Appendix F - WinSLAMM Retrofit Stormwater Management Options Report

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Lincoln, Nebraska, Retrofit Stormwater Management Options
- Performance and Relative Costs -

Contents

Introduction

This report describes the expected performance of many alternative stormwater control programs that were evaluated in nine land use categories based on Antelope Creek study area site surveys. The earlier report (R. Pitt. *Lincoln, Nebraska, Standard Land Use Characteristics and Pollutant Sources*, Prepared for Wright Water Engineers, Inc., Denver, CO. April 22, 2011) described these land use areas, the expected stormwater characteristics, and pollutant sources. The discussion of pollutant sources helped to frame the stormwater control program alternatives to examine. This report contains the following main sections that supplement the earlier calibration, characterization, and sources report:

- Introduction
- Descriptions of stormwater control practices (including discussions of factors affecting the use of different controls, combinations of practices, plus variability and uncertainty of predicted outcomes)
- Analysis results (including selecting the most suitable stormwater control program)
- An appendix containing detailed modeling results for all constituents and land uses

Land Uses

This current report is a continuation of the prior report and focusses on stormwater control programs that can be used in the Antelope Creek watershed. The land uses identified in the Antelope Creek study area were examined with more than 25 alternative stormwater control programs in each. Calculated performance attributes are presented and evaluated for each of the following nine land use categories:

- Commercial areas:
    - Strip malls
    - Shopping center
- Light Industrial areas
- Institutional areas:
    - Schools
    - Churches
    - Hospitals
- Residential areas:
    - Low density
    - Medium density, constructed before 1960
    - Medium density, constructed between 1960 and 1980

Stormwater Controls Examined

The stormwater controls examined in the Antelope Creek study area varied somewhat for the different land uses (based on available space and other compatibility issues mostly, plus from the earlier source analyses). The controls examined included the following:

- Roof runoff controls: rain gardens, disconnections, rain barrels and larger water tanks
- Pavement controls: disconnections, biofiltration, and porous pavement
- Street side drainage controls: grass swales and curb-cut biofilters
- Public works practices: street cleaning and catchbasin cleaning
- Outfall controls: wet detention ponds

Some of these controls (especially the roof and pavement controls) are at source areas and their maximum benefits are restricted by the fraction of the constituent of concern originating from those areas. As an example, consider stormwater beneficial uses using roof runoff for irrigation of landscaped areas. In some of the land uses, roof runoff contributes less than 20% of the total runoff, so the controls are restricted to that somewhat low maximum benefit for the whole area. The drainage system and outfall controls (swales, curb-cut biofilters, and wet detention ponds) can basically treat all of the runoff from the land use and are not restricted by source contributions. If land is available, they can therefore have larger theoretical benefits. The range of difficulties and land requirements varies, mostly depending on available opportunities. In some communities, extensive retro-fitting is occurring including installation of curb-cut biofilters. These can also be installed during scheduled repaving and sidewalk repairs that usually occur in many areas every few decades. Rain gardens are usually installed by the home owners with no cost to the city. The public works practices usually get the most attention, especially street cleaning, as they can be used with no change to the land. Redevelopment and new construction times are the most suitable for installation of many of these controls in order to have the least interferences with current residents and for the least costs and optimal locations.

The designs of the individual control practices are described in this report, along with the WinSLAMM unit process calculation procedures. Calculated runoff, TSS, and *E. coli* conditions for each scenario, and also the estimated costs (capital costs, land costs, maintenance costs, total annual costs, and total present value cost) and the unit removal costs for runoff (dollars per cubic feet removed, compared to the base conditions) and for TSS (dollars per pound removed, compared to the base conditions) are summarized. Scatterplots relating the calculated percent removals of these three stormwater constituents vs. the total annual costs (dollars per 100 acres per year) are also shown. The most suitable stormwater control programs meeting the removal objectives at the least cost can be identified from these figures (also considering other factors affecting the selection process as described earlier, such as groundwater contamination potential, maintenance requirements, suitability for retrofitting, etc.). Detailed information for all constituents examined (runoff volume, Rv, TSS, TDS, total and filterable phosphorus, nitrates, total and filterable TKN, total and filterable COD, total and filterable copper, total and filterable lead, total and filterable zinc, fecal coliform bacteria, and *E. coli* bacteria) is presented for each land use and soil combinations for each set of stormwater controls in the appendix.

Selection of Most Appropriate Stormwater Control Program

For runoff volume controls, each land use group had similar most cost-effective controls, as shown on the following list for the controls having at least 25% levels of runoff volume reduction potential in areas having clay load soils in the infiltration areas. Other control options have similar potential levels of control, but the others are likely more costly. These are listed in order with the first control having the lowest level of maximum control, but the highest unit cost-effectiveness; and the last control listed having the highest level of maximum control, but the lowest unit cost-effectiveness. Therefore, if low to moderate levels of control are suitable, the first control option may be best, but if maximum control levels are needed, then the last control option listed would be needed:

- Strip mall and shopping center areas:
    - Porous pavement (in half of the parking areas)
    - Curb-cut biofilters (along 80% of the curbs) for strip malls or biofilters in parking areas (10 percent of the source area) for shopping centers
    - Biofilters in parking areas (10 percent of the source area) and curb-cut biofilters (along 40% of the curbs)

- Light industrial areas:
    - Curb-cut biofilters (along 40% of the curbs)
    - Roofs and parking areas half disconnected
    - Roofs and parking areas all disconnected

• School, church, and hospital institutional areas:
- Small rain tank (0.10 ft^3 storage per ft^2 of roof area) for schools and churches; rain tank (0.25 ft^3 storage per ft^2 of roof area) for hospitals
- Roofs and parking areas half disconnected
- Roofs and parking areas all disconnected

• Low and medium density residential areas:
- Curb-cut biofilters (along 20% of the curbs)
- Curb-cut biofilters (along 40% of the curbs)
- Curb-cut biofilters (along 80% of the curbs)

For suspended solids, all areas show that wet detention ponds are the most cost-effective control option, irrespective of the conditions. Obviously, other factors may influence the selection of the "best" stormwater control program for an area, beyond least cost for the level of control needed. As an example, wet detention ponds, while being the most cost-effective, are likely very difficult to retrofit into existing areas. However, these analyses indicate that these controls should not be rejected without careful evaluations and searching for potential locations.

There are many attributes and characteristics associated with a stormwater management plan that need to be considered during the selection process. An example decision analysis process is shown for the Lincoln, NE, medium residential area (1960-1980) that represents the largest fraction of the Antelope Creek study area. Some of the characteristics of concern include: *E. coli* discharge reductions, nutrient discharge reductions, costs (initial and maintenance costs, plus total annual costs), land requirements, runoff volume discharge reductions, and TSS discharge reductions. As described in this report, WinSLAMM can calculate these attributes for a broad selection of alternative stormwater programs.

In the simplest case, the selection of the most suitable control can be based on examining the calculated outcomes and filtering them according to set objectives, and then choosing the least costly alternative. As an example, if the runoff reduction objectives were expressed in expected biological conditions of "good" and the required particulate solids (TSS) mass discharge reductions needed were at least 75%, seven of the 29 control programs for this land use would be satisfactory. The least costly alternative involves the use of curb-cut biofilters along at least 20 percent of the total curb length. If this control program meets other objectives (mainly approval of the residents living in the area, and design specifics to overcome possible problems associated with snowmelt and clogging can be developed), this would be a good choice, and is being more frequently used in many US communities.

Formal decision analysis methods can be used when conflicting and complex attributes and objectives make the simpler filtering method described above impractical. Good decision analysis methods are a powerful tool that can be used to compare the rankings of alternative stormwater management programs for different groups of stakeholders. In many cases, final rankings may be similar amongst the interested parties, although their specific reasons vary. This tool also completely documents the decision making process, enabling full disclosure. In this example, the top ranked alternatives are generally similar for each hypothetical stakeholder group, even with very different trade-off values. The municipal governments and local resident's trade-offs are quite similar, but are quite different from the regulatory agency's trade-off values. The overall top ranked alternative is the curb-cut biofilters at 40% of the curb line. This alternative ranked first for the municipal government and local resident stakeholder groups and second for the regulatory agency. The top ranked alternative for the regulatory agency (the curb-cut biofilters at 80% of the curb line) ranked much lower for the other two stakeholder groups due to its much higher costs. The small wet pond plus the curb-cut biofilters at 40% of the curb line ranked second for the municipal government stakeholders and third for the regulatory agency and the local government stakeholder groups.

Other Considerations Affecting Selection and Use of Stormwater Controls

Certain site conditions may restrict the applicability of some of the controls and need to be considered during the selection process. Some of these examined in the report are summarized below:

- The sodium adsorption ratio (SAR) can radically degrade the performance of an infiltration device, especially when clays are present in the infiltration layers of a device, and snowmelt containing deicing salts enters the device. Soils with an excess of sodium ions, compared to calcium and magnesium ions, remain in a dispersed condition, and are almost impermeable to rain or applied water. A "dispersed" soil is extremely sticky when wet, tends to crust, and becomes very hard and cloddy when dry. Water infiltration is therefore severely restricted. SAR has been documented to be causing premature failures of biofiltration devices in northern communities. These failures occur when snowmelt water is allowed to enter a biofilter that has clay in the soil mixture. In order to minimize this failure, do not allow snowmelt water to enter a biofilter unit. As an example, roof runoff likely has little salt and SAR problems seldom occur for roof runoff rain gardens. The largest problem is associated with curb-cut biofilters or parking lot biofilters in areas with snowmelt entering these devices, especially if clay is present in the engineered backfill soil. The biofilter fill soil should not have any clay. It appears that even a few percent clay can cause a problem, but little information is currently available on the tolerable clay content of biofilter soils. The most robust engineered soil mixtures used in biofilters should be mixtures of sand and an organic material (such as compost if nutrient leaching is not an issue, or Canadian peat for a more stable material having little nutrient leaching potential).

- The designs of infiltration devices need to be checked based on their clogging potential. As an example, a relatively small and efficient biofilter (in an area having a high native infiltrating rate) may capture a large amount of sediment. Having a small surface area, this sediment would accumulate rapidly over the area, possibly reaching a critical clogging load early in its design lifetime. Infiltration and bioretention devices may show significantly reduced infiltration rates after about 2 to 5 lb/ft^2 (10 to 25 kg/m^2) of particulate solids have been loaded.

- The potential for infiltrating stormwaters to contaminate groundwaters is dependent on the concentrations of the contaminants in the infiltrating stormwater and how effective those contaminants may travel thru the soils and vadose zone to the groundwater. Source stormwaters from residential areas are not likely to be contaminated with compounds having significant groundwater contaminating potential (with the exception of high salinity snowmelt waters). In contrast, commercial and industrial areas are likely to have greater concentrations of contaminants of concern that may affect the groundwater adversely. Therefore, pretreatment of the stormwater before infiltration may be necessary, or the use of specially selected media in the biofilter can be used.

- Most of the control options examined in this report are intended for retrofitting in existing urban areas. Therefore, their increased costs and availability of land will be detrimental in developing highly effective control programs. The range of difficulties and land requirements varies, mostly depending on available opportunities. In some communities (especially those with combined sewer overflows), extensive retro-fitting is occurring, including installation of curb-cut biofilters.

Modeling Approach

WinSLAMM version 9.5 was previously used to analyze the water quality (stormwater pollution loading) and runoff volume for the land uses found in the Antelope Creek study area (R. Pitt. *Lincoln, Nebraska, Standard Land Use Characteristics and Pollutant Sources*, Prepared for Wright Water Engineers, Inc., Denver, CO. April 22, 2011). This current report is a continuation of that prior report and focusses on stormwater control programs that can be used in the Antelope Creek watershed. The nine land uses identified in the Antelope Creek study area were examined with more than 25 alternative stormwater control programs in each. Calculated performance attributes are then presented and evaluated for each of the nine land use categories. Relative cost data (focusing on expected total annual costs), along with discharge volume and load reductions are also summarized. The following is a brief discussion of the WinSLAMM model and how it was used in these calculations.

WinSLAMM Background Information

WinSLAMM was developed to evaluate stormwater runoff volume and pollutant loadings in urban areas using small storm hydrology. The model determines the runoff based on local rain records and calculates runoff volumes and pollutant loadings from each individual source area within each land use category for each rain. Examples of source areas include: roofs, streets, small landscaped areas, large landscaped areas, sidewalks, and parking lots.

The model can use any length of rainfall record as determined by the user, from single rainfall events to several decades of rains. The rainfall file used in these calculations for Lincoln, NE, was developed from hourly data obtained from EarthInfo CDROMs, using the four years from 1996 through 1999. The model applied a series of stormwater control practices, including rain barrels and water tanks for stormwater irrigation, pavement and roof disconnections, roof rain gardens, infiltration/biofiltration in parking lots and as curb-cut biofilters, street cleaning, wet detention ponds, grass swales, porous pavement, catchbasins, and selected combinations of these practices. The model evaluates the practices through engineering calculations of the unit processes based on the actual designs and sizes of the controls specified and determines how effectively these practices remove runoff volume and pollutants.

WinSLAMM does not use a percent imperviousness or a curve number to general runoff volume or pollutant loadings. The model applies runoff coefficients to each “source area” within a land use category. Each source area has a different runoff coefficient equation based on factors such as: slope, type and condition of surface, soil properties, etc., and calculates the runoff expected for each rain. The runoff coefficients were developed using monitoring data from typical examples of each site type under a broad range of conditions. The runoff coefficients are continuously updated as new research data becomes available.

Each source area also has a unique pollutant concentration (event mean concentrations - EMCs - and a probability distribution) assigned to it. The EMCs for a specific source area vary depending on the rain depth. The source area’s EMCs are based on extensive monitoring conducted in North America by the USGS, Wisconsin DNR, University of Alabama, and other groups. These monitoring efforts isolated source areas (roofs, lawns, streets, etc.) for different land uses and examined long term data on the runoff quality. The pollutant concentrations are also continuously updated as new research data become available.

For each rainfall in a data set, WinSLAMM calculates the runoff volume and pollutant load (EMC x runoff volume) for each source area. The model then sums the loads from the source areas to generate a land use or drainage basin subtotal load. The model continues this process for the entire rain series described in the rain file. It is important to note that WinSLAMM does not apply a “unit load” to a land use. Each rainfall produces a unique load from a modeled area based on the specific source areas in that modeled area.

The model was used to predict stormwater management practice effectiveness as presented in this project report. The model replicates the physical processes occurring within the practice. For example, for a wet detention pond, the model incorporates the following information for each rain event:

1. Runoff hydrograph, pollution load, and sediment particle size distribution from the drainage basin to the pond,
2. Pond geometry (depth, area),
3. Hydraulics of the outlet structure,
4. Particle settling time and velocity within the pond based on retention time

Stokes Law and Newton's settling equations are used in conjunction with conventional surface overflow rate calculations and modified Puls-storage indication hydraulic routing methods to determine the sediment amounts and characteristics that are trapped in the pond. Again, it is important to note that the model does not apply "default" percent efficiency values to a control practice. Each rainfall is analyzed and the pollutant control effectiveness will vary based on each rainfall and the pond's antecedent condition. This report describes how each stormwater control practice examined in Antelope Creek is evaluated in WinSLAMM.

The model's output is comprehensive and customizable, and typically includes:

1. Runoff volume, pollutant loadings and EMCs for a period of record and/or for each event.
2. The above data pre- and post- for each stormwater management practice.
3. Removal by particle size from stormwater management practices applying particle settling.
4. Other results can be selected related to flow-duration relationships for the study area, impervious cover model expected biological receiving water conditions, and life-cycle costs of the controls.

A full explanation of the model's capabilities, calibration, functions, and applications can be found at www.winslamm.com. For this project, the parameter files were calibrated using the local Lincoln MS4 monitoring data, supplemented by additional information from regional data from the National Stormwater Quality Database (NSQD), available at: http://www.unix.eng.ua.edu/~rpitt/Research/ms4/mainms4.shtml

Calibration of WinSLAMM to Simulate Local Observed Stormwater Conditions

All models need to be calibrated to result in the most effective information. WinSLAMM calibrations for Lincoln were based on a multi-step process. Much source area monitoring data are available from different locations (mainly from California, Alabama, Ontario, and Wisconsin). These data are summarized in a series of peer-reviewed chapters in modeling monographs:

- Pitt, R., R. Bannerman, S. Clark, and D. Williamson. "Sources of pollutants in urban areas (Part 1) – Older monitoring projects." In: Effective Modeling of Urban Water Systems, Monograph 13. (edited by W. James, K.N. Irvine, E.A. McBean, and R.E. Pitt). CHI. Guelph, Ontario, pp. 465 – 484 and 507 – 530. 2005.
- Pitt, R., R. Bannerman, S. Clark, and D. Williamson. "Sources of pollutants in urban areas (Part 2) – Recent sheetflow monitoring results." In: Effective Modeling of Urban Water Systems, Monograph 13. (edited by W. James, K.N. Irvine, E.A. McBean, and R.E. Pitt). CHI. Guelph, Ontario, pp. 485 – 530. 2005.
- Pitt, R., D. Williamson, and J. Voorhees. "Review of historical street dust and dirt accumulation and washoff data." Effective Modeling of Urban Water Systems, Monograph 13. (edited by W. James, K.N. Irvine, E.A. McBean, and R.E. Pitt). CHI. Guelph, Ontario, pp 203 – 246. 2005.

