BMP-REALCOST

Best Management Practices – Rational Estimation of Actual Likely Costs of Stormwater Treatment

A SPREADSHEET TOOL FOR EVALUATING BMP EFFECTIVENESS AND LIFE CYCLE COSTS

User's Manual and Documentation

Version 1.0

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Prepared by:

Chris Olson
Larry A. Roesner
Colorado State University
Department of Civil and Environmental Engineering
Fort Collins, CO 80523

&

Ben Urbonas
Urban Watersheds Research Institute
Denver, CO

&

Ken MacKenzie
Urban Drainage Flood Control District
2480 West 26th Avenue
Suite 156-B
Denver, Colorado 80211

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1. INTRODUCTION

This section includes important information related to the purpose, development and appropriate use of the model.

1.1. Disclaimer

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1.2. History and Revisions

<u>BMP Whole Life Cycle Cost Effectiveness Analysis Tool - Version 1.0</u> (released August 2009) - Prepared by Chris Olson (Colorado State University) with Ben Urbonas (Urban Watersheds Research Institute), Dr. Larry Roesner (Colorado State University) and Ken MacKenzie (Urban Drainage Flood Control District).

<u>BMP-REALCOST – Version 1.0</u>

This model supersedes the previously-unnamed version 1.0 released in August 2009.

- Permeable pavements now applied as site control BMPs instead of source controls.
- Changed land cost computations to be a function of the BMP size using the land consumption coefficient (C_{LC}) which relates the area of land consumed to the size of the BMP.
- BMP capture efficiency can now be edited by user on "RunoffMitigation" worksheet

- Rehabilitation/replacement costs are now amortized based on the number of years of benefits that follow each occurrence. Generally this results in lower net present costs than computed in previous versions.
- Some land costs were revised to better reflect Denver-area costs.
- Column for maintenance activity "beta" values were added to maintenance cost tables
- Cost charts were revised to show annual costs and cumulative costs
- New chart was added to display scenario runoff reduction effectiveness

1.3. BMP-REALCOST Overview

BMP-REALCOST was developed to assist engineers, planners, developers, consultants and decision makers in determining the life cycle costs and effectiveness of structural stormwater runoff best management practices (BMP) as they are applied within an urban/suburban setting. The intent of this model is to provide the practicing professional and decision maker with facts and fiscal information on what effects their choices will have on the economic and environmental resources of the owners and/or the municipality within which systems of stormwater management BMPs are implemented. The decisions made to select the types of BMPs within a municipality and its new developments/redevelopments will have many long-term ramifications that include (1) the effectiveness in the protection of the receiving waters, (2) long-term cost of operating and maintaining the BMPs, and (3) the administrative costs that the municipality will need to budget for over the years to make sure that the BMPs deployed within its boundaries continue to function as originally designed.

This model is built into Microsoft Excel format and many of the operations are performed using macros written in Visual Basic for Applications. The model operates by first having the user input information describing the physical characteristics of a watershed that affect runoff quality and quantity (e.g., contributing area, land use, imperviousness, etc.). Second, the user enters information that describes what type(s) of BMP(s) will be applied to the watershed/development and the area (number of impervious acres) from which each BMP will receive runoff. Next the user decides whether to use default cost and BMP effectiveness values, or input their own. The model then takes the user-entered (or default) information and estimates the size of each BMP, determines the number of BMP(s) needed to treat the watershed, produces estimates of average annual runoff quality and quantity for the entire watershed/development, and calculates life cycle costs for the BMP(s) selected.

1.4. Appropriate Use

The model was developed as a planning-level tool, where some output accuracy is sacrificed in order to make the model easy-to-use and require minimal data inputs. As such, the model uses several simplifying assumptions which are further described within this report. <u>The results should not be used as a substitute for, or as a comparative resource for, final BMP designs, more intensive rainfall/runoff modeling techniques or "engineer's estimates".</u>

The model was developed using many of the recommendations and methods provided in the Urban Drainage Flood Control District's (UDFCD) Urban Storm Drainage Criteria Manual (USDCM) (UDFCD 2004), therefore this model should only be applied to areas where the USDCM design criteria are valid.

1.5. Assumptions

The following are fundamental assumptions used in developing the model.

1. The user has adequate knowledge of stormwater management to apply BMPs appropriately, considering the land use and relative size of BMP. For example, the effectiveness results of applying a sediment/oil/grease separator (SOG) to a residential area may indicate that loading of certain constituents (such as metals or oils) will actually increase after the BMP is installed. This could occur because SOGs are typically installed in areas where high influent metals and oil loads exist and although the SOG may remove some of the metals, a relatively high concentration may be measured in the effluent. If the effluent concentration is greater than the influent concentration, an apparent increase would result. In addition, specifying a BMP to treat an area much larger or smaller than is typically specified could cause both the costs and effectiveness to be highly inaccurate.

2. BMPs with water quality capture volume (WQCV) are assumed to effectively treat 85% of the annual runoff. BMPs designed to capture the excess urban runoff volume (EURV) effectively treat 98% of the annual runoff.
3. Unless otherwise noted (with EURV naming convention), BMPs with storage volume are sized to store the water quality capture volume (WQCV) only. They do not include additional storage for larger storms.
4. Computations for peak runoff rates using the Rational Method are made using several simplifying assumptions for waterway length and conveyance length. See Section 5.4.2.
5. Values for effluent event mean concentrations were not available for all of the BMPs included in the model, therefore some values were substituted and/or assumed until better information is available.
6. Values for land use event mean concentrations were not available for all of the constituents included in the model; therefore some values were substituted and/or assumed until better information is available.
7. BMP effectiveness does not change over time. It is assumed that adequate maintenance will be performed to keep BMP effectiveness relatively consistent from year to year.
8. The default maintenance costs were developed assuming proactive maintenance (i.e. keeping facilities properly maintained), as opposed to reactive maintenance (i.e. only performing maintenance once something breaks and/or the BMP effectiveness is compromised). Through a series of interviews with agencies responsible for BMP maintenance, overall it was generally agreed upon that proactive maintenance is less costly than reactive maintenance.
9. The default costs for proprietary systems are assumed to be an average cost considering the wide variety of systems available.
10. The computed costs for permeable pavement do not account for potential cost savings from the reduced need for additional stormwater infrastructure, nor do they account for the “foregone” costs of installing and/or maintaining typical, impervious pavement. Without accounting for these cost savings, permeable pavement will always appear to be a more expensive option.

2. MODEL STRUCTURE

The model was developed using multiple worksheets within a single Excel workbook. A brief description of each worksheet is included on the "Information" worksheet that is automatically loaded each time the model is opened. The worksheet tabs are color-coded according to their intended use, as described in Table 1.

Table 1 : Explanation of worksheet tab colors

Worksheet Tab Color	Worksheet Purpose
Blue	These worksheets contain cells that require the user to input information
Purple	These worksheets contain cells that have default parameter values already defined (i.e. cost curves, event mean concentrations, etc.), but can be edited by the user if necessary.
Green	These worksheets are "Read-Only" worksheets. Editing these worksheets may adversely affect model processes.

The model requires many input parameter values, some of which must be defined by the user and others that are computed automatically by the model. Each parameter is categorized and color-coded (similar to worksheet tabs) as described in Table 2.

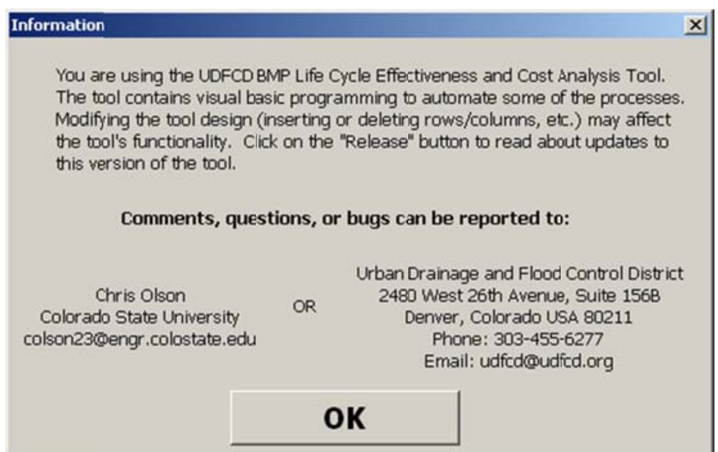
Table 2 : Explanation of cell and column colors

Cell/Column Color	Category	Purpose
Blue	User-Defined	The user must enter a value, make a selection from a drop-down box, or use the default value already entered (if available).
Green	Model-Defined	These cells/columns are "read-only" and are populated automatically by the model. Editing these cells and/or columns may adversely affect model processes.

3. GETTING STARTED

This section describes the step-by-step process for setting up and evaluating the results of the model. Being a "getting started" guide, these are the minimum steps necessary to operate the model using default values for costs and BMP effectiveness parameters. More advanced options exist for changing the default values that are used by the model and the steps for doing so are described in Section 0.

NOTE: Before getting started, ensure that macros are enabled in Microsoft Excel. Upon opening the workbook, an informational pop-up box (shown below) should appear, indicating that macros have been enabled.



3.1. Entering Required Inputs

All of the required inputs to the model are entered on the "InputParameters" worksheet under one of the following headings:

Project-Specific Precipitation and Cost Parameters

Watershed Parameters

Select Regional-Control BMP

Select Site-Control BMP

Recall from Section 2 that cells or columns color-coded in blue require the user to input a value or use the default value (if provided). Green cells or columns cannot be modified by the user.

3.1.1. Project-Specific Cost and Precipitation Parameters

The model requires several parameters for project-specific precipitation and life cycle cost calculations. Some default values have been entered that generally should be applicable to the Denver, Colorado region, however because some of these values are likely to vary from project to project it is recommended that the user review and verify the applicability of the default values before using them. Each required parameter is described below.

Project-Specific Precipitation and Cost Parameters				
Planning Horizon (yrs)	?	50	Default	Restore Default Values
Current/Regional ENR CCI	?	8141	Default	
Inflation Rate (%)	?	4.60%	Default	
Rate of Return (%)	?	5.00%	Default	
Admin. Costs as % of Maint. (%)	?	12.00%	Default	
Select Location for Precip. Values	?	Denver		
Mean Annual Precipitation (in)	?	15.8		
2-Year, 1-Hour Precipitation (in)	?	0.95		
Mean Storm Depth (in)	?	0.43	Default	

Planning Horizon

The planning horizon of the project(s) defines the time over which the net present value of the project costs will be estimated. The default value is 50 years and is the value recommended by UDFCD and other water resource organizations, recognizing the longevity of such projects and the difficulty in financing their construction.

Current ENR Construction Cost Index

The user should input the current Engineering News Record (ENR) Construction Cost Index (CCI) for the region of analysis, to adjust the default costs used in the model for time and location. Default costs were programmed into the model in May 2008 dollars, based on the 20-City averaged ENR CCI (ENR CCI: 8141).

Inflation Rate

The inflation rate describes how costs will increase in the future. The default value is 4.6%, which is the historical annual increase of the ENR CCI from 1958 to May, 2008 (ENR 2008). UDFCD recommends using a 50-year planning horizon analysis for large projects; however the user may choose to use a different inflation rate value (based on more recent trends) if the planning horizon of the project is not 50 years.

Rate of Return

The rate of return describes how monies that are set aside now for future costs will appreciate into the future. The default value used is 5%, however the rate may vary from agency to agency and a reasonable estimate is probably available from the municipality's financial manager.

Administrative Costs

The additional costs for the administration of a BMP maintenance program are accounted for by entering a value (percentage) that defines the administration costs as a percentage of the annual maintenance costs.   The default rate is 12%, however this rate may vary from agency to agency and a reasonable estimate is may be available from the department's manager.

Precipitation

The user selects a location (from the drop-down box) that is closest to the location of the project. This selection then specifies the precipitation data to be used by the model. The user also has the option of selecting "Other" as the location of the project and entering precipitation values specific to the project location. Two separate precipitation values are used by the model. The first is the average annual precipitation depth, which is used in calculating annual runoff volume and pollutant loadings generated from the watershed. The second is the 2-Year, 1-Hour rainfall depth which is used for calculating the appropriate size of BMPs that are designed to treat a specified flowrate. The precipitation values for each available location are presented in Table 3.

Table 3 : Precipitation data for selected locations in Front Range of Colorado

Location	Mean Annual Precipitation (in)	2-Year, 1-Hour (in)
Arvada	15.8	0.95
Aurora	15.8	1.0
Boulder	15.8	0.87
Denver Metro	15.8	0.95
Lakewood	15.8	0.99
Longmont	15.8	1.02
Parker	15.8	0.97
Westminster	15.8	0.98

Sources:
Mean Annual - National Weather Service (2008)
2-Year, 1-Hour – Figure RA-1 in USDCM, Vol. 1 (UDFCD 2004)

Mean Storm Depth

The user inputs the mean storm depth for the location of the project. (The default value of 0.43 inches is applicable for the Front Range of Colorado). This value is used to compute the size of volume-based BMPs. A map of mean storm depths across the contiguous United States can be accessed by clicking on the "?" button.

3.1.2. Watershed Parameters

This section describes how runoff-generating characteristics of a watershed of interest should be input into the model.

Delineating Subcatchments

First, the user must identify the total number of subcatchments located within the area of interest. The steps for doing so are described below. Note that the total number of subcatchments cannot exceed 40 in one workbook.

As the spreadsheet layout suggests, each subcatchment can only have one value for contributing area, land use, total imperviousness, source controls, effective imperviousness, soil type, runoff coefficient, BMP type, and BMP density (i.e. number of impervious acres contributing per BMP). The following protocol is recommended for determining the number of subcatchments needed within a watershed:

1. Determine the number of land uses in the watershed. Assign a subcatchment to each land use and calculate a contributing area.

2. For each subcatchment, is there more than one type of source control being implemented? If yes, then divide the subcatchment(s) up by source control.
3. For each subcatchment, is there more than one type of soil present? If yes, than divide the subcatchment(s) up by soil type.
4. For each subcatchment, is there more than one type of BMP being applied? If yes, then divide the subcatchment(s) up by BMP type.
5. For each subcatchment, will each individual BMP within that subcatchment capture runoff from a (relatively) equal area? (In other words, if more than one BMP is to be implemented within the same subcatchment, does each BMP have an equal number of impervious acres draining to it?). If not, than divide the subcatchment into additional subcatchments, so that the appropriate number of impervious acres draining to each BMP can be input.
6. For each subcatchment, is the slope relatively uniform? If no, then divide the subcatchment(s) into additional subcatchments and calculate the slope for each. Also recalculate the contributing area of all subcatchments.

Entering Subcatchment Parameters

Once the total number of subcatchments (each with its own unique combination of watershed parameters) is determined, then the watershed parameters may be entered as described in the following steps. Input of the watershed parameters follows a left-to-right progression from column to column for each subcatchment, starting with Column C.

Watershed Parameters

Subcatchment No.	Subcatchment ID	Area (ac)	Land Use	Total Imperviousness (%)	Source Control (LID)	Effective Imperviousness (%)	NRCS Soil Type	Subarea Slope (%)	Effective Runoff Coefficient
1		50.00	Commercial	95%	PP	95%	C	1.00%	0.80

For each subcatchment:

1. Enter a subcatchment ID in Column C (this is optional…the model will still run if left blank).
2. Enter a contributing area in total acres in Column D.
3. Select a land use type from the dropdown list in Column E. The available land use types are presented in Table 4.

Table 4 : Land use types available within the model

Land Use Type
Commercial
Industrial – Light
Industrial – Heavy
Residential – Single Family (1,000 sf)
Residential – Single Family (2,000 sf)
Residential – Single Family (3,000 sf)
Residential – Single Family (4,000 sf)
Residential – Single Family (5,000 sf)
Residential – Multi-Unit (detached)
Residential – Large Lot (>1/2 acre)
Residential – Apartments
Parks, Cemeteries
Institutional (universities, office parks)
Paved Areas
Undeveloped

4. Enter a value for total imperviousness in Column F, OR, click on the "Enter Default Imperviousness Values" button to have the model automatically fill in the values based on UDFCD recommended values (shown in Table 5 below). When all values are updated, the button will turn from red to green.
5. Select an appropriate source control method from the dropdown list in Column G to apply to the subcatchment. (For more information on applying/selecting source controls, see Section 5.2.2).
6. Enter a value for effective imperviousness in Column H, OR, click on the "Calculate Effective Imperviousness" button to have the model automatically compute the values based on UDFCD protocols. When all values are updated, the button will turn from red to green. (For more information on how effective imperviousness is computed, see Section 5.2.3).

Table 5 : Default values of total imperviousness for each land use type

Land Use Type	Percent Imperviousness
Commercial	95
Industrial – Light	80
Industrial – Heavy	90
Residential – Single Family (1,000 sf)	28*
Residential – Single Family (2,000 sf)	39*
Residential – Single Family (3,000 sf)	51*
Residential – Single Family (4,000 sf)	62*
Residential – Single Family (5,000 sf)	72*

Residential – Multi-Unit (detached)	60
Residential – Large Lot (>1/2 acre)	27*
Residential – Apartments	80
Parks, Cemeteries	5
Institutional	50
Paved Area	100
Undeveloped	2

Source: UDFCD Design Manual, Vol.1 – Table RO-3

* - Average values taken from Figures RO 3-5 in UDFCD Design Manual, Vol. 1

7. Select the dominant NRCS soil type for the subcatchment from the dropdown list in Column I.
8. Enter the average slope of the subcatchment as a percentage in Column J. The slope should be relatively uniform throughout the subcatchment for best results.
9. Enter a value for effective runoff coefficient in Column K, OR, click on the "Calculate Runoff Coefficients" button to compute the value based on UDFCD protocols. When all values are updated, the button will turn red to green. (For more information on how effective runoff coefficients are computed, see Section 5.3).

3.2. BMP Parameters

The section describes how to apply BMPs to the subcatchments. The first step is to determine whether to apply a single regional-control BMP or multiple site-control BMPs. The regional control BMP will treat runoff from all of the subcatchments combined, whereas site-control BMPs are applied at the subcatchment level only. The BMP types available for each type of control are presented in Table 6.

Table 6 : Available BMP types for Site Control and Regional Control

Site Control BMPs	Regional Control BMPs
Concrete Grid Pavers(1)	
Constructed Wetland Basin	Constructed Wetland Basin
Constructed Wetland Channel	Constructed Wetland Channel
Extended Detention Basin - WQCV(2)	Extended Detention Basin- WQCV(2)
Extended Detention Basin - EURV(3)	Extended Detention Basin - EURV(3)
(U) Inlet Inserts	Retention Pond - WQCV(2)
None	Retention Pond - EURV(3)
Porous Landscape Detention – Infiltration(4)	Sand Filter Basin – Infiltration(4)
Porous Landscape Detention – Underdrain(5)	Sand Filter Basin - Underdrain(5)
Retention Pond – WQCV(2)	

Retention Pond – EURV(3)
Sand Filter Basin – Infiltration(4)
Sand Filter Basin - Underdrain(5)
(U) Media Filter Vault
Sand Filter Vault
(U) Hydrodynamic Separator
(U) Sediment/Oil/Grease Separator
(U) Vault w/ Capture Volume

Notes:
(1) – Type of permeable pavement, designed for infiltration or underdrained
(2) – BMPs designed to capture water quality capture volume only
(3) – BMPs designed to capture the excess urban runoff volume
(4) – BMPs designed to infiltrate full water quality capture volume
(5) – BMPs designed with underdrains

Regional-Control BMPs

To apply a regional-control BMP, follow these steps.

1. Select the regional-control BMP button

Select Regional-Control BMP

2. Select the BMP to be applied from the dropdown list in Cell O24.
3. Input a land cost value into Cell T24 for the location where the regional BMP will be installed. For applicable land costs for different land use types, reference the table on the “LandCosts” worksheet.
4. Click on the “Calculate BMP Sizes” button to compute the size of the BMP required. The button will turn green when all values are updated.

Site-Control BMPs

To apply a site-control BMP, follow these steps.

1. Select the site-control BMP button.

Select Site-Control BMP

2. Select the BMP to be applied to each subcatchment in Column O.

3. For all BMPs that are NOT permeable pavements, enter the number of impervious acres that will runoff to each individual BMP located within the subcatchment into Column P. The value entered should be within the ranges presented in Table 7 for best results. If the number of impervious acres draining to each BMP is less than the total number of impervious acres in the subcatchment, then more than one BMP will be applied, each with the same number of impervious acres contributing. Inappropriately applying very large or very small impervious areas to certain BMPs may result in unrealistic results. For these types of BMPs, no value is needed in Column Q.
4. For permeable pavement BMPs, enter the number of impervious acres that will "run-on" to the permeable pavement (RAPP), not including the permeable pavement into Column P. Then, enter the surface area of the permeable pavement (SAPP) into Column Q. The ratio of RAPP:SAPP should be less than or equal to 5 to ensure that PPs do not clog too fast. In other words, no more than 5 impervious acres may "run-on" to 1 acre of permeable pavement.
5. Click on the "Calculate BMP Sizes" button to compute the size and number of the BMPs required for each subcatchment. The button will turn green when all values are updated.

3.3. Generating and Interpreting Model Results

To generate model outputs, select the "Report" worksheet and click on the "Update Summary Report" button 

to generate/update summary results. Model results are output into several different worksheets, each of which is described in the following sections.

Table 7 : Range of impervious acres applicable for each BMP

BMPs	Impervious Acres to each BMP	
	Minimum	Maximum
Constructed Wetland Basin	2	-
Constructed Wetland Channel	2	-
Extended Detention Basin - WQCV[(1)]	2	-
Extended Detention Basin - EURV[(2)]	2	-
(U) Inlet Inserts	0.1	0.25
Porous Landscape Detention – Infiltration[(3)]	0.1	5
Porous Landscape Detention – Underdrain[(4)]	0.1	5

Retention Pond – WQCV(1)	2	-
Retention Pond – EURV(2)	2	-
Sand Filter Basin – Infiltration(3)	0.1	5
Sand Filter Basin - Underdrain(4)	0.1	5
Media Filter Vault	0.1	2
Sand Filter Vault	0.1	2
(U) Hydrodynamic Separator	0.1	2
(U) Sediment/Oil/Grease Separator	0.1	2
(U) Vault w/ Capture Volume	0.1	2
Permeable Pavements	(1)	

Notes:
(1) - Permeable pavements can have unlimited size as long as the impervious run-on area is equal to or less than 5x the PP surface area

3.3.1. "Report" Worksheet

The "Report" tab of the spreadsheet summarizes the costs and effectiveness of the selected BMP scenario in tabular and chart forms.

Summary of Water Quality Table

The water quality results summary table is presented as Table 8.

Table 8: Summary of Water Quality Results table

Constituent	Watershed Pollutant Load (lb/yr)	Discharged Pollutant Load (lb/yr)	Pollutant Reduction (%)	Cost per Unit Removed ($/lb)
Total Suspended Solids	5737.69	1060.49	82%	$19.01
Total Phosphorus	10.71	5.08	53%	$15,783.30
Total Nitrogen	84.15	33.89	60%	$1,768.58
Total Kjeldahl Nitrogen	58.65	36.13	38%	$3,947.49
Total Zinc	6.12	1.67	73%	$19,981.32
Dissolved Zinc	2.41	0.73	70%	$52,834.49
Total Lead	1.50	0.27	82%	$72,027.71
Dissolved Lead	0.42	0.09	79%	$269,362.71
Total Copper	1.10	0.32	70%	$115,173.35
Dissolved Copper	0.49	0.23	53%	$342,792.22

The values displayed under the heading **"Watershed Pollutant Load"** are the sum of annual pollutant loads generated from all subcatchments. It is presumed that these would be the pollutant loadings to the receiving water if no source controls or BMPs were in place.

The values displayed under the heading "**Discharged Pollutant Load**" are the total annual pollutant loads entering the receiving water from all subcatchments, with the selected source controls and BMP(s) in place. These values account for pollutant reductions due to infiltration and treatment of runoff within the source controls and BMPs.

The values displayed under the heading **"Pollutant Reduction"** are the annual percent reduction of each pollutant that is achieved with the selected source controls and BMP(s) in place.

The values displayed under the heading **"Cost per Unit Removed"** are the total life cycle costs for removing one unit of pollutant during the planning horizon of the project.

The **"Summary of Watershed and Discharged Pollutant Loads"** chart (Figure 1) graphically presents the values in the summary table.

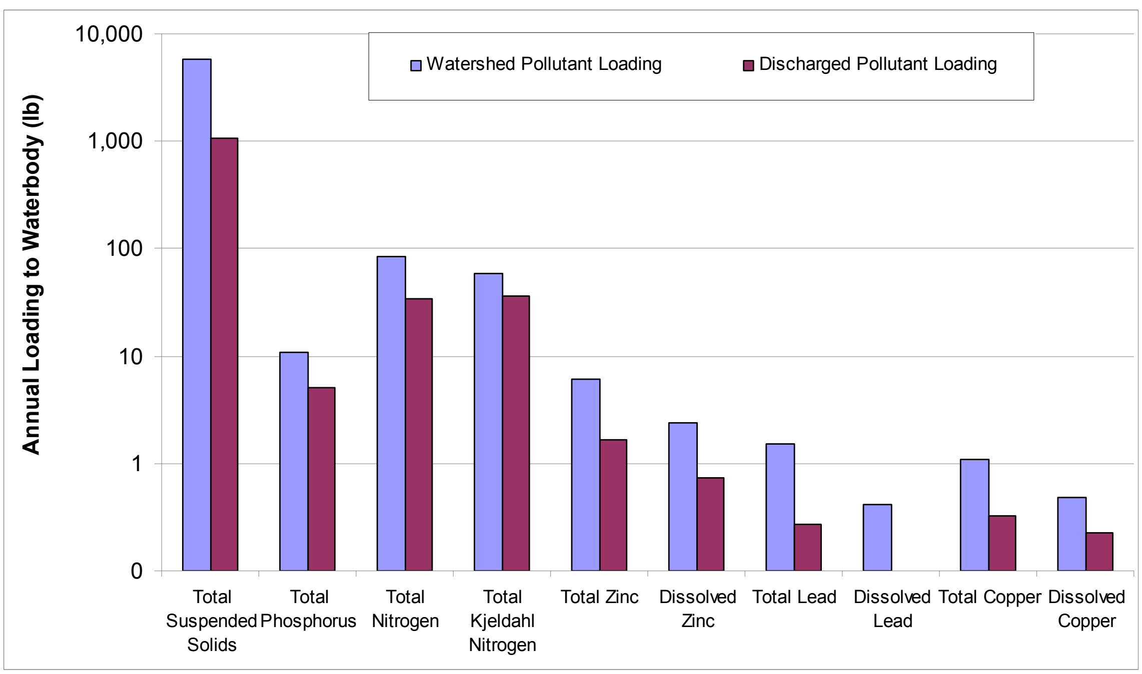


Figure 1: Summary of pollutant load reporting chart

Summary of Runoff Table

The Runoff summary table is presented as Table 9.

Table 9: Summary of Runoff results table

Summary of Average Annual Runoff Results

Subcatch ment No.	Watershed Runoff (ft^3/yr)	Discharge to Receiving Water (ft^3/yr)	Runoff Reduction (%)	Peak Flow Control
1	2,068,777	1,506,131	27%	Yes
2	620,633	446,515	28%	Yes
3	3,073,661	2,243,772	27%	Yes
4	3,996,626	2,917,537	27%	Yes
5	2,115,370	2,009,601	5%	Yes
Totals	**1,273,079**	**667,761**	**48%**	**590,228**

The values displayed under the heading **"Watershed Runoff"** are the total annual runoff volumes (in cubic feet) generated from each subcatchment, if no source controls or BMP(s) were in place. These volumes are a function of the precipitation and runoff coefficient computed using the total imperviousness. If a regional BMP is being used than only one row of values will appear representing the total runoff volume from all subcatchments together.

The values displayed under the heading **"Discharge to Receiving Water"** are the total annual runoff volumes entering the receiving water from each subcatchment, with the selected source controls and BMPs in place. These values account for runoff reduction due to losses such as infiltration and evaporation that occur within the selected source controls and BMP(s). If a regional BMP is being used than only one row of values will appear representing the total discharge volume from the regional BMP.

The values under the heading **"Runoff Reduction"** are the annual percent reduction of runoff volume from each subcatchment that is achieved with the selected source controls and BMP(s) in place.

The values under the heading **"Peak Flow Control"** inform the user which subcatchments utilize BMPs that can be designed to control peak flows discharged to receiving waters.

The **"Summary of Annual Runoff Volume Reduction"** chart (Figure 2) graphically presents the total runoff generated from the subcatchments, the runoff reduced due to source controls and BMPs and the total runoff discharged to the receiving waters.

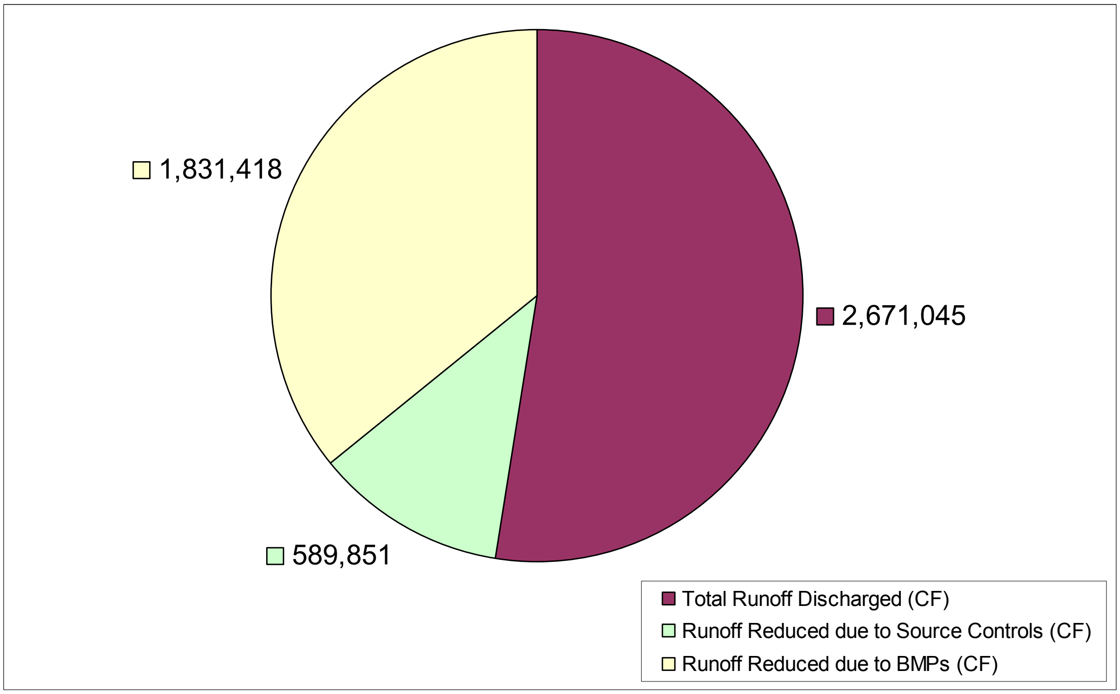


Figure 2: Summary of annual runoff volume reduction chart

Summary of Costs

The Cost summary table with example data is presented as Table 10.

Table 10: Summary of Net Present Value Cost table

Summary of NPV Costs			
NPV of Capital Costs	**NPV of Rehabilitation Costs**	**NPV of Maintenance Costs**	**NPV of Administrative Costs**
$626,711	$531,843	$196,822	$26,809
$55,646	$19,865	$25,335	$4,636
$106,445	$147,767	$272,158	$34,254
$198,488	$275,543	$567,318	$69,673
$987,291	**$975,017**	**$1,061,634**	**$135,373**

Total NPV	**$3,159,314**
All Costs for 50 years	

The values displayed in each cell are the net present value of the costs associated with the selected source controls and BMPs for each subcatchment. If a regional BMP is being modeled, than only one row of values will appear representing the total costs for the regional BMP and any source controls applied. All costs are summed and reported as the "Total NPV" value.

The **"Annual Cost Summary"** charts (Figure 3 and Figure 4) graphically displays the annual and cumulative costs for capital, rehabilitation, maintenance, and administration of all BMPs for the defined planning horizon.

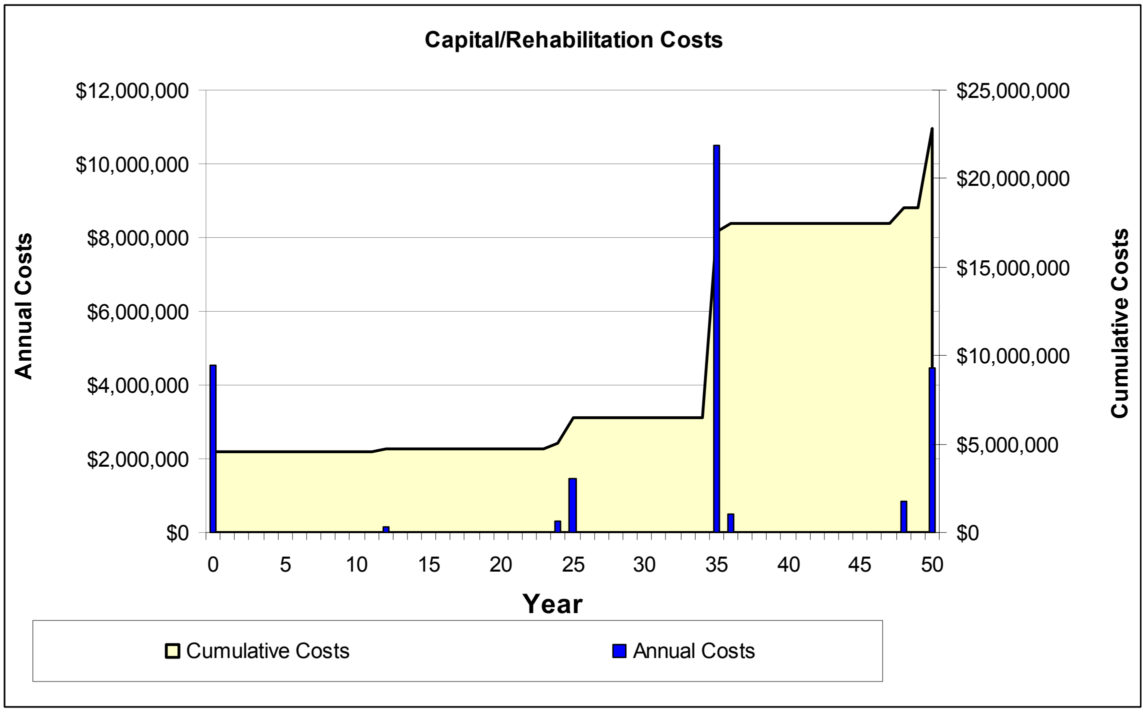


Figure 3: Annual capital and rehabilitation cost summary chart

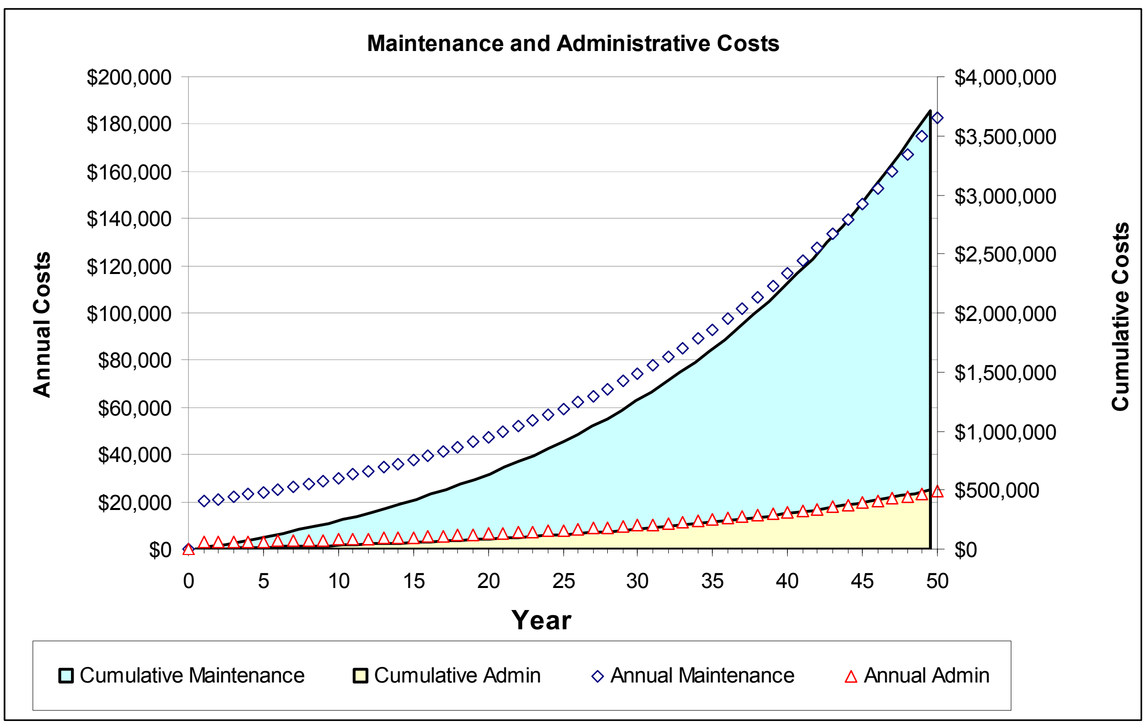


Figure 4: Annual maintenance and administrative cost summary chart

3.3.2. "NPVCosts" Worksheet

The “NPVCosts” worksheet presents a breakdown of all annual costs over the defined planning horizon of the project. This worksheet is “Read-Only” and any modifications to it may adversely affect model computations. The equations used to calculate each value are described in Section 5.15.

3.3.3. “CapitalCosts” Worksheet

The “CapitalCosts” worksheet summarizes the capital and rehabilitation costs of the BMPs selected for each subcatchment. This worksheet is “Read-Only” and any modifications to it may adversely affect model computations.

3.3.4. “OMCosts” Worksheet

The “OMCosts” worksheet summarizes the maintenance and administrative costs of the BMPs selected for each subcatchment. This worksheet is “Read-Only” and any modifications to it may adversely affect model computations.

3.3.5. “WatershedLoading” Worksheet

The “WatershedLoading” worksheet summarizes the annual pollutant loads generated from each subcatchment. These loads are what would enter the receiving water(s) if no source controls or BMPs were implemented. This worksheet is “Read-Only” and any modifications to it may adversely affect model computations.

3.3.6. “DischargeLoading” Worksheet

The “DischargeLoading” worksheet summarizes the annual pollutant loads for each subcatchment that would enter the receiving water(s) using the selected source controls and BMP(s). This worksheet is “Read-Only” and any modifications to it may adversely affect model computations.

3.3.7. “Runoff” Worksheet

The “Runoff” worksheet summarizes the annual runoff volumes that are generated from the contributing area, reduced through various source control and BMP processes (evaporation, infiltration, etc.), and released to the receiving water(s) for each subcatchment. It also shows which subcatchments have BMPs in place that will attenuate peak flows. This worksheet is “Read-Only” and any modifications to it may adversely affect model computations.

4. <u>ADVANCED OPTIONS</u>

This section describes how to modify or override the model's default values in order to more accurately represent a specific project. *The default values included in the model are based on best available information at the time of model release, and therefore should only be modified or replaced with values are also based on sound science.*

4.1. Modifying Runoff Mitigation Values

The "RunoffMitigation" worksheet contains information used to evaluate the effectiveness of BMPs at mitigating increased runoff volumes generated from urbanization. Each BMP has three values associated with it. The first value under the "Runoff Capture Efficiency" heading is the percentage of annual runoff that is captured and fully treated by the BMP. The second value under the "BMP Runoff Volume Reduction" heading is the percentage of total runoff volume that is "lost" (i.e. not discharged through the BMP outlet) within the BMP, generally due to infiltration and evapotranspiration processes. The third value indicates whether or not the BMP is capable of reducing peak runoff flows through losses and/or storage. The default values for each parameter are presented in Table 11. Sources and methods used to develop default parameter values are documented in Section 5.16.1.

4.2. Modifying Water Quality Values

The "WaterQuality" worksheet contains information used in computing pollutant loads with and without BMPs. The worksheet includes two tables of information, one containing "BMP Effluent Event Mean Concentrations" and another containing "Land Use Event Mean Concentrations".

