



Operation and Maintenance of Green Infrastructure

Why Must Management Practices be Maintained?

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

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.

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

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

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."

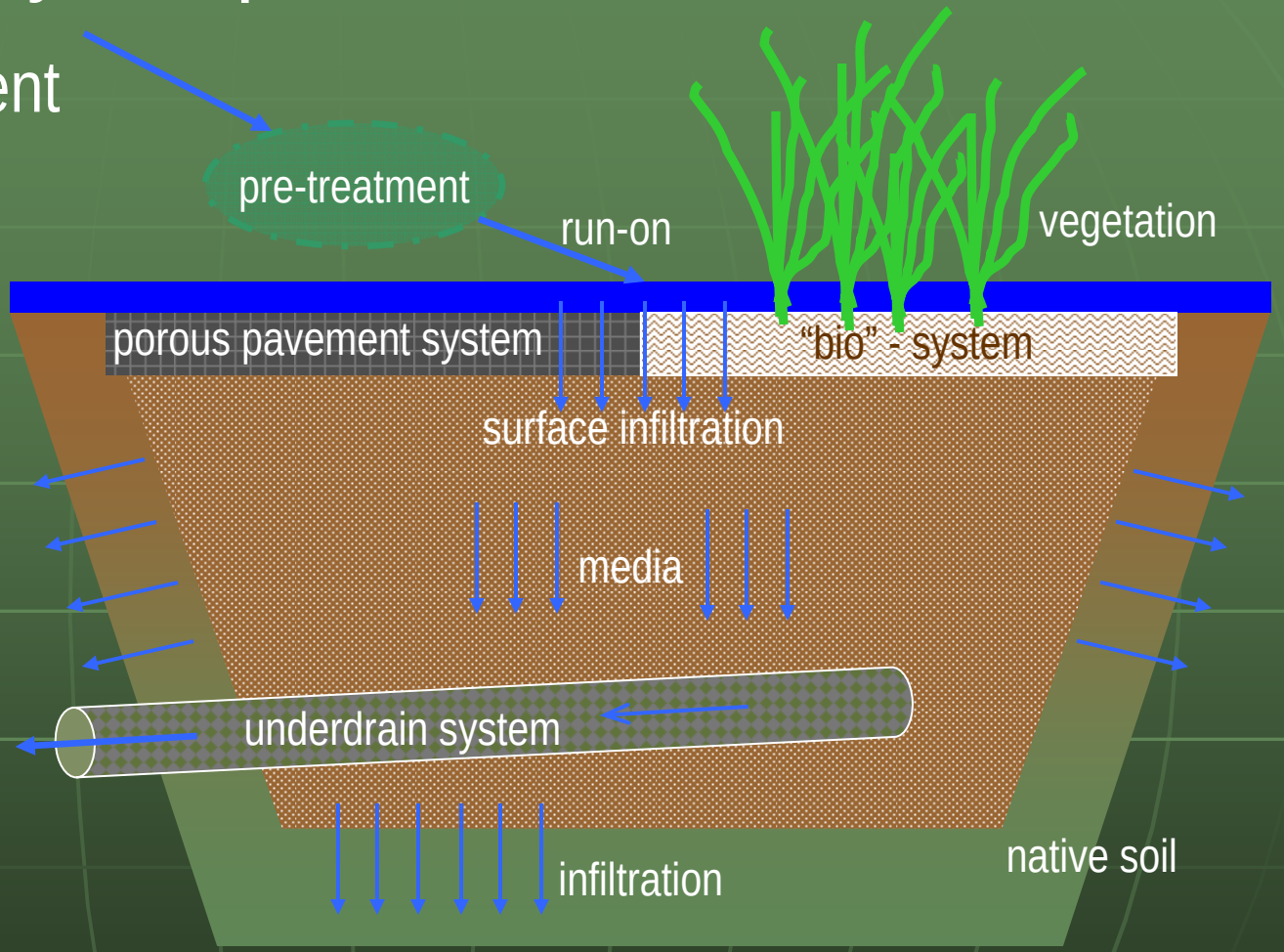
WERF 2005 Performance and Whole Life Costs of Best Management Practices and Sustainable Urban Drainage Systems

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

Key Components for O&M

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



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.