These data have been used to create calibrated WinSLAMM models in several locations that have since been verified using outfall data. The most extensive data are from the Birmingham, AL area and from the state of Wisconsin. Land use (and stormwater) data from throughout the nation are also available from many research reports. These data were separated into several regional groups. The Lincoln area is included in the Central US area and was originally based on the Wisconsin calibration and verification model sets. The Central model files were then modified based on outfall data from the Central US region as contained in the NSQD. Finally, these Central US files were further modified using the events monitored in Lincoln as part of their MS4 monitoring program, as described in the earlier Antelope Creek stormwater source report.

The Lincoln rain file was used to calculate long-term stormwater conditions. The four year period from 1996 through 1999 was used. A longer period was not possible due to missing observations. Winter conditions were also defined as being from December 20 to February 10 of each year. During these winter periods, no stormwater calculations were made.

During the Lincoln calibration process, the calculated long-term averaged modeled concentrations were compared to the monitored concentrations for each site. Factors were applied uniformly to each land use in the Lincoln pollutant and particulate solids parameter files to adjust the long-term modeled concentrations to best match the monitored/observed values. The runoff parameter file was not modified as it has been shown to compare well to observed conditions under a wide range of situations, and no local runoff quantity data were available for the local monitoring locations.

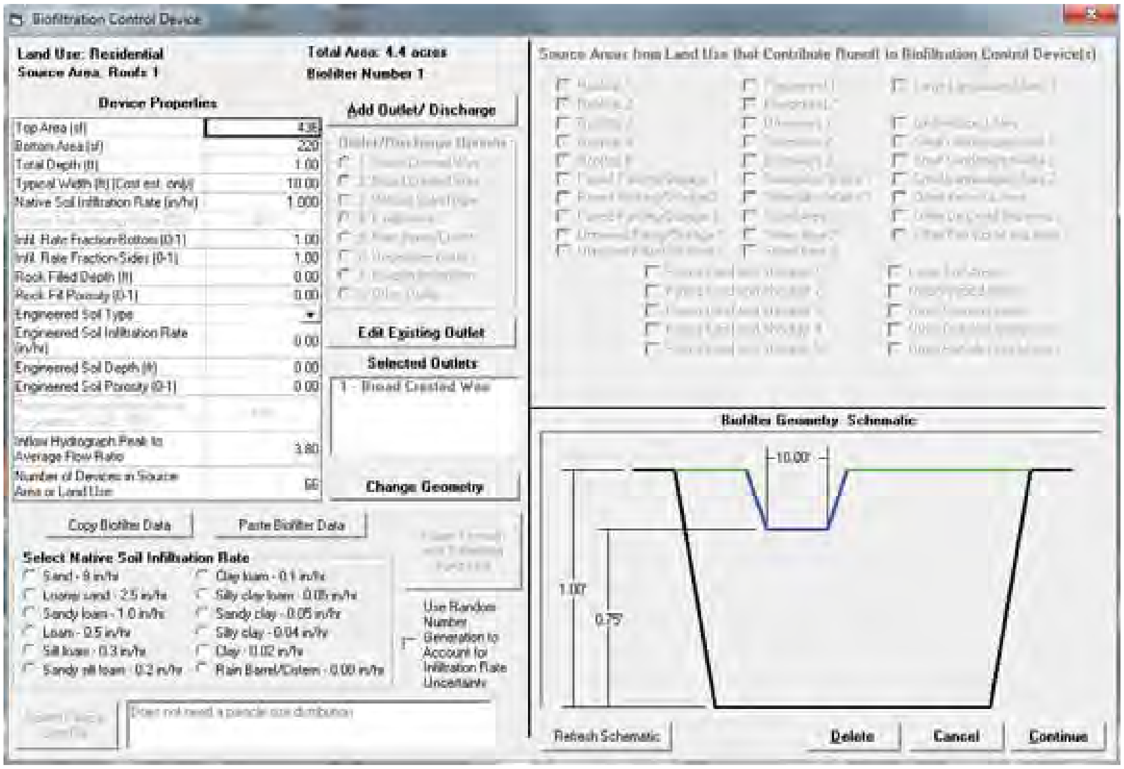
Description of Control Practices

The following subsections describe how WinSLAMM models the performance of the various stormwater control practices considered in this evaluation, plus some individual control production functions. These production functions were used to help determine the range of designs to apply to each land use category to represent the likely best performing sizes and combinations of control practices. As indicated, WinSLAMM calculates the expected performance of the controls based on the unit processes available in the control and the specific designs applied to site specific conditions.

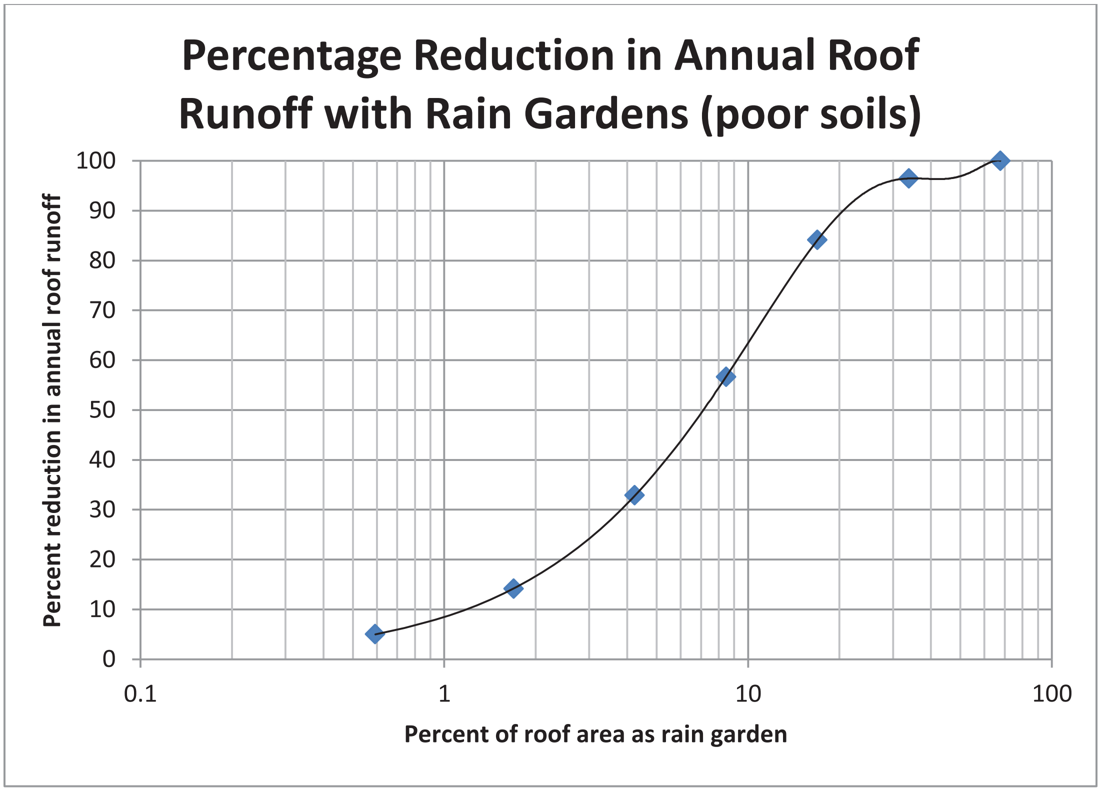
Roof Runoff Controls

Rain Gardens

Rain gardens are simple bioretention devices located adjacent to roofs. The following screen dump from the biofilter information screen in WinSLAMM describes one of the rain gardens used in these analyses. Each rain garden has a top surface area of 436 ft^2, corresponding to 1% of one acre. The number of rain gardens was changed for each scenario corresponding to the size of the rain garden compared to the roof area. In this example, this relatively large rain garden is about 20 by 22 ft in area; however, the performance is directly dependent on the total areas of all the rain gardens being considered in the area. The rain gardens are only excavated to an overall depth of 1 ft, with no fill soil (and no underdrains). In many cases, amendments are tilled into rain garden excavations, usually to improve the tilth and organic content in order to better support the plants and to improve infiltration. The surface 1 ft is left open to provide surface storage 9 inches deep (several inches act as on overflow). Clay loam soils having 0.1 in/hr and sandy loam soils having 1.0 in/hr infiltration rates were examined for each scenario to represent a likely range of urban soil conditions. The only outlet used (besides the natural infiltration) is a surface overflow along one edge of the rain garden that is 3 inches lower than the other edges.



The following figure is a plot of the performance of rain gardens as a percentage of the roof area, based on long-term continuous modeling. This figure was used to select rain gardens having total surface areas of 3 and 15% of the total roof areas in each land use. Even though these are more cost-effective if treating runoff from directly connected roofs, the modeling scenarios examined all roofs in each area (both directly connected roofs draining to the drainage system and roofs already draining to adjacent landscaped areas) in order to maximize the potential control of the roof runoff by rain gardens. The 3% rain gardens are expected to reduce the annual roof runoff volumes by about 25%, while the large rain gardens that are 15% of the roof areas are expected to reduce the annual roof runoff volumes by about 75%.



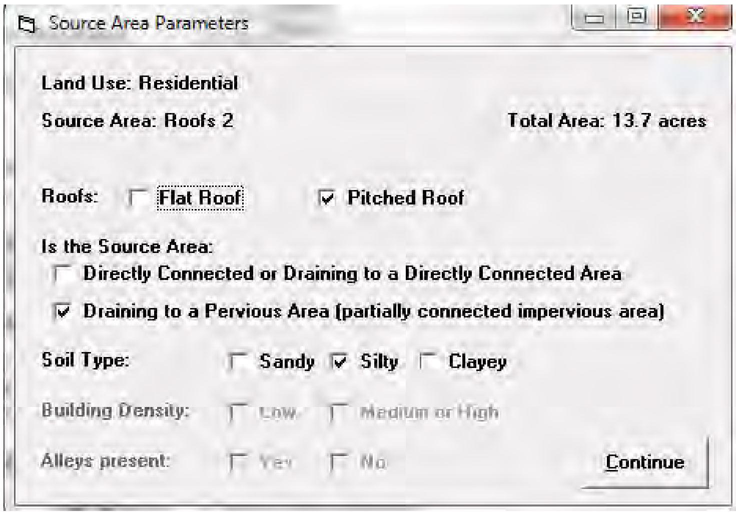
Rain gardens can be very effective in reducing runoff discharges from roofs, but they need to be relatively large, especially in areas having poor soils. Care is also necessary in their construction to prevent compaction and sealing the soils. In many cases, incorporating compost or peat into the top soil layers can enhance their performance. Many references are also available describing plant choices for rain gardens. These are typically constructed and maintained by the individual property owners and are located on private property. Biofilters, described later under pavement controls, are more sophisticated versions of rain gardens.

Disconnections of Roof Downspouts

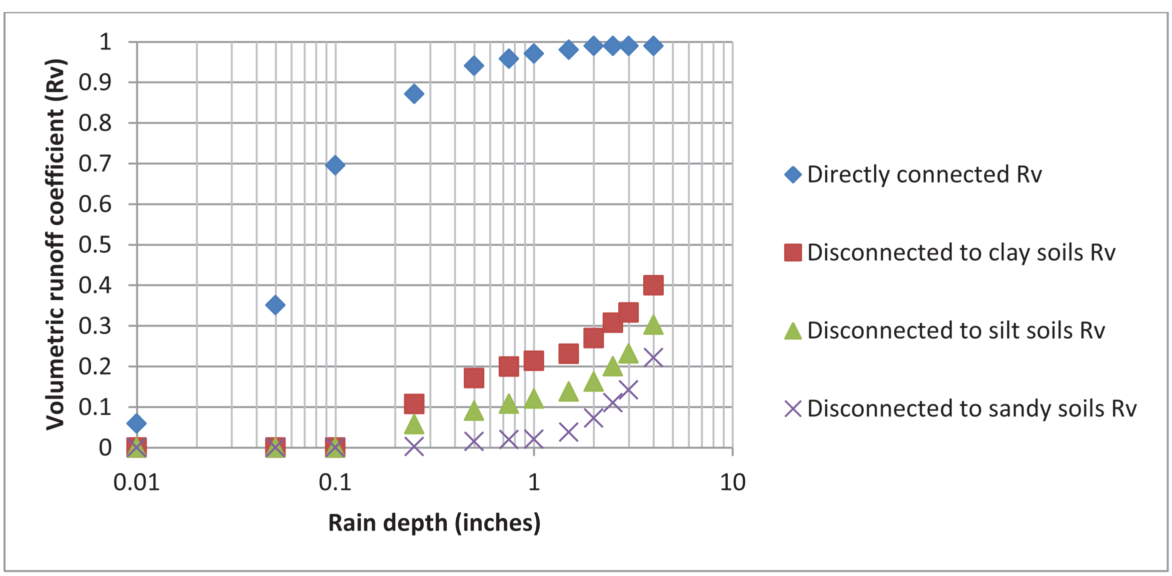
Another option for the control of runoff from directly connected roofs is to disconnect the roof drain downspouts that are currently directed towards pavement that in turn are directly connect to the drainage system. When disconnecting downspouts, the water needs to be redirected over pervious ground, most commonly regular turf grass located adjacent to the downspouts. This is most effective if the water is discharged to relatively flat lawns in good conditions that have flow path lengths of at least 10 feet for small residential roofs. If the soils have poor infiltration characteristics (such as for the clay loam soil conditions), the amount of water that can be infiltrated may be relatively high if the roofs comprise small fractions of the pervious areas. In this case, the available flow paths are also relatively long, increasing the infiltration potential.

WinSLAMM version 9.5 was used to make a preliminary analysis of the benefits of disconnecting the directly connected roofs to allow the runoff to flow across the pervious areas. The new version 10 being completed will be able to more directly calculate these benefits through grass filtering processes. These results can be roughly compared to the benefits associated with rain gardens and rain barrels/tanks, the other roof runoff control options being considered in these analyses. For clay loam soils, disconnecting the roof downspouts in most residential areas (having suitable flow paths) is expected to result in annual reductions of the roof runoff by about 80%. This would increase to about 90% and 95% for areas having silty and sandy soils, respectively.

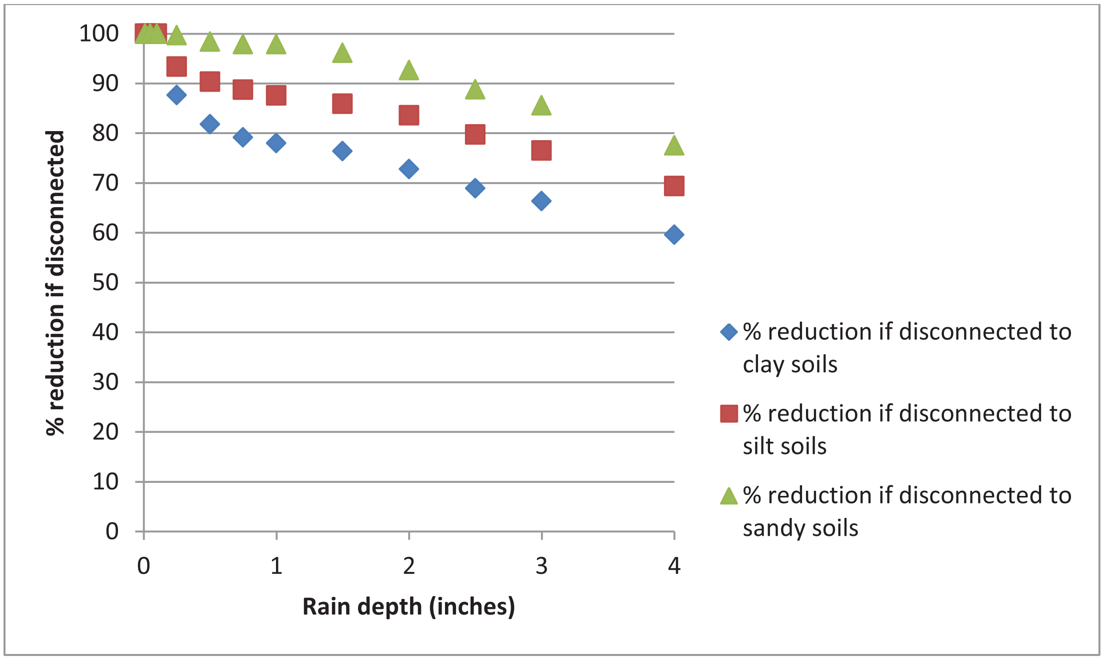
The following is the WinSLAMM entry screen showing how the roof areas are disconnected during a model analysis:



The following plots illustrate the expected benefits of these disconnection practices for different individual rains, up to 4 inches in depth, for residential areas. The volumetric runoff coefficient (Rv), the ratio of runoff volume to rainfall volume falling on an area, is seen to increase with increasing rain depths. For directly connected pitched roofs, the Rv is about 0.7 for 0.1 inch rains, and is quite close to 1.0 for rains larger than about 2 inches in depth. When disconnected to clayey soils, runoff is not expected until the rain depth is greater than about 0.1 inches and the Rv starts to climb steeply with rains larger than several inches in depth. It is expected to be very large for very large and unusual rains that can cause severe flooding, irrespective if they are disconnected or not. However, the benefits for small and intermediate rains are large.