4.2.1. BMP Effluent Event Mean Concentrations:

Values in this table are the concentrations of pollutants expected in the effluent (discharge) of each BMP. The primary source of data for these values was the Analysis of Treatment Performance Report (Geosyntec Consultants & Wright Water Engineers 2008), which documents expected BMP effluent EMCs based on statistical analyses of the data in the International BMP Database (Geosyntec Consultants & Wright Water Engineers 2009). However the report did not provide statistics for all BMPs included in the model, therefore some additional analyses and assumptions were necessary. Details of how these values were developed are included in Appendix A. The user may edit these values if needed, however it is not recommended unless they are being replaced by values reported in an updated version of the report cited above. Any updated versions of the analyses report should be available at www.bmpdatabase.org

Table 11: Default values for runoff capture efficiency, volume and peak runoff reduction

BMP	Runoff Capture Efficiency (%)	Runoff Volume Reduction (%)	Peak Runoff Reduction Capability
Concrete Grid Pavers - Infiltration	(1)	100%	Yes
Concrete Grid Pavers - Underdrain	(1)	(2)	Yes
Constructed Wetland Basin	85%	5%	Yes
Constructed Wetland Channel	85%	0%	Yes
Extended Detention Basin - WQCV	85%	30%	Yes
Extended Detention Basin - EURV	98%	30%	Yes
Hydrodynamic Separator	85%	0%	No
Inlet Inserts	85%	0%	No
Media Filter Vault	85%	0%	No
Porous Concrete Pavement - Infiltration	(1)	100%	Yes
Porous Concrete Pavement - Underdrain	(1)	(2)	Yes
Porous Gravel Pavement - Infiltration	(1)	100%	Yes
Porous Gravel Pavement - Underdrain	(1)	(2)	Yes
Permeable Interlocking Concrete Pavers - Infiltration	(1)	100%	Yes
Permeable Interlocking Concrete Pavers - Underdrain	(1)	(2)	Yes
Porous Landscape Detention - Infiltration	85%	100%	Yes
Porous Landscape Detention - Underdrain	85%	53%	Yes
Reinforced Grass Pavement - Infiltration	(1)	100%	Yes
Reinforced Grass Pavement - Underdrain	(1)	(2)	Yes
Retention (Wet) Pond - WQCV	85%	7%	Yes
Retention (Wet) Pond – EURV	98%	7%	Yes
Sand Filter Basin - Infiltration	85%	100%	Yes
Sand Filter Basin – Underdrain	85%	30%	Yes
Sand Filter Vault	85%	0%	No
Sediment/Oil/Grease Separator	[illegible]	0%	No
Vault w/ Capture Volume	85%	0%	Yes

Notes:

(1) - $\lambda = \min(100\% - (RAPP/SAPP)*5\%, 95\%)$

(2) - $\theta = \max(50\% - (RAPP/SAPP)*3\%, 10\%)$

4.2.2. Land Use Event Mean Concentrations:

The values in this table represent the concentrations of pollutants expected in runoff generated from a variety of land uses. Most values are based on the results of sampling stormwater runoff in and around Denver, CO; which are documented in Table SQ-5 in the USDCM (UDFCD 2004) and included in Table 12 below. However, those results did not provide values for dissolved zinc, dissolved lead and dissolved copper for each land use, therefore ratios of the total recoverable/dissolved fractions of each metal were estimated based on work performed by Maestre and Pitt (2005), as documented in Appendix A. The user may edit these values if needed, however it is not recommended unless they are being updated from the sources cited above. The reports, should they be updated, may be available *http://rpitt.eng.ua.edu/Research/ms4/Paper/Mainms4paper.html* and *www.udfcd.org*.

Table 12: Table of land use average event mean concentrations for the Denver, CO region

Constituent	Units	Industrial	Commercial	Residential	Undevelope d
Total Suspended Solids	(mg/L)	399	225	240	400
Total Dissolved Solids	(mg/L)	58	129	119	678
Biochemical Oxygen Demand	(mg/L)	29	33	17	4
Chemical Oxygen Demand	(mg/L)	232	173	95	72
Total Nitrogen	(mg/L)	2.7	3.3	3.4	3.4
Total Kjeldahl Nitrogen	(mg/L)	1.8	2.3	2.7	2.9
Nitrate plus Nitrite	(mg/L)	0.91	0.96	0.65	0.50
Total Phosphorus	(mg/L)	0.43	0.42	0.65	0.40
Dissolved Phosphorus	(mg/L)	0.20	0.15	0.22	0.10
Cadmium, Total Recoverable	(µg/L)	3	1	n/d	n/d
Copper, Total Recoverable	(µg/L)	84	43	29	40
Lead, Total Recoverable	(µg/L)	130	59	53	100
Zinc, Total Recoverable	(µg/L)	520	240	180	100

n/d = below detection limit

4.3. Modifying Land Cost Values

The values in the table on the "LandCost" worksheet and shown in Table 20 are the unit land costs ($ per acre) used by the model to compute total land costs for BMP implementation. These costs are considered applicable for *new* developments on previously undeveloped land or land on which any existing structures have minimal value. The costs associated with redevelopment, are likely to be higher due to the value of structures already existing on that land. The user may edit the values in the table with values more representative of the project location if necessary

Table 13: Unit Land Costs Based on Land Use

Land Use	Unit Land Cost ($/acre)
Commercial	$200,000
Industrial – Light	$200,000
Industrial – Heavy	$200,000
Residential – Single Family	$130,000
Residential – Multi-Unit (detached)	$175,000
Residential – Large Lot (>1/2 acre)	$130,000
Residential – Apartments	$200,000
Parks, Cemeteries	$35,000
Institutional	$130,000
Paved Area	$200,000
Undeveloped	$35,000

4.4. Modifying BMP Cost Values

The default cost parameters for each BMP are located on separate worksheets, each named with an abbreviation of the BMP (Table 14).

Table 14: BMP cost worksheet names

Worksheet Name	BMP
CGP	Concrete Grid Pavers
CWB	Constructed Wetland Basin
CWC	Constructed Wetland Channel
EDB (WQCV)	Extended Detention Basin w/ WQCV only
EDB (EURV)	Extended Detention Basin w/ EURV
HS	Hydrodynamic Separator
II	Inlet Inserts
MFV	Media Filter Vault
PCP	Porous Concrete Pavement
PGP	Porous Gravel Pavement
PICP	Permeable Interlocking Concrete Pavers
PLD	Porous Landscape Detention
RGP	Reinforced Grass Pavement
RP (WQCV)	Retention (Wet) Pond w/ WQCV only
RP (EURV)	Retention (Wet) Pond w/ EURV

SFB	Sand Filter Basin
SFV	Sand Filter Vault
SOG	Sediment/Oil/Grease Separator
VCV	Vault w/ Capture Volume

For all of the cost worksheets, the user can input a value into any blue-shaded cell and that input value will override any default value included in the model. Other options are described below.

4.4.1. Editing Capital Cost Parameters

The capital cost input table is presented in Figure 5. First, select the option to use by clicking on the appropriate selection button shown below. To compute capital costs, the user has the option of using a parametric equation (Option 1) or using a cost-curve generating option (Option 2). Option 1 is the default option.

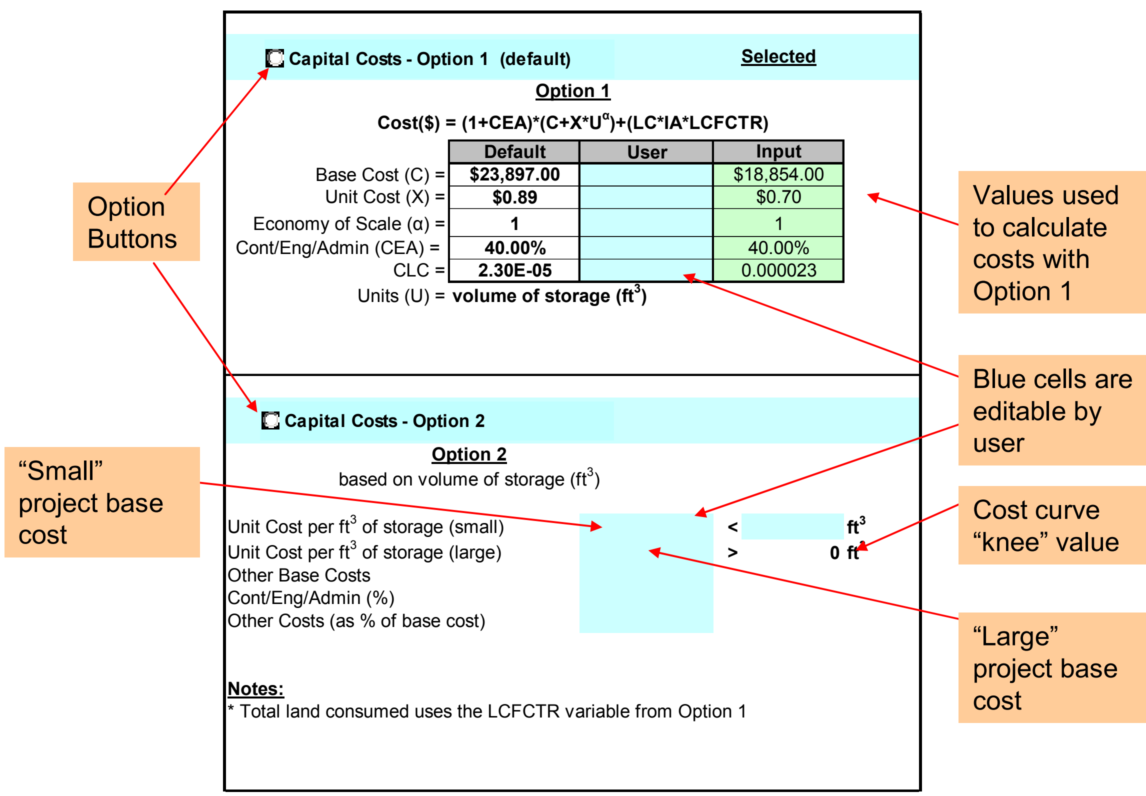


Figure 5: Capital cost input table

Option 1 Editing

If Option 1 is selected, the user may override any of the default values by entering a value in the blue-shaded cell to the right of the default value cell. After doing so, the "Input" value will change from the default value to the user-defined value. The "Input" value is the value used in the model computations.

Option 2 Editing

If Option 2 is selected, the user must enter a value into each of the blue-shaded cells. This option generates two linear cost functions which intersect at the value input into cell "F27", otherwise known as the "knee" in the curve. These two functions together generate a cost curve, with higher unit costs for a BMP smaller than the "knee" value and lower unit costs for a BMP larger than the "knee" value.

With both options, the user can view the cost curve (Figure 6) that is generated in the chart located below the capital cost data entry cells. This allows the user to efficiently determine the construction costs of a variety of BMP sizes.

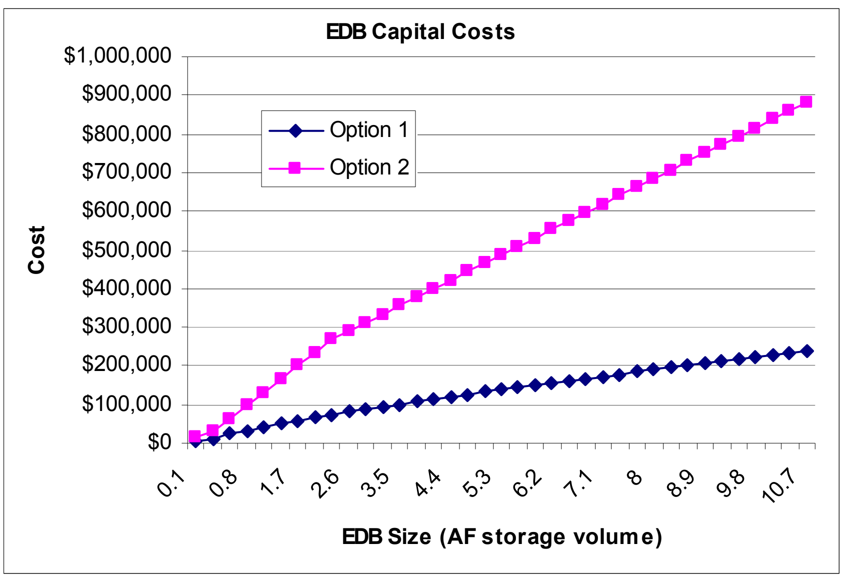


Figure 6: Chart showing example cost curves generated using the capital cost input tables

4.4.2. Editing Maintenance Cost Parameters

The procedures for editing maintenance cost parameters on the maintenance cost table (Table 15) are explained below.

Table 15: Maintenance cost input tables

“Constant” cost activities

“Variable” cost activities

ANNUAL MAINTENANCE COSTS

		Frequency per Year			Hours per Unit			Labor Crew Size			Hourly Labor Rate			Overhead Factor (%)			Equipment Cost per Hr			Other Costs per Unit			Lump Sum	Total Cost		
Activity	**Units**	**Default**	**User**	**Input**	**Default**	**User**	**Input**	**Default**	**User**	**Input**	**Default**	**User**	**Input**	**Default**	**User**	**Input**	**Default**	**User**	**Input**	**Default**	**User**	**Input**	**Per Unit**	**per Unit**	**Beta Value**	**Annual Cost**
Compliance Inspection[1]	each	1		**1**	0.33		**0.33**	1		**1**	$23.31		**$18.39**	100%		**100%**	$10.15		**$8.01**	$0.00		**$0.00**		$14.78	-	$14.78
Inlet/Outlet Cleaning	each	6		**6**	0.5		**0.5**	2		**2**	$23.31		**$18.39**	100%		**100%**	$10.15		**$8.01**	$0.00		**$0.00**		$40.79	-	$244.71
Nuisance Control	each	12		**12**	0.5		**0.5**	1		**1**	$23.31		**$18.39**	100%		**100%**	$10.15		**$8.01**	$35.00		**$27.61**		$50.01	-	$600.11
Outlet Maintenance	each	0.25		**0.25**	12		**12**	3		**3**	$23.31		**$18.39**	100%		**100%**	$102.88		**$81.17**	$200.00		**$157.79**		$2,455.97	-	$613.99
				0			**0**			**0**			**$0.00**			**0%**			**$0.00**			**$0.00**		$0.00	-	$0.00
				0			**0**			**0**			**$0.00**			**0%**			**$0.00**			**$0.00**		$0.00	-	$0.00
				0			**0**			**0**			**$0.00**			**0%**			**$0.00**			**$0.00**		$0.00	-	$0.00
				0			**0**			**0**			**$0.00**			**0%**			**$0.00**			**$0.00**		$0.00	-	$0.00
				0			**0**			**0**			**$0.00**			**0%**			**$0.00**			**$0.00**		$0.00	-	$0.00
The activities listed below are a function of the BMP size																										**Annual Cost per AF**
Lawn Mowing/Lawn Care	acre	6		**6**	2		**2**	2		**2**	$23.31		**$18.39**	100%		**100%**	$41.42		**$32.68**	$0.00		**$0.00**		$212.49	1	$1,274.91
Sediment Removal (non-routine)	CY	0.05		**0.05**	0.08		**0.08**	4		**4**	$23.31		**$18.39**	100%		**100%**	$220.19		**$173.72**	$10.00		**$7.89**		$33.56	323	$541.96
Sediment Removal (routine)	CY	0.5		**0.5**	0.33		**0.33**	2		**2**	$23.31		**$18.39**	100%		**100%**	$56.73		**$44.76**	$10.00		**$7.89**		$46.94	16	$375.49
				0			**0**			**0**			**$0.00**			**0%**			**$0.00**			**$0.00**		$0.00		$0.00
				0			**0**			**0**			**$0.00**			**0%**			**$0.00**			**$0.00**		$0.00		$0.00
				0			**0**			**0**			**$0.00**			**0%**			**$0.00**			**$0.00**		$0.00		$0.00
				0			**0**			**0**			**$0.00**			**0%**			**$0.00**			**$0.00**		$0.00		$0.00
																									Subtotal 1	$1,458.81
																									Subtotal 2	$2,192.36

(1) - Compliance Inspection is added as an administrative cost

OR

Annual maintenance costs as percentage of capital costs	

“Percentage” cost option

Selecting Cost Estimating Option

The user has two options for estimating annual maintenance costs. Option 1 (the default option) is to develop bottom-up cost estimates using the information contained within the maintenance activity cost table. Option 2 is to compute annual maintenance costs as a simple percentage of the construction costs. To use and/or edit Option 1, continue with the following directions.

Selecting Option 1 – Using Maintenance Cost Table

To estimate costs using the maintenance table, make sure that cell “M37” is blank. The computational macros for this option only run when “M37” is blank.

Override Default Values in the Maintenance Cost Table

To override a default value from an existing activity in the maintenance cost table, input a value into the blue-shaded “user” cell to the right of the “default” cell. The “input” cell value will change from the default value to the user-defined value. The “input” value is the value used by the model.

Deleting an Activity from the Maintenance Cost Table

To remove a maintenance activity from the maintenance table, simply delete all values in the row of that activity. You will not be able to delete the equations in the green-shaded cells as those cells are protected. To ensure that all data from deleted correctly, the value in Column AG of that row should equal $0.00.

Adding an Activity to the Maintenance Cost Table

The maintenance table contains entry cells for two types of activities. The first activity is one in which the annual costs will not vary significantly according to the size of the BMP. These activities must be added in rows 18-26. The second activity type is one in which the annual costs do vary significantly with the size of the BMP. These activities must be added in rows 28-34.

To add an activity to the maintenance table, simply fill in appropriate values for each cost component as is done with the default activities. The user should enter the values into the blue-shaded “user” cells (not the white “default” cells) to signify that the activity has been added by the user and is not a model default activity.

An example of how to determine the β-value is shown below. The derivation of β values for default activities is described in Appendix C.

Example 1: An extended detention basin size (storage) is measured in AF and sediment removal costs are estimated in cubic yards (CY). Sediment removal occurs once 20% of the EDB storage is filled with sediment. We must find a β-value that relates the required volume of sediment removal (in CY) to the size of the EDB (in AF).

$$\beta = \frac{0.2AF(SedimentRemoval)}{1AF(BMPSize)} * \frac{1613CY}{1AF} = 323\frac{CY(SedimentRemoval)}{1AF(BMPSize)}$$

By unit conversion, we find a β-value of 323.

Option 2 – Using Percentage of Construction Costs

To compute annual maintenance costs as a percentage of the BMP construction costs, simple input the appropriate percentage value into cell “M37”. This will override the values in the maintenance cost table (but the values will still be visible).

4.5. Importing Inputs from another Workbook

Users can easily transfer their inputs and user-defined values to new versions of the model using the “Import Data from Another Model” button found on the “InputParameters” page. All user-defined information will be imported from the older model to the new model, however the model must be re-run in order to generate results with the newly imported data.

5. TECHNICAL DETAILS

This section documents the methods used to compute BMP effectiveness and life cycle costs.

5.1. Precipitation Data

The model requires two precipitation parameter inputs, mean annual precipitation depth and the 2-Year, 1-Hour total rainfall depth. The mean annual precipitation for the Denver, Colorado region is 15.8 inches, as reported on the National Weather Service website (NWS 2008). The 2-Year, 1-Hour rainfall depths for locations near Denver, Colorado region are shown in Figure 7. A summary of precipitation data is provided in Table 3.

5.2. Watershed Imperviousness

Watershed imperviousness is a commonly used metric for describing the extent of development in an urban area and empirical equations used to estimate BMP size and rainfall-runoff relationships were developed as a function of the effective imperviousness. The model uses “total” and “effective” imperviousness values in its computations. Effective imperviousness is computed as a function of the total imperviousness and the level of source controls applied to the watershed. Each is described in the following sections.

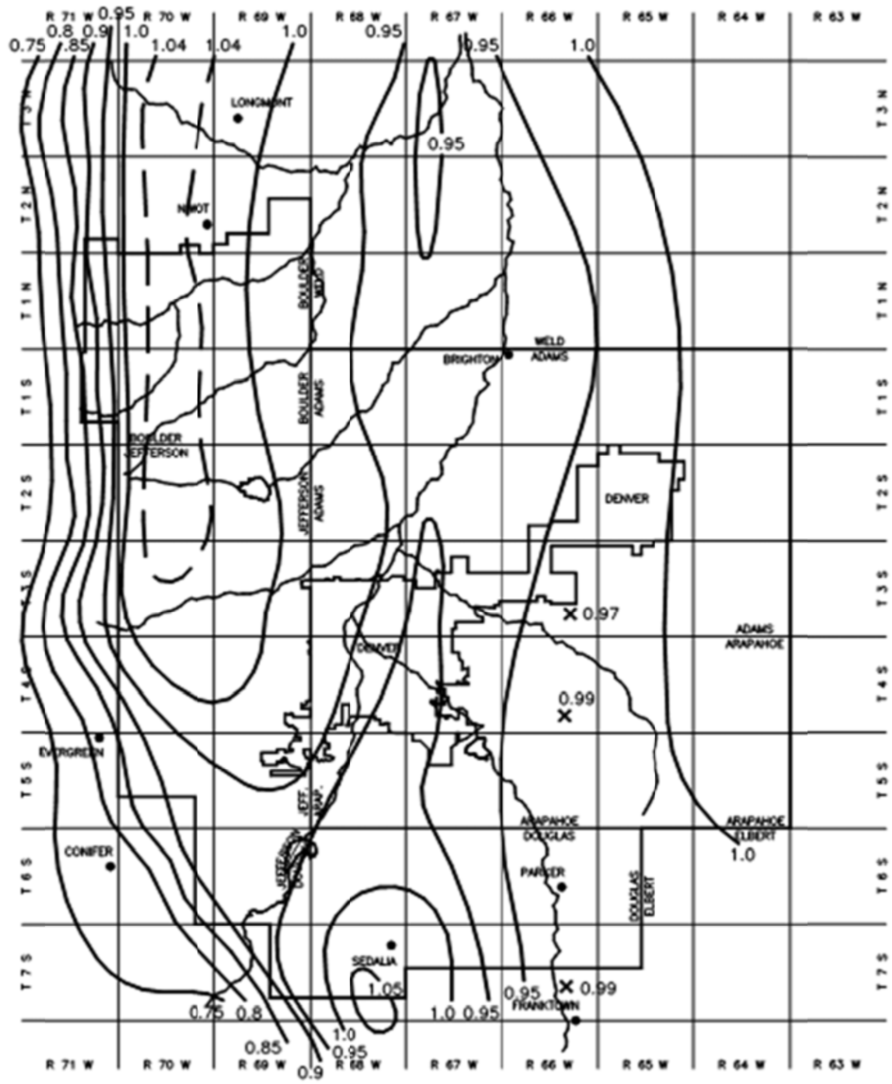


Figure 7: Map showing 2-Year, 1-Hour rainfall depths for locations near Denver, CO (UDFCD 2004).

5.2.1. Land Use Total Imperviousness

Total imperviousness is the percentage of a subcatchment (development, watershed, etc.) that is covered by impermeable surfaces (roads, roofs, parking lots, etc.) that do not allow precipitation to infiltrate into the soil. Typical values of total imperviousness as a function of land use are suggested in the USDCM (UDFCD 2004) and presented in Table 5.

5.2.2. Source Controls

Source controls, also sometimes referred to as low impact development (LID) techniques, refer to the use of grass buffers, grass swales, porous pavements and other features to minimize directly-connected impervious areas (MDCIA), thus reducing effective imperviousness. The model allows the user to choose from one of three levels of source control; “Level 0”, “Level 1”, “Level 2”. Each option is described below. The affects of implementing source controls on effective imperviousness are described in the following section.

Level 0 – Level 0 source control generally refers to traditional development with roof downspouts and driveways draining directly to curb and gutter systems.

Level 1 – The primary intent of Level 1 MDCIA is to direct the runoff from impervious surfaces to flow over grass-covered areas and porous pavement, and to increase overland travel time so as to encourage the removal of the heavier suspended solids before runoff leaves the site, enters a curb and gutter, or enters another stormwater collection system. Thus, at Level 1, as many of the impervious surfaces as possible are made to drain over grass buffer strips before reaching a stormwater conveyance system (UDFCD 2004). Level 1 source controls are less effective in areas with high total imperviousness because there is not adequate space available to implement grass swales and buffer strips.

Level 2 - As an adjunct to Level 1, this level replaces solid street curb and gutter systems with no curb or slotted curbing and low-velocity grass-lined swales and pervious street shoulders. Conveyance systems and storm sewer inlets will still be needed to collect runoff at downstream intersections and crossings where stormwater flow rates exceed the capacity of the swales. Small culverts will be needed at street crossings and at individual driveways until inlets are provided to convey the flow to a storm sewer (UDFCD 2004). Level 2 source controls are less effective in areas with high total imperviousness because there is not adequate space available to implement grass swales and buffer strips.

5.2.3. Land Use Effective Imperviousness

Effective imperviousness is the percentage of a watershed that is impervious and drains runoff directly to the paved or piped stormwater collection system. It is a function of the total imperviousness and any source controls applied to the watershed, and is used to compute the size of storage BMPs and the runoff coefficient used to estimate runoff volume and peak flow rates. Empirical methods for estimating effective imperviousness have been developed by UDFCD and are described below according to the level of source controls applied.

None – When no source controls are implemented, the effective imperviousness is equal to the total imperviousness.

Level 1 & Level 2 – Level 1 and Level 2 source controls reduce the effective imperviousness by an amount that is dependent on the total imperviousness of the watershed. The model uses UDFCD's methods for reducing effective imperviousness, as illustrated in Figure 8.

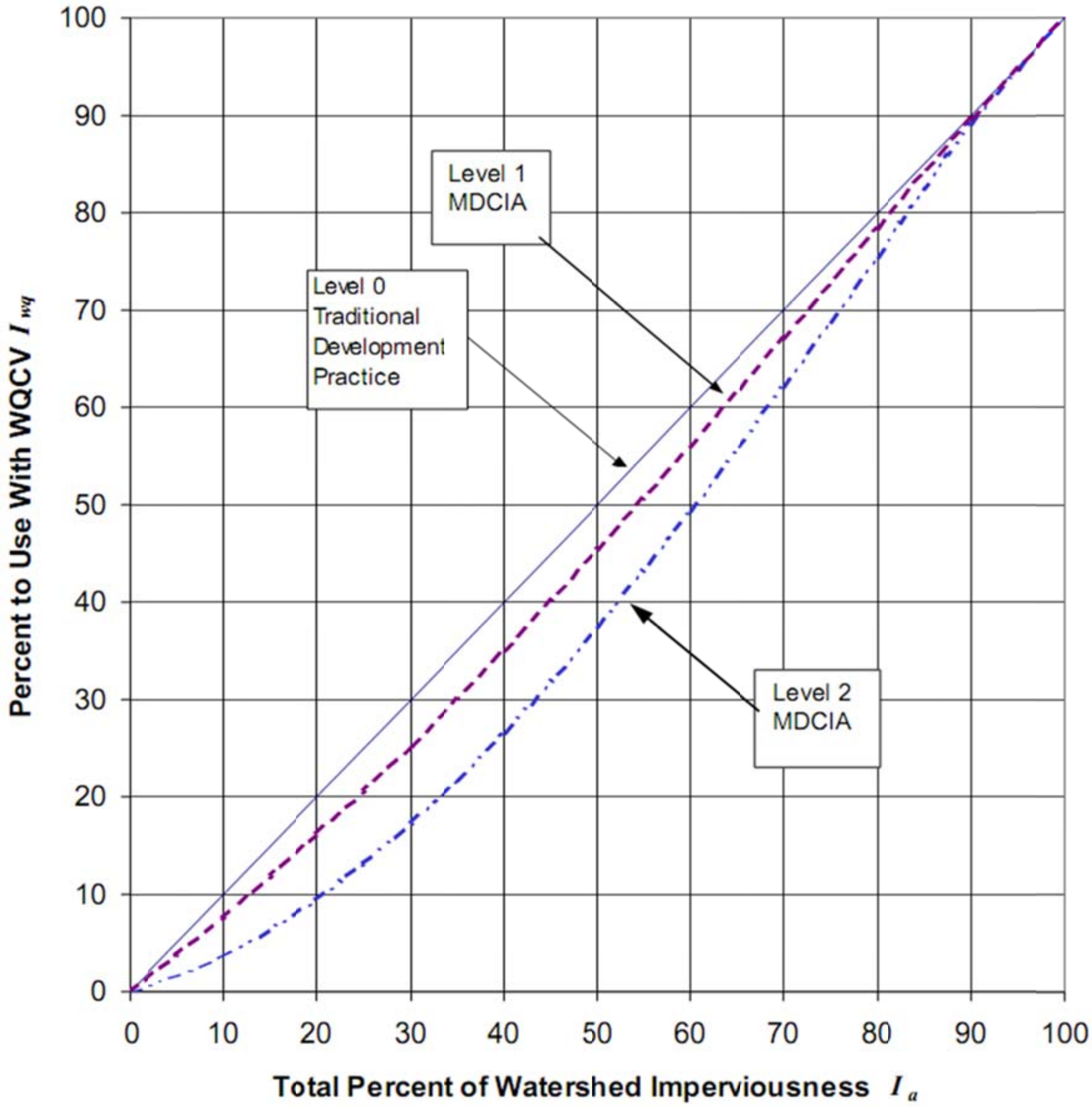


Figure 8: Effective imperviousness adjustments for Level 1 and Level 2 MDCIA.

For programming purposes, the plots in Figure 8 were converted to the regression equations (1), (2) and (3), which are imbedded within the model macros.

Level 0 $$EI = TI \quad \textbf{(1)}$$

Level 1 $$EI = 0.2156TI^2 + 0.8005TI \quad \textbf{(2)}$$

Level 2 $$EI = -0.5014TI^3 + 1.2301TI^2 + 0.2764TI \quad \textbf{(3)}$$

Where *EI* = Effective imperviousness and *TI* = Total imperviousness.

5.3. Runoff Coefficients

UDFCD has developed empirical equations for estimating watershed runoff coefficients as a function of the imperviousness of the watershed. The UDFCD equations are used in the model and are provided below (UDFCD 2004).

$$C_A = K_A + \left(1.31I^3 - 1.44I^2 + 1.135I - 0.12\right) \text{ for } C_A>0 \text{ otherwise } C_A=0 \quad \textbf{(4)}$$

$$C_{CD} = K_{CD} + \left(0.858I^3 - 0.786I^2 + 0.774I + 0.04\right) \quad \textbf{(5)}$$

$$C_B = \left(C_A + C_{CD}\right)/2 \quad \textbf{(6)}$$

Where I = watershed imperviousness (use total to compute total runoff generated, use effective to compute total runoff that leaves a subcatchment), C_A = runoff coefficient for NRCS Type A soils, C_B = runoff coefficient for NRCS Type B soils, C_{CD} = runoff coefficient for NRCS Type C & D soils, K_A = correction factor for Type A soils (Table 16) and K_{CD} = correction factor for Type C & D soils (Table 16).

Table 16 : Table of correction factors for calculating runoff coefficients

Soil Type	Storm Return Period	
	2–Year	5-Year
A	0	-0.08I + 0.09
C & D	0	-0.10I + 0.11

The model uses a 2-year return storm period (correction factors = 0) for generating runoff and the 5-year correction factors are used to calculate the time of concentration for the Rational Method.

5.4. BMP Size

BMPs are classified as either storage BMPs, conveyance BMPs or PP (

Table 17). Storage BMPs capture and treat a specified volume of runoff and are measured according to their design storage volume. Conveyance BMPs convey and treat a specified flow rate and are measured according to their 2-year design flow capacity and PPs are measured according to their surface area. The size of storage and conveyance BMPs are computed as described in the following sections. PP surface area (*SAPP*) is input by the user, therefore there is no “PP sizing” algorithm.

Table 17: BMP design classification

BMP	Design Classification
Concrete Grid Pavers	PP
Constructed Wetland Basin	Storage
Constructed Wetland Channel	Conveyance
Extended Detention Basin	Storage
Hydrodynamic Separator	Conveyance
Inlet Inserts	Conveyance
Media Filter Vault	Conveyance
Permeable Interlocking Concrete Pavers	PP
Porous Concrete Pavement	PP
Porous Gravel Pavement	PP
Porous Landscape Detention	Storage
Reinforced Grass Pavement	PP
Retention (Wet) Pond	Storage
Sand Filter Basin	Storage
Sand Filter Vault	Storage
Sediment/Oil/Grease Separator	Conveyance
Vault w/ Capture Volume	Storage

5.4.1. *Storage BMPs*

UDFCD has developed design criteria for sizing volume-based structural BMPs so that the runoff from approximately 85% of the annual precipitation events is captured and effectively treated for water quality purposes. The water quality capture volume (WQCV) refers to a specific depth of precipitation that should be captured by the BMP, and is a function of the contributing area effective imperviousness and the required drawdown time of the BMP. Multiplying the WQCV by the contributing area gives the recommended storage volume for capturing and treating 85% of annual precipitation events. The procedures used for computing the WQCV are as follows. **Note**: The WQCV computed for each BMP does not account for additional storage that may be required for flood control. Equation (7) is UDFCD's empirical equation for estimating the WQCV of a BMP.

$$WQCV = a * (0.91EI^3 - 1.19EI^2 + 0.78EI) \qquad \textbf{(7)}$$

Where $WQCV$ = water quality capture volume (watershed-inches), a = coefficient based on suggested drawdown time for the BMP, and EI = effective imperviousness of the watershed (%).

UDFCD also has procedures for designing the storage volume of EDBs and RPs to capture and treat the excess urban runoff volume (EURV) for both water quality and flow control purposes. The EURV is the additional runoff that is generated when undeveloped land is urbanized and is dependent on the imperviousness and soil type of the watershed. Equations (7), (9), and (10) are used to compute the EURV for soil types A, B and C/D, respectively.

$$EURV_A = 1.1 * (2.0491EI - 0.1113) \quad \textbf{(8)}$$

$$EURV_B = 1.1 * (1.2846EI - 0.0461) \quad \textbf{(9)}$$

$$EURV_{C/D} = 1.1 * (1.1381EI - 0.0339) \quad \textbf{(10)}$$

Where $EURV$ = excess urban runoff volume (watershed-inches) and EI = effective imperviousness of the watershed (%).

The design volume of BMPs are then computed using Equation (11) for volume measured in acre-feet (AF) or Equation (12) for volume measured in cubic feet (ft^3).

$$DesignVolume(AF) = StorageVolume / 12 * CA * ASF \quad \textbf{(11)}$$

$$DesignVolume(ft^3) = StorageVolume / 12 * CA * ASF * 43{,}560 \quad \textbf{(12)}$$

Where C*A* = contributing area (acres), *ASF* = additional storage factor and *StorageVolume* = WQCV or EURV (watershed-inches). Drawdown time ("*a*") and additional storage factor ("*ASF*") values for each volume-based BMP in the model are presented in Table 18. The drawdown time coefficients are values recommended by UDFCD. The ASF values were determined as described below.

Table 18: Volume-based BMP design factors

BMP	Drawdown Time Coefficient, *a*	Additional Storage Factor, *ASF*
Extended Detention Basin	1.0	1.2
Retention (Wet) Pond - WQCV	0.8	2.6
Retention (Wet) Pond – EURV	0.8	1.5
Sand Filter Basin	1.0	1.0
Vault w/ Capture Volume	0.8	1.1
Sand Filter Vault	0.8	1.0
Constructed Wetland Basin	0.9	1.75

Porous Landscape Detention	0.8	1.0

Extended Detention Basin – additional 20% storage is needed for sediment accumulation
Retention Pond (WQCV) – additional 160% storage is needed for the permanent pool and sediment accumulation.
Retention Pond (EURV) – additional 50% storage is needed for permanent pool and sediment accumulation.
Constructed Wetland Basin – additional 75% storage is needed for permanent pool and sediment accumulation.
Vault with Capture Volume – additional 10% storage is needed for sediment accumulation.

5.4.2. *Conveyance BMPs*

UDFCD recommends sizing flow-based BMPs to convey the 2-year peak flow rate. The peak flow rate is computed from the Rational Method, using UDFCD methods for estimating time of concentration and design rainfall intensity. UDFCD has additional design criteria for constructed wetland channels (CWC) that must be met after the design flow rate is determined.

Peak flow rates are estimated from the Rational Method, Equation (13).

$$Q = C * i * CA \tag{13}$$

Where Q = peak flow rate (cfs), C = runoff coefficient for contributing area, i = rainfall intensity (in/hr), CA = contributing area (acres).

The rainfall intensity is computed using Equation (14), derived by UDFCD and applicable to the Front Range region of Colorado.

$$i = \frac{28.5P_1}{(10+Tc)^{0.786}} \tag{14}$$

Where P_1 = 2-Year, 1-hour point rainfall depth (inches) and Tc = time of concentration (minutes).

The time of concentration is the sum of the travel times for initial (overland) flow, *Ti*, and channelized flow, *Tt*.

$$Tc = Ti + Tt \tag{15}$$

For locations within the Front Range region of Colorado, the travel time for initial (overland) flow, *Ti*, is the lesser of the two values computed in Equations (16) and (17).

$$Ti = \frac{0.395(1.1 - C_5)\sqrt{L_{OF}}}{S^{0.33}} \tag{16}$$

$$Ti = \frac{L_{OF}}{180} + 10 \tag{17}$$

Where C_5 = runoff coefficient for 5-year frequency, S = watershed slope (ft/ft) and L_{OF} = overland flow length (ft).

Travel time for channelized flow is computed with Equation (18).

$$Tt = \frac{L_{CF}}{V} \tag{18}$$

Where L_{CF} = channelized flow length (ft) and V = average velocity (ft/s) computed using Equation (19).

$$V = C_v S^{0.5} \tag{19}$$

Where C_v = conveyance coefficient[1] and S = watershed slope (ft/ft).

To minimize the number of required user inputs, the overland and channelized flow lengths are automatically computed by the model, assuming a square, v-shaped draining watershed, as shown in Figure 9. These assumed lengths are considered reasonable for planning-level studies.

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[1] The conveyance coefficient is assumed to be 20, the value used for paved areas and shallow paved swales which are expected in urban watersheds.

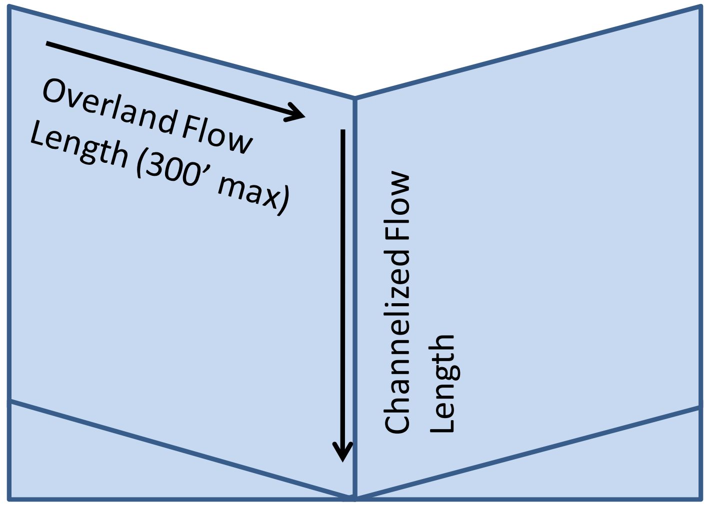

Figure 9: Diagram showing overland and channelized flow lengths assuming v-shaped watershed

Overland and channelized flow lengths are computed using Equations (20) and (21), respectively.

$$L_{OF} = 0.5 * \sqrt{CIA * 43560} \tag{20}$$

$$L_{CF} = \sqrt{CIA * 43560} \tag{21}$$

Where L_{OF} = overland flow length (ft) (maximum of 300 ft), L_{CF} = channelized flow length (ft) and *CIA* = contributing area to the BMP (acres).

5.4.3. Permeable Pavements (PP)

The surface area of PPs are input by the user.

5.5. Number of BMPs

When applying BMPs to a subcatchment, *BMP-REALCOST* assumes that no area in that subcatchment is left untreated, therefore the number of BMPs (*N*) in each subcatchment is computed using Equation (22) and rounded to the next highest integer.

$$N = (CA * I_T)/CIA \tag{22}$$

where *CA* = subcatchment total area (acres) and *CIA* = contributing impervious area (acres) for BMPs (input by the user) or CIA = (*RAPP* + *SAPP*) for PP. To evaluate untreated areas in a scenario, the user can select BMP type "None" to be applied to a subcatchment. Using the regional control option, $N = 1$.

5.6. Construction Costs

Construction costs are represented in the form of a parametric equation (23) where costs are expressed as a function of the size of the BMP, a base cost and an exponent term that can reflect economies of scale realized with some construction projects.

$$ConCost = C + XU^{\alpha} \tag{23}$$

Where *ConCost* = total construction cost, *C* = base cost, *X* = unit cost, *U* = size of the BMP (ft^2, ft^3, AF, cfs, acres) and α = economies of scale factor.

The size of the BMP is the storage volume for storage BMPs, design flow rate for conveyance BMPs and surface area for PPs. This method of computing construction costs was chosen because it achieves the model objectives of being able to evaluate multiple BMP sizes within one scenario, is able to reflect economies of scale and is simple enough for users to adjust the cost equation to fit their needs.

5.6.1. Development of Construction Cost Equations

Muller Engineering (2009) developed construction cost estimates for each of the BMPs included in the model based on UDFCD BMP design criteria and unit costs available from Denver-area construction projects completed in the past 5 years. For each BMP, construction costs for three different sizes were estimated. The estimates were adjusted to May 2008 national average costs using the ENR CCI (ENR CCI = 8141), assuming that the original estimates were representative of 2008 costs in the Denver region (ENR CCI = 5782). Plots of BMP cost versus size were created and best-fit lines were applied to generate a cost equation. The methods and assumptions used to develop the construction cost estimates are documented in the memorandum prepared by Muller Engineering (2009), which is included in as Appendix B in this manual. The following sections present the plots and equations generated for each BMP.

Constructed Wetland Basins, Extended Detention Basins and Retention Ponds with Water Quality Control Volume

Figure 10 presents the plots and cost equations generated for constructed wetland basins, extended detention basins and retention ponds designed for the WQCV.

