Appendix A – BMP Fact Sheets

Legend	
H/M/L	High/Medium/Low effectiveness relative to other BMPs

TYPICAL PROPERTIES	
Location	Surface / Subsurface
Popularity	High
Longevity	Durable
Primary constraint	Space / Groundwater

PRIMARY FUNCTION(S)	
H	Water Quality Improvement
H	Volume Control
M	Peak Reduction
M	Flow Duration Control

COST	
M	Capital Cost
M	Minor Maintenance Cost
H	Major Maintenance Cost
L	Maintenance Frequency

BIORETENTION

Bioretention systems (a.k.a. rain gardens) are vegetated shallow depressions used to temporarily store stormwater prior to infiltration, evapotranspiration, or discharge via an underdrain or surface outlet structure. By filtering stormwater through an engineered soil mix, bioretention systems can be designed to target a variety of pollutants. The primary stormwater pollutant removal mechanisms in bioretention systems include filtration, shallow sedimentation, sorption and infiltration. Additional removal mechanisms include biochemical processes in the underlying engineered planting media such as adsorption and microbial transformations of dissolved pollutants. When properly incorporated into a road shoulder or median, bioretention systems can reduce the connectivity of impervious cover, accent the natural landscape, and provide aesthetic benefits.

Where should bioretention systems be used?

Bioretention systems can be used practically anywhere there is adequate open space available (typically 3-5% of the drainage area). While they are best suited to areas having well-drained soils that are not constrained by a high water table or geotechnical hazards, an underdrain and/or impermeable liner may be used to overcome site constraints. Use of native vegetation will enable these bioretention systems to be implemented in low rainfall areas without irrigation after plants are established.

TARGET CONSTITUENTS	
H	Sediment
H	Metals
M	Organics
M	Nutrients
M	Bacteria
M	Trash and debris
M	Oil and grease

UNIT PROCESSES	
H	Volume reduction
M	Gravity separation
H	Media filtration & sorption
L	Vegetative filtration
H	Plant uptake & microbial transformations

PRIMARY CONSTRAINTS	
M	Surface space req.
M	Subsurface space req.
M	Hydraulic head req.
M	Water table req.
H	Soil permeability req.
L	Public acceptance
H	Steep slopes / stability

ENHANCEMENTS / VARIATIONS
Engineered soils
Underdrains
Impermeable Liner
Outlet modifications

Table 1: Site Suitability Guidelines for Bioretention Facilities

Tributary Area	< 5 acres; 217,800 sq. ft.
Typical BMP area as percentage of tributary area	< 5 percent
Proximity to steep sensitive slopes	On slopes steeper than 15% or within 50 feet of a steep slope or landslide hazard area, underdrains should be used, and a geotechnical investigation should be performed. None of the systems are recommended for slopes steeper than 20%.
Depth to seasonally high groundwater table	< 5 ft, underdrains are recommended > 5 ft, underdrain is optional, depending on soil type
Hydrologic soil group/infiltration rate	• If measured infiltration rate < 2 inches/hour, bioretention with an underdrain is recommended • If measured infiltration rate is > 2 inches per hour, underdrain is optional

1 – Tributary area is the area of the site draining to the BMP. Tributary areas provided here should be used as a general guideline only. Tributary areas can be larger or smaller in some instances.

Variations and Enhancements

There are two types of bioretention systems that can be used for stormwater management, depending on the site needs and constraints:

Bioretention without an Underdrain (rain gardens) – These systems are designed to retain and infiltrate the water quality design volume from a site. Rain gardens can be implemented in areas where there are no hazards that would preclude infiltration (such as geotechnical concerns, shallow groundwater, or contaminant plumes or hazards) and where soil infiltration rates are relatively high.

Bioretention with an Underdrain – Bioretention with an underdrain can be implemented in two ways. Placement of the underdrain at the bottom of the facility is recommended when infiltration is hazardous due to geotechnical concerns, contaminant plumes, very high infiltration rates (>3.6 in/hr) with high pollutant generating source areas (e.g., gas stations), or other groundwater concerns. In all of these cases, or other where infiltration is simply not desired, the bioretention facility should be lined. The second option involves installing a raised underdrain in the facility. This is a good solution when infiltration rates are moderately low and infiltration is still desired. During a storm event, runoff will percolate down to the gravel sump and fill up the pore volume until the water level reaches the raised underdrain. The underdrain will then discharge treated stormwater back to the storm drain system, which allows for partial infiltration of all storms and complete treatment of the water quality design volume. Underdrains can improve plant health and control vector problems in poorly draining soils

In addition to underdrains, the following structural and operational enhancements can also increase performance in bioretention facilities:

- Check dams or drop structures are recommended where slopes exceed 6%. Shallower slopes enhance sediment removal by causing stormwater to pond for longer periods.
- Soil amendments, such as sand, zeolite, granular activated carbon, peat, and other materials, can provide sorption sites for the removal of dissolved and suspended pollutants and can also be used to increase or decrease infiltration and improve plant growth.

Advantages and Benefits

- Many design variations available to tailor facility to site constraints & local needs
- Aesthetically pleasing
- Volume and peak reduction
- Efficient removal of many pollutants
- Wide regulatory acceptance/preference

Risks and Limitations

- Potentially high maintenance burden if proper pretreatment is not provided
- Not recommended for runoff with high sediment content without pretreatment
- Requires extra attention to plant health (e.g. irrigation), especially in initial stages
- Susceptible to clogging, short circuiting, and bio-fouling if not properly designed
- Not suitable for larger drainage areas

Sizing and Design Considerations:

- Drawdown time of planting media should be less than a few hours.
- Recommended maximum ponding depth is 12 inches.
- Recommended minimum planting media depth is 2 feet (3 feet preferred).
- Recommended planting media composition: 60 to 70% sand, 15 to 25% compost, and 10 to 20% clean topsoil; organic content 8 to 12%; pH 5.5 to 7.5.
- Overflow outlets are recommended.

Construction Considerations

- Provide energy dissipation and a flow spreader at each concentrated inlet point. Sheet flow inputs into the bioretention facility do not require energy dissipation.
- If infiltration is considered desirable do not operate heavy machinery along the bottom of the bioretention facility during construction. If compaction occurs, till the bottom of the facility, re-grade and vegetate.
- Treated wood and galvanized metal should be avoided anywhere inside a bioretention area.

Maintenance

Routine Maintenance	• Maintain vegetation as frequently as needed to preserve aesthetics in urban areas • Remove trash and debris and visible floatables such as oil and grease • Remove minor sediment accumulations near inlet/outlet structures • Stabilize and repair eroded banks • Perform minor structural repairs to inlet/outlet structures • Eliminate vectors and conditions that promote vectors
Major Maintenance	• Remove and properly dispose of sediment (expected every 40 years or sooner) • Re-grade bioretention area to restore design longitudinal bottom slope • Aerate compacted areas to restore infiltration capacity

Cost:

Costs provided below are reference estimates only. Site-specific conditions and design choices can significantly affect implementation costs.

Table 2: Bioretention Implementation and Maintenance Costs

COST PER AREA SERVED (Area Served < 3 acres)				COST PER AREA SERVED (Area Served > 3 acres)			
New Construction	Retrofit	Annual Minor Maint.	*Annual Major Maint.	New Construction	Retrofit	Annual Minor Maint.	*Annual Major Maint.
$ 24,500	$ 35,400	$ 952	$ 149	$ 13,900	$ 20,200	$ 484	$ 52

Note: The costs provided in the table above will not scale linearly with changes in area served and will vary significantly with changes in design assumptions and site specific conditions. *These costs are subject to change as the Project Team discusses and refines the assumptions used to develop them.*

*Annual major maintenance cost based on assumed major maintenance task frequencies ranging from 1 to 50 years

Related DOT Guidance

AZ	www.azdot.gov/Inside_ADOT/OES/Water_Quality/Stormwater/PDF/adot_post_construction_bmp_manual.pdf
DE	http://www.dnrec.state.de.us/DNREC2000/Divisions/Soil/Stormwater/New/GT_Stds%20%26%20Specs_06-05.pdf
GA	www.georgiastormwater.com/
ID	http://itd.idaho.gov/enviro/Stormwater/BMP/default.htm
MD	http://www.mde.state.md.us/programs/Water/StormwaterManagementProgram/SoilErosionandSedimentControl/Documents/MD%20SWM%20Volume%201.pdf
NJ	nj.gov/dep/stormwater/bmp_manual2.htm
NV	http://www.nevadadot.com/uploadedFiles/NDOT/About_NDOT/NDOT_Divisions/Engineering/Hydraulics/2006_PlanningAndDesignGuide.pdf
OH	http://www.dot.state.oh.us/Divisions/Engineering/Hydraulic/LandD/Pages/TableofContents.aspx
OR	ftp://ftp.odot.state.or.us/techserv/geo-environmental/Hydraulics/Hydraulics%20Manual/Table_of_Contents_rev_Nav.pdf and http://www.oregon.gov/ODOT/HWY/OOM/mg/02/act125_waterqualityfacilandtables.pdf
PA	ftp://ftp.dot.state.pa.us/public/bureaus/design/PUB584/PDM-TOC.pdf
RI	http://www.dem.state.ri.us/programs/benviron/water/permits/ripdes/stwater/t4guide/desman.htm
WA	http://www.wsdot.wa.gov/publications/manuals/fulltext/M31-16/HighwayRunoff.pdf

Related DOT Guidance and Additional Resources

Cahill Associates, Inc. Pennsylvania Stormwater Best Management Practices Manual. 2006. http://www.elibrary.dep.state.pa.us/dsweb/View/Collection-8305

City of Portland, Oregon. Stormwater Management Manual. 2008. http://www.portlandonline.com/bes/index.cfm?c=47953&

Coastal Georgia Regional Development Center. Green Growth Guidelines. 2006. http://coastalgadnr.org/cm/green/guide

North Carolina State University. Bioretention at North Carolina State University BAE. http://www.bae.ncsu.edu/topic/bioretention/index.html

Prince Georges County Bioretention Manual, 2009. http://www.princegeorgescountymd.gov/Government/AgencyIndex/DER/ESG/Bioretention/pdf/Bioretention%20Manual_2009%20Version.pdf

Virginia Department of Conservation and Recreation. Virginia DCR Stormwater Design Specification No. 9: Bioretention. 2010. (refer to Appendix 9-A: Urban Bioretention).

Legend	
H/M/L	High/Medium/Low effectiveness relative to other BMPs

TYPICAL PROPERTIES	
Location	Surface
Popularity	High
Longevity	Durable
Primary constraint	Space

PRIMARY FUNCTION(S)	
M	Water Quality Improvement
M	Volume Control
M	Peak Reduction
M	Flow Duration Control

COST	
M	Capital Cost
M	Minor Maintenance Cost
M	Major Maintenance Cost
L	Maintenance Frequency

DRY EXTENDED DETENTION

Dry extended detention (ED) basins (also known as dry ponds) are BMPs intended to primarily provide peak shaving and sedimentation treatment. Dry ED basins do not have a permanent pool; they are designed to drain completely between storm events. Where soil conditions allow, they can provide significant volume reductions with infiltration. The side slopes, bottom, and forebay of dry ED basins are typically vegetated.

Dry ED basins can be designed to function as either on-line or off-line BMPs. If designed just for water quality treatment, it is recommended that the dry ED basins be implemented in an off-line configuration and not used for flood flow conveyance. For off-line basins, a flow diversion structure (i.e., flow splitter) should be used to divert the water quality design volume to the basin. On-line basins should be designed to pass the required flood event per local design standards without damage to the basin, as well as to minimize re-entrainment of pollutants. For both types of basins, influent flows enter a sediment forebay where coarse solids are removed prior to flowing into the main cell of the basin, where finer sediment and associated pollutants settle as storm water is detained and slowly released through a controlled outlet structure. Low flows are often infiltrated within the basin if the basin is unlined. If standing water is a concern, a low flow drain can be installed.

TARGET CONSTITUENTS	
H	Sediment
M	Metals
M	Organics
L	Nutrients
L	Bacteria
H	Trash and debris
M	Oil and grease

UNIT PROCESSES	
M	Volume reduction
H	Gravity separation
L	Media filtration & sorption
L	Vegetative filtration
L	Plant uptake & microbial transformations

PRIMARY CONSTRAINTS	
M	Surface space req.
M	Subsurface space req.
M	Hydraulic head req.
M	Water table req.
M	Soil permeability req.
H	Public acceptance
H	Steep slopes / stability

ENHANCEMENTS / VARIATIONS
Engineered soils
Impermeable Liner
Outlet modifications
Forebay

Where should a dry extended detention basin be used?

Dry extended detention basins can be applied to any area where sufficient space is available to treat larger tributary areas. Dry extended detention basins can be designed for multiple beneficial uses, such as sports fields or park areas, and typically are readily accepted by communities.

Table 1: Site Suitability Guidelines for Dry Extended Detention Basins

Tributary Area[1]	> 10 acres
Typical BMP area as percentage of tributary area (including settling chamber)	< 2%
Proximity to steep sensitive slopes	A geotechnical evaluation is recommended for basins placed on slopes greater than 15% or within 200 feet from a hazardous slope or landslide area.
Depth to seasonally high groundwater table	< 5 feet, liner required > 5 feet, no liner needed
Hydrologic soil group	Any
Unsuitable locations	Dry ED basins should not be placed within intermittent stream beds or in locations where an elevated threat of groundwater contamination may exist. Water levels should not be above those allowed by local zoning ordinances.

1 – Tributary area is the area of the site draining to the BMP. Tributary areas provided here should be used as a general guideline only. Tributary areas can be larger or smaller in some instances.

Variations and Enhancements

Enhancements that minimize space constraints, maximize contact time, or assist with volume reduction are the main categories of enhancements available for dry ED basins. A dry ED basin can sometimes be retrofitted into existing flood control basins or integrated into the design of a park, athletic field, or other green space. Hybrid dry ED basins that incorporate a sand filter or planting media underneath the basin are an option for increasing volume reduction. Perforated risers, multiple orifice plate outlets, or similar multi-stage outlets are recommended for flood control retrofit applications to ensure adequate detention time for small storms while still providing peak flow attenuation for the flood design storms.

Advantages and Benefits

- Volume and peak flow reduction
- Suspended solids and particulate-bound pollutant removal
- Potential for multiple beneficial uses
- Appropriate for large tributary areas

Risks and Limitations

- Large footprint required
- Significant earthwork required
- Must be sited in areas where current flood control structures are not adversely affected
- Not recommended for areas with high groundwater table

Sizing and Design Considerations:

- Space allocation: 25% forebay, 75% main basin recommended
- The outlet should preferably be designed to release the bottom 50% of the detention volume (half-full to empty) over 24 to 32 hours, and the top half (full to half-full) in 12 to 16 hours.
- The flow-path length to width ratio at half basin height should preferably be a minimum of 3:1 (L:W)
- All dry ED basins should be free draining and a low flow channel is recommended. A low flow channel is a narrow, shallow trench filled with pea gravel and encased with filter fabric that runs the length of the basin to drain dry weather flows.
- A basin should be large enough to allow for equipment access via a graded access ramp.
- The bottom and slopes of the dry ED basin should be vegetated.

Construction Considerations

- To the extent possible, avoid compacting the bottom of the basin to maintain soil permeability.
- The use of treated wood or galvanized metal inside basin should be avoided.

Inspection and Maintenance

Inspection	• At a minimum, should be inspected twice per year to ensure the structure operates in the manner originally designed. • Should be inspected after major rain storms to correct any identified deficiencies. • Periodically observe function under wet weather conditions
Routine Maintenance	• Trash and debris removal • Remove minor sediment accumulation near inlet and outlet structures • Stabilize/repair eroded banks and fill in animal burrows if present • Minor structural repairs to inlet/outlet structures, valves, etc. • Eliminate pests and conditions that promote breeding of pests
Major Maintenance	• Remove dead, diseased, or dying trees and woody vegetation that interfere with facility maintenance • Correct problems associated with berm settlement • Repair berm/dike breaches and stabilize eroded parts of the berm • Repair and rebuild spillway as needed to reverse the effects of severe erosion • Remove sediment build up in forebay and main basin area • Re-grade main basin bottom to restore bottom slope • Aerate compacted areas to promote infiltration if volume reductions are desired • Repair or replace gates, fences, flow control structures, and inlet/outlet structures as needed to maintain full functionality

Cost

Costs provided below are reference estimates only. Site-specific conditions and design choices can significantly impact implementation costs.

Table 2: Dry Extended Detention Basin Implementation and Maintenance Costs

COST PER AREA SERVED (Area Served < 3 acres)				COST PER AREA SERVED (Area Served > 3 acres)			
New Construction	Retrofit	Annual Minor Maint.	Annual Major Maint.	New Construction	Retrofit	Annual Minor Maint.	Annual Major Maint.
$ 29,200	$ 58,800	$ 573	$ 512	$ 9,700	$ 19,500	$ 270	$ 209

Note: The costs provided in the table above will not scale linearly with changes in area served and will vary significantly with changes in design assumptions and site specific conditions. *These costs are subject to change as the Project Team discusses and refines the assumptions used to develop them.*
*Annual major maintenance cost based on assumed major maintenance task frequencies ranging from 1 to 50 years

Related DOT Guidance

CA	www.dot.ca.gov/hq/oppd/stormwtr/ppdg/swdr2012/PPDG-May-2012.pdf
GA	www.georgiastormwater.com/
ID	http://itd.idaho.gov/enviro/Stormwater/BMP/default.htm
MA	http://www.mhd.state.ma.us/downloads/projDev/2009/MHD_Stormwater_Handbook.pdf
NJ	nj.gov/dep/stormwater/bmp_manual2.htm
NV	http://www.nevadadot.com/uploadedFiles/NDOT/About_NDOT/NDOT_Divisions/Engineering/Hydraulics/2006_PlanningAndDesignGuide.pdf
OH	http://www.dot.state.oh.us/Divisions/Engineering/Hydraulic/LandD/Pages/TableofContents.aspx
OR	ftp://ftp.odot.state.or.us/techserv/geo-environmental/Hydraulics/Hydraulics%20Manual/Table_of_Contents_rev_Nav.pdf and http://www.oregon.gov/ODOT/HWY/OOM/mg/02/act125_waterqualityfacilandtables.pdf
PA	ftp://ftp.dot.state.pa.us/public/bureaus/design/PUB584/PDM-TOC.pdf
RI	http://www.dem.state.ri.us/programs/benviron/water/permits/ripdes/stwater/t4guide/desman.htm
TX	http://ftp.dot.state.tx.us/pub/txdot-info/library/pubs/bus/storm_water/5sedimentationcontrol.pdf
WA	http://www.wsdot.wa.gov/publications/manuals/fulltext/M31-16/HighwayRunoff.pdf

Additional Resources

Cahill Associates, Inc. Pennsylvania Stormwater Best Management Practices Manual. 2006. http://www.elibrary.dep.state.pa.us/dsweb/View/Collection-8305

City of Portland, Oregon. Stormwater Management Manual. 2008. http://www.portlandonline.com/bes/index.cfm?c=47953&

Coastal Georgia Regional Development Center. Green Growth Guidelines. 2006. http://coastalgadnr.org/cm/green/guide

Nashville, Tennessee. Stormwater Management Manual, Volume 4. 2009. http://www.nashville.gov/stormwater/regs/SwMgt_ManualVol04_2009.asp

U.S. EPA. National Menu of Stormwater Best Management Practices. http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm

Legend	
H/M/L	High/Medium/Low effectiveness relative to other BMPs

TYPICAL PROPERTIES	
Location	Surface
Popularity	High
Longevity	High
Primary constraint	Space

PRIMARY FUNCTION(S)	
M	Water Quality Improvement
L	Volume Control
L	Peak Reduction
L	Flow Duration Control

COST	
L	Capital Cost
L	Minor Maintenance Cost
L	Major Maintenance Cost
H	Maintenance Frequency

FILTER STRIPS

Filter strips are vegetated surfaces that are designed to provide treatment for sheet flows from adjacent surfaces. Filter strips decrease runoff velocity, filter out total suspended solids and associated pollutants, and provide some infiltration into underlying soils. The primary unit treatment processes at work in filter strips are straining and filtration through the vegetation and growing media of the filter strip. Other unit processes include shallow sedimentation, volume reduction, biochemical processes and plant uptake. Filter strips should typically be used as pre-treatment and not as standalone BMPs unless site conditions are conducive and/or design modifications are made to enhance the level of treatment that is provided. Since filter strips are most effective when incoming stormwater runoff is delivered as shallow sheet flow, flow spreaders and careful design and construction may be required to ensure sheet flow loading of filter strips achieves its purpose.

Where should a filter strips be used?

Due to their simplicity and low cost, filter strips are well suited to treating runoff from roads and highways, small parking lots (such as rest areas), and other impervious surfaces. Filter strips are also good for use as vegetated buffers between developed areas and natural drainages. Again, filter strips are typically intended for pre-treatment and not as standalone BMPs.

Table 1: Site Suitability Guidelines for Filter Strips

TARGET CONSTITUENTS	
H	Sediment
M	Metals
L	Organics
L	Nutrients
L	Bacteria
L	Trash and debris
H	Oil and grease

UNIT PROCESSES	
L	Volume reduction
L	Gravity separation
M	Media filtration & sorption
H	Vegetative filtration
M	Plant uptake & microbial transformations

CONSTRAINTS	
H	Surface space req.
L	Subsurface space req.
L	Hydraulic head req.
L	Water table req.
L	Soil permeability req.
H	Public acceptance
M	Steep slopes / stability

ENHANCEMENTS / VARIATIONS
Flow spreaders
Compost amendments

Tributary Area	< 2 acres
Typical BMP area as percentage of tributary area	>5 %[1]
Site slope	2-6% in flow direction; 4% maximum slope in lateral direction [2] recommended
Depth to seasonally high groundwater table	> 2 ft
Hydrologic soil group	Any[3]

1 – Tributary area is the area of the site draining to the BMP. The maximum recommended length of tributary area in the direction of flow is 150'. Tributary areas can be larger or smaller in some instances.
2 – If site slope exceeds value specified or if site is within 200 ft from the top of a hazardous slope or landslide area, a geotechnical investigation is recommended.
3 – Filter strips are not recommended in areas with highly erodible soils.

Variations and Enhancements

Enhancements that overcome site constraints, maximize contact time, aid in trapping and securing pollutants or facilitate volume reduction are the main categories of enhancements and design variations that are available for filter strips. Flow spreaders that help distribute flows evenly across the entire width of the filter strip are key components that are highly recommended. Flow spreaders can be designed as shallow infiltration trenches that promote interflow through the shallow soils below the filter strip for improved volume reduction and filtration of pollutants. Amended soils may also be included in the design to provide additional sorption sites, support plant growth, and improve volume reduction and drainage properties of the filter strip.