Agenda

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

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/

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

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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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)

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

City of Los Angeles

STORMWATER OBSERVATION REPORT FORM

- STANDARD URBAN STORMWATER MITIGATION PLAN (SUSMP) -
- SITE SPECIFIC MITIGATION PLAN -

STORMWATER OBSERVATION *means the visual observation of the stormwater related Best Management Practices (BMPs) for conformance with the approved SUSMP/Site Specific Mitigation Plan at significant construction stages and at completion of the project. Stormwater observation does not include or waive the responsibility for the inspections required by Section 108 or other sections of the City of Los Angeles Building Code.*

STORMWATER OBSERVATION *must be performed by the engineer or architect responsible for the approved SUSMP/Site Specific Mitigation Plan or designated staff in their employment.*

STORMWATER OBSERVATION REPORT *must be signed and stamped (see below) by the engineer or architect responsible for the approved SUSMP and submitted to the city prior to the issuance to the certificate of occupancy.*

Project Address:	Building Permit No.:
Name of Engineer or Architect responsible for the approved SUSMP/Site Specific Mitigation Plan:	Phone Number:
Name of SUSMP/Site Specific Mitigation Plan Observer:	Phone Number:

As-Built Certification

I DECLARE THAT THE FOLLOWING STATEMENTS ARE TRUE TO THE BEST OF MY KNOWLEDGE:

1. I AM THE ENGINEER OR ARCHITECT RESPONSIBLE FOR THE APPROVED SUSMP/SITE SPECIFIC MITIGATION PLAN, AND

2. I OR DESIGNATED STAFF UNDER MY RESPONSIBLE CHARGE, HAS PERFORMED THE REQUIRED SITE VISITS AT EACH SIGNIFICANT CONSTRUCTION STAGE AND AT COMPLETION TO VERIFY THAT THE BEST MANAGEMENT PRACTICES AS SHOWN ON THE APPROVED PLAN HAVE BEEN CONSTRUCTED AND INSTALLED IN ACCORDANCE WITH THE APPROVED SUSMP/SITE SPECIFIC MITIGATION PLAN.

Stamp of Engineer or Architect responsible for the approved SUSMP

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Maintenance Guidance

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

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

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 roads, streets and parking lots. This runoff is called stormwater. To manage stormwater, many treatment devices, called BMPs, have been built. These devices include: wet retention 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 function, aesthetic and human health concerns. Some communities are considering hiring contractors to do this work, but it is a specialized area, making education and training important before you begin. As a result of his training you will:

- Understand stormwater, how it affects 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

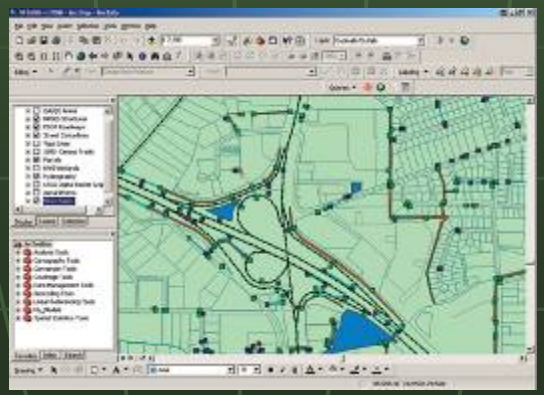
About the Training

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 appeal 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 U.S. mailed to all attendees upon the posting of Exam Results.

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

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



Inspections

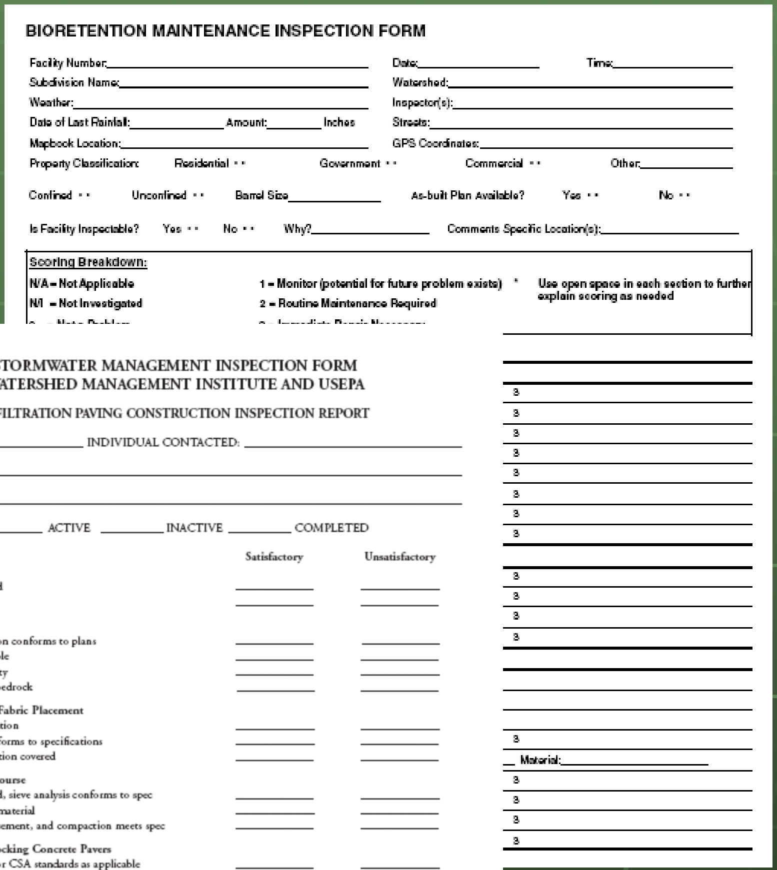
- When
  - At regular intervals
  - After significant rainfall events
- Use a checklist
- Focus on preventative measures to avoid costly corrective repairs