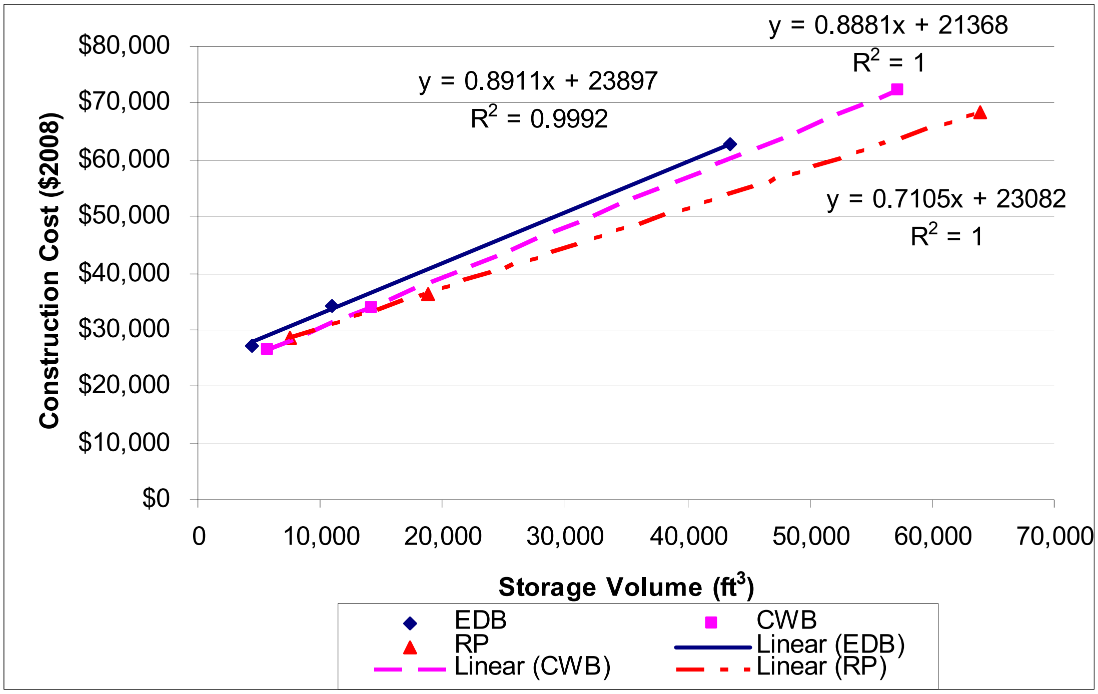

Figure 10: Cost equations developed for constructed wetland basins, extended detention ponds and retention ponds with WQCV.

Sand Filter Basins, Porous Landscape Detention, Vaults with Capture Volume and Sand Filter Vaults

Figure 11 presents the plots and cost equations generated for sand filter basins, porous landscape detention, vaults with capture volume and sand filter vaults designed for the WQCV. Note that the costs for PLDs assume that the PLD is "unconstrained", meaning that is does not have concrete sidewalls.

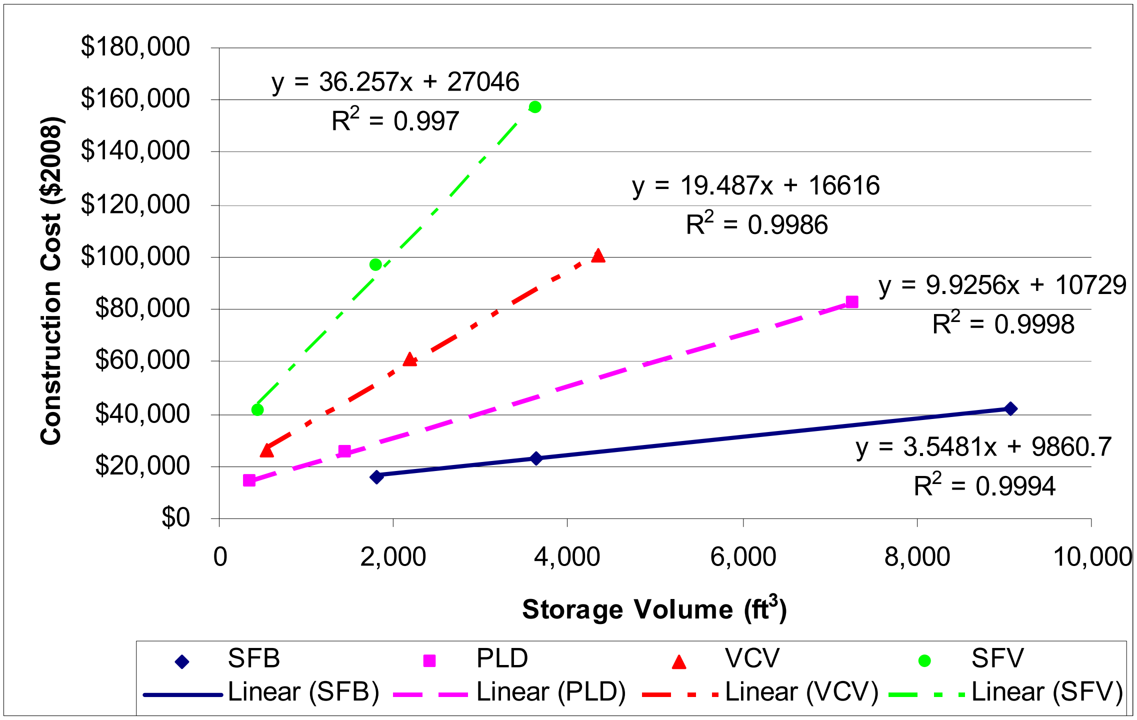

Figure 11: Cost equations developed for sand filter basins, porous landscape detention, vaults with capture volume and sand filter vaults designed for the WQCV.

Permeable Pavements

Figure 12 presents the plots and cost equations generated for concrete grid pavers (also known as modular block pavement), permeable interlocking concrete pavers (also known as cobblestone block pavers), reinforced grass pavement, porous concrete pavement and porous gravel pavement.

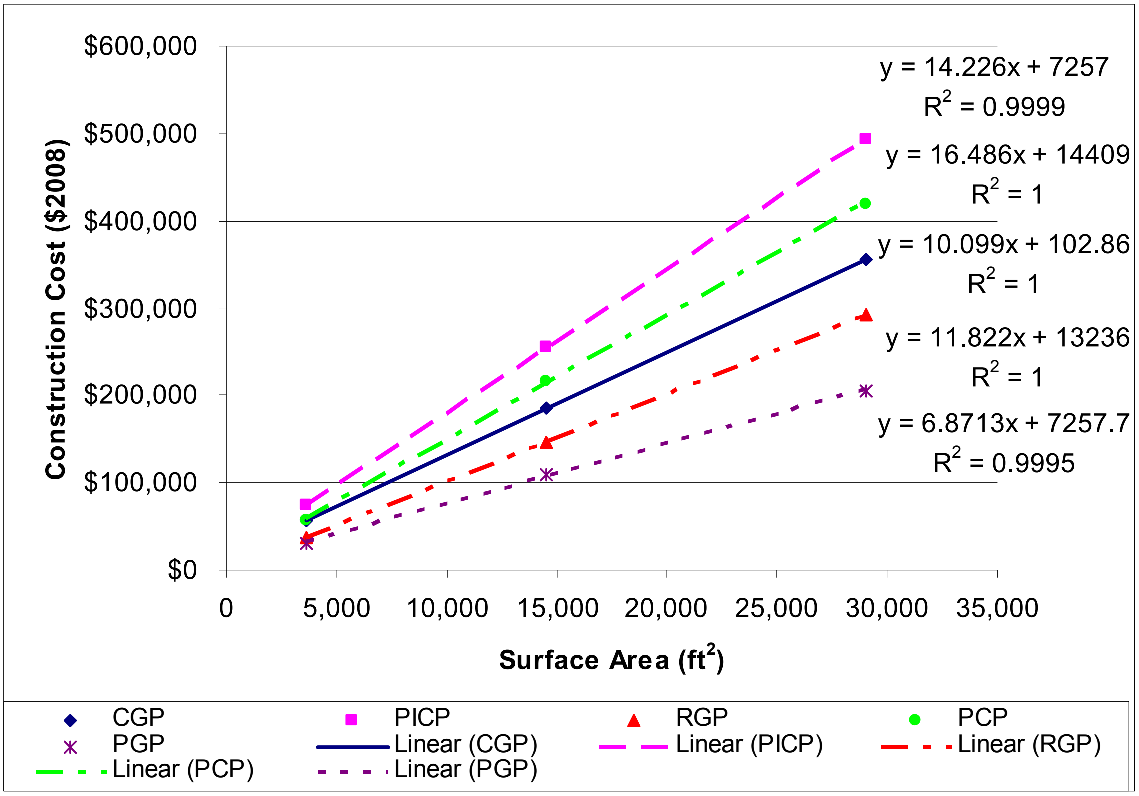

Figure 12: Cost equations developed for permeable pavements.

Hydrodynamic Separators, Sediment/Oil/Grease Separators, Media Filter Vaults and Inlet Inserts

Figure 13 presents the plots and cost equations generated for hydrodynamic separators, sediment/oil/grease separators, media filter vaults[2] and inlet inserts[3]. The construction costs for inlet inserts assume that each insert has a design flowrate of approximately 0.4 cfs and that each insert costs approximately $856 to install.

[2] The costs for media filter vaults are based on two proprietary devices, the EcoStorm Plus and StormFilter. The Filterra system is not representative of the devices being evaluated for this category, therefore its costs were removed from consideration in the model.

[3] The costs of inlet inserts are based on two propriety devices, the Ultra Urban Filter with Smart Sponge and the FlexStorm. The Hydroscreen device is not representative of the devices being evaluated for this category, therefore its costs were removed from consideration in the model.

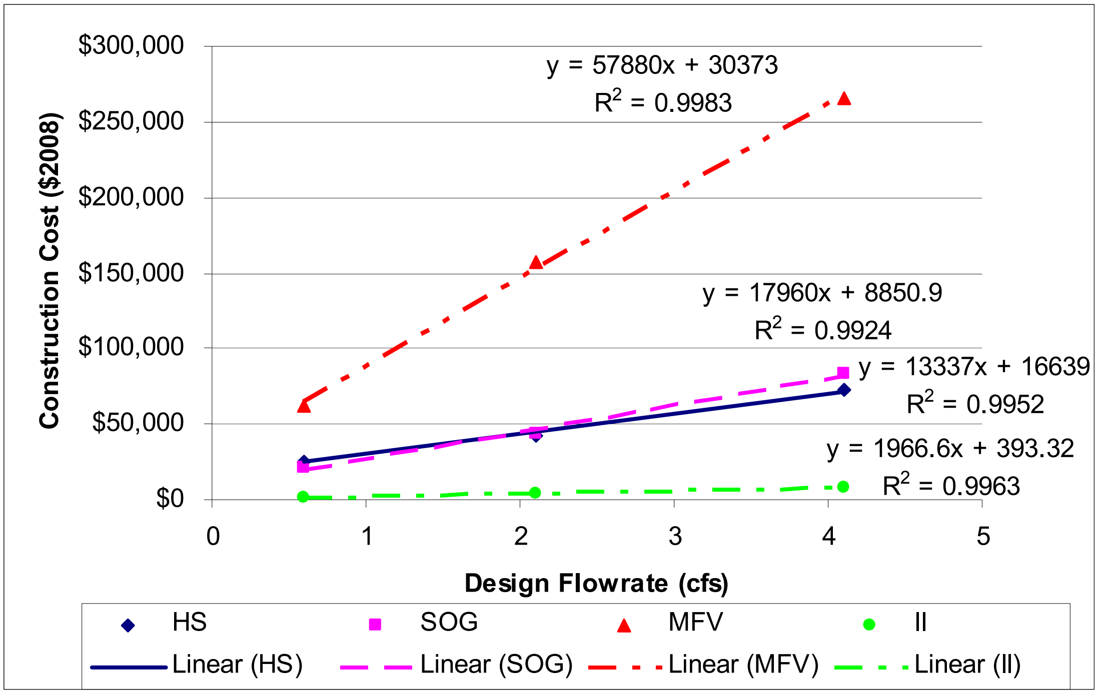

Figure 13: Cost equations developed for proprietary devices.

Extended Detention Basins and Retention Ponds with Excess Urban Runoff Volume

Figure 14 presents the plots and cost equations generated for constructed wetland basins, extended detention basins and retention ponds designed for the EURV.

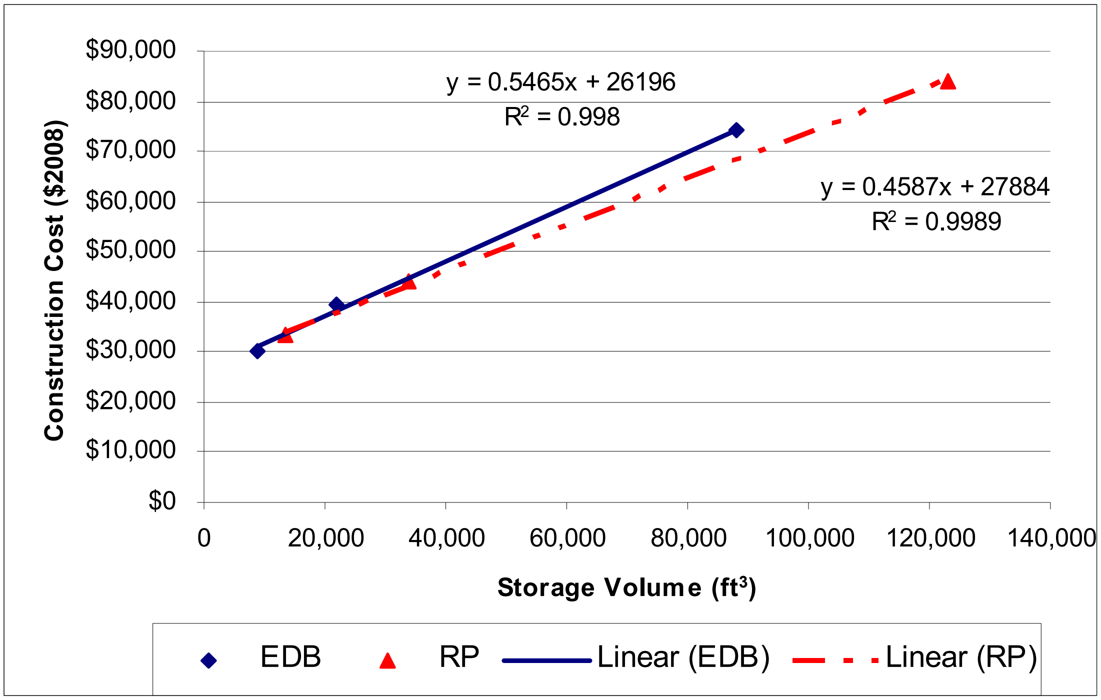

Figure 14: Cost equations developed for extended detention ponds and retention ponds with EURV.

Constructed Wetland Channel

Construction costs for CWCs are dependent on both the design flowrate of the channel (which controls the cross sectional area of the channel) and the length of the channel. Figure 15 shows the relationship of construction costs per 100 linear feet of channel to the design flowrate.

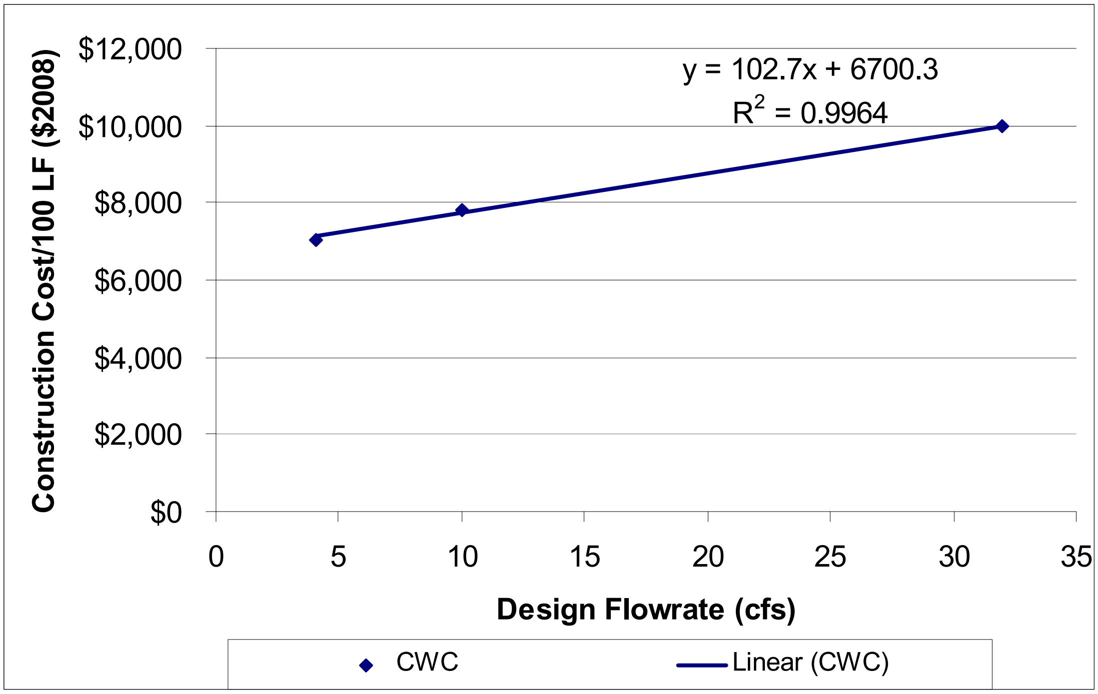

Figure 15: Unit construction cost equation developed for constructed wetland channels.

To estimate the total construction costs, the unit cost taken from Figure 15 is then multiplied by the length of the channel, which is assumed to be equal to the square root of the area draining to the channel, Equation (24). This assumes that the contributing area is square and the channel bisects the area as in a classic "V-shaped" watershed model.

$$L = \sqrt{CIA * 43{,}560} \tag{24}$$

Where L = channel length (ft) and CIA = contributing area to the BMP (acres).

5.6.2. Construction Cost Equations Used in Model

Table 19 summarizes the default equations used to compute BMP construction cost estimates in the model. The costs are adjusted to May 2008, nationally-averaged costs using the Engineering News Record (ENR) Construction Cost Index (CCI) value of 8,141 (ENR 2008). The procedures for adjusting costs using this index are documented in Sections 5.13 and 5.14.

Table 19: Summary of construction cost equations used in the model

BMP	Cost Equation ($2008)
Constructed Wetland Basin	$21,368 + $0.89(V)
Constructed Wetland Channel[1]	$6,700 + $102.70(F)
Extended Detention Basin (WQCV)	$23,897 + $0.89(V)
Extended Detention Basin (EURV)	$26,196 + $0.55(V)
Hydrodynamic Separator	$16,639 + $13,337(F)
Inlet Inserts	$393.32 + $1,967(F)
Media Filter Vault	$30,373 + $57,880(F)
Porous Landscape Detention	$10,729 + $9.93(V)
Retention (Wet) Pond (WQCV)	$23,082 + $0.71(V)
Retention (Wet) Pond (EURV)	$27,884 + $0.46(V)
Sand Filter Basin	$9,861 + $3.55(V)
Sand Filter Vault	$27,046 + $36.26(V)
Sediment/Oil/Grease Separator	$8,851+ $17,960(F)
Vault with Capture Volume	$16,616 + $19.49(V)
Concrete Grid Pavers (Modular Blocks)	$102.86 + $10.10(SA)
Permeable Interlocking Concrete Pavers (Cobblestone Blocks)	$7,257 + $14.23(SA)
Porous Concrete Pavement	$14,409 + $16.49(SA)
Porous Gravel Pavement	$7,258 + $6.87(SA)
Reinforced Grass Pavement	$13,236 + $11.82(SA)

Notes:
1 - cost per 100 linear feet of channel
F = design flowrate (cfs)
SA = surface area (ft^2)
V = storage volume (ft^3)

5.7. Land Costs

Land costs are a function of the land required for the BMP and the cost of the land on which the BMP will be constructed. For storage BMPs, the land required can be computed as a function of the BMP size and a derived coefficient referred to as the "land consumption coefficient" (C_{LC}), with land costs then being computed using Equation (25).

$$LandCost = LC * U * CLC \quad \textbf{(25)}$$

Where *LandCost* = cost of land required for the BMP, *LC* = cost of land based on land use ($/acre), *U* = size of the BMP (ft^2, ft^3, AF, cfs, acres) and *CLC* = factor relating the land required for the BMP to its size (acres/unit).

Permeable pavements and BMPs located underground do not have land costs associated with them.

The land required for constructed wetland channels is equal to the surface area of the channel, which is the product of the channel top width and length. Land costs for CWCs are computed using Equation (26).

$$LandCost = LC * Tw * L \qquad \textbf{(26)}$$

Where *LandCost* = cost of land required for the BMP, *LC* = cost of land based on land use ($/acre), *L* = channel length (ft) and *Tw* = channel top width (ft).

The channel length is determined using Equation (24). The channel top width is computed using an iterative procedure that solves for the appropriate channel cross-section area required to convey the design flowrate, as recommended by UDFCD.

5.7.1. Cost of Land Based on Land Use

The cost of land is a function of the land use. The default land cost values used in the model (Table 13) are average values of the ranges reported in Strecker et al (2005) (Table 20) with some modifications for the Denver-region. These costs are considered applicable for *new* developments on previously undeveloped land or land on which any existing structures have minimal value. The costs associated with redevelopment, are likely to be higher due to the value of structures already existing on that land.

Table 20: Land cost estimates as function of land use

Land Use	Land Cost ($/acre)
Unimproved Land	$25,000 – 50,000
Residential	$75,000 – 200,000
Commercial	$100,000 – 300,000
High Density	$500,000 – 3,000,000

5.7.2. Land Required for BMPs (CLC)

Recognizing that the area of land required for BMPs is related to the size of the BMP, a "land consumption coefficient" (CLC) was derived to quantify this relationship based on UDFCD BMP design recommendations. The following sections describe the methods and assumptions used to develop this relationship for each BMP that requires land.

Constructed Wetland Basin

The CLC for CWBs = 0.00002 acres/ft^3, assuming average depth of 2 feet and an area equal to 75% of the CWB surface area be set aside for maintenance access and other considerations.

Constructed Wetland Channel

The CLC for CWCs = 1 acre/acre, assuming that the land required for CWCs is equal to the surface area of the BMP. Because the size of CWCs are calculated and reported in terms of their design flowrate (cfs), the tool computes the surface area of the CWC internally as a function of the channel top width and channel length.

Extended Detention Basin -WQCV/EURV

The CLC for EDBs = 0.000016 acres/ft^3, assuming average depth of 2.5 feet and an area equal to 75% of the EDB surface area be set aside for maintenance access and other considerations.

Porous Landscape Detention

The CLC for PLDs = 0.000023 acres/ft^3, assuming that the WQCV can "pond" to a depth of 1 foot on the surface of the PLD.

Retention Pond -WQCV/EURV

The CLC for RPs = 0.000013 acres/ft^3, assuming average depth of 3 feet and an area equal to 75% of the RP surface area be set aside for maintenance access and other considerations.

Sand Filter Basin

The CLC for SFBs = 0.000013 acres/ft^3, assuming average depth of 3 feet and an area equal to 75% of the SFB surface area be set aside for maintenance access and other considerations.

Underground BMPs

Underground BMPs do not consume any land and the CLCs are set equal to 0%.

Table 21 summarizes the CLC values used in the model.

Table 21: CLC values used for computing BMP land costs

BMP	CLC	Units
Constructed Wetland Basin	0.000020	Acres/ft^3
Constructed Wetland Channel	1	Acres/acre
Extended Detention Basin-EURV	0.000016	Acres/ft^3
Extended Detention Basin-WQCV	0.000016	Acres/ft^3
Hydrodynamic Separator	0	Acres/cfs
Inlet Inserts	0	Acres/cfs
Media Filter Vault	0	Acres/cfs
Permeable Pavements	0	Acres/acre
Porous Landscape Detention	0.000023	Acres/ft^3
Retention (Wet) Pond-EURV	0.000013	Acres/ft^3
Retention (Wet) Pond-WQCV	0.000013	Acres/ft^3
Sand Filter Basin	0.000013	Acres/ft^3
Sand Filter Vault	0	Acres/ft^3
Sediment/Oil/Grease Separator	0	Acres/cfs
Vault w/ Capture Volume	0	Acres/ft^3

5.8. Contingency, Engineering and Administration Costs

The additional costs attributable to contingencies, engineering, permitting, erosion control, administration, etc. are assumed to be 40% of the construction costs, as estimated for Denver-area projects by Urbonas (2008).

5.9. Capital Cost Calculations

Capital costs include construction costs, land costs and additional costs attributed to contingencies, engineering, administration etc., and are computed using Equation (27).

$$CCost = (1 + CEA) * (C + XU^{\alpha}) + LandCost \tag{27}$$

Where *CCost* = capital cost for an individual BMP, *CEA* = factor accounting for contingencies/engineering/administration (%), *C* = base cost ($), *X* = unit cost ($ per unit), *U* = BMP Size (AF, ft^3, ft^2, acre, cfs), α = economy of scale factor and *LandCost* = land costs ($).

The default values of each variable, for each BMP type, are presented in Table 22.

Table 22: Default values of capital cost parameters used in the model

BMP	CEA (%)	C($)	X($/unit)	Units	α	CLC
Constructed Wetland Basin	40	$21,368	$0.89	ft^3	1	0.000020
Constructed Wetland Channel	40	$6,700	$102.70	ft^3	1	1
Extended Detention Basin (WQCV)	40	$23,897	$0.89	ft^3	1	0.000016
Extended Detention Basin (EURV)	40	$26,196	$0.55	ft^3	1	0.000016
Hydrodynamic Separator	40	$16,639	$13,337	cfs	1	0
Inlet Inserts	40	$393.32	$1,967	cfs	1	0
Media Filter Vault	40	$30,373	$57,880	cfs	1	0
Porous Landscape Detention	40	$10,729	$9.93	ft^3	1	0.000023
Retention (Wet) Pond (WQCV)	40	$23,082	$0.71	ft^3	1	0.000013
Retention (Wet) Pond (EURV)	40	$27,884	$0.46	ft^3	1	0.000013
Sand Filter Basin	40	$9,861	$3.55	ft^3	1	0.000013
Sand Filter Vault	40	$27,046	$36.26	ft^3	1	0
Sediment/Oil/Grease Separator	40	$8,851	$17,960	cfs	1	0
Vault with Capture Volume	40	$16,616	$19.49	ft^3	1	0
Concrete Grid Pavers	40	$102.86	$10.10	ft^2	1	0
Permeable Interlocking Concrete Pavers	40	$7,257	$14.23	ft^2	1	0
Porous Concrete Pavement	40	$14,409	$16.49	ft^2	1	0
Porous Gravel Pavement	40	$7,258	$6.87	ft^2	1	0
Reinforced Grass Pavement	40	$13,236	$11.82	ft^2	1	0

5.10. Maintenance Cost Calculations

As with capital costs, it was preferred to develop cost equations that related annual maintenance costs to the size of the BMP. Annual maintenance costs for a single BMP typically reflect the costs of performing a wide variety of activities. Those activities can generally be divided into two types; those with costs that vary according to the size of the BMP ("variable" maintenance costs) and those that do not ("constant" maintenance costs). Equation (28) was developed for estimating annual maintenance costs as a function of multiple maintenance activities in both types.

$$MCost = C_C + C_V * U \tag{28}$$

Where U = BMP Size (AF, ft^3, ft^2, acre, cfs), $MCost$ = annual maintenance costs, C_C = annual cost for all "constant" maintenance activities and C_V = annual unit cost for all "variable" maintenance activities.

Table 23 shows the maintenance cost equations developed for each BMP. The methods and assumptions used to develop the cost equation are explained in Appendix C.

Table 23: Annual maintenance cost equations

BMP	C_C($)	C_V($/unit)	Units
Constructed Wetland Basin	$0	$1,956	AF
Constructed Wetland Channel	$0	$960	Acre
Extended Detention Basin (WQCV)	$1,849	$2,782	AF
Extended Detention Basin (EURV)	$1,849	$2,782	AF
Hydrodynamic Separator	$0	$749	cfs
Inlet Inserts	$165	$0	cfs
Media Filter Vault	$0	$835	cfs
Porous Landscape Detention	$0	$0.62	CF
Retention (Wet) Pond (WQCV)	$1,521	$1,598	AF
Retention (Wet) Pond (EURV)	$1,521	$1,598	AF
Sand Filter Basin	$0	$1,096	AF
Sand Filter Vault	$0	$1.86	CF
Sediment/Oil/Grease Separator	$0	$832	cfs
Vault with Capture Volume	$0	$0.66	CF
Concrete Grid Pavers	$0	$125	Acre
Permeable Interlocking Concrete Pavers	$0	$125	Acre
Porous Concrete Pavement	$0	$125	Acre
Porous Gravel Pavement	$0	$5,647	Acre
Reinforced Grass Pavement	$0	$4,040	Acre

5.11. Rehabilitation/Replacement Cost Calculations

Rehabilitation/replacement costs are computed as percentage of the original construction costs of the BMP using Equation (29).

$$RCost = R * ConCost \quad \textbf{(29)}$$

Where *RCost* = rehabilitation/replacement costs for an individual BMP, *R* = percentage of construction costs and *ConCost* = construction costs of BMP.

5.11.1. Reoccurrence Interval of Rehabilitation/Replacement Costs

Rehabilitation and replacement costs reoccur at time intervals equal to the expected design life of each BMP. With a few exceptions (described below), the design life assumed in the model is based on the average of a range of values of expected design lives reported by USDOT (2002).

Inlet Inserts

The estimated design life of two common inlet inserts is reported to be 1-3 years on average, therefore replacement is assumed to occur every 2 years in the model.

Hydrodynamic Separators and Sediment/Oil/Grease Separators

The design life for "manufactured systems" reported in USDOT (2002) is assumed to represent those structures that are primary constructed with precast concrete. However, the HSs and SOGs in this model are assumed to be representative of the more recent proprietary models that include relatively sophisticated hydraulic controls and screens constructed of steel or some other metallic material. These materials do not last as long as concrete, therefore a design life of 25 years is assumed in this model.

5.11.2. Rehabilitation/Replacement Costs as a Percentage of Construction Costs

There was no information reported in the literature for rehabilitation and replacement costs of BMPs, therefore estimates of costs as a percentage of the original construction costs were made using best engineering judgment. The assumptions made to do so are explained in the following paragraphs.

Large, Aboveground BMPs with Extensive Infrastructure

The BMPs that fall under this category include constructed wetland basins, constructed wetland channels, extended detention basins and retention ponds. The majority of construction costs can be attributed to excavation and installation of infrastructure such as berms, wingwalls, grade controls, outlet structures, etc. Once the design lives of these BMPs are exceeded, it is assumed that most of the installed infrastructure will require rehabilitation and/or replacement. Replacing these items is assumed to cost approximately 80% of the original construction costs. The 20% savings from the original construction costs is assumed to come from not requiring extensive re-excavation. Note that these costs do not include the costs of sediment removal, which usually occurs more frequently, and is included as a maintenance cost in this model.

"Filtering" BMPs

"Filtering" BMPs include porous landscape detention, sand filter basins and sand and media filter vaults. Most of the construction costs of these BMPs can be attributed to excavation and installation of the filtering media. Once the design life of these BMPs is exceeded, it is assumed that the filtering media would need to be removed and replaced at a cost equal to the original construction cost. This assumes that removal of the filtering media would require a similar effort as the original excavation and installation of new media would be similar to the original media installation effort.

Belowground BMPs

The BMPs that fall under this category are hydrodynamic separators, sediment/oil/grease separators, and vaults with capture volume. Much of the original construction costs can be attributed to excavation, device procurement and installation. Once the design life of these BMPs is exceeded, it is assumed that they must be completely removed and new devices installed, at a cost of approximately 120% of the original construction costs. The additional 20% of costs is assumed to account for additional effort needed to remove and dispose of the existing device. The costs of excavation, procurement and installation of the new device are assumed to be similar to the original costs.

Inlet Inserts

The costs of replacing inlet inserts are assumed to be similar to the original costs which primarily include procurement and installation.

Permeable Pavements

The construction costs of permeable pavements can mostly be attributed to grading of the site and installation of the subbase and pavement material. At the end of the design life, it is assumed that replacement of the pavement would include demolition/removal and replacement of the pavement material at a cost of approximately 80% of the original construction costs.

Table 24 presents the percentage value and cost reoccurrence interval for each BMP.

Table 24: Rehabilitation/replacement cost percentages and frequency estimates

BMP	Frequency (years)	Cost (as % of construction costs)
Constructed Wetland Basin	35	80%
Constructed Wetland Channel	35	80%
Extended Detention Basin (WQCV)	35	80%
Extended Detention Basin (EURV	35	80%
Hydrodynamic Separator	25	120%
Inlet Inserts	2	100%
Media Filter Vault	12	100%
Porous Landscape Detention	12	100%
Retention (Wet) Pond (WQCV)	35	80%
Retention (Wet) Pond (EURV)	35	80%
Sand Filter Basin	8	100%
Sand Filter Vault	12	100%
Sediment/Oil/Grease Separator	25	120%
Vault with Capture Volume	75	120%
Concrete Grid Pavers	18	80%
Permeable Interlocking Concrete Pavers	18	80%
Porous Concrete Pavement	18	80%
Porous Gravel Pavement	18	80%
Reinforced Grass Pavement	18	80%

5.12. Administrative Cost Calculations

Administrative costs are calculated using the following equation (30).

$$ACost = I + D * MCost \qquad \textbf{(30)}$$

Where *ACost* = annual administrative costs for an individual BMP, *I* = annual compliance inspection costs, *D* = percentage (of annual maintenance costs) and *MCost* = annual maintenance costs.

Annual compliance inspection costs were estimated to be approximately $19 per BMP per year (see Appendix C for details). The percentage of annual maintenance costs is assumed to be 12%.

5.13. Cost Adjustments for Time

Cost data reported in the literature were adjusted for inflation to May 2008 dollars using Equation (31) with the 20-city average value of the ENR CCI (ENR 2008). Table 25 presents average annual 20-city ENR CCI values from 1986 to 2008.

$$Cost(present) = Cost(base\ year) \bullet \frac{ENRCCI(base\ year)}{ENRCCI(present)} \quad \textbf{(31)}$$

Table 25: Engineering News Record 20-City construction cost index (1986-2008)

Year	20-City ENR CCI	Year	20-City ENR CCI
1986	4295	1998	5920
1987	4406	1999	6059
1988	4519	2000	6221
1989	4615	2001	6334
1990	4732	2002	6538
1991	4835	2003	6695
1992	4985	2004	7115
1993	5210	2005	7446
1994	5408	2006	7888
1995	5471	2007	8089
1996	5620	May 2008	8141
1997	5826		

Source: ENR (2008)

5.14. Cost Adjustments for Location

Cost data can also be adjusted for location to account for regional differences in construction costs (materials, labor, etc.). Along with the 20-city nationally-averaged index, ENR also publishes regional indices for 20 cities in the United States. These indices adjust costs from the 20-city nationally-averaged costs using Equation (32).

Table 26 presents the regional index and factor for each city for May 2008. The regional factor can vary over time however it is generally consistent over short time periods. Recently, the regional factor for Denver has been in the range of 0.7-0.75. This factor is useful for determining the regional ENR CCI when only the 20-City average ENR CCI is available.

$$Cost(regional) = Cost(national) \bullet \frac{ENRCCI(regional)}{ENRCCI(national)} \quad \textbf{(32)}$$

Table 26: Engineering News Record regional cost indices (May 2008)

City	Regional CCI	Regional Factor (Regional/National)
20-City average	8141	-
Atlanta	5290	0.65
Baltimore	5537	0.68
Birmingham	5535	0.68
Boston	10004	1.23
Chicago	11176	1.37
Cincinnati	7602	0.93
Cleveland	8555	1.05
Dallas	5005	0.61
Denver	5782	0.71
Detroit	9071	1.11
Kansas City	9303	1.14
Los Angeles	9224	1.13
Minneapolis	9620	1.18
New Orleans	4549	0.56
New York	12482	1.53
Philadelphia	9874	1.21
Pittsburgh	7617	0.94
St. Louis	8769	1.08
San Francisco	9174	1.13
Seattle	8642	1.06

Source: ENR (2008)

5.15. Net Present Cost Calculations

The net present costs (NPC) for all BMPs in a subcatchment, k, is computed using as

$$NPC_k = N_{n,k}\left[\sum_{y=0}^{PH}\begin{bmatrix} (1+CEA)CCost_{n,k} + LCost_{n,k} + \\ \left[\left(RCost_{n,k}^{y} * RDF_{n,k}^{y} + MCost_{n,k}^{y} + ACost_{n,k}^{y}\right)\left(\frac{1+IR_f}{1+ROR_f}\right)^{y}\right]\end{bmatrix}\right] \quad \textbf{(33)}$$

where N = number of BMPs, CEA = contingencies/engineering/administrative costs (%), $CCost$ = construction costs ($), $LCost$ = land costs ($), $RCost$ = rehabilitation/replacement costs ($), $MCost$ = operation and maintenance costs ($), $ACost$ = admininstrative/management costs ($), PH = planning horizon (yrs), IR_f = average inflation rate (%)/100, ROR_f = average rate of return (%)/100, y = time from present (yrs), subscript n denotes the specific BMP type and subscript k denotes the individual subcatchment. RDF is the rehabilitation cost discount factor (unitless) that "discounts" rehabilitation costs in years when the design life of the rehabilitated BMP exceeds the number of years remaining in the planning horizon, thus ensuring that the same number of years are used for both cost and benefit calculations. RDF is computed as

$$RDF_{n,k}^{y} = \left\{ \begin{array}{ll} 1 & if(PH-y) \geq DL \\ \left[\dfrac{IR_f\left(1+IR_f\right)^{DL_n}}{\left(1+IR_f\right)^{DL_n} - 1}\right]\left[\dfrac{\left(1+ROR_f\right)^{(PH-y)}}{ROR_f\left(1+ROR_f\right)^{(PH-y)}}\right] & if(PH-y) < DL \end{array} \right\} \quad \textbf{(34)}$$

Where DL = design life of the BMP (years).

The NPC for a complete scenario with BMPs in multiple subcatchments is computed as

$$NPC_K = \sum_{k=1}^{K} NPC_k \quad \textbf{(35)}$$

where K = number of subcatchments. If a regional BMP is being evaluated for the scenario, then k = K = 1, reflecting that costs are computed for one BMP only.

5.15.1. Inflation Rate

The inflation rate describes how the costs for maintenance, administration, and rehabilitation/replacements will increase in the future. The average long-term inflation rate for these activities was estimated by evaluating the annual change in the 20-city average ENR CCI. Over the past 50 years, the 20-city average ENR CCI has increased from 759 in 1958 to 8141 in May 2008 (ENR 2008). During that time, the average annual increase in ENR CCI was 4.6%.

5.15.2. Planning Horizon

The planning horizon of a project defines the time over which the net present value of the project costs will be evaluated. A planning horizon of 50 years is recommended by UDFCD and other water resource organizations, recognizing the longevity of such projects and the difficulty in financing their construction.

5.15.3. Rate of Return

The rate of return (ROR) describes how monies that are set aside (invested) in the present day will appreciate in the future. The future worth of these investments can then be used to pay for future costs such as maintenance and administration. There was no information in the literature documenting typical ROR values for municipalities and/or stormwater management agencies, therefore a rough estimate of 5% was assumed.

5.16. BMP Effectiveness Calculations

This model evaluates the effectiveness of BMPs using two different measures:

1. The reduction in annual runoff volume discharged to the receiving waters and,
2. The reduction in annual pollutant loading to the receiving waters

As explained in the following sections, both measures are computed in accordance with Strecker et al's (2001) recommendations for evaluating the effectiveness of BMPs.

5.16.1. Runoff Volume Reduction

Runoff volume reduction RVR (ft^3/yr) is computed for each subcatchment *k* by

$$RVR_k = RVT_k - RVRW_k \qquad \textbf{(36)}$$

where RVT = total volume of runoff generated from a subcatchment (ft^3/yr) and $RVRW$ = the volume of runoff discharged to the receiving water (ft^3/yr). RVT (ft^3/yr) is computed by multiplying the average annual runoff depth, estimated using the Simple Method (Schueler 1987), by the subcatchment area

$$RVT_k = P * Pj * RC_{T,k} * CA_k \qquad \textbf{(37)}$$

where P = annual precipitation depth (in), Pj = fraction of annual storms producing runoff (value = 0.9 assuming 90% of annual precipitation produces runoff), RC_T (unitless) is the 2-year runoff coefficient computed using the subcatchment *total* imperviousness, and CA is the subcatchment total area (acres).

The total volume of runoff that reaches the inlet of downstream BMPs, $RVIN_T$ (ft^3/yr), can be computed by

$$RVIN_{T,k} = P * Pj * RC_{E,k} * CA_k \qquad \textbf{(38)}$$

where RC_E = 2-year runoff coefficient computed using the subcatchment *effective* imperviousness, which accounts for volume reduction due to source controls in the subcatchment.

Runoff that reaches the inlet of downstream BMPs is either fully treated by the BMP or bypasses full treatment when the BMP capacity is exceeded. The volume of runoff that receives full treatment, $RVIN_F$ (ft^3/yr), and the volume that bypasses treatment, $RVIN_B$ (ft^3/yr), can be computed using Equations (39) and (40)

$$RVIN_{F,k} = RVIN_{T,k} * \lambda_n / 100 \qquad \textbf{(39)}$$

$$RVIN_{B,k} = RVIN_{T,k} * (1 - \lambda_n / 100) \qquad \textbf{(40)}$$

where λ_n = BMP capture efficiency (%) for a BMP type n (Table 11). For storage BMPs designed to capture the WQCV and EURV, λ = 85% and 98% respectively. The former value is derived from the fundamental basis of the WQCV which is to capture 80-90% of the average annual runoff (UDFCD 2004) and the latter value from UDFCD modeling EURV results (UDFCD unpublished data). No studies could be found documenting λ for conveyance BMPs, therefore *BMP-REALCOST* uses λ = 85% assuming that those BMPs are designed to effectively treat the same number of storms as storage BMPs designed for the WQCV. Methods for estimating λ for PPs are described below.

Finally, $RVRW$ (ft^3/yr) is computed as

$$RVRW_k = RVIN_{F,k} * (1 - \theta_n / 100) + RVIN_{B,k} \qquad \textbf{(41)}$$

where θ_n = is the percentage of $RVIN_F$ that is removed from the surface water system via infiltration and/or evapotranspiration in BMP type n (Table 11). θ values are defined for storage and conveyance BMPs based on the findings of Strecker et al (2005) who reported values for the ratio of measured inflow/measured outflow for several BMPs using data contained in the International BMP Database and UDFCD (unpublished data) who estimated the same ratios for other BMPs. The methods used to derive θ values for PPs are described below.