Advantages and Benefits

- Excellent choice as a pre-treatment BMP
- Simple design and construction
- Low profile and aesthetically pleasing
- Low cost and low maintenance requirements

Risks and Limitations

- Need to be sited adjacent to impervious surfaces to receive sheet flows.
- Poor soils not capable of supporting vegetation will need amendments

Sizing and Design Considerations

- Size filter strip width and slopes to handle the design flow rate such that flow in the filter strip does not exceed 1 inch or 1 ft/sec.
- Recommended grass height is 2 to 4 inches.
- Recommended minimum length in the direction of flow is 15 feet (25 feet preferred) and maximum length is 150 feet.
- Recommended slope of the filter strip in the direction of flow is between 2% and 6%.

Construction Considerations

- If infiltration is considered desirable minimize the use of heavy machinery on the filter strip area. If compaction occurs, re-grade and vegetate.
- Provide energy dissipation and a flow spreader at each concentrated inlet point (e.g., curb cuts). Sheet flow inputs along the length of the filter strip do not require energy dissipation.
- Low permeability soils should be amended to facilitate infiltration and promote plant growth.
- Avoid using treated wood or galvanized metals.

Inspection and Maintenance

Inspection	• At a minimum, inspect twice per year (preferably in spring and fall) in the first year following construction and annually thereafter.
Routine Maintenance	• Remove trash and debris • Maintain vegetation as frequently as needed to preserve aesthetics and safety • Remove visible floatables such as oil and grease • Clean and reset flow spreaders as needed to maintain even distribution of low flows • Remove minor sediment accumulation, and obstructions near inlet and outlet structures as needed • Re-seed and restore patches of vegetation as needed
Major Maintenance	• Re-grade filter strip to restore slope both in the direction of flow and in the direction perpendicular to flow • Aerate compacted areas restore infiltration capacity • Re-vegetate filter strip

Cost

Cost information provided below are reference estimates only. Site specific conditions and design choices can significantly impact implementation costs.

Table 2: Filter Strip Implementation and Maintenance Costs

COST PER AREA SERVED (Area Served < 3 acres)				COST PER AREA SERVED (Area Served > 3 acres)			
New Construction	Retrofit	Annual Minor Maint.	*Annual Major Maint.	New Construction	Retrofit	Annual Minor Maint.	*Annual Major Maint.
$ 11,147	$ 30,940	$ 491	$ 135	$ 1,890	$ 5,247	$ 246	$ 88

Note: The costs provided in the table above will not scale linearly with changes in area served and will vary significantly with changes in design assumptions and site specific conditions. *These costs are subject to change as the Project Team discusses and refines the assumptions used to develop them*.

*Annual major maintenance cost based on assumed major maintenance task frequencies ranging from 1 to 3 years

Related DOT Guidance

AZ	www.azdot.gov/Inside_ADOT/OES/Water_Quality/Stormwater/PDF/adot_post_construction_bmp_manual.pdf
CA	www.dot.ca.gov/hq/oppd/stormwtr/ppdg/swdr2012/PPDG-May-2012.pdf
DE	http://www.dnrec.state.de.us/DNREC2000/Divisions/Soil/Stormwater/New/GT_Stds%20%26%20Specs_06-05.pdf
GA	www.georgiastormwater.com/
ID	http://itd.idaho.gov/enviro/Stormwater/BMP/default.htm
MA	http://www.mhd.state.ma.us/downloads/projDev/2009/MHD_Stormwater_Handbook.pdf
NJ	nj.gov/dep/stormwater/bmp_manual2.htm
NV	http://www.nevadadot.com/uploadedFiles/NDOT/About_NDOT/NDOT_Divisions/Engineering/Hydraulics/2006_PlanningAndDesignGuide.pdf
NY	www.dec.ny.gov/chemical/29072.html
OH	http://www.dot.state.oh.us/Divisions/Engineering/Hydraulic/LandD/Pages/TableofContents.aspx
OR	ftp://ftp.odot.state.or.us/techserv/geo-environmental/Hydraulics/Hydraulics%20Manual/Table_of_Contents_rev_Nav.pdf and http://www.oregon.gov/ODOT/HWY/OOM/mg/02/act125_waterqualityfacilandtables.pdf
PA	ftp://ftp.dot.state.pa.us/public/bureaus/design/PUB584/PDM-TOC.pdf
RI	http://www.dem.state.ri.us/programs/benviron/water/permits/ripdes/stwater/t4guide/desman.htm
TX	http://ftp.dot.state.tx.us/pub/txdot-info/library/pubs/bus/storm_water/5sedimentationcontrol.pdf
WA	http://www.wsdot.wa.gov/publications/manuals/fulltext/M31-16/HighwayRunoff.pdf

Additional Resources

Cahill Associates, Inc. Pennsylvania Stormwater Best Management Practices Manual. 2006. http://www.elibrary.dep.state.pa.us/dsweb/View/Collection-8305

City of Austin, TX, 1988. Water Quality Management. Environmental Criteria Manual. Environmental and Conservation Services.

Claytor, R.A., and T.R. Schueler. 1996. Design of Stormwater Filtering Systems. The Center for Watershed Protection, Silver Spring, MD.

Coastal Georgia Regional Development Center. Green Growth Guidelines. 2006. http://coastalgadnr.org/cm/green/guide

Legend	
H/M/L	High/Medium/Low effectiveness relative to other BMPs

TYPICAL PROPERTIES	
Location	**Surface/Subsurface**
Popularity	**Medium**
Longevity	**Medium**
Primary constraint	**Soils**

PRIMARY FUNCTION(S)	
H	**Water Quality Improvement**
H	**Volume Control**
M	**Peak Reduction**
H	**Flow Duration Control**

COST	
M	**Capital Cost**
M	**Minor Maintenance Cost**
H	**Major Maintenance Cost**
M	**Maintenance Frequency**

INFILTRATION FACILITES

For the purposes of this factsheet, infiltration facilities include infiltration /exfiltration trenches, galleries and basins. Infiltration facilities are stormwater management controls that provide storage to capture and hold stormwater runoff and allow it to infiltrate into the surrounding native soils. The primary unit treatment process at work in infiltration facilities are infiltration, filtration and shallow sedimentation. Other unit processes include biochemical processes, microbial transformations, and plant uptake for vegetated systems.

Infiltration trenches are typically long narrow, relatively shallow gravel and sand filled trenches while infiltration basins are typically a shallow basin with a permeable bed typically consisting of media such as sand and aggregate installed over permeable native soils. Infiltration basins store stormwater runoff in the basin on top of the media as well as in the pore spaces of the media and aggregate layers. Infiltration trenches on the other hand typically have little or no storage above the media and utilize the pore spaces of the media and gravel in the trench to hold stormwater for infiltration. Infiltration facilities provide excellent reduction of pollutant loads since the pollutants loads in stormwater runoff that is infiltrated are effectively removed from the surface drainage system.

Where should an infiltration facility be used?

Infiltration basins are typically used as part of a centralized end-of-pipe treatment train while infiltration trenches can be placed around the perimeters of parking lots and along road shoulders. Pre-treatment using filter strips and other coarse sediment removal BMPs is recommended to prevent clogging.

TARGET CONSTITUENTS	
L	Sediment
H	Metals
H	Organics
H	Nutrients
H	Bacteria
H	Trash and debris
H	Oil and grease

UNIT PROCESSES	
H	Volume reduction
L	Gravity separation
H	Media filtration & sorption
L	Vegetative filtration
L	Plant uptake & microbial transformations

CONSTRAINTS	
M	Surface space req.
M	Subsurface space req.
L	Hydraulic head req.
H	Water table req.
H	Soil permeability req.
L	Public acceptance
M	Steep slopes / stability

ENHANCEMENTS / VARIATIONS
Flow spreaders
Engineered media
Vegetation

Infiltration facility use within the ROW must be carefully planned to minimize damage to the road subgrade from infiltrated runoff.

Table 1: Site Suitability Guidelines for Infiltration Facilities

Tributary Area	< 5 acres
Typical BMP area as percentage of tributary area	>5 %[1]
Proximity to steep sensitive slopes	Not recommended on slopes steeper than 15% or within 50 feet of a steep slope or landslide hazard area.
Depth to seasonally high groundwater table	> 5 ft
Hydrologic soil group	A and B soils or if measured infiltration rate is > 2 inches per hour

1 – Tributary area is the area of the site draining to the BMP. Tributary areas can be larger or smaller in some instances.

Variations and Enhancements

Enhancements and design variations that overcome site constraints, improve infiltration rate, delay or prevent clogging, maximize contact time, and aid in trapping and securing pollutants are available for infiltration facilities. Flow spreaders that help distribute flows evenly across the entire width of the infiltration facility are highly recommended for infiltration basins. The use of vegetation whenever possible is recommended to help prevent the formation of crusts on the surface of the infiltration facility, which impedes percolation of captured runoff. Engineered media may also be included in the design to provide additional sorption sites, support plant growth, target specific pollutants, and improve volume reduction and drainage properties of the infiltration facility.

Advantages and Benefits

- Less frequent maintenance than many other BMPs
- Suspended solids and particulate-bound pollutant removal
- Volume reduction, peak flow reduction and flow duration control are provided
- Removal of dissolved pollutants that may be hard to treat with other options
- Typically have relatively small footprints
- Easily integrated into existing development

Risks and Limitations

- Increased risk to groundwater if proper treatment is not provided prior to infiltration
- Susceptible to clogging if proper pre-treatment is not provided
- Infiltrating too close to the road subgrade can impact longevity of the road
- Requires permeable soils
- Not recommended for areas with high groundwater table

Sizing and Design Considerations

- Infiltration facilities are not recommended for use as sediment control facilities.

- The bottom of infiltration facility bed should be native soil, over-excavated to at least one foot in depth and replaced uniformly without compaction. Amending the excavated soil with 2-4 inches (~15-30%) of coarse sand is recommended.
- Minimum recommended infiltration trench width is 24 inches
- Recommended maximum infiltration facility bottom slope is 3% for infiltration trenches and less than 1% for infiltration basins.
- If underdrains are provided, they should preferably be made of slotted pipe. As compared to round-hole perforated pipe, slotted underdrains provide greater intake capacity, clog resistant drainage, and reduced entrance velocity into the pipe, thereby reducing the chances of solids migration.

Construction Considerations

- Minimize the use of heavy machinery on the bottom of the infiltration facility. If the use of heavy equipment on the base of the facility cannot be avoided, the infiltrative capacity should be restored by tilling or aerating prior to placing the infiltrative bed.
- If no underdrains are provided, the exposed soils should be inspected by a civil engineer or geologist after excavation to confirm that soil conditions are suitable.
- For infiltration basins, provide energy dissipation and a flow spreader at each concentrated inlet point (e.g., curb cuts). Sheet flow inputs along the length of infiltration trenches do not require energy dissipation.
- Low permeability soils should be amended to facilitate infiltration and promote plant growth.
- Avoid using treated wood or galvanized metals.

Inspection and Maintenance

Inspection	• At a minimum, inspection within the first 3 months following the completion of construction and twice per year thereafter is recommended.
Routine Maintenance	• Remove trash and debris • Maintain vegetation as needed, if present in facility. • Clean and reset flow spreaders as needed to maintain even distribution of low flows • Remove sediment accumulation and obstructions near inlet/outlet structures as needed • Eliminate vectors and conditions that promote vectors • Breakup surface crust (if present); add vegetation if appropriate to limit crust formation • Periodically observe function under wet weather conditions
Major Maintenance	• Remove top layer and sediment capture layer (i.e., sand and choking stone layer or geotextile fabric). If slow draining conditions persist, entire trench or basin may need to be excavated and replaced • Repair or replace tears in geotextile or filter fabric (if present)

Cost

Costs provided below are reference estimates only and are based on implementation costs of sand filters. Site-specific conditions and design choices can significantly affect implementation costs.

Table 2: Infiltration Facility Implementation and Maintenance Costs

COST PER AREA SERVED (Area Served < 3 acres)				COST PER AREA SERVED (Area Served > 3 acres)			
New Construction	Retrofit	Minor Maint.	Major Maint.	New Construction	Retrofit	Minor Maint.	Major Maint.
$ 88,000	$ 113,800	$ 573	$ 89	$ 48,100	$ 62,300	$ 246	$ 45

Note: The costs provided in the table above will not scale linearly with changes in area served and will vary significantly with changes in design assumptions and site specific conditions. *These costs are subject to change as the Project Team discusses and refines the assumptions used to develop them.*

*Annual major maintenance cost based on assumed major maintenance task frequencies ranging from 1 to 40 years

Related DOT Guidance

AZ	www.azdot.gov/Inside_ADOT/OES/Water_Quality/Stormwater/PDF/adot_post_construction_bmp_manual.pdf
CA	www.dot.ca.gov/hq/oppd/stormwtr/ppdg/swdr2012/PPDG-May-2012.pdf
DE	http://www.dnrec.state.de.us/DNREC2000/Divisions/Soil/Stormwater/New/GT_Stds%20%26%20Specs_06-05.pdf
GA	www.georgiastormwater.com/
ID	http://itd.idaho.gov/enviro/Stormwater/BMP/default.htm
MA	http://www.mhd.state.ma.us/downloads/projDev/2009/MHD_Stormwater_Handbook.pdf
MD	http://www.mde.state.md.us/programs/Water/StormwaterManagementProgram/SoilErosionandSedimentControl/Documents/MD%20SWM%20Volume%201.pdf
NJ	nj.gov/dep/stormwater/bmp_manual2.htm
NV	http://www.nevadadot.com/uploadedFiles/NDOT/About_NDOT/NDOT_Divisions/Engineering/Hydraulics/2006_PlanningAndDesignGuide.pdf
NY	www.dec.ny.gov/chemical/29072.html
OH	http://www.dot.state.oh.us/Divisions/Engineering/Hydraulic/LandD/Pages/TableofContents.aspx
PA	ftp://ftp.dot.state.pa.us/public/bureaus/design/PUB584/PDM-TOC.pdf
RI	http://www.dem.state.ri.us/programs/benviron/water/permits/ripdes/stwater/t4guide/desman.htm
WA	http://www.wsdot.wa.gov/publications/manuals/fulltext/M31-16/HighwayRunoff.pdf

Additional Resources

Cahill Associates, Inc. Pennsylvania Stormwater Best Management Practices Manual. 2006. http://www.elibrary.dep.state.pa.us/dsweb/View/Collection-8305

City of Portland, Oregon. Stormwater Management Manual. 2008. http://www.portlandonline.com/bes/index.cfm?c=47953&

Coastal Georgia Regional Development Center. Green Growth Guidelines. 2006. http://coastalgadnr.org/cm/green/guide

Nashville, Tennessee. Stormwater Management Manual, Volume 4. 2009. http://www.nashville.gov/stormwater/regs/SwMgt_ManualVol04_2009.asp

U.S. EPA. National Menu of Stormwater Best Management Practices. http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm

Virginia Department of Conservation and Recreation. (1999) Virginia Stormwater Management Handbook. Division of Soil and Water Conservation. http://www.dcr.virginia.gov/stormwater_management/documents/Chapter_3-10.pdf

Legend	
H/M/L	High/Medium/Low effectiveness relative to other BMPs

TYPICAL PROPERTIES	
Location	**Surface / Subsurface**
Popularity	**High**
Longevity	**Durable**
Primary constraint	**Space**

PRIMARY FUNCTION(S)	
H	**Water Quality Improvement**
L	**Volume Control**
M	**Peak Reduction**
L	**Flow Duration Control**

COST	
M	**Capital Cost**
L	**Minor Maintenance Cost**
H	**Major Maintenance Cost**
L	**Maintenance Frequency**

MEDIA BED FILTERS

Media bed filters can be installed as surface or subsurface features. They treat stormwater runoff via sedimentation, entrapment, and straining of solids. Other unit treatment processes include filtration, sorption, precipitation, ion exchange and biochemical processes, depending on the media used. Media bed filters typically include a constructed media bed that receives water at the surface and allows it to pond on the surface if inflows exceed the rate of percolation through the bed. A system of connected underdrain pipes under the media bed collect and route flows that have percolated through the media bed to the outlet. Both engineered media and sand can be used, depending on the pollutants of concern. Commonly used media include sand, compost, zeolite, activated carbon, peat, and blended combinations of such media. Sand is often used in media bed filters because of cost and availability. Media bed filters can be categorized as 1) surface media bed filters, which are surface installed, open air structures, 2) perimeter media bed filters, which are typically enclosed systems installed just below grade around the perimeter of an impervious area such as a parking lot, and 3) underground media bed filters, which are deployed in underground vaults typically for extremely space-limited applications.

<u>Where should a media bed filter be used?</u>

Media bed filters are versatile stormwater treatment BMPs with few constraints that can be used in wide variety of applications. The primary constraints for media bed filters are space and the availability of hydraulic head to drive flows

TARGET CONSTITUENTS	
H	Sediment
H	Metals
L	Organics
M	Nutrients
M	Bacteria
H	Trash and debris
M	Oil and grease

UNIT PROCESSES	
L	Volume reduction
M	Gravity separation
H	Media filtration & sorption
H	Vegetative filtration
L	Plant uptake & microbial transformations

CONSTRAINTS	
M	Surface space req.
M	Subsurface space req.
H	Hydraulic head req.
L	Water table req.
L	Soil permeability req.
L	Public acceptance
L	Steep slopes / stability

ENHANCEMENTS / VARIATIONS
Engineered Media
Under drains
Impermeable Liner
Outlet modifications
Vegetation

through the media bed to the outlet while allowing the entire media bed to drain. Several design options and design variations exist for overcoming typical site constraints such as lack of surface space, shallow ground water, soil permeability, steep slopes, etc.

Table 1: Site Suitability Guidelines for Media Bed Filters

Tributary Area	< 10 acres for surface media filter, < 2 acres for perimeter media filter, and < 1 acre for underground media filter
Typical BMP area as percentage of tributary area (including settling chamber)	2% to 4%
Proximity to steep sensitive slopes	If system is fully contained and includes a liner, underdrain system, and overflow to a storm drain system, then slopes may exceed 15%.
Depth to seasonally high groundwater table	> 2 feet with underdrains > 10 feet without underdrains
Hydrologic soil group	Any
Unsuitable locations	Media filters should not be placed within 200 feet of drinking water wells if media filter does not have an underlying impermeable liner or is not contained within a concrete vault.

[1] Tributary area is the area of the site draining to the BMP. Tributary areas provided here should be used as a general guideline only.

Variations and Enhancements

Enhancements and design variations that overcome site constraints, target specific pollutants, and increase flow rates and resistance to clogging are available for media filters. Typical enhancements and design variations include:

- Media enhancements – blended media with specific properties to increase flow rates, minimize clogging, promote surface vegetation growth, and provide removal of target pollutants
- Impermeable liner – an impermeable liner can be added to the design to mitigate the effect of poor / saturated native soils, and protect ground water for sites with shallow ground water (less than 4 feet below the surface)
- Subsurface installation – for highly constrained sites, the media bed filter can be installed in an underground vault to avoid surface conflicts
- Outlet modifications – perforated risers and orifice plates can be used to provide increased contact time as needed to target specific pollutants
- Vegetation – plantings on the surface of the media bed can prevent the development of a crust which can limit percolation of influent flows into the media bed.
- Baffles / dividers / spreaders – These can help distribute flows evenly to prevent the development of preferential flow paths in the media and allow the entire media bed to be used.
- Design variations – well-known design variations include the Austin sand filter, the Washington D.C. sand filter, and the Delaware sand filter. Primary differences lie in the location (above/below ground), space requirements, surface areas, and quantity of runoff treated.

Advantages and Benefits

- Many optional enhancements and design variations to overcome site constraints and target specific pollutants.
- Good retrofit suitability
- Efficient removal of particulate pollutants

Risks and Limitations

- Subsurface installations are out of sight and therefore prone to neglect
- Potentially high maintenance burden due to clogging if proper pretreatment is not provided
- Requires adequate vertical relief to avoid permanently saturated media bed
- Requires proximity to storm drains to route flows to and from media bed
- Little or no volume reduction
- Susceptible to short circuiting and bio-fouling if not properly designed

Sizing and Design Considerations:

- Recommended forebay size is 20 – 25% of total volume if no other pretreatment is provided
- Recommended minimum media filter bed depth is 24 inches (36 inches or more preferred)
- Longitudinal slope along length of filter bed should not exceed 2%
- Recommended maximum ponding depth above filter bed is 3 feet
- Underdrain pipe should have a minimum diameter of 6 inches and 0.5% minimum slope.

Construction Considerations

- Sheet flow inputs along the perimeter of a surface media bed filter do not require energy dissipation but may require pre-treatment for the removal of fines.
- If infiltration is desired, minimize the use of heavy machinery on the media filter bed bottom and omit the impermeable liner.
- Avoid using treated wood or galvanized metals.

Inspection and Maintenance

Inspection	• At a minimum, inspect within 24 hours of every rain storm greater than 0.10 inches within first few months following the completion of construction and twice per year thereafter
Routine Maintenance	• Remove trash and debris • Perform minor structural repairs to inlet/outlet structures • Clean and reset flow spreaders as needed to maintain even distribution of low flows • Remove minor sediment accumulation, debris and obstructions near inlet and outlet structures as needed
Major Maintenance	• Scrape top 2 - 4 inches of media and replace with new media to restore filtration rate. Deeper scraping may be needed if fine particulates are found below the top layer. • Clean underdrain and outlet piping to alleviate surface ponding • Replace media if ponding or loss of infiltrative capacity persists • Repair damage to flow control structures including inlet, outlet and overflow structures

Cost

Cost provided below are reference estimates only based on sand filter costs. Site-specific conditions and design choices can significantly impact implementation costs.

Table 2: Media Bed Filter Implementation and Maintenance Costs

COST PER AREA SERVED (Area Served < 3 acres)				COST PER AREA SERVED (Area Served > 3 acres)			
New Construction	Retrofit	Annual Minor Maint.	*Annual Major Maint.	New Construction	Retrofit	Annual Minor Maint.	*Annual Major Maint.
$ 88,000	$ 113,800	$ 359	$ 238	$ 48,100	$ 62,300	$ 126	$ 81

Note: The costs provided in the table above will not scale linearly with changes in area served and will vary significantly with changes in design assumptions and site specific conditions. *These costs are subject to change as the Project Team discusses and refines the assumptions used to develop them*.