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

Example Inspection Forms

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



BIORETENTION MAINTENANCE INSPECTION FORM

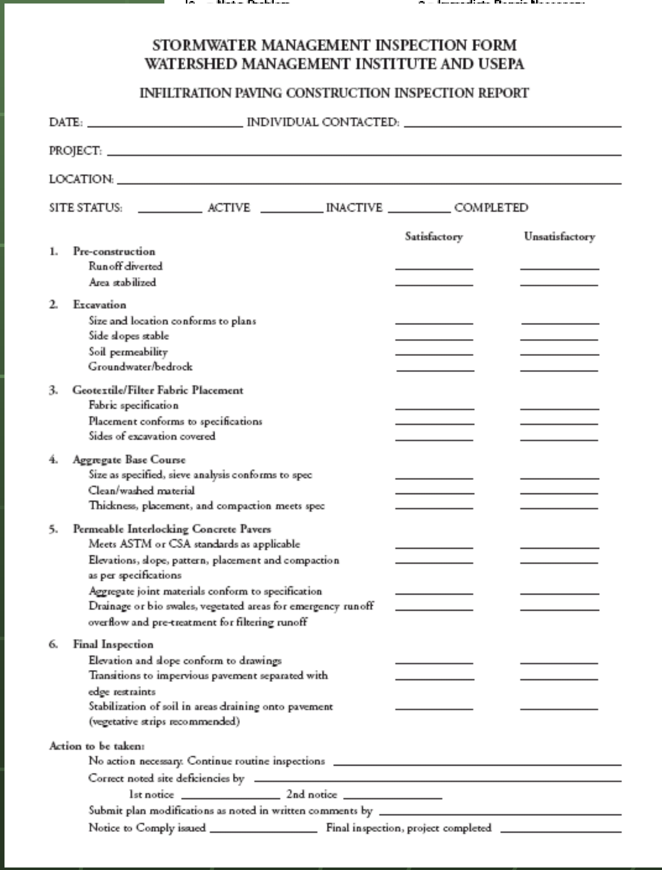
Facility Number: ______ Date: ______ Time: ______
Subdivision Name: ______ Watershed: ______
Weather: ______ Inspector(s): ______
Date of Last Rainfall: ______ Amount: ______ Inches Streets: ______
Mapbook Location: ______ GPS Coordinates: ______
Property Classification: Residential Government Commercial Other: ______

Confined Unconfined Barrel Size ______ As-built Plan Available? Yes No

Is Facility Inspectable? Yes No Why? ______ Comments Specific Location(s): ______

Scoring Breakdown:
N/A = Not Applicable
N/I = Not Investigated
1 = Monitor (potential for future problem exists)
2 = Routine Maintenance Required
* Use open space in each section to further explain scoring as needed

Material: ______



STORMWATER MANAGEMENT INSPECTION FORM
WATERSHED MANAGEMENT INSTITUTE AND USEPA

INFILTRATION PAVING CONSTRUCTION INSPECTION REPORT

DATE: ______ INDIVIDUAL CONTACTED: ______
PROJECT: ______
LOCATION: ______
SITE STATUS: ______ ACTIVE ______ INACTIVE ______ COMPLETED