If a regional BMP is being evaluated, then RC_T and RC_E in equations (37) and (38), respectively, are area-weighted values for all of the subcatchments and CA (in the same equations) is the sum of all subcatchment contributing areas; such that the calculated value of RVT is the total runoff volume generated from all subcatchments and $RVIN$ is the runoff volume reaching the regional BMP.

Permeable Pavement Capture Efficiency and Runoff Volume Reduction

Capture Efficiency

Very few studies have been conducted to assess the capture efficiency of permeable pavements. Those studies that have were limited to only a few of types of permeable pavements with no impervious runon area and were conducted in regions (southeast and northwest US) with very different hydrology than Colorado. Given the lack of applicable field data, PP capture efficiencies were estimated based on experience and engineering judgment. Field experiences have shown that PPs have considerable infiltration capacity (at times exceeding tens or hundreds of inches per hour), enough to safely assume that 100% of runoff would be captured when the impervious runon area:PP area (RAPP:SAPP) ratio is less than or equal to 5:1 (the maximum recommended for use in this model). However, experiences have also shown that incorrect construction (e.g. inadequate grading, “oversmoothing” of porous concrete, etc.) in some portions of the installation can result in some runoff being generated from PP installations. The extent of those construction errors has not been quantified, however using engineering judgment we have reasoned that construction errors may result in up to 5% of the annual runoff not being adequately captured on a PP area with no runon area. Assuming the volume of runoff not captured due to construction errors would increase linearly as the RAPP:SAPP ratio was increased, the following equation was developed to estimate the capture efficiency of PPs under RAPP:SAPP ratios less than or equal to 5:1. The equation reflects a maximum capture efficiency of 95% assuming no impervious runon area, declining linearly with increasing RAPP:SAPP ratios.

$$\lambda = \min(100\% - (RAPP/SAPP)*5\%, 95\%)$$

Runoff Volume Reduction

If the PP is designed to infiltrate all captured runoff, then 100% of the captured runoff will infiltrate and be removed from the surface water system. If the PP is underdrained, then a certain percentage of the infiltrated water will be underdrained and the remaining percentage will be removed from the surface water system via infiltration (if subbase is unlined) and/or ET. Unpublished data collected from UDFCD, using two different PP types with a 3:1 runon:PP area ratio, suggests that approximately 40% of the captured runoff is lost due to infiltration and/or ET in unlined, underdrained systems. It should be noted that these installations contained sand filter layer approximately 6” thick. Intuitively, that percentage might increase with lower runon:PP ratios and decrease with higher runon:PP ratios, with some minimum value (~10%) that always occur due to water retention in the subbase pore space. The following function is used to estimate the percentage (θ) of infiltrate that is lost to infiltration and/or ET;

$$\theta = \max(50\% - (RAPP/SAPP)*3\%, 10\%)$$

5.16.2. Pollutant Load Reduction

Pollutant load reduction, *PLR* (lb/yr), for a subcatchment *k* and pollutant *m* is computed as

$$PLR_{k,m} = PLT_{k,m} - PLRW_{k,m} \quad \textbf{(42)}$$

where *PLT* = total pollutant load generated from the subcatchment (lb/yr) and *PLRW* = pollutant load discharged to the receiving water (lb/yr). *PLT* is given by

$$PLT_{k,m} = RVT_{k,m} * EMCLU_{k,m} \quad \textbf{(43)}$$

where *RVT* = total runoff volume generated from the subcatchment (ft^3/yr) and *EMCLU* = pollutant event mean concentration (mg/L) assigned to the subcatchment land use classification (Table 27). These values are derived from UDFCD reported values and information provided by Maestre et al (2005), as documented in Appendix A.

Table 27: Land use average EMCs in stormwater runoff for Denver, CO

Constituent	Units	Industrial	Commercial	Residential	Undeveloped
Total Suspended Solids	mg/L	399	225	240	400
Total Nitrogen	mg/L	2.7	3.3	3.4	3.4
TKN	mg/L	1.8	2.3	2.7	2.9
Nitrate + Nitrite	mg/L	0.91	0.96	0.65	0.50
Total Phosphorus	mg/L	0.43	0.42	0.65	0.40
Dissolved Phosphorus	mg/L	0.20	0.15	0.22	0.10
Copper, Total	µg/L	84	43	29	40
Copper, Dissolved	µg/L	32	19	17	23
Lead, Total	µg/L	130	59	53	100
Lead, Dissolved	µg/L	26	16	13	25
Zinc, Total	µg/L	520	240	180	100
Zinc, Dissolved	µg/L	292	95	78	43

Source: UDFCD (2004) with modifications using Maestre et al (2005)

Similar to runoff volume, the pollutant load discharged to the receiving water is the sum of the "fully-treated" load and the "bypassed" load. Bypassed runoff is assumed to retain the concentrations of pollutants as generated from the subcatchment (*EMCLU*), whereas runoff treated by a BMP type *n* has effluent concentrations (*EMCeff*) unique to that BMP. Accordingly, *PLRW* (lb/yr) is computed as

$$PLRW_{k,m} = RVIN_{B,k} * EMCLU_{k,m} + RVIN_{F,k} * (1-\theta_n/100) * EMCeff_{n,m} \quad \textbf{(44)}$$

where $RVIN_B$ = runoff volume that bypasses BMP treatment (ft^3/yr), *EMCLU* = pollutant event mean concentration (mg/L) assigned to the subcatchment land use classification, $RVIN_F$ = runoff volume that received full BMP treatment (ft^3/yr), θ_n = is the percentage of $RVIN_F$ that is removed from the surface water system via infiltration and/or evapotranspiration in BMP type *n* and *EMCeff* = pollutant event mean concentration (mg/L) assigned to the particular BMP type (Table 28). Geosyntec Consultants and Wright Water Engineers (2008) have reported median values of effluent EMCs from a variety of structural BMPs using data contained within the International Stormwater BMP Database. With some modifications and assumptions (described in Appendix A), the model uses the reported values for *EMCeff* values from each BMP.

If a regional BMP is being evaluated PLT_m is the sum of $PLT_{k,m}$ for all subcatchments; $RVIN_{B,k}$ and $RVIN_{F,k}$ are computed using *RVIN* for a regional BMP (as discussed at the end of the *Runoff Volume Reduction* section of this paper); and $EMCLU_{k\ m}$ is the volume-weighted average EMC for runoff from all subcatchments for pollutant *m*.

5.16.3. Cost Effectiveness

The unit cost of reducing pollutant loads, *CPLR* ($/lb) and runoff volume, *CRVR* ($/$ft^3$), for an entire scenario (i.e. all subcatchments, *k*) over the planning horizon (*PH*) of a project can be computing using equations (45) and (46), respectively.

$$CPLR_m = \sum_{k=1}^{K} NPC_k / \left(PLR_{k,m} * PH\right) \tag{45}$$

$$CRVR = \sum_{k=1}^{K} NPC_k / \left(RVR_k * PH\right) \tag{46}$$

where NPC = net present costs ($), PLR = pollutant load reduction ($/lb), subscript m denotes the pollutant, RVR = runoff volume reduction (ft^3/yr), PFR = peak flow reduction (ft^3/yr).

Table 28: BMP Effluent EMCs used in the model

BMP	Total Suspended Solids (mg/L)	Total Phosphorus (mg/L)	Total Nitrogen (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Total Zince (mg/L)	Dissolved Zinc (mg/L)	Total Lead (mg/L)	Dissolved Lead (mg/L)	Total Copper (mg/L)	Dissolved Copper (mg/L)
Constructed Wetland Basin	17.77	0.14	1.15	1.05	0.03071	0.01791	0.00326	0.00087	0.00423	0.00736
Constructed Wetland Channel	37.25	0.37	1.91	1.35	0.03071	0.01790	0.00875	0.00087	0.00423	0.00736
Extended Detention Basin	31.04	0.19	2.72	1.89	0.06020	0.02584	0.01577	0.00206	0.01210	0.00737
Hydrodynamic Separator	49.96	0.28	1.48	0.94	0.07212	0.05480	0.00428	0.00195	0.01180	0.02350
Inlet Inserts	38.00	0.12	0.70	1.90	0.09867	0.06867	0.00663	0.00077	0.01370	0.00872
Media Filter Vault	15.86	0.14	0.76	1.55	0.03763	0.05125	0.00376	0.00118	0.01025	0.00900
Porous Landscape Detention	23.92	0.34	0.78	1.51	0.03983	0.02540	0.00670	0.00196	0.01066	0.00840
Retention (Wet) Pond	13.37	0.12	1.43	1.09	0.02935	0.03286	0.00532	0.00248	0.00636	0.00473
Sand Filter Basin	15.86	0.14	0.76	1.55	0.03763	0.05125	0.00376	0.00118	0.01025	0.00900
Sand Filter Vault	15.86	0.14	0.76	1.55	0.03763	0.05125	0.00376	0.00118	0.01025	0.00900
Sediment/Oil/Grease Separator	41.80	1.27	2.07	1.48	0.14025	0.19175	0.01220	0.00227	0.01278	0.01365
Vault with Capture Volume	31.04	0.19	2.72	1.89	0.06020	0.02584	0.01577	0.00206	0.01210	0.00737

Source: International BMP Database (Geosyntec Consultants and Wright Water Engineers 2008 and 2009)

Table 29: Summary of BMPs that provide peak flow attenuation

BMP	Peak Flow Attenuation
Constructed Wetland Basin	Yes
Constructed Wetland Channel	Yes
Extended Detention Basin (WQCV)	Yes
Extended Detention Basin (EURV	Yes
Hydrodynamic Separator	No
Inlet Inserts	No
Media Filter Vault	No
Porous Landscape Detention	Yes
Retention (Wet) Pond (WQCV)	Yes
Retention (Wet) Pond (EURV)	Yes
Sand Filter Basin	Yes
Sand Filter Vault	No
Sediment/Oil/Grease Separator	No
Vault with Capture Volume	Yes

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A. Methods and assumptions used to determine land use and BMP effluent event mean concentrations

This appendix documents how land use and BMP effluent event mean concentrations were identified for use in the model.

A.1. Land Use Event Mean Concentrations

UDFCD (UDFCD 2004) has reported average land use EMC values for 13 constituents in urban stormwater from four different land uses in the Denver, Colorado metropolitan region (Table A-1) It is recognized that the data from which these value were estimated were highly variable from site to site and event to event, however over the long term they may be expected to be reasonably accurate and thus are used in the model.

Table A-1: Land Use Average EMCs for Denver Metropolitan Area

Constituent	Units	Industrial	Commercial	Residential	Undeveloped
Total Suspended Solids	mg/L	399	225	240	400
Total Nitrogen	mg/L	2.7	3.3	3.4	3.4
TKN	mg/L	1.8	2.3	2.7	2.9
Nitrate + Nitrite	mg/L	0.91	0.96	0.65	0.50
Total Phosphorus	mg/L	0.43	0.42	0.65	0.40
Dissolved Phosphorus	mg/L	0.20	0.15	0.22	0.10
Copper, Total	µg/L	84	43	29	40
Lead, Total	µg/L	130	59	53	100
Zinc, Total	µg/L	520	240	180	100

Source: Table SQ-5 (UDFCD, 2004)

UDFCD did not provide values for dissolved zinc, dissolved lead and dissolved copper for each land use, therefore ratios of the total recoverable/dissolved fractions of each metal were estimated based on analyses performed by Maestre and Pitt (2005) on data contained in the National Stormwater Quality Database (NSQD), Version 1.1. The results of their analysis are summarized in Table A-2

Table A-2: Computed total:dissolved metals fractions based on values reported in the National Stormwater Quality Database, Version 1.1

Constituent	Industrial	Commercial	Residential
Lead	4.98:1	3.6:1	4:1
Copper	2.6:1	2.25:1	1.71:1
Zinc	1.78:1	2.54:1	2.32:1

There were no dissolved values reported for undeveloped or open space in the NSQD, therefore the total:dissolved fractions computed for residential land use was applied for undeveloped land use also.

A.2. *BMP Effluent Event Mean Concentrations*

The primary source of data for these values was the Analysis of Treatment Performance Report (report) (Geosyntec Consultants & Wright Water Engineers 2008), which reports expected BMP effluent EMCs based on statistical analyses of the data in the International BMP Database (database) (Geosyntec Consultants & Wright Water Engineers 2009). The data were analyzed using two methods, one method weighs the average results from each individual BMP equally and reports "Median of Average Effluent EMC" values and another method weighs each individual event equally (potentially putting more weight on the results from one specific BMP which was thoroughly monitored) and reports "Median of Effluent EMC" values. The first method that provides "Median of Average Effluent EMC" values is a better indicator of how well a particular type of BMP may be expected to perform across a variety of sites, and those values (with a few exceptions discussed below) are used in the model. However, effluent EMC values were not reported for all of the BMPs included in the model, therefore some additional analyses and assumptions were necessary.

When additional analyses were required, first the BMP codes and descriptions included in the database were used to sort which specific BMPs fell under each BMP category. Second the names of each specific BMP were cross-referenced within the "Statistical Summary_wo_WSDOT.xls" spreadsheet (developed by the database team and available at

<http://www.bmpdatabase.org/ResearchToolsMasterDB.htm#StatSummary> and the "raw outflow mean [EMC]" value for each constituent was found. Last, the median of all reported average EMC values for each BMP was computed, thus giving the "Median of Average Effluent EMC" value that is used in the model.

The following paragraphs explain what values are used for each BMP and the justification for doing so.

A.2.1. Vault w/ Capture Volume

The report does not provide results specifically for this BMP, however data collected from these BMPs were included in the analyses for the "Detention Basin" category, therefore the model uses the EMC values reported for that category.

A.2.2. Constructed Wetland Basin

EMC values reported for "Wetland Basins" are used in the model, with the following exceptions:

- Dissolved Zinc – the data set was insufficient to compute a "Median of Average Effluent EMC" value for this constituent, therefore the value reported using the “Median of Effluent EMC” method (17.90 μg/L) is used.

- Dissolved Copper – the data set was insufficient to compute a “Median of Average Effluent EMC” value for this constituent, therefore the value reported using the “Median of Effluent EMC” method (7.36 μg/L) is used.

A.2.3. Constructed Wetland Channel

EMC values reported for “Wetland Channels” are used in the model, with the following exceptions:

- Total Zinc – the data set was insufficient to compute a “Median of Average Effluent EMC” value for this constituent, therefore the value reported for Constructed Wetland Basins (30.71 μg/L) is used.

- Dissolved Zinc – the data set was insufficient to compute a “Median of Average Effluent EMC” value for this constituent, therefore the value reported using the “Median of Effluent EMC” method (17.90 μg/L) for is used.

- Dissolved Lead – the data set was insufficient to compute a “Median of Average Effluent EMC” value for this constituent, therefore the value reported for Constructed Wetland Basins (0.87 μg/L) is used.

- Total Copper – There is no reported values for this constituent, therefore the value reported for Constructed Wetland Basins (4.23 μg/L) is used.

- Dissolved Copper – There is no reported value for this constituent and the data set for Constructed Wetland Basins was insufficient to compute a "Median of Average Effluent EMC" value for this constituent, therefore the value reported using the "Median of Effluent EMC" method (7.36 μg/L) for Constructed Wetland Basins is used.

A.2.4. Extended Detention Basin

Extended detention basins were included within the category "Detention Basins", therefore the EMC values reported for that category are used in the model.

A.2.5. Sand Filter Vault

Data collected from sand filter vaults were analyzed under the category "Media Filter", along with several other filtering-type BMPs. In an attempt to differentiate between the different types of BMPs, EMC values were computed for the following BMPs which were categorized as "Sand Filters" in the database: 5/78, Eastern SF, La Costa PR, Lakewood Sand Filter, Parkrose SF, Sand Filter and Termination. Table A-3 summarizes the data retrieved and computed average effluent value.

A.2.6. Media Filter Vault

Data collected from media filter vaults were analyzed under the category "Media Filter", along with several other filtering-type BMPs. In an attempt to differentiate between the different filtering BMPs, EMC values were computed for the following BMPs which were categorized either "Combination of Media or Layered Media Filter", "Compost Mixed with Sand", "Peat Mixed with Sand" or "Other Media Filter" in the database:

Table A-3: Summary of sand filter data obtained from the International BMP Database

Parameter	# of BMPs	# of Samples	Median of Average Outflow EMC	Units
Total Suspended Solids	7	83	10.25	mg/L
Total Phosphorus	6	66	0.13	mg/L
Total Nitrogen	5	63	0.80	mg/L
Total Kjeldahl Nitrogen	6	66	1.44	mg/L
Total Zinc	7	90	34.56	µg/L
Dissolved Zinc	5	62	25.85	µg/L
Total Lead	5	63	1.37	µg/L
Dissolved Lead	5	63	1.03	µg/L
Total Copper	6	66	9.56	µg/L
Dissolved Copper	6	66	8.25	µg/L

BMP 57, Tree Filter, Bioretention System (D1), Lakewood, MCTT Filtering Chamber, Via Verde, Compost 1 and Hal Marshall Bioretention Cell. Table A-4 summarizes the data retrieved and computed average effluent value.

Table A-4: Summary of media filter data obtained from the International BMP Database

Parameter	# of BMPs	# of Samples	Median of Average Outflow EMC	Units
Total Suspended Solids	6	60	9.19	mg/L
Total Phosphorus	5	47	0.16	mg/L
Total Nitrogen	3	33	0.98	mg/L
Total Kjeldahl Nitrogen	3	33	1.26	mg/L
Total Zinc	7	74	34.69	µg/L
Dissolved Zinc	3	30	16.84	µg/L
Total Lead	5	53	2.05	µg/L
Dissolved Lead	3	30	1.16	µg/L
Total Copper	5	53	7.38	µg/L
Dissolved Copper	3	30	7.14	µg/L

A.2.7. (U) Hydrodynamic Separator

Although values are reported for "hydrodynamic devices" in the Analysis of Treatment Performance Report (Geosyntec Consultants & Wright Water Engineers 2008), the analysis included some devices (i.e. treatment trains, up-flow devices, etc.) that do not adequately represent the devices that are being simulated in the model. Data from the following BMPs were used to compute the values summarized in Table A-5: Addison-Wesley Interceptor, Aqua Swirl, Continuous Deflectie Separation, Continuous Deflective Separation Unit, Filmore CDS, Vortechnics, Vortechnics Model 11000 and Vortechs No 5000.

Table A-5: Summary of hydrodynamic separator data obtained from the International BMP Database

Parameter	# of BMPs	# of Samples	Median of Average Outflow EMC	Units
Total Suspended Solids	8	116	47.28	mg/L
Total Phosphorus*	5	133	0.20	mg/L
Total Nitrogen	1	9	2.54	mg/L
Total Kjeldahl Nitrogen	2	47	1.99	mg/L
Total Zinc	6	68	60.81	µg/L
Dissolved Zinc	3	33	47.33	µg/L
Total Lead	2	23	6.30	µg/L
Dissolved Lead	2	23	3.14	µg/L
Total Copper	2	23	15.87	µg/L
Dissolved Copper	2	23	25.21	µg/L

(*) one BMP was not included due to an unusually high value - possibly input error

A.2.8. (U) Sediment/Oil/Grease Separator

The Analysis of Treatment Performance Report (Geosyntec Consultants & Wright Water Engineers 2008) did not report EMC values specifically for SOGs, however the database did contain information on these devices. Data from the following devices were used to compute the EMC values summarized in Table A-6: Alameda, ARC Oil Separator, Baffle Box, Baysaver 1, Boeing Oil/Water Separator, Environment 21 V2B1, Stormceptor STC 3600, Urban Storm Treatment Unit in Madison, WI (Stormceptor), Warr Oil and Grit Separator and Willis Drive Baffle Box.

Table A-6: Summary of sediment/oil/grease separator data obtained from the International BMP Database

Parameter	# of BMPs	# of Samples	Median of Average Outflow EMCs	Units
Total Suspended Solids	10	106	43.86	mg/L
Total Phosphorus	6	34	0.62	mg/L
Total Nitrogen	2	7	1.99	mg/L
Total Kjeldahl Nitrogen	2	12	3.05	mg/L
Total Zinc	5	43	97.08	µg/L
Dissolved Zinc	2	17	191.23	µg/L
Total Lead	3	26	15.86	µg/L
Dissolved Lead	2	17	3.66	µg/L
Total Copper	5	33	11.25	µg/L
Dissolved Copper	2	17	11.60	µg/L

A.2.9. Inlet Inserts

Although values are reported for "media filters" in the Analysis of Treatment Performance Report (Geosyntec Consultants & Wright Water Engineers 2008), the analysis included some devices that are not inlet inserts (i.e. sand filters, media filter vaults, etc.). In order to differentiate between types of media filters, EMC values reported for BMPs under the categories "Geotextile Fabric Membrane (Vertical) Filter" were sorted and analyzed separate from all other media filter BMPs. The names of those BMPs in the database are: Rosemead SG, Las Flores SG, Foothill SG, Rosemead FF, Las Flores FF and Footfill FF. The "SG" and "FF" in the names are presumed to stand for "stream guard" and "fossil filter", two types of propriety inlet insert devices. Table A-7 summarizes the data retrieved and computed average effluent value.

Table A-7: Summary of inlet insert data obtained from the International BMP Database

Parameter	# of BMPs	# of Samples	Median of Average Outflow EMCs	Units
Total Suspended Solids	6	88	67.79	mg/L
Total Phosphorus	6	77	0.13	mg/L
Total Nitrogen	6	78	1.10	mg/L
Total Kjeldahl Nitrogen	6	78	2.15	mg/L
Total Zinc	6	88	124.40	μg/L
Dissolved Zinc	6	89	87.01	μg/L
Total Lead	6	88	7.80	μg/L
Dissolved Lead	6	88	1.85	μg/L
Total Copper	6	88	15.49	μg/L
Dissolved Copper	6	89	10.34	μg/L

A.2.10. Porous Landscape Detention

Porous landscape detention (i.e. raingardens, bioretention, etc.) are categorized under "Media Filters" and have a similar treatment mechanism as other media filters that have a mixture of sand and some organic media. PLDs were lumped with other types of similar media filters to determine EMC values for "media filter vaults", therefore the same EMC values are applied to PLDs in the model.

A.2.11. Retention Pond

The EMC values documented in the report for the category "Retention Ponds" are used in the model.

A.2.12. Sand Filter Basin

The EMC values computed for "sand filter vaults" also are applied to sand filter basins in the model.

A.2.13. Permeable Pavements

NOTE: This section added for BMP-REALCOST Version 1.0

The BMP database includes data from 14 permeable pavement installations, 7 of which are classified as "permeable/porous asphalt" installations which are not included in this model. Also, none of the 7 installations were classified as "porous gravel pavement" (or similar) so no data were available for that PP type. Table A-8 lists the Test Site ID, BMP ID, BMP Name, and classification of PP installation taken from the BMP Database (V.2 – dated 12/19/2009).

Table A-8: Summary of PP installations with data available in the International BMP Database

Test Site ID	BMPID	BMP Name	Classification
-1973863093	-2078844540	Austin Concrete Lot	PCP
227406308	-1113891649	Austin Lattice Block Lot	CGP
433547851	1366687752	Dayton Grass Pavement Parking Lot	RGP
1079453569	-758940276	Porous Concrete Infiltration Basin	PCP
1168373495	1615281267	Modular Block Porous Pavement	PICP
1168980705	-2061314701	Cobblestone Porous Pavement	PICP
1255059849	-1166835566	PICP	PICP
-1973863093	-2078844540	Austin Concrete Lot	PCP
227406308	-1113891649	Austin Lattice Block Lot	CGP
433547851	1366687752	Dayton Grass Pavement Parking Lot	RGP

Note: The classification was determined by the authors of this study for use in the BMP cost model and may differ from the classification listed in the BMP database due to classification aggregations.

Given the limited data available for all PP types as a whole, BMP effluent statistics were computed from and applied to all PP installations aggregated together. In other words, each PP type will have the same BMP effluent values, based on all data that was available in the BMP database at the time. As more PP data in collected and input into the BMP database, it is likely that the data may be disaggregated by BMP type to better represent which PP types are more efficient than others. Table A-9 summarizes the data retrieved and computed average effluent value.

Table A-9: Summary of permeable pavement data obtained from the International BMP Database

Parameter	# of BMPs	# of Samples	Median of Average Outflow EMCs	Units
Total Suspended Solids	6	73	26.4	mg/L
Total Phosphorus	5	62	0.15	mg/L
Total Nitrogen	7	112	1.19	mg/L
Total Kjeldahl Nitrogen	5	61	1.38	mg/L
Total Zinc	6	68	30.7	µg/L
Dissolved Zinc	3	48	15.4	µg/L
Total Lead	6	68	12.2	µg/L
Dissolved Lead	2	46	1.02	µg/L
Total Copper	4	52	11.9	µg/L
Dissolved Copper	9	153	18.0	µg/L

C. Methods, Sources and Assumptions Used to Develop Maintenance Cost Estimates

C.1. Introduction

As with capital costs, it was preferred to develop cost equations that related annual maintenance costs to the size of the BMP. Annual maintenance costs for a single BMP typically reflect the costs of performing a wide variety of activities. Those activities can generally be divided into two components; those with costs that vary according to the size of the BMP ("variable" maintenance costs) and those that do not ("constant" maintenance costs). The following equation was developed for estimating annual maintenance costs as a function of multiple maintenance activities in both components.

$$MCost = \sum_{i=1}^{n}\left(F_i * A_i\right) + \sum_{j=1}^{m}\left(F_j * A_j * \beta_j\right) * BMPSize \qquad \textbf{(C-1)}$$

Where *MCost* = annual maintenance costs for an individual BMP, *A* = maintenance cost for one unit of activity, *F* = frequency of maintenance per year, *β*= coefficient specifying the number of maintenance units per unit of BMP size[1], *BMPSize* = number of units of BMP Size (AF, ft^3, ft^2, acre, cfs), *i* = indicates activities with "constant" maintenance costs, *j* = indicates activities with "variable" maintenance costs, *n* = number of "constant" maintenance activities for BMP and *m* = number of "variable" maintenance activities for BMP.

Substituting a single variable for the summation terms, Equation (C-1) can be rewritten as (C-2);

$$MCost = Cc + Cv * BMPSize \qquad \textbf{(C-2)}$$

Where *Cc* = total annual cost for "constant" maintenance activities and *Cv* = total annual unit cost for "variable" maintenance activities.

To use the equations above, it was necessary to determine the following information for each BMP:

[1] For example, if it is determined that approximately 1 acre of lawn needs mowing for every 3 acre-feet of storage volume for RPs, then the coefficient value would be 0.33.

1. What typical maintenance activities are required or recommended?
2. How often does maintenance occur?
3. How much does one unit of maintenance cost?
4. What is the relationship (β-value) between unit maintenance costs and BMP size for that activity?

C.2. Methodology

The methods, assumptions and data sources used to answer the four questions listed above are described in this section.

C.2.1. Necessary Maintenance Activities

Published lists of recommended BMP maintenance activities are readily available. In Chapter 3 of the Urban Storm Drainage Criteria Manual (USDCM) (UDFCD 2004), UDFCD provides maintenance recommendations for many of the BMPs included in this model. Other lists can be found on the EPA's stormwater fact sheets http://www.epa.gov/npdes/stormwater/menuofbmps).

Table C-1 lists the maintenance activities for each BMP included in the model.

Table C-1: Recommended maintenance activities

BMP	Activity	Frequency
All	Inspection	1
CGP	Sweeping/Vacuuming	2
CWB	Litter and Debris Removal	1
CWB	Sediment Removal (forebay)	0.5
CWB	Sediment Removal (basin)	0.05
CWC	Litter and Debris Removal	1
CWC	Vegetation/Woody Debris Removal	0.2
EDB	Inlet/Outlet Cleaning	6
EDB	Nuisance Control	12
EDB	Outlet Maintenance	0.25
EDB	Lawn Mowing/Lawn Care	6
EDB	Sediment Removal (forebay/micropool)	0.5
EDB	Sediment Removal (basin)	0.05
HS	Sediment Removal	4
HS	Traffic Control	4

BMP	Activity	Frequency
II	Sediment Removal	6
MFV	Sediment Removal	2
PCP	Sweeping/Vacuuming	2
PGP	Gravel Finish Grading	12
PICP	Sweeping/Vacuuming	2
PLD	Annual Cleanup/Planting	1
RGB	Lawn Mowing/Lawn Care	15
RP	Nuisance Control	12
RP	Lawn Mowing/Lawn Care	6
RP	Sediment Removal (forebay/micropool)	0.5
RP	Sediment Removal (basin)	0.05
RP	Vegetation/Woody Debris Removal	0.33
SFB	Lawn Mowing/Lawn Care	6
SFB	Sediment Removal (forebay)	0.5
SFB	Scarify Top Sand Layer	1
SFV	Scarify Top Sand Layer	1
SOG	Sediment Removal	4
SOG	Traffic Control	4
VCV	Sediment Removal	0.2

C.2.2. Frequency of Maintenance

The frequency of maintenance describes how often maintenance is performed (reported in number of times per year) and varies according to the BMP for which it is being performed. If the activity was only performed once every several years, than the value would be less than 1. (For example: An activity performed once per five years would have a value of 0.2 times per year.). The frequencies in Table C-1 were obtained from interviews with stormwater maintenance personnel (Front Range Agencies 2008) and from UDFCD recommendations in the USDCM (UDFCD, 2004).

C.2.3. Maintenance Activity Unit Costs

The maintenance activity unit costs are the costs to perform one unit of maintenance (for example, the cost to remove 1 cubic foot of sediment from a BMP). These costs were developed using "bottom-up" or "unit-pricing" cost estimating procedures. Equation (C-3) is used to compute the maintenance unit cost for each activity.

2008$

$$A = E * CS * \left(LR + LR * OH\right) + E * EC + OC \tag{C-3}$$

Where A = maintenance unit cost, E = efficiency of maintenance, CS = labor crew size, LR = hourly labor rate, OH = overhead factor, EC = equipment costs and OC = other costs.

Annual O&M unit cost estimates were prepared using information collected during interviews with seven stormwater utilities in the Denver, Colorado region, RSMeans 2005 Site Work & Landscape Cost Data Guide (RSMeans 2005) and vendor-provided information. When sufficient cost information was provided from the stormwater utilities it was used in the cost calculations. However, at times the utilities could not provide any or all of the necessary information, so RS Means data was used to complement it.

C.2.4. Data Collection from Interviews with Stormwater Utilities

Personnel from seven stormwater utilities located near Denver, CO were interviewed to gather information and costs on BMP maintenance. The interviewee(s) was asked to estimate the average amount of resources (materials, equipment, personnel, etc.) and the average frequency of maintenance required for its BMPs, based on proactive maintenance[2]. In most cases, the interviewee(s) found it difficult to estimate "average" values, particularly for frequency of maintenance and maintenance efficiency (number of hours required), because they varied considerably from individual BMP to individual BMP. Nevertheless, the interviewee(s) usually provided a "best guess" at the values.

Several utilities reported cost information for extended detention basins, hydrodynamic separators and sediment/oil/grease separators; which are generally the most popular BMPs used in the area. Only one utility could provide costs for a single sand filter vault and porous concrete parking lot, another provided costs for a single constructed wetland channel, and another provided "average" costs for retention ponds based on multiple ponds located in its jurisdiction. The information collected during these interviews is summarized in Table C-2 and Table C-3.

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[2] Keeping with project objectives which are to estimate the costs of proactive maintenance, not reactive.

C.2.5. Unit Cost Estimating Using RS Means

The RSMeans 2005 Site Work & Landscape Cost Data Guide (RSMeans 2005) was used to complement the information gathered from the utility interviews. A summary of the unit costs used from RS Means is provided in Table C-4 and Table C-5 All costs were adjusted from 2005 dollars to 2008 dollars using the ENR CCI, and then regionally adjusted to the Denver region using the RS Means region multiplier of 0.927.

C.2.6. Hourly Labor Rate

Average labor rates for stormwater maintenance personnel were collected from five agencies located near Denver, Colorado (Table C-3). The average labor rate between these was approximately $23.31 (in 2008 dollars).

C.2.7. Overhead Factor

It is assumed that overhead costs for maintenance personnel (insurance, vacation, retirement contribution, etc.) is approximately equal to the hourly labor rate, therefore this value is 100%.

C.2.8. Equipment Costs

Equipment costs are reported in Table C-3 and Table C-5 as hourly costs per piece of equipment. Generally, when more than one reported cost existed for the same equipment, the average of those costs was used in the model.

C.2.9. Other Costs

Other costs for materials, disposal, etc. are reported in Table C-3 and Table C-5 as unit costs. Generally, when more than one unit cost was reported for the same item, the average of those costs was used in the model.

Table C-2: Summary of maintenance activity information reported by Front Range Agencies

Activity	Units	Frequency	Hours per Unit	Crew	Equipment	Other Costs	Lump Sum Cost
			Hydrodynamic Separator				
Sediment Removal	CY	4	0.5	3	Jet-Vac Truck	Sediment Disposal (wet)	-
Sediment Removal	CY	4	2	2	Jet-Vac Truck	Sediment Disposal (wet)	-
Sediment Removal	CY	4	1.5	2	Jet-Vac Truck	Sediment Disposal (wet)	-
Sediment Removal	CY	4	4	2	Jet-Vac Truck	Sediment Disposal (wet)	-
Sediment Removal	CY	4	2	2	Jet-Vac Truck	Sediment Disposal (wet)	-
Traffic Control	(a)	(a)	(a)	3(b)	Jet-Vac Truck	-	-
Traffic Control	(a)	(a)	(a)	3(b)	Jet-Vac Truck	-	-
Traffic Control	(a)	(a)	(a)	1	Pick-up Truck	-	-
Notes: – frequency and efficiency dependent on sediment removal – requires another street crew							
			Extended Detention Basin				
Inlet/Outlet Cleaning	Each	6(c)	0.5	2	Pick-up Truck	-	-
Inlet/Outlet Cleaning	Each	6(c)	0.5	1	Pick-up Truck	-	-
Inspection	Each	6(c)	0.2	1	Pick-up Truck	-	-
Inspection	Each	6(c)	0.75	1	Pick-up Truck	-	-
Lawn Mowing/Care	Acre	3	2	2	Pick-up Truck Tractor w/ Mower	-	-
Nuisance Control	Each	24	0.8	1	Pick-up Truck	-	-
Nuisance Control	Each	12	0.25	2	Pick-up Truck	-	-
Nuisance Control	Each	10	0.5	1	Pick-up Truck	Mosquito/Algae Tablets ($35)	-
Outfall Maintenance (Rip-rap repair)	Each	0.2	12	3	Pick-up Truck (2) 3-CY Dumptrucks Skidsteer	6 CY Rip-Rap(d)	-

Activity	Units	Frequency	Hours per Unit	Crew	Equipment	Other Costs	Lump Sum Cost
Outfall Maintenance (Rip-rap repair)	Each	0.33	-	-	-	-	$7,500
Sediment Removal (routine)	CY	0.5	0.33	2	Small Dumptruck Skidsteer	Sediment Disposal	-
Sediment Removal (non-routine)	CY	0.1	0.08	4	Pick-up Truck Large Backhoe (2) Large Dumptrucks	Sediment Disposal	-
Notes: – after each major storm, assume 6 per year – assumed volume of riprap							
Constructed Wetland Channel							
Debris and Litter Removal	Each	4	1.5	2	Pick-up Truck	-	-
Porous Concrete							
Outlet Cleaning	Each	1	1	2	Jet-Vac Truck	-	-
Retention Pond							
Inspection	Each	6[(e)]	0.2	1	Pick-up Truck	-	-
Inspection	Each	6[(e)]	0.75	1	Pick-up Truck	-	-
Lawn Mowing/Care	Acre	3	2	2	Pick-up Truck Tractor w/ Mower	-	-
Tree Trimming	Each	0.33	2	5	Pick-up Truck	-	-
Nuisance Control	Each	10	1	1	Pick-up Truck	Mosquito/Algae Tablets ($70)	-
Notes: – after each major storm, assume 6 per year							
Sediment/Oil/Grease Separator							
Sediment Removal	CY	4	1	3	Jet-Vac Truck	Sediment Disposal (wet)	-
Sediment Removal	CY	4	1.33	2	Jet-Vac Truck	Sediment Disposal (wet)	-
Sediment Removal	CY	12	-	-	-	-	$277

Activity	Units	Frequency	Hours per Unit	Crew	Equipment	Other Costs	Lump Sum Cost
Traffic Control	(f)	(f)	(f)	3(g)	Jet-Vac Truck	-	-
Traffic Control	(f)	(f)	(f)	3(g)	Jet-Vac Truck	-	-
Traffic Control	(f)	(f)	(f)	1	Pick-up Truck	-	-
Notes: – frequency and efficiency dependent on sediment removal – requires another street crew							
				Sand Filter Vault			
Remove Top Sand Layer	CY	1	1.6	2	Skidsteer Dumptruck	Sediment Disposal	-

Table C-3: Summary of labor, equipment and materials costs reported by Front Range Agencies

Hourly Labor Rates	Equipment Costs		Other Costs	
	Equipment	**Hourly Cost**	**Material/Other**	**Unit Cost**
$20.33	Backhoe	$46.01	Sediment Disposal	$10/CY
$21.24	Backhoe	$62.00	Sediment Disposal	$10/CY
$24.00	Backhoe Trailer	$9.99	Sediment Disposal	$5/CY
$26.00	Dumptruck (tandem)	$54.73	Sediment Disposal (wet)	$100/CY
$25.00	Flatbed Truck	$10.02		
	Jet-Vac Truck	$44.02		
	Jet-Vac Truck	$83.00		
	Jet-Vac Truck	$101.00		
	Jet-Vac Truck	$200		
	Pick-up Truck	$10.29		
	Pick-up Truck	$10.00		
	Skidsteer	$14.96		

Table C-4: RS Means and Vendor-Provided Cost Information for Maintenance Activities

Activity	Units	Hours per Unit	Crew	Equipment	Other Costs	RS Means # / Vendor
Selective Clearing	Acre	32	1	Pick-up Truck Brush Saw	-	02230-200-0020
Scarify Subsoil	MSF	0.067	1	Skidsteer w/ Scarifier	-	02910-710-3050
Site Maintenance, Hand Pick-up	MSF	0.267	1	Pick-up Truck	-	02985-700-1130
Flower Bed Maintenance, Spring Prepare	MSF	4	1	Pick-up Truck	-	02985-700-1200
Flower Bed Maintenance, Fall Clean-up	MSF	8	1	Pick-up Truck	-	02985-700-0830
Finish Grading, Large Area	SY	0.008	2	Grader	-	02310-100-0100
Vendor Provided Information for Inlet Insert Maintenance						
Inlet Filter Maintenance	each	0.17	2	Pick-up Truck	Debris Disposal	AbTech (2009) and ADS (2009)
Vendor Provided Information for Media Filter Vault Maintenance						
Sediment Removal	CY	2	2	Jet-Vac Truck	Sediment Disposal	Contech (2009)

Table C-5: RS Means Cost Information for Equipment and Materials

Equipment/Material	Units	Unit Cost	RS Means #
Dumptruck, Large (12-ton)	Hr	$55.18	01590-200-5250
Skidsteer, 1 CY	Hr	$34.81	01590-200-4890
Tractor w/ Rotary Mower	Hr	$28.99	02230-200-1080
Excavator, 1 CY	Hr	$99.68	01590-200-0150
Dumptruck, Small (1.5-ton)	Hr	$19.18	01590-200-5450
Brush Saw	Hr	$2.44	Crew Description A-1C
Street Sweeper	Hr	$78.29	01500-500-3400
Grader	Hr	$31.81	Crew Description B-11L
Rip-Rap (18” thickness)	SY	$15.79	02370-450-200

C.2.10. Efficiency of Maintenance

The efficiency of maintenance variable accounts for how much time each maintenance activity requires. More specifically, the actual value represents the number of hours required to complete one unit of maintenance. For example, if it requires approximately 30 minutes to mow 1 acre of grass, then E = 0.5. Generally, when more than one efficiency value was reported for the same activity, the average of those costs was used in the model.

C.2.11. Labor Crew Size

The labor crew size is the number of maintenance personnel needed to complete the maintenance activity. Generally, when more than crew size was reported for the same activity, the average of those values was used in the model.

C.2.12. Summary

Table C-6 shows the computed maintenance unit costs for each activity, alongside the estimated values of each variable as presented in the preceding sections.