The following graph illustrates the percentage reductions associated with disconnecting the directly connected roofs for the three main soil categories in residential areas. The percentage reduction is about 75% for 1.5 inch rains, being greater for smaller rains. These levels of control can also be achieved using rain gardens in relatively small areas, or by using water tanks and irrigating the landscaped areas with the captured water, if the available landscaped area is relatively large. However, these other controls should only be retrofitted at homes that currently have directly connected roof drains and if disconnecting is not feasible due to poor flow paths or limited space.

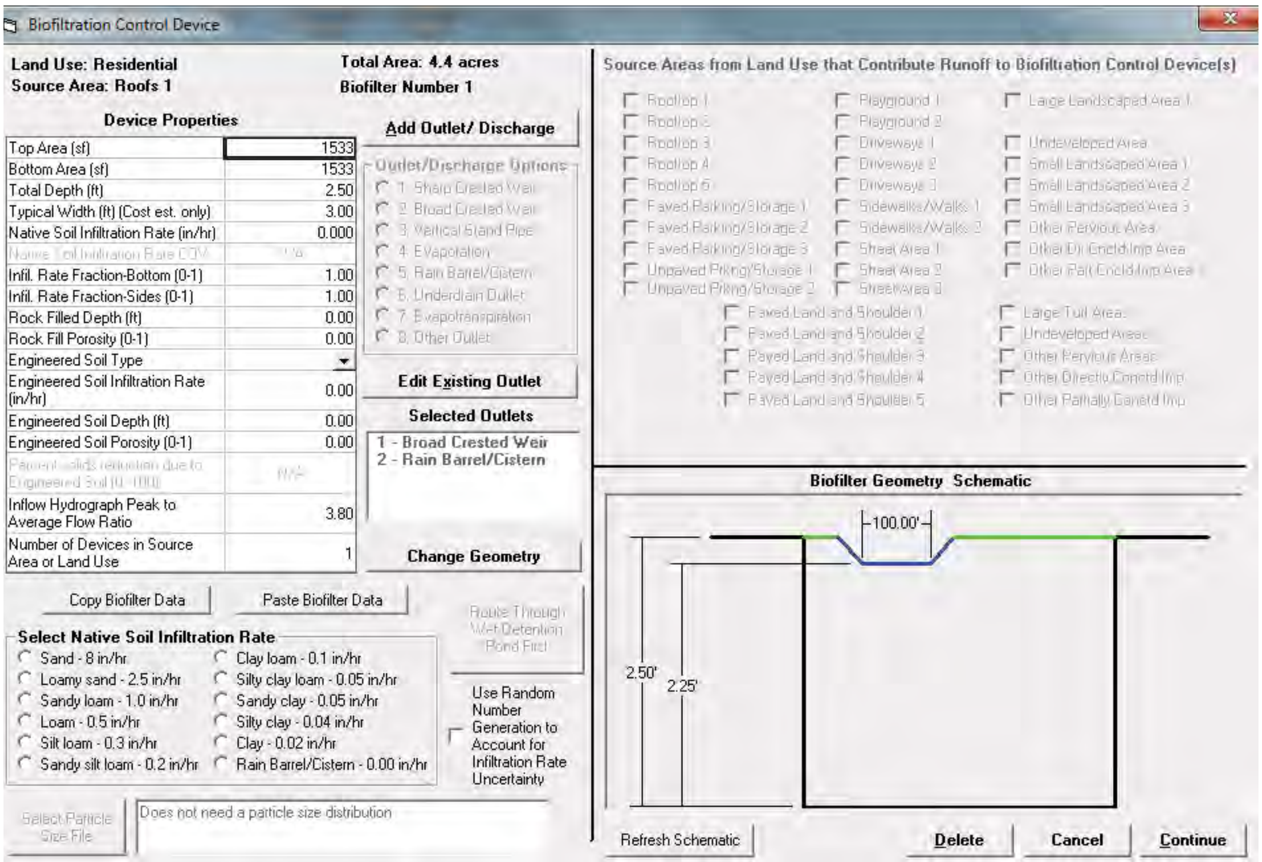


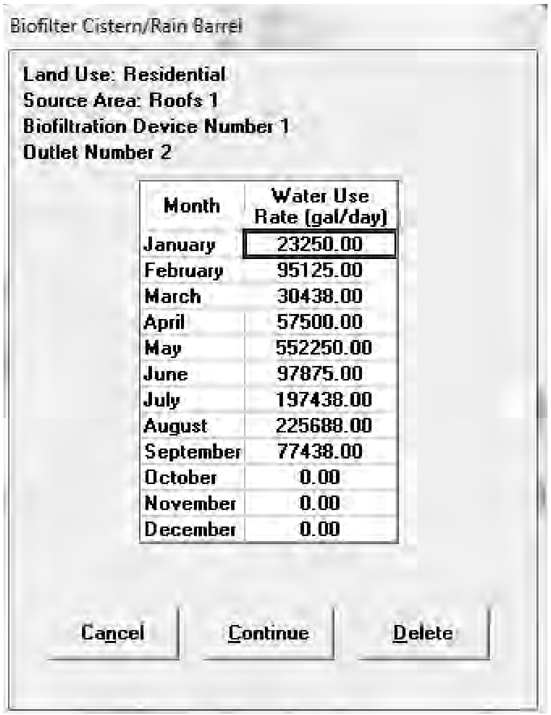
Rain Barrels and Water Tanks for Irrigation using Roof Runoff

Rain barrels are a very simple method for collecting roof runoff for beneficial uses. In these analyses, irrigation of turf grass landscaping around the buildings is the use provided. In some cases, especially for new construction, in-house beneficial uses of stormwater may also be available (such as for toilet flushing). The irrigation opportunity that can be met by the use of stored stormwater is the additional water needed to supplement the long-term monthly average rainfall infiltration in order to match the evapotranspiration requirements for the area. As will be shown in these analyses, small rain barrels provide limited direct benefits, so larger water tanks are also considered in these analyses. Also, in order to be most beneficial, these calculations assume that the irrigation rates are controlled by soil moisture conditions in order to match the ET requirements closely. This level of control is usually most effectively achieved with a single large storage tank connected to an automatic irrigation system. Numerous smaller rain barrels are more difficult to optimally control.

The water harvesting potential for the retrofitted rain barrels and water tanks was calculated based on supplemental irrigation requirements for the basic landscaped areas. The irrigation needs were determined to be the amount of water needed to satisfy the evapotranspiration needs of typical turf grasses, after the normal amounts of infiltration of rainfall added moisture to the soil.

The following is the form used for rain barrel or cistern/water tanks in WinSLAMM version 9.5 (version 10 currently being completed has a more stream-lined water beneficial use/water barrels input screen (but the calculations and data needs are the same). This is the same form used for the biofilters, but conditions relevant to rain barrels and water beneficial use are selected (top and bottom area the same, no native soil infiltration and no fill material needed. The two discharges include the required overflow (just the tank upper rim) and the monthly water use requirements (the irrigation demands to match ET deficits after considering the rain water infiltration).




Biofilter Cistern/Rain Barrel

Land Use: Residential
Source Area: Roofs 1
Biofiltration Device Number 1
Outlet Number 2

Month	Water Use Rate (gal/day)
January	23250.00
February	95125.00
March	30438.00
April	57500.00
May	552250.00
June	97875.00
July	197438.00
August	225688.00
September	77438.00
October	0.00
November	0.00
December	0.00

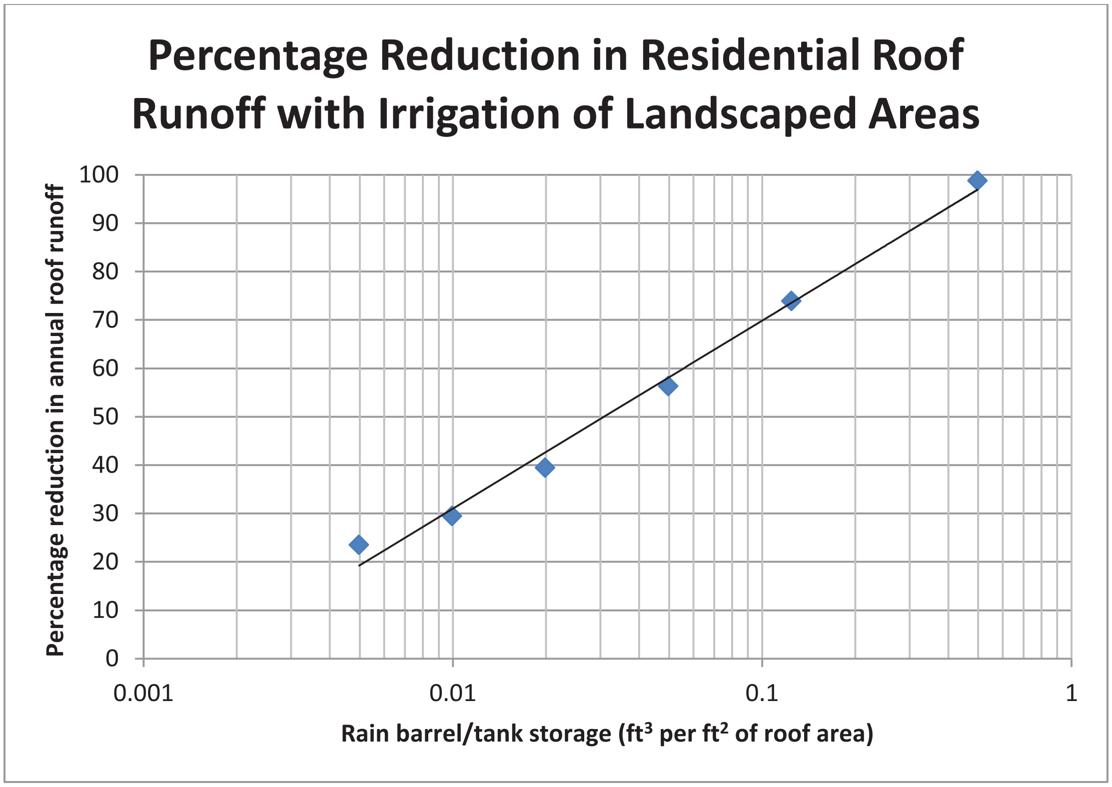
Cancel Continue Delete

The following tables show the calculations for the maximum water demands, by month, for the nine different land uses examined for these analyses. The water demand was calculated based on long-term modeling of Lincoln, NE, rainfall conditions and calculating the amount of infiltrating rainwater that was available to partially meet the ET requirements for the turf grass landscaped areas. This water demand is the balance of the ET not being met by the rainfall contributions. For each land use, the maximum irrigable land for 100 acres of the land use area was used to calculate the monthly water demand, as shown on the following tables:

month	Water demand to meet local ET for Lincoln, NE (gal/day/acre of landscaped area)	total irrig use (gal/day) for 14 acres of irrigated land per 100 acres of strip malls	total irrig use (gal/day) for 12 acres of irrigated land per 100 acres of shopping centers	total irrig use (gal/day) for 15 acres of irrigated land per 100 acres of light industrial areas	total irrig use (gal/day) for 48 acres of irrigated land per 100 acres of schools
Jan	372	5,208	4,352	5,692	17,670
Feb	1522	21,308	17,807	23,287	72,295
Mar	487	6,818	5,698	7,451	23,133
Apr	920	12,880	10,764	14,076	43,700
May	8836	123,704	103,381	135,191	419,710
Jun	1566	21,924	18,322	23,960	74,385
Jly	3159	44,226	36,960	48,333	150,053
Aug	3611	50,554	42,249	55,248	171,523
Sep	1239	17,346	14,496	18,957	58,853
Oct	0	0	0	0	0
Nov	0	0	0	0	0
Dec	0	0	0	0	0

month	total irrig use (gal/day) for 44 acres of irrigated land per 100 acres of churches	total irrig use (gal/day) for 33 acres of irrigated land per 100 acres of hospitals	total irrig use (gal/day) for 66 acres of irrigated land per 100 acres of low density residential areas	total irrig use (gal/day) for 58 acres of irrigated land per 100 acres of medium density residential areas (before 1960)	total irrig use (gal/day) for 63 acres of irrigated land per 100 acres of medium density residential areas (1960 to 1980)
Jan	16,182	12,239	24,589	21,725	23,250
Feb	66,207	50,074	100,604	88,885	95,125
Mar	21,185	16,022	32,191	28,441	30,438
Apr	40,020	30,268	60,812	53,728	57,500
May	384,366	290,704	584,060	516,022	552,250
Jun	68,121	51,521	103,513	91,454	97,875
Jly	137,417	103,931	208,810	184,486	197,438
Aug	157,079	118,802	238,687	210,882	225,688
Sep	53,897	40,763	81,898	72,358	77,438
Oct	0	0	0	0	0
Nov	0	0	0	0	0
Dec	0	0	0	0	0

The following figure summarizes the calculated benefits of storage and irrigation use of the runoff collected from directly connected residential roofs in the area. As an example, the use of a single rain barrel is expected to provide about a 24% reduction in runoff through irrigation to match ET. However, more than 25 would be needed to reduce the roof's contributions by 90%. In order to match the benefits of disconnection of the connected downspouts (about 78% reductions), about 25 rain barrels would be needed. Twenty-five rain barrels correspond to a total storage quantity about equal to 0.12 ft (1.4 inches). Six different water tankage scenarios were examined for each land use, as the ratio of roof area to landscaped area varied. The resulting storage volumes and numbers of 35 gallon rain barrels and 6 ft tall by 6 ft diameter water tanks that were used in the modeling are shown on these tables for each land use.



The number of rain barrels or water tanks per acre of roof and landscaped area is the same for each land use, but because the roof areas varied by lands use, the number of each storage container varied. The wide range of storage volumes was considered because the irrigation potential varied for each land use.