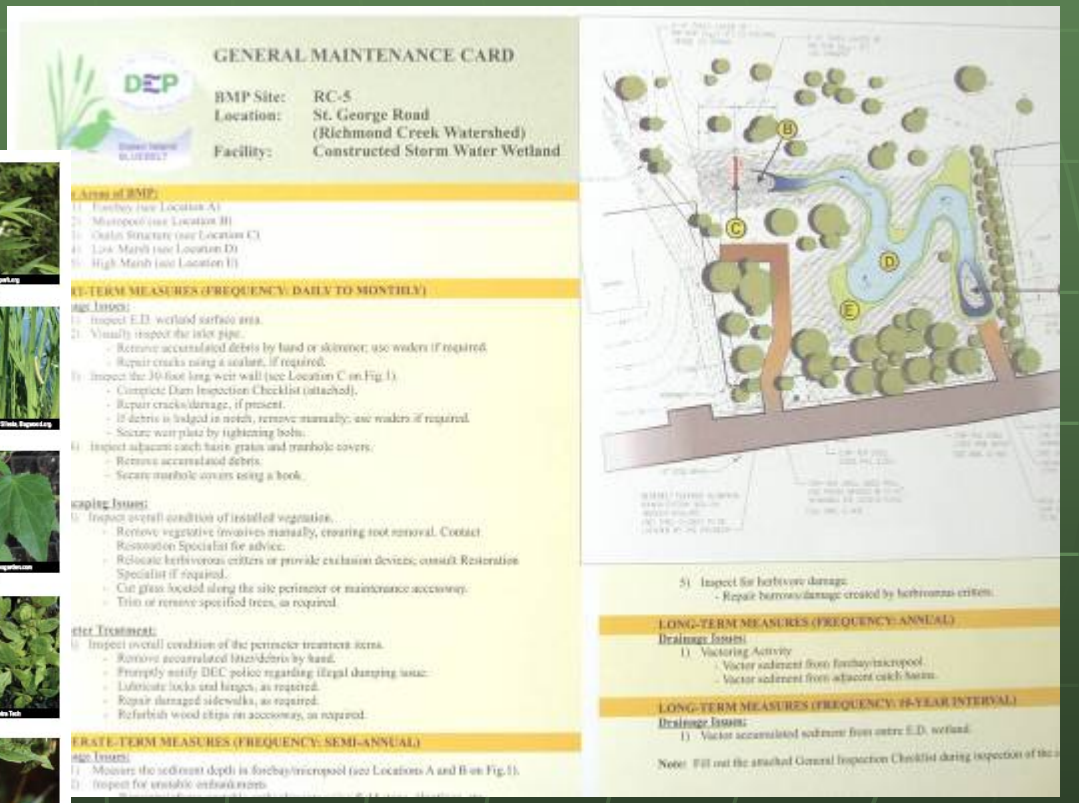
	Satisfactory	Unsatisfactory
1. Pre-construction		
Runoff diverted		
Area stabilized		
2. Excavation		
Size and location conforms to plans		
Side slopes stable		
Soil permeability		
Groundwater/bedrock		
3. Geotextile/Filter Fabric Placement		
Fabric specification		
Placement conforms to specifications		
Sides of excavation covered		
4. Aggregate Base Course		
Size as specified, sieve analysis conforms to spec		
Clean/washed material		
Thickness, placement, and compaction meets spec		
5. Permeable Interlocking Concrete Pavers		
Meets ASTM or CSA standards as applicable		
Elevations, slope, pattern, placement and compaction as per specifications		
Aggregate joint materials conform to specification		
Drainage or bio swales, vegetated areas for emergency runoff overflow and pre-treatment for filtering runoff		
6. Final Inspection		
Elevation and slope conform to drawings		
Transitions to impervious pavement separated with edge restraints		
Stabilization of soil in areas draining onto pavement (vegetative strips recommended)		

Action to be taken:
No action necessary. Continue routine inspections ______
Correct noted site deficiencies by ______
1st notice ______ 2nd notice ______
Submit plan modifications as noted in written comments by ______
Notice to Comply issued ______ Final inspection, project completed ______