Table C-6: Summary of Maintenance Unit Costs Developed for the UDFCD BMP Effectiveness and Cost Analysis Model

Activity	Units	Hours per Unit	Crew Size	Equipment Required	Equipment Cost/hr[1]	Other Materials	Other Costs	Cost per Unit[2]
Inspection	Each	0.33	1	Pickup Truck	$10.15	-	-	$19
Inlet/Outlet Cleaning	Each	0.5	2	Pickup Truck	$10.15	-	-	$52
Nuisance Control (EDB)	Each	0.5	1	Pickup Truck	$10.15	Product	$35	$63
Nuisance Control (RP)	Each	1	1	Pickup Truck	$10.15	Product	$70	$127
Outfall Maintenance	Each	12	3	Pickup Truck Large Dumptruck Skidsteer	$10.15 $55.18 $37.55	Rip-Rap	$200[3]	$3,113
Lawn Mowing/Lawn Care	Acre	2	2	Pickup Truck Tractor w/ Rotary Mower	$10.15 $31.27	-	-	$269
Sediment Removal – Non-Routine[4]	CY	0.08	4	Pickup Truck Large Excavator 2 Large Dumptrucks	$10.15 $99.68 $110.36	Sediment Disposal	$10	$43
Sediment Removal – Routine[5]	CY	0.33	2	Small Dumptruck Skidsteer	$19.18 $37.55	Sediment Disposal	$10	$59
Sediment Removal [6]	CY	1.2	2	Jet-Vac Truck	$110	Sediment Disposal	$100	$344
Sediment Removal[7]	CY	2	2	Jet-Vac Truck	$110	Sediment Disposal	$100	$558
Traffic Control[8]	CY	1.2	2	Pickup Truck	$10.15	-	-	$124
Traffic Control[8]	CY	2	2	Pickup Truck	$10.15	-	-	$277
Vegetation/Woody Debris Removal	Acre	16	2	Pickup Truck Brush Saw	$10.15 $2.62	-	-	$1,696
Scarify Top Sand Layer (SFB)	Acre	3	1	Skidsteer w/ Scarifiers	$37.55	-	-	$253

Activity	Units	Hours per Unit	Crew Size	Equipment Required	Equipment Cost/hr[1]	Other Materials	Other Costs	Cost per Unit[2]
Remove Top Sand Layer (SFV)[9]	CY	2	2	Skidsteer Small Dumptruck	\$37.55 \$19.18	Sand Disposal	\$10	\$310
Litter & Debris Removal	Acre	6	2	Pickup Truck	\$10.15	-	-	\$620
Annual Cleanup	MSF	4	2	Pickup Truck	\$10.15	-	-	\$414
Annual Planting	MSF	2	2	Pickup Truck	\$10.15	-	-	\$207
Finish Grading	Acre	6	1	Grader	\$31.81	-	-	\$471
Pavement Sweeping	Acre	0.5	1	Street Sweeper/Vacuum	\$78.29	-	-	\$62
Inlet Filter Maintenance	Each	0.17	2	Pick-up Truck	\$10.15	Debris Disposal	\$10	\$165

[1] Unless otherwise noted, hourly equipment costs include rental and operating costs, as reported in RSMeans 2005.
[2] Assumes labor rate of \$23.31 per hour and overhead costs equal to 100% of labor rate
[3] Assumes approximately 6 CY of rip-rap
[4] Applicable to large basin facilities such as extended detention basins, retention (wet) ponds, and constructed wetland basins
[5] Sediment removal from forebay for large basin facilities
[6] Applicable to hydrodynamic separators and sediment/oil/grease separators.
[7] Applicable to media filter vaults
[8] Required for sediment removal from underground structures, therefore the efforts are a function of the amount of sediment needing removal
[9] Costs apply for "Delaware-type" filters where access to the filter is available by removing inlet grates, allowing access for equipment

C.3. BMP Size/Unit Maintenance Cost Relationship (β-value)

Relationships between BMP size and unit maintenance costs were determined using BMP design recommendation and other assumptions. The reported β-value represents the number of maintenance units per unit of BMP size plus the appropriate unit conversions.

C.3.1. Concrete Grip Pavers

Pavement Sweeping/Vacuuming – Pavement sweeping and/or vacuuming occurs over the entire surface area of the installation. The β-value = 1

Sweeping/Vacuuming (acres) = Surface Area (acres) * 1(acre/acre) **(C-4)**

C.3.2. Constructed Wetland Basin

Sediment Removal (routine) – Routine sediment removal is assumed to be performed when the basin forebay has reached its sediment holding capacity (20% of the total forebay volume). The basin forebay volume should be about 10% of the total pond volume, therefore the amount of sediment removed from the forebay is equal to 2% of the total basin volume. The β-value = 32.27, including the unit conversion from AF to CY.

Sediment Removed (CY) = Volume (AF) * 32.27 (CY/AF) **(C-5)**

Sediment Removal (non-routine) – Non-routine sediment removal is assumed to be performed when 20% of the storage volume has accumulated sediment. The β-value = 322.67, including the unit conversion from AF to CY.

Sediment Removed (CY) = Volume (AF) * 322.67(CY/AF) **(C-6)**

Litter and Debris – The area requiring litter and debris removal is assumed to 50% of the total area consumed by the basin. Assuming 1 acre of land consumed per AF of storage volume, the β-value = 0.5

Litter and Debris Removal (acre) = Volume (AF) * 0.5 (acres/AF) **(C-7)**

C.3.3. Constructed Wetland Channel

The size of CWCs are reported as the design flowrate (cfs), however maintenance costs are computed as a function of the surface area of the channel.

Vegetation/Woody Debris Removal – The area requiring vegetation and woody debris removal is assumed to be the total area consumed by the channel. The β-value = 1

Vegetation/Woody Debris Removal (acre) = Area of Channel (acre) * 1(acres/acres) **(C-8)**

Litter and Debris – The area requiring litter and debris removal is assumed to be the total area consumed by the channel. The β-value = 1

Litter and Debris Removal (acre) = Area of Channel (acre) * 1(acres/acres) **(C-9)**

C.3.4. Extended Detention Basin

Sediment Removal (routine) – Routine sediment removal is assumed to be performed when the EDB forebay has reached its sediment holding capacity (20% of the total forebay volume). The EDB forebay volume should be about 5% of the total EDB volume, therefore the amount of sediment removed from the forebay is equal to 1% of the total EDB volume. The β-value = 16.13, including the unit conversion from AF to CY.

Sediment Removed (CY) = Volume (AF) * 16.13(CY/AF) **(C-10)**

Sediment Removal (non-routine) – Non-routine sediment removal is assumed to be performed when the EDB has reached its sediment holding capacity (20% of total EDB volume). The β-value = 322.67, including the unit conversion from AF to CY.

Sediment Removed (CY) = Volume (AF) * 322.67 (CY/AF) **(C-11)**

Lawn Care/Lawn Mowing – Lawn care/mowing is assumed to be required over the entire area consumed by the EDB. Assuming 1 acre of land required per AF of storage volume, the β-value = 1.

$$\text{Lawn Care/Lawn Mowing (acre)} = \text{Volume (AF)} * 1 \text{ (acre/AF)} \qquad \textbf{(C-12)}$$

C.3.5. Hydrodynamic Separator

Sediment Removal – Sediment removal is assumed to be performed when the sediment holding capacity of the system is full. Each proprietary system has a unique relationship between sediment holding capacity and design flowrate, therefore a regression equation was developed using the relationships from three systems with information readily available[3]. The relationships and regression equation are presented in Figure C-1.

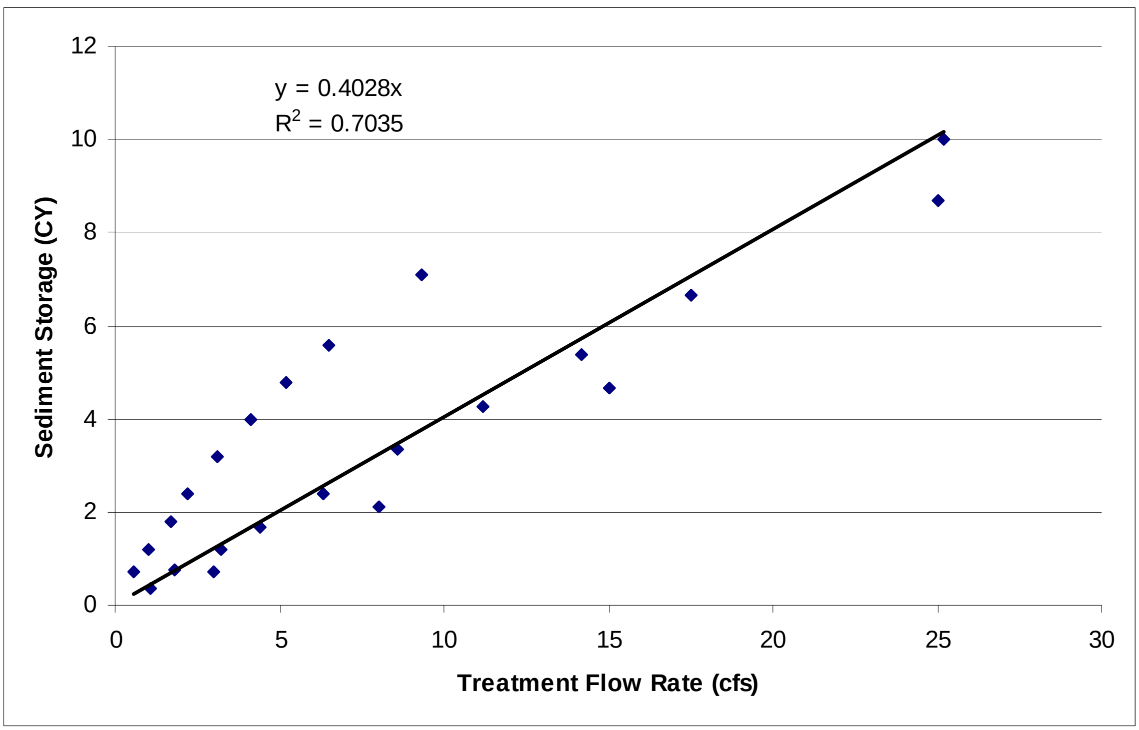

Figure C-1: Sediment storage and design flowrate relationships for hydrodynamic separators

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[3] The systems used to establish the relationship were the Downstream Defender, Aqua-Swirl, and Vortechs; using information provided in product brochures.

The β-value for sediment removal in hydrodynamic separators is 0.4

Sediment Removed (CY) = Design Flowrate (cfs) * 0.4 (CY/cfs) **(C-13)**

Traffic Control – Traffic control is assumed to be required during sediment removal maintenance, therefore the same relationship described for sediment removal applies for traffic control. The β-value = 0.4

C.3.6. Media Filter Vault

Sediment Removal – Sediment removal is assumed to be performed when the sediment holding capacity of the system is full. Information available from two proprietary media filter systems suggest an average sediment holding capacity of 18 ft^3 (0.67 CY) per cfs of design flow.

Sediment Removal (CY) = Flowrate (cfs) * 0.67 (CY/cfs) **(C-14)**

Traffic Control – Traffic control is assumed to be required during sediment removal maintenance, therefore the same relationship described for sediment removal applies for traffic control. The β-value = 0.67

C.3.7. Permeable Interlocking Concrete Pavers

Pavement Sweeping/Vacuuming – Pavement sweeping and/or vacuuming occurs over the entire surface area of the installation. The β-value = 1

Sweeping/Vacuuming (acres) = Surface Area (acres) * 1(acre/acre) **(C-15)**

C.3.8. Porous Concrete Pavement

Pavement Sweeping/Vacuuming – Pavement sweeping and/or vacuuming occurs over the entire surface area of the installation. The β-value = 1

Sweeping/Vacuuming (acres) = Surface Area (acres) * 1(acre/acre) **(C-16)**

C.3.9. Porous Gravel Pavement

Gravel Finish Grading - Grading occurs over the entire surface area of the installation. The β-value = 1

$$\text{Gravel Grading (acres)} = \text{Surface Area (acres)} * 1\text{(acre/acre)} \qquad \textbf{(C-17)}$$

C.3.10. Porous Landscape Detention

Annual Cleanup/Planting – The area requiring cleanup and planting is assumed to be the total surface area consumed by the BMP, which is the same as the storage volume of the PLD when assuming that water can pond up to 1 foot on top of the PLD. The β-value = 0.001.

$$\text{Cleanup and Planting (MSF)} = \text{Volume(CF)} * 0.001\text{(MSF/CF)} \qquad \textbf{(C-18)}$$

C.3.11. Reinforced Grass Pavement

Lawn Care/Lawn Mowing – Lawn care/mowing is assumed to be required over the entire surface area of the installation (β-value = 1).

$$\text{Lawn Care/Lawn Mowing (acre)} = \text{Surface Area (acres))} * 1\text{(acre/acre)} \qquad \textbf{(C-19)}$$

C.3.12. Retention (Wet) Pond

Lawn Care/Lawn Mowing – Lawn care/mowing is assumed to be required over 50% of the area consumed by the BMP. Assuming 0.5 acres of land required per AF of storage volume, the β-value = 0.25.

$$\text{Lawn Care/Lawn Mowing (acre)} = \text{Volume (AF)} * 0.25\text{(acres/AF)} \qquad \textbf{(C-20)}$$

Sediment Removal (routine) – Routine sediment removal is assumed to be performed when the pond forebay has reached its sediment holding capacity (20% of the total forebay volume). The pond forebay volume should be about 5% of the total pond volume, therefore the amount of sediment removed from the forebay is equal to 1% of the total pond volume. The β-value = 16.13.

$$\text{Sediment Removed (CY)} = \text{Volume (AF)} * 16.13\text{(CY/AF)} \qquad \textbf{(C-21)}$$

Sediment Removal (non-routine) – Non-routine sediment removal is assumed to be performed when the pond has reached its sediment holding capacity (20% of total pond volume). The β-value = 322.67

$$\text{Sediment Removed (CY)} = \text{Volume (AF)} * 322.67\text{(CY/AF)} \qquad \textbf{(C-22)}$$

Vegetation/Woody Debris Removal – The area requiring vegetation and woody debris removal is assumed to 10% of the total area consumed by the pond. Assuming 0.5 acres of land required per 1 AF of storage volume, the β-value = 0.05.

$$\text{Vegetation/Woody Debris Removal (acre)} = \text{Volume (AF)} * 0.05\text{(acres/AF)} \qquad \textbf{(C-23)}$$

C.3.13. Sand Filter Basin

Lawn Care/Lawn Mowing – Lawn care/mowing is assumed to be required over 50% of the area consumed by the BMP. Assuming that 1 acre of land is required per 1.5 AF of storage volume, the β-value = 0.33.

$$\text{Lawn Care/Lawn Mowing (acre)} = \text{Volume (AF)} * 0.33 \text{ (acres/AF)} \qquad \textbf{(C-24)}$$

Sediment Removal (routine) – Routine sediment removal is assumed to be performed when the basin forebay has reached its sediment holding capacity (20% of the total forebay volume). The forebay volume should be about 5% of the total basin volume, therefore the amount of sediment removed from the forebay is equal to 1% of the total pond volume. The β-value = 16.13.

$$\text{Sediment Removed (CY)} = \text{Volume (AF)} * 16.13\text{(CY/AF)} \qquad \textbf{(C-25)}$$

Scarify Top Sand Layer – Scarifying is required over the entire surface area of the sand filter, which is 1 ft^2 per CF of storage volume. The β-value = 0.33.

$$\text{Scarifying Area (acre)} = \text{Volume (AF)} * 0.33 \text{ (acres/AF)} \qquad \textbf{(C-26)}$$

C.3.14. Sand Filter Vault

Remove top media layer – Assuming that the top two inches are removed from the surface area of the vault, the surface area is approximately 33% of the total volume of media (i.e. the SFV is three feet deep), and the total volume of media is approximately 300% of the total volume of water storage (33% pore openings in media), the β-value = 0.006 including the unit conversion from CF to CY.

$$\text{Top Sand Layer (CY)} = \text{Volume (CF)} *0.006\text{(CY/CF)} \qquad \textbf{(C-27)}$$

C.3.15. Sediment/Oil/Grease Separator

Sediment Removal – Sediment removal is assumed to be performed when the sediment holding capacity of the system is full. Each proprietary system has a unique relationship between sediment holding capacity and design flowrate, therefore a regression equation was developed using the relationships from three systems with information readily available[4]. The relationships and regression equation are presented in Figure C-2.

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[4] The systems used to establish the relationship were the VortClarex, Stormceptor, Baysaver and V2B1; using information provided in product brochures.

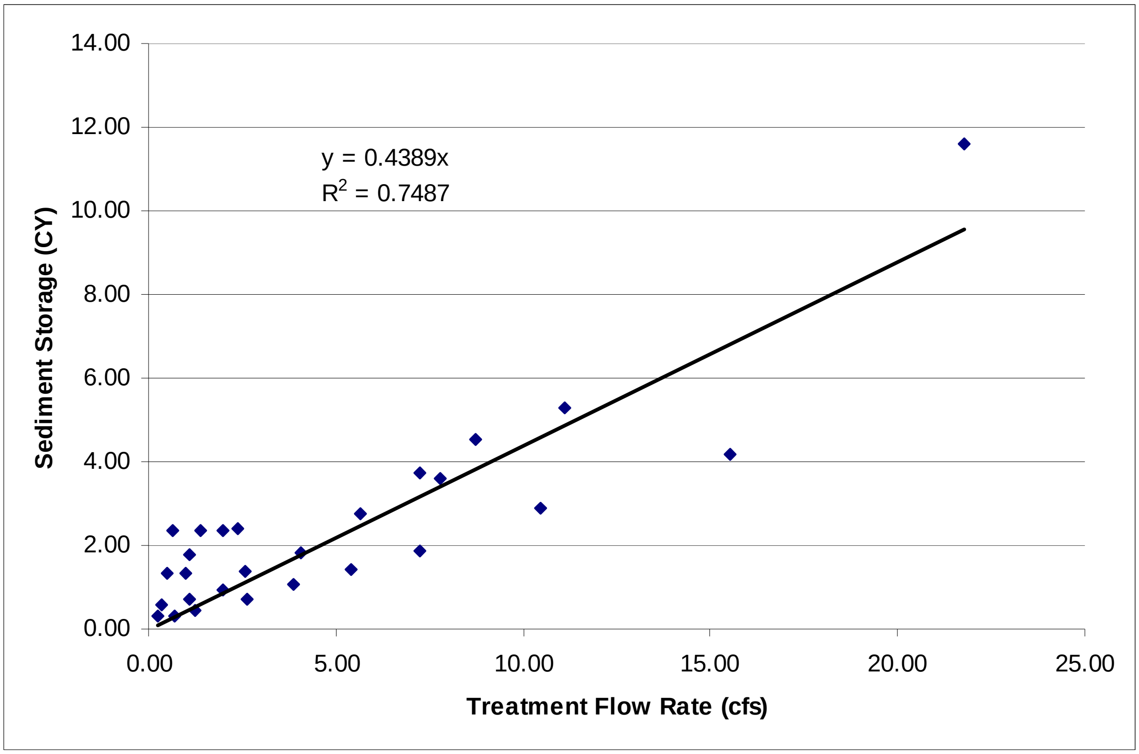


Figure C-2: Sediment storage and design flowrate relationships for sediment/oil/grease separators

The β-value for sediment removal in sediment/oil/grease separators is 0.44

Sediment Removed (CY) = Design Flowrate (cfs) * 0.44(CY/cfs) **(C-28)**

Traffic Control – Traffic control is assumed to be required during sediment removal maintenance, therefore the same relationship described for sediment removal applies for traffic control. The β-value = 0.4

C.3.16. Vault with Capture Volume

Sediment Removal (routine) – Routine sediment removal is assumed to be performed when the vault has reached its sediment holding capacity (20% of the total volume). The β-value = 0.007 including the unit conversion from CF to CY.

Sediment Removed (CY) = Volume (CF) * 0.007 (CY/CF) **(C-29)**

C.4. Maintenance Cost Equations

The maintenance cost equations developed for each BMP are described below. It should be noted that these cost equations are set as "default" values in the model, however the maintenance cost tables are user-editable and can be changed to fit any known maintenance costs.

C.4.1. Compliance Inspection

One activity that is common to all BMPs is inspection and the maintenance tables for each BMP include inspections. However in the model, inspections are considered administrative activities, not maintenance activities, therefore the costs of performing inspections are added to the annual administrative costs instead of the annual maintenance costs.

C.4.2. Concrete Grid/ Permeable Interlocking Concrete Block Pavers

Table C-7 summarizes the maintenance activities and their individual annual costs for cobblestone and modular block pavement. Equation (C-30) is used to compute total annual maintenance costs.

Table C-7: CGP/PICP maintenance activity costs

Activity	Type	Freq	A	β-value	Annual Cost*
-	-	-	-	-	-
				Total =	**-**
Sweeping/Vacuuming	Variable	2	$62	1	$125
				Total =	**$125**

Notes:

* – for unit-type activities, the annual cost is per acre of installation surface area

2008$ $$MCost = \$125 * BMPSize(acres) \qquad \textbf{(C-30)}$$

C.4.3. Constructed Wetland Basin

Table C-8 summarizes the maintenance activities and their individual annual costs for CWBs. Equation (C-31) is used to compute total annual maintenance costs.

Table C-8: CWB maintenance activity costs

Activity	**Type**	**Freq**	**A**	**β-value**	**Annual Cost***
-	-	-	-	-	-
				Total =	**-**
Litter and Debris Removal	Unit	1	$620	0.5	$310
Sediment Removal (routine)	Unit	0.5	$60	32.27	$960
Sediment Removal (non-routine)	Unit	0.05	$43	322.67	$686
				Total =	**$1,956**

Notes:

* – for unit-type activities, the annual cost is per AF of storage volume

2008$ $$MCost = \$1{,}956 * BMPSize(AF) \quad \textbf{(C-31)}$$

C.4.4. Constructed Wetland Channel

Table C-9 summarizes the maintenance activities and their individual annual costs for CWCs. Equation (C-32) is used to compute total annual maintenance costs.

Table C-9: CWC maintenance activity costs

Activity	**Type**	**F**	**A**	**β-value**	**Annual Cost***
-	-	-	-	-	-
				Total =	**-**
Litter and Debris Removal	Unit	1	$620	1	$620
Vegetation/Woody Debris Removal	Unit	0.2	$1,969	1	$339
				Total =	**$960**

Notes:

* – for unit-type activities, the annual cost is per acre of surface area

2008$ $$MCost = \$960 * BMPSize(acres)$$ **(C-32)**

C.4.5. Extended Detention Basin

Table C-10 summarizes the maintenance activities and their individual annual costs for EDBs. Equation (C-33) is used to compute total annual maintenance costs for EDBs.

Table C-10: EDB maintenance activity costs

Activity	Type	F	A	β-value	Annual Cost*
Inlet/Outlet Cleaning	Lump sum	6	$52	-	$310
Nuisance Control	Lump sum	12	$63	-	$761
Outlet Maintenance	Lump sum	0.25	$3,113	-	$778
				Total =	**$1,849**
Lawn Mowing/Lawn Care	Unit	6	$269	1	$2,151
Sediment Removal (routine)	Unit	0.5	$60	16.13	$480
Sediment Removal (non-routine)	Unit	0.05	$43	322.67	$686
				Total =	**$2,782**

Notes:

* – for unit-type activities, the annual cost is per AF of EDB storage

2008$ $$MCost = \$1{,}849 + \$2{,}782 * BMPSize(AF)$$ **(C-33)**

C.4.6. Hydrodynamic Separator

Table C-11 summarizes the maintenance activities and their individual annual costs for EDBs. Equation (C-34) is used to compute total annual maintenance costs.

Table C-11: HS maintenance activity costs

Activity	Type	F	A	β-value	Annual Cost*
-	-	-	-	-	-
				Total =	**-**
Sediment Removal	Unit	4	$344	0.4	$550
Traffic Control	Unit	4	$124	0.4	$199
				Total =	**$749**

Notes:

* – for unit-type activities, the annual cost is per cfs of design flowrate

2008$ $$MCost = \$749 * BMPSize(cfs) \quad \textbf{(C-34)}$$

C.4.7. Inlet Inserts

Table C-12 summarizes the maintenance activities and their individual annual costs for EDBs. Equation (C-35) is used to compute total annual maintenance costs.

Table C-12: II maintenance activity costs

Activity	Type	F	A	β-value	Annual Cost
Filter Replacement	Lump sum	6	$166	-	$166
				Total =	**$166**
-	-	-	-	-	-
				Total =	**-**

Notes:

2008$ $$MCost = \$166 \quad \textbf{(C-35)}$$

C.4.8. Media Filter Vault

Table C-13 summarizes the maintenance activities and their individual annual costs for EDBs. Equation (C-36) is used to compute total annual maintenance costs.

Table C-13: MFV maintenance activity costs

Activity	Type	F	A	β-value	Annual Cost*
-	-	-	-	-	-
				Total =	**-**
Sediment Removal	Unit	2	$416	0.67	$558
Traffic Control	Unit	2	$207	0.67	$277
				Total =	**$835**

Notes:

* – for unit-type activities, the annual cost is per cfs of design flowrate

2008$ $$MCost = \$835 * BMPSize(cfs) \quad \textbf{(C-36)}$$

C.4.9. Porous Concrete Pavement

Table C-14 summarizes the maintenance activities and their individual annual costs for EDBs. Equation (C-37) is used to compute total annual maintenance costs.

Table C-14: PCP maintenance activity costs

Activity	Type	F	A	β-value	Annual Cost*
-	-	-	-	-	-
				Total =	**-**
Sweeping/Vacuuming	Unit	2	$62	1	$125
				Total =	**$125**

Notes:

* – for unit-type activities, the annual cost is per acre of installation surface area.

2008$ $$MCost = \$125 * BMPSize(acres) \quad \textbf{(C-37)}$$

C.4.10. Porous Gravel Pavement

Table C-15 summarizes the maintenance activities and their individual annual costs for EDBs. Equation (C-38) is used to compute total annual maintenance costs.

Table C-15: PGP maintenance activity costs

Activity	Type	F	A	β-value	Annual Cost*
-	-	-	-	-	-
				Total =	**-**
Gravel Finish Grading	Unit	12	$471	1	$5,647
				Total =	**$5,647**

Notes:

* – for unit-type activities, the annual cost is per acre of installation surface area.

2008$ $$MCost = \$5{,}647 * BMPSize \quad \textbf{(C-38)}$$

C.4.11. Porous Landscape Detention

Table C-16 summarizes the maintenance activities and their individual annual costs for EDBs. Equation (C-39) is used to compute total annual maintenance costs.

Table C-16: PLD maintenance activity costs

Activity	Type	F	A	β-value	Annual Cost*
-	-	-	-	-	-
				Total =	**-**
Annual Cleanup	Unit	1	$414	0.001	$0.41
Annual Planting	Unit	1	$207	0.001	$0.21
				Total =	**$0.62**

Notes:

* – for unit-type activities, the annual cost is per CF of storage volume

2008$ $$MCost = \$0.62 * BMPSize(CF) \quad \textbf{(C-39)}$$

C.4.12. Reinforced Grass Pavement

Table C-17 summarizes the maintenance activities and their individual annual costs for EDBs. Equation (C-40) is used to compute total annual maintenance costs.

Table C-17: RGP maintenance activity costs

Activity	Type	F	A	β-value	Annual Cost*
-	-	-	-	-	-
				Total =	**-**
Lawn Mowing/Lawn Care	Unit	15	$269	1	$4,040
				Total =	**$4,040**

Notes:

* – for unit-type activities, the annual cost is per acre of installation surface area

2008$ $$MCost = \$4{,}040 * BMPSize(acres) \quad \textbf{(C-40)}$$

C.4.13. Retention Pond

Table C-18 summarizes the maintenance activities and their individual annual costs for EDBs. Equation (C-41) is used to compute total annual maintenance costs.

Table C-18: RP maintenance activity costs

Activity	Type	F	A	β-value	Annual Cost*
Nuisance Control	Lump sum	12	$127	-	$1,521
				Total =	**$1,521**
Lawn Mowing/Lawn Care	Unit	6	$269	1	$404
Sediment Removal (routine)	Unit	0.5	$60	16.13	$480
Sediment Removal (non-routine)	Unit	0.05	$43	322.67	$686
Vegetation/Woody Debris Removal	Unit	0.33	$1,696	0.05	$28
				Total =	**$1,598**

Notes:

* – for unit-type activities, the annual cost is per AF of storage volume

2008$ $$MCost = \$1{,}521 + \$1{,}598 * BMPSize(AF)$$ **(C-41)**

C.4.14. Sand Filter Basin

Table C-19 summarizes the maintenance activities and their individual annual costs for EDBs. Equation (C-42) is used to compute total annual maintenance costs.

Table C-19: SFB maintenance activity costs

Activity	Type	F	A	β-value	Annual Cost*
-	-	-	-	-	-
				Total =	**-**
Lawn Mowing/Lawn Care	Unit	6	$269	0.33	$533
Sediment Removal (routine)	Unit	0.5	$60	16.13	$480
Scarify Top Sand Layer	Unit	1	$253	0.33	$83
				Total =	**$1,096**

Notes:

* – for unit-type activities, the annual cost is per AF of storage volume

2008$ $$MCost = \$1{,}096 * BMPSize(AF) \quad \textbf{(C-42)}$$

C.4.15. Sand Filter Vault

Table C-20 summarizes the maintenance activities and their individual annual costs for EDBs. Equation (C-43) is used to compute total annual maintenance costs.

Table C-20: SFV maintenance activity costs

Activity	Type	F	A	β-value	Annual Cost*
-	-	-	-	-	-
				Total =	**-**
Remove Top Sand Layer	Unit	1	$310	0.006	$1.86
				Total =	**$1.86**

Notes:

* – for unit-type activities, the annual cost is per CF of storage volume

2008$ $$MCost = \$1.86 * BMPSize(CF) \quad \textbf{(C-43)}$$

C.4.16. Sediment/Oil/Grease Separator

Table C-21 summarizes the maintenance activities and their individual annual costs for EDBs. Equation (C-44) is used to compute total annual maintenance costs.

Table C-21: SOG maintenance activity costs

Activity	Type	F	A	β-value	Annual Cost*
-	-	-	-	-	-
				Total =	**-**
Sediment Removal	Unit	4	$344	0.44	$605
Traffic Control	Unit	4	$129	0.44	$227
				Total =	**$832**

Notes:

* – for unit-type activities, the annual cost is per cfs of design flowrate.

2008$ $$MCost = \$832 * BMPSize(cfs) \quad \textbf{(C-44)}$$

C.4.17. Vault with Capture Volume

Table C-22 summarizes the maintenance activities and their individual annual costs for VCVs. Equation (C-45) is used to compute total annual maintenance costs.

Table C-22: VCV maintenance activity costs

Activity	Type	F	A	β-value	Annual Cost*
-	-	-	-	-	-
				Total =	**-**
Sediment Removal	Unit	0.2	$344	0.007	$0.48
Traffic Control	Unit	0.2	$129	0.007	$0.18
				Total =	**$0.66**

Notes:

* – for unit-type activities, the annual cost is per CF of storage volume

2008$ $$MCost = \$0.66 * BMPSize(CF) \quad \textbf{(C-45)}$$

B. Permanent BMP Construction Cost Estimates

Muller Engineering Company, Inc.
Consulting Engineers
Irongate 4, Suite 100
777 South Wadsworth Blvd.
Lakewood, Colorado 80226
(303) 988-4939

Memorandum

Permanent BMP Construction Cost Estimates

To: Ken MacKenzie / UDFCD
Holly Piza / UDFCD

From: Melanie Chenard / Muller Engineering Company
Jim Wulliman / Muller Engineering Company
Bruce Behrer / Muller Engineering Company

Date: August 3, 2009

Muller Engineering Company has prepared order-of-magnitude opinions of probable construction cost for a variety of permanent stormwater best management practices (BMPs). Each BMP was sized for the water quality capture volume (WQCV) per UDFCD criteria, excess urban runoff volume (EURV), an estimated water quality flow rate, or other sizing criteria, as applicable. Each BMP was sized for three different contributing impervious areas, ranging from 0.25 ac to 20 ac. The BMPs were organized into several categories, each with their own basis of sizing, as shown in Table 1.

Table 1. Types of BMPs and Basis of Sizing

Type of BMP	Basis of Sizing	Number of BMPs Evaluated
WQCV BMPs	WQCV, per criteria	8
Porous Pavement BMPs	One-half of upstream impervious area	5
Proprietary BMPs	Water quality event peak discharge	4
Channel BMPs	2-year / 100-year peak discharge	1
EURV BMPs	EURV, per criteria	3

Table 2, on the next page, lists all of the BMPs evaluated and the basis of their sizing. Sizing calculations are shown in Appendix A.

Summary charts showing construction cost opinions for all of the BMPs are provided in Appendix B. Spreadsheets showing design assumptions, quantity estimates, unit costs and total costs, along with any plan or section drawings of BMPs are provided in Appendices C, D, E, and F, respectively, for WQCV BMPs, porous pavement BMPs, proprietary BMPs, and channel BMPs.

Quantities were estimated based on BMP configurations shown in Volume 3 of the Urban Storm Drainage Criteria Manual (USDCM), where available, and construction unit costs were applied based on recent bids received/reviewed by Muller, CDOT 2008 Cost Data, UDFCD Bid Tabulation Data, and manufacturer-provided data. Past project cost data originated from recent projects constructed in the past 5 years within the Denver metropolitan area and so adjustments for inflation and geographic location were not made.

Table 2. BMPs Evaluated and Their Relative Size

	Impervious area, ac	**0.25**	**1**	**2**	**5**	**20**
	WQCV BMPs	**Water Quality Capture Volume, AF**				
1	Extended Detention Basin (EDB)			0.10	0.25	1.00
2	Constructed Wetland Basin (CWB)			0.08	0.19	0.75
3	Retention Pond (RP)			0.07	0.17	0.67
4	Sand Filter Basin (SFB)		0.04	0.08	0.21	
5	Porous Landscape Detention (PLD) with media walls	0.01	0.03		0.17	
6	Porous Landscape Detention (PLD) without media walls	0.01	0.03		0.17	
7	Underground Vault with WQCV	0.01	0.04	0.10		
8	Underground Sand Filter Vault	0.01	0.04	0.08		
	Porous pavement BMPs	**Area, ac**				
9	Modular Block Pavement (MBP)	0.08	0.33	0.66		
10	Cobblestone Block Pavement (CBP)	0.08	0.33	0.66		
11	Reinforced Grass Pavement (RGP)	0.08	0.33	0.66		
12	Porous Concrete Pavement (PCP)	0.08	0.33	0.66		
13	Porous Gravel Pavement (PGP)	0.08	0.33	0.66		
	Proprietary BMPs	**Water Quality Event Peak Discharge, cfs**				
14	Hydrodynamic Separators	0.3	1.1	2.1		
15	Oil/grease/sediment Separators	0.3	1.1	2.1		
16	Media Filters	0.3	1.1	2.1		
17	Inlet Filters	0.3	1.1	2.1		
	Channel BMPs	**2-year Peak Discharge, cfs**				
18	Constructed Wetland Channel (CWC)			4.1	10	32
	EURV BMPs	**Excess Urban Runoff Volume, AF**				
1	Extended Detention Basin (EDB)			0.20	0.51	2.02
2	Constructed Wetland Basin (CWB)			0.20	0.51	2.02
3	Retention Pond (RP)			0.20	0.51	2.02

The order-of-magnitude opinions of probable construction cost presented herein are approximate and intended primarily for comparative purposes. Design configurations were simplified and assumptions were made in an effort to represent the cost of an “average” installation of each BMP; however, varying site conditions can have tremendous impact on the actual cost of any BMP and the costs shown herein are not intended to be absolute. The costs of manufactured products can be especially sensitive to design assumptions and specific site conditions. Because of the uncertainty associated with proprietary BMP design approaches, effectiveness, and costs, we have shown these construction cost opinions as possible ranges for each type of proprietary BMP rather than plotting costs associated with any one manufacturer’s product.

The BMPs examined do not necessarily have the same treatment effectiveness, even if they are sized for similar contributing impervious areas. Therefore, comparing costs of the BMPs for the same impervious area does not in itself reveal the relative treatment costs per pound of pollutant removed.

We have appreciated the opportunity to work with you on this evaluation of BMP cost information and look forward to further discussions with you.

Appendix A

BMP Sizing Calculations

UDFCD BMP Construction Cost Evaluation

7/31/2009

Drainage Area

Contributing area, ac	0.25	1	2	5	20
% imperviousness	100%	100%	100%	100%	100%
Impervious area, ac	**0.25**	**1**	**2**	**5**	**20**

Rational Method Flows

Asssumed width of contributing area, ft	60	120	165	260	500
Length of contributing area, ft	182	363	528	838	1742
L/W	3.0	3.0	3.2	3.2	3.5
Tc	11	12	13	15	20
100-year rainfall intensity	6.8	6.6	6.3	5.9	5.1
100-year C	0.96	0.96	0.96	0.96	0.96
100-year peak flow	**1.6**	**6.3**	**12**	**28**	**98**
2-year rainfall intensity	2.5	2.4	2.3	2.2	1.8
2-year C	0.89	0.89	0.89	0.89	0.89
2-year peak flow	**0.6**	**2.1**	**4.1**	**10**	**32**
WQ event rainfall intensity	1.3	1.3	1.2	1.2	0.9
WQ event C	0.88	0.88	0.88	0.88	0.88
WQ event peak flow	**0.3**	**1.1**	**2.1**	5.1	16.7

WQCV

Porous pavements

Ratio of porous to total impervious area	0.33	0.33	0.33	0.33	0.33
Porous area, ac	**0.08**	**0.33**	**0.66**	1.65	6.6

Extended Detention Basin (EDB)

Drain time, hrs	40				
a	1	1	1	1	1
Additional volume for sediment storage	20%	20%	20%	20%	20%
WQCV, in	0.5	0.5	0.5	0.5	0.5
WQCV with sediment storage, in	0.6	0.6	0.6	0.6	0.6
WQCV with sediment storage, CF	545	2178	**4356**	**10890**	**43560**
WQCV with sediment storage, AF	0.01	0.05	**0.10**	**0.25**	**1.00**

Sand Filter Basin (SFB)

Drain time, hrs	40				
a	1	1	1	1	1
WQCV, in	0.5	0.5	0.5	0.5	0.5
WQCV, CF	454	**1815**	**3630**	**9075**	36300
WQCV, AF	0.01	**0.04**	**0.08**	**0.21**	0.83

Constructed Wetland Basin (CWB)

Drain time, hrs	24				
a	0.9	0.9	0.9	0.9	0.9
Additional volume for sediment storage	0%	0%	0%	0%	0%
WQCV, in	0.45	0.45	0.45	0.45	0.45
WQCV, CF	408	1634	**3267**	**8168**	**32670**
WQCV, AF	0.01	0.04	**0.08**	**0.19**	**0.75**

Retention Pond (RP)

Drain time, hrs	12				
a	0.8	0.8	0.8	0.8	0.8
Additional volume for sediment storage	0%	0%	0%	0%	0%
WQCV, in	0.4	0.4	0.4	0.4	0.4
WQCV, CF	363	1452	**2904**	**7260**	**29040**
WQCV, AF	0.01	0.03	**0.07**	**0.17**	**0.67**

Porous Landscape Detention (PLD)

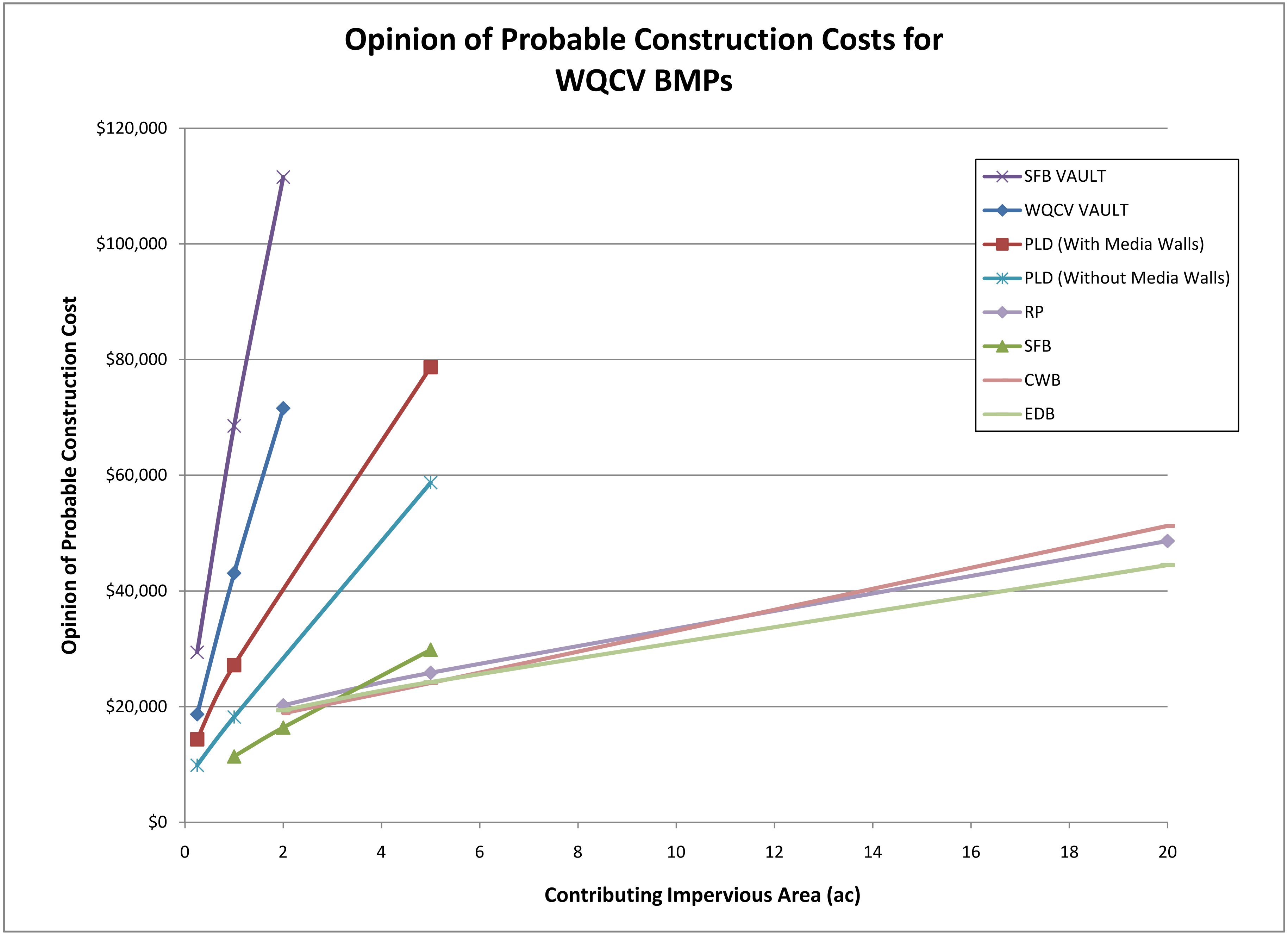
Drain time, hrs	12				
a	0.8	0.8	0.8	0.8	0.8
Additional volume for sediment storage	0%	0%	0%	0%	0%
WQCV, in	0.4	0.4	0.4	0.4	0.4
WQCV, CF	**363**	**1452**	2904	**7260**	29040
WQCV, AF	**0.01**	**0.03**	0.07	**0.17**	0.67
Max WQCV depth, in	12	12	12	12	12
Min area, ac	0.01	0.03	0.07	0.17	0.67

