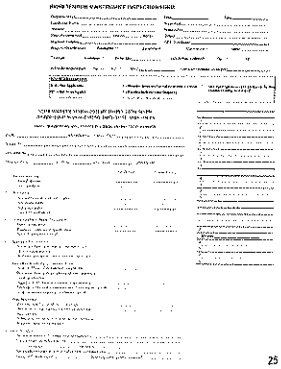
Example Inspection Forms

- California Stormwater Quality Association (CASQA)
- North Carolina State University
- Seattle Public Utilities



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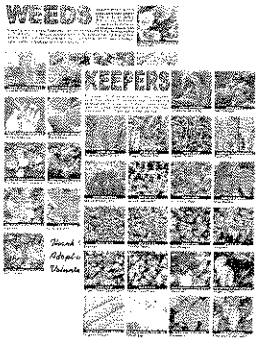
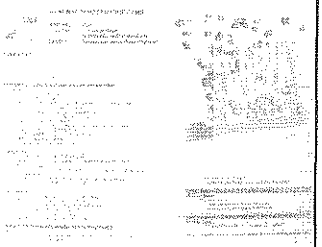
Example Guides

Lansing, MI Plant Guide



New York DEP Maintenance Cards



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Examples of Reported Incidents

- Blockages at inlets/outlets due to silt and debris accumulation
- Erosion of side slopes following heavy rainfall event
- Structural damage from continued drought or heavy rainfall
- Pollution incidences
- Vandalism to signs, fences and vegetation
- Mechanical component failure

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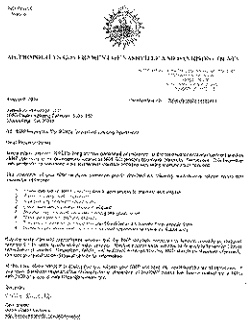
Compliance Assurance

Need to ensure that management practices on private property are inspected, maintained, and repaired when needed.



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Agenda

- Policies and procedures
- During design and construction
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- **Typical maintenance needs**
- Costs
- Summary

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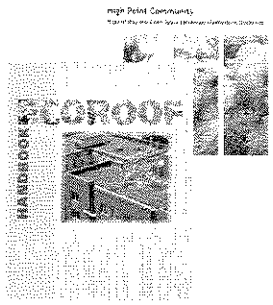
Example O&M Manuals

- Seattle, WA High Point Community
- Portland OR
- Minnesota Stormwater
- Georgia Stormwater Management Manual
- Michigan LID
- Etc.



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Sedimentation

- When should sediment be removed and to what depth?
  - Capacity measure with transects
  - When infiltration capacity diminished below design, and/or standing water > 72 hours
  - Should have as-builts or reference marker
- Is sediment contaminated?
  - Soil test prior to disposal

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Vegetation Management

- Avoid scalping grass
- Encourage biodiversity
- Weeding: know which ones are weeds or invasives (guide or manual)
- Soil test if vegetation problems: soil pH may affect nutrient availability, root growth and microbial population
- Mulch layer: prevents weeds, adds organic matter, conserves moisture, cools soil, should not float
- Watering requirements: usually necessary during root establishment, but not afterwards; adapted to local climate

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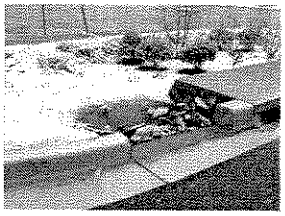
Structures

- Keep structures free and clear of debris and in good working order



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Filtration/Infiltration

- Bioretention and Biofiltration
- Infiltration capacity
  - Design for specified rate, know your limits (nominally drains within 24 to 48 hours)
  - Measure after construction
  - Measure periodically, check for decline
  - If surface capacity is compromised, check deeper
  - What's the cause of decreased infiltration? Sediment or compaction
- IF there's an underdrain check it
  - Could be clogged with sediment or roots
  - Should have cleanout

34

Infiltration Rates

	Number of tests	Avg Infil (in/hr)	COV
Noncompacted sandy soils	36	13	0.4
Compacted sandy soils	39	1.4	1.3
Noncompacted and dry clayey soils	18	9.8	1.5
All other clayey soils (compacted and dry, plus all wetter conditions)	60	0.2	2.4

Source: Pitt, Chen

35

Tasks and Schedule Generalized for Vegetation Management Practices

- Observations (quick and simple) – monthly and after significant rain events
- Trash removal – monthly (or more frequently) combine with observations
- Inspections with measurements for sediment and infiltration – annually
- Sediment removal – track accumulation with inspections,
- Vegetation Management
  - Mulch – refresh yearly if needed, replace 3-inches or 3-years
  - Weed/prune – monthly for new plantings, semi-annual once established
  - Plant replacement – anually as needed
  - Water – check in droughts, water as needed
- Fertilizer applications – only if needed, soil test first

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Green Roofs

- Plant Care: trimming, edging & fertilizing not necessary. Plant replacement may be needed.
- Unhealthy plant causes: too much or too little water, fertilization, HVAC condensate, air vent damage, people.
- Weeding: on a green roof weeds are plants that can penetrate the membrane, dry out and cause a fire hazard, are invasives. Manual or mechanical removal.
- Debris removal: 1 or 2 times per year
- Leaks rare, but if they occur they are usually around membrane penetrations such as vents.