25 acres of roof area in 100 acres of strip mall area	number of 35 gal barrels per acre of roof	number of 35 gal barrels per 100 acres of site	number of 6 ft dia 6 ft tall tanks per acre of roof	number of 6 ft dia 6 ft tall tanks per 100 acres of site
2.5 ft tall barrels:				
few rain barrels (at 0.01 ft^3/ft^2)	93	931	3	26
rain barrel (at 0.02 ft^3/ft^2)	186	1862	5	51
many rain barrels (at 0.05 ft^3/ft^2)	465	4655	13	128
6 ft tall tanks:				
small rain tank (at 0.10 ft^3/ft^2)			26	107
rain tank (at 0.25 ft^3/ft^2)			64	267
large rain tank (0.75 ft^3/ft^2)			192	801

27 acres of roof area in 100 acres of shopping center area	number of 35 gal barrels per acre of roof	number of 35 gal barrels per 100 acres of site	number of 6 ft dia 6 ft tall tanks per acre of roof	number of 6 ft dia 6 ft tall tanks per 100 acres of site
2.5 ft tall barrels:				
few rain barrels (at 0.01 ft^3/ft^2)	93	1009	3	28
rain barrel (at 0.02 ft^3/ft^2)	186	2018	5	56
many rain barrels (at 0.05 ft^3/ft^2)	465	5046	13	139
6 ft tall tanks:				
small rain tank (at 0.10 ft^3/ft^2)			26	116
rain tank (at 0.25 ft^3/ft^2)			64	289
large rain tank (0.75 ft^3/ft^2)			192	868

5.6 acres of roof area in 100 acres of light industrial area	number of 35 gal barrels per acre of roof	number of 35 gal barrels per 100 acres of site	number of 6 ft dia 6 ft tall tanks per acre of roof	number of 6 ft dia 6 ft tall tanks per 100 acres of site
2.5 ft tall barrels:				
few rain barrels (at 0.01 ft^3/ft^2)	93	209	3	6
rain barrel (at 0.02 ft^3/ft^2)	186	417	5	11
many rain barrels (at 0.05 ft^3/ft^2)	465	1043	13	29
6 ft tall tanks:				
small rain tank (at 0.10 ft^3/ft^2)			26	24
rain tank (at 0.25 ft^3/ft^2)			64	60
large rain tank (0.75 ft^3/ft^2)			192	179

24 acres of roof area in 100 acres of school area	number of 35 gal barrels per acre of roof	number of 35 gal barrels per 100 acres of site	number of 6 ft dia 6 ft tall tanks per acre of roof	number of 6 ft dia 6 ft tall tanks per 100 acres of site
2.5 ft tall barrels:				
few rain barrels (at 0.01 ft^3/ft^2)	93	894	3	25
rain barrel (at 0.02 ft^3/ft^2)	186	1787	5	49
many rain barrels (at 0.05 ft^3/ft^2)	465	4469	13	123
6 ft tall tanks:				
small rain tank (at 0.10 ft^3/ft^2)			26	102
rain tank (at 0.25 ft^3/ft^2)			64	256
large rain tank (0.75 ft^3/ft^2)			192	769

24 acres of roof area in 100 acres of church area	number of 35 gal barrels per acre of roof	number of 35 gal barrels per 100 acres of site	number of 6 ft dia 6 ft tall tanks per acre of roof	number of 6 ft dia 6 ft tall tanks per 100 acres of site
2.5 ft tall barrels:				
few rain barrels (at 0.01 ft^3/ft^2)	93	894	3	25
rain barrel (at 0.02 ft^3/ft^2)	186	1787	5	49
many rain barrels (at 0.05 ft^3/ft^2)	465	4469	13	123
6 ft tall tanks:				
small rain tank (at 0.10 ft^3/ft^2)			26	102
rain tank (at 0.25 ft^3/ft^2)			64	256
large rain tank (0.75 ft^3/ft^2)			192	769

20 acres of roof area in 100 acres of hospital area	number of 35 gal barrels per acre of roof	number of 35 gal barrels per 100 acres of site	number of 6 ft dia 6 ft tall tanks per acre of roof	number of 6 ft dia 6 ft tall tanks per 100 acres of site
2.5 ft tall barrels:				
few rain barrels (at 0.01 ft^3/ft^2)	93	741	3	20
rain barrel (at 0.02 ft^3/ft^2)	186	1482	5	41
many rain barrels (at 0.05 ft^3/ft^2)	465	3705	13	102
6 ft tall tanks:				
small rain tank (at 0.10 ft^3/ft^2)			26	85
rain tank (at 0.25 ft^3/ft^2)			64	212
large rain tank (0.75 ft^3/ft^2)			192	637

1.8 acres of roof area in 100 acres of low density residential area	number of 35 gal barrels per acre of roof	number of 35 gal barrels per 100 acres of site	number of 6 ft dia 6 ft tall tanks per acre of roof	number of 6 ft dia 6 ft tall tanks per 100 acres of site
2.5 ft tall barrels:				
few rain barrels (at 0.01 ft^3/ft^2)	93	67	3	2
rain barrel (at 0.02 ft^3/ft^2)	186	134	5	4
many rain barrels (at 0.05 ft^3/ft^2)	465	335	13	9
6 ft tall tanks:				
small rain tank (at 0.10 ft^3/ft^2)			26	8
rain tank (at 0.25 ft^3/ft^2)			64	19
large rain tank (0.75 ft^3/ft^2)			192	58

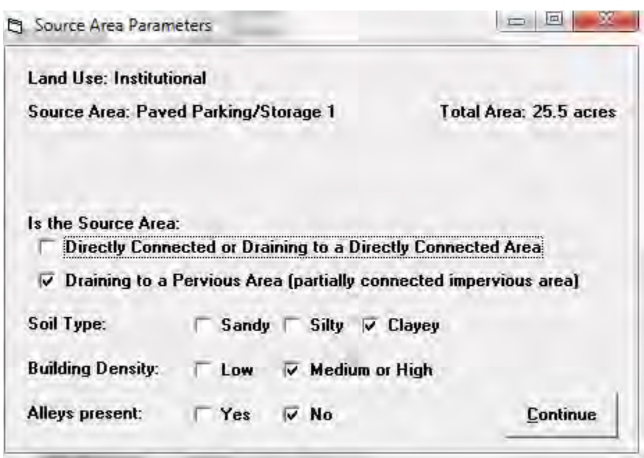
2.8 acres of roof area in 100 acres of pre 1960 medium density residential area	number of 35 gal barrels per acre of roof	number of 35 gal barrels per 100 acres of site	number of 6 ft dia 6 ft tall tanks per acre of roof	number of 6 ft dia 6 ft tall tanks per 100 acres of site
2.5 ft tall barrels:				
few rain barrels (at 0.01 ft^3/ft^2)	93	104	3	3
rain barrel (at 0.02 ft^3/ft^2)	186	209	5	6
many rain barrels (at 0.05 ft^3/ft^2)	465	521	13	14
6 ft tall tanks:				
small rain tank (at 0.10 ft^3/ft^2)			26	12
rain tank (at 0.25 ft^3/ft^2)			64	30
large rain tank (0.75 ft^3/ft^2)			192	90

4.4 acres of roof area in 100 acres of 1960 to 1980 medium density residential area	number of 35 gal barrels per acre of roof	number of 35 gal barrels per 100 acres of site	number of 6 ft dia 6 ft tall tanks per acre of roof	number of 6 ft dia 6 ft tall tanks per 100 acres of site
2.5 ft tall barrels:				
few rain barrels (at 0.01 ft^3/ft^2)	93	164	3	5
rain barrel (at 0.02 ft^3/ft^2)	186	328	5	9
many rain barrels (at 0.05 ft^3/ft^2)	465	819	13	23
6 ft tall tanks:				
small rain tank (at 0.10 ft^3/ft^2)			26	19
rain tank (at 0.25 ft^3/ft^2)			64	47
large rain tank (0.75 ft^3/ft^2)			192	141

Pavement Controls

Disconnections

Disconnections for roof runoff and for pavements are calculated in similar manners and require similar information in version 9.5. In the upcoming version 10, more direct analyses will be used to calculate the benefits of grass filters. In version 9.5, the results of extensive field monitoring at many locations having varying amounts of disconnected pavement (and roofs) were examined and compared. The model reduces the effective runoff coefficients as a function of land use, the soil type, the building density, and if alleys are present. These factors have all been found to significantly affect the drainage efficiency of an area. The following is the input screen for modifying the pavement connections for an area.

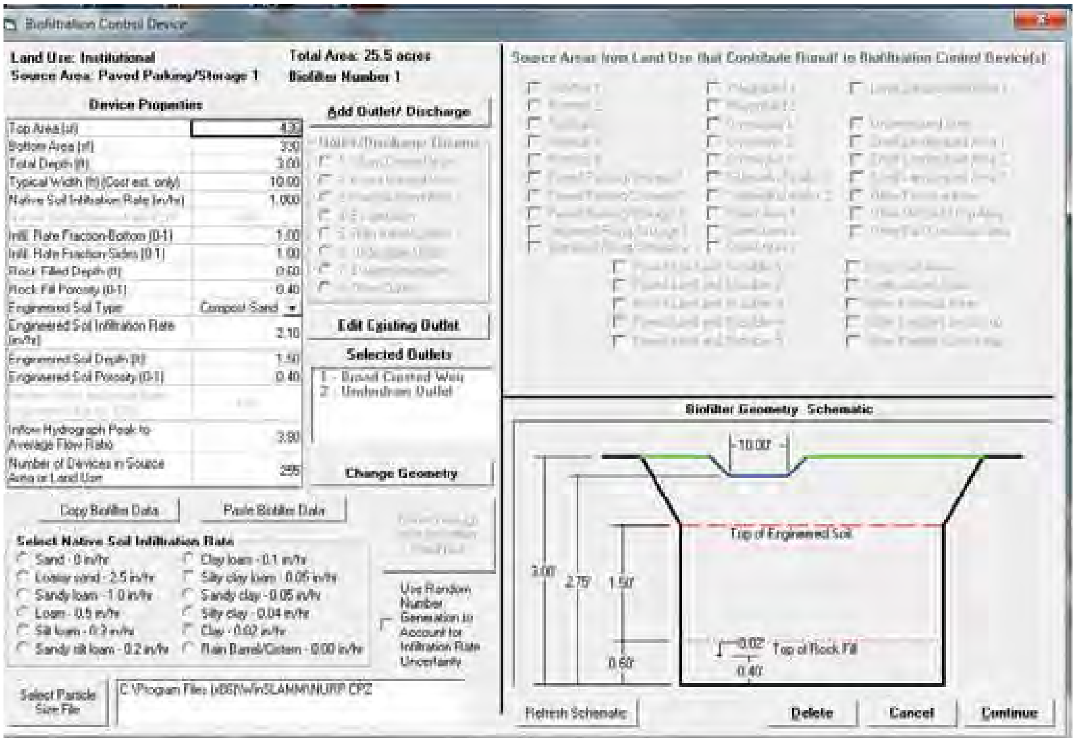


Biofiltration

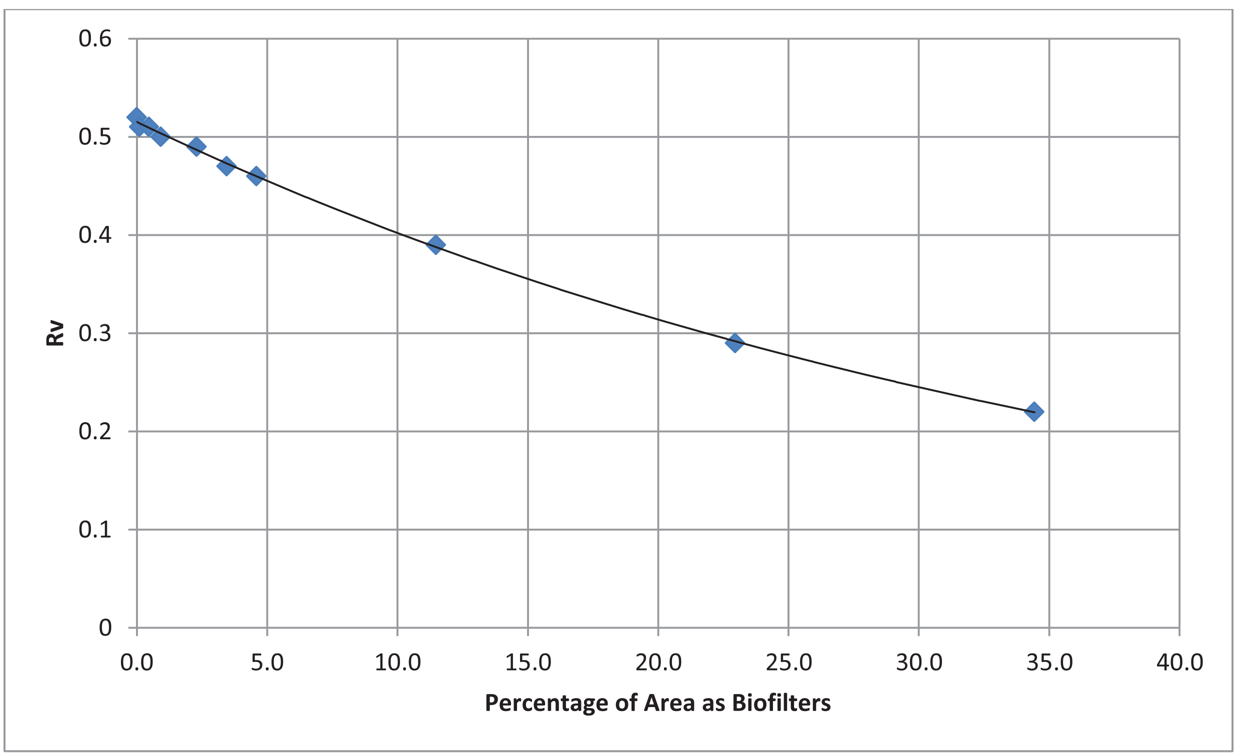
The performance of biofiltration devices is affected by several unit processes that are modeled in WinSLAMM. Modified puls hydraulic routing with surface overflow calculations are the basic processes used in the modeling of these devices. However, several layers in the biofilter are also considered. As runoff enters the device, water infiltrates through the engineered soil or media fill. If the entering rain-runoff cannot all be infiltrated through the surface layer, water will pond. If the ponding becomes deep, it may overflow through a surface outlet. The percolating water moves down through the device until it reaches the bottom and intercepts the native soil. If the native soil infiltration rate is less than the percolation water rate, then there is no subsurface ponding; if the native soil infiltration rate is slower than the percolation water rate, ponding will occur. This ponding may buildup to the surface of the device and add to the surface ponding. If an underdrain is present (usually with a subsurface storage layer), the subsurface ponding water will be intercepted by the drain which is then discharged to the surface water, but later in the event and is filtered by the media. With the water percolating through the fill, particulates and particulate-bound pollutants are trapped by the fill through filtering actions. Therefore, the underdrain water usually has a lower particulate solids content than the surface waters entering the device. The calculations are sensitive to the amounts of the different media used as fill and its characteristics (especially its porosity and percolation rate; and if evapotranspiration (ET) is used, the wilting point). The hydraulic routing uses the sum of the void volumes in the device to determine the effluent hydrograph, while the different infiltration/percolation rates affect the internal ponding. The stage-discharge relationships of the outlet devices are all modeled using conventional hydraulic processes. The ET loss calculations are based on the changing water content in the root zone at each time increment, and the ET adjustment factors for the mixture of plants in the device.

Biofilters can be used as control devices in individual source areas, in land uses, as a part of the drainage system or at the outfall. If modeled as an outfall biofilter, the biofiltration control can be used with an upstream wet detention pond for pretreatment. To model biofilters in a source area, as in these examples, the geometry and other characteristics of a typical biofilter are described, then the number of biofilters in the source area is entered. The model divides the total source area runoff flows by the number of biofilters in the source area, creates a complex triangular hydrograph for that representative flow fraction that is then routed through that biofilter, and then multiplies the resulting losses by the number of biofilters for the total source area.

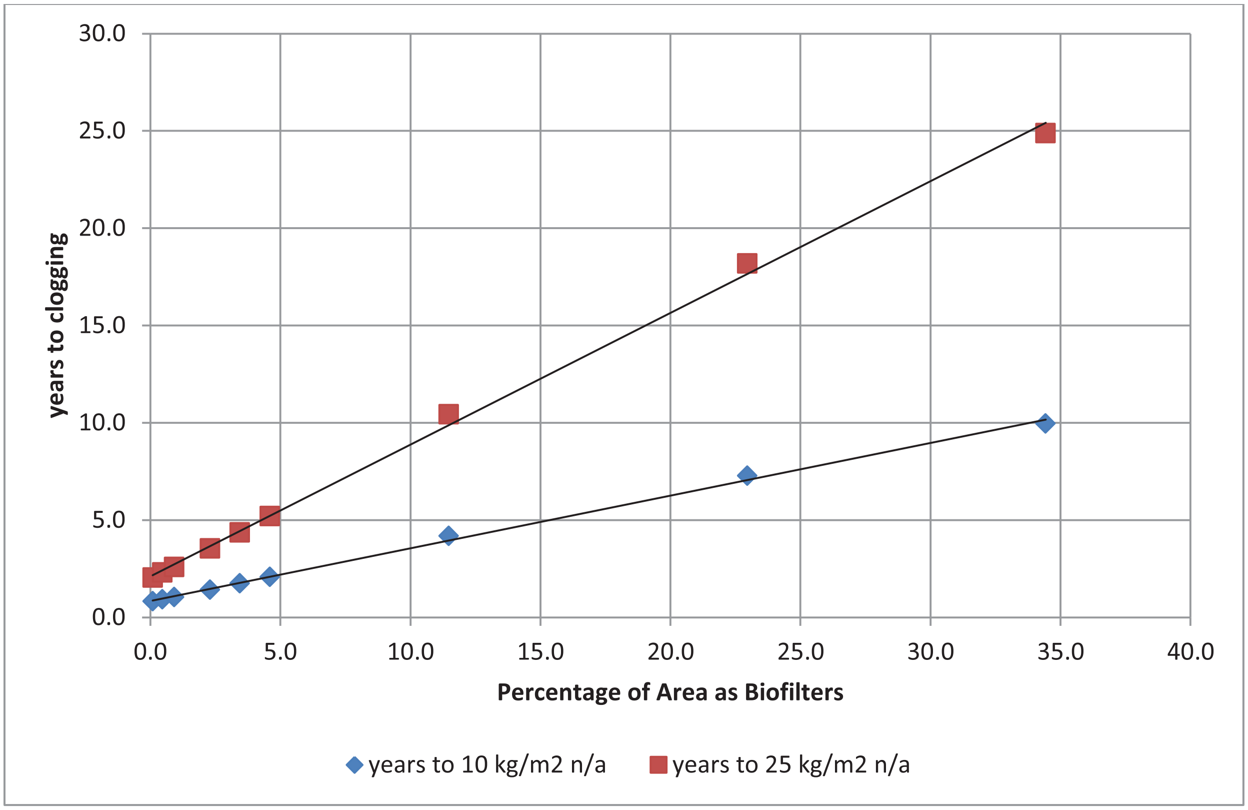
The following is the WinSLAMM input form for the biofilters that were examined. The biofilters described on this form were located in paved parking areas, and contains a SmartDrain. The production functions were prepared by varying the number of these standard sized units. The total area of the devices is the critical measure of application of the biofilters.