Example Guides

Lansing, MI Plant Guide

New York DEP Maintenance Cards

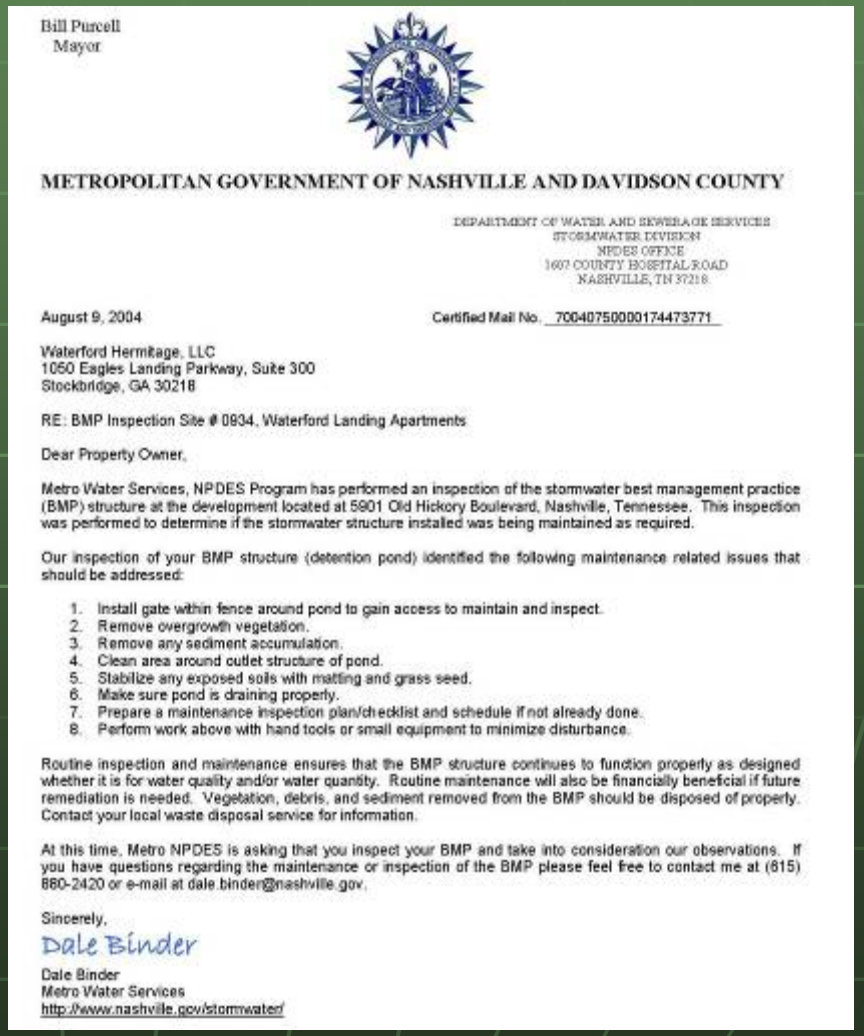


Examples of Reported Incidents

- 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

Compliance Assurance

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



Bill Purcell
Mayor

METROPOLITAN GOVERNMENT OF NASHVILLE AND DAVIDSON COUNTY

DEPARTMENT OF WATER AND SEWERAGE SERVICES
STORMWATER DIVISION
NPDES OFFICE
1607 COUNTY HOSPITAL ROAD
NASHVILLE, TN 37218

August 9, 2004 Certified Mail No. 70040750000174473771

Waterford Hermitage, LLC
1050 Eagles Landing Parkway, Suite 300
Stockbridge, GA 30218

RE: BMP Inspection Site # 0934, Waterford Landing Apartments

Dear Property Owner,

Metro Water Services, NPDES Program has performed an inspection of the stormwater best management practice (BMP) structure at the development located at 5901 Old Hickory Boulevard, Nashville, Tennessee. This inspection was performed to determine if the stormwater structure installed was being maintained as required.

Our inspection of your BMP structure (detention pond) identified the following maintenance related issues that should be addressed:

1. Install gate within fence around pond to gain access to maintain and inspect.
2. Remove overgrowth vegetation.
3. Remove any sediment accumulation.
4. Clean area around outlet structure of pond.
5. Stabilize any exposed soils with matting and grass seed.
6. Make sure pond is draining properly.
7. Prepare a maintenance inspection plan/checklist and schedule if not already done.
8. Perform work above with hand tools or small equipment to minimize disturbance.

Routine inspection and maintenance ensures that the BMP structure continues to function properly as designed whether it is for water quality and/or water quantity. Routine maintenance will also be financially beneficial if future remediation is needed. Vegetation, debris, and sediment removed from the BMP should be disposed of properly. Contact your local waste disposal service for information.

At this time, Metro NPDES is asking that you inspect your BMP and take into consideration our observations. If you have questions regarding the maintenance or inspection of the BMP please feel free to contact me at (615) 880-2420 or e-mail at dale.binder@nashville.gov.

Sincerely,

Dale Binder

Dale Binder
Metro Water Services
http://www.nashville.gov/stormwater/

Agenda

- Policies and procedures
- During design and construction
- Maintenance implementation
- Typical maintenance needs
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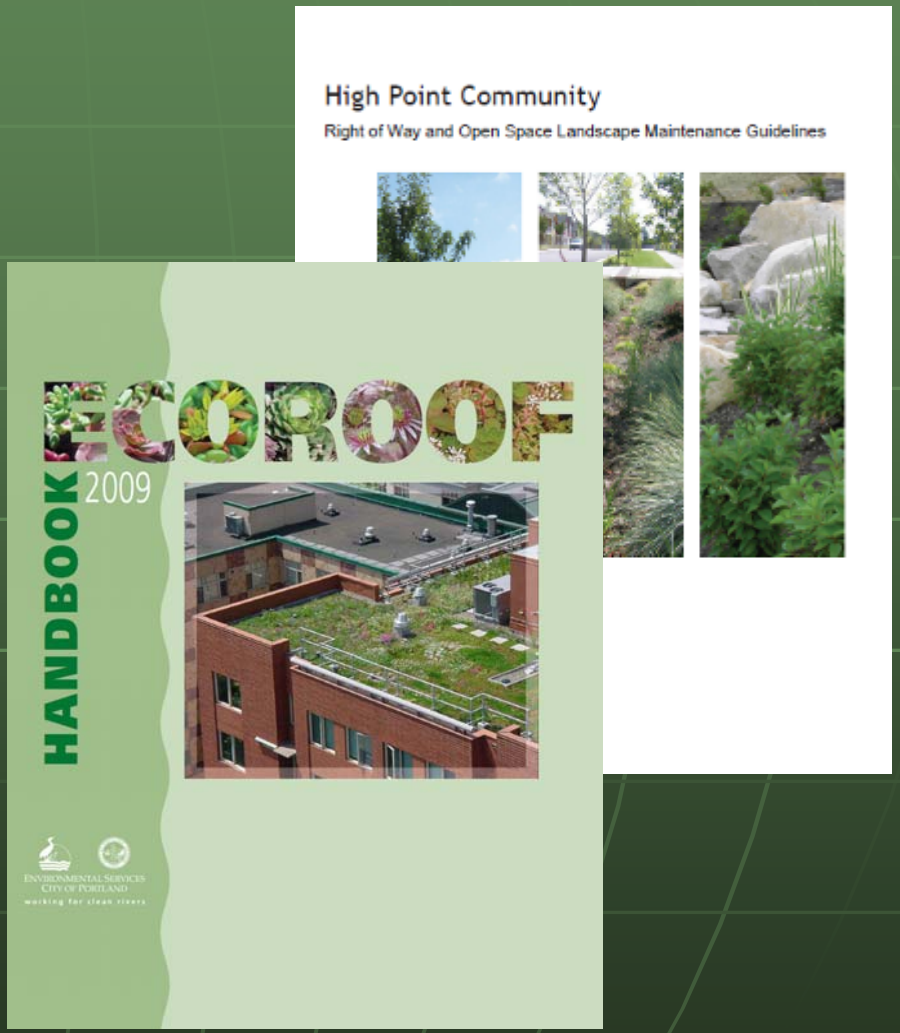
Example O&M Manuals