*Annual major maintenance cost based on assumed major maintenance task frequencies ranging from 1 to 35 years

Related DOT Guidance

AZ	www.azdot.gov/Inside_ADOT/OES/Water_Quality/Stormwater/PDF/adot_post_construction_bmp_manual.pdf
CA	www.dot.ca.gov/hq/oppd/stormwtr/ppdg/swdr2012/PPDG-May-2012.pdf
GA	www.georgiastormwater.com/
ID	http://itd.idaho.gov/enviro/Stormwater/BMP/default.htm
MA	http://www.mhd.state.ma.us/downloads/projDev/2009/MHD_Stormwater_Handbook.pdf
MD	http://www.mde.state.md.us/programs/Water/StormwaterManagementProgram/SoilErosionandSedimentControl/Documents/MD%20SWM%20Volume%201.pdf
NJ	nj.gov/dep/stormwater/bmp_manual2.htm
NY	www.dec.ny.gov/chemical/29072.html
OR	ftp://ftp.odot.state.or.us/techserv/geo-environmental/Hydraulics/Hydraulics%20Manual/Table_of_Contents_rev_Nav.pdf and http://www.oregon.gov/ODOT/HWY/OOM/mg/02/act125_waterqualityfacilandtables.pdf
RI	http://www.dem.state.ri.us/programs/benviron/water/permits/ripdes/stwater/t4guide/desman.htm
TX	http://ftp.dot.state.tx.us/pub/txdot-info/library/pubs/bus/storm_water/5sedimentationcontrol.pdf
WA	http://www.wsdot.wa.gov/publications/manuals/fulltext/M31-16/HighwayRunoff.pdf

Additional Resources

Cahill Associates, Inc. Pennsylvania Stormwater Best Management Practices Manual. 2006. http://www.elibrary.dep.state.pa.us/dsweb/View/Collection-8305

Claytor, R.A., and T.R. Schueler. 1996. Design of Stormwater Filtering Systems. The Center for Watershed Protection, Silver Spring, MD.

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Metropolitan Washington Council of Governments (MWCOG), March, 1992, "A Current Assessment of Urban Best Management Practices: Techniques for Reducing Nonpoint Source Pollution in the Coastal Zone".

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Legend	
H/M/L	High/Medium/Low effectiveness relative to other BMPs

TYPICAL PROPERTIES	
Location	Surface
Popularity	High
Longevity	Durable
Primary constraint	Space

PRIMARY FUNCTION(S)	
M	Water Quality Improvement
M	Volume Control
L	Peak Reduction
L	Flow Duration Control

COST	
M	Capital Cost
L	Minor Maintenance Cost
H	Major Maintenance Cost
L	Maintenance Frequency

SWALES

Biofiltration swales are vegetated stormwater conveyances that treat runoff by filtration, shallow sedimentation, and infiltration. Additional minor pollutant removal mechanisms include biochemical processes in the underlying planting media such as adsorption and microbial transformations of dissolved pollutants. If designed as on-line drainage system features capable of conveying peak flow rates, biofiltration swales can provide downstream channel and flood protection. However, on-line biofiltration swales are more vulnerable to re-suspension of captured sediment if not carefully designed and maintained. When properly incorporated into an overall site design, swales may reduce impervious cover, accent the natural landscape, and provide aesthetic benefits.

An effective biofiltration swale aims to provide uniform sheet flow through a densely vegetated area (bottom of swale) for a period of 5-9 minutes.

Where should a swale be used?

Vegetated swales rely on dense turf vegetation with a thick thatch, growing on a moderately permeable soil and are well suited to treat runoff from roads and highways, driveways, small parking lots, and other impervious surfaces. They are also good for use as vegetated buffers between impervious areas and natural drainages. These BMPs are typically intended for pre-treatment and not as a standalone BMP. Swales decrease runoff velocity, filter out sediment and associated pollutants, and provide some infiltration into underlying soils.

TARGET CONSTITUENTS	
H	Sediment
H	Metals
L	Organics
M	Nutrients
L	Bacteria
L	Trash and debris
M	Oil and grease

UNIT PROCESSES	
M	Volume reduction
M	Gravity separation
H	Media filtration & sorption
H	Vegetative filtration
H	Plant uptake & microbial transformations

PRIMARY CONSTRAINTS	
M	Surface space req.
NA	Subsurface space req.
M	Hydraulic head req.
L	Water table req.
L	Soil permeability req.
H	Public acceptance
M	Steep slopes / stability

ENHANCEMENTS / VARIATIONS
Amended soils
Under drains
Flow spreaders
Vegetated swales
Rock swales

Table 1: Site Suitability Guidelines for Vegetated Swales

Tributary Area	< 5 acres
Typical BMP area as percentage of tributary area	<1 %[1]
Site slope	2-6% longitudinal slope[2,3]
Depth to seasonally high groundwater table	< 5 feet use underdrains > 5 feet underdrain not required
Hydrologic soil group	Any[3]

1 - Tributary area is the area of the site draining to the BMP. Tributary areas provided here should be used as a general guideline only. Tributary areas can be larger or smaller in some instances.
2 - If the longitudinal slope of the vegetated swale exceeds 6%, check dams should be provided.
3 - If the vegetated swale is located within 10 feet from a structure, has a longitudinal slope less than 1.5% or has poorly drained soils (hydrologic soil groups “C” or “D”), underdrains should be incorporated.

Variations and Enhancements

Enhancements that maximize contact time, aid in trapping and securing of pollutants and assist with volume reduction are available for vegetated swales. Flow spreaders that distribute runoff evenly across the width of the vegetated swale are highly recommended. These flow spreaders may also be designed as infiltration trenches that promote increased interflow through the shallow soils for improved retention of runoff and filtration of pollutants. Amended soils may be added to provide additional sorption sites and help support plant growth. Soil amendments can also help to increase evapotranspiration and infiltration losses.

Advantages and Benefits of vegetated swales

- Good treatment performance for suspended solids and particulate-bound pollutants
- Simple design and construction
- Low hydraulic head requirements
- Relatively low capital and maintenance costs

Risks and Limitations of vegetated swales

- Limited removal of dissolved constituents
- Not suited for treating very large areas
- Shallow grades may lead to ponding
- Poor soils not capable of supporting vegetation will need amendments
- Shaded areas may impact vegetation growth

Sizing and Design Considerations

- Size width and side-slopes to handle the design flow rate such that flow depths in the vegetated swale do not exceed a recommended depth of 4 inches. Ideally flows should beat least 2 inches less than grass height.
- Recommended longitudinal slope of the vegetated swale is between 1% and 6%
- Design flow velocity should not exceed 1 ft/s to keep the vegetation upright

Construction Considerations

- Provide energy dissipation and a flow spreader at each concentrated inlet point. Sheet flow inputs along the length of the vegetated swale do not require energy dissipation.
- If infiltration is considered desirable, minimize the use of heavy machinery on the vegetated swale bottom area. If compaction occurs, re-grade and vegetate.
- Low permeability soils should be amended to facilitate infiltration and promote plant growth.
- Avoid using treated wood or galvanized metals.

Inspection and Maintenance

Inspection	• At a minimum, inspection twice per year (preferably in spring and fall) in the first year following construction and annually thereafter is recommended.
Routine Maintenance	• Maintain vegetation as frequently as needed to preserve aesthetics and safety • Remove trash and debris • Remove visible floatables such as oil and grease • Remove minor sediment accumulations
Major Maintenance	• Re-grade vegetated swale to restore design longitudinal bottom slope • Aerate compacted areas to restore infiltration capacity

Cost

Implementation cost per acre treated is significantly larger for small projects treating 3-acres or less and for retrofit situations. Site-specific conditions and design choices can significantly impact implementation costs.

Table 2: Swale Implementation and Maintenance Costs

COST PER AREA SERVED (Area Served < 3 acres)				COST PER AREA SERVED (Area Served > 3 acres)			
New Construction	Retrofit	Annual Minor Maint.	*Annual Major Maint.	New Construction	Retrofit	Annual Minor Maint.	*Annual Major Maint.
$ 19,499	$ 37,460	$ 491	$ 258	$ 2,287	$ 4,394	$ 246	$ 182

Note: The costs provided in the table above will not scale linearly with changes in area served and will vary significantly with changes in design assumptions and site specific conditions. *These costs are subject to change as the Project Team discusses and refines the assumptions used to develop them*.

*Annual major maintenance cost based on assumed major maintenance task frequencies ranging from 1 to 30 years

Related DOT Guidance

AZ	www.azdot.gov/Inside_ADOT/OES/Water_Quality/Stormwater/PDF/adot_post_construction_bmp_manual.pdf
CA	www.dot.ca.gov/hq/oppd/stormwtr/ppdg/swdr2012/PPDG-May-2012.pdf
DE	http://www.dnrec.state.de.us/DNREC2000/Divisions/Soil/Stormwater/New/GT_Stds%20%26%20Specs_06-05.pdf
GA	www.georgiastormwater.com/
ID	http://itd.idaho.gov/enviro/Stormwater/BMP/default.htm
MA	http://www.mhd.state.ma.us/downloads/projDev/2009/MHD_Stormwater_Handbook.pdf
MD	http://www.mde.state.md.us/programs/Water/StormwaterManagementProgram/SoilErosionandSedimentControl/Documents/MD%20SWM%20Volume%201.pdf
NV	http://www.nevadadot.com/uploadedFiles/NDOT/About_NDOT/NDOT_Divisions/Engineering/Hydraulics/2006_PlanningAndDesignGuide.pdf
NY	www.dec.ny.gov/chemical/29072.html
PA	ftp://ftp.dot.state.pa.us/public/bureaus/design/PUB584/PDM-TOC.pdf
RI	http://www.dem.state.ri.us/programs/benviron/water/permits/ripdes/stwater/t4guide/desman.htm
TX	http://ftp.dot.state.tx.us/pub/txdot-info/library/pubs/bus/storm_water/5sedimentationcontrol.pdf
WA	http://www.wsdot.wa.gov/publications/manuals/fulltext/M31-16/HighwayRunoff.pdf

Additional Resources

Cahill Associates, Inc. Pennsylvania Stormwater Best Management Practices Manual. 2006. http://www.elibrary.dep.state.pa.us/dsweb/View/Collection-8305

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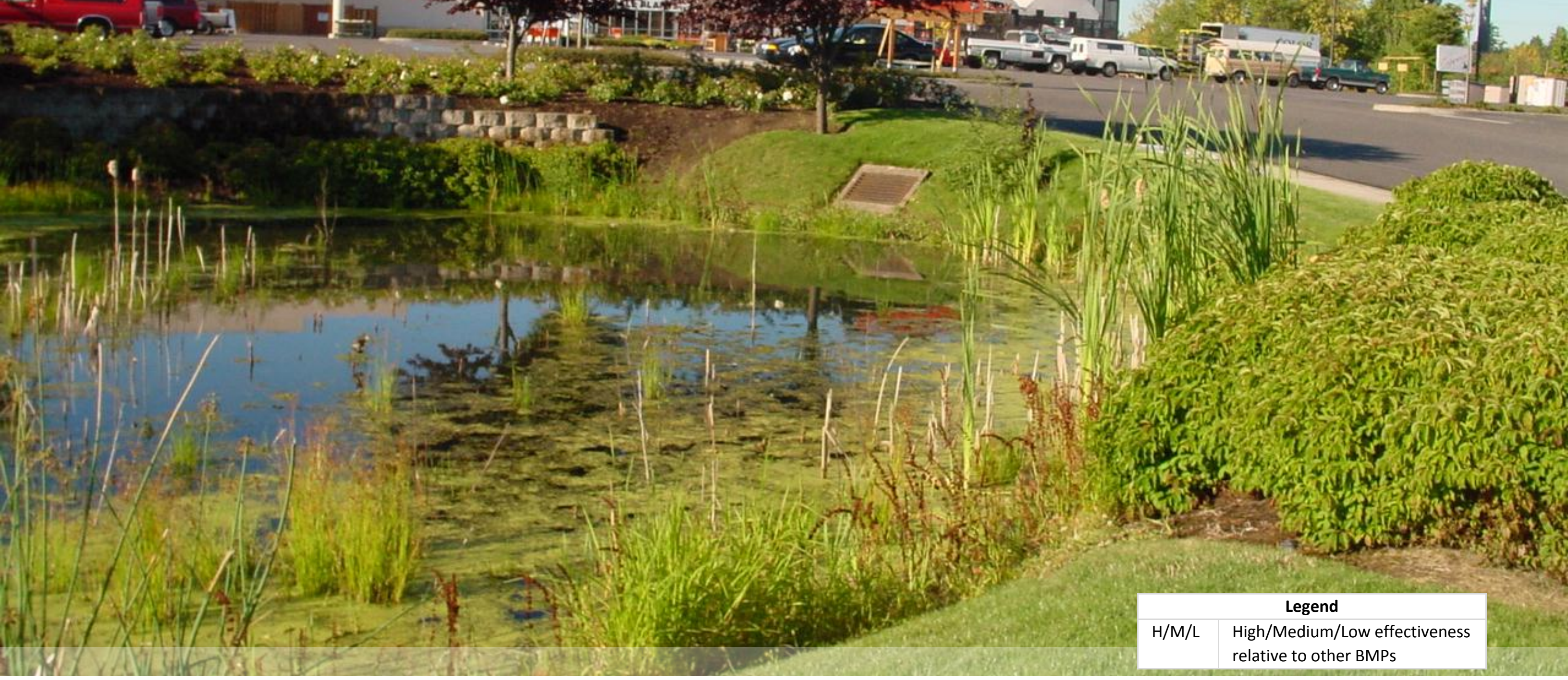


Legend	
H/M/L	High/Medium/Low effectiveness relative to other BMPs

TYPICAL PROPERTIES	
Location	**Surface**
Popularity	**High**
Longevity	**High**
Primary constraint	**Space**

PRIMARY FUNCTION(S)	
H	**Water Quality Improvement**
L	**Volume Control**
L	**Peak Reduction**
L	**Flow Duration Control**

COST	
H	**Capital Cost**
M	**Minor Maintenance Cost**
H	**Major Maintenance Cost**
L	**Maintenance Frequency**

WET POND

Wet ponds (a.k.a. retention basins) are constructed, naturalistic ponds with a permanent or seasonal pool of water (also called “wet pool” or “dead storage”). Aquascape facilities, such as artificial lakes, are a special form of wet ponds that can incorporate innovative design elements to allow them to function as a storm water treatment facility in addition to being an aesthetic water feature. Wet ponds require base flows to exceed or match losses through evaporation and/or infiltration and they should be designed with the outlet positioned and/or operated in such a way as to maintain a permanent pool. Wet ponds can be designed to provide extended detention (ED) of incoming flows using the volume above the permanent pool surface.

The benefits of wet ponds are similar to those of wetland basins and include peak flow attenuation (with ED), varying amounts of volume reduction, and pollutant removal. The main pollutant removal mechanism in wet ponds is sedimentation; other pollutant reduction processes occurring in wet ponds include adsorption and biochemical processes such as microbially-mediated transformations (e.g., biodegradation and precipitation) and plant uptake and storage. The permanent pool of water in the wet ponds improves treatment of fine particulates and associated pollutants and provides extended treatment of dry weather flows. Permanent pools also allow wet ponds to be designed as aesthetically pleasing water features with additional recreational, wildlife habitat, and educational benefits. A well-designed wet pond provides improved water quality treatment by increasing the average hydraulic residence time of storm water in the facility.

Wet ponds work best when the water already present in the permanent pool is

TARGET CONSTITUENTS	
H	Sediment
H	Metals
M	Organics
M	Nutrients
M	Bacteria
L	Trash and debris
M	Oil and grease

UNIT PROCESSES	
L	Volume reduction
H	Gravity separation
L	Media filtration & sorption
L	Vegetative filtration
H	Plant uptake & microbial transformations

PRIMARY CONSTRAINTS	
M	Surface space req.
M	Subsurface space req.
L	Hydraulic head req.
L	Water table req.
L	Soil permeability req.
M	Public acceptance
H	Steep slopes / stability

ENHANCEMENTS / VARIATIONS
Impermeable Liners
Internal berms/baffles
Water supply
Aeration/circulation

displaced by incoming flows with minimal mixing and no short-circuiting. Short-circuiting occurs when quiescent areas or “dead zones” develop in the basin where pockets of water remain stagnant, causing incoming storm water to bypass these zones. Longer residence times (and thus better water quality) are achieved when the permanent wet pool volume is greater than or equal to the water quality design volume.

Where should a wet pond be used?

Wet ponds can be applied to any location where sufficient space is available to treat larger tributary areas. Wet ponds require base flows (at least seasonally) and they should be designed operated in such a way as to maintain a permanent pool.

Table 1: Site Suitability Guidelines for Wet Ponds

Tributary Area	> 10 acres
Typical BMP area as percentage of tributary area	2-5%
Proximity to steep sensitive slopes	Basins placed on slopes greater than 15% or within 200 feet from a hazardous slope or landslide area may require a geotechnical investigation
Depth to seasonally high groundwater table	N/A - A liner may be required if located in wellhead protection area.
Hydrologic soil group	Any[2]

1 – Tributary area is the area of the site draining to the BMP. Tributary areas provided here should be used as a general guideline only. Tributary areas can be larger or smaller in some instances.
2 – “A” Soils may require a pond liner. “B” soils may require infiltration testing to ensure base flows match or exceed losses.

Variations and Enhancements

Wet ponds can be designed to provide additional peak flow attenuation by using a perforated riser outlet or other outlet control device that provides extended detention above the permanent pool. If extended detention is provided, the recommended drain time from the overflow stage to the permanent pool should be between 36 to 48 hours. Water quality benefits can also be improved with a larger permanent pool with shallower depths and denser perimeter vegetation. However, the main pool must be greater than 3 feet deep to ensure an open water pool; otherwise the system would function more like a treatment wetland.

For locations with ephemeral base flow, the wet pond may be designed with a seasonal wet pool. Careful hydraulic design and plant selection would be necessary to ensure the selected riparian and aquatic vegetation could survive periodic dry periods. Wet ponds intended to function as a permanent aesthetic water feature require base flows sufficient to maintain the permanent pool or an additional water supply (e.g., potable, reclaimed, etc.) to supplement base flows during low flow periods.

Advantages and Benefits

- Volume and peak flow reduction
- Suspended solids and particulate-bound pollutant removal
- May address dissolved constituents and nutrients
- Aesthetically pleasing

Risks and Limitations

- Requires consistent source of water during dry periods
- Large footprint required
- Significant capital cost
- Mosquitos and other vector control may be required
- Safety concerns associated with open water

Sizing and Design Considerations

- If there is no extended detention provided, wet ponds should be sized to provide a minimum wet pool volume equal to the water quality design volume plus an additional 10%.
- At least 25% of the basin area should be deeper than 3 feet to prevent the growth of emergent vegetation across the entire basin. If greater than 50% of the wet pool area is in excess of 6 feet deep, a recirculation device, such as a fountain or aerator, may be needed to prevent stratification, stagnation and low dissolved oxygen conditions.
- Inlets and outlets should be placed to maximize the flow path, and thus the residence time, through the facility.
- Residence time should be a maximum of 7 days during dry weather
- The wet pond should be divided into two cells separated by a berm or baffle. The first cell should contain between 25 to 35 % of the total volume.

Inspection and Maintenance

Inspection	• Inspect after major rain storms to correct any identified deficiencies. • At a minimum, inspection twice per year to ensure the structure operates in the manner originally designed is recommended.
Routine Maintenance	• Remove minor sediment accumulation near inlet and outlet structures • Stabilize/repair eroded banks and fill in animal burrows if present • Remove any evidence of visual contamination from floatables such as oil and grease • Eliminate pests and conditions suitable for creating ideal breeding habitat • Remove algae mats as needed to prevent coverage of more than 20% of pond surface • Mow berms routinely if applicable to maintain aesthetic appeal and to suppress weeds
Major Maintenance	• Correct problems associated with berm settlement • Repair berm/dike breaches and stabilize eroded parts of the berm • Repair and rebuild spillway as needed to reverse the effects of severe erosion • Remove sediment build up in forebay and wet pool area • Re-grade basin bottom to restore bottom slope • Repair or replace gates, fences, flow control structures, and inlet/outlet structures as needed to maintain full functionality

Cost

Costs provided below are reference estimates only. Site-specific conditions and design choices can significantly impact implementation costs.

Table 2: Wet Pond Implementation and Maintenance Costs

COST PER AREA SERVED (Area Served < 3 acres)				COST PER AREA SERVED (Area Served > 3 acres)			
New Construction	Retrofit	Annual Minor Maint.	*Annual Major Maint.	New Construction	Retrofit	Annual Minor Maint.	*Annual Major Maint.
$ 32,600	$ 52,100	$ 523	$ 4,480	$ 13,100	$ 20,900	$ 173	$ 2,361

Note: The costs provided in the table above will not scale linearly with changes in area served and will vary significantly with changes in design assumptions and site specific conditions. *These costs are subject to change as the Project Team discusses and refines the assumptions used to develop them.*
*Annual major maintenance cost based on assumed major maintenance task frequencies ranging from 1 to 5 years

Related DOT Guidance

CA	www.dot.ca.gov/hq/oppd/stormwtr/ppdg/swdr2012/PPDG-May-2012.pdf
GA	www.georgiastormwater.com/
ID	http://itd.idaho.gov/enviro/Stormwater/BMP/default.htm
MA	http://www.mhd.state.ma.us/downloads/projDev/2009/MHD_Stormwater_Handbook.pdf
MD	http://www.mde.state.md.us/programs/Water/StormwaterManagementProgram/SoilErosionandSedimentControl/Documents/MD%20SWM%20Volume%201.pdf
NJ	nj.gov/dep/stormwater/bmp_manual2.htm
NY	www.dec.ny.gov/chemical/29072.html
OR	ftp://ftp.odot.state.or.us/techserv/geo-environmental/Hydraulics/Hydraulics%20Manual/Table_of_Contents_rev_Nav.pdf and http://www.oregon.gov/ODOT/HWY/OOM/mg/02/act125_waterqualityfacilandtables.pdf
PA	ftp://ftp.dot.state.pa.us/public/bureaus/design/PUB584/PDM-TOC.pdf
RI	http://www.dem.state.ri.us/programs/benviron/water/permits/ripdes/stwater/t4guide/desman.htm
TX	http://ftp.dot.state.tx.us/pub/txdot-info/library/pubs/bus/storm_water/5sedimentationcontrol.pdf
WA	http://www.wsdot.wa.gov/publications/manuals/fulltext/M31-16/HighwayRunoff.pdf

Additional Resources

Cahill Associates, Inc. Pennsylvania Stormwater Best Management Practices Manual. 2006. http://www.elibrary.dep.state.pa.us/dsweb/View/Collection-8305

City of Portland, Oregon. Stormwater Management Manual. 2008. http://www.portlandonline.com/bes/index.cfm?c=47953&

Coastal Georgia Regional Development Center. Green Growth Guidelines. 2006. http://coastalgadnr.org/cm/green/guide

Hunt, W. and W. Lord. "Maintenance of Stormwater Wetlands and Wet Ponds." Urban Waterways. North Carolina State University and North Carolina Cooperative Extension. Raliegh, NC., 2006.