Biofiltration Control Device
Land Use: Institutional
Source Area: Paved Parking/Storage 1
Total Area: 25.5 acres
Biofilter Number 1
Device Properties
Top Area (sf) 4.30
Bottom Area (sf) 3.30
Total Depth (ft) 3.00
Typical Width (ft) (Cost est. only) 10.00
Native Soil Infiltration Rate (in/hr) 1.000
Infil. Rate Fraction-Bottom (0-1) 1.00
Infil. Rate Fraction-Sides (0-1) 1.00
Rock Filled Depth (ft) 0.60
Rock Fill Porosity (0-1) 0.40
Engineered Soil Type Compost-Sand
Engineered Soil Infiltration Rate (in/hr) 2.10
Engineered Soil Depth (ft) 1.50
Engineered Soil Porosity (0-1) 0.40
Inflow Hydrograph Peak to Average Flow Ratio 3.80
Number of Devices in Source Area or Land Use 255
Add Outlet/ Discharge
Edit Existing Outlet
Selected Outlets
1 - Broad Crested Weir
2 - Underdrain Outlet
Change Geometry
Copy Biofilter Data
Paste Biofilter Data
Select Native Soil Infiltration Rate
Sand - 8 in/hr
Loamy sand - 2.5 in/hr
Sandy loam - 1.0 in/hr
Loam - 0.5 in/hr
Silt loam - 0.3 in/hr
Sandy silt loam - 0.2 in/hr
Clay loam - 0.1 in/hr
Silty clay loam - 0.05 in/hr
Sandy clay - 0.05 in/hr
Silty clay - 0.04 in/hr
Clay - 0.02 in/hr
Rain Barrel/Cistern - 0.00 in/hr
Use Random Number Generation to Account for Infiltration Rate Uncertainty
Select Particle Size File
C:\Program Files (x86)\WinSLAMM\NURP.CPZ
Source Areas from Land Use that Contribute Runoff to Biofiltration Control Device(s)
Biofilter Geometry Schematic
10.00'
Top of Engineered Soil
3.00'
2.75'
1.50'
0.02'
Top of Rock Fill
0.60'
0.40'
Refresh Schematic
Delete
Cancel
Continue



0.6
0.5
0.4
0.3
0.2
0.1
0
Rv
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
Percentage of Area as Biofilters

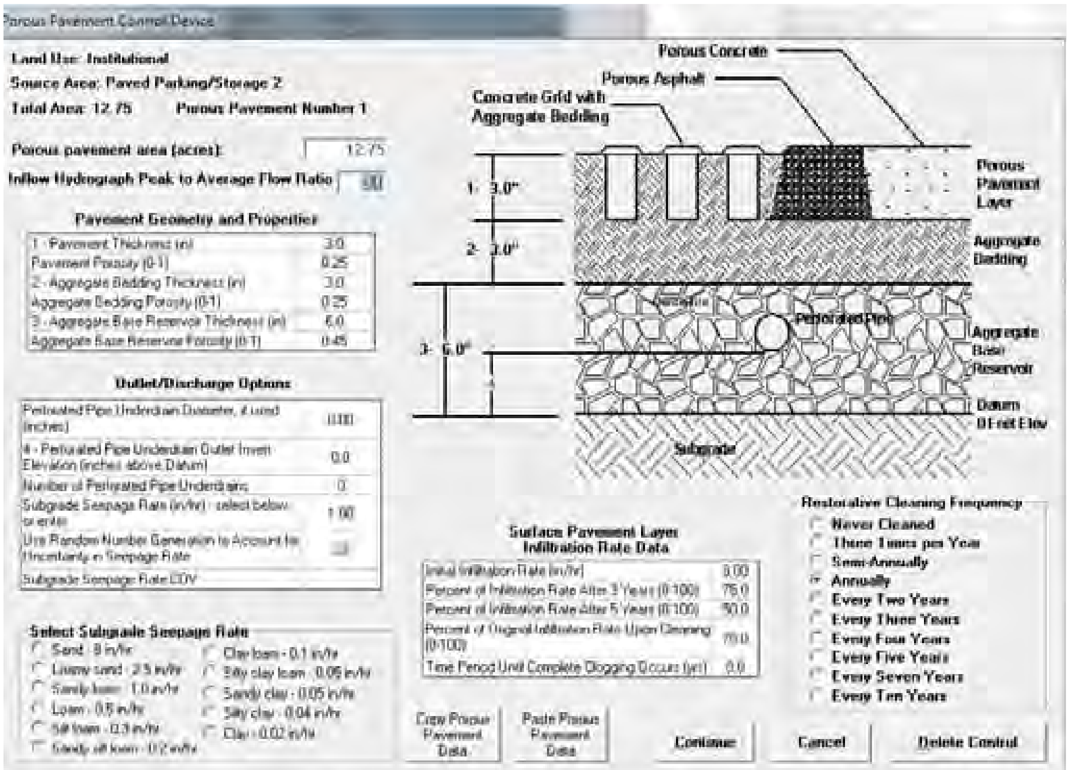


The above production functions were based on typical pavement conditions and relate the area of the paved area dedicated as biofilters to their expected performance. In this example, almost 25% of the paved area would have to be dedicated as biofilters to produce about half the runoff compared to an uncontrolled area, a clearly unworkable option. When examining the clogging potential of biofilters for very dirty paved parking areas, biofilters between about 12 and 34% of the area are needed to prevent clogging loadings (assumed to be between 10 and 25 kg/m^2 within a 10 year period of time). Cleaner sites could have smaller biofilters, while even dirtier sites would need larger biofilters in order to have a ten year service life, assumed to be the goal for these areas. Pretreatment is another option to extend the service life of the biofilters. Pollutant reductions are maximized when the biofilters are about 10% of the area, with no further benefits.

These production functions were used to select the range of biofilters to use for treating paved areas in the different land uses. For clay loam soil conditions, the biofilters examined were 3, 10, and 25% of the paved contributing area, while for sandy soil conditions, the biofilters examined were 3 and 10% of the paved areas.

Porous Pavement

Porous pavement structures can be designed to totally eliminate all runoff from the area covered by the porous pavement. WinSLAMM version 9.5 doesn't allow any run-on to the porous pavement; only rainfall directly onto the porous pavement is considered. Version 10 does allow run-on from adjacent areas. The following screen shows the information entered to analyze porous pavements:



The following is a summary from the porous pavement HELP screens in WinSLAMM: The porous pavement control option uses full routing calculations associated with pond storage in conjunction with other porous pavement features. The “outlet” options for porous pavement include subgrade seepage as well as an optional underdrain, which is modeled as an orifice. The porous pavement control device option also has a surface seepage rate that limits the amount of runoff that can enter the storage system. This surface seepage rate can be reduced to account for clogging over time, and the surface seepage rate can be partially restored with cleaning at a stated cleaning frequency. The porous pavement control device infiltrates water originating from the rainfall hitting the pavement surface area only - it does not accept run-on from other surfaces. The runoff volume reaching the porous pavement surface is therefore equal to the rainfall volume directly falling on the porous pavement. The porous pavement surface area can be any suitable porous pavement material, including paver blocks, porous concrete, porous asphalt, or any other porous surface or just turf reinforcement. Porous pavements are usually installed over a subsurface storage layer that can dramatically increase the infiltration performance of the device.

The porous pavement control option can be used as a control device only in individual source areas. Porous pavements are usually located at paved parking and storage areas, paved playgrounds, paved driveways, or paved walkways. They should be used only in relatively clean areas (walkways or driveways or other surfaces that receive little traffic, for example), to minimize groundwater contamination potential. Porous pavements direct the infiltrating water to subsurface soil layers, usually beneath much or the organic surface soils that tend to sorb many pollutants. Salts used for ice control in northern areas are also problematic when considering infiltrating stormwater. Therefore, only use porous pavements in areas needing minimal salt applications. Consider biofiltration devices to infiltrate water from more contaminated sites, as they can use amended soils to help trap contaminants before infiltration, or use other appropriate pre-treatment before infiltration. No common pretreatment device is suitable for the removal of salts, however, so minimal use is the preferred control option in that case.

Pavement Geometry and Properties:

1. Pavement thickness (inches): Enter the thickness of the surface pavement.

2. Pavement porosity (unit less): Enter the porosity (the ratio of air volume to total volume) of the surface pavement. This ratio can range from zero to one.

3. Aggregate bedding thickness (inches): Enter the thickness of the aggregate bedding layer.

4. Aggregate bedding porosity (unit less): Enter the porosity (the ratio of air volume to total volume) of the aggregate bedding. This ratio can range from zero to one.

5. Aggregate base reservoir thickness (inches): Enter the thickness of the aggregate base reservoir.

6. Aggregate base reservoir thickness porosity (unit less): Enter the porosity (the ratio of air volume to total volume) of the aggregate base reservoir thickness. This ratio can range from zero to one.

Outlet/Discharge Options:

7. Underdrain diameter (inches): Enter the diameter of the underdrain. This is an optional outlet. The model calculates flow through the underdrain as an orifice; it assumes that the discharge flow is not limited by friction through underdrain pipe slots or pipe friction (the water velocity is usually very slow). Any water entering the underdrain is re-directed to surface flows; it is not infiltrated. WinSLAMM adds this runoff volume (and associated pollutants) back to the surface drainage system. An underdrain is usually specified to minimize ponding on the surface of the porous pavement such as when the aggregate grade base reservoir nears capacity.

8. Underdrain outlet invert elevation (inches above datum): Enter the elevation of the invert of the underdrain outlet. The model assumes that all porous pavement surfaces are flat and that the underdrains also have minimal gradient.

9. Number of underdrains. Enter the number of underdrains in the porous pavement control device.

10. Subgrade seepage rate (in/hr): Enter the subgrade seepage rate. Default values for selected soil types are listed in the radio buttons below the data entry table, or you can enter your own values, if known. You can also vary this value stochastically by electing to use the random number generator.

11. Random number generator: Check this box to generate a random subgrade seepage value for each rainfall event. These values are randomly generated based upon a log normal distribution.

12. Subgrade seepage rate COV: Enter the Coefficient of Variation (COV) for the seepage rate you are using if you intend to generate seepage rates stochastically. The COV values are given if you use the radio buttons to select the seepage rate, and are based on numerous field tests. Soil seepage rates can vary greatly over short distances, even for the same soil textures, usually due to compaction, roots, soil animals, etc.

Surface Pavement Layer Infiltration Rate Data:

13. Initial infiltration rate (in/hr): Enter the infiltration rate through the surface layer when the pavement was newly installed. Any rain having intensities greater than this initial infiltration rate will not enter the porous pavement structure, but will run off. The rain intensities are calculated using the complex triangular distribution in WinSLAMM. Initial infiltration rates for porous pavements are usually very large (ranging from 5 to 20, or even more, in/hr, based on the specifications for the material used).

14. Percent of infiltration rate after three years (0-100): Enter the percent of the initial surface infiltration rate you expect the surface to have after three years without cleaning. If you expect it to maintain the initial rate, then enter 100. This, and the next parameter, determines how fast the pavement surface water infiltration rate degrades with time. This value is highly dependent on the type of pavement material Paver blocks may clog more slowly; areas with more traffic clog faster; tracking of mud or other debris also hastens clogging; many site factors affect long-term performance, and this value should be based on regional monitoring for similar conditions and similar porous pavement materials. A suitable value may be about 75%, indicating a 25% reduction over the first three years of porous pavement life.

15. Percent of infiltration rate after five years (0-100): Enter the percent of the initial surface infiltration rate you expect the surface to have after five years without cleaning. If you expect it to maintain the initial rate, then enter 100. This factor is also dependent on site conditions. A suitable factor may be 50% after five years.

16. Percent of original infiltration rate restored upon cleaning (0-100): Enter the percent of the initial surface infiltration rate the surface will have after it is cleaned. If there is more than one cleaning, the surface infiltration rate will return to this percentage of the initial rate after every cleaning. If you expect it to maintain the initial rate, then enter 100. In most cases, typical porous pavement restorative cleaning activities cannot completely restore the initial rate. However, this factor should also be determined locally. A suitable value may be about 85%, but can vary widely.

17. Time period until complete clogging occurs (years): This is the time when complete failure of the surface infiltration rate occurs. It can be regenerated to whatever percent of the initial infiltration rate you entered for the previous variable upon cleaning. This is also dependent on local conditions. With no cleaning, most porous pavements are expected to eventually completely clog. A value of about 10 years may be a suitable value.

18. Restorative cleaning frequency: Enter how often the porous pavement surface will be cleaned. All stormwater controls need maintenance, and porous pavement is no exception. Commercial paved areas may be cleaned quite frequently to remove large debris, but standard pavement cleaning is usually not adequate to maintain an acceptable infiltration rate. Special cleaning operations are needed, but may be much less frequent. Consult the manufacture of the porous pavement for proper cleaning techniques and frequencies. Once a year may be a suitable value, but will depend on local conditions.

The storage provided by the pore space in the pavement (asphalt, concrete, block, or turf reinforcement grids) plus in the bedding and in the storage rock reservoir easily exceeds the depth of rain for even the most severe rains in an area. The reservoir volume than needs to drain through the underlying natural soils before the next rain, or the storage volume is reduced. In these calculations, all porous pavements are 3 inches thick with a 3 inch bedding layer and a 6 inch storage layer. They were used for half of the paved parking areas, in the assumed overflow parking areas that receive little parking. Due to groundwater concerns, porous pavement was not considered in areas having heavy traffic or parking. These were assumed to be cleaned yearly. The model used a decreasing rate of infiltration as the porous pavement aged, and good recovery was obtained when cleaned. The largest detriments to porous pavements include:

1) high costs, especially when retrofitting in an existing paved area

2) relatively high efficiency of transport of contaminants to the subsurface areas