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



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

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

Structures

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

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

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

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

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.

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

Chicago Green Alley Maintenance: Once or twice per year

Eagle

Tymco

Johnston

Power Washing

Pelican: stiff bristles, vacuum action

Little Wonder

Permeable Pavement Performance

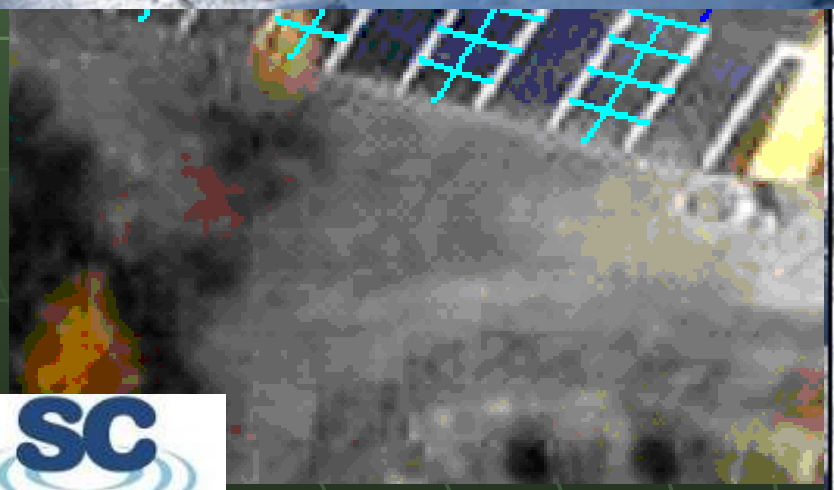
- 16 year old porous pavement in Philadelphia reported zero discharge during Hurricane Floyd in 1999 (10” rain/24 hours)
- Functions in cold weather
- 75% reduction in salt use (Toronto & NH) from reduced surface freezing

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.