Nashville, Tennessee. Stormwater Management Manual, Volume 4. 2009. http://www.nashville.gov/stormwater/regs/SwMgt_ManualVol04_2009.asp

U.S. EPA, 2006, Stormwater Menu of BMPs: Wet Detention Basin. 4 Nov. 2010. http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm, Office of Water, Washington DC.

Virginia Department of Conservation and Recreation. (1999). Virginia Stormwater Management Handbook. http://www.dcr.virginia.gov/stormwater_management/documents/Chapter_3-06.pdf

Legend	
H/M/L	High/Medium/Low effectiveness relative to other BMPs

TYPICAL PROPERTIES	
Location	Surface
Popularity	Medium
Longevity	High
Primary constraint	Space

PRIMARY FUNCTION(S)	
H	Water Quality Improvement
L	Volume Control
M	Peak Reduction
M	Flow Duration Control

COST	
H	Capital Cost
M	Minor Maintenance Cost
H	Major Maintenance Cost
L	Maintenance Frequency

WETLAND BASIN

Wetland basins typically include components such as an inlet with energy dissipation, a sediment forebay for settling out coarse solids and facilitating maintenance, a basin with shallow sections (1 to 2 feet deep) planted with emergent vegetation, deeper areas or micro pools (3 to 5 feet deep), and a water quality outlet structure. The interactions between the incoming storm water runoff, aquatic vegetation, wetland soils, and the associated physical, chemical, and biological unit processes are a fundamental part of wetland basins. Therefore, it is critical that dry weather base flows exceed evaporation and infiltration losses to prevent loss of aquatic biota and to avoid stagnation and vector problems. The primary unit treatment processes at work in wetland basins include sedimentation, sorption, biochemical processes, coagulation, flocculation, plant uptake and microbial transformations. Infiltration is typically not a goal of wetland basins; any volume reduction that occurs is mainly through evapotranspiration. Wetland basins are generally designed as "plug flow" systems where the water already present in the permanent pool is displaced by incoming flows with minimal mixing and minimal short circuiting. Short circuiting occurs when quiescent areas or "dead zones" develop in the wetland basin where pockets of water remain stagnant, causing other volumes to bypass using preferential flow paths through the basin. The treatment performance of a wetland basin is improved when the permanent wet pool volume is equal to or greater than the design water quality volume, resulting in longer residence times as incoming flows displace volumes that have been detained in the permanent pool for an extended period of time.

TARGET CONSTITUENTS	
M	Sediment
H	Metals
H	Organics
M	Nutrients
L	Bacteria
M	Trash and debris
H	Oil and grease

UNIT PROCESSES	
L	Volume reduction
H	Gravity separation
M	Media filtration & sorption
L	Vegetative filtration
H	Plant uptake & microbial transformations

PRIMARY CONSTRAINTS	
H	Surface space req.
L	Subsurface space req.
L	Hydraulic head req.
L	Water table req.
L	Soil permeability req.
L	Public acceptance
H	Steep slopes / stability

ENHANCEMENTS / VARIATIONS
Impermeable Liners
Meandering low flow channel
Extended detention

Where should a wetland basin be used?

Wetland basins are typically used as part of a centralized end-of-pipe treatment train. However, wetland basins can be applied anywhere sufficient space and base flows are available. Wetland basins are typically used to treat large tributary areas. They must be designed with the outlet positioned and/or operated in such a way as to maintain a permanent pool of water. In highly permeable soils, the wetland basin may need to be lined in order for base flows to match or exceed losses.

Table 1: Site Suitability Guidelines for Wetland Basins

Tributary Area	> 10 Acres and < 10 sq. mi.
Typical BMP area as percentage of tributary area	5 – 12%[1]
Proximity to steep sensitive slopes	Wetland basins placed near slopes greater than 15% or within 200 feet of a hazardous slope or landslide area require a geotechnical investigation
Hydrologic soil group	Any [2]

1 - Tributary area is the area of the site draining to the BMP. Tributary areas provided here should be used as a general guideline only.

2 – "A" Soils may require a liner. "B" soils may require infiltration testing to ensure base flows match or exceed losses.

Variations and Enhancements

Enhancements that overcome site constraints, facilitate "plug flow", and aid in trapping and securing pollutants are the main categories of enhancements and design variations that are available for wetland basins. Water quality benefits can be improved with a larger permanent pool, shallower depths in the wetland basin, and denser vegetation. Carefully selected vegetation with known pollutant uptake potential may also improve performance. Outlet design may be used to leverage seasonal changes in inflows to provide extended treatment of low flows. Extended detention can also be incorporated to provide peak flow reduction benefits.

Advantages and Benefits

- Can be designed to be an aesthetically pleasing amenity
- Can create wildlife habitat
- Provides enhanced pollutant removal benefits
- Can treat large tributary areas

Risks and Limitations

- Requires continuous baseflows; supplemental water may be required if water level is to be maintained
- Large footprint area
- Mosquitos and other vector control may be required
- Careful management required, including periodic drawdown and invasive species removal
- Safety concerns associated with open water

Sizing and Design Considerations

- Sediment forebay should be 4-8 feet deep and contain 10-20% of the total wetland volume.
- Emergent wetland vegetation should account for 50-70% of the permanent pool surface area.
- A range of depths intermixed throughout the wetland basin to a maximum of 5 feet is recommended with at least 50% of the basin less than 1 foot deep.
- Recommended minimum freeboard is 1 foot
- The flow path length-to-width ratio should be a minimum of 3:1, but preferably at least 4:1
- Residence time should be a maximum of 7 days during dry weather.
- Water balance calculations should demonstrate that adequate water supply will be present to maintain a permanent pool during a drought year when precipitation is 50% of average.

Construction Considerations

- Base flows should be temporarily diverted around the facility during construction.
- The use of treated wood or galvanized metal anywhere inside the facility should be avoided.

Inspection and Maintenance

Inspection	• At a minimum, inspections twice per year for the first 3 years following the completion of construction and annually thereafter is recommended.
Routine Maintenance	• Remove trash and debris • Stabilize / repair eroded banks and fill in animal burrows if present • Remove visible floatables such as oil and grease • Eliminate pests, vectors and conditions suitable for creating ideal breeding habitat • Replace or repair wetland basin liner as needed if liner included in design • Remove minor sediment accumulation, and obstructions near inlet and outlet structures as needed • Remove algae mats as needed to prevent coverage of more than 20% of wetland surface • Mow berms routinely if applicable to maintain aesthetic appeal and to suppress weeds
Major Maintenance	• Remove dead, diseased, or dying trees and woody vegetation that interfere with facility function and maintenance • Correct problems associated with berm settlement • Repair berm/dike breaches and stabilize eroded parts of the berm • Repair and rebuild spillway as needed to reverse the effect of severe erosion • Remove sediment build up in forebay and main wetland area to restore original sediment holding capacity • Re-grade main wetland bottom to restore bottom slope as needed • Repair or replace gates, fences, flow control structures, and inlet / outlet structures as needed

Cost

Costs provided below are reference estimates only. Site-specific conditions and design choices can significantly affect implementation costs.

Table 2: Wetland Basin Implementation and Maintenance Costs

COST PER AREA SERVED (Area Served < 3 acres)				COST PER AREA SERVED (Area Served > 3 acres)			
New Construction	Retrofit	Annual Minor Maint.	*Annual Major Maint.	New Construction	Retrofit	Annual Minor Maint.	*Annual Major Maint.
$ 32,800	$ 52,300	$ 359	$ 4,359	$ 13,700	$ 21,900	$ 126	$ 2,124

Note: The costs provided in the table above will not scale linearly with changes in area served and will vary significantly with changes in design assumptions and site specific conditions. *These costs are subject to change as the Project Team discusses and refines the assumptions used to develop them.*
*Annual major maintenance cost based on assumed major maintenance task frequencies ranging from 1 to 50 years

Related DOT Guidance

GA	www.georgiastormwater.com/
ID	http://itd.idaho.gov/enviro/Stormwater/BMP/default.htm
MA	http://www.mhd.state.ma.us/downloads/projDev/2009/MHD_Stormwater_Handbook.pdf
MD	http://www.mde.state.md.us/programs/Water/StormwaterManagementProgram/SoilErosionandSedimentControl/Documents/MD%20SWM%20Volume%201.pdf
NJ	nj.gov/dep/stormwater/bmp_manual2.htm
NY	www.dec.ny.gov/chemical/29072.html
OH	http://www.dot.state.oh.us/Divisions/Engineering/Hydraulic/LandD/Pages/TableofContents.aspx
PA	ftp://ftp.dot.state.pa.us/public/bureaus/design/PUB584/PDM-TOC.pdf
TX	http://ftp.dot.state.tx.us/pub/txdot-info/library/pubs/bus/storm_water/5sedimentationcontrol.pdf
WA	http://www.wsdot.wa.gov/publications/manuals/fulltext/M31-16/HighwayRunoff.pdf

Additional Resources

Cahill Associates, Inc. Pennsylvania Stormwater Best Management Practices Manual. 2006. http://www.elibrary.dep.state.pa.us/dsweb/View/Collection-8305

City of Portland, Oregon. Stormwater Management Manual. 2008. http://www.portlandonline.com/bes/index.cfm?c=47953&

Coastal Georgia Regional Development Center. Green Growth Guidelines. 2006. http://coastalgadnr.org/cm/green/guide

Nashville, Tennessee. Stormwater Management Manual, Volume 4. 2009. http://www.nashville.gov/stormwater/regs/SwMgt_ManualVol04_2009.asp

U.S. EPA. National Menu of Stormwater Best Management Practices. http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm

Virginia Department of Conservation and Recreation. (1999) Virginia Stormwater Management Handbook. Division of Soil and Water Conservation. http://www.dcr.virginia.gov/stormwater_management/documents/Chapter_3-10.pdf

Legend	
H/M/L	High/Medium/Low effectiveness relative to other BMPs

TYPICAL PROPERTIES	
Location	Surface
Popularity	Medium
Longevity	High
Primary constraint	Space

PRIMARY FUNCTION(S)	
H	Water Quality Improvement
L	Volume Control
L	Peak Reduction
L	Flow Duration Control

COST	
H	Capital Cost
M	Minor Maintenance Cost
H	Major Maintenance Cost
L	Maintenance Frequency

WETLAND CHANNEL

A wetland channel is a conveyance BMP that is constructed to enhance water quality by leveraging dense vegetation to slow down runoff and maximize contact time for unit treatment processes to operate on storm water pollutants. The interactions between the incoming storm water runoff, aquatic vegetation, wetland soils, and the associated physical, chemical, and biological unit processes are a fundamental part of wetland channels. Therefore, it is critical that dry weather base flows exceed evaporation and infiltration losses to prevent loss of aquatic biota and to avoid stagnation and vector problems. The primary unit treatment processes in wetland channels are filtration, sedimentation, microbial transformations and plant uptake. Infiltration is typically not a goal of wetland channels and any volume reduction that occurs is mainly through evapotranspiration. Wetland channels are linear features similar to vegetated swales, but depend on base flows, aquatic vegetation, and micro pools to fulfill their functions.

Where should a wetland channel be used?

Wetland channels are typically used in place of swales in areas where dry weather base flows are available or areas where soils are saturated for a significant portion of the year. Wetland channels function best with near-flat longitudinal slopes in the direction of the flow.

TARGET CONSTITUENTS	
M	Sediment
H	Metals
H	Organics
M	Nutrients
L	Bacteria
M	Trash and debris
H	Oil and grease

UNIT PROCESSES	
L	Volume reduction
M	Gravity separation
M	Media filtration & sorption
M	Vegetative filtration
H	Plant uptake & microbial transformations

PRIMARY CONSTRAINTS	
H	Surface space req.
L	Subsurface space req.
M	Hydraulic head req.
L	Water table req.
L	Soil permeability req.
L	Public acceptance
H	Steep slopes / stability

ENHANCEMENTS / VARIATIONS
Impermeable Liners
Meandering Channel
Micro Pools
Grade control structures

Table 1: Site Suitability Guidelines for Wetland Channels

Tributary Area	> 10 Acres and < 10 sq. mi.
Typical BMP area as percentage of tributary area	1 – 5%[1]
Proximity to steep sensitive slopes	A geotechnical investigation is recommended for wetland channels placed near slopes greater than 15% or within 200 feet of a hazardous slope or landslide area
Hydrologic soil group	Any [2]

1 - Tributary area is the area of the site draining to the BMP. Tributary areas provided here should be used as a general guideline only. Tributary areas can be larger or smaller in some instances.
2 – "A" Soils may require a pond liner. "B" soils may require infiltration testing to ensure base flows match or exceed losses.

Variations and Enhancements

Enhancements that overcome site constraints, facilitate "plug flow", and aid in trapping and securing pollutants are the main categories of enhancements and design variations that are available for wetland channels. Water quality benefits can be improved with distributed micro pools alternating with shallower depth areas along the length of the wetland channel. Well selected vegetation with known pollutant uptake potential may also improve performance. Grade control structures and judicious outlet design may also be used to leverage seasonal changes in inflows to provide extended treatment of low flows.

Advantages and Benefits

- Can be designed as an aesthetically pleasing amenity
- Can create wildlife habitat
- Provides enhanced pollutant removal benefits
- Works in saturated soils that are otherwise are of low value for other activities

Risks and Limitations

- Requires a continuous baseflow
- Mosquitos and other vector control may be required
- Careful management required, including invasive species removal
- Without proper design and maintenance, captured pollutants can be mobilized and flushed out

Sizing and Design Considerations:

- Provide pre-treatment upstream of wetland channels whenever possible
- Emergent wetland vegetation should account for 50-70% of the wetland channel surface area.
- A range of depths intermixed throughout the wetland channel to a maximum of 5 feet is recommended with at least 50% of the channel less than 1 foot deep.
- Residence time should be a maximum of 7 days during dry weather.
- Water balance calculations should demonstrate that adequate water supply will be present to maintain a permanent pool of water during a drought year when precipitation is 50% lower than average.

Construction Considerations

- Base flows should be temporarily diverted around the facility during construction.
- The use of treated wood or galvanized metal anywhere inside the facility should be avoided.

Inspection and Maintenance

Inspection	• At a minimum, inspect twice per year for the first 3 years following the completion of construction and annually thereafter.
Routine Maintenance	• Remove trash and debris • Stabilize / repair eroded banks and fill in animal burrows if present • Remove visible floatables such as oil and grease • Eliminate pests and vectors and conditions suitable for creating ideal breeding habitat • Replace or repair wetland channel liner as needed if liner included in the design • Remove minor sediment accumulation, and obstructions near inlet and outlet structures as needed • Remove algae mats as needed to prevent coverage of more than 20% of wetland surface • Mow berms routinely, if applicable, to maintain aesthetic appeal and to suppress weeds
Major Maintenance	• Remove dead, diseased, or dying trees and woody vegetation that interfere with facility function and maintenance • Correct problems associated with berm settlement • Repair berm/side slope breaches and stabilize eroded parts of the berm or side slope • Repair and rebuild spillway as needed to reverse the effect of severe erosion • Remove sediment build up to restore original sediment holding capacity • Re-grade wetland channel to restore bottom slope as needed • Repair or replace gates, fences, flow control structures, and inlet / outlet structures as needed

Cost

- Cost information provided below are reference estimates only
- Site specific conditions and design choices can significantly impact implementation costs.

Table 2: Wetland Channel Implementation and Maintenance Costs

COST PER AREA SERVED (Area Served < 3 acres)				COST PER AREA SERVED (Area Served > 3 acres)			
New Construction	Retrofit	Annual Minor Maint.	*Annual Major Maint.	New Construction	Retrofit	Annual Minor Maint.	*Annual Major Maint.
$ 32,800	$ 52,300	$358	$2,989	$ 13,700	$ 21,900	$126	$1,341

Note: The costs provided in the table above will not scale linearly with changes in area served and will vary significantly with changes in design assumptions and site specific conditions. *These costs are subject to change as the Project Team discusses and refines the assumptions used to develop them*.

*Annual major maintenance cost based on assumed major maintenance task frequencies ranging from 1 to 50 years

Related DOT Guidance

ID	http://itd.idaho.gov/enviro/Stormwater/BMP/default.htm
MA	http://www.mhd.state.ma.us/downloads/projDev/2009/MHD_Stormwater_Handbook.pdf
MD	http://www.mde.state.md.us/programs/Water/StormwaterManagementProgram/SoilErosionandSedimentControl/Documents/MD%20SWM%20Volume%201.pdf

Additional Resources

Cahill Associates, Inc. Pennsylvania Stormwater Best Management Practices Manual. 2006. http://www.elibrary.dep.state.pa.us/dsweb/View/Collection-8305

City of Portland, Oregon. Stormwater Management Manual. 2008. http://www.portlandonline.com/bes/index.cfm?c=47953&

Coastal Georgia Regional Development Center. Green Growth Guidelines. 2006. http://coastalgadnr.org/cm/green/guide

Nashville, Tennessee. Stormwater Management Manual, Volume 4. 2009. http://www.nashville.gov/stormwater/regs/SwMgt_ManualVol04_2009.asp

Urban Drainage and Flood Control District. Urban Storm Drainage Criteria Manual Volume 3. http://www.udfcd.org/downloads/pdf/critmanual/Volume%203%20PDFs/chapter%204%20fact%20sheets/T-09%20Constructed%20Wetland%20Channel.pdf

U.S. EPA. National Menu of Stormwater Best Management Practices. http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm

Virginia Department of Conservation and Recreation. (1999) Virginia Stormwater Management Handbook. Division of Soil and Water Conservation. http://www.dcr.virginia.gov/stormwater_management/documents/Chapter_3-10.pdf

Appendix B – Unit Costs and Quantitative Assumptions for Capital Cost Estimates

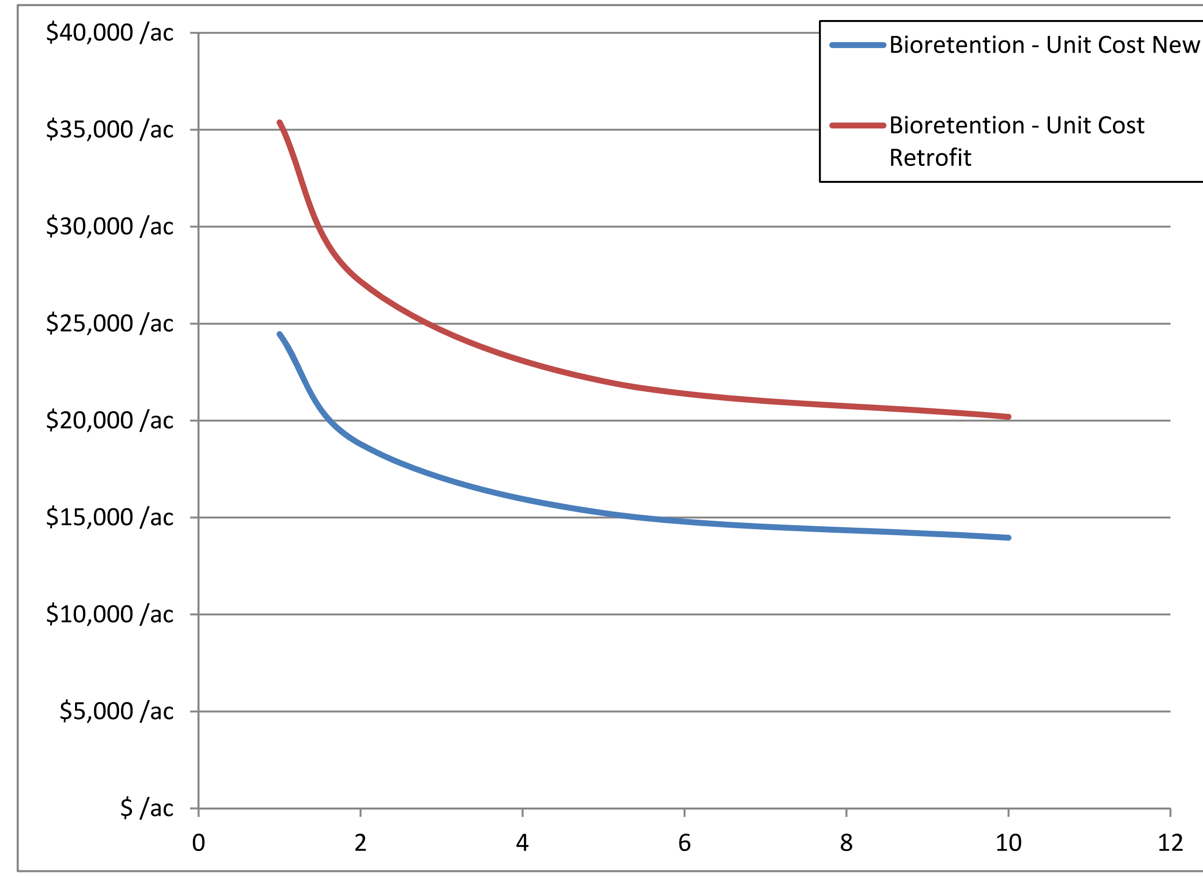
Bioretention

Design Parameter	Unit	Value
Tributary Drainage Area	ac	10
Design storm	in	0.75
Runoff Coef	-	0.9
Water Quality Volume	ft^3	24502.5

BMP Cost Estimate

Tributary Drainage Area (ac)	Bioretention		Bioretention - Unit Cost	
	New	Retrofit	New	Retrofit
1	$ 24,458	$ 35,380	$24,458 /ac	$35,380 /ac
2	$ 37,568	$ 54,345	$18,784 /ac	$27,172 /ac
5	$ 76,136	$ 110,136	$15,227 /ac	$22,027 /ac
10	$ 139,611	$ 201,957	$13,961 /ac	$20,196 /ac