EURV

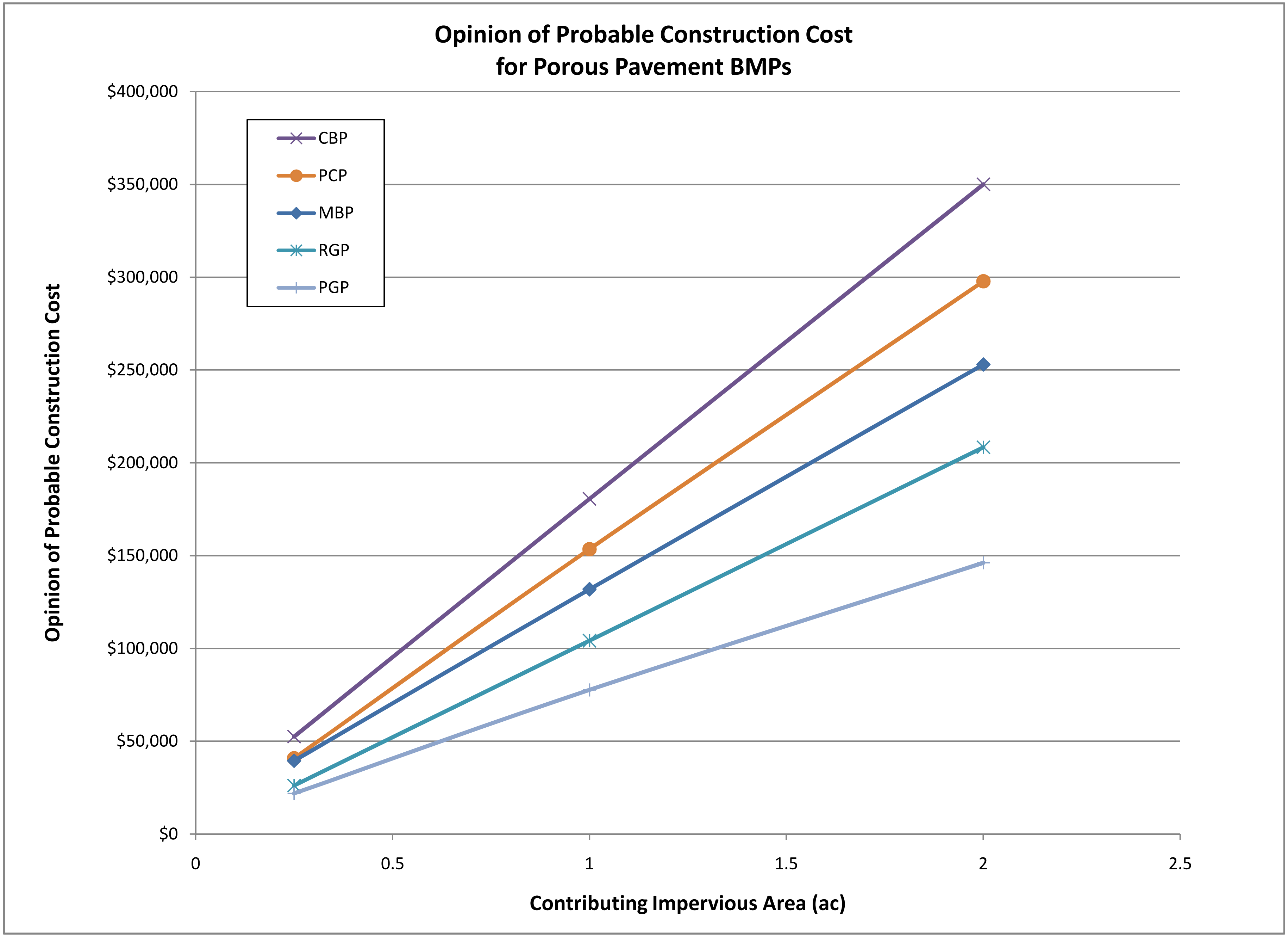
EURV, in	1.21	1.21	1.21	1.21	1.21
EURV, CF	1102	4409	**8818**	**22045**	**88181**
EURV, AF	0.03	0.10	**0.20**	**0.51**	**2.02**
Max release rate, cfs	0.25	1	2	5	20

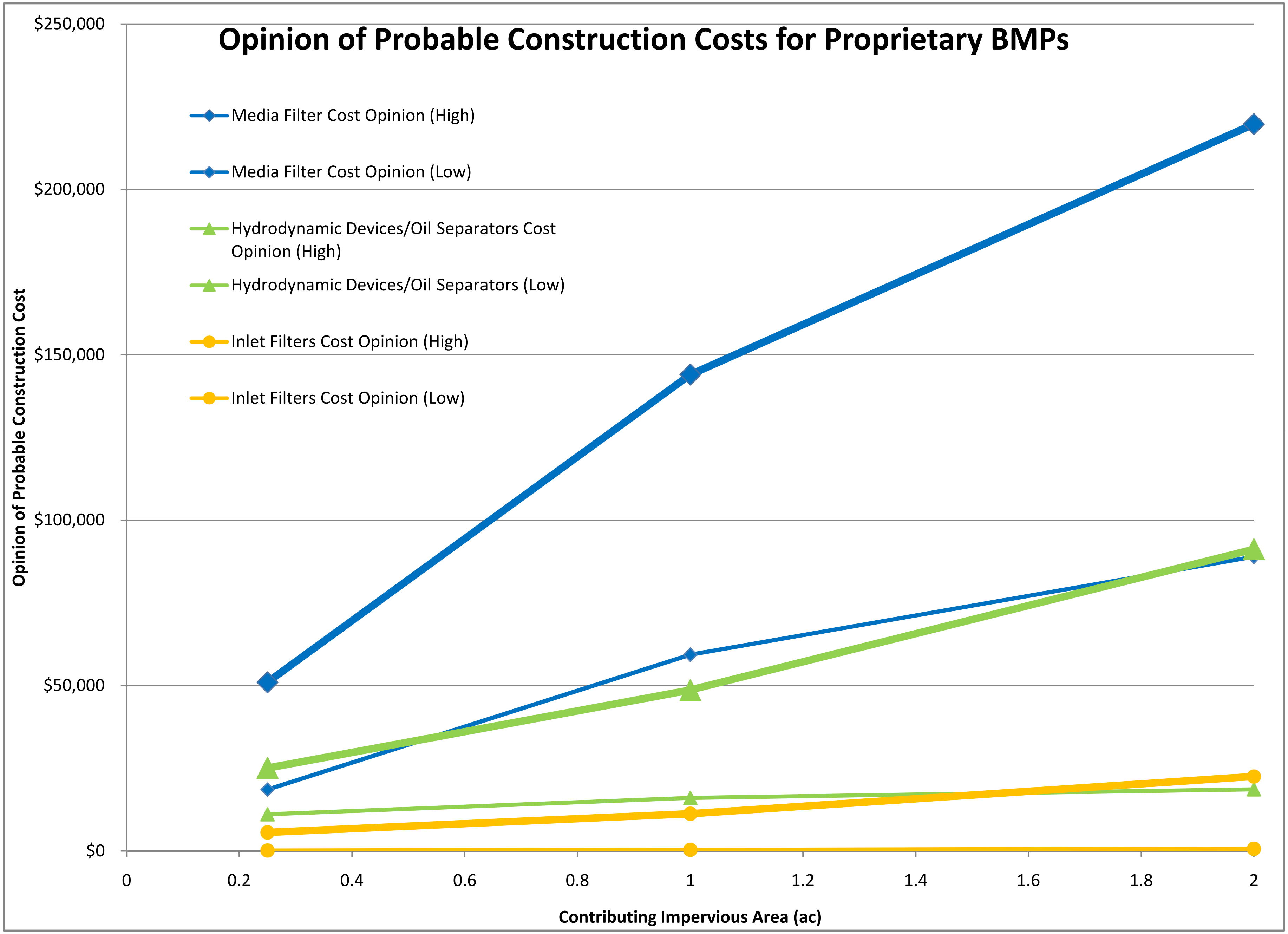
Appendix B

Summary Charts Showing Order-of-Magnitude Opinions of Probable Construction Cost

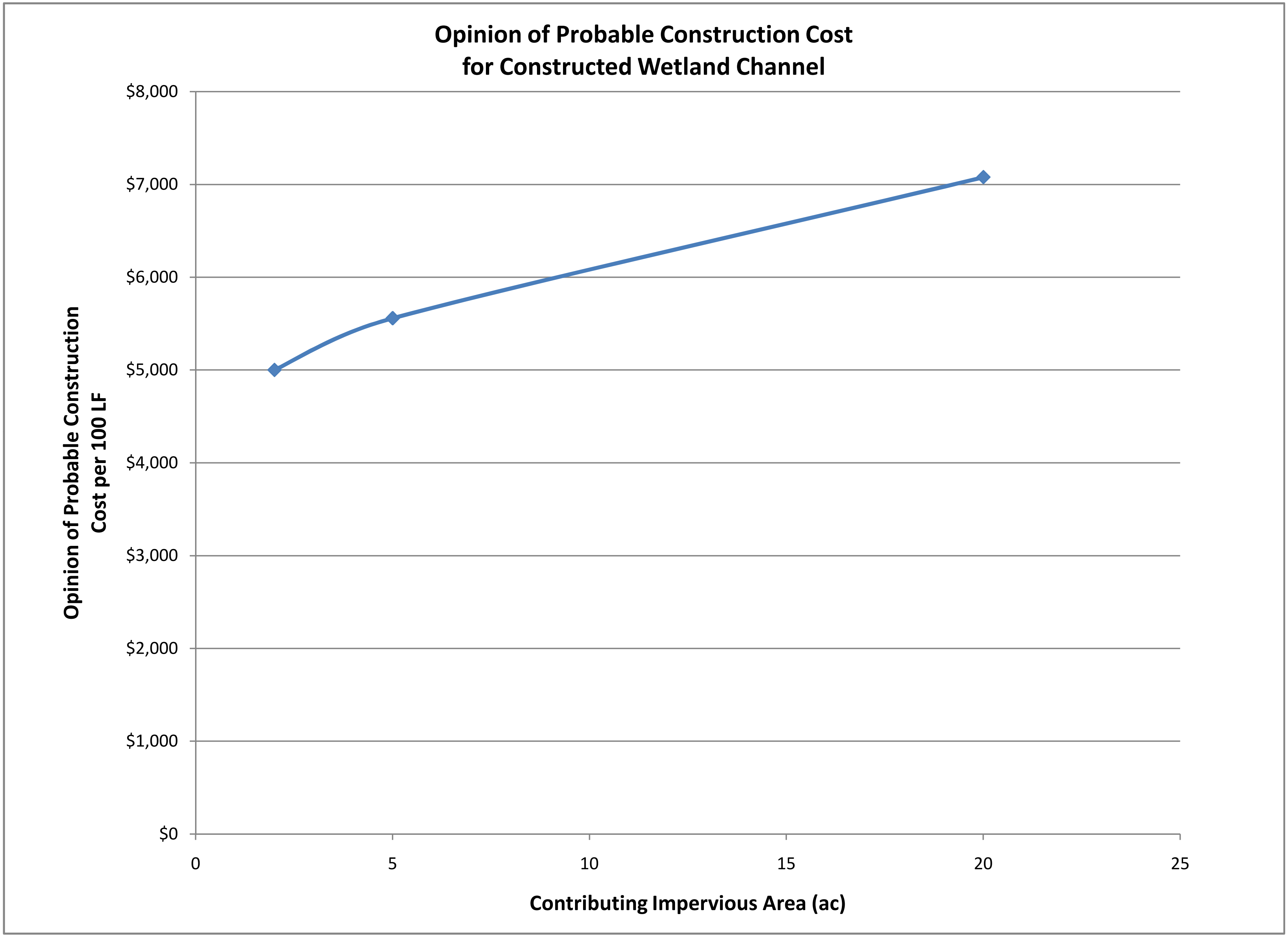


Opinion of Probable Construction Costs for
WQCV BMPs
$120,000
$100,000
$80,000
$60,000
$40,000
$20,000
$0
Opinion of Probable Construction Cost
0
2
4
6
8
10
12
14
16
18
20
Contributing Impervious Area (ac)
SFB VAULT
WQCV VAULT
PLD (With Media Walls)
PLD (Without Media Walls)
RP
SFB
CWB
EDB

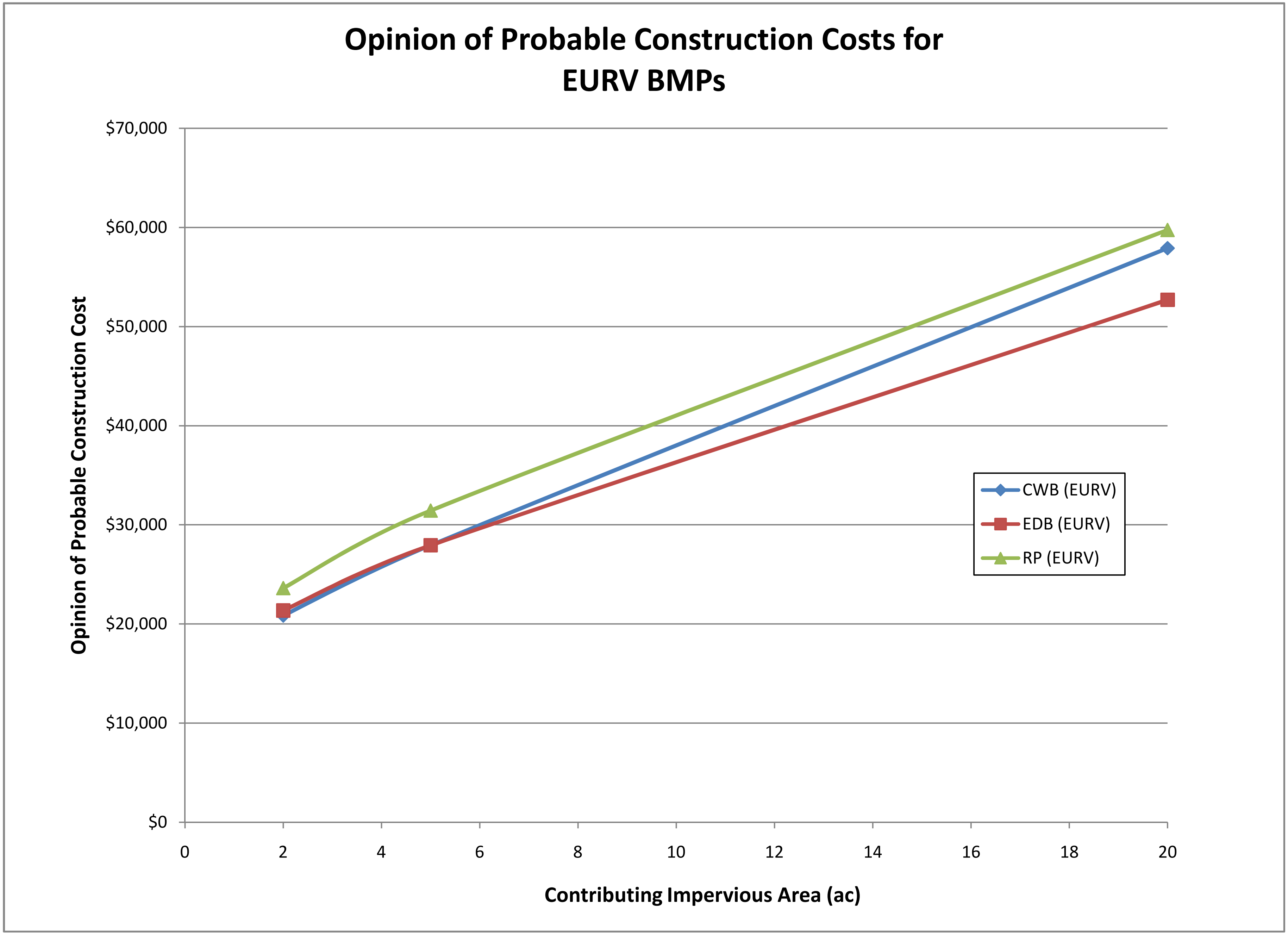

Opinion of Probable Construction Cost
for Porous Pavement BMPs
Opinion of Probable Construction Cost
$400,000
$350,000
$300,000
$250,000
$200,000
$150,000
$100,000
$50,000
$0
0
0.5
1
1.5
2
2.5
Contributing Impervious Area (ac)
CBP
PCP
MBP
RGP
PGP



Opinion of Probable Construction Costs for Proprietary BMPs
Media Filter Cost Opinion (High)
Media Filter Cost Opinion (Low)
Hydrodynamic Devices/Oil Separators Cost Opinion (High)
Hydrodynamic Devices/Oil Separators (Low)
Inlet Filters Cost Opinion (High)
Inlet Filters Cost Opinion (Low)
$250,000
$200,000
$150,000
$100,000
$50,000
$0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Opinion of Probable Construction Cost
Contributing Impervious Area (ac)



Opinion of Probable Construction Cost
for Constructed Wetland Channel
Opinion of Probable Construction Cost per 100 LF
$8,000
$7,000
$6,000
$5,000
$4,000
$3,000
$2,000
$1,000
$0
0
5
10
15
20
25
Contributing Impervious Area (ac)


Opinion of Probable Construction Costs for
EURV BMPs
Opinion of Probable Construction Cost
$70,000
$60,000
$50,000
$40,000
$30,000
$20,000
$10,000
$0
0
2
4
6
8
10
12
14
16
18
20
Contributing Impervious Area (ac)
CWB (EURV)
EDB (EURV)
RP (EURV)

Appendix C

Cost Spreadsheets and Figures for WQCV BMPs

Extended Detention Basin (EDB) with WQCV

Design Information

WQCV depth range	2-4	ft
Forebay depth	2	ft
Forebay volume (% of WQCV)	4%	
Basin length:width ratio	3	
Side slopes (H:V)	5	
Maintenance road width	10	ft
Maintenance road slope	0.10	ft/ft
Maintenance road thickness	1.0	ft

	Contributing Impervious Area						
	2 ac		**5 ac**		**20 ac**		
WQCV (incl. sediment storage)	4356	cf	10890	cf	43560	cf	
WQCV depth	2	ft	2	ft	4	ft	
100-yr peak flow	12	cfs	28	cfs	98	cfs	
WQ event peak flow	2.1	cfs	5.1	cfs	16.7	cfs	used for calculating pipe size assuming 1% slope
Forebay volume	174	cf	436	cf	1742	cf	
Forebay area	87	sf	218	sf	871	sf	
Area at 1/2 WQCV depth	2178	sf	5445	sf	10890	sf	
Width at 1/2 WQCV depth	27	ft	43	ft	60	ft	
Length at 1/2 WQCV depth	81	ft	128	ft	181	ft	
Top area	3356	sf	7249	sf	16110	sf	
Bottom area	1200	sf	3841	sf	6470	sf	
Emergency spillway width (assume 1' head)	4	ft	9	ft	33	ft	
Maintenance road length	121	ft	168	ft	261	ft	
Trickle channel width	2	ft	2	ft	4	ft	
Trickle channel length	54	ft	85	ft	120	ft	

				2 Acre Site		5 Acre Site		20 Acre Site		
Item No.	**Item**	**Unit**	**Unit Price**	**Quantity**	**Total**	**Quantity**	**Total**	**Quantity**	**Total**	**Notes**
1	Excavation and backfill	CY	$5	161	$807	403	$2,017	807	$4,033	100% WQCV for 2 & 5 acre sites, 50% WQCV for 20 acre site
2	Concrete forebay	CY	$400	2	$800	5	$2,000	17	$6,800	qty based on area*2 for sides, ramps, etc.
3	Outlet structure - 2.1 and 5.1 cfs capacity	LS	$10,000	1	$10,000	1	$10,000	0	$0	
4	Outlet structure - 17 cfs capacity	LS	$15,000	0	$0	0	$0	1	$15,000	
5	Riprap spillway protection	CY	$60	5	$300	12	$720	44	$2,640	1.5' thickness; 4:1 slope
6	Concrete spillway weir	CY	$400	0.3	$120	0.4	$160	0.9	$360	
7	Maintenance access road (aggregate base course)	CY	$40	45	$1,800	62	$2,480	97	$3,880	basin length + 2 bottom accesses
8	Upland seeding and mulching	AC	$2,000	0.10	$200	0.20	$400	0.45	$900	120% of top area
9	18" RCP	LF	$50	50	$2,500	50	$2,500	0	$0	
10	24" RCP	LF	$55	0	$0	0	$0	50	$2,750	
11	Concrete trickle channel	CY	$400	4	$1,600	6	$2,400	13	$5,200	2/3 basin length, 6" thick, 4" deep

SUBTOTAL		$18,127	$22,677	$41,563
Mobilization and site prep	7%	$1,269	$1,587	$2,909
TOTAL COST		**$19,396**	**$24,264**	**$44,473**

Constructed Wetlands Basin (CWB) with WQCV

Design Information

WQCV depth	2	ft
Forebay depth (below permanent pool)	3	ft
Permanent pool volume (% of WQCV)	75%	
Forebay volume (% of WQCV)	8%	
Basin length:width ratio	3	
Side slopes (H:V)	5	
Maintenance road width	10	ft
Maintenance road slope	0.10	ft/ft
Maintenance road thickness	1.0	ft
Wetland vegetation area (% of permanent pool)	60%	

	Contributing Impervious Area						
	2 ac		**5 ac**		**20 ac**		
WQCV	3267	cf	8168	cf	32670	cf	
100-yr peak flow	12	cfs	28	cfs	98	cfs	
WQ event peak flow	2.1	cfs	5.1	cfs	16.7	cfs	used for calculating pipe size assuming 1% slope
Permanent pool volume	2450	cf	6126	cf	24503	cf	
Forebay volume	261	cf	653	cf	2614	cf	
Forebay area	87	sf	218	sf	871	sf	
Area at 1/2 WQCV depth	1634	sf	4084	sf	16335	sf	
Width at 1/2 WQCV depth	23	ft	37	ft	74	ft	
Length at 1/2 WQCV depth	70	ft	111	ft	221	ft	
Top area	2667	sf	5660	sf	19387	sf	
Permanent pool area	800	sf	2708	sf	13483	sf	
Average permanent pool depth	3.1	ft	2.3	ft	1.8	ft	
Emergency spillway width (assume 1' head)	4	ft	9	ft	33	ft	
Maintenance road length	110	ft	151	ft	261	ft	

				2 Acre Site		5 Acre Site		20 Acre Site		
Item No.	**Item**	**Unit**	**Unit Price**	**Quantity**	**Total**	**Quantity**	**Total**	**Quantity**	**Total**	**Notes**
1	Excavation and backfill	CY	$5	212	$1,059	529	$2,647	1513	$7,563	Permanent pool plus: 100% WQCV for 2 & 5 acre sites, 50% WQCV for 20 acre site
2	Concrete forebay	CY	$400	4	$1,600	9	$3,600	33	$13,200	qty based on area*2 for sides, ramps, etc.
3	Outlet structure - 2.1 and 5.1 cfs capacity	LS	$10,000	1	$10,000	1	$10,000	0	$0	
4	Outlet structure - 17 cfs capacity	LS	$15,000	0	$0	0	$0	1	$15,000	
5	Riprap spillway protection	CY	$60	4	$240	8	$480	29	$1,740	1.5' thickness; 4:1 slope
6	Concrete spillway weir	CY	$400	0.3	$120	0.4	$160	0.9	$360	
7	Maintenance access road (aggregate base course)	CY	$40	41	$1,640	56	$2,240	97	$3,880	basin length + 2 bottom accesses
8	Upland seeding and mulching	AC	$2,000	0.09	$180	0.14	$280	0.28	$560	2*(top area-permanent pool area)
9	Wetland vegetation	AC	$15,000	0.02	$300	0.04	$600	0.19	$2,850	
10	18" RCP	LF	$50	50	$2,500	50	$2,500	0	$0	
11	24" RCP	LF	$55	0	$0	0	$0	50	$2,750	

		2 Acre Site	5 Acre Site	20 Acre Site
SUBTOTAL		$17,639	$22,507	$47,903
Mobilization and site prep	7%	$1,235	$1,575	$3,353
TOTAL COST		**$18,873**	**$24,083**	**$51,256**

Retention Pond (RP) with WQCV

Design Information

WQCV depth range	2-5	ft
Forebay depth (below permanent pool)	3	ft
Permanent pool volume range (% of WQCV)	120%-200%	
Forebay volume (% of WQCV)	8%	
Basin length:width ratio	3	
Side slopes (H:V)	5	
Maintenance road width	10	ft
Maintenance road slope	0.10	ft/ft
Maintenance road thickness	1.0	ft
Wetland vegetation area (% of permanent pool)	35%	

	Contributing Impervious Area						
	2 ac		**5 ac**		**20 ac**		
WQCV	2904	cf	7260	cf	29040	cf	
WQCV depth	2	ft	2	ft	3	ft	
100-yr peak flow	12	cfs	28	cfs	98	cfs	
WQ event peak flow	2.1	cfs	5.1	cfs	16.7	cfs	used for calculating pipe size assuming 1% slope
Permanent pool volume (% of WQCV)	160%		160%		120%		
Permanent pool volume	4646	cf	11616	cf	34848	cf	
Forebay volume	232	cf	581	cf	2323	cf	
Forebay area	77	sf	194	sf	774	sf	
Area at 1/2 WQCV depth	1452	sf	3630	sf	9680	sf	
Width at 1/2 WQCV depth	22	ft	35	ft	57	ft	
Length at 1/2 WQCV depth	66	ft	104	ft	170	ft	
Top area	2432	sf	5121	sf	13313	sf	
Permanent pool area	672	sf	2339	sf	6497	sf	
Average permanent pool depth	6.9	ft	5.0	ft	5.4	ft	
Emergency spillway width (assume 1' head)	4	ft	9	ft	33	ft	
Maintenance road length	106	ft	144	ft	230	ft	

				2 Acre Site		5 Acre Site		20 Acre Site		
Item No.	**Item**	**Unit**	**Unit Price**	**Quantity**	**Total**	**Quantity**	**Total**	**Quantity**	**Total**	**Notes**
1	Excavation and backfill	CY	$5	280	$1,398	699	$3,496	1828	$9,142	Permanent pool plus: 100% WQCV for 2 & 5 acre sites, 50% WQCV for 20 acre site
2	Concrete forebay	CY	$400	2	$800	4	$1,600	15	$6,000	qty based on area*2 for sides, ramps, etc.
3	Outlet structure - 2.1 and 5.1 cfs capacity	LS	$10,000	1	$10,000	1	$10,000	0	$0	
4	Outlet structure - 17 cfs capacity	LS	$15,000	0	$0	0	$0	1	$15,000	
5	Riprap spillway protection	CY	$60	4	$240	10	$600	36	$2,160	1.5' thickness
6	Concrete spillway weir	CY	$400	0.3	$120	0.4	$160	0.9	$360	
7	Maintenance access road (aggregate base course)	CY	$40	39	$1,560	53	$2,120	85	$3,400	basin length + 2 bottom accesses
8	Upland seeding and mulching	AC	$2,000	0.09	$180	0.13	$260	0.32	$640	2*(top area-permanent pool area)
9	Wetland vegetation	AC	$15,000	0.01	$150	0.02	$300	0.06	$900	
10	Underdrain (incl. bedding and backfill)	LF	$30	66	$1,980	104	$3,131	170	$5,112	
11	18" RCP	LF	$50	50	$2,500	50	$2,500	0	$0	
12	24" RCP	LF	$55	0	$0	0	$0	50	$2,750	

SUBTOTAL		$18,928	$24,166	$45,465
Mobilization and site prep	7%	$1,325	$1,692	$3,183
TOTAL COST		**$20,253**	**$25,858**	**$48,647**

Sand Filter Basin (SFB)

Design Information

a)	Max WQCV depth	3	ft	
b)	Length to width ratio (L/W)	2		
c)	Depth of sand layer	18	in	1.5 ft
d)	Depth of gravel layer	8	in	0.67 ft
e)	Total depth (a+c+d)	5.17	ft	

		Contributing Impervious Area		
		1.0 ac	**2.0 ac**	**5.0 ac**
g)	WQCV	1815 cf	3630 cf	9075 cf
h)	Area	605 sf	1210 sf	3025 sf
i)	Width	17 ft	25 ft	39 ft
j)	Length	36 ft	48 ft	78 ft
k)	# of runs of underdrain (20' spacing)	1	2	2
l)	Pipe diameter	18 in	24 in	30 in

				0.25 Acre Site		1 Acre Site		5 Acre Site		
Item No.	**Item**	**Unit**	**Unit Price**	**Quantity**	**Total**	**Quantity**	**Total**	**Quantity**	**Total**	**Notes**
1	Excavation and backfill	CY	$5	180	$900	310	$1,550	710	$3,550	e*(i+e)*(j+e)
2	Sand	CY	$40	34	$1,360	67	$2,680	168	$6,720	h*c
3	Gravel	CY	$40	15	$600	30	$1,200	75	$3,000	h*d
4	4" perforated PVC pipe and fittings (incl. cleanouts)	LF	$20	36	$720	96	$1,920	156	$3,120	j*k
5	Geotextile	SY	$4	203	$812	356	$1,424	816	$3,264	2*(i+e)*(j+e)
6	Outlet structure - 6.3 and 12 cfs capacity	LS	$3,700	1	$3,700	1	$3,700	0	$0	Type C Inlet
7	Outlet structure - 28 cfs capacity	LS	$4,300	0	$0	0	$0	1	$4,300	Type D Inlet
8	Riprap outlet protection	CY	$60	0.9	$54	1.7	$102	2.6	$156	$9*l^2*1.25$
9	18" RCP	LF	$50	50	$2,500	0	$0	0	$0	
10	24" RCP	LF	$55	0	$0	50	$2,750	0	$0	
11	30" RCP	LF	$75	0	$0	0	$0	50	$3,750	

SUBTOTAL		$10,646	$15,326	$27,860
Mobilization and site prep	7%	$745	$1,073	$1,950
TOTAL COST		**$11,391**	**$16,399**	**$29,810**

	Add impermeable liner	SY	$6	101	$606	178	$1,068	408	$2,448
	Deduct geotextile	SY	$4	-101	-$404	-178	-$712	-408	-$1,632

ADD IMPERMEABLE LINER	$202	$356	$816

Porous Landscape Detention (PLD)

Design Information

a)	Max WQCV depth	1 ft	
b)	Length to width ratio (L/W)	2	
c)	Depth of sand/peat layer	18 in	1.5 ft
d)	Depth of gravel layer	8 in	0.67 ft
e)	Total depth (a+c+d)	3.17 ft	
f)	Concrete perimeter wall area (e*0.5+1.5*0.5)	3.58 sf	
	Concrete rundown length	4.50 ft	
	Concrete rundown width	3.00 ft	
	Concrete rundown thickness	4.00 in	0.33 ft

		Contributing Impervious Area		
		0.25 ac	**1.0 ac**	**5.0 ac**
g)	WQCV	363 cf	1452 cf	7260 cf
h)	Area	363 sf	1452 sf	7260 sf
i)	Width	13 ft	27 ft	60 ft
j)	Length	28 ft	54 ft	121 ft
k)	# of runs of underdrain (20' spacing)	1	2	3
l)	# of concrete rundowns (10' spacing)	3	6	13

				0.25 Acre Site		**1 Acre Site**		**5 Acre Site**		
Item No.	**Item**	**Unit**	**Unit Price**	**Quantity**	**Total**	**Quantity**	**Total**	**Quantity**	**Total**	**Notes**
1	Excavation and backfill	CY	$5	60	$300	210	$1,050	920	$4,600	e*(i+e)*(j+e)
2	Concrete perimeter walls	CY	$400	11	$4,400	22	$8,800	49	$19,600	f*(2i+2j)
3	Concrete rundowns	CY	$400	0.5	$200	1	$400	2.2	$880	
4	Sand/peat mixture	CY	$40	20	$800	81	$3,240	403	$16,120	h*c
5	Gravel	CY	$40	9	$360	36	$1,440	179	$7,160	h*d
6	4" perforated PVC pipe and fittings (incl. cleanouts)	LF	$20	28	$560	108	$2,160	363	$7,260	j*k
7	Geotextile	SY	$4	112	$448	383	$1,532	1743	$6,972	2*(i+e)*(j+e)
8	Outlet structure - 1.6 and 6.3 cfs capacity	LS	$3,700	1	$3,700	1	$3,700	0	$0	Type C inlet
9	Outlet structure - 28 cfs capacity	LS	$4,300	0	$0	0	$0	1	$4,300	Type D inlet
10	Landscaping	SF	$0.40	363	$145	1452	$581	7260	$2,904	
11	18" RCP	LF	$50	50	$2,500	50	$2,500	0	$0	
12	30" RCP	LF	$75	0	$0	0	$0	50	$3,750	
	SUBTOTAL				$13,413		$25,403		$73,546	
	Mobilization and site prep	7%			$939		$1,778		$5,148	
	TOTAL COST				**$14,352**		**$27,181**		**$78,694**	
	Add impermeable liner	SY	$6	56	$336	192	$1,152	871	$5,226	
	Deduct geotextile	SY	$4	-56	-$224	-192	-$768	-871	-$3,484	
	ADD IMPERMEABLE LINER				$112		$384		$1,742	
	Deduct concrete perimeter walls	CY	$400	-11	-$4,400	-22	-$8,800	-49	-$19,600	
	Deduct concrete rundowns	CY	$400	-0.5	-$200	-1	-$400	-2.2	-$880	
	Add riprap rundowns	CY	$60	2	$120	4	$240	8.8	$528	double width and thickness of concrete
	DEDUCT FOR UNCONSTRAINED CONFIGURATION				-$4,480		-$8,960		-$19,952	
	Unconstrained Configuration Total Cost				**$9,872**		**$18,221**		**$58,742**	

Underground Vault with WQCV Detention

Design Information

Vault height	6.5	ft
Freeboard	1.5	ft
WQCV depth	5	ft
Vault length:width ratio	2	
Concrete wall thickness	0.67	ft
Depth of cover	1	ft
Bedding thickness	1	ft

	Contributing Impervious Area		
	0.25 ac	**1.0 ac**	**2.0 ac**
WQCV	544.8 cf	2178 cf	4356 cf
WQCV Area	109 sf	436 sf	871 sf
Width	7.4 ft	14.8 ft	20.9 ft
WQCV Length	14.8 ft	29.5 ft	41.7 ft
Total length	18.4 ft	33.2 ft	45.4 ft
Total vault area	136 sf	490 sf	948 sf

				0.25 Acre Site		1.0 Acre Site		2.0 Acre Site		
Item No.	**Item**	**Unit**	**Unit Price**	**Quantity**	**Total**	**Quantity**	**Total**	**Quantity**	**Total**	**Notes**
1	Excavation and backfill	CY	$5	50	$248	178	$892	345	$1,726	
2	Structural concrete	CY	$800	18	$14,400	45	$36,000	76	$60,800	includes orifice plate, manhole covers, manhole steps, etc.
3	Bedding material	CY	$40	8	$320	22	$880	41	$1,640	
4	18" RCP	LF	$50	50	$2,500	50	$2,500	0	$0	
5	24" RCP	LF	$55	0	$0	0	$0	50	$2,750	

SUBTOTAL		$17,468	$40,272	$66,916
Mobilization and site prep	7%	$1,223	$2,819	$4,684
TOTAL COST		**$18,690**	**$43,091**	**$71,600**

Underground Sand Filter Vault

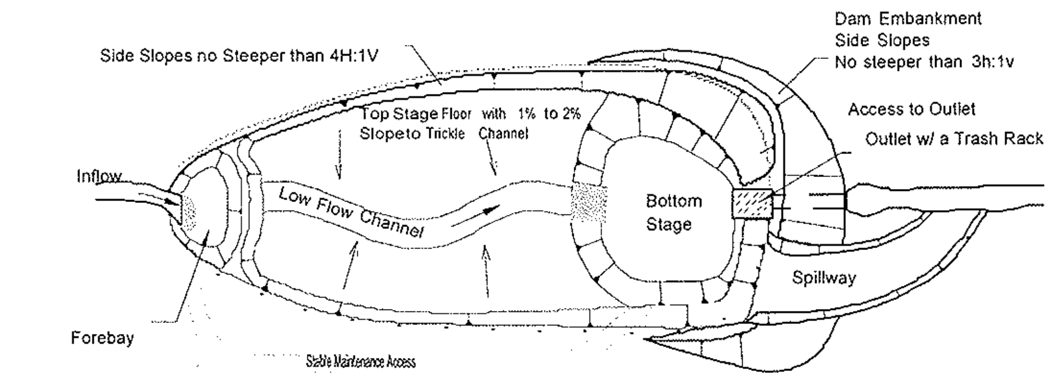
Design Information

Vault height over sand filter	6.5	ft
WQCV depth	3	ft
Sand filter length:width ratio	2	
Concrete wall thickness	0.67	ft
Sand layer thickness	1.5	ft
Gravel layer thickness	0.67	ft
Total vault height	8.67	ft
Upstream weir wall height	3.17	ft
Downstream weir wall height	5.17	ft
Depth of cover	1	ft
Bedding thickness	1	ft

	Contributing Impervious Area					
	0.25 ac		**1.0 ac**		**2.0 ac**	
WQCV	454	cf	1815	cf	3630	cf
WQCV Area	151	sf	605	sf	1210	sf
Width	8.7	ft	17.4	ft	24.6	ft
Sand filter length	17.4	ft	34.8	ft	49.2	ft
Total length	24.7	ft	42.1	ft	56.5	ft
Total vault area	215	sf	733	sf	1390	sf

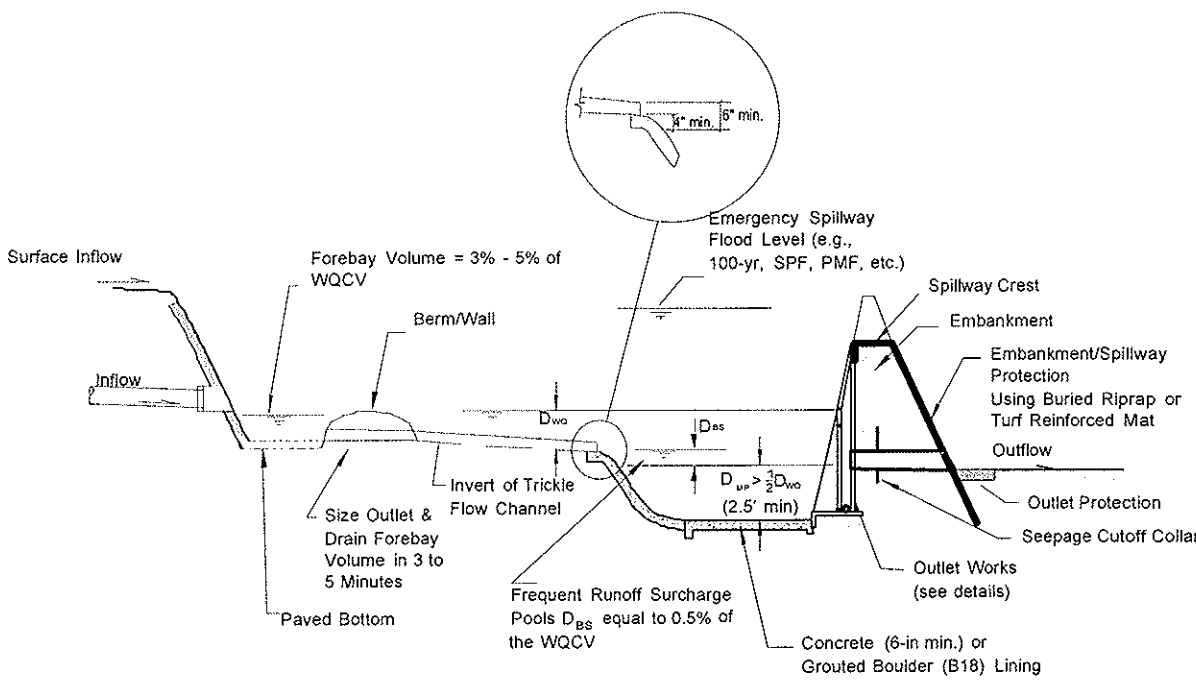
				0.25 Acre Site		**1.0 Acre Site**		**2.0 Acre Site**		
Item No.	**Item**	**Unit**	**Unit Price**	**Quantity**	**Total**	**Quantity**	**Total**	**Quantity**	**Total**	**Notes**
1	Excavation and backfill	CY	$5	96	$480	326	$1,630	619	$3,095	
2	Structural concrete	CY	$800	29	$23,200	70	$56,000	114	$91,200	includes orifice plate, manhole covers, manhole steps, etc.
3	Sand	CY	$40	9	$360	34	$1,360	68	$2,720	
4	Gravel	CY	$40	4	$160	15	$600	30	$1,200	
5	Underdrain (4" Schedule 40 perforated PVC)	LF	$20	17	$348	35	$696	49	$984	
6	Bedding material	CY	$40	11	$440	32	$1,280	58	$2,320	
7	18" RCP	LF	$50	50	$2,500	50	$2,500	0	$0	
8	24" RCP	LF	$55	0	$0	0	$0	50	$2,750	

SUBTOTAL		$27,488	$64,066	$104,269
Mobilization and site prep	7%	$1,924	$4,485	$7,299
TOTAL COST		**$29,412**	**$68,550**	**$111,568**



Note: Provide energy dissipating inlet such as impact basin for pipes and GSB drop or baffle chute for channel/swales.