Salt Reduction and Porous Asphalt

DMA 1-HR AFTER PLOWING, 11AM ~4*C



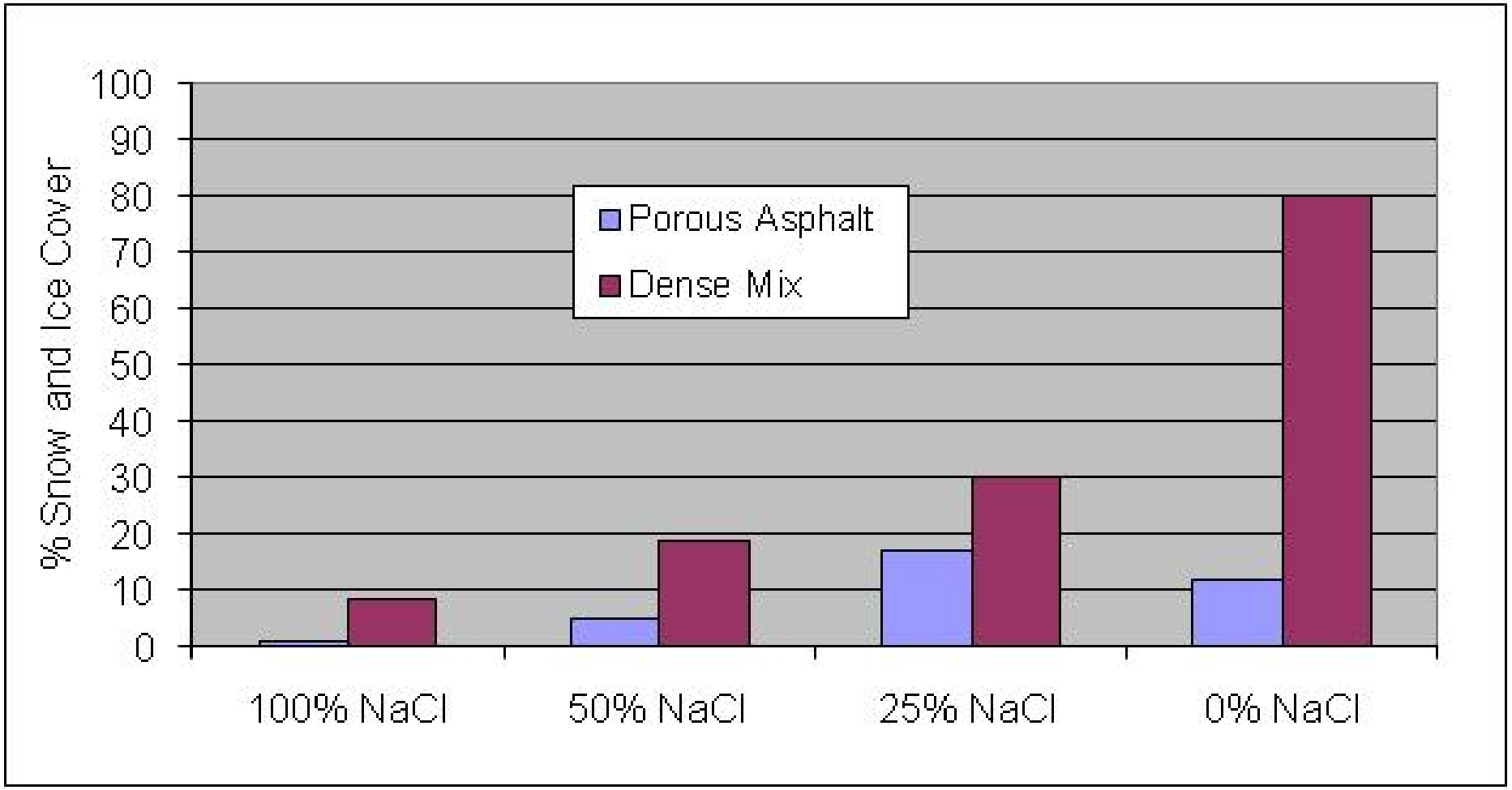
PA 1-HR AFTER PLOWING, 11 AM ~4*C

UNIVERSITY OF NEW HAMPSHIRE
STORMWATER CENTER

Conditions after thawing and refreezing of melt-water (3/18/07)(a) PA at 9AM (left); (b) DMA at 9AM (rt)

Conditions after thawing and refreezing of melt-water (2/16/08) (a) PA at 1PM (left); (b) DMA at 1PM (rt)

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



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STORMWATER CENTER

- More snow & ice present on DMA

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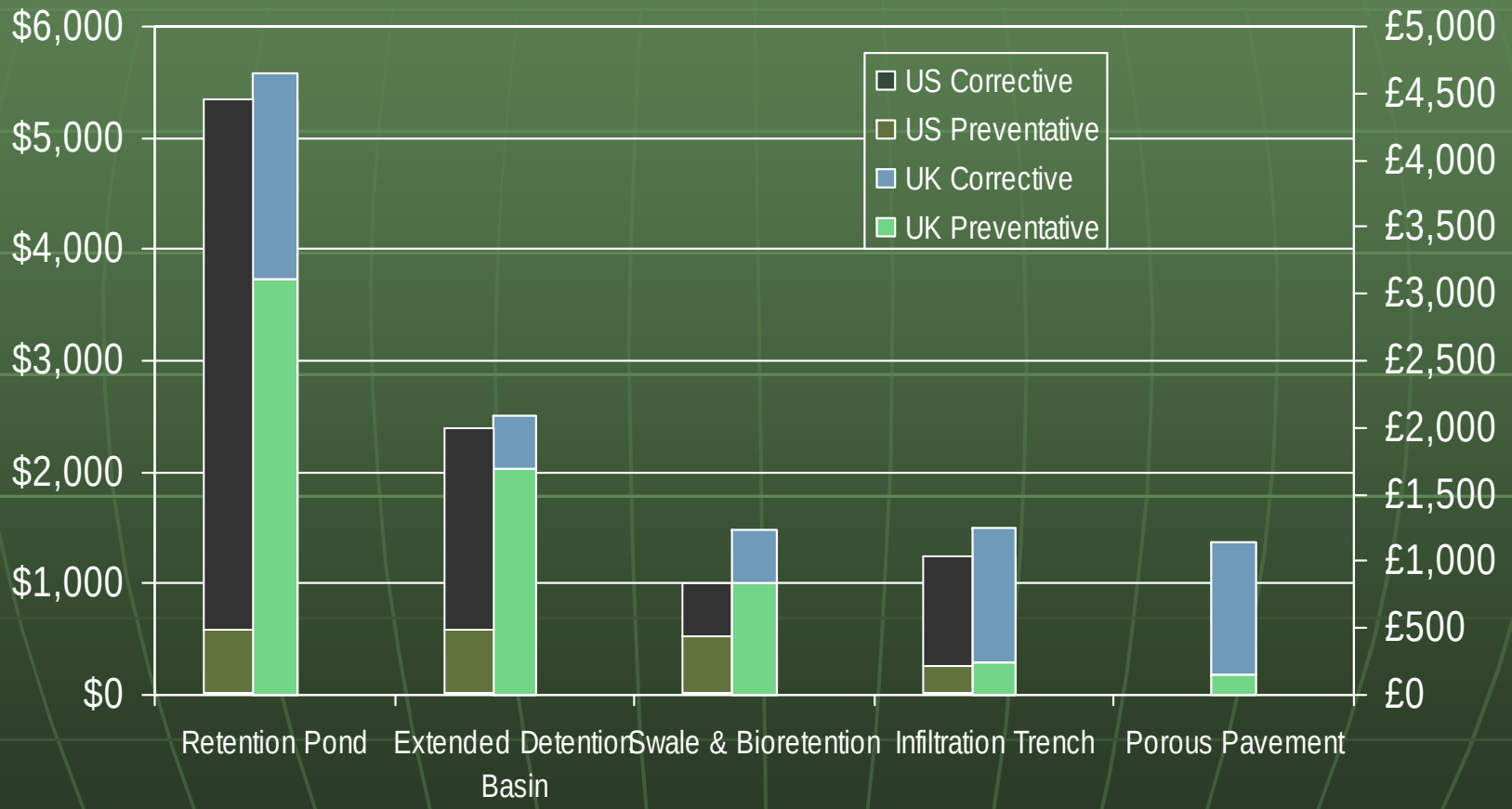
Typical O&M Costs for BMPs