CAPITAL COSTS				
Total Facility Base Costs	**Unit**	**Quantity**	**Unit Cost**	**Cost**
Mobilization	LS	1	$ 935	$ 935
Clearing & Grubbing	AC	0.00	$ 8,825	$ -
Excavation/Embankment	CY	0	$ 58	$ -
Rock Media	CY	0	$ 10	$ -
Permeable Media	CY	0	$ 40	$ -
Pipe	LF	0	$ 96	$ -
Maintenance Access Ramp/Pad	LS	1	$ 8,000	$ 8,000
Revegetation/Erosion Controls	AC	0.00	$ 1,991	$ -
Traffic Control	LS	1	$ 850	$ 850
Metal Beam Guard Rail	LF	0	$ 24	$ -
Signage, Public Education Materials, etc.	LS	1	$ 500	$ 500
New Construction	**TOTAL**			$ 10,285
Retrofit	**TOTAL**			$ 14,878



Extended Detention Dry Basins

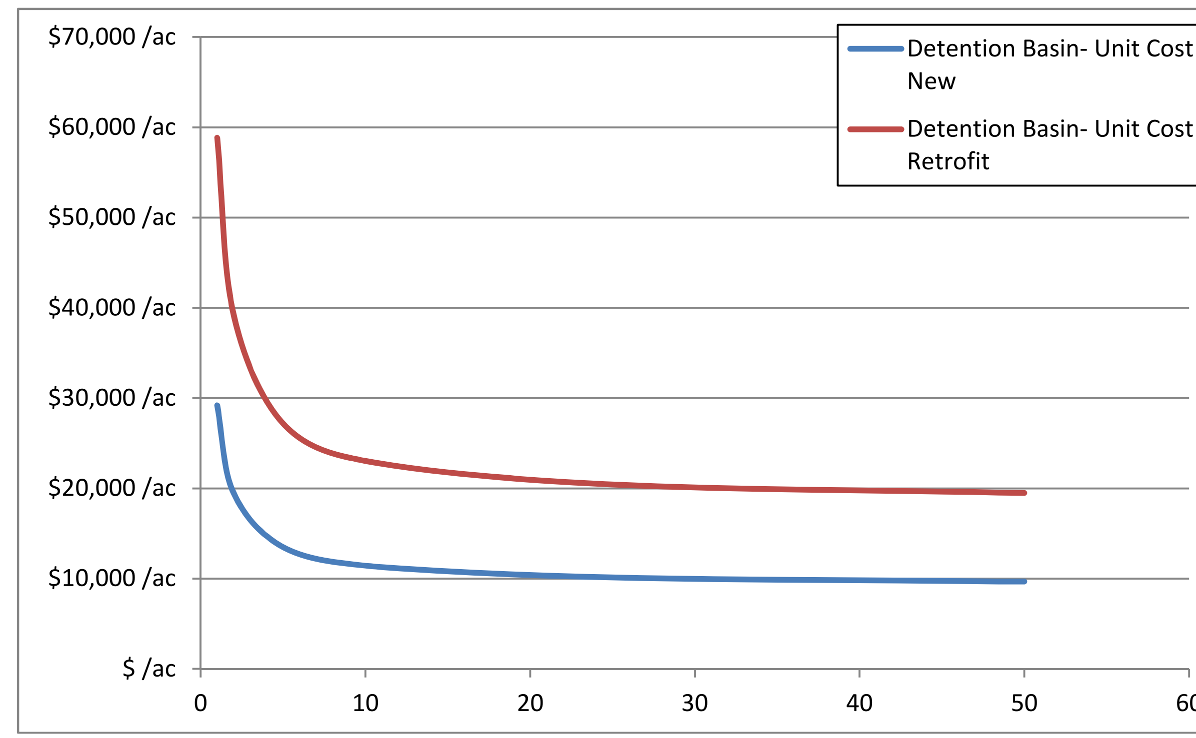
Design Parameter	Unit	Value
Tributary Drainage Area	ac	1
Design storm	in	0.75
Runoff Coef	-	0.9
Water Quality Volume	ft^3	2450.3

BMP Cost Estimate

Tributary Drainage Area (ac)	Detention Basin		Detention Basin- Unit Cost	
	New	Retrofit	New	Retrofit
1	$ 29,184	$ 58,843	$29,184 /ac	$58,843 /ac
2	$ 38,922	$ 78,478	$19,461 /ac	$39,239 /ac
5	$ 67,447	$ 135,992	$13,489 /ac	$27,198 /ac
10	$ 114,267	$ 230,395	$11,427 /ac	$23,039 /ac
25	$ 253,192	$ 510,507	$10,128 /ac	$20,420 /ac
50	$ 483,117	$ 974,101	$9,662 /ac	$19,482 /ac

CAPITAL COSTS

Total Facility Base Costs	Unit	Quantity	Unit Cost	Cost
Mobilization	LS	1	$ 2,653	$ 2,653
Clearing & Grubbing	AC	0.02	$ 8,825	$ 165
Structure Excavation	CY	109	$ 58	$ 6,328
Inlet Structure(s)	EA	1	$ 875	$ 875
Energy Dissipation Apron	EA	1	$ 2,072	$ 2,072
Outflow Riser Structure	LF	3	$ 538	$ 1,614
Overflow Structure (RSP)	CY	3.7	$ 600	$ 2,222
Maintenance Vehicle Pullout	EA	1	$ 8,000	$ 8,000
Pipe	LF	10	$ 96	$ 959
Erosion Control (Hydroseed)	AC	0.02	$ 1,991	$ 37
Traffic Control	LS	1	$ 2,412	$ 2,412
Signage, Public Education Materials	LS	1	$ 500	$ 500
Metal Beam Guard Rail	LF	57	$ 24	$ 1,347
New Construction	TOTAL			$ 29,184
Retrofit	TOTAL			$ 58,844



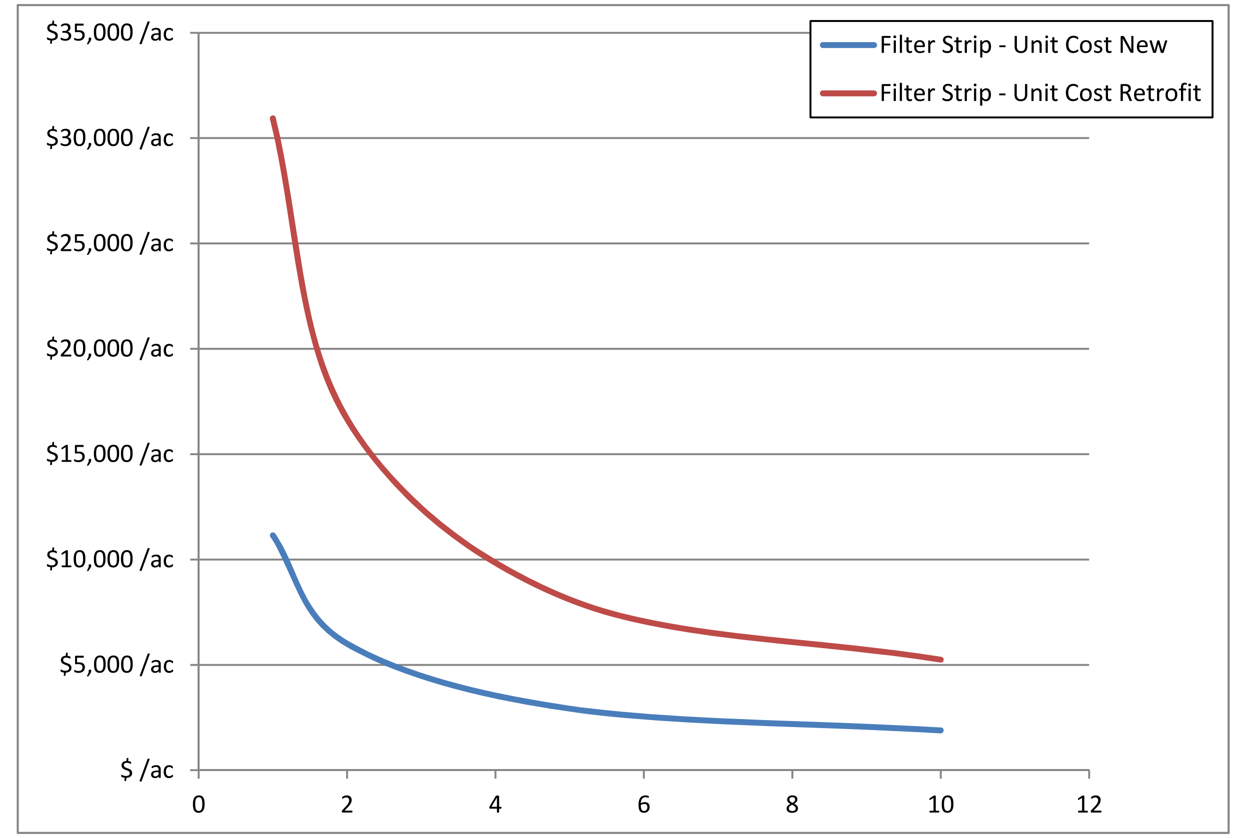
Filter Strip

Design Parameter	Unit	Value
Tributary Drainage Area	ac	10
Design storm	in	0.75
Runoff Coef	-	0.9
Water Quality Volume	ft^3	24502.5

BMP Cost Estimate

Tributary Drainage Area (ac)	Filter Strip		Filter Strip - Unit Cost	
	New	Retrofit	New	Retrofit
1	$ 11,147	$ 30,940	$11,147 /ac	$30,940 /ac
2	$ 12,009	$ 33,332	$6,005 /ac	$16,666 /ac
5	$ 14,595	$ 40,510	$2,919 /ac	$8,102 /ac
10	$ 18,904	$ 52,470	$1,890 /ac	$5,247 /ac

CAPITAL COSTS				
Total Facility Base Costs	**Unit**	**Quantity**	**Unit Cost**	**Cost**
Mobilization	LS	1	$ 935	$ 935
Clearing & Grubbing	AC	0.00	$ 8,825	$ -
Maintenance Access Ramp/Pad	LS	1	$ 8,000	$ 8,000
Erosion Control (Hydroseed)	AC	0.00	$ 1,488	$ -
Traffic Control	LS	1	$ 850	$ 850
Signage, Public Education Materials, etc.	LS	1	$ 500	$ 500
New Construction	TOTAL			$ 10,285
Retrofit	TOTAL			$ 28,547



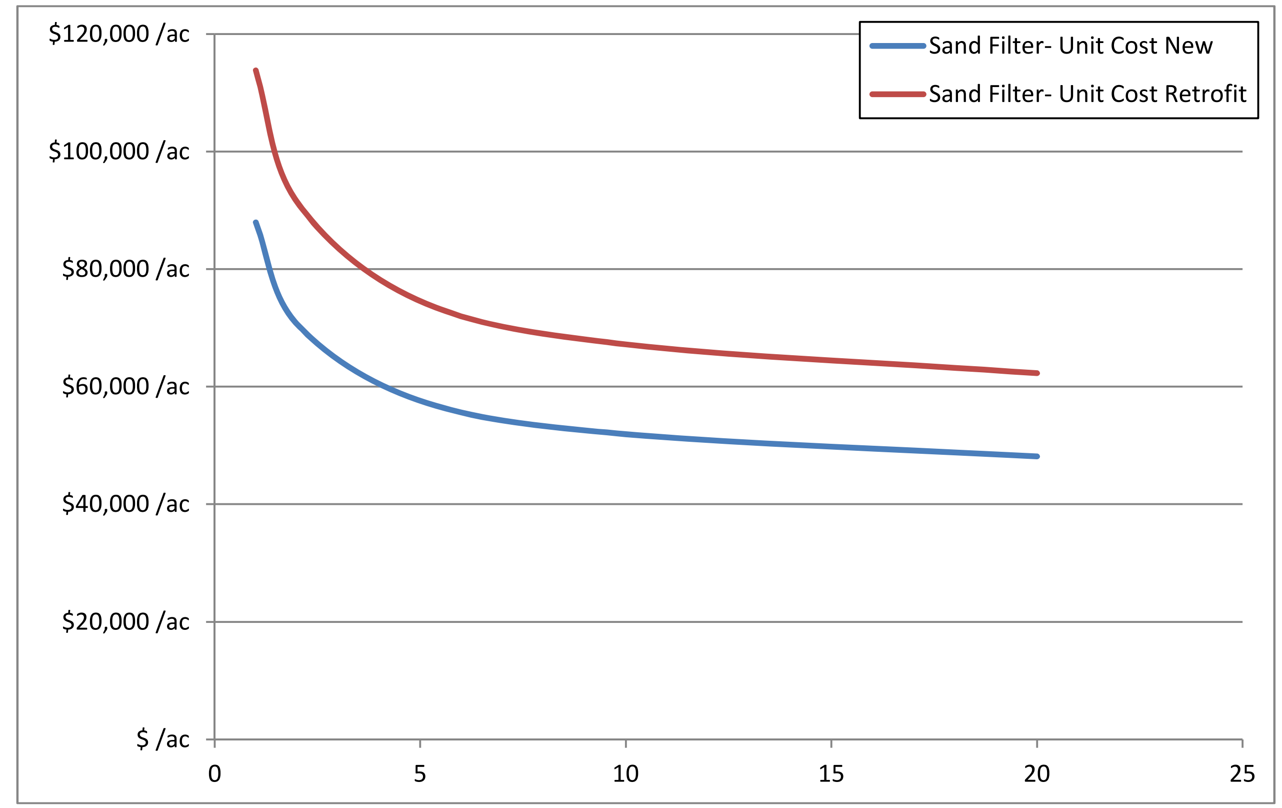
Media Filter

Design Parameter	Unit	Value
Tributary Drainage Area	ac	1
Design storm	in	0.75
Runoff Coef	-	0.9
Water Quality Volume	ft^3	2450.3
Sedimentation Vault Surface Area	ft^2	613
Filter Vault Surface Area	ft^2	136

BMP Cost Estimate

Tributary Drainage Area (ac)	Sand Filter		Sand Filter- Unit Cost	
	New	Retrofit	New	Retrofit
1	$ 87,953	$ 113,835	$87,953 /ac	$113,835 /ac
2	$ 141,407	$ 183,019	$70,704 /ac	$91,510 /ac
5	$ 288,074	$ 372,846	$57,615 /ac	$74,569 /ac
10	$ 519,245	$ 672,044	$51,925 /ac	$67,204 /ac
20	$ 962,715	$ 1,246,015	$48,136 /ac	$62,301 /ac

CAPITAL COSTS				
Total Facility Base Costs	**Unit**	**Quantity**	**Unit Cost**	**Cost**
Mobilization	LS	1	$ 6,035	$ 6,035
Clearing & Grubbing	AC	0.02	$ 8,825	$ 190
Diversion Structure	EA	1	$ 1,488	$ 1,488
Structure Excavation	CY	113	$ 58	$ 6,591
Minor Concrete	CY	38	$ 848	$ 32,415
Inlet Structure(s)	EA	1	$ 875	$ 875
6" Perforated Plastic Pipe Underdrain	LF	16	$ 10	$ 159
Pipe	LF	20	$ 96	$ 1,918
Maintenance Vehicle Pullout	LS	1	$ 8,000	$ 8,000
Sand / Media	CY	7.6	$ 86	$ 649
Traffic Control	LS	1	$ 5,486	$ 5,486
Signage, Public Education Materials	LS	1	$ 500	$ 500
Metal Beam Guard Rail	LF	88	$ 24	$ 2,074
New Construction	TOTAL			$ 66,380
Retrofit	TOTAL			$ 85,914

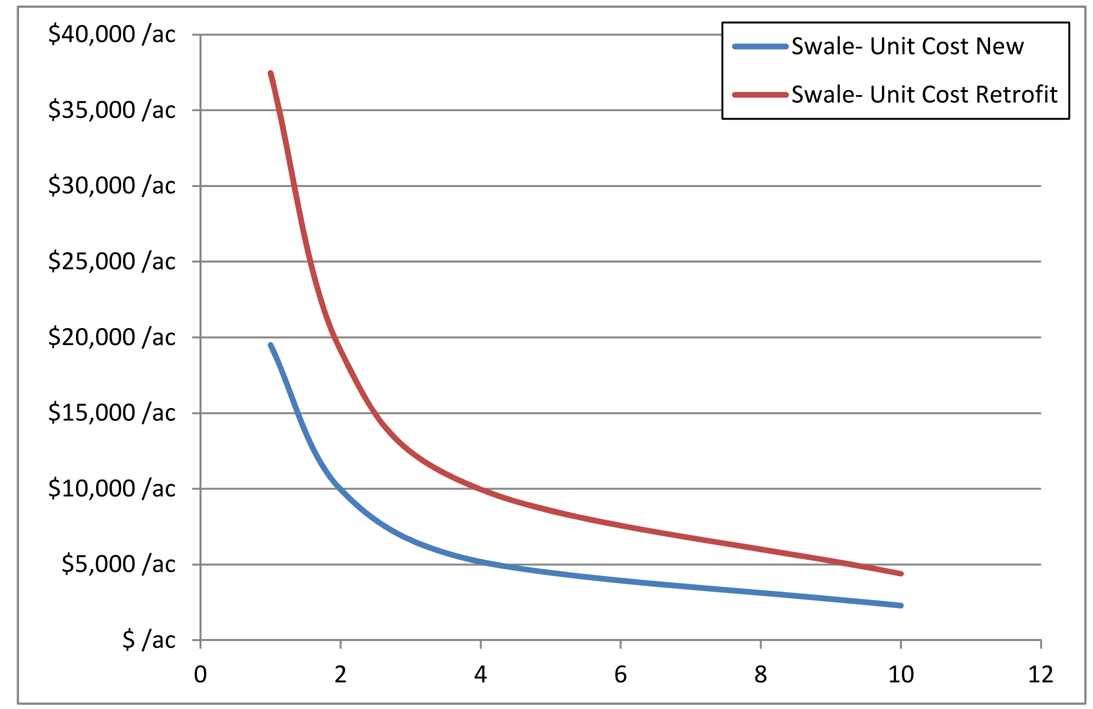


Vegetated Swale

Design Parameter	Unit	Value
Tributary Drainage Area	ac	10.00
Rainfall Intensity	in/hr	0.2
Runoff Coef	-	0.9
Length	ft	100
Swale area	ft2	800

BMP Cost Estimate

Tributary Drainage Area (ac)	Swale		Swale- Unit Cost	
	New	Retrofit	New	Retrofit
1	$ 19,499	$ 37,460	$19,499 /ac	$37,460 /ac
2	$ 19,912	$ 38,253	$9,956 /ac	$19,127 /ac
4	$ 20,738	$ 39,840	$5,185 /ac	$9,960 /ac
10	$ 22,872	$ 43,940	$2,287 /ac	$4,394 /ac



CAPITAL COSTS				
Total Facility Base Costs	**Unit**	**Quantity**	**Unit Cost**	**Cost**
Mobilization	LS	1	$ 1,735	$ 1,735
Clearing & Grubbing	AC	0.02	$ 8,825	$ 203
Structure Excavation	CY	30	$ 58	$ 1,722
Inlet Structure(s)	EA	1	$ 875	$ 875
Energy Dissipation Apron	EA	1	$ 2,072	$ 2,072
Overflow Structure (RSP)	CY	0.0	$ 600	$ -
Maintenance Vehicle Pullout	EA	1	$ 8,000	$ 8,000
Erosion Control (Hydroseed)	AC	0.02	$ 1,991	$ 46
Traffic Control	LS	1	$ 1,577	$ 1,577
Signage, Public Education Materials	LS	1	$ 500	$ 500
Metal Beam Guard Rail	LF	100	$ 24	$ 2,357
New Construction	TOTAL			$ 19,086
Retrofit	TOTAL			$ 36,667

Wet Ponds

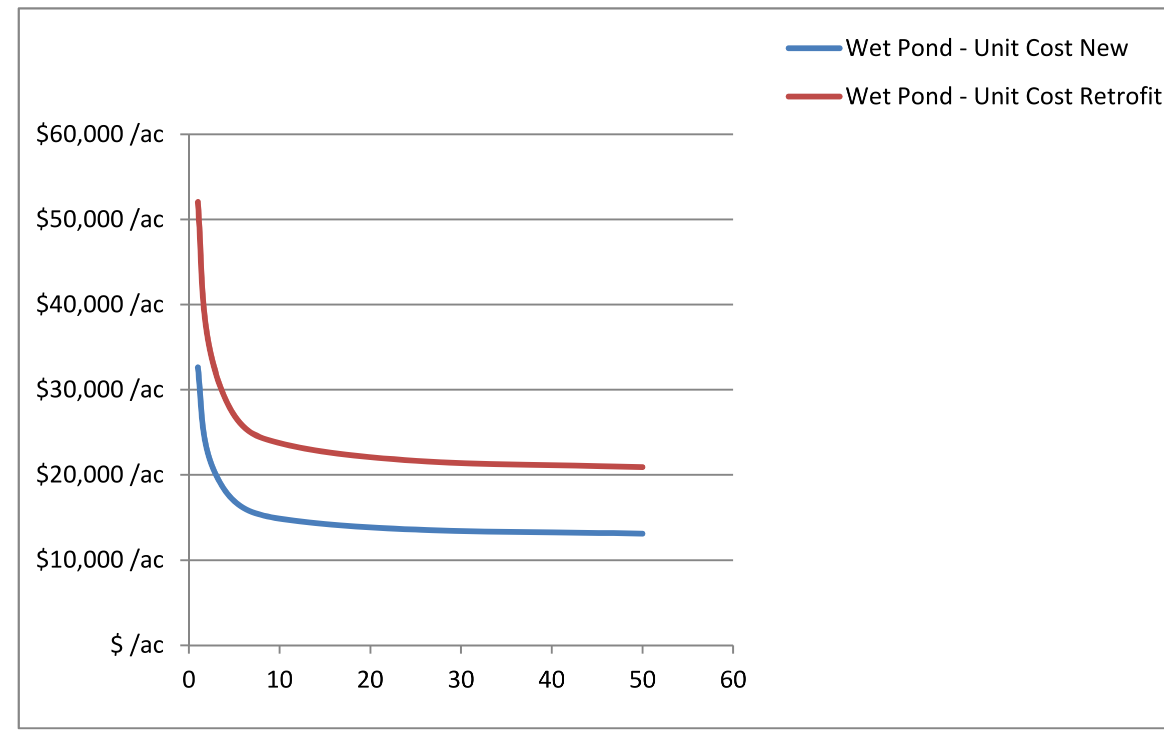
Design Parameter	Unit	Value
Tributary Drainage Area	ac	1
Design storm	in	0.75
Runoff Coef	-	0.9
Water Quality Volume	ft^3	2450.3