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Permeable Pavements

Activity	Schedule
▪ Ensure free of sediment ▪ Check that system dewaters between storms	Monthly
▪ Ensure contributing area is clear of debris and stabilized	As needed, based on inspection
▪ Vacuum sweep	Typically 3 to 4 times per year
▪ Inspect for surface deterioration or spalling	Annually
▪ Total rehabilitation including top and base course as needed	Upon failure

Source: Georgia Stormwater Management Manual

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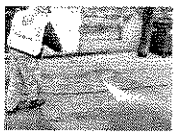
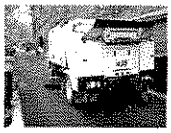
Chicago Green Alley Maintenance: Once or twice per year

Eagle



Power Washing



Tymco

Pelican: stiff bristles, vacuum action

Johnston

Little Wonder

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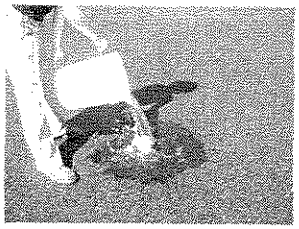
Permeable Pavement Performance

- 16 year old porous pavement in Philadelphia reported zero discharge during Hurricane Floyd in 1999 (10" rain/24 hours)
- Functions in cold weather
- 75% reduction in salt use (Toronto & NH) from reduced surface freezing



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Permeable Pavement Studies

Generally, studies have found high infiltration rates initially, a decrease, and then a leveling off with time, even without regular maintenance. Because the initial infiltration rates of permeable pavement are so high (100s in/hr) the long term infiltration capacity remains high even with clogging. Four permeable paver types were installed for testing in a parking lot in the City of Renton, WA in 1996. A follow up study in 2001 and 2002 found that the pavers infiltrated nearly all stormwater and showed no signs of wear.

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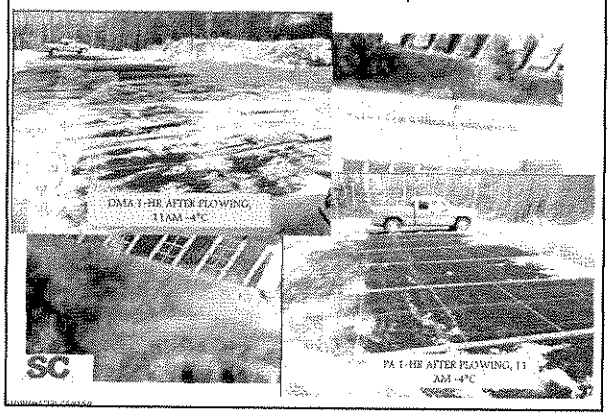
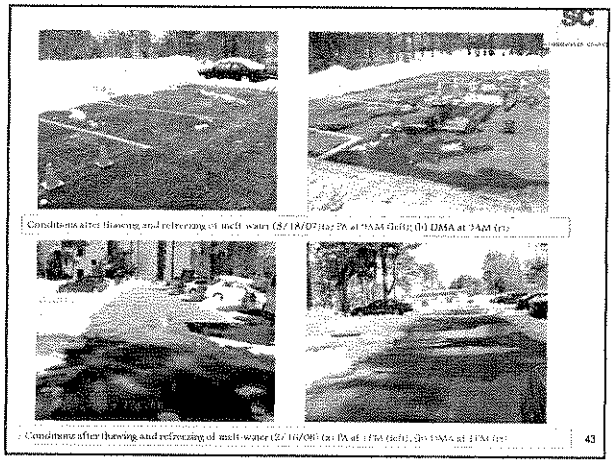
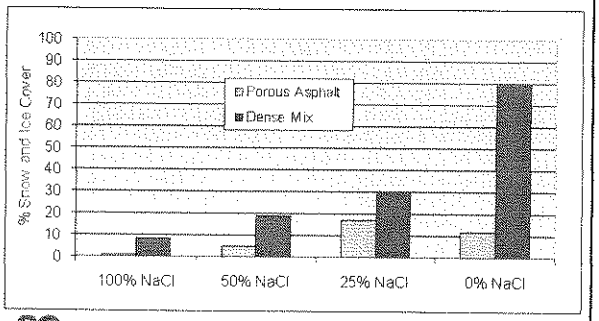
Salt Reduction and Porous Asphalt





Comparison of snow/ice percent cover for asphalt study area (winter '06-'07)