3) cleaning is needed to maintain high infiltration rates

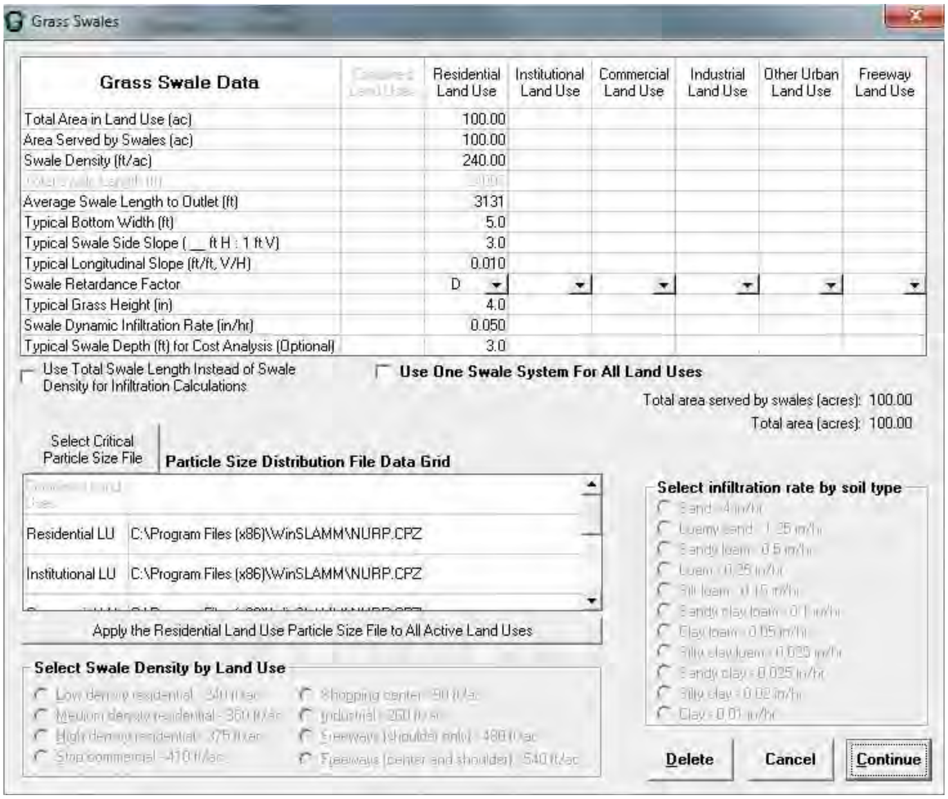
Street Side Drainage Controls

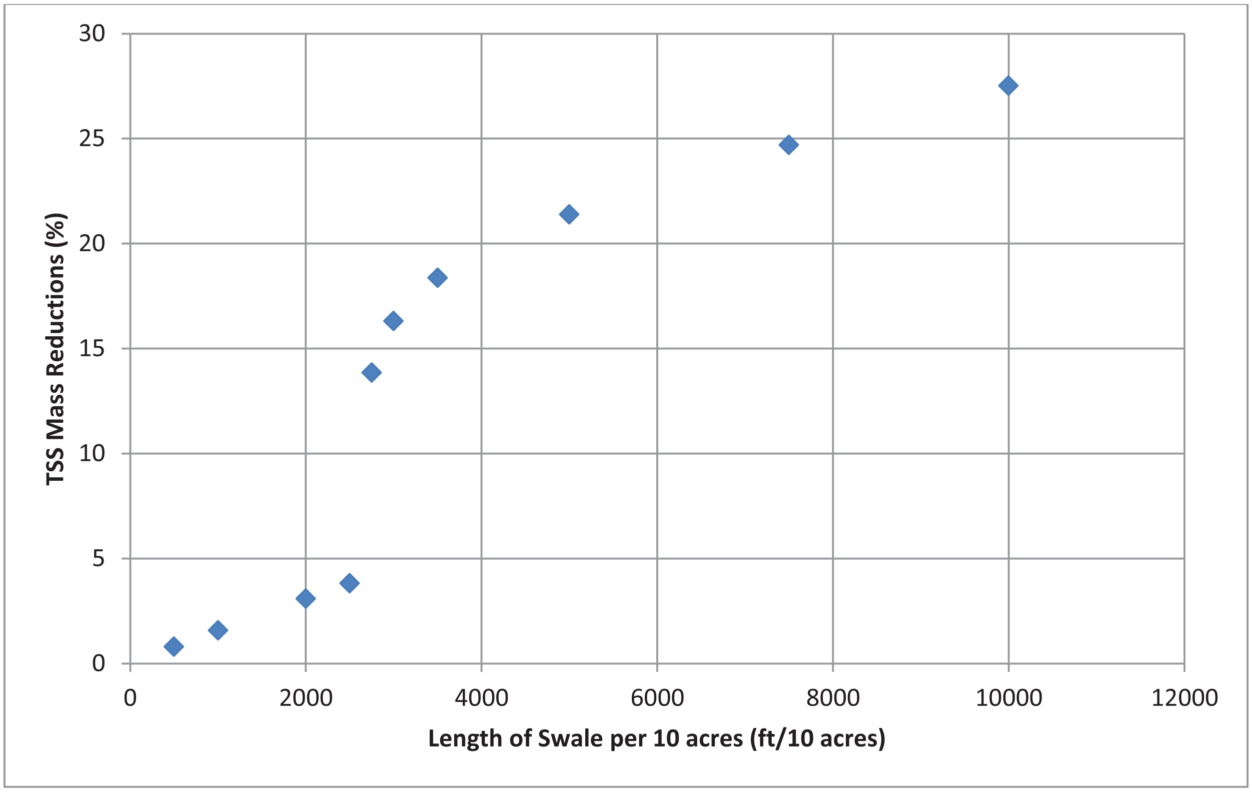
Grass Swales

Grass filters have broad, shallow flows, while grass swales have concentrated flows. Grass filters are modeled as a special case of grass swales in version 9.5 of WinSLAMM. The model calculations are based on extensive pilot-scale and field measurements of grass swales and filters conducted for the Alabama Dept. of Transportation. The algorithms used to determine the Manning's n values used in grass swale hydraulic calculations were developed from the master's thesis work by Jason Kirby (Kirby, J.T., S.R. Durrans, R. Pitt, and P.D. Johnson. "Hydraulic resistance in grass swales designed for small flow conveyance." Journal of Hydraulic Engineering, Vol. 131, No. 1, Jan. 2005.) as part of a WERF-supported research project: Johnson, P.D., R. Pitt, S.R. Durrans, M. Uremia, and S. Clark. Metals Removal Technologies for Urban Stormwater. Water Environment Research Foundation. WERF 97-IRM-2. ISBN: 1-94339-682-3. Alexandria, VA. 701 pgs. Oct. 2003. The particle trapping algorithms were based on the master's thesis research conducted by Yukio Nara (Nara, Y., R. Pitt, S.R. Durrans, and J. Kirby. "Sediment transport in grass swales." In: Stormwater and Urban Water Systems Modeling. Monograph 14. edited by W. James, K.N. Irvine, E.A. McLean, and R.E. Pitt. CHI. Guelph, Ontario, pp. 379 402. 2006.), supported by the University Transportation Center for Alabama: "Alabama Highway Drainage Conservation Design Practices - Particulate Transport in Grass Swales and Grass Filters", by Yukio Nara and Robert Pitt, University Transportation Center for Alabama, University of Alabama, Tuscaloosa, Alabama, November, 2005.

Grass swale performance is determined by routing a complex triangular hydrograph through the swales described in the model by the user. Runoff volume reductions are determined by infiltration losses, and particulate losses are determined through particle trapping. Runoff volume is reduced by the dynamic infiltration rate of the swales for each six minute time step of the hydrograph. The flow and the swale geometry are used to determine the Manning's n to iteratively determine the depth of flow in the swale for each time step, using traditional VR-n curves that were extended by Kirby to cover the smaller flows found in typical drainage swales. Using the calculated depth of flow for each time increment, the model calculates the wetted perimeter (based on the swale cross-sectional shape) which is then multiplied by the total swale length to determine the area used to infiltrate the runoff. The settling frequency and resultant particulate trapping is calculated for each of the thirty-one particle size fractions in the selected particle size distribution file. The resulting particulate concentrations are then combined into one of eight groups of particle sizes, where it is evaluated to determine if it is below the irreducible concentration values for each particle size group. No resulting concentration values are allowed to go below the irreducible concentration values unless the inflow value is already below that level. For grass swales, no particles smaller than 50 µm are trapped due to turbulent resuspensions of the small particles.

The following is the grass swale information screen in WinSLAMM used in these calculations. The swale density (and resulting total swale length) was varied to develop the production function curves that describe swale performance by swale density for the different land uses.

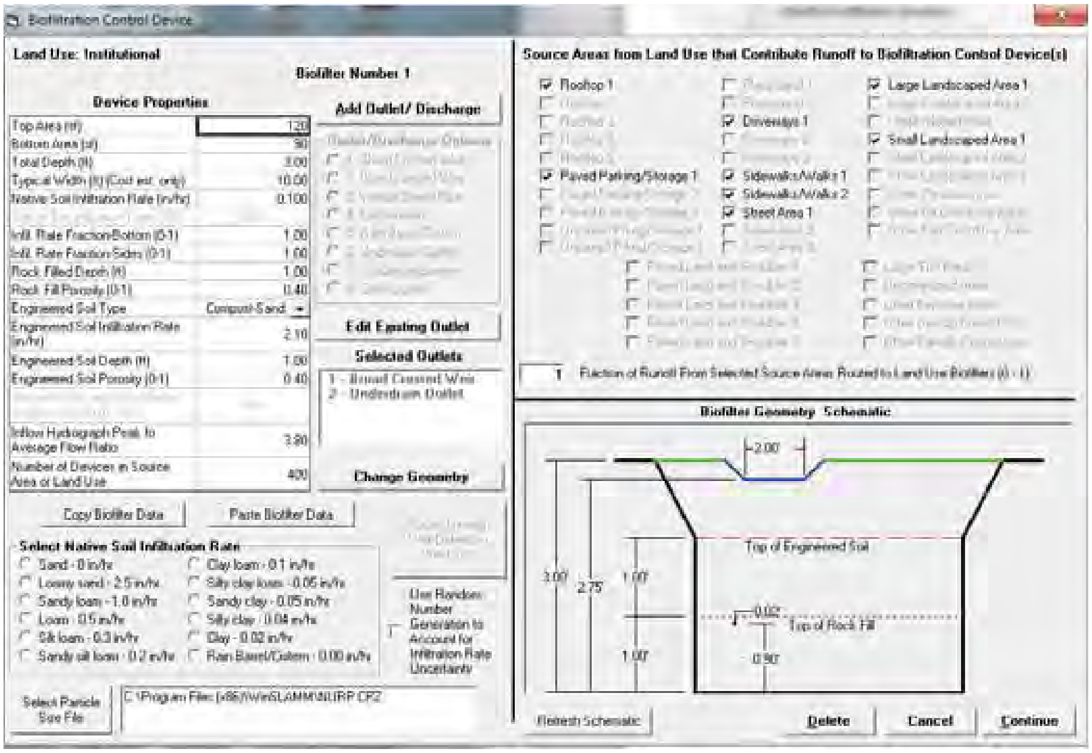




The above production functions show the resulting TSS reductions after treatment in grass swales. The lengths of the swales are shown as length per area (ft per 10 acres). Similar to the biofilters, the benefits of grass swales in reducing runoff volumes is limited because of compacted soils. The plot of TSS mass reductions shows that two mechanisms are responsible for sediment removal. For short swales, the sediment reduction is only associated with the volume reduction of the flowing water. After about 2,800 ft/10 acres, sediment deposition also occurs after sufficient length is available to overcome scour, after about 3,000 ft/10 acres, the sediment reductions change less rapidly.

Curb-cut Biofilters

The mechanisms available for treatment of stormwater in curb-cut biofilters are the same as previously described for parking area biofilters. For these devices, the curb face is cut and the water is allowed to flow into an excavation adjacent to the curb line, usually in an area between the sidewalks and the streets. If this area is too narrow, a curb-extension biofilter may be used. In this case, the excavated area extends out into the street, usually consuming a section of the parking lane. The earlier production functions were examined and sizes of these devices for the Lincoln land uses were determined. Curb-cut biofilters consuming 20, 40, and 80% of the length of the curb length were examined in these calculations, for both clay loam and sandy loam soil conditions in the biofilters, for each land use. The following is the input screen used for these controls:



Public Works Practices

Street Cleaning

The street cleaning control option can be applied to streets and alleys. There are two options for entering in street cleaning dates. 1) Enter Street Cleaning Dates, or 2) Enter a Street Cleaning Frequency. Note that if a street cleaning event occurs on the same day as a rainfall event (such as on April 1 when the 'One Pass Each Spring' option is selected), then the street cleaning event is cancelled for that event.

• Entering a street cleaning frequency. Select the 'Street Cleaning Frequency' check box, and then the desired frequency. This frequency will be applied from the beginning date to the ending date of the model run. The spring pass occurs on the day that the winter season ends during every year in the model run. The fall pass occurs on October 31st of every year of the model run.

· Type of Street Cleaner. Select the type of street cleaner. The program will enter the proper coefficients M and B after you have selected the street cleaner productivity, parking density and parking control option.

· Street cleaning productivity. Select the default productivity by entering the parking density and the parking control status. The parking density options are:

1. None - There is no parking along the street being swept.
2. Light - There is significant spacing between parked cars such that street cleaners can easily get to the curb, between cars, for significant sections of the street.
3. Medium - There is enough spacing between parked cars such that street cleaners can get to the curb for at least some sections of the street.
4. Extensive (short term) - There is not enough space between cars to allow street cleaners to get to the curb for some time during a 24-hour period.

5. Extensive (long term) - There is not enough space between cars to allow street cleaners to get to the curb. This condition persists for most or all of a 24-hour period.

· The parking control status indicates whether parking options such as limited parking hours or alternate side-of-the-street parking have been regulated by the municipality.

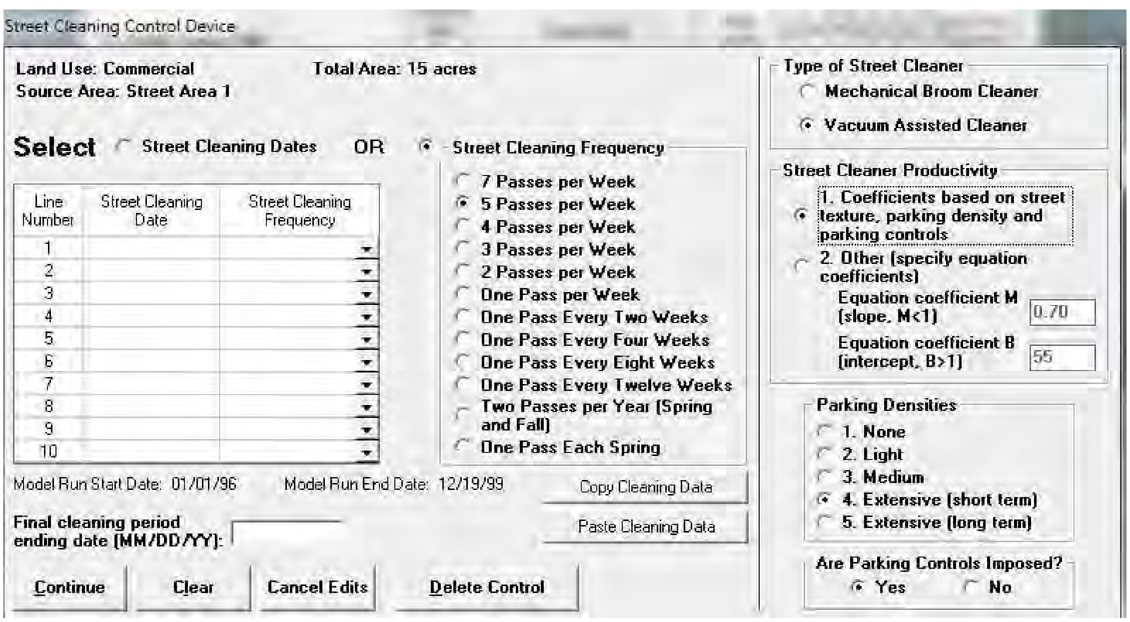
· Street cleaner productivity can also be described by entering the equation coefficients for the linear street cleaning equation, Y = mx + b, where is Y is the residual street dirt loading after street cleaning and x is the before street cleaning load (in lbs/curb-mile). Enter values for:

· m (slope, less than 1)

· b (intercept, greater than or equal to 1)

Where m is the minimum removal fraction, or street cleaning effectiveness, and b is the minimum street dirt loading, after intensive street cleaning.

The following is the street cleaning data entry screen used for these analyses:

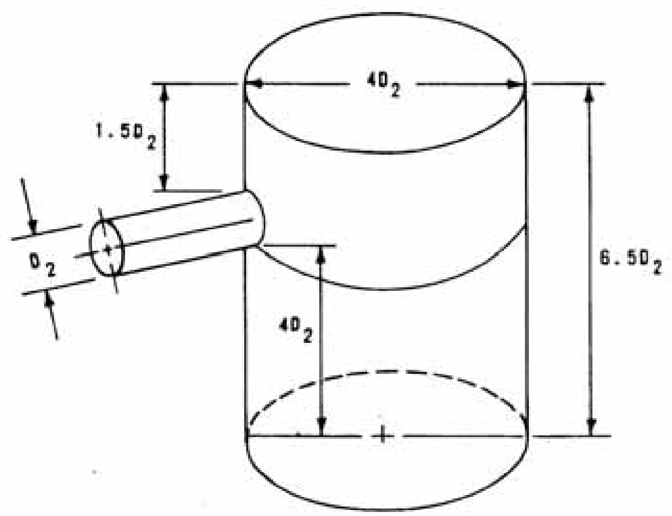


Catchbasin Cleaning

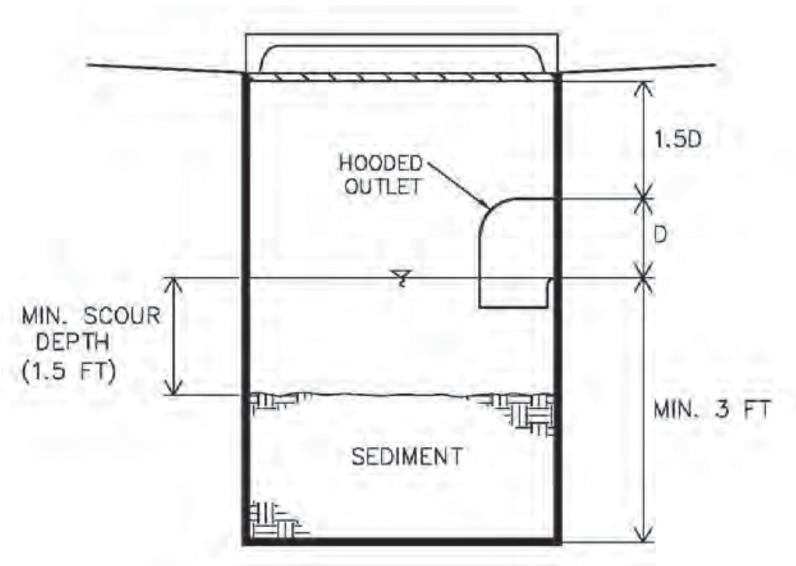
Catchbasins are chambers or sumps installed in a storm sewer, usually at the curb stormwater inlet to the drainage system. Catchbasins have a sump area below the inlet intended to retain captured sediment. By trapping coarse sediment, the catchbasin prevents trapped solids from clogging the sewer or being washed into receiving waters. However, the sumps must be cleaned out periodically to maintain their sediment trapping ability.