PLAN
Not to scale



PROFILE
Not to scale

Figure EDB-1 –Extended Detention Basin (EDB) Plan and Sections

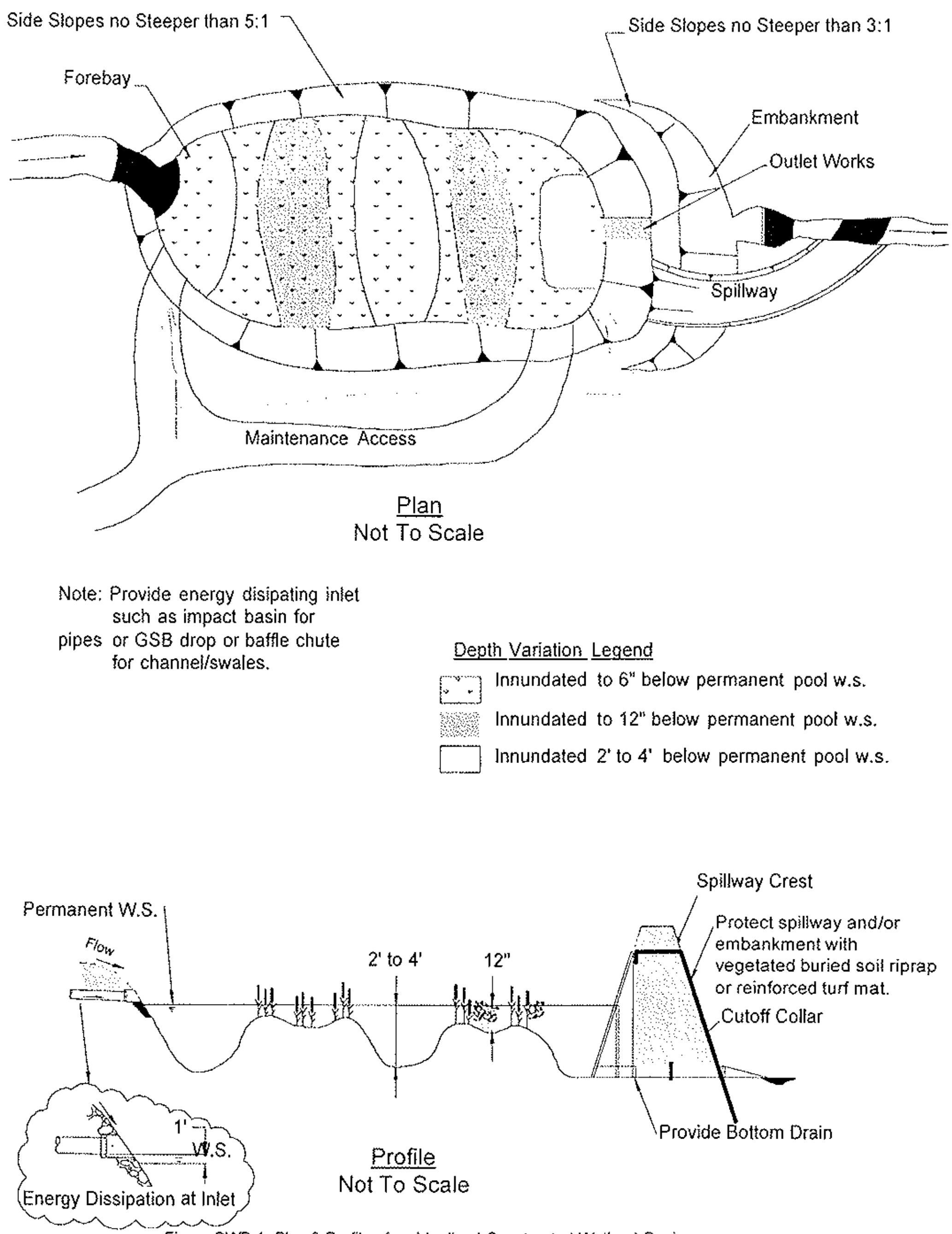


Figure CWB-1 Plan & Profile of an Idealized Constructed Wetland Basin

Figure CWB-1 – Constructed Wetland Basin – Plan and Cross-Section

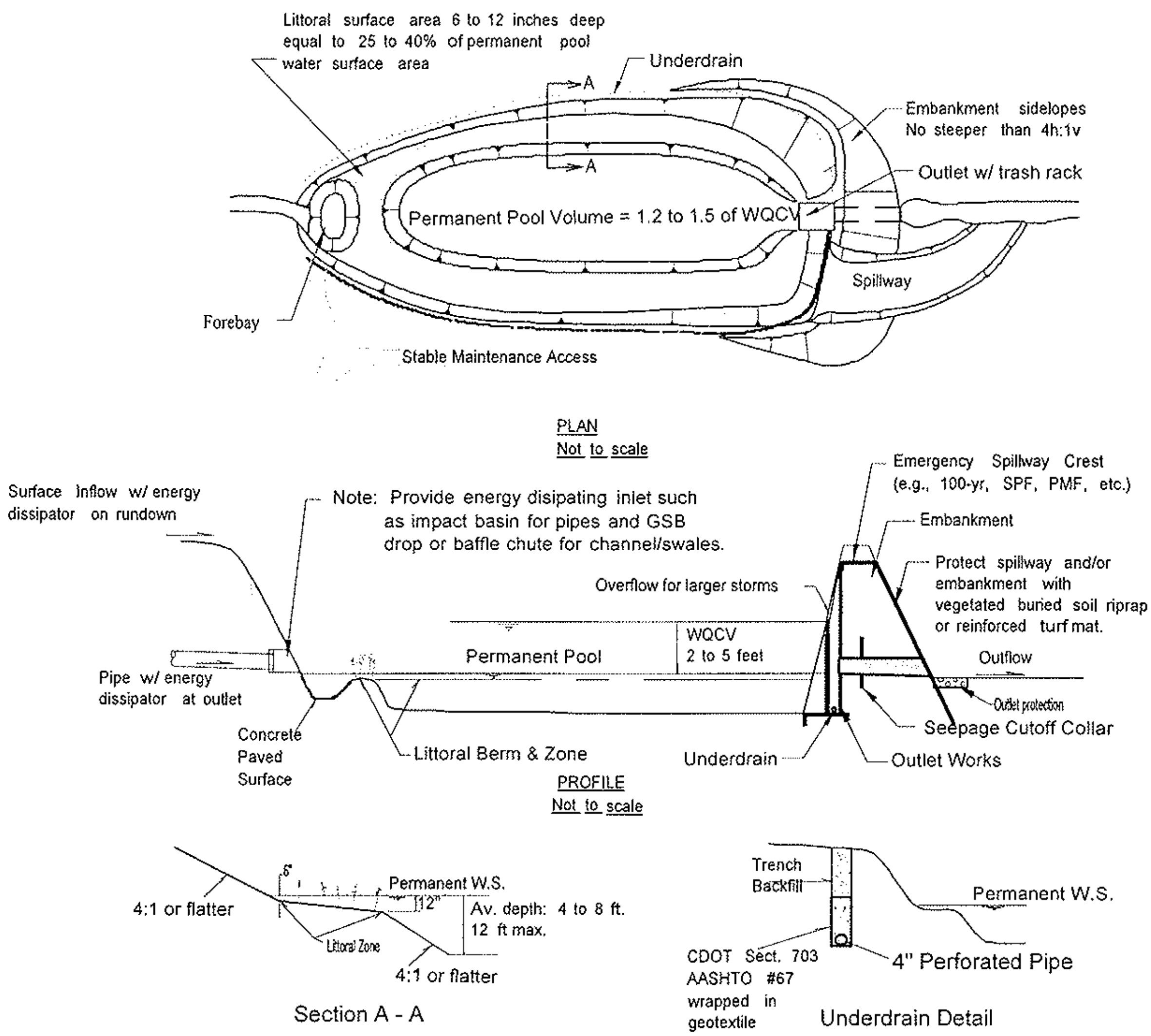


Figure RP-1 –Retention Pond (RP) – Plan and Sections

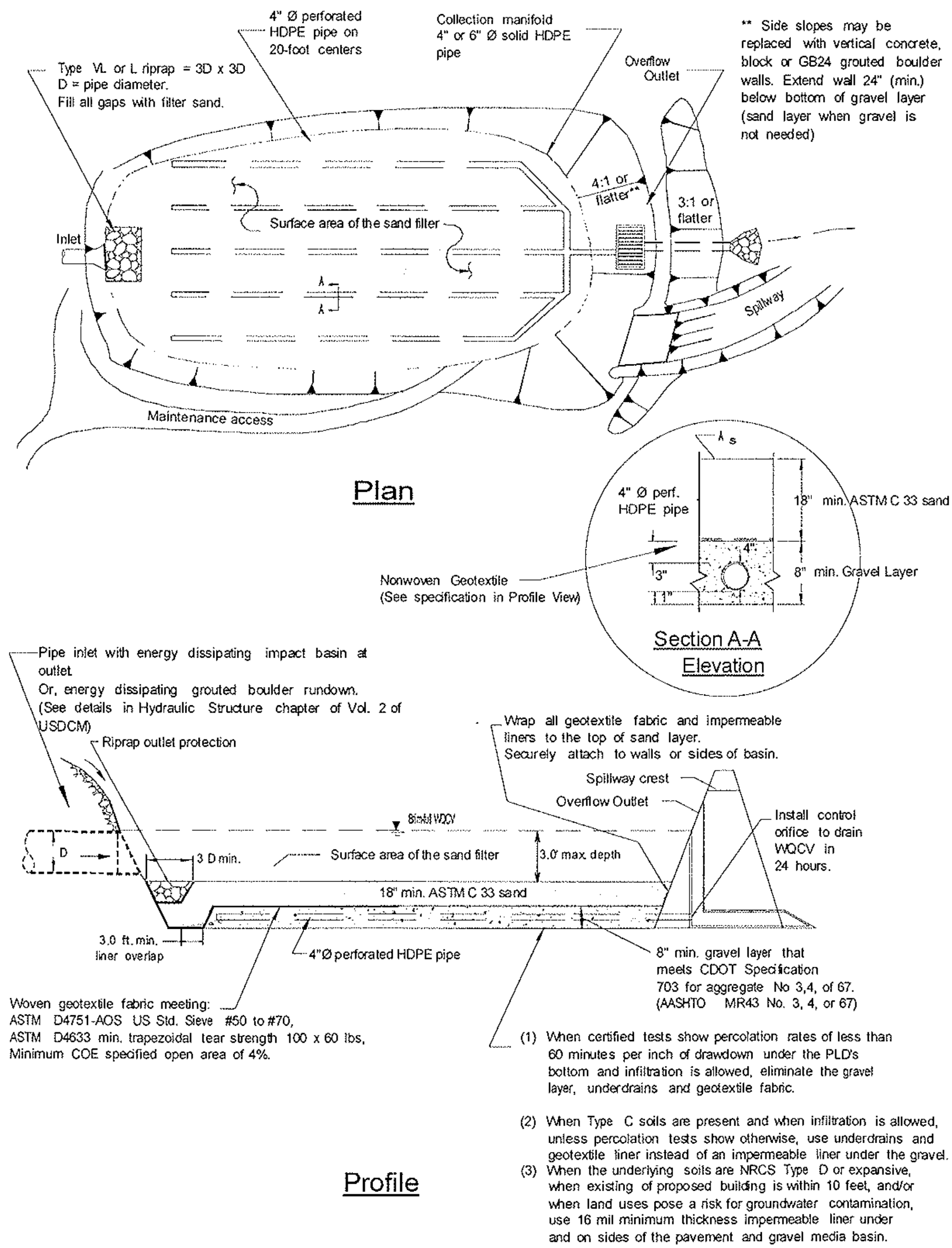


Figure SFB-1 –Sand Filter Basin (SFB) – Plan and Sections

5.7 Design Example

Design forms that provide a means of documenting the design procedure are included in the DESIGN FORMS chapter. A completed form follows the figures and serves as a design example.

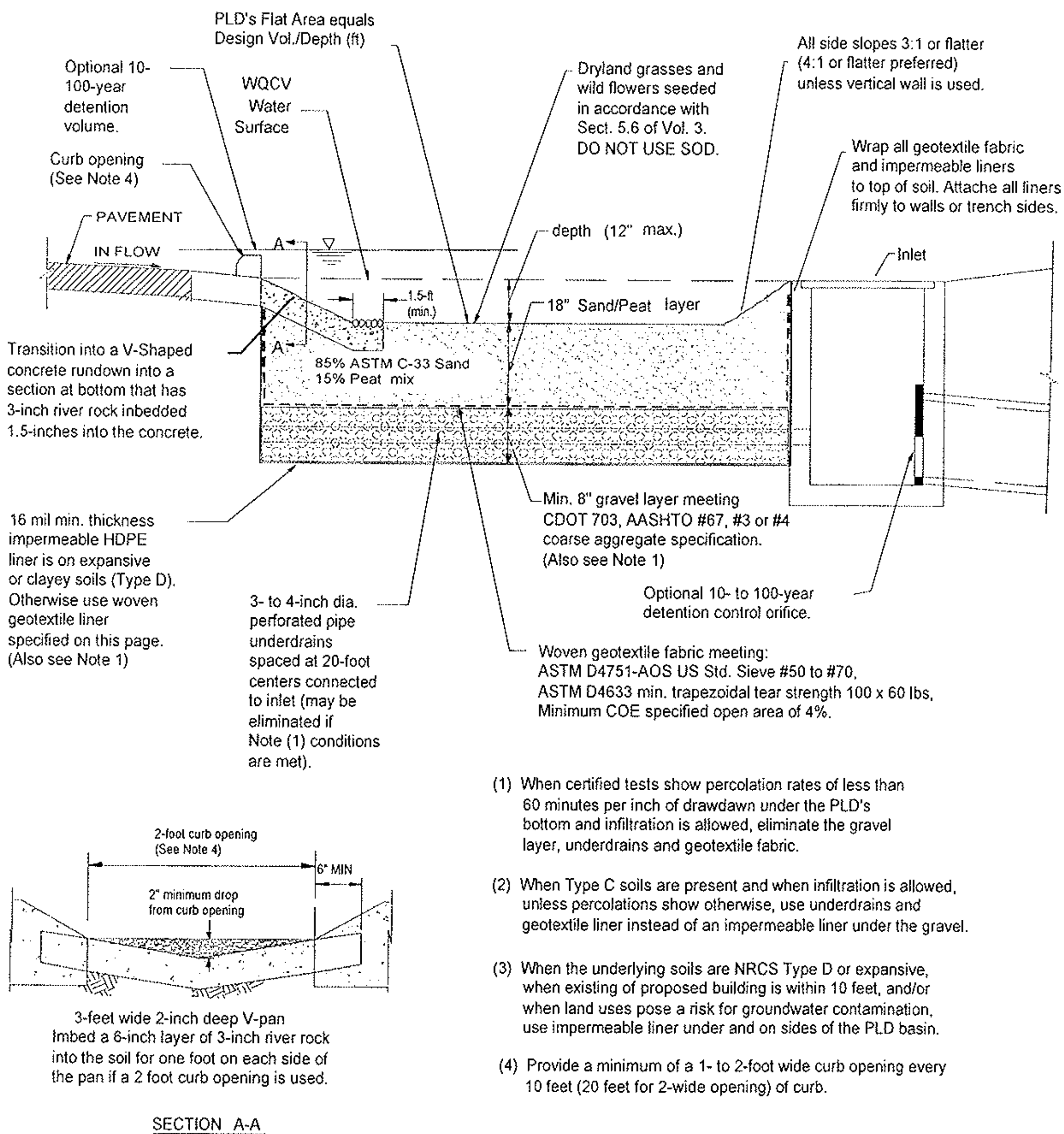
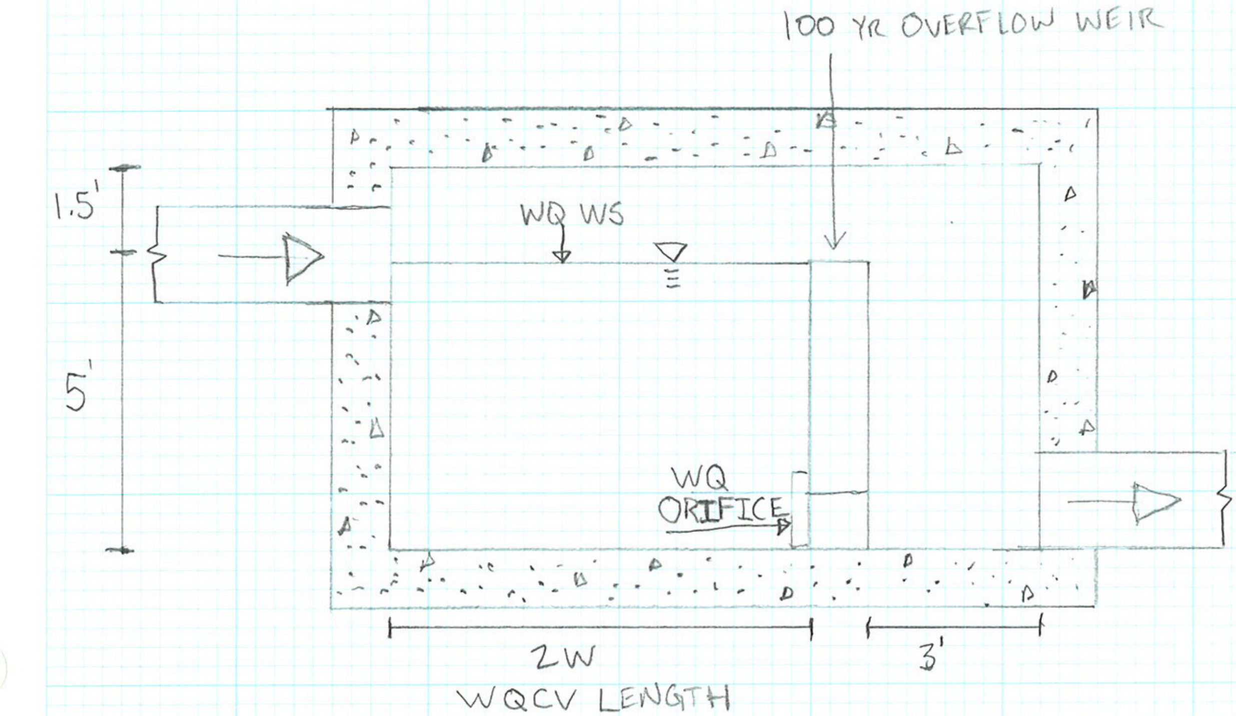


Figure PLD-1 – Porous Landscape Detention – Typical Sections

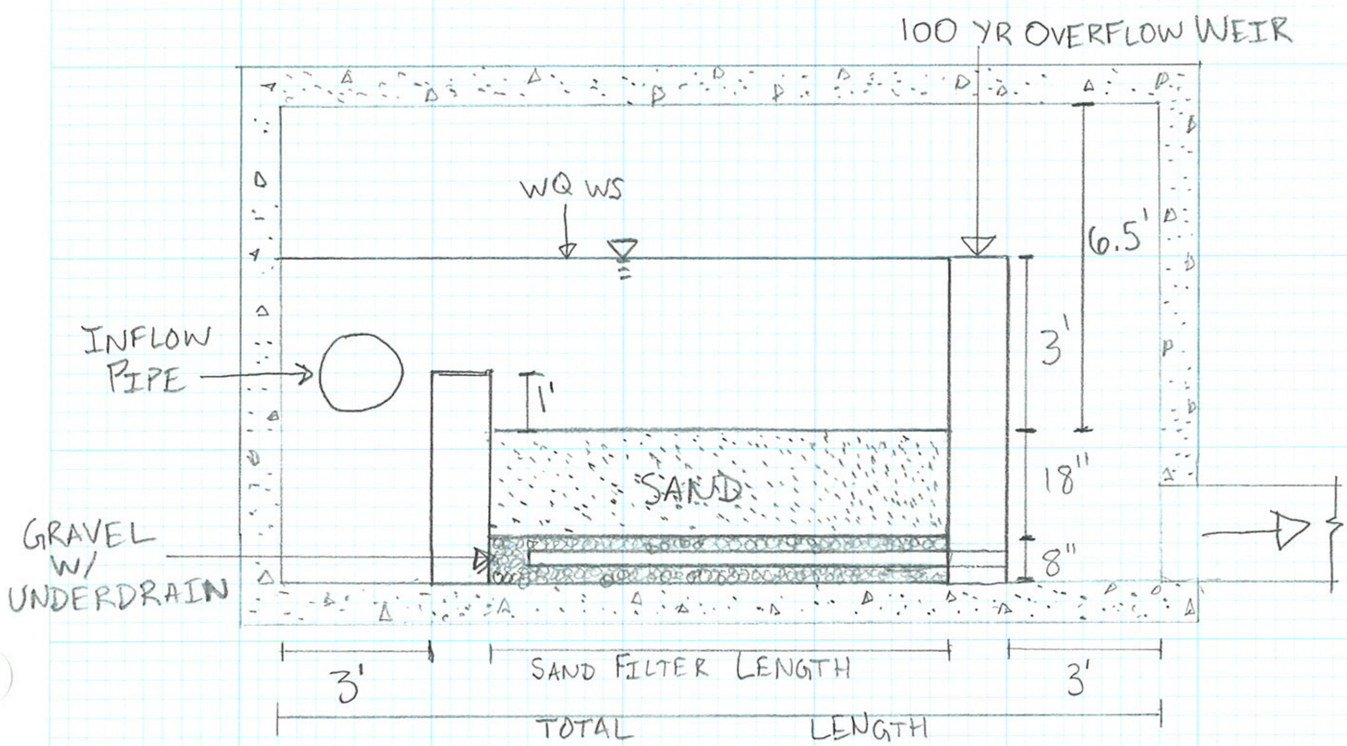
Muller Engineering Company, Inc.
DESIGN NOTES AND COMPUTATIONS

Subject: ______ Sheet No. ______ Of ______

Prepared By: ______ Checked By: ______ Date: ______ Project No.: ______



UNDERGROUND WQCV VAULT



UNDERGROUND SAND FILTER VAULT

Appendix D

Cost Spreadsheets and Figures for Porous Pavement BMPs

Modular Block Pavement (MBP)

Design Information

a	Void area	40%		
b	Design area ratio (impervious:pervious area)	2		
c	Modular block height	3.15 in	0.26 ft	8 cm
d	Leveling course thickness	2 in	0.17 ft	
e	Base course thickness	8 in	0.67 ft	
f	Underdrain layer thickness	6 in	0.5 ft	
g	Perimeter wall cutoff depth	12 in	1 ft	
h	Perimeter wall thickness	6 in	0.5 ft	
i	Total wall height	31.15 in	2.60 ft	
j	Slope	0.02 ft/ft		
k	Lmax between cells	20.00		
l	Area of 4" pipe	12.57 in^2	0.087 ft^2	
m	Area of Single Paver Block		2.5 ft^2	

		Contributing Impervious Area (ac)		
		0.25	**1.0**	**2.0**
	Pavement area	0.083 ac	0.333 ac	0.667 ac
A	Pavement area	3630 sf	14520 sf	29040 sf
L	Pavement length	20 ft	40 ft	40 ft
W	Pavement width	181.5 ft	363 ft	726 ft
n	Number of cells	1	2	2
o	Length of each cell	20	20	20

sand=(A*d+c*A*a)/27
geotextile = n*[W*(4c+4d+2e+2f+2o)]/9
UnderDrain=Width* Cells
Concrete Walls= (2*L+2*W)*h*i/27
Base layer=(e*A+n*(f^2-l)*W)/27
Impermeable barriers=(n-1)*(3*f+e)*W/9
Excavation Calculations=Area*(c+d+e)/27+(5*5*5)*n/27+Item no. 9
4" PVC Pipe =5*n+(n-1)*20+50

				0.25 Acre Site		1.0 Acre Site		2.0 Acre Site	
Item No.	**Item**	**Unit**	**Unit Price**	**Quantity**	**Total**	**Quantity**	**Total**	**Quantity**	**Total**
1	Excavation and backfill	CY	$5	171	$857	637	$3,187	1261	$6,307
2	Paver Blocks - includes leveling course and in-fill material	SF	$4	3630	$14,520	14520	$58,080	29040	$116,160
3	Base course (AASHTO No. 3 coarse aggregate)	CY	$40	91	$3,629	363	$14,516	726	$29,032
4	Geotextile	SY	$4	888	$3,553	3,553	$14,213	7,107	$28,427
5	Underdrain (4" Schedule 40 perforated PVC)	LF	$12	182	$2,178	726	$8,712	1,452	$17,424
6	Concrete perimeter walls	CY	$400	19	$7,749	39	$15,498	74	$29,458
7	Impermeable flow barriers	SY	$6	0	$0	87	$524	175	$1,049
8	4" PVC pipe	LF	$12	55	$660	80	$960	80	$960
9	Utility vault (incl. riser pipes, orifice, etc.)	EA	$3,800	1	$3,800	2	$7,600	2	$7,600
	SUBTOTAL				$36,946		$123,290		$236,416
	Mobilization and site prep	7%			$2,586		$8,630		$16,549
	TOTAL COST				**$39,532**		**$131,920**		**$252,965**
	Add impermeable liner	SY	$6	468	$2,806	1,871	$11,225	3,742	$22,449
	Deduct geotextile	SY	$4	-468	-$1,871	-1,871	-$7,483	-3,742	-$14,966
	ADD IMPERMEABLE LINER				$935		$3,742		$7,483

`

Cobblestone Block Pavement (CBP)

Design Information

a	Void area	8%					
b	Design area ratio (impervious:pervious area)	2					
c	Cobblestone block height	3.15	in	0.262	ft	8	cm
d	Leveling course thickness	2	in	0.167	ft		
e	Base course thickness	7	in	0.583	ft		
f	Sand layer thickness (including cushion layer)	7	in	0.583	ft		
g	Underdrain layer thickness	6	in	0.5	ft		
h	Perimeter wall cutoff depth	12	in	1	ft		
i	Perimeter wall thickness	6	in	0.5	ft		
j	Total wall height	37.15	in	3.10	ft		
k	Slope	0.02	ft/ft				
l	Lmax between cells	20.00					
m	Area of 4" pipe	12.57	in^2	0.087	ft^2		
p	Length of geotextile under ASTM C-33 Sand	24	in	2			

		Contributing Impervious Area (ac)					
		0.25		**1.0**		**2.0**	
	Pavement area	0.083	ac	0.333	ac	0.667	ac
A	Pavement area	3630	sf	14520	sf	29040	sf
L	Pavement length	20	ft	40	ft	40	ft
W	Pavement width	181.5	ft	363	ft	726	ft
n	Number of cells	1		2		2	
o	Length of each cell	20		20		20	

in-fill & leveling=(area*e+c*area*a)/27
Base layer=[(e*A+n*(f*f-m)*W)]/27
Sand=(A*f)/27
geotextile = n*[W*(7c+7d+5e+3f+2g+3o+p)]/9
UnderDrain=W*n+5*n+(n-1)*20+50
Concrete Walls= (2*L+2*W)*i*j/27
Impermeable barriers=(n-1)*(3*g+f+e+f)*W/9
Excavation Calculations=Area*(c+d+e+f)/27+(5*5*5)*n/27+Item no. 1(

				0.25 Acre Site		1.0 Acre Site		2.0 Acre Site	
Item No.	**Item**	**Unit**	**Unit Price**	**Quantity**	**Total**	**Quantity**	**Total**	**Quantity**	**Total**
1	Excavation and backfill	CY	$5	242	$1,211	914	$4,568	1813	$9,067
2	Paver Block - includes leveling course and in-fill material	SF	$5.50	3,630	$19,965	14,520	$79,860	29,040	$159,720
3	Base course (AASHTO No. 67 coarse aggregate)	CY	$40	80	$3,181	318	$12,723	636	$25,446
4	Sand (ASTM C-33)	CY	$40	78	$3,137	314	$12,548	627	$25,096
5	Geotextile	SY	$4	1,425	$5,701	5,701	$22,803	11,402	$45,606
6	Underdrain (4" Schedule 40 perforated PVC)	LF	$12	182	$2,178	726	$8,712	1,452	$17,424
7	Concrete perimeter walls	CY	$400	23	$9,242	46	$18,483	88	$35,132
8	Impermeable flow barriers	SY	$6	0	$0	94	$565	188	$1,129
9	4" PVC pipe	LF	$12	55	$660	80	$960	80	$960
10	Utility vault (incl. riser pipes, orifice, etc.)	EA	$3,800	1	$3,800	2	$7,600	2	$7,600
	SUBTOTAL				$49,075		$168,822		$327,181
	Mobilization and site prep	7%			$3,435		$11,818		$22,903
	TOTAL COST				**$52,510**		**$180,640**		**$350,084**
	Add impermeable liner	SY	$6	488	$2,927	1,951	$11,709	3,903	$23,417
	Deduct geotextile	SY	$4	-488	-$1,951	-1,951	-$7,806	-3,903	-$15,612
	ADD IMPERMEABLE LINER				$976		$3,903		$7,806

Reinforced Grass Pavement (RGP)

Design Information

a	Ring Void Percentage	92.00%			
b	Design area ratio (impervious:pervious area)	2			
c	Leveling course thickness (sand)	1	in	0.083	ft
d	Base course thickness (sandy gravel)	10	in	0.833	ft
e	Ring Height	1	in	0.083	ft

	Contributing Impervious Area (ac)		
	0.25	**1.0**	**2.0**
Pavement area	0.083 ac	0.333 ac	0.667 ac
Pavement area	3630 sf	14520 sf	29040 sf
Pavement length	20 ft	40 ft	40 ft
Pavement width	181.5 ft	363 ft	726 ft

sand=((area*c)+(area*e*a))/27
Base Course=(area*d)/27
geotextile=((Length+2(c+d))*Width)/9
Excavation Calculation=Area*(c+d)/27

				0.25 Acre Site		**1.0 Acre Site**		**2.0 Acre Site**	
Item No.	**Item**	**Unit**	**Unit Price**	**Quantity**	**Total**	**Quantity**	**Total**	**Quantity**	**Total**
1	Excavation and backfill	CY	$5	123	$616	493	$2,465	986	$4,930
2	Sand (ASTM C-33)	CY	$40	22	$860	86	$3,442	172	$6,884
4	Base course (60% AASHTO No. 67 Aggregate, 40% ASTM C-33 Sand)	CY	$40	112	$4,481	448	$17,926	896	$35,852
3	Geotextile	SY	$4	440	$1,761	1,687	$6,749	3,375	$13,498
5	GrassPave	SF	$4	3630	$14,520	14520	$58,080	29040	$116,160
6	Sod	SF	$0.60	3630	$2,178	14520	$8,712	29040	$17,424
	SUBTOTAL				$24,417		$97,374		$194,747
	Mobilization and site prep	7%			$1,709		$6,816		$13,632
	TOTAL COST				**$26,127**		**$104,190**		**$208,380**
	Add impermeable liner	SY	$6	440	$2,642	1,687	$10,124	3,375	$20,247
	Deduct geotextile	SY	$4	-440	-$1,761	-1,687	-$6,749	-3,375	-$13,498
	ADD IMPERMEABLE LINER				$881		$3,375		$6,749

Porous Concrete Pavement (PCP)

Design Information

a	Design area ratio (impervious:pervious area)	2			
b	Base course thickness	8	in	0.666667	ft
c	Sand layer thickness (including cushion)	7	in	0.583333	ft
d	Underdrain layer thickness	6	in	0.5	ft
e	Slope	0.02	ft/ft		
f	Lmax between cells	20.00	ft		
g	Area of 4" pipe	12.57	in^2	0.087266	ft^2
h	Length of geotextile under ASTM C-33 Sand	24.00	in	2	ft
i	Concrete thickness	5.00	in	0.416667	ft

		Contributing Impervious Area (ac)					
		0.25		**1.0**		**2.0**	
	Pavement area	0.083	ac	0.333	ac	0.667	ac
A	Pavement area	3630	sf	14520	sf	29040	sf
L	Pavement length	20	ft	40	ft	40	ft
W	Pavement width	181.5	ft	363	ft	726	ft
n	Number of cells	1		2		2	
o	Length of each cell	20		20		20	

Base course=(A*b+(d^2-g)*n*W)/27
Sand=A*c/27
geotextile =n*W*(4*b+2*c+2*o)/9
UnderDrain=W*n+5*n+(n-1)*20+50
Impermeable flow barrier=(n*W*(h+2*d+b+c))/9
Excavation Calculations=Area*(i+b+c)/27+(5*5*5)*n/27

				0.25 Acre Site		**1.0 Acre Site**		**2.0 Acre Site**		
Item No.	**Item**	**Unit**	**Unit Price**	**Quantity**	**Total**	**Quantity**	**Total**	**Quantity**	**Total**	
1	Excavation and backfill	CY	$5	229	$1,144	906	$4,528	1802	$9,009	
2	Porous concrete	CY	$350	56	$19,606	224	$78,426	448	$156,852	unit cost 130% std concrete paving
3	Base course (AASHTO No. 3 coarse aggregate)	CY	$40	91	$3,629	363	$14,516	726	$29,032	
4	Sand (ASTM C-33)	CY	$40	78	$3,137	314	$12,548	627	$25,096	
5	Geotextile	SY	$4	884	$3,536	3,536	$14,144	7,072	$28,287	
6	Underdrain (4" Schedule 40 perforated PVC)	LF	$12	182	$2,178	726	$8,712	1,452	$17,424	
7	Impermeable flow barrier	SY	$6	86	$514	343	$2,057	686	$4,114	
8	4" PVC pipe	LF	$12	55	$660	80	$960	80	$960	
9	Utility vault (incl. riser pipes, orifice, etc.)	EA	$3,800	1	$3,800	2	$7,600	2	$7,600	
	SUBTOTAL				$38,204		$143,490		$278,374	
	Mobilization and site prep	7%			$2,674		$10,044		$19,486	
	TOTAL COST				**$40,878**		**$153,534**		**$297,860**	
	Add impermeable liner	SY	$6	454	$2,723	1,815	$10,890	3,630	$21,780	
	Deduct geotextile	SY	$4	-454	-$1,815	-1,815	-$7,260	-3,630	-$14,520	
	ADD IMPERMEABLE LINER				$908		$3,630		$7,260	

Porous Gravel Pavement (PGP)

Design Information

a	Design area ratio (impervious:pervious area)	2			
b	Base course thickness	12	in	1	ft
c	Sand layer thickness (including cushion)	7	in	0.583333	ft
d	Underdrain layer thickness	6	in	0.5	ft
e	Slope	0.02	ft/ft		
f	Lmax between cells	20.00	ft		
g	Area of 4" pipe	12.57	in^2	0.087266	ft^2
h	Length of geotextile under ASTM C-33 Sand	24.00	in	2	ft

		Contributing Impervious Area (ac)					
		0.25		**1.0**		**2.0**	
	Pavement area	0.083	ac	0.333	ac	0.667	ac
A	Pavement area	3630	sf	14520	sf	29040	sf
L	Pavement length	20	ft	40	ft	40	ft
W	Pavement width	181.5	ft	363	ft	726	ft
n	Number of cells	1		2		2	
o	Length of each cell	20		20		20	

Base course=(A*b+(d^2-g)*n*W)/27
Sand=A*c/27
geotextile =n*W*(4*b+2*c+2*o)/9
UnderDrain=W*n+5*n+(n-1)*20+50
Impermeable flow barrier=(n*W*(h+2*d+b+c))/9
Excavation Calculations=Area*(b+c)/27+(5*5*5)*n/27

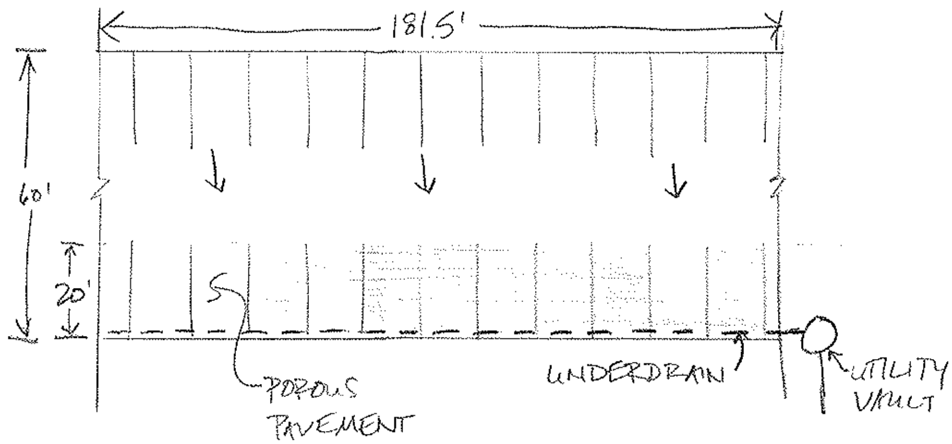
				0.25 Acre Site		1.0 Acre Site		2.0 Acre Site	
Item No.	**Item**	**Unit**	**Unit Price**	**Quantity**	**Total**	**Quantity**	**Total**	**Quantity**	**Total**
1	Excavation and backfill	CY	$5	218	$1,088	861	$4,304	1712	$8,561
2	Base course (AASHTO No. 3 coarse aggregate)	CY	$40	136	$5,422	542	$21,686	1084	$43,372
3	Sand (ASTM C-33)	CY	$40	78	$3,137	314	$12,548	627	$25,096
4	Geotextile	SY	$4	911	$3,643	3,643	$14,574	7,287	$29,148
5	Underdrain (4" Schedule 40 perforated PVC)	LF	$12	182	$2,178	726	$8,712	1,452	$17,424
6	Impermeable flow barrier	SY	$6	92	$555	370	$2,218	739	$4,437
7	4" PVC pipe	LF	$12	55	$660	80	$960	80	$960
8	Utility vault (incl. riser pipes, orifice, etc.)	EA	$3,800	1	$3,800	2	$7,600	2	$7,600
	SUBTOTAL				$20,482		$72,602		$136,598
	Mobilization and site prep	7%			$1,434		$5,082		$9,562
	TOTAL COST				**$21,916**		**$77,684**		**$146,160**
	Add impermeable liner	SY	$6	467	$2,803	1,869	$11,213	3,738	$22,425
	Deduct geotextile	SY	$3	-467	-$1,402	-1,869	-$5,606	-3,738	-$11,213
	ADD IMPERMEABLE LINER				$1,402		$5,606		$11,213

Muller Engineering Company, Inc.
DESIGN NOTES AND COMPUTATIONS

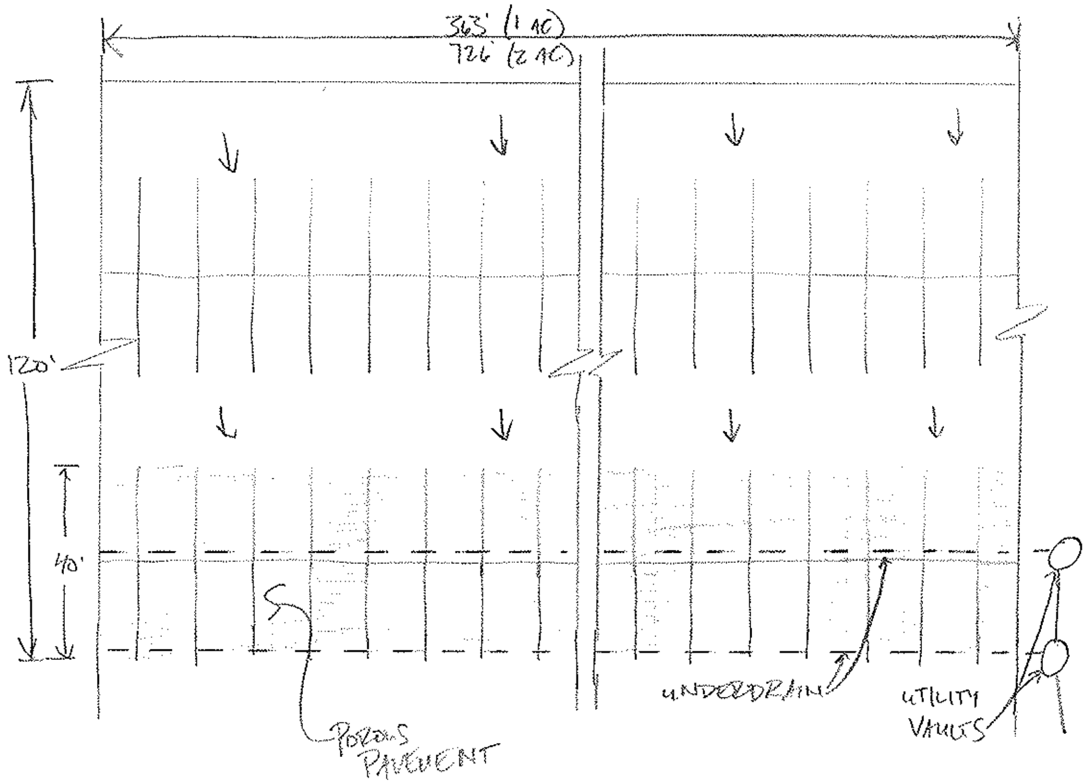
Subject: Porous Pavement Layout Sheet No. ______ Of ______