BMP Cost Estimate

Tributary Drainage Area (ac)	Wet Pond		Wet Pond - Unit Cost	
	New	Retrofit	New	Retrofit
1	$ 32,631	$ 52,051	$32,631 /ac	$52,051 /ac
2	$ 45,815	$ 73,082	$22,908 /ac	$36,541 /ac
5	$ 84,681	$ 135,079	$16,936 /ac	$27,016 /ac
10	$ 148,734	$ 237,254	$14,873 /ac	$23,725 /ac
25	$ 339,360	$ 541,331	$13,574 /ac	$21,653 /ac
50	$ 655,454	$ 1,045,550	$13,109 /ac	$20,911 /ac

CAPITAL COSTS

Total Facility Base Costs	Unit	Quantity	Unit Cost	Cost
Mobilization	LS	1	$ 2,966	$ 2,966
Clearing & Grubbing	AC	0.02	$ 8,825	$ 165
Structure Excavation	CY	109	$ 58	$ 6,328
Inlet Structure(s)	EA	1	$ 875	$ 875
Energy Dissipation Apron	EA	1	$ 2,072	$ 2,072
Outflow Riser Structure	LF	3	$ 538	$ 1,614
Overflow Structure (RSP)	CY	3.7	$ 600	$ 2,222
Impermeable Membrane (Basin Liner -if necessary)	SY	91	$ 19	$ 1,756
Maintenance Vehicle Pullout	EA	1	$ 8,000	$ 8,000
Pipe	LF	20	$ 96	$ 1,918
Wetland Seeding	SF	816.75	$ 0.21	$ 172
Traffic Control	LS	1	$ 2,697	$ 2,697
Signage, Public Education Materials	LS	1	$ 500	$ 500
Metal Beam Guard Rail	LF	57	$ 24	$ 1,347
New Construction	TOTAL			$ 32,631
Retrofit	TOTAL			$ 52,052



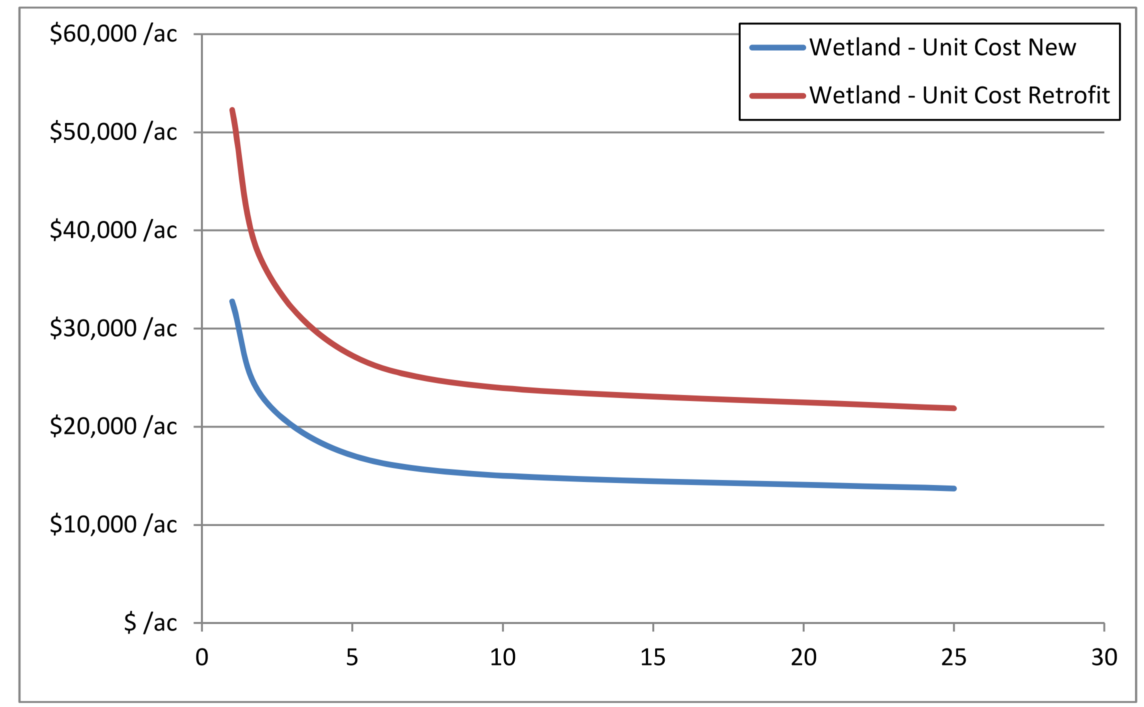
Wetland Basins

Design Parameter	Unit	Value
Tributary Drainage Area	ac	1
Design storm	in	0.75
Runoff Coef	-	0.9
Water Quality Volume	ft^3	2450.3

BMP Cost Estimate

Tributary Drainage Area (ac)	Wetland		Wetland - Unit Cost	
	New	Retrofit	New	Retrofit
1	$ 32,770	$ 52,273	$32,770 /ac	$52,273 /ac
2	$ 46,092	$ 73,524	$23,046 /ac	$36,762 /ac
5	$ 85,374	$ 136,185	$17,075 /ac	$27,237 /ac
10	$ 150,120	$ 239,464	$15,012 /ac	$23,946 /ac
25	$ 342,824	$ 546,857	$13,713 /ac	$21,874 /ac

CAPITAL COSTS				
Total Facility Base Costs	**Unit**	**Quantity**	**Unit Cost**	**Cost**
Mobilization	LS	1	$ 2,979	$ 2,979
Clearing & Grubbing	AC	0.03	$ 8,825	$ 248
Structure Excavation	CY	109	$ 58	$ 6,328
Inlet Structure(s)	EA	1	$ 875	$ 875
Energy Dissipation Apron	EA	1	$ 2,072	$ 2,072
Outflow Riser Structure	LF	3	$ 538	$ 1,614
Overflow Structure (RSP)	CY	3.7	$ 600	$ 2,222
Maintenance Vehicle Pullout	EA	1	$ 8,000	$ 8,000
Wetland topsoil	CY	23	$ 75.00	$ 1,702
Pipe	LF	20	$ 96	$ 1,918
Wetland Seeding	SF	1225	$ 0.21	$ 257
Traffic Control	LS	1	$ 2,708	$ 2,708
Signage, Public Education Materials	LS	1	$ 500	$ 500
Metal Beam Guard Rail	LF	57	$ 24	$ 1,347
New Construction	TOTAL			$ 32,770
Retrofit	TOTAL			$ 52,273



Appendix C – Unit Costs and Quantitative Assumptions for Maintenance Cost Estimates

BMP: Bioretention Area
MAINTENANCE ACTIVITIES

Minor / Major Maintenance	ROUTINE ACTION	MAINTENANCE INDICATOR	FIELD MEASUREMENT	MEASUREMENT FREQUENCY	MAINTENANCE ACTIVITY	Frequency (# of times per year)	Hours per Event (< 3 acre)	Hours per Event (> 3 acre)	Average Labor Crew Size	Avg. (Pro-Rated) Labor Rate/Hr. ($)	Equipment	Equipment Cost/Hour ($)	Materials & Incidentals Cost or Disposal Cost/Event ($)	Total cost per visit (<3 acres) ($)	Total cost per visit (>3 acres) ($)	Total cost per year (<3 acres) ($)	Total cost per year (>3 acres) ($)
Major	Standing Water	Standing water for more than 96 hrs	Visual observation	Annually, 96 hours after a target storm event	Drain facility. Corrective action prior to wet season. Consult engineers if immediate solution is not evident.	1.0	1.0	1.0	2	$ 74.97	Utility Truck	$ 14.39		$ 164	$ 164	$ 164	$ 164
Major	Sediment Management	Sediment depth exceeds 10% of the facility design	Measure depth at apparent maximum and minimum accumulation of sediment. Calculate average depth	Annually, prior to start of wet season	Remove and properly dispose of sediment. Regrade if necessary. (expected every 40 years)	0.0	8.0	16.0	2	$ 74.97	Utility Truck, 10-15 yd Truck, Backhoe	$ 56.02	$ 400.00	$ 2,048	$ 4,695	$ 51	$ 117
Major	Underdrains	Evidence of Clogging	Visual Observation	Annually, prior to start of wet season	Corrective action prior to wet season. Consult engineers if immediate solution is not evident.	1.0	0.5	0.5	2	$ 74.97	Utility Truck	$ 14.39		$ 82	$ 82	$ 82	$ 82
Minor	Vegetation Management for Aesthetics (optional)	Average vegetation height greater than 12-inches, emergence of trees or woody vegetation,	Visual observation and random measurements through out the side slope area	Annually, prior to start of wet season	Cut vegetation to an average height of 6-inches and remove trimmings. Remove any trees, or woody vegetation.	1.0	2.0	7.0	2	$ 74.97	Utility Truck	$ 14.39	$ 50.00	$ 379	$ 1,325	$ 379	$ 1,325
Minor	Soil Repair	Evidence of erosion	Visual observation	Annually, prior to start of wet season	Reseed/revegetate barren spots prior to wet season.	1.0	4.0	4.0	2	$ 74.97	Utility Truck	$ 14.39	$ 150.00	$ 807	$ 1,182	$ 807	$ 1,182
Minor	Trash and Debris	Trash and Debris present	Visual observation	Annually, prior to start of wet season	Remove and dispose of trash and debris	1.0	2.0	2.0	2	$ 74.97	Utility Truck	$ 14.39		$ 329	$ 329	$ 329	$ 329
Minor	General Maintenance Inspection	Inlet structures, outlet structures, side slopes or other features damaged, significant erosion, burrows, emergence of trees or woody vegetation, graffiti or vandalism, fence damage, etc.	Visual observation	Annually, prior to start of wet season	Corrective action prior to wet season. Consult engineers if immediate solution is not evident.	1.0	1.0	2.0	2	$ 74.97	Utility Truck	$ 14.39		$ 164	$ 329	$ 164	$ 329
Minor	Reporting					1.0	3.0	3.0	1	$ 74.97				$ 225	$ 225	$ 225	$ 225
					Average Annual Total		24.4	36.8								$ 2,202	$ 3,754

Labor Rate	$74.97/hr

Equipment	Equipment Cost
Utility Truck	$14.39/hr
10-15 yd truck	$28.27/hr
Backhoe	$13.36/hr
Vactor	$62.70/hr
Sweeper	$123.26/hr

	Hours (< 3 acre)	Hours (> 3 acre)	Total cost per year (<3 acres) ($)	Total cost per year (>3 acres) ($)
Less than 3 acre Minor Maintenance	21.0		$ 1,904	
Less than 3 acre Major Maintenance	3.4		$ 298	
Greater than 3 acre Minor Maintenance		33.0		$ 3,390
Greater than 3 acre Major Maintenance		3.8		$ 364

BMP: Dry Detention Basin
MAINTENANCE ACTIVITIES

Minor / Major Maintenance	ROUTINE ACTION	MAINTENANCE INDICATOR	FIELD MEASUREMENT	MEASUREMENT FREQUENCY	MAINTENANCE ACTIVITY	Frequency (# of times per year)	Hours per Event (< 3 acre)	Hours per Event (> 3 acre)	Average Labor Crew Size	Avg. (Pro-Rated) Labor Rate/Hr. ($)	Equipment	Equipment Cost/Hour ($)	Materials & Incidentals Cost or Disposal Cost/Event ($)	Total cost per visit (<3 acres) ($)	Total cost per visit (>3 acres) ($)	Total cost per year (<3 acres) ($)	Total cost per year (>3 acres) ($)
Major	Slope Stability	Evidence of erosion	Visual observation	Annually, prior to start of wet season	Reseed/revegetate barren spots prior to wet season.	1.0	4.0	4.0	2	$ 74.97	Utility Truck	$ 14.39	$ 150.00	$ 807	$ 1,182	$ 807	$ 1,182
Major	Standing Water	Standing water for more than 96 hrs	Visual observation	Annually, 96 hours after a target storm event	Drain facility. Corrective action prior to wet season. Consult engineers if immediate solution is not evident.	1.0	1.0	1.0	2	$ 74.97	Utility Truck	$ 14.39		$ 164	$ 164	$ 164	$ 164
Major	Sediment Management	Sediment depth exceeds 10% of the facility design	Measure depth at apparent maximum and minimum accumulation of sediment. Calculate average depth	Annually, prior to start of wet season	Remove and properly dispose of sediment. Regrade if necessary. (expected every 50 years)	0.02	8.0	16.0	3	$ 74.97	Utility Truck, 10-15 yd Truck, Backhoe	$ 56.02	$ 400.00	$ 2,647	$ 5,895	$ 53	$ 118
Minor	Vegetation Management for Aesthetics (optional)	Average vegetation height greater than 12-inches, emergence of trees or woody vegetation,	Visual observation and random measurements through out the side slope area	Annually, prior to start of wet season	Cut vegetation to an average height of 6-inches and remove trimmings. Remove any trees, or woody vegetation.	2.0	1.0	2.0	2	$ 74.97	Utility Truck	$ 14.39	$ 50.00	$ 214	$ 504	$ 429	$ 1,007
Minor	Trash and Debris	Trash and Debris present	Visual observation	Annually, prior to start of wet season	Remove and dispose of trash and debris	1.0	2.0	2.0	2	$ 74.97	Utility Truck	$ 14.39		$ 329	$ 329	$ 329	$ 329
Minor	General Maintenance Inspection	Inlet structures, outlet structures, side slopes or other features damaged, significant erosion, burrows, emergence of trees or woody vegetation, graffiti or vandalism, fence damage, etc.	Visual observation	Annually, prior to start of wet season	Corrective action prior to wet season. Consult engineers if immediate solution is not evident.	1.0	1.0	2.0	2	$ 74.97	Utility Truck	$ 14.39		$ 164	$ 329	$ 164	$ 329
Minor	Reporting					1.0	3.0	3.0	1	$ 74.97				$ 225	$ 225	$ 225	$ 225
					Average Annual Total		23.5	30.0								$ 2,171	$ 3,354

Labor Rate	$74.97/hr

Equipment	Equipment Cost
Utility Truck	$14.39/hr
10-15 yd truck	$28.27/hr
Backhoe	$13.36/hr
Vactor	$62.70/hr
Sweeper	$123.26/hr

Less than 3 acre Minor Maintenance		13.0									$ 1,147	
Less than 3 acre Major Maintenance		10.5									$ 1,025	
Greater than 3 acre Minor Maintenance			19.0									$ 1,890
Greater than 3 acre Major Maintenance			11.0									$ 1,465

BMP: Filter Strip
MAINTENANCE ACTIVITIES

Minor / Major Maintenance	ROUTINE ACTION	MAINTENANCE INDICATOR	FIELD MEASUREMENT	MEASUREMENT FREQUENCY	MAINTENANCE ACTIVITY	Frequency (# of times per year)	Hours per Event (< 3 acre)	Hours per Event (> 3 acre)	Average Labor Crew Size	Avg. (Pro-Rated) Labor Rate/Hr. ($)	Equipment	Equipment Cost/Hour ($)	Materials & Incidentals Cost or Disposal Cost/Event ($)	Total cost per visit (<3 acres) ($)	Total cost per visit (>3 acres) ($)	Total cost per year (<3 acres) ($)	Total cost per year (>3 acres) ($)
Major	Vegetation Repair	Less than 90 percent coverage in strip invert/swale or less than 70 percent on swale side slope	Visual observation	Annually, prior to start of wet season	Reseed/revegetate barren spots prior to wet season. (expected every 3 years)	0.3	4.0	8.0	2	$ 74.97	Utility Truck	$ 14.39	$ 150.00	$ 807	$ 1,840	$ 269	$ 613
Minor	Vegetation Management for Aesthetics (optional)	Average vegetation height greater than 12-inches, emergence of trees or woody vegetation,	Visual observation and random measurements through out the side slope area	Once during wet season, once during dry season.(depending on growth)	Cut vegetation to an average height of 6-inches and remove trimmings. Remove any trees, or woody vegetation.	2.0	1.0	2.0	2	$ 74.97	Utility Truck	$ 14.39	$ 50.00	$ 214	$ 504	$ 429	$ 1,007
Minor	Trash and Debris	Trash and Debris present	Visual observation	Annually, prior to start of wet season	Remove and dispose of trash and debris	1.0	1.0	1.0	2	$ 74.97	Utility Truck	$ 14.39		$ 164	$ 164	$ 164	$ 164
Minor	General Maintenance Inspection	Inlet structures, outlet structures, side slopes or other features damaged, significant erosion, burrows, emergence of trees or woody vegetation, graffiti or vandalism, fence damage, etc.	Visual observation	Annually, prior to start of wet season	Corrective action prior to wet season. Consult engineers if immediate solution is not evident.	1.0	1.0	2.0	2	$ 74.97	Utility Truck	$ 14.39		$ 164	$ 329	$ 164	$ 329
Minor	Reporting					1.0	3.0	3.0	1	$ 74.97				$ 225	$ 225	$ 225	$ 225
Average Annual Total							13.7	22.3								$ 1,251	$ 2,338

Labor Rate	$74.97/hr

Equipment	Equipment Cost
Utility Truck	$14.39/hr
10-15 yd truck	$28.27/hr
Backhoe	$13.36/hr
Vactor	$62.70/hr
Sweeper	$123.26/hr

	Frequency	Hours per Event (< 3 acre)	Hours per Event (> 3 acre)								Total cost per year (<3 acres) ($)	Total cost per year (>3 acres) ($)
Less than 3 acre Minor Maintenance		11.0									$ 982	
Less than 3 acre Major Maintenance		2.7									$ 269	
Greater than 3 acre Minor Maintenance			17.0									$ 1,725
Greater than 3 acre Major Maintenance			5.3									$ 613

BMP: Infiltration Basin
MAINTENANCE ACTIVITIES

Minor / Major Maintenance	ROUTINE ACTION	MAINTENANCE INDICATOR	FIELD MEASUREMENT	MEASUREMENT FREQUENCY	MAINTENANCE ACTIVITY	Frequency (# of times per year)	Hours per Event (< 3 acre)	Hours per Event (> 3 acre)	Average Labor Crew Size	Avg. (Pro-Rated) Labor Rate/Hr. ($)	Equipment	Equipment Cost/Hour ($)	Materials & Incidentals Cost or Disposal Cost/Event ($)	Total cost per visit (<3 acres) ($)	Total cost per visit (>3 acres) ($)	Total cost per year (<3 acres) ($)	Total cost per year (>3 acres) ($)
Major	Sediment Management	Sediment depth exceeds 10% of the facility design or drain time exceed 96 hours.	Measure depth at apparent maximum and minimum accumulation of sediment. Calculate average depth. Visual observation of drain time.	Annually, prior to start of wet season	Remove and properly dispose of sediment. Regrade if necessary. (expected every 40 years)	0.03	24.0	40.0	3	$ 74.97	Utility Truck, 10-15 yd Truck, Backhoe	$ 56.02	$ 400.00	$ 7,142	$ 12,637	$ 179	$ 316
Minor	Vegetation Management for Aesthetics (optional)	Average vegetation height greater than 12-inches, emergence of trees or woody vegetation,	Visual observation and random measurements through out the side slope area	Annually, prior to start of wet season	Cut vegetation to an average height of 6-inches and remove trimmings. Remove any trees, or woody vegetation.	2.0	1.0	2.0	2	$ 74.97	Utility Truck	$ 14.39	$ 50.00	$ 214	$ 504	$ 429	$ 1,007
Minor	Trash and Debris	Trash and Debris present	Visual observation	Annually, prior to start of wet season	Remove and dispose of trash and debris	1.0	2.0	2.0	2	$ 74.97	Utility Truck	$ 14.39		$ 329	$ 329	$ 329	$ 329
Minor	General Maintenance Inspection	Inlet structures, outlet structures, side slopes or other features damaged, significant erosion, burrows, emergence of trees or woody vegetation, graffiti or vandalism, fence damage, etc.	Visual observation	Annually, prior to start of wet season	Corrective action prior to wet season. Consult engineers if immediate solution is not evident.	1.0	1.0	1.0	2	$ 74.97	Utility Truck	$ 14.39		$ 164	$ 164	$ 164	$ 164
Minor	Reporting					1.0	3.0	3.0	1	$ 74.97				$ 225	$ 225	$ 225	$ 225
					Average Annual Total		**14.8**	**20.0**								**$ 1,325**	**$ 2,041**

Labor Rate	$74.97/hr

Equipment	Equipment Cost
Utility Truck	$14.39/hr
10-15 yd truck	$28.27/hr
Backhoe	$13.36/hr
Vactor	$62.70/hr
Sweeper	$123.26/hr

	Hours per Event (< 3 acre)	Hours per Event (> 3 acre)	Total cost per year (<3 acres) ($)	Total cost per year (>3 acres) ($)
Less than 3 acre Minor Maintenance	**13.0**		**$ 1,147**	
Less than 3 acre Major Maintenance	**1.8**		**$ 179**	
Greater than 3 acre Minor Maintenance		**17.0**		**$ 1,725**
Greater than 3 acre Major Maintenance		**3.0**		**$ 316**

BMP: Media Filter
MAINTENANCE ACTIVITIES

Minor / Major Maintenance	ROUTINE ACTION	MAINTENANCE INDICATOR	FIELD MEASUREMENT	MEASUREMENT FREQUENCY	MAINTENANCE ACTIVITY	Frequency (# of times per year)	Hours per Event (< 3 acre)	Hours per Event (> 3 acre)	Average Labor Crew Size	Avg. (Pro-Rated) Labor Rate/Hr. ($)	Equipment	Equipment Cost/Hour ($)	Materials & Incidentals Cost or Disposal Cost/Event ($)	Total cost per visit (<3 acres) ($)	Total cost per visit (>3 acres) ($)	Total cost per year (<3 acres) ($)	Total cost per year (>3 acres) ($)
Major	Drain time	Drain time exceeds 96 hours	Visual observation	Annually, 96 hours after a target storm event	Drain facility. Remove and dispose of sediment, trash and debris. Check orifice. Notify engineer to consider removing top 2 inches of media and dispose of sediment. Restore media depth to 18 inches when overall media depth drops to 12 inches. Complete prior to wet season. (expected every 6 years)	0.2	8.0	8.0	3	$ 74.97	Utility Truck	$ 14.39		$ 1,914	$ 1,914	$ 319	$ 319
Major	Sediment Management	Sediment depth exceeds 10% of volume within sedimentation chamber.	Measure depth at apparent maximum and minimum accumulation of sediment. Calculate average depth	Annually, prior to start of wet season	Remove and properly dispose of sediment. Regrade if necessary. (expected every 35 years)	0.03	8.0	16.0	3	$ 74.97	Utility Truck, 10-15 yd Truck, Backhoe	$ 56.02	$ 400.00	$ 2,647	$ 5,895	$ 76	$ 168
Major	Underdrains	Evidence of Clogging	Visual Observation	Annually, prior to start of wet season	Corrective action prior to wet season. Consult engineers if immediate solution is not evident.	1.0	0.5	0.5	2	$ 74.97	Utility Truck	$ 14.39		$ 82	$ 82	$ 82	$ 82
Minor	Trash and Debris	Trash and Debris present	Visual observation	Annually, prior to start of wet season	Remove and dispose of trash and debris	1.0	2.0	2.0	2	$ 74.97	Utility Truck	$ 14.39		$ 329	$ 329	$ 329	$ 329
Minor	General Maintenance Inspection	Inlet structures, outlet structures, filter fabric, significant erosion, burrows, emergence of trees or woody vegetation, graffiti or vandalism, fence damage, etc.	Visual observation	Annually, prior to start of wet season	Corrective action prior to wet season. Consult engineers if immediate solution is not evident.	1.0	1.0	2.0	2	$ 74.97	Utility Truck	$ 14.39		$ 164	$ 329	$ 164	$ 329
Minor	Reporting					1.0	3.0	3.0	1	$ 74.97				$ 225	$ 225	$ 225	$ 225
					Average Annual Total		14.7	17.4								$ 1,195	$ 1,452