Catchbasins with sumps are effective for trapping coarse sediment and large debris and trash. If outfitted with hoods over the outlets, the capture of floatables and other litter can be improved. In addition to reducing sediment loads, catchbasin cleaning may also reduce the load of oxygen demanding substances that reach surface water. However, in the absence of suitable cleaning, they may make water quality worse due to the degradation of captured material.

Catchbasin performance is calculated by assuming flow through a settling area defined by the surface area of the catchbasin. The particulate removal in this settling area is assumed to occur due to ideal settling as described by Stokes Law (for laminar flow), or Newton's law (for turbulent flow). Catchbasin performance has been monitored during many field trials during EPA-sponsored research, and by other international researchers. Metcalf and Eddy (Lager, et al. 1977) developed an idealized catchbasin geometry based on laboratory and field experiments, as shown below:



According to this diagram, if the outlet diameter is 12 inches, the total height of the device should be at least 6.5 feet, the diameter of the manhole would be 48 inches, and the bottom edge of the outlet pipe would be located 48 inches above the device bottom and 18 inches below the top. In almost all full-scale field investigations, this design has been shown to withstand extreme flows with little scouring losses, no significant differences between supernatant water quality and runoff quality, and minimal insect problems. It will trap the bed-load from the stormwater (especially important in areas using sand for traction control) and will trap a low to moderate amount of suspended solids (about 30 to 45% of the annual loadings). The largest size fractions of the sediment in the flowing stormwater will be trapped (typically larger than 50 µm), in preference to the finer material that has greater amounts of associated pollutants. Their hydraulic capacities are designed using conventional procedures (grating and outlet dimensions), while the sump is designed based on the desired cleaning frequency. Pitt and Khambhammettu reviewed the performance of catchbasins from many sources, and recommended a basic catchbasin configuration having an appropriately sized sump with a hooded outlet. The following is the basic recommended configuration showing the hooded outlet for enhanced floatable control:

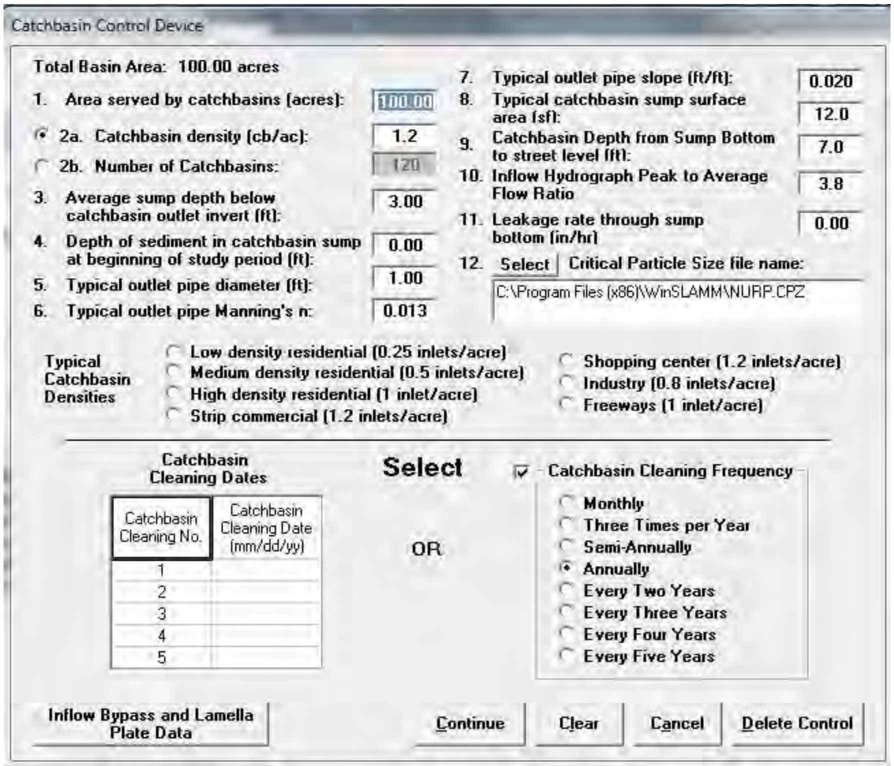


If the water velocity through the catchbasin is slow, slowly falling particles can be retained. If the water velocity is fast, then only the heaviest (fastest falling) particles are likely to be retained. The critical particle settling velocity is equal to the ratio of the discharge water rate to the surface area of the catchbasin. Particles having settling velocities greater than this ratio will be removed. Only increasing the surface area or decreasing the outflow rate will increase settling efficiency. Increasing the catchbasin sump depth does lessen the possibility of bottom scour and increases the estimated time between sump cleanings. Since the settling velocity increases as particle size increases (using Stokes or Newton's law and appropriate shape factors, specific gravity and viscosity values), the catchbasin water quality performance (or percent removal) is determined from the particle size distribution of the solids in the runoff entering the catchbasin. This is done by determining the settling velocity and then calculating the particle size associated with that settling velocity, which is referred to as the critical particle size. The percent of the particles that will settle is then determined from the particle size distribution of the total suspended solids (TSS) concentration of the sediment in the stormwater runoff.

Field test results indicate that the performance of catchbasins is strongly related to the inflowing water rate. The standard surface-overflow-rate (SOR) approach used in water and wastewater treatment facilities, and in sedimentation controls in WinSLAMM, normalizes the inflowing water rate with the surface area of the catchbasin. Detailed scour tests (computational fluid dynamics modeling and full-scale tests) were conducted to verify this approach and to measure critical scour conditions (Avila, H., R. Pitt, and S.E. Clark).

The model assumes that catchbasins with sumps are located at inlets or with minimal flow-through capability. Sumps that are constructed in series would have increasingly larger flow rates in each device, which is not what the program would be modeling. This condition may be evaluated by creating a series of .dat files for the catchbasin series. Each catchbasin would include separate source areas for the upstream drainage areas and the contributing drainage areas. To evaluate flow but not loading in each file, the upstream source areas should have the other control practice activated with 100% control of solids, only. This will allow the program to evaluate each catchbasin with the appropriate flow, from all source areas, while accounting for the loading only from the immediately contributing area.

The following is the data entry form for catchbasins in WinSLAMM:



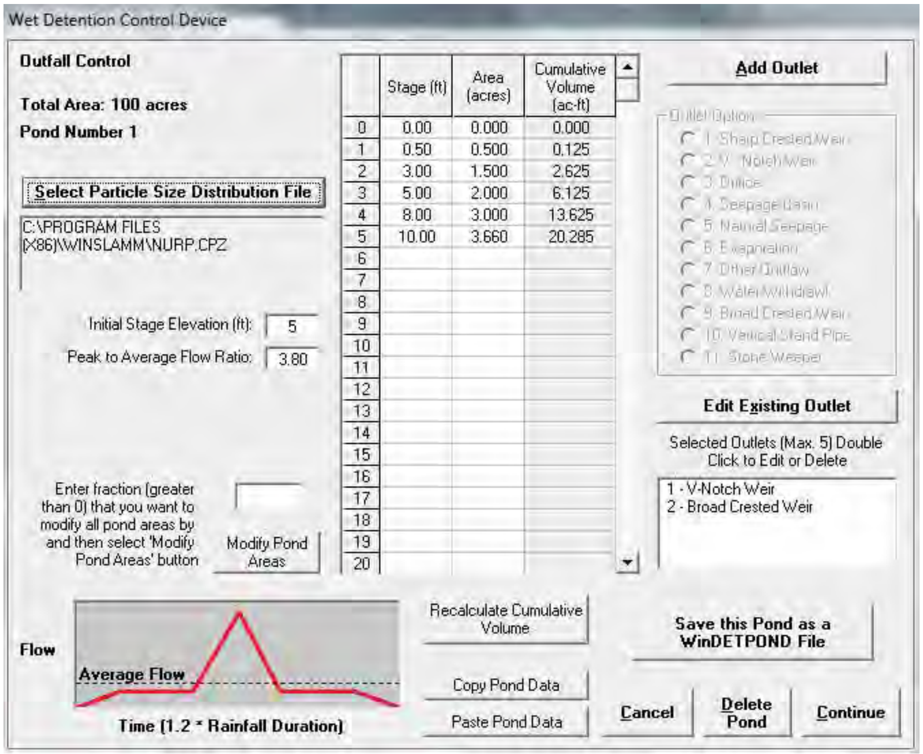
Outfall Controls

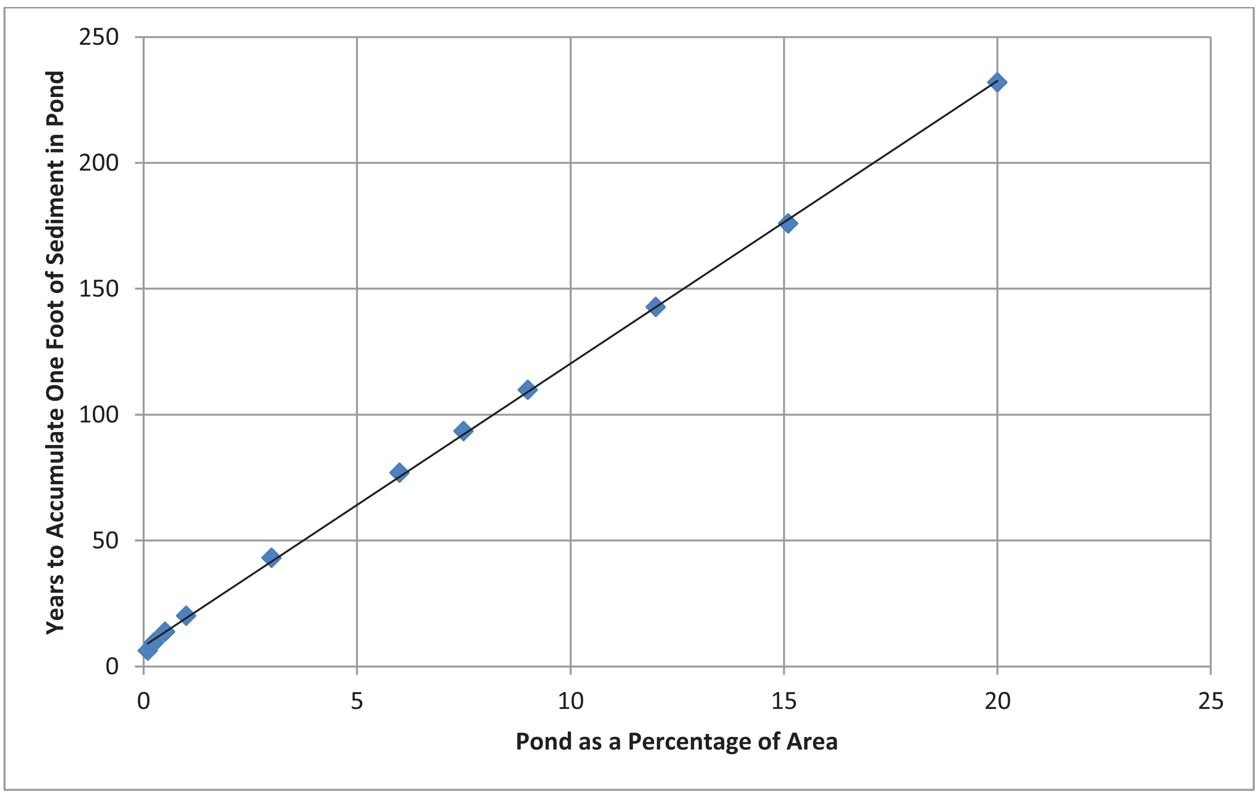
Wet Detention Ponds

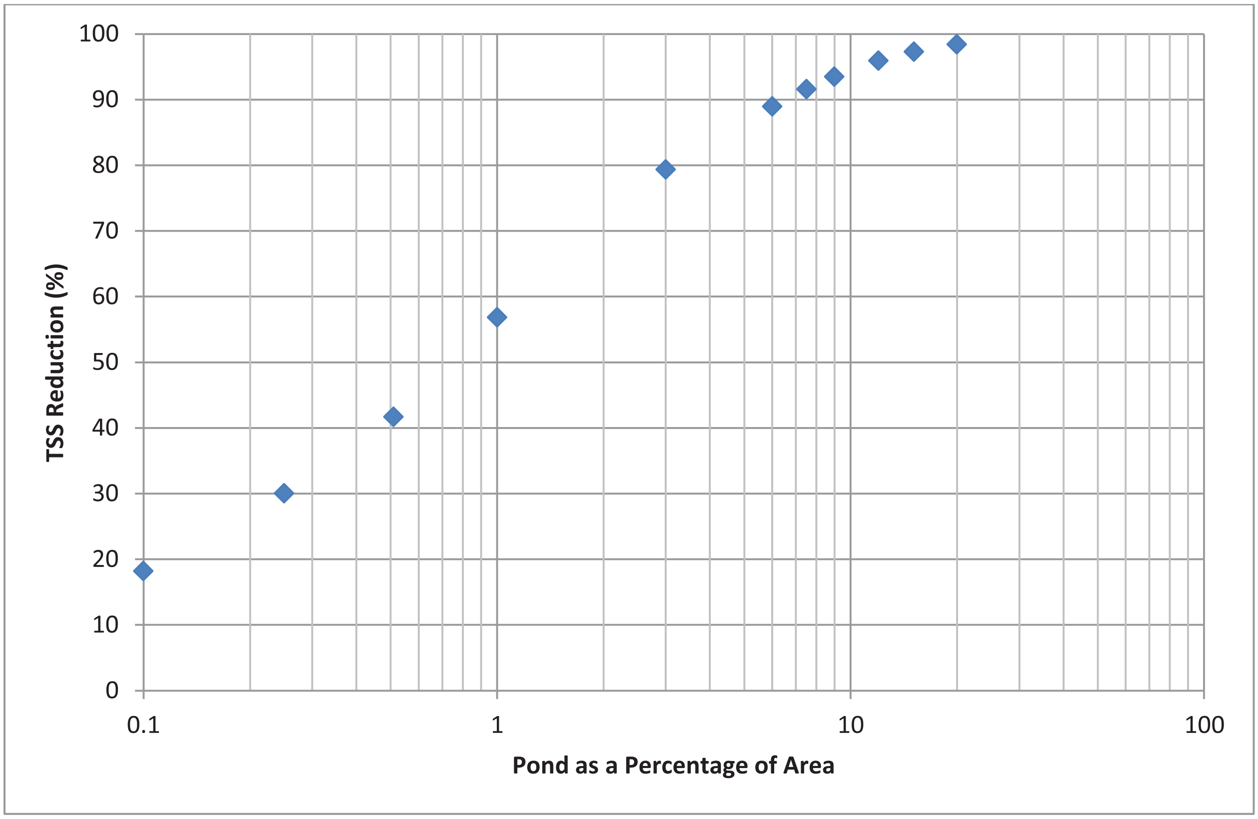
Wet detention ponds are probably the most common management practice for the control of stormwater runoff quality. If properly designed, constructed, and maintained, they can be very effective in controlling a wide range of pollutants and peak runoff flow rates. There is probably more information concerning the design and performance of detention ponds in the literature than for any other stormwater control device. Wet detention ponds are a very robust method for reducing stormwater pollutants. They typically show significant pollutant reductions as long as a few design-related attributes are met. Many details are available to enhance performance, and safety, that should be followed. Many processes are responsible for the pollutant removals observed in wet detention ponds. Physical sedimentation is the most significant removal mechanism.

WinSLAMM uses conventional procedures to calculate hydraulic conditions (pond storage-indication routing) and the behavior of particulates in stormwater as it passes through a detention pond (surface overflow rates described by the Hazen equation and quiescent settling using Stoke's and Newton's laws). WinSLAMM was specifically developed for continuous long-term evaluations using lengthy rain series. Whereas most computer-based pond models require time increment direction from the user and frequently crash due to unstable algorithms, WinSLAMM predicts reasonable calculation increments based on the duration of each rain and interevent period. If the calculation appears to approach unstable conditions, it automatically starts over with a smaller calculation increment. In addition, if the pond design is too small or if the outfall is inadequate, causing catastrophic overflow conditions, the program doesn't crash, but continues using the last known outfall or surface area value, and notes that the pond overflowed. The tabular output of the model can also be easily imported into spreadsheets and graphing programs to produce statistical summaries of the pond performance.

The following screens are used to enter information pertaining to a wet detention pond for analysis with WinSLAMM. The following production functions were prepared by varying the surface area of the pond for different analysis trials.







The wet detention pond is the most effective control for particulate pollutants, as it is usually able to reduce the sediment down to much smaller particle sizes than either biofilters or swales. Wet detention ponds, however, do not provide any volume reductions. It would take about 50 years to accumulate a foot of sediment (average depth) in a pond that is about 3% of the drainage area (a typical size for an industrial area) for typical conditions. With the dirtier sites, the sediment accumulation rate would be much greater. The percentage TSS reductions are much greater for wet detention ponds than for the swales or biofilters. A pond that is 3% of the drainage area would result in about 80% TSS reductions, while about 6.5% of the site would be needed for the pond if the TSS reduction was 90%.