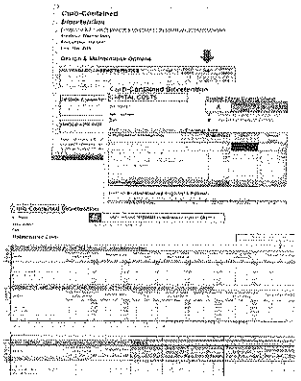


SC

- More snow & ice present on DMA

WERF Whole Life Cost Model

- Spreadsheet cost estimation tool designed to estimate whole life costs of several BMPs
- Capital and maintenance costs
- Peer reviewed
- Customizable



Download cost tools from: www.werf.org/bmpcost

EPA webcast archived www.epa.gov/greeninfrastructure

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Sidewalk Planters

From Lansing Michigan Bioretention Maintenance Guidance

Task	Description	Frequency (once established)	Annual labor and material cost[1]	Volunteer assistance
Weeding	Weeding to control unwanted vegetation, no herbicides	Spring, midsummer, late summer	Labor, $2000 Material, $100	Yes
Litter removal	Litter removal for aesthetics and function	Every 2 weeks (May – October)	Labor, $4000 Material, $200	Yes
Plant trimming	Maintain original balance and proportion of species	Spring and fall	Labor, $1500 Material, $100	Yes
Plant replacement	Replace dead or diseased plants, as noted in fall	Spring	Labor, $1000 Material, $500	
Mulching	Placement of 50mm (2 in.) of untreated mulch	Every 2 years and as needed	Labor, $700 Material, $1000	Yes
Pruning	Prune trees and shrubs to maintain aesthetics	Spring and fall or as needed	Labor, $700 Material, $1000	No
Drought weather watering	Water plants during times of severe drought	As needed	Labor, $250/drought Material $100	No
Sump cleaning	Inspect and remove litter and sediment from sump	Semiannually or as needed	Labor, $2500	No
Underdrain maintenance	Inspect and clean underdrain to avoid basement flooding	1 block each year	Labor, $650	No

[1]Labor cost assumes only citycrews are used without assistance fromvolunteers

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Agenda

- Policies and procedures
- During design and construction
- Maintenance implementation
- Typical maintenance needs
- Summary

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Summary

- Planning
  - Identify O&M requirements and responsibilities
  - Establish necessary administrative and accountability mechanisms
  - Provide education and training
- Design with maintenance in mind
- Watch out for material substitutions, compaction and siltation during construction
- Inspect and track your progress
- Focus on preventative maintenance efforts

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Agenda

- Policies and procedures
- During design and construction
- Maintenance implementation
- Typical maintenance needs
- **Costs**
- Summary

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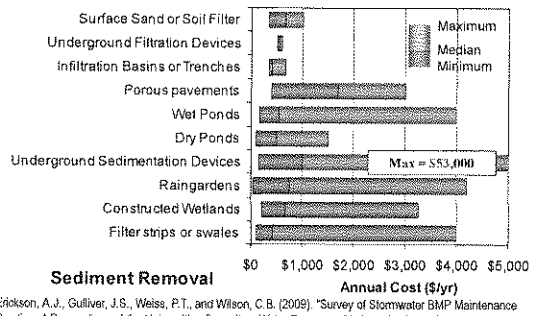
Costs for Non-Routine Maintenance Activities



Sediment Removal

Erickson, A.J., Gulliver, J.S., Weiss, P.T., and Wilson, C.B. (2009). "Survey of Stormwater BMP Maintenance Practices." *Proceedings of the Universities Council on Water Resources/National Institutes for Water Resources Annual Conference*. July 7-9, Chicago, IL.

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Typical O&M Costs for BMPs

Annual Cost as percentage of Construction Cost

	USEPA (1999)	Weiss et al. (2005)
Sand Filters	11% -13%	0.9% - 9.5%
Infiltration Trenches	5% - 20%	5.1% -- 126%
Infiltration Basins	1% - 3% 5% - 10%	2.8% - 4.9%
Wet Ponds	Not reported	1.9% - 10.2%
Dry Ponds	<1%	1.8% - 2.7%
Rain Gardens	5% - 7%	0.7% - 10.9%
Constructed Wetlands	2%	4% - 14.2%
Swales	5% - 7%	4% - 178%
Filter Strips	$320/Acre (maintained)	-

Weiss, P.T., J. S. Gulliver and A. J. Erickson, (2005). "The Cost and Effectiveness of Stormwater Management Practices," Minnesota Department of Transportation Report 2005-23. http://www.cts.umn.edu/Publications/ResearchReports/reportdetail.html?id=1023

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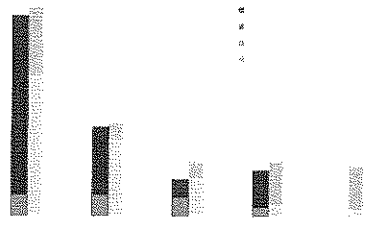
Preventative and Corrective Maintenance Costs in the US and UK



Source: WERF Performance and Whole Life Costs of Best Management Practices and Sustainable Urban Drainage Systems Final Report 2005 Project 01-CTS-21T

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