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

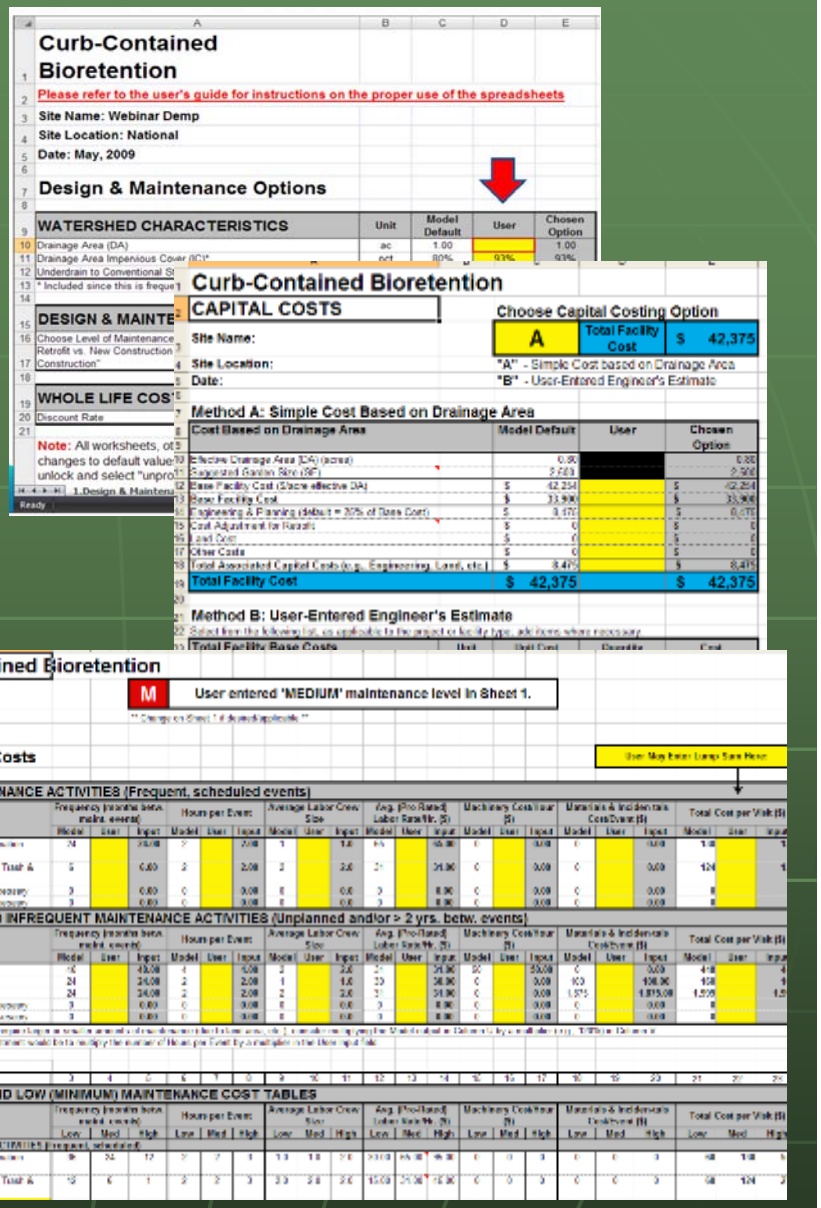
Preventative and Corrective Maintenance Costs in the US and UK



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

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

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 thinning	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 city crews are used without assistance from volunteers

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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