	Hours per Event (< 3 acre)	Hours per Event (> 3 acre)	Total cost per year (<3 acres) ($)	Total cost per year (>3 acres) ($)
Less than 3 acre Minor Maintenance	9.0		$ 718	
Less than 3 acre Major Maintenance	5.7		$ 477	
Greater than 3 acre Minor Maintenance		11.0		$ 882
Greater than 3 acre Major Maintenance		6.4		$ 570

Labor Rate	$74.97/hr

Equipment	Equipment Cost
Utility Truck	$14.39/hr
10-15 yd truck	$28.27/hr
Backhoe	$13.36/hr
Sweeper	$123.26/hr
	$53.97/hr

BMP: Vegetated Swale
MAINTENANCE ACTIVITIES

Minor / Major Maintenance	ROUTINE ACTION	MAINTENANCE INDICATOR	FIELD MEASUREMENT	MEASUREMENT FREQUENCY	MAINTENANCE ACTIVITY	Frequency (# of times per year)	Hours per Event (< 3 acre)	Hours per Event (> 3 acre)	Average Labor Crew Size	Avg. (Pro-Rated) Labor Rate/Hr. ($)	Equipment	Equipment Cost/Hour ($)	Materials & Incidentals Cost or Disposal Cost/Event ($)	Total cost per visit (<3 acres) ($)	Total cost per visit (>3 acres) ($)	Total cost per year (<3 acres) ($)	Total cost per year (>3 acres) ($)
Major	Vegetation Repair	Less than 90 percent coverage in strip invert/swale or less than 70 percent on swale side slope	Visual observation	Annually, prior to start of wet season	Reseed/revegetate barren spots prior to wet season.	1.0	2.0	4.0	2	$ 74.97	Utility Truck	$ 14.39	$ 150.00	$ 479	$ 1,182	$ 479	$ 1,182
Major	Sediment Management	Sediment at or near vegetation height, channeling of flow, inhibited flow due to change in slope.	Measure depth at apparent maximum and minimum accumulation of sediment. Calculate average depth	Annually, prior to start of wet season	Remove and properly dispose of sediment. If flow is channeled regrade as necessary. (expected every 30 years)	0.0	4.0	8.0	2	$ 74.97	Utility Truck, 10-15 yd Truck, Backhoe	$ 56.02	$ 300.00	$ 1,124	$ 2,698	$ 37	$ 90
Minor	Vegetation Management for Aesthetics (optional)	Average vegetation height greater than 12-inches, emergence of trees or woody vegetation,	Visual observation and random measurements through out the side slope area	Once during wet season, once during dry season.(depending on growth)	Cut vegetation to an average height of 6-inches and remove trimmings. Remove any trees, or woody vegetation.	2.0	1.0	2.0	2	$ 74.97	Utility Truck	$ 14.39	$ 50.00	$ 214	$ 504	$ 429	$ 1,007
Minor	Trash and Debris	Trash and Debris present	Visual observation	Annually, prior to start of wet season	Remove and dispose of trash and debris	1.0	1.0	1.0	2	$ 74.97	Utility Truck	$ 14.39		$ 164	$ 164	$ 164	$ 164
Minor	General Maintenance Inspection	Inlet structures, outlet structures, side slopes or other features damaged, significant erosion, burrows, emergence of trees or woody vegetation, graffiti or vandalism, fence damage, etc.	Visual observation	Annually, prior to start of wet season	Corrective action prior to wet season. Consult engineers if immediate solution is not evident.	1.0	1.0	2.0	2	$ 74.97	Utility Truck	$ 14.39		$ 164	$ 329	$ 164	$ 329
Minor	Reporting					1.0	3.0	3.0	1	$ 74.97				$ 225	$ 225	$ 225	$ 225
					Average Annual Total		15.3	25.5								$ 1,498	$ 2,997

Labor Rate	$74.97/hr

Equipment	Equipment Cost
Utility Truck	$14.39/hr
10-15 yd truck	$28.27/hr
Backhoe	$13.36/hr
Vactor	$62.70/hr
Sweeper	$123.26/hr

	Hours (< 3 acre)	Hours (> 3 acre)	Total cost per year (<3 acres)	Total cost per year (>3 acres)
Less than 3 acre Minor Maintenance	11.0		$ 982	
Less than 3 acre Major Maintenance	4.3		$ 516	
Greater than 3 acre Minor Maintenance		17.0		$ 1,725
Greater than 3 acre Major Maintenance		8.5		$ 1,272

BMP: Wet Pond
MAINTENANCE ACTIVITIES

Minor / Major Maintenance	ROUTINE ACTION	MAINTENANCE INDICATOR	FIELD MEASUREMENT	MEASUREMENT FREQUENCY	MAINTENANCE ACTIVITY	Frequency (# of times per year)	Hours per Event (< 3 acre)	Hours per Event (> 3 acre)	Average Labor Crew Size	Avg. (Pro-Rated) Labor Rate/Hr. ($)	Equipment	Equipment Cost/Hour ($)	Materials & Incidentals Cost or Disposal Cost/Event ($)	Total cost per visit (<3 acres) ($)	Total cost per visit (>3 acres) ($)	Total cost per year (<3 acres) ($)	Total cost per year (>3 acres) ($)
Major	Vegetation Management	Vegetation coverage / density impeding flow	Visual, visible vegetation growth or emergent vegetation growth	Annually, prior to start of wet season	1. Have a biologist survey the wet pond to determine if any birds are nesting or other sensitive animals are present. If birds are nesting, with advice from the biologist, proceed with the maintenance. 2.Lower and maintain the water level to expose the area to be maintained, do not completely drain basin. 3. Mechanically remove all plants vegetation. 4. Dispose of the vegetation material in a landfill or other appropriate disposal area. 5. Restock mosquito fish as recommended by vector control agency.	1.0	24.0	40.0	4	$ 74.97	Utility Truck, 10-15 yd Truck	$ 42.66	$ 200.00	$ 8,421	$ 14,402	$ 8,421	$ 14,402
Major	Sediment Management	Sediment depth exceeds 10% of the forebay	Measure depth of sediment.	Annually, prior to start of wet season	Remove and properly dispose of sediment. Prior to start of wet season, restore vegetation to the plan shown on the as-built drawings. (expected every 5 years)	0.2	16.0	24.0	4	$ 74.97	Utility Truck, 10-15 yd Truck, Backhoe	$ 56.02	$ 600.00	$ 6,294	$ 10,642	$ 1,259	$ 2,128
Minor	24-hour draw down measured between the rim of the outlet structure and invert of the WQ orifice in the outlet structure.	Drawdown greater than 24 hours or water is flowing over weir.	Evaluate drain time from inlet and outlet flow data loggers or observe 24 hours after design storm (0.60 in) Observation of water flowing over spillway.	Once during wet season and after completion or modification of the facility,	If greater than 24 hours then discharge water to permanent pool elevation, clear outlet of debris. Notify engineer if needed.	1.0	2.0	2.0	2	$ 74.97	Utility Truck	$ 14.39		$ 329	$ 329	$ 329	$ 329
Minor	Trash and Debris	Trash and Debris present	Visual observation	Annually, prior to start of wet season	Remove and dispose of trash and debris	1.0	2.0	2.0	2	$ 74.97	Utility Truck	$ 14.39		$ 329	$ 329	$ 329	$ 329
Minor	General Maintenance Inspection	Inlet structures, outlet structures, side slopes or other features damaged, significant erosion, burrows, emergence of trees or woody vegetation, graffiti or vandalism, fence damage, etc.	Visual observation	Annually, prior to start of wet season	Corrective action prior to wet season. Consult engineers if immediate solution is not evident.	1.0	1.0	2.0	2	$ 74.97	Utility Truck	$ 14.39		$ 164	$ 329	$ 164	$ 329
Minor	Reporting					1.0	3.0	3.0	1	$ 74.97				$ 225	$ 225	$ 225	$ 225
					Average Annual Total		121.8	194.2								$ 10,726	$ 17,741

Labor Rate	$74.97/hr

Equipment	Equipment Cost
Utility Truck	$14.39/hr
10-15 yd truck	$28.27/hr
Backhoe	$13.36/hr
Vactor	$62.70/hr
Sweeper	$123.26/hr

Less than 3 acre Minor Maintenance		13.0									$ 1,047	
Less than 3 acre Major Maintenance		108.8									$ 9,680	
Greater than 3 acre Minor Maintenance			15.0									$ 1,211
Greater than 3 acre Major Maintenance			179.2									$ 16,530

BMP: Wetland Channel
MAINTENANCE ACTIVITIES

Minor / Major Maintenance	ROUTINE ACTION	MAINTENANCE INDICATOR	FIELD MEASUREMENT	MEASUREMENT FREQUENCY	MAINTENANCE ACTIVITY	Frequency (# of times per year)	Hours per Event (< 3 acre)	Hours per Event (> 3 acre)	Average Labor Crew Size	Avg. (Pro-Rated) Labor Rate/Hr. ($)	Equipment	Equipment Cost/Hour ($)	Materials & Incidentals Cost or Disposal Cost/Event ($)	Total cost per visit (<3 acres) ($)	Total cost per visit (>3 acres) ($)	Total cost per year (<3 acres) ($)	Total cost per year (>3 acres) ($)
Major	Vegetation Management	Vegetation coverage / density impeding flow	Visual, visible vegetation growth or emergent vegetation growth	Annually, prior to start of wet season	1. Have a biologist survey the wetland channelto determine if any birds are nesting or other sensitive animals are present. If birds are nesting, with advice from the biologist, proceed with the maintenance. 2.Mechanically remove all plants vegetation. 3. Dispose of the vegetation material in a landfill or other appropriate disposal area.	1.0	16.0	24.0	4	$ 74.97	Utility Truck, 10-15 yd Truck	$ 42.66	$ 200.00	$ 5,681	$ 8,921	$ 5,681	$ 8,921
Major	Sediment Management	Sediment depth exceeds 10% of the facility design	Measure depth of sediment.	Annually, prior to start of wet season	Remove and properly dispose of sediment. Prior to start of wet season, restore vegetation to the plan shown on the as-built drawings. (expected every 50 years)	0.02	40.0	60.0	4	$ 74.97	Utility Truck, 10-15 yd Truck, Backhoe	$ 56.02	$ 600.00	$ 14,836	$ 23,454	$ 297	$ 469
Minor	Trash and Debris	Trash and Debris present	Visual observation	Annually, prior to start of wet season	Remove and dispose of trash and debris	1.0	2.0	2.0	2	$ 74.97	Utility Truck	$ 14.39		$ 329	$ 329	$ 329	$ 329
Minor	General Maintenance Inspection	Inlet structures, outlet structures, side slopes or other features damaged, significant erosion, burrows, emergence of trees or woody vegetation, graffiti or vandalism, fence damage, etc.	Visual observation	Annually, prior to start of wet season	Corrective action prior to wet season. Consult engineers if immediate solution is not evident.	1.0	1.0	2.0	2	$ 74.97	Utility Truck	$ 14.39		$ 164	$ 329	$ 164	$ 329
Minor	Reporting					1.0	3.0	3.0	1	$ 74.97				$ 225	$ 225	$ 225	$ 225
					Average Annual Total		**76.2**	**111.8**								**$ 6,695**	**$ 10,272**

Labor Rate	$74.97/hr

Equipment	Equipment Cost
Utility Truck	$14.39/hr
10-15 yd truck	$28.27/hr
Backhoe	$13.36/hr
Vactor	$62.70/hr
Sweeper	$123.26/hr

Less than 3 acre Minor Maintenance		**9.0**								**$ 718**	
Less than 3 acre Major Maintenance		**67.2**								**$ 5,977**	
Greater than 3 acre Minor Maintenance			**11.0**								**$ 882**
Greater than 3 acre Major Maintenance			**100.8**								**$ 9,390**

BMP: Wetland Basin
MAINTENANCE ACTIVITIES

Minor / Major Maintenance	ROUTINE ACTION	MAINTENANCE INDICATOR	FIELD MEASUREMENT	MEASUREMENT FREQUENCY	MAINTENANCE ACTIVITY	Frequency (# of times per year)	Hours per Event (< 3 acre)	Hours per Event (> 3 acre)	Average Labor Crew Size	Avg. (Pro-Rated) Labor Rate/Hr. ($)	Equipment	Equipment Cost/Hour ($)	Materials & Incidentals Cost or Disposal Cost/Event ($)	Total cost per visit (<3 acres) ($)	Total cost per visit (>3 acres) ($)	Total cost per year (<3 acres) ($)	Total cost per year (>3 acres) ($)
Major	Vegetation Management	Vegetation coverage / density impeding flow	Visual, visible vegetation growth or emergent vegetation growth	Annually, prior to start of wet season	1. Have a biologist survey the wet basin to determine if any birds are nesting or other sensitive animals are present. If birds are nesting, with advice from the biologist, proceed with the maintenance. 2.Lower and maintain the water level to expose the area to be maintained, do not completely drain basin. 3. Mechanically remove all plants vegetation. 4. Dispose of the vegetation material in a landfill or other appropriate disposal area. 5. Restock mosquito fish as recommended by vector control agency.	1.0	24.0	40.0	4	$ 74.97	Utility Truck, 10-15 yd Truck	$ 42.66	$ 200.00	$ 8,421	$ 14,402	$ 8,421	$ 14,402
Major	Sediment Management	Sediment depth exceeds 10% of the facility design	Measure depth of sediment.	Annually, prior to start of wet season	Remove and properly dispose of sediment. Prior to start of wet season, restore vegetation to the plan shown on the as-built drawings. (expected every 50 years)	0.02	40.0	60.0	4	$ 74.97	Utility Truck, 10-15 yd Truck, Backhoe	$ 56.02	$ 600.00	$ 14,836	$ 23,454	$ 297	$ 469
Minor	Trash and Debris	Trash and Debris present	Visual observation	Annually, prior to start of wet season	Remove and dispose of trash and debris	1.0	2.0	2.0	2	$ 74.97	Utility Truck	$ 14.39		$ 329	$ 329	$ 329	$ 329
Minor	General Maintenance Inspection	Inlet structures, outlet structures, side slopes or other features damaged, significant erosion, burrows, emergence of trees or woody vegetation, graffiti or vandalism, fence damage, etc.	Visual observation	Annually, prior to start of wet season	Corrective action prior to wet season. Consult engineers if immediate solution is not evident.	1.0	1.0	2.0	2	$ 74.97	Utility Truck	$ 14.39		$ 164	$ 329	$ 164	$ 329
Minor	Reporting					1.0	3.0	3.0	1	$ 74.97				$ 225	$ 225	$ 225	$ 225
					Average Annual Total		108.2	175.8								$ 9,436	$ 15,753

Labor Rate	$74.97/hr

Equipment	Equipment Cost
Utility Truck	$14.39/hr
10-15 yd truck	$28.27/hr
Backhoe	$13.36/hr
Vactor	$62.70/hr
Sweeper	$123.26/hr

	Hours per Event (< 3 acre)	Hours per Event (> 3 acre)	Total cost per year (<3 acres) ($)	Total cost per year (>3 acres) ($)
Less than 3 acre Minor Maintenance	9.0		$ 718	
Less than 3 acre Major Maintenance	99.2		$ 8,718	
Greater than 3 acre Minor Maintenance		11.0		$ 882
Greater than 3 acre Major Maintenance		164.8		$ 14,871

Appendix D – Annotated Bibliography of Post-Construction Stormwater Treatment BMP Research Underway or Initiated in the Last 24 Months

Appendix D – Annotated Bibliography of Post-Construction Stormwater Treatment BMP Research Underway or Initiated in the Last 24 Months

Annotated bibliographies are provided for the following five research categories:

- BMP Selection and Design
- BMP Performance Monitoring
- Volume Reduction and Impacts of Infiltration
- Economics of BMP Implementation
- Watershed Mitigation Approaches

While some non-DOT research is presented below, the focus of the summarized research is related to post-construction highway runoff management. The list of identified studies is not exhaustive – it is intended to provide a sampling of the relevant research in this area. Many of the summarized efforts below include much more exhaustive literature reviews of various elements of post-construction stormwater discharge control.

1.1 BMP Selection and Design

National Cooperative Highway Research Program (in process). Synthesis 20-05/Topic 43-06: Pollutant Load Reductions for Total Maximum Daily Load (TMDL) Reductions for Highways. http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3216.

This study gathered information on TMDL practices used by many sectors, including DOTs and other sectors, nationally and internationally, to determine effective practices for highway applications. It developed a tool box of traditional stormwater control practices as well as alternative practices and maintenance activities that can be employed by state DOTs for compliance and tracking. The study provided a detailed summary of findings for all practices identified, including descriptions of applicability to highways, design standards, site development criteria, potential impacts to the environment or cultural resources, types of pollutants treated, costs associated with implementation, and maintenance requirements. It documented survey responses and synthesized the responses into useful categories for conveying significant results. The study also identified websites, other locations of information and significant documents and provided sources for obtaining the documents.

National Cooperative Highway Research Program (in process). Project 25-32: Measuring and Removing Dissolved Metals from Storm Water in Highly Urbanized Areas. http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2737.

In NCHRP Project 25-32, the research team is developing accurate and scientifically defensible testing protocols to provide a reliable and repeatable measure of dissolved metals content in stormwater. Further, the team is developing conceptual design specifications for at least two cost-effective stormwater treatment practices that could be used to effectively remove dissolved metals in highly urbanized areas. The treatments should be able to meet or surpass the removal levels required by typical current environmental regulations. The conceptual designs will address different degrees of complexity in the urban environment; for example, one to address areas near steep embankments or areas with 50-75% impervious surface, and another to address the most difficult cases with 75-100% impervious surface. Each can consist of an individual treatment or treatment train as required to meet the dissolved metals reduction objectives.

Limouzin, M., Lawler, D. & Barrett, M. (2012, August). CRWR Online Report 10-5: Performance Comparison of Stormwater Biofiltration Designs. http://www.crwr.utexas.edu/reports/pdf/2010/rpt10-05.pdf.

A biofiltration system is a stormwater BMP that uses a biologically active filtration bed to remove contaminants. This type of BMP is preferred because it provides the opportunity for pollutant uptake (particularly nutrients) by vegetation in an aesthetically pleasing design. The goals of this research, proposed by the City of Austin, Texas, are to assess the role of plants in nutrient removal and to compare the pollutant removal effectiveness of biofiltration systems containing different media, plant species, and designs. A laboratory column study was conducted with 19 experiments using synthetic stormwater and one experiment using real stormwater. The results of this study show a significant improvement in nutrient removal with the presence of plants and a submerged zone with a carbon source in the filter. The columns without plants were found to export up to twice the nitrate/nitrite input, whereas the columns with plants showed significant removal of all nutrients (Nitrate 30-50%, Total Kjeldahl Nitrogen 65-85%, Total Phosphorus 80-90%). The difference between the two biofiltration media was not significant. Metals (Copper, Lead, Zinc) removal by all columns was very high (>95%) compared to similar field studies. Total Suspended Solids removal remained high through the whole set of experiments for all the columns (85-95%).

National Cooperative Highway Research Program (in process). Project 25-42: Bridge Stormwater Runoff Analysis and Treatment Options. http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3194.

Currently, most bridge stormwater runoff discharges directly without treatment to the water bodies below. While many state DOTs and local agencies are required to provide treatment to the runoff from on-grade pavements, collection and treatment or other mitigation strategies for bridge runoff management pose particular challenges. In particular, BMPs for on-grade pavement may have limited effectiveness when applied to bridges. For example, some research suggests that bridge runoff may carry different concentrations of particulate and dissolved constituents than comparable runoff from adjoining on-grade roadways. In addition, bridges account for a very small portion of the highway systems' runoff. Addressing increasingly stringent highway runoff regulatory requirements by applying on-grade runoff management practices to bridges is not only costly but may compromise worker and road-user safety with undetermined benefits to water quality. Guidance on BMPs for bridge runoff may then differ substantially from what is likely to be effective for on-grade pavements. NCHRP 25-42 will provide current knowledge regarding bridge runoff and its impact on receiving waters and identify practices in use, pointing to those which appear to be effective and beneficial, building on NCHRP Report 474: Assessing the Impacts of Bridge Deck Runoff Contaminants in Receiving Waters (Volumes 1 and 2) and NCHRP Report 565: Evaluation of Best Management Practices for Highway Runoff Control. NCHRP 25-42 is pulling together the information from disparate sources, resolving apparent inconsistencies or conflicting findings, and extracting effective guidance for management of stormwater runoff from bridges. The research team will develop a guide, for DOTs and others, for managing bridge runoff to protect environmental quality and meet regulatory requirements.

National Cooperative Highway Research Program (2012). Project 25-31: Guidelines for Evaluating and Selecting Modifications to Existing Roadway Drainage Infrastructure to Improve Water Quality in Ultra-Urban Areas. NCHRP Report 728 http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=1642.

The transportation community is faced with a need to reduce pollutant loadings from existing facilities to achieve watershed TMDLs or to meet other regulatory requirements. Existing infrastructure was designed for efficient drainage and flood control, and offers several possibilities for retrofits to enhance water quality.