Combinations of Stormwater Control Practices

Combinations of stormwater controls can usually be more effective than individual practices. For biofilters, swales, and wet detention ponds, the increased benefit over the use of ponds alone in minor. However, the other controls can be effective pre-treatment to minimize maintenance in the pond. Again, in this example, the accumulation rate of sediment in the pond is relatively low, so this pre-treatment benefit may not be necessary.

Small wet ponds were used in up to five combinations of stormwater controls:

1) small wet detention ponds and curb-cut biofilters along 40% of the curbs
2) small wet detention ponds and biofilters that are 10% of the paved parking areas (or rain gardens that area 15% of the roof areas in residential areas)
3) small wet detention ponds and medium sized rain tanks to irrigate landscaped areas
4) small wet detention ponds and grass swales

5) small wet detention ponds, curb-cut biofilters along 40% of the curbs, and parking lot biofilters 10% of the paved parking area, or roof gardens that are 15% of the roof areas

As noted, small and moderate-sized controls were examined in combination with each. These are usually the most cost-effective.

Variability and Uncertainty

WinSLAMM contains various Monte Carlo components that enable uncertainly to be evaluated during the model runs. These are available for the infiltration rates for the various infiltration and biofiltration devices, and for the pollutant concentrations. During field investigations, these model parameters have been recognized as having the greatest variabilities that are not explained by the model. The Monte Carlo elements are described by probability distributions, with average and coefficient of variability values (COV) provided, and assumes log-normal distributions of the actual values. If these uncertainty options are selected, the model randomly selects a value of the parameter from this distribution for each rain event. The long-term simulations therefore result in calculated concentrations and loadings of the constituents and the runoff volumes that vary in a similar manner as observed during monitoring. For the calculations in this report, when different options are being compared, the Monte Carlo option was not used as that may affect the average ordering of the different options. However, several different scenarios were repeatedly analyzed and the different concentrations and loads were examined to estimate the likely variability in the model outcomes.

The following table summarizes these results by showing the groups of constituents associated with different ranges of variability and uncertainty. As an example, WinSLAMM is able to predict the runoff volumes and particulate solids loads more accurately than the other constituents. With COV values (the relative standard deviations compared to the average values) of about 5% of the average values, the 95% confidence range of these constituents would be within about 10% of the average (for normal distributions, about 95% of the data is obtained within ± 2 times the standard deviation values). However, for zinc concentrations, the 95% confidence interval is about ± 20 to 30% of the average values. The bacteria data has an even wider range for the confidence interval, as expected (± 60 to 70% for *E. coli* and even wider for fecal coliforms). Therefore, when comparing the ranked sets of control programs that are sorted by expected *E. coli* reductions, control programs that are within about 30% of each other may be difficult to distinguish in practice. In contrast, runoff volume and TSS mass load reduction predictions are expected to be much more precise and it may be possible to distinguish control programs that are much closer.

COV (standard deviation as a percentage of average concentration)	
<5%	runoff volume Rv total and filterable TKN TSS
5 to 10%	total and filterable copper total and filterable lead nitrates
10 to 15%	total and filterable zinc total and filterable COD TDS
30 to 35%	*E. coli* bacteria total and filterable phosphorus
65%	fecal coliform bacteria

Analysis Results

The following subsections contain figures and tables summarizing the performance of the various control programs for each land use and for two soil conditions. The tables are ranked according to the control practice abilities in removing *E. coli*, which has a large coefficient of variability. Runoff volume reductions and TSS reductions are also plotted showing relative unit removal costs. This section shows these plots and summary tables by land use and for clay loam and sandy loam soil conditions at the infiltration devices. The general area soil conditions are all in the silt category, so the only differences based on the sandy loam or clay loam soil are for infiltration or biofiltration devices (not for disconnections, or any of the other practices). The land uses examined were from the land use surveys conducted in the watershed area and were described in the previous stormwater pollutant source report. The land uses include:

- Commercial areas:
  - Strip malls
  - Shopping center
- Light Industrial areas
- Institutional areas:
  - Schools
  - Churches
  - Hospitals
- Residential areas:
  - Low density
  - Medium density, constructed before 1960
  - Medium density, constructed between 1960 and 1980

As noted above, each of these nine land use areas were examined for clay loam (0.1 in/hr) and sandy loam (1 inch/hr) conditions in the infiltration/biofiltration devices. The designs were similar (as described previously), but the infiltration rates were changed to correspond to the soil conditions in the control devices themselves.

The following tables show the calculated runoff, TSS, and *E. coli* conditions for each scenario, and also the estimated costs (capital costs, land costs, maintenance costs, total annual costs, and total present value cost) and the unit removal costs for runoff (dollars per cubic feet removed, compared to the base conditions) and for TSS (dollars per pound removed, compared to the base conditions). The figures are scatterplots relating the calculated percent removals of these three stormwater constituents vs. the total annual costs (dollars per 100 acres per year). The most suitable stormwater control programs meeting the removal objectives at the least cost can be identified from these figures (also considering other factors affecting the selection process as described later such as groundwater contamination potential, maintenance requirements, suitability for retrofitting, etc.). As an example, the volume reduction plot for strip mall commercial areas having clay loam soils at the infiltration/biofiltration control locations indicates that several stormwater control programs are more cost-effective than others at similar levels of volume reductions. If the desired volume reduction was 25%, six of the stormwater control programs could meet this level of control, at least, as summarized in the following table:

Control Program for Commercial Strip Mall Land Use	Volume Reduction (% reduction compared to base conditions for clay loam conditions in the biofilters)	Volume Reduction (% reduction compared to base conditions for sandy loam conditions in the biofilters)	Total Annual Costs ($/100 acres/yr)
Porous pavement (in half of the parking areas)	25%	25%	$180,400
Curb-cut biofilters (along 80% of the curbs)	29	67	$166,500
Biofilters in parking areas (10 percent of the source area)	29	47	$314,000
Small wet pond plus biofilters in parking areas (10 percent of the source area)	29	47	$341,800
Biofilters in parking areas (25 percent of the source area)	40	not analyzed for sandy loam conditions	$785,000
Small wet pond plus biofilters in parking areas (10 percent of the source area) and curb-cut biofilters (along 40% of the curbs)	43	80	$424,600

The least costly option having at least 25% runoff reductions is shown to be the curb-cut biofilters along 80% of the curbs. This option is expected to result in about 29% runoff volume reductions with clay loam soil conditions, so theoretically, the application of this control could be reduced somewhat with some further cost savings (to about 70% of the curbs and $143,500). In this example, the use of porous pavement on half of the parking areas would result in about 25% runoff volume reductions (right at the removal goal), but at about 25% increased costs. This larger cost may be justified if other factors are important. It would be very challenging to install this many curb-cut biofilters, for example; however, the biofilters could be more easily maintained and retrofitted in an existing area and offer some additional protection to the groundwater. The other controls are all likely to be substantially more costly. Using parking lot island biofilters (that are about 10 percent of the paved area in size) would cost almost twice compared to the curb-cut biofilters. Adding a small wet pond adds costs but would not provide any additional runoff volume reductions (but would provide additional sediment reductions). Increasing the size of the parking lot island biofilters to 25% of the paved parking drainage areas (very large) would result in substantially greater runoff volume controls (up to about 40%), but at 2.5 times the cost of the smaller (or fewer) parking lot biofilters. Adding a small wet pond to the fewer parking lot biofilters, plus using some curb-cut biofilters results in the largest runoff volume reductions expected for the alternatives examined. If only runoff volume (and filterable pollutants) were of consideration, but at a higher control level, it would be worthwhile to also examine this last option without the pond (this would provide the same 43% calculated reductions, but the annual costs would be reduced to slightly less than $400,000 per 100 acres per year, or about 2.8 times the least cost option for 25% control, with an associated increase in performance of about 1.7 times. The declining unit cost returns with increasing removals are obvious on the plots. However, if the larger removal rates are needed, the more costly control options would likely be needed.

As noted on the further plots, the same size of controls in a sandy loam area has the same annual costs for the same stormwater control programs as for clay soil conditions, but the performance is substantially greater for programs using infiltration or biofiltration devices. The porous pavement benefits do not change as the clay loam soil is sufficient to remove the same amount of runoff due to the storage volume provided. The large 25%

biofilter areas were not evaluated for sandy soil conditions as they would not likely be used. The runoff volume removal rates for the other control programs are expected to be about double with sandy loam soils compared to clay loam soils for this land use, at the same annual costs.

Detailed information for all constituents examined (runoff volume, Rv, TSS, TDS, total and filterable phosphorus, nitrates, total and filterable TKN, total and filterable COD, total and filterable copper, total and filterable lead, total and filterable zinc, fecal coliform bacteria, and *E. coli* bacteria) is presented for each land use and soil combinations for each set of stormwater controls in the appendix.

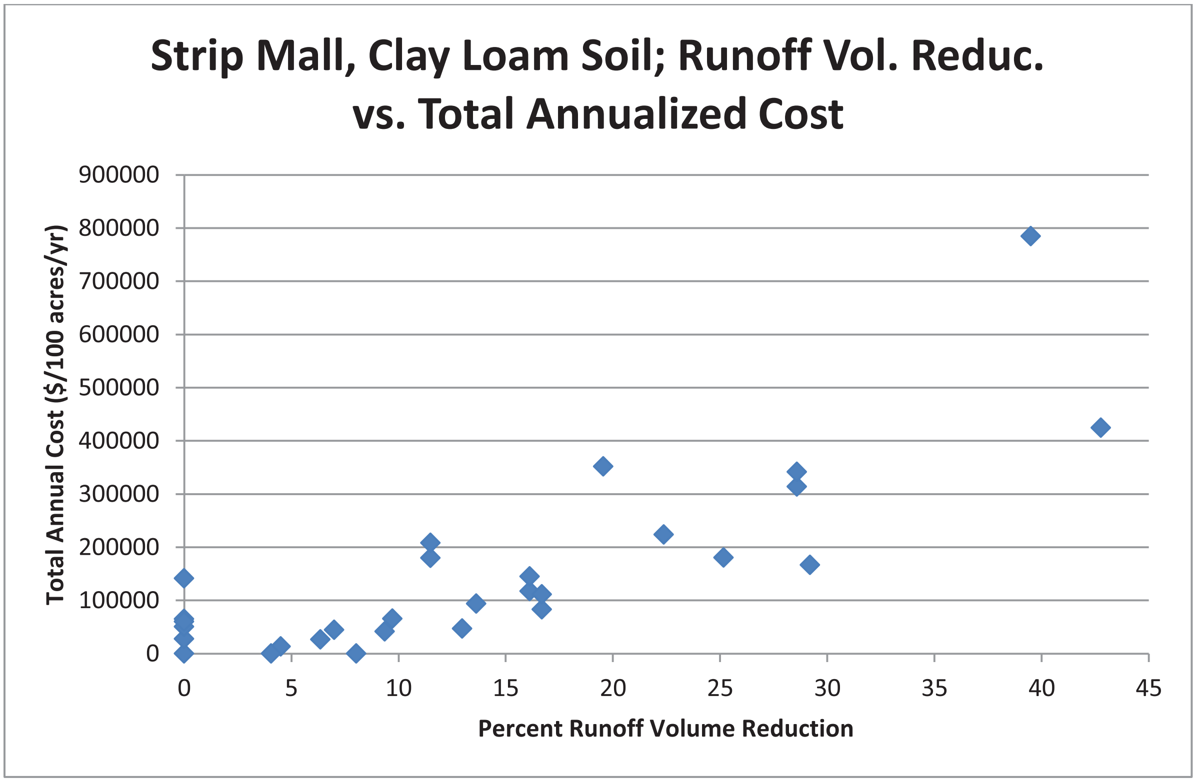
Each appendix table lists the amounts and concentrations expected for a homogeneous 100 acre site for four years of rains. The total amounts therefore represent these conditions. As an example, on the first appendix table, the first line shows the information for the base condition (from the land use land cover survey) for the strip mall commercial areas. The total runoff volume shown is 25,715,040 ft^3 (it was not possible to show many of these total yield values with an appropriate number of significant figures in these tables). The 25.7 million cubic feet of runoff represents the total amount of runoff expected for a 100 acre site exposed to all of the rains occurring in the 4 year test period of rainfall. The sum or yield values therefore need to be reduced by 1/400 to obtain the annual runoff or discharge amounts from one acre for one year. The annual unit acre runoff quantity for this condition is therefore about 64,300 ft^3/acre/year. This is shown to represent about 64% of the total rainfall quantity that fell on this site. The concentration values shown on these appendix tables are not affected by the size of the area or the length of the rain record, but the long records result in more reasonable flow-weighted average values with smaller effects from extreme events that may occur. As an example, the base condition is expected to have a total suspended solids (TSS) concentration of about 410 mg/L, with a total discharge of about 660,000 lbs of TSS for 100 acres over 4 years (or 1,640 lbs/ac/yr). During the 4 year study period, a total of 107.41 inches of rain fell during 340 separate rain events. The largest single rain was 2.63 inches in depth, and the average rain was 0.32 inches.

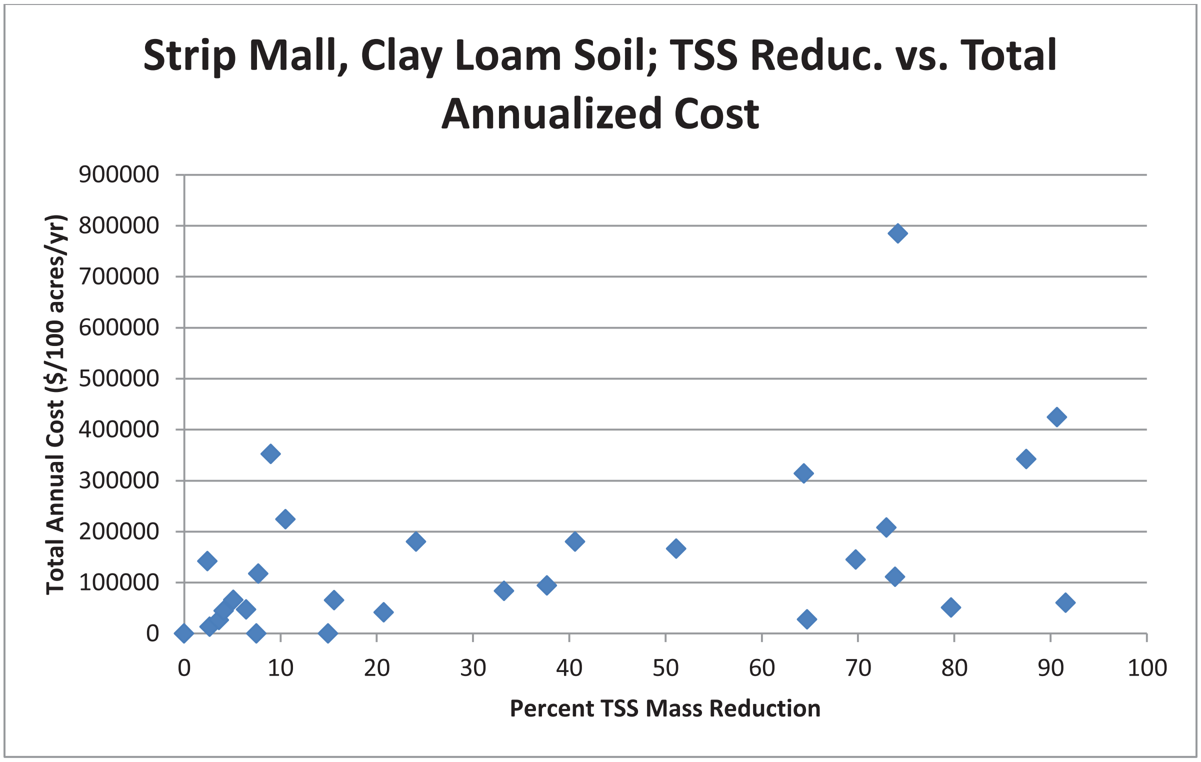
In most cases, total and filterable forms of each pollutant are shown. The control practices were previously described, along with the combinations examined. Also, clay loam and sandy loam soil conditions are examined for each case. The performance of the alternative control programs can be assessed by examining the resulting loadings and concentrations. The filterable forms of the contaminants are reduced through volume reducing infiltration practices (biofilters at parking areas, curb-cut biofilters, disconnected impervious areas, porous pavement, rain gardens, grass swales), plus the beneficial use practices (rain barrels and rain tanks), and combinations of these practices. The particulate-bound pollutants are removed by these same practices, plus the sedimentation practices (wet detention ponds), and the catchbasin and street cleaning public works practices. The removal of the specific pollutants is therefore highly dependent on how the pollutant partitions between the particulate-bound phase and the filterable phase. The bacteria, even though traditionally captured on a small aperture filter, are treated as filterable constituents for these analyses. Some of the bacteria are bound to small particulates and tend to migrate with those materials. Therefore, the calculated bacteria conditions are conservative, with