Prepared By: MDC Checked By: ______ Date: ______ Project No.: ______

0.25 AC SITE



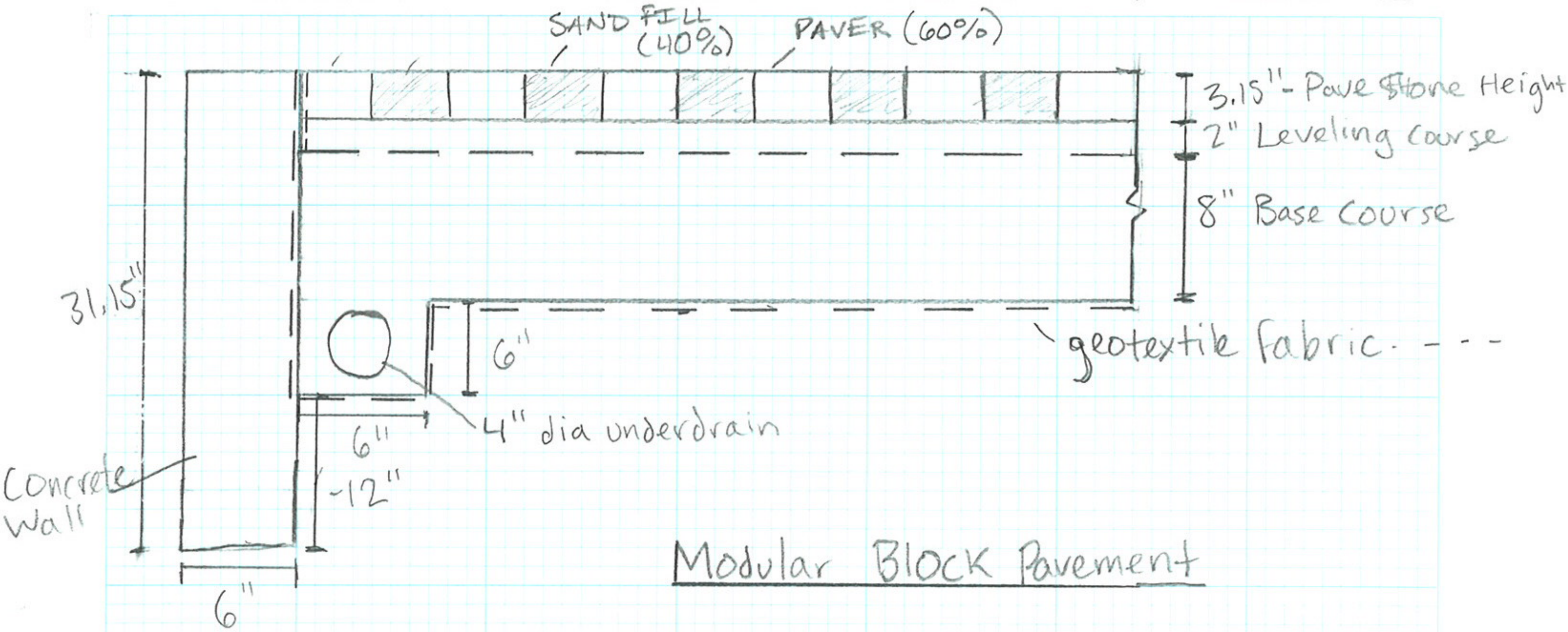
1.0 AC SITE
2.0 AC SITE



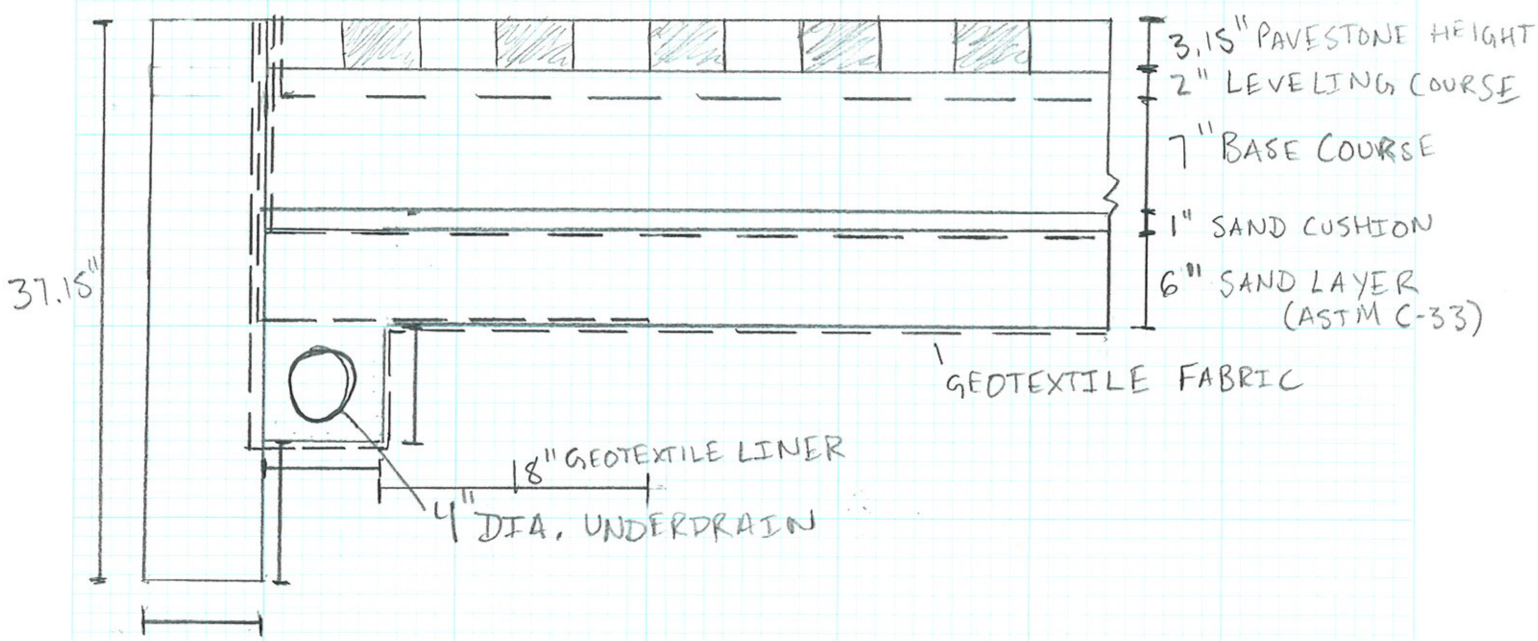
Muller Engineering Company, Inc.
DESIGN NOTES AND COMPUTATIONS

Subject: ____________ Sheet No. ______ Of ______

Prepared By: ________ Checked By: ________ Date: ________ Project No.: ________



Modular Block Pavement

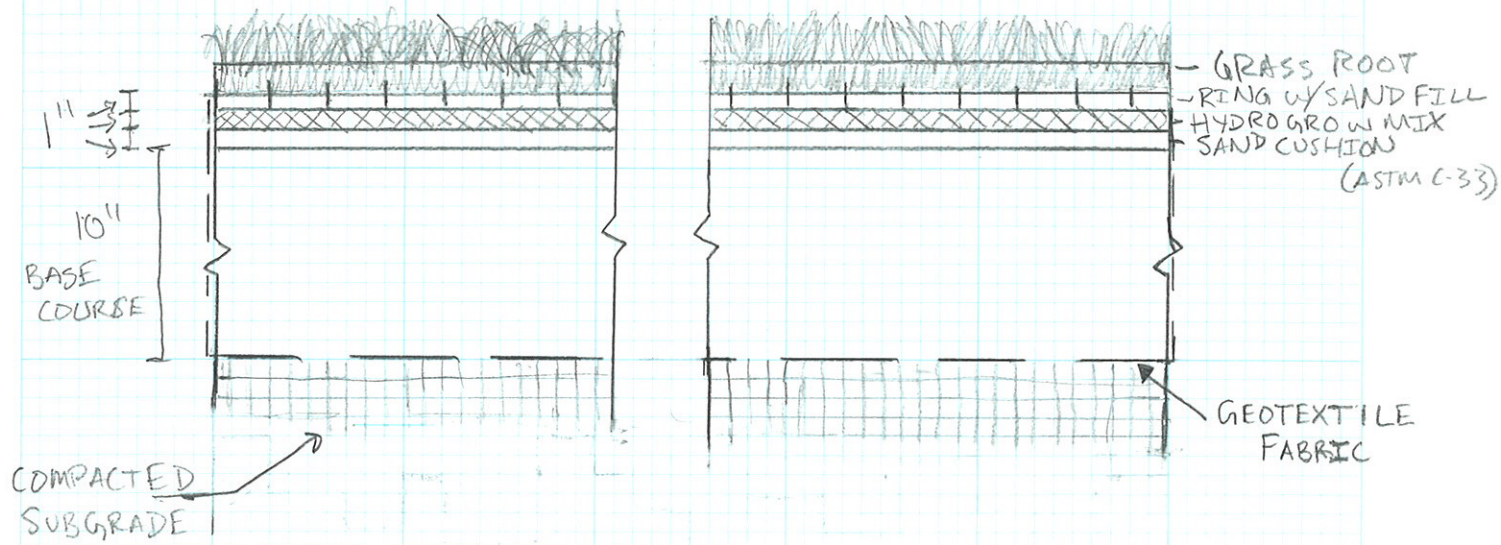


COBBLESTONE BLOCK PAVEMENT

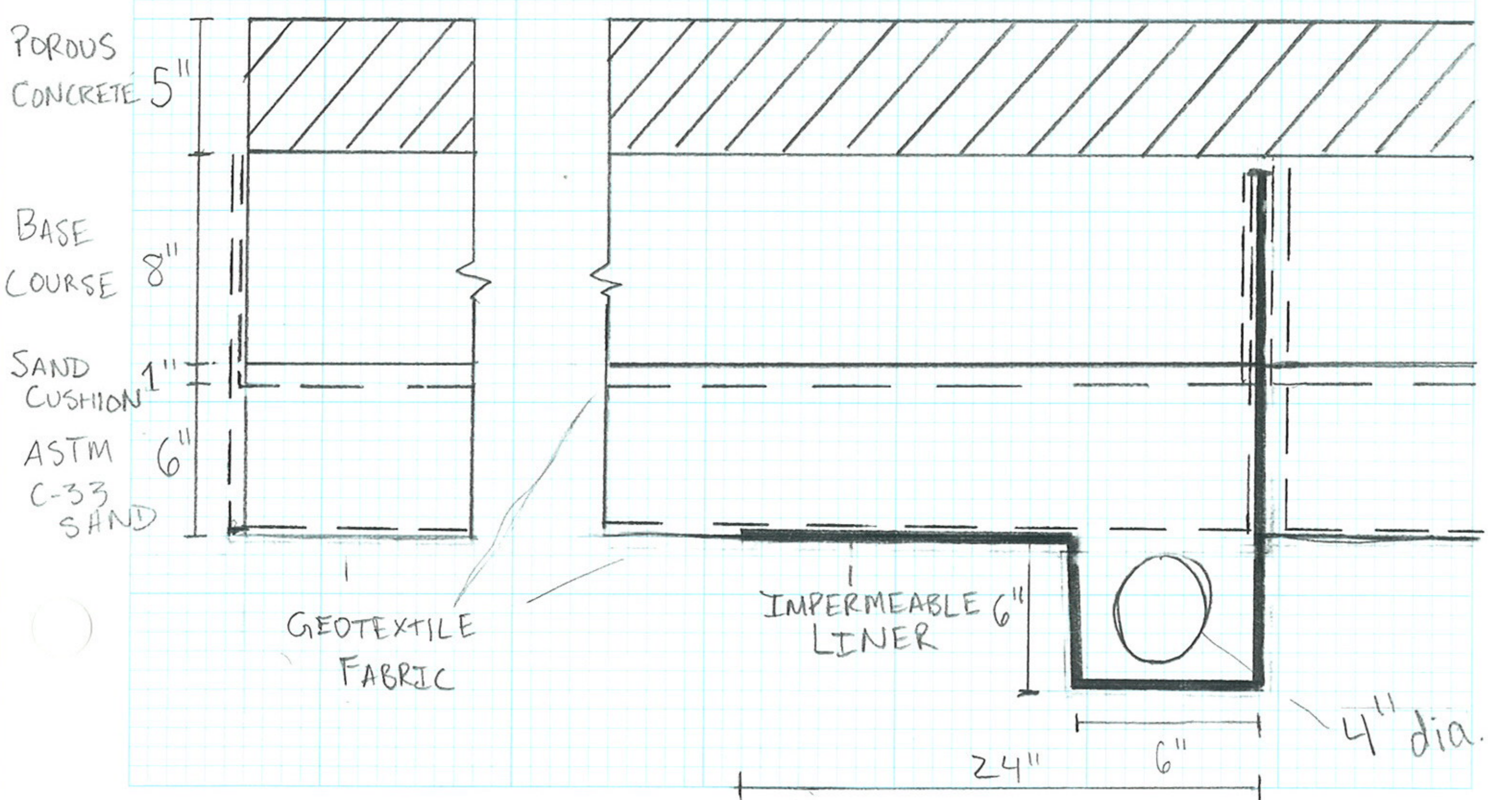
Muller Engineering Company, Inc.
DESIGN NOTES AND COMPUTATIONS

Subject: ______ Sheet No. ____ Of ____

Prepared By: ______ Checked By: ______ Date: ______ Project No.: ______



REINFORCED GRASS PAVEMENT

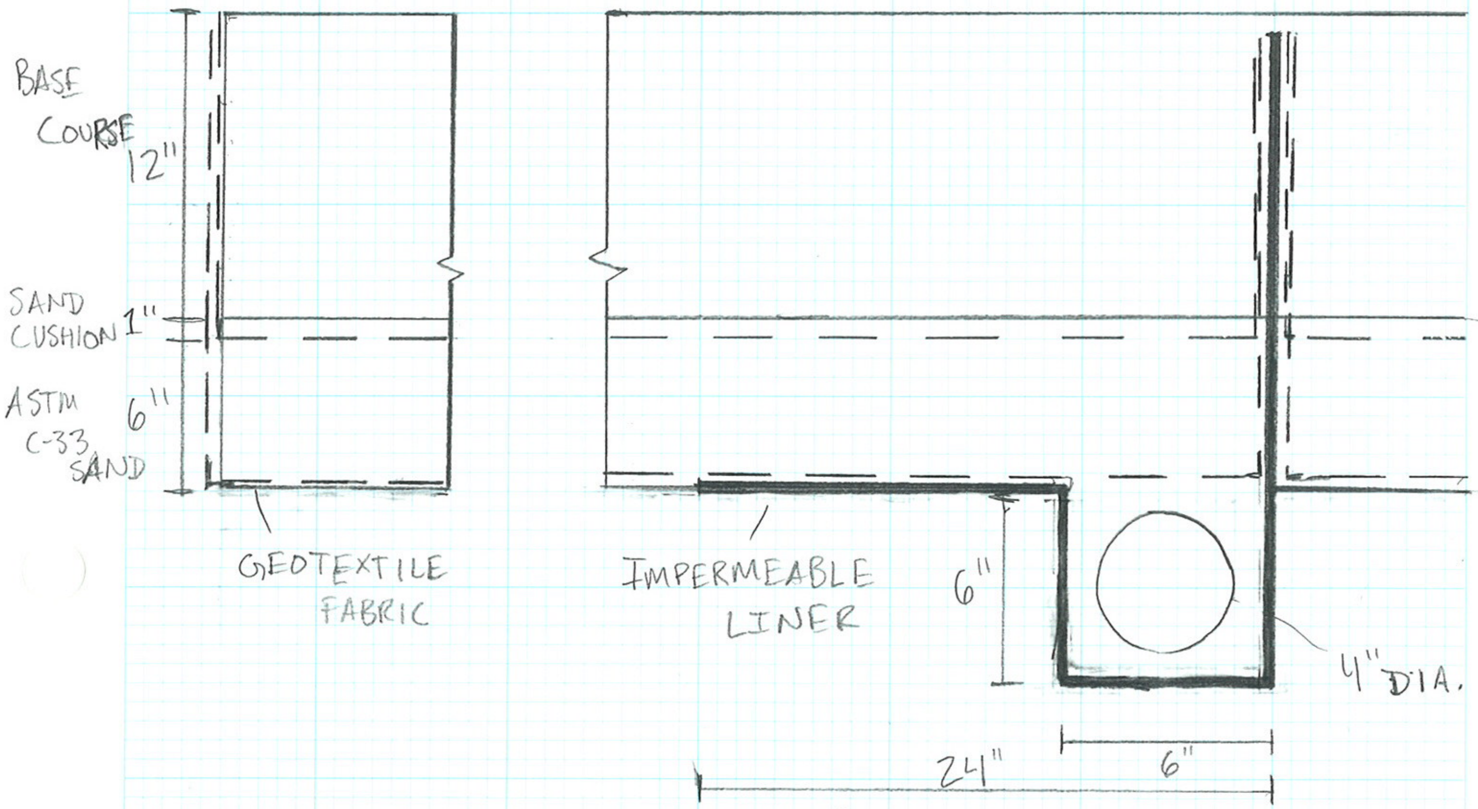


POROUS CONCRETE PAVEMENT

Muller Engineering Company, Inc.
DESIGN NOTES AND COMPUTATIONS

Subject: ______ Sheet No. ______ Of ______

Prepared By: ______ Checked By: ______ Date: ______ Project No.: ______



POROUS GRAVEL PAVEMENT

Appendix E

Summary of Types, Sizing, and Cost Information for Proprietary BMPs

Type of Device	Manufacturer	Information	0.25 acre					1 acre					2 acre				
Hydrodynamic Separators			Model Number	Volume of Model (cf)	% Of WQCV (w/ Sediment Sto.	Cost	Installed Cost	Model Number	Volume of Model	% Of WQCV (w/ Sediment Sto.	Cost	Installed Cost	Model Number	Volume of Model	% Of WQCV (w/ Sediment Sto.	Cost	Installed Cost
Vortechs	CONTECH Stormwater Solutions	Hydrodynamic Separator with swirl chamber, baffle wall.	V2000	120	22.0	$16,500	$24,750	V 5000	273	12.5	$24,600	$36,900.0	V 11000	480	11.0	$41,000	$61,500
Stormceptor STC	Imbrium	Hydrodynamic Separator, different types including submerged, in-line, series, and inlet version. Was informed that prices were very close to the OSR model (see Oil/Grease Separators)	STC 450i	60.15	11.0	$8,000	$12,000	STC 900	120	5.5	$11,000	$16,500.0	STC 2400	321	7.4	$21,000	$31,500
Contech CDS	CONTECH Stormwater Solutions	Hydrodynamic Separator	CDS 2015	92	16.8	$7,500	$11,250	CDS 2020	103	4.7	$13,000	$19,500	CDS 3020	167	3.8	$23,500	$35,250
ecoStorm	WaterTectonics	Hydrodynamic Separator, price includes shipping	Model 1	141	26.0	$16,700	$25,050	Model 2	251	11.5	$32,400	$48,600	Model 3	393	9.0	$51,100	$76,650
						Average:	**$18,263**				**Average:**	**$30,375**				**Average:**	**$51,225**
Oil/Grease/Sediment Separator			Model Number			Cost	Installed Cost	Model Number			Cost	Installed Cost	Model Number			Cost	Installed Cost
Stormceptor OSR	Imbrium	Oil and Grease Separator, Fiberglass Construction Available	OSR 065			$7,400	$11,100	OSR 140			$10,700	$16,050	OSR 250			$18,600	$27,900
SandOil	OldCastle Precast	Sand/Oil Interceptor															
ecoLine B	WaterTectonics	Oil and Grease Separator, Prices include shipping	160 gpm Model-Dual Tank			$12,900	$19,350	630 gpm Model-Dual Tank			$30,400	$45,600	2x 630 gpm Model-Dual Tank			$60,800	$91,200
						Average:	**$15,225**				**Average:**	**$30,825**				**Average:**	**$59,550**
Media Filtration			Model Number	Filter Area (sq. ft.)	System gpm/sf	Cost	Installed Cost	Model Number	Filter Area	System gpm/sf	Cost	Installed Cost	Model Number	Filter Area	System gpm/sf	Cost	Installed Cost
ecoStorm Plus	WaterTectonics	Porous Concrete Media Filter w/Hydrodynamic Separator and sediment sump with outlet preventing floatable oils from escaping	A single ecoStorm Plus with an upstream CB drop structure	78.5	2	$34,000	$51,000	2 ecoStorm Plus units with a Model 2 ecoStorm upstream	157.1	3	$96,000	$144,000	3 ecoStorm Plus units with a Model 3 ecoStorm upstream	235.6	4	$146,500	$219,750
Filterra	Filterra Bioretention Systems	BioFilter with a form of plant life in boxes of different size.	Filterra 4x8 plus 1 Type R Inlet @ $4000	32	4	$9,700	$18,550	2 Filterra 6x10s at $17,100 ea plus 2 Type R inlets @$4000 ea	120	4	$34,200	$59,300	3 Filterra 6x10s at $17,100 ea plus 3 Type R inlets @ $4000 ea	180	5	$51,300	$88,950
StormFilter	CONTECH Construction Products	Media Filter involving different cartridges	9 Cartridge Vault		2	$25,000	$37,500	33 Cartdrige Vault		2	$52,500	$78,750	63 Cartridge Vault		2	$105,000	$157,500
Oil/Water Filter	OldCastle Precast	Media Filter includes sudge weir and Coalescing Media	160 OW					640 OW					2*480 OW at				
						Average:	**$35,683**				**Average:**	**$94,017**				**Average:**	**$155,400**
Inlet Inserts			# of Inlets		System gpm/sf	Unit Cost	Total Installed Cost	# of Inlets		System gpm/sf	Unit Cost	Total Installed Cost	# of Inlets		System gps/sf	Unit Cost	Total Installed Cost
Hydroscreen	Hydroscreen, LLC	Inlet Filter for fitting on curbs, pricing is based $/sq. ft	1		5.4	$3,750	$5,625	2		9.88	$7,500	$11,250	4		9.43	$15,000	$22,500
Ultra Urban Filter with Smart Sponge	AbTech Industries	Model Used is 13"x14"x13", Pricing for Filter + Collar. Collar price depending on material used, which changes with each project: Max add $300 to Filter Cost	4		80	$700.00	$1,050	8		80	1100	$1,650	16		80	1900	$2,850
FlexStorm	FleXstorm Inlet Filters	Inlet Filter that fits most gutters, differing prices for different size gutters. Filters generally hold 2 to 3 cubic feet of waste, $110 avg cost	4		200	$110	$165	8		200	220	$330	16		200	440	$660
						Average:	$2,280				Average:	$4,410				Average:	$8,670

Appendix F

Cost Spreadsheets and Figures for Channel BMPs

Constructed Wetlands Channel (CWC)

Design Information

	Contributing Impervious Area		
	2 ac	**5 ac**	**20 ac**
2-yr peak flow	4.1 cfs	10 cfs	32 cfs
100-yr peak flow	12 cfs	28 cfs	98 cfs
Bottom width	8 ft	8 ft	8 ft
Side slopes	4 H:V	4 H:V	4 H:V
100-yr depth (n=0.080)	1.5 ft	2.3 ft	4.0 ft
Channel depth	2.5 ft	3.3 ft	5.0 ft
Channel area	45 sf	70 sf	140 sf
Height of riprap protection above channel invert	2 ft	2 ft	2 ft
Channel length	100 ft	100 ft	100 ft

UNIT COSTS PER 100 LINEAR FEET OF CHANNEL

				2 Acre Site		5 Acre Site		20 Acre Site		
Item No.	**Item**	**Unit**	**Unit Price**	**Quantity**	**Total**	**Quantity**	**Total**	**Quantity**	**Total**	**Notes**
1	Excavation and backfill	CY	$5	167	$835	259	$1,295	519	$2,595	
2	Riprap bank protection (9" Type VL)	CY	$60	56	$3,360	56	$3,360	56	$3,360	
3	Wetland vegetation	AC	$15,000	0.02	$300	0.02	$300	0.02	$300	channel bottom
4	Upland seeding and mulching	AC	$2,000	0.09	$180	0.12	$240	0.18	$360	channel banks plus equal width at top of bank

		2 Acre Site	5 Acre Site	20 Acre Site
SUBTOTAL		$4,675	$5,195	$6,615
Mobilization and site prep	7%	$327	$364	$463
TOTAL COST / 100 LF		**$5,002**	**$5,559**	**$7,078**

CWC - 2 acre site

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.080	
Channel Slope	0.00100	ft/ft
Left Side Slope	4.00	ft/ft (H:V)
Right Side Slope	4.00	ft/ft (H:V)
Bottom Width	8.00	ft
Discharge	12.00	ft^3/s =100-yr peak

Results

Normal Depth	$\boxed{1.46}$	ft
Flow Area	20.29	ft^2
Wetted Perimeter	20.07	ft
Top Width	19.71	ft
Critical Depth	0.39	ft
Critical Slope	0.13626	ft/ft
Velocity	0.59	ft/s
Velocity Head	0.01	ft
Specific Energy	1.47	ft
Froude Number	0.10	
Flow Type	Subcritical	

GVF Input Data

Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Downstream Velocity	Infinity	ft/s
Upstream Velocity	Infinity	ft/s
Normal Depth	1.46	ft
Critical Depth	0.39	ft
Channel Slope	0.00100	ft/ft
Critical Slope	0.13626	ft/ft

CWC - 5 acre site

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.080	
Channel Slope	0.00100	ft/ft
Left Side Slope	4.00	ft/ft (H:V)
Right Side Slope	4.00	ft/ft (H:V)
Bottom Width	8.00	ft
Discharge	28.00	ft³/s = 100-yr peak

Results

Normal Depth	2.23	ft
Flow Area	37.61	ft²
Wetted Perimeter	26.35	ft
Top Width	25.80	ft
Critical Depth	0.65	ft
Critical Slope	0.11786	ft/ft
Velocity	0.74	ft/s
Velocity Head	0.01	ft
Specific Energy	2.23	ft
Froude Number	0.11	
Flow Type	Subcritical	

GVF Input Data

Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Downstream Velocity	Infinity	ft/s
Upstream Velocity	Infinity	ft/s
Normal Depth	2.23	ft
Critical Depth	0.65	ft
Channel Slope	0.00100	ft/ft
Critical Slope	0.11786	ft/ft

CWC - 20 acre site

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.080	
Channel Slope	0.00100	ft/ft
Left Side Slope	4.00	ft/ft (H:V)
Right Side Slope	4.00	ft/ft (H:V)
Bottom Width	8.00	ft
Discharge	98.00	ft^3/s = 100-yr peak

Results

Normal Depth	3.97	ft
Flow Area	94.96	ft^2
Wetted Perimeter	40.77	ft
Top Width	39.79	ft
Critical Depth	1.33	ft
Critical Slope	0.09708	ft/ft
Velocity	1.03	ft/s
Velocity Head	0.02	ft
Specific Energy	3.99	ft
Froude Number	0.12	
Flow Type	Subcritical	

GVF Input Data

Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Downstream Velocity	Infinity	ft/s
Upstream Velocity	Infinity	ft/s
Normal Depth	3.97	ft
Critical Depth	1.33	ft
Channel Slope	0.00100	ft/ft
Critical Slope	0.09708	ft/ft

CWC - 2-yr peak flow

Project Description

Friction Method	Manning Formula
Solve For	Discharge

Input Data

Roughness Coefficient	0.035	
Channel Slope	0.00100	ft/ft
Normal Depth	2.00	ft
Left Side Slope	4.00	ft/ft (H:V)
Right Side Slope	4.00	ft/ft (H:V)
Bottom Width	8.00	ft

Results

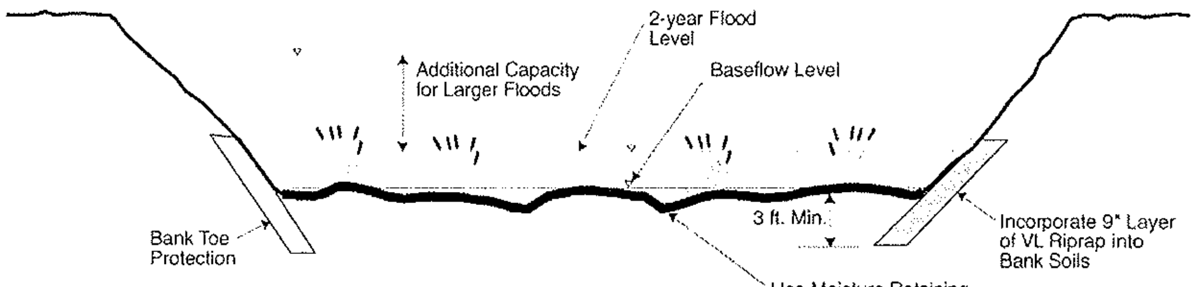
Discharge	51.34	ft³/s ⇒ OK for all 3 sites
Flow Area	32.00	ft²
Wetted Perimeter	24.49	ft
Top Width	24.00	ft
Critical Depth	0.92	ft
Critical Slope	0.02048	ft/ft
Velocity	1.60	ft/s
Velocity Head	0.04	ft
Specific Energy	2.04	ft
Froude Number	0.24	
Flow Type	Subcritical	

GVF Input Data

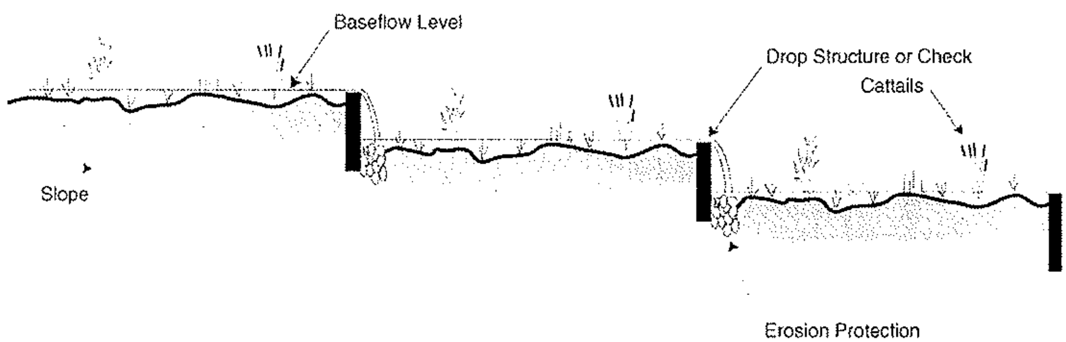
Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Downstream Velocity	Infinity	ft/s
Upstream Velocity	Infinity	ft/s
Normal Depth	2.00	ft
Critical Depth	0.92	ft
Channel Slope	0.00100	ft/ft
Critical Slope	0.02048	ft/ft



SECTION
NOT TO SCALE



SECTION
NOT TO SCALE

Figure CWC-1—Plan and Section of a Constructed Wetland Channel

Appendix G

Cost Spreadsheets for EURV BMPs

Extended Detention Basin (EDB) with EURV

Design Information

EURV depth range	3-5	ft
Forebay depth	2	ft
Forebay volume (% of WQCV)	4%	
Basin length:width ratio	3	
Side slopes (H:V)	5	
Maintenance road width	10	ft
Maintenance road slope	0.10	ft/ft
Maintenance road thickness	1.0	ft

	Contributing Impervious Area 2 ac		5 ac		20 ac		
WQCV (incl. sediment storage)	4356	cf	10890	cf	43560	cf	
EURV	8818	cf	22045	cf	88181	cf	
EURV depth	3	ft	3	ft	5	ft	
100-yr peak flow	12	cfs	28	cfs	98	cfs	
Max allowable release rate	2.0	cfs	5.0	cfs	20	cfs	used for calculating pipe size assuming 1% slope
Forebay volume	174	cf	436	cf	1742	cf	
Forebay area	87	sf	218	sf	871	sf	
Area at 1/2 EURV depth	2939	sf	7348	sf	17636	sf	
Width at 1/2 EURV depth	31	ft	49	ft	77	ft	
Length at 1/2 EURV depth	94	ft	148	ft	230	ft	
Top area	5042	sf	10543	sf	25928	sf	
Bottom area	1286	sf	4604	sf	10594	sf	
Emergency spillway width (assume 1' head)	4	ft	9	ft	33	ft	
Maintenance road length	154	ft	208	ft	330	ft	
Trickle channel width	2	ft	2	ft	4	ft	
Trickle channel length	63	ft	99	ft	153	ft	

				2 Acre Site		5 Acre Site		20 Acre Site		
Item No.	Item	Unit	Unit Price	Quantity	Total	Quantity	Total	Quantity	Total	Notes
1	Excavation and backfill	CY	$5	327	$1,633	816	$4,082	1633	$8,165	100% EURV for 2 & 5 acre sites, 50% EURV for 20 acre site
2	Concrete forebay	CY	$400	2	$800	5	$2,000	17	$6,800	qty based on area*2 for sides, ramps, etc.
3	Outlet structure - 2.0 and 5.0 cfs capacity	LS	$10,000	1	$10,000	1	$10,000	0	$0	
4	Outlet structure - 20 cfs capacity	LS	$15,000	0	$0	0	$0	1	$15,000	
5	Riprap spillway protection	CY	$60	6	$360	15	$900	51	$3,060	1.5' thickness; 4:1 slope
6	Concrete spillway weir	CY	$400	0.3	$120	0.4	$160	0.9	$360	
7	Maintenance access road (aggregate base course)	CY	$40	57	$2,280	77	$3,080	122	$4,880	basin length + 2 bottom accesses
8	Upland seeding and mulching	AC	$2,000	0.14	$280	0.30	$600	0.72	$1,440	120% of top area
9	18" RCP	LF	$50	50	$2,500	50	$2,500	0	$0	
10	24" RCP	LF	$55	0	$0	0	$0	50	$2,750	
11	Concrete trickle channel	CY	$400	5	$2,000	7	$2,800	17	$6,800	2/3 basin length, 6" thick, 4" deep

SUBTOTAL		$19,973	$26,122	$49,255
Mobilization and site prep	7%	$1,398	$1,829	$3,448
TOTAL COST		**$21,371**	**$27,951**	**$52,703**

Constructed Wetlands Basin (CWB) with EURV

Design Information

EURV depth range	3-5	ft
Forebay depth (below permanent pool)	3	ft
Permanent pool volume (% of WQCV)	75%	
Forebay volume (% of WQCV)	8%	
Basin length:width ratio	3	
Side slopes (H:V)	5	
Maintenance road width	10	ft
Maintenance road slope	0.10	ft/ft
Maintenance road thickness	1.0	ft
Wetland vegetation area (% of permanent pool)	60%	

	Contributing Impervious Area						
	2 ac		**5 ac**		**20 ac**		
WQCV	3267	cf	8168	cf	32670	cf	
EURV	8818	cf	22045	cf	88181	cf	
EURV depth	3	ft	4	ft	5	ft	
100-yr peak flow	12	cfs	28	cfs	98	cfs	
Max allowable release rate	2.0	cfs	5.0	cfs	20	cfs	used for calculating pipe size assuming 1% slope
Permanent pool volume	2450	cf	6126	cf	24503	cf	
Forebay volume	261	cf	653	cf	2614	cf	
Forebay area	87	sf	218	sf	871	sf	
Area at 1/2 EURV depth	2939	sf	5511	sf	17636	sf	
Width at 1/2 EURV depth	31	ft	43	ft	77	ft	
Length at 1/2 EURV depth	94	ft	129	ft	230	ft	
Top area	5042	sf	9340	sf	25928	sf	
Permanent pool area	1286	sf	2482	sf	10594	sf	
Average permanent pool depth	1.9	ft	2.5	ft	2.3	ft	
Emergency spillway width (assume 1' head)	4	ft	9	ft	33	ft	
Maintenance road length	154	ft	189	ft	290	ft	

				2 Acre Site		5 Acre Site		20 Acre Site		
Item No.	**Item**	**Unit**	**Unit Price**	**Quantity**	**Total**	**Quantity**	**Total**	**Quantity**	**Total**	**Notes**
1	Excavation and backfill	CY	$5	417	$2,087	1043	$5,217	2540	$12,702	Permanent pool plus: 100% EURV for 2 & 5 acre sites, 50% EURV for 20 acre site
2	Concrete forebay	CY	$400	4	$1,600	9	$3,600	33	$13,200	qty based on area*2 for sides, ramps, etc.
3	Outlet structure - 2.0 and 5.0 cfs capacity	LS	$10,000	1	$10,000	1	$10,000	0	$0	
4	Outlet structure - 20 cfs capacity	LS	$15,000	0	$0	0	$0	1	$15,000	
5	Riprap spillway protection	CY	$60	4	$240	10	$600	36	$2,160	1.5' thickness; 4:1 slope
6	Concrete spillway weir	CY	$400	0.3	$120	0.4	$160	0.9	$360	
7	Maintenance access road (aggregate base course)	CY	$40	57	$2,280	70	$2,800	107	$4,280	basin length + 2 bottom accesses
8	Upland seeding and mulching	AC	$2,000	0.18	$360	0.32	$640	0.71	$1,420	2*(top area-permanent pool area)
9	Wetland vegetation	AC	$15,000	0.02	$300	0.04	$600	0.15	$2,250	
10	18" RCP	LF	$50	50	$2,500	50	$2,500	0	$0	
11	24" RCP	LF	$55	0	$0	0	$0	50	$2,750	

SUBTOTAL		$19,487	$26,117	$54,122
Mobilization and site prep	7%	$1,364	$1,828	$3,789
TOTAL COST		**$20,851**	**$27,945**	**$57,911**

Retention Pond (RP) with EURV

Design Information

EURV depth range	3-6	ft
Forebay depth (below permanent pool)	3	ft
Permanent pool volume range (% of WQCV)	120%-200%	
Forebay volume (% of WQCV)	8%	
Basin length:width ratio	3	
Side slopes (H:V)	5	
Maintenance road width	10	ft
Maintenance road slope	0.10	ft/ft
Maintenance road thickness	1.0	ft
Wetland vegetation area (% of permanent pool)	35%	

	Contributing Impervious Area						
	2 ac		**5 ac**		**20 ac**		
WQCV	2904	cf	7260	cf	29040	cf	
EURV	8818	cf	22045	cf	88181	cf	
EURV depth	3	ft	4	ft	6	ft	
100-yr peak flow	12	cfs	28	cfs	98	cfs	
Max allowable release rate	2.0	cfs	5.0	cfs	20	cfs	used for calculating pipe size assuming 1% slope
Permanent pool volume (% of WQCV)	160%		160%		120%		
Permanent pool volume	4646	cf	11616	cf	34848	cf	
Forebay volume	232	cf	581	cf	2323	cf	
Forebay area	77	sf	194	sf	774	sf	
Area at 1/2 EURV depth	2939	sf	5511	sf	14697	sf	
Width at 1/2 EURV depth	31	ft	43	ft	70	ft	
Length at 1/2 EURV depth	94	ft	129	ft	210	ft	
Top area	5042	sf	9340	sf	23996	sf	
Permanent pool area	1286	sf	2482	sf	7198	sf	
Average permanent pool depth	3.6	ft	4.7	ft	4.8	ft	
Emergency spillway width (assume 1' head)	4	ft	9	ft	33	ft	
Maintenance road length	154	ft	209	ft	330	ft	

				2 Acre Site		5 Acre Site		20 Acre Site		
Item No.	**Item**	**Unit**	**Unit Price**	**Quantity**	**Total**	**Quantity**	**Total**	**Quantity**	**Total**	**Notes**
1	Excavation and backfill	CY	$5	499	$2,493	1247	$6,234	2924	$14,618	Permanent pool plus: 100% EURV for 2 & 5 acre sites, 50% EURV for 20 acre site
2	Concrete forebay	CY	$400	2	$800	4	$1,600	15	$6,000	qty based on area*2 for sides, ramps, etc.
3	Outlet structure - 2.0 and 5.0 cfs capacity	LS	$10,000	1	$10,000	1	$10,000	0	$0	
4	Outlet structure - 20 cfs capacity	LS	$15,000	0	$0	0	$0	1	$15,000	
5	Riprap spillway protection	CY	$60	7	$420	17	$1,020	58	$3,480	1.5' thickness
6	Concrete spillway weir	CY	$400	0.3	$120	0.4	$160	0.9	$360	
7	Maintenance access road (aggregate base course)	CY	$40	57	$2,280	77	$3,080	122	$4,880	basin length + 2 bottom accesses
8	Upland seeding and mulching	AC	$2,000	0.18	$360	0.32	$640	0.78	$1,560	2*(top area-permanent pool area)
9	Wetland vegetation	AC	$15,000	0.02	$300	0.02	$300	0.06	$900	
10	Underdrain (incl. bedding and backfill)	LF	$30	94	$2,817	129	$3,858	210	$6,299	
11	18" RCP	LF	$50	50	$2,500	50	$2,500	0	$0	
12	24" RCP	LF	$55	0	$0	0	$0	50	$2,750	

SUBTOTAL		$22,091	$29,391	$55,848
Mobilization and site prep	7%	$1,546	$2,057	$3,909
TOTAL COST		**$23,637**	**$31,448**	**$59,757**

Appendix H

Resource Contact Information

PERMANENT BMP COST ESTIMATES - RESOURCES

Manufacturer	Products	Contact Name	Contact Information
CONTECH Stormwater Solutions	Vortechs, Contech CDS, StormFilter	Duane Herring	herringd@contech-cpi.com
Imbrium/Rinker Materials	Stormceptor STC, Stormceptor OSR	Brian Schram	BSchram@cemexusa.com
WaterTectonics	EcoStorm, EcoLine B, EcoStorm Plus	TJ Mothersbaugh	tj@watertectonics.com
Filterra Bioretention Systems	Filterra Media Filtration	Will Harris	wharris@filterra.com
Hydroscreen, LLC	Hydroscreen Inlet Filter	Bob Weir	303-333-6071
AbTech Industries	Urban Filter with Smart Sponge	Chris Bradley	480-874-4000
FlexStorm Inlet Filters	FleXstorm Inlet Filter	Jamie Ringenbach	jr@inletfilters.net
StevensCorp	grasspave2	Jay Stevens	jay@stevenscorp.com
Pavestone	Grasstone II, Uni Eco-Stone	John Rowe	303-287-3700 johnrowe@pavestone.com