NCHRP Report 728 provides guidelines to evaluate and select hydraulic modifications to existing drainage infrastructure that will help mitigate potential impacts of highway runoff on receiving waters. The guidelines are directed specifically at roadway facilities in dense urban areas that can be particularly difficult and costly to retrofit because of space limitations, high pollutant loadings, hydrologic flashiness, hydraulic constraints, legacy contamination, utility conflicts, and other issues. They will assist transportation agencies in meeting regulatory requirements under the Clean Water Act, National Pollutant Discharge Elimination System (NPDES) permits, Total Maximum Daily Load (TMDL) allocations, endangered species protection, and watershed protection initiatives. The guidelines are accompanied by a Microsoft® Excel-based design and sizing tool on a CD-ROM bound into the back of this report. The tool generates best management practice (BMP) performance curves that relate the performance and design criteria for selected BMP controls described in the guidelines for each of the 15 U.S. rain zones. One of the significant features of the tool is that it allows users to explore BMP performance and retrofit sizing and design options based on user-selected design criteria and inputs. The guidelines will be of particular interest to planners, designers, and engineers with a basic understanding of the technical issues of BMP selection and design as applied to ultra-urban retrofit settings.

1.2 BMP Performance Monitoring and Analyses

Poresky, A., Bracken, C., Strecker, E. & Clary, J. (2012, May). International Stormwater Best Management Practices (BMP) Database Addendum 1 to Volume Reduction Technical Summary (January 2011) Expanded Analysis of Volume Reduction in Bioretention BMPs. http://www.bmpdatabase.org/Docs/Bioretention Volume Reduction Addendum 5 31 12.pdf.

Since the preparation of the 2011 report, many new studies have been added to the Database. The bioretention category has had the most substantial growth, expanding from 7 studies to 20 studies considered appropriate for volume-related analysis. Additionally, the bioretention category generally includes studies for which volume reduction was a primary study objective. For these reasons, a re-analysis of this expanded bioretention dataset has been undertaken and is provided in this Addendum. In addition to updating the bioretention analyses conducted in 2011, this Addendum presents the results of several additional types of visualizations, statistics, and regression analyses related to volume.

Barrett, M. (2012, October). CRWR Online Report 10-7: Evaluation of Sand Filter Performance. http://www.crwr.utexas.edu/reports/pdf/2010/rpt10-07.pdf.

The City of Austin has required the use of sand filters for many years to mitigate the impacts of urban stormwater runoff. Through those years, a number of monitoring efforts have been undertaken to understand the level of pollutant reduction achieved. The objective of this report is to compare the performance of five facilities that differ substantially in their design, to determine the impact on pollutant removal. This analysis found that design factors such as pretreatment, maximum water depth, and filter area have little effect on pollutant removal. Pollutant removal was also not a function of time, indicating that the accumulation of material on and within the filter had little impact on water quality. The discharge from the facilities exhibited a distinct first flush that might be attributed to the accumulation of sediment and associated pollutants in the underdrain system at the end of storm events. The exception was nitrate, which had a first flush that was correlated with the time since the last event, indicating nitrification was occurring in the filter. In general, removal efficiency and discharge concentration were not consistently related to the hydraulic residence time. Consequently, reaction kinetics did not appear to be a limiting factor in pollutant removal.

California Department of Transportation (2012, June). Evaluation of Storm Water Data Reports for Fiscal Year 2011/2012. http://www.dot.ca.gov/hq/oppd/stormwtr/Studies/Final-Summary-Report-06-28-2012.pdf.

This report summarizes the independent quality assurance/quality control (QA/QC) reviews conducted in fiscal year (FY) 2011/12 on a total of 50 Storm Water Data Reports (SWDRs) prepared during FY 2010/11. The reviews were performed to evaluate whether the SWDRs have been prepared in accordance with the current version of the Project Planning and Design Guide (PPDG) (July 2010), which facilitates compliance with the Caltrans NPDES Permit (Order No.1999-06-DWQ, NPDES No. CAS00003), the Storm Water Management Plan (May 2003), and the Construction General Permit (Order No. 2009-009-DWQ). Based on the review of the information provided, all the SWDRs (100%) prepared by or for Caltrans, based on this sampling, conform to the requirements. The SWDRs reviewed were based on projects at the Plans, Specifications, and Estimates (PS&E) phase and were primarily Long Forms (49 of the 50 SWDRs reviewed) with net new impervious area. In addition to an overall review of SWDRs, another focus was to confirm that Districts are using the new T-1 checklist and to determine if existing infiltration features or design pollution prevention BMPs could benefit stormwater treatment.

Clary, J. & Leisenring, M. (2012, July). International Stormwater Best Management Practices (BMP) Database Narrative Overview of BMP Database Study Characteristics. http://www.bmpdatabase.org/Docs/Simple Summary BMP Database July 2012 Final.pdf.

This document provides a condensed overview of the types of studies and data contained in the BMP Database and identifies some of the areas with data gaps. The audience for this document is primarily researchers who will find it useful to have a quick snapshot of basic information about various BMP categories such as how many studies are available, whether category-level data sets are adequately developed for purposes of analyses, the geographic distribution of the data, age of BMP designs, age and duration of the BMP monitoring period, and related information. This document is also intended to provide an initial framework for identifying data categories that may be appropriate for further in-depth analysis with regard to BMP design and watershed factorial analysis.

Eck, B., Klenzendorf, J., Charbeneau, R. & Barrett, M. (2010). Investigation of Stormwater Quality Improvements Utilizing Permeable Friction Course. Center for Transportation Research, University of Texas at Austin.
http://www.utexas.edu/research/ctr/pdf_reports/0_5220_2.pdf.

This report describes research into the water quality and hydraulics of the Permeable Friction Course (PFC). Water quality monitoring of three locations in the Austin area indicates up to a 90% reduction in pollutant discharges from PFC compared to conventional pavement. This reduction is the result of accumulation of pollutants within the pavement and the reduction in pollutants washed off of vehicles during storm events. The project also developed a methodology for measuring permeability of the pavement in situ. This required overcoming several instances where conventional assumptions in permeability measurements were violated. In particular, flow through the pavement at the heads evaluated was nonlinear and not consistent with Darcy's law. One dimensional steady state and two dimensional dynamic models of flow in PFC were developed. The latter model is capable of predicting surface and subsurface flow from highways of various geometries.

Klenzendorf, J. B., Charbeneau, R. J. & Barrett, M. E. (2010, May). CRWR Online Report 10-1: Hydraulic Conductivity Measurement of Permeable Friction Course (PFC) Experiencing Two-Dimensional Nonlinear Flow Effects. http://www.crwr.utexas.edu/reports/pdf/2010/rpt10-01.pdf.

Permeable Friction Course (PFC) is a layer of porous asphalt pavement with a thickness of up to 50 millimeters overlain on a conventional impervious hot mix asphalt or Portland cement concrete roadway surface. PFC is used for its driver safety and improved stormwater quality benefits associated with its ability to drain rainfall runoff from the roadway surface. PFC has recently been approved as a stormwater best management practice in the State of Texas. The drainage properties of PFC are typically considered to be governed primarily by two hydraulic properties: porosity and hydraulic conductivity. Both of these hydraulic properties are expected to change over the life of the PFC layer due to clogging of the pore space by trapped sediment. Therefore, proper measurement of the hydraulic properties can be problematic. Laboratory and field tests are necessary for accurately determining the hydraulic conductivity of the PFC layer in order to ensure whether the driver safety and water quality benefits will persist in the future. During testing, PFC experiences a nonlinear flow relationship, which can be modeled using the Forchheimer equation. Due to the two-dimensional flow patterns created during testing, the hydraulic conductivity cannot be directly measured. Therefore, numerical modeling of the two-dimensional nonlinear flow relationship is required to convert the measureable flow characteristics into the theoretical flow characteristics in order to properly determine the isotropic hydraulic conductivity. This numerical model utilizes a new scalar quantity, defined as the hydraulic conductivity ratio, to allow for proper modeling of nonlinear flow in two-dimensional cylindrical coordinates.

Leisenring, M., Clary, J., Jeray, J. & Hobson, P. (2012, May). International Stormwater Best Management Practices (BMP) Database BMP Performance Summary: Chesapeake Bay and Related Areas. http://www.bmpdatabase.org/Docs/BMP Database Chesapeake Bay Paper May 2012_Final_wAttachments.pdf.

A targeted performance analysis of BMP Database studies located in or near the Chesapeake Bay is provided in this technical summary. As part of this effort, additional test sites and BMP studies located in or near the Chesapeake Bay watershed were identified and entered into the BMP Database. This expanded data set was used to provide a current summary and assessment of treatment effectiveness by BMP type for sediment, nitrogen, and phosphorus, as summarized in the remainder of this technical summary.

Leisenring, M., Clary, J. & Hobson, P. (2012, July). International Stormwater Best Management Practices (BMP) Database Manufactured Devices Performance Summary. http://www.bmpdatabase.org/Docs/2012 Manufactured Device Analysis/BMP Database manufactured_Devices_PerformanceSummary_Final.pdf.

The purpose of this paper is to provide a performance summary of manufactured devices contained in the BMP Database after subdividing this broad BMP category based on their dominant treatment process. This analysis does not provide summaries of manufactured device performance by manufacturer and does not provide endorsement for any particular manufactured device. Many different vendor technologies are commercially available for which there are no data currently included in the BMP Database. To be included in the BMP Database, proprietary manufactured devices must meet the conditions of the BMP Database Proprietary Device Policy (see http://www.bmpdatabase.org/Policies.htm).

Leisenring, M., Clary, J. & Hobson, P. (2012, July). International Stormwater Best Management Practices (BMP) Database Pollutant Category Summary Statistical Addendum: TSS, Bacteria, Nutrients, and Metals. http://www.bmpdatabase.org/Docs/2012

Water Quality Analysis Addendum/BMP Database Categorical_SummaryAddendumReport_Final.pdf.

In 2010, the Water Environment Research Foundation (WERF), FHWA, and the American Society of Civil Engineers' Environmental and Water Resources Institute (EWRI) co-sponsored a comprehensive stormwater BMP performance analysis technical paper series relying on data contained in the International Stormwater BMP Database. This series, published in 2011, included papers for solids, bacteria, nutrients, and metals, with each paper summarizing the regulatory context of the constituent category, primary sources, fate and transport processes, removal mechanisms, and statistical summaries of BMP performance for data contained in the International Stormwater BMP Database. This report is an update of the statistical summaries provided in that series to include the data from over 50 new studies added to the database in late 2011 after the publication of the series. This report is not intended to replace the discussion of the previous technical papers because only the statistical summaries are included.

1.3 Volume Reduction and Impacts of Infiltration

National Cooperative Highway Research Program (in process). Project 25-41: Guidance for Achieving Volume Reduction of Highway Runoff in Urban Areas. http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3193.

The research team for NCHRP Project 25-41 is developing guidelines for reducing the runoff volume from limited-access highway facilities in urban areas to meet proposed EPA regulatory requirements. The guidelines will provide assistance to state DOTs and other transportation agencies to identify or develop viable solutions that can be applied within the highway right-of-way, including typical current methods as well as new and innovative approaches appropriate for specific site conditions (e.g., soil type, climate, utilities, right-of-way constraints, and local hydrology). The project is evaluating potential solutions by comparing factors such as expected cost, performance, safety, effects on surrounding infrastructure, maintenance requirements, roadway operations, and life span. In cases where it is not feasible or practical to achieve adequate runoff volume reduction within the highway right-of-way, the guidelines are identifying and evaluating other approaches and solutions outside the highway right-of-way to reduce the volume of runoff.

National Cooperative Highway Research Program (in process). Synthesis 20-05/Topic 43-12: Reducing the Effects of Roadway Deicers on the Natural Environment. http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3222.

The study examined the availability and applicability of both structural and non-structural BMPs in minimizing the environmental impacts of deicing chemicals by 1) documenting the state of practice; 2) highlighting successes and learning from problems encountered previously; and 3) identifying cultural, managerial, technological, and other solutions to facilitating a wider application of BMPs as well as critical knowledge gaps to be addressed. Safety remains the primary goal of transportation agencies and chloride deicers are still the most efficient and cost effective means of meeting that goal. However, recognizing the environmental concerns associated with the use of chloride deicers, DOTs need effective strategies of mitigating such impacts. Chloride use and the associated environmental issues can vary by region, climate, population density, soil type, etc., so a "one-size-fits-all" approach is unlikely to work. This synthesis documented the range of strategies used by transportation agencies to minimize the environmental impact of chloride roadway deicers, lessons learned, and knowledge gaps that could be filled by future research. The scope of this study included solid and liquid chloride (sodium chloride, magnesium chloride, calcium chloride). Information gathered included mitigation strategies for:

- Handling and storage of materials, such as paved and covered storage, runoff capture, and shed design.
- Application strategies, such as improved anti-icing/de-icing/pre-wetting practices, application rates, plowing and equipment practices, and data-driven decision support.
- Controlling pavement runoff, such as the use of salt-tolerant plants to buffer roadway; controlled release of highway runoff to mitigate spikes in deicer concentrations; use of ponds, wetlands, vegetated swales and filter strips etc. to reduce the rate and contents of deicer runoff.
- Alternative methods, such as snow fences, liquid-only routes, pavement design, salt sensitive areas.
- Performance measures for monitoring the use and environmental impact of chloride deicers.
- Management strategies, such as introducing accountability for salt use, training.
- Results-based standards.

United States Geological Survey and Federal Highway Administration (in process). National Synthesis on Potential Sources, Fate and Transport, and Potential Effects of Chloride in Surface- and Groundwater Resources of the Conterminous United States. http://webdmamrl.er.usgs.gov/g1/FHWA/Cl.htm.

The U.S. Geological Survey (USGS) and the Federal Highway Administration (FHWA) are currently cooperating in a national project to evaluate Chloride in the Nation's Waters. The Chloride (Cl) ion is receiving increasing attention as population growth makes increasing demands on available water resources and anthropogenic activities increase solute loads in natural waters. Cl is a growing concern because anthropogenic inputs may increase Cl concentrations to the U.S. EPA taste criterion for potable waters (250 mg/L) and to the U.S. EPA suggested limits of 230 mg/L for chronic aquatic life exposure and 860 mg/L for acute aquatic life exposure in surface waters. The Cl ion is ubiquitous in natural waters, has a wide variety of sources, readily moves through surface and groundwaters, and is difficult to remove from runoff and water supplies. Cl concentrations in natural waters range from less than 1 mg/L in pristine water bodies without atmospheric or geologic Cl sources to about 275,000 mg/l in continental brines. This national synthesis is a cooperative effort between the USGS and FHWA designed to provide the information necessary for watershed managers to assess all potential sources of Cl in a given watershed as part of a total water and solute budget. This will include information necessary to develop a localized water budget; to develop water-quality transport curves; to estimate natural, agricultural, and anthropogenic sources of Cl; to examine interrelationships among water-quality constituents and to use the National Water Information System Web to identify and interpret available groundwater, surface-water and water-quality data. This effort also will provide a summary of field methods including geophysical techniques and automated monitoring of runoff, stream flow, and groundwater. A report is expected in 2014.

1.4 Economics of BMP Implementation and Maintenance

National Cooperative Highway Research Program (in process). Project 25-40: Long-Term Performance and Life-Cycle Costs of Stormwater Best Management Practices. http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3192.

This active project is developing guidelines for the selection and maintenance of highway-related stormwater Best Management Practices based on long-term performance and life-cycle costs. For each broad category of BMP type, while providing flexibility to address the local context (e.g., topography, geology, climate, urban versus rural, soil type, site constraints), the final products will provide decision-making guidance on the following:

- Defining long-term performance and selecting appropriate performance measures;
- Predicting long-term performance, service life, and maintenance costs based on the best current information and practice;
- Determining appropriate inspection schedules and procedures;
- Determining appropriate maintenance schedules and procedures;
- Incorporating long-term performance and life-cycle costs into the BMP selection process; Ensuring that funding, staffing, and training requirements are understood and considered by all relevant functional areas within the transportation agency for the selection, installation, inspection, and maintenance of BMPs; and
- Identifying life-cycle data collection and analysis protocols to facilitate future evaluation of long-term BMP performance.

To the extent possible, the researchers will also compare the long-term performance of structural BMPs to viable non-structural approaches.

Barr Engineering Company. (2011). Best Management Practices Construction Costs, Maintenance Costs, and Land Requirements. http://www.pca.state.mn.us/index.php/view-document.html?gid=17134

Barr Engineering summarized the costs for eight types of BMPs, including both construction and operating costs. BMPs evaluated included bioretention with underdrain, bioretention without underdrain, wet pond, constructed wetlands, infiltration trench/basin, underground infiltration, pervious pavement, and grass swale/channel. Data sources included publicly available data and Barr project files. Construction costs are given for 69 projects and 25 of those include data for maintenance. Individual project costs are given per ft^3 of WQV. Some BMPs showed economies of scale.

Capitol Region Watershed District (CRWD). (2012). BMP Performance and Cost-Benefit Analysis: Arlington Pascal Project 2007-2010. http://www.capitolregionwd.org/wp-content/uploads/2012/09/2007_2010_BMP_Performance_MainBody1.pdf

This report summarizes a project in Minnesota in which 18 BMPs were constructed to reduce volume and pollutant loading. Design, construction and O&M costs for these BMPs are detailed and broken down by BMP type. BMPs included in the project included underground and infiltration practice, a stormwater pond, 8 underground infiltration trenches, and 8 rain gardens. Costs are given per ft^3 of storage volume. An expected life of 35 years is used for calculations.

Flynn, K., Linkous, B. & Buechter. M. (2012). Operation and Maintenance Assessment for Structural Stormwater BMPs. http://www.ewri-swi.org/minutes/task_comm/EWRI_Paper_BMP_Maintenance_Task_Committee_2012.pdf

The ASCE/EWRI Stormwater BMP Maintenance Task Committee performed a literature review and created a national survey on the topic of effectiveness of BMP O&M practices in the U.S. It found that the level of O&M guidance provided for wastewater facilities (e.g. in-person training and significant written documentation) is rarely provided for stormwater facilities, but that some states and local governments are beginning to make maintenance a legal requirement. Maintenance guidelines and protocols are discussed for major classes of BMPs.

This report also provides a more detailed review of three BMP maintenance cost studies:

- BMP Retrofit Pilot Program Final Report (Caltrans 2010) (CTSW-RT-01-050) – Shows annual maintenance costs, but study period wasn't long enough to include major maintenance work like sediment removal, etc. Costs given per m^3 of BMP storage volume.

- Philadelphia Water Department Green Infrastructure Maintenance and Monitoring program. – Gives a cost range for 4 BMP types. Ranges are very widely spread and costs are listed in cost per ft^2 of impervious area. (PWD Green Infrastructure Maintenance and Monitoring Program, 2010 Annual Report)

Maintenance for Stormwater Treatment Practices (Erickson et al. 2010) – Surveyed MN and WI cities/counties on stormwater BMP maintenance practices and maintenance costs. Includes sediment removal costs. http://onlinelibrary.wiley.com/doi/10.1111/j.1936-704X.2010.00393.x/pdf

Houle, J., Roseen, R., Ballestero, T., Puls, T., Sherrard, J. (in press). A Comparison of Maintenance Cost, Labor Demands, and System Performance for LID and Conventional Stormwater Management. (Accepted for publication – Journal of Environmental Engineering).

Houle, et al. used a 4.5-acre commuter parking lot at the University of New Hampshire Stormwater Center as a stormwater source for several uniformly sized BMPs run in parallel. These BMPs included a vegetated swale, a wet pond, a dry pond, a sand filter, a subsurface gravel wetland, three bioretention systems (averaged), and porous asphalt.

Operations and maintenance demands (labor hours, costs, task type, and complexity) and pollutant removal were recorded for these BMPs. Costs are presented on a per watershed area treated and per mass of pollutant removed basis. Annualized maintenance costs were found to be lower for vegetated filtration systems and porous asphalt than for wet or dry ponds

O'Connor, T. P., Muthukrishnan, S., Barshatzky, K. & Wallace, W. (2012). Trace metal accumulation in sediments and benthic macroinvertebrates before and after maintenance of a constructed wetland. Water Environment Research, Volume 84, Number 4, pp. 370 - 381. http://www.ingentaconnect.com/content/wef/wer/2012/00000084/00000004/art00011.

Stormwater BMPs require regular maintenance. The impact on trace metal concentrations in a constructed stormwater wetland BMP on Staten Island, New York, was investigated by analyzing sediment concentrations and tissue residues of the dominant macroinvertebrates (*Tubifex tubifex*) prior and subsequent to maintenance. Trace metal concentrations were assessed using standard serial extraction (for sediment) and acid digestion (for tissue burdens) techniques, followed by quantitative determination using graphite furnace atomic absorption spectrometry and inductively coupled plasma optical emission spectrometry, respectively. The results suggest that disturbance of sediment during maintenance of the BMP resulted in an increase in the most mobile fraction of trace metals, especially those associated with finer grained sediments (< 63 µm), and as a consequence, measured metal concentrations in macroinvertebrates increased. Regressions of a subset of metal concentrations (copper, lead, and zinc) in sediment and the macroinvertebrate tissue burden samples generally increased as a result of maintenance. A follow-up sampling event 9 months after maintenance demonstrated that the most readily available form of trace metal in the BMP was reduced, which supports (1) long-term sequestration of metals in the BMP and (2) that elevated bioavailability following maintenance was potentially a transient feature of the disturbance. This study suggests that in the long-term, performing sediment removal might help reduce bioavailability of trace metal concentrations in both the BMP and the receiving water to which a BMP discharges. However, alternative practices might need to be implemented to reduce trace metal bioavailability in the short-term.

Sample, D., Heaney, J., Wright, L. Chi-Yuan Fan, Fu-Hsiung Lai, & Field, R. (2003). Costs

1.5 Watershed Planning and Mitigation Approaches

National Cooperative Highway Research Program (in process). Project 25-37: A Watershed Approach to Mitigating Stormwater Impacts.
http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3189.

State DOTs are exploring a variety of approaches and regulatory mechanisms to achieve compliance with water quality permits that are based on watershed-based Total Maximum Daily Load limitations and receiving water quality standards. The current legislative and regulatory climate has placed a spotlight on watershed protection, stormwater pollutant reduction, and hydrologic impairment, and state DOTs and natural resource and regulatory agencies have begun to consider watershed approaches to regulatory compliance in transportation project construction and system operations and maintenance. While the potential environmental benefits of the approach justify its use, in highly urbanized areas, DOTs sometimes simply have no space in the right-of-way for surface treatment. Nearby options may also be limited, and thus additional approaches to accomplishing mitigation requirements are needed, including off-site mitigation and non-traditional techniques and strategies that allow greater environmental benefits to be achieved. The NCHRP 25-37 research team is developing a comparative decision-making framework, based on watershed needs, to enable DOTs to identify and implement cost-effective and environmentally beneficial water quality solutions for stormwater impacts. The product will also include a toolbox of feasible water quality solutions for stormwater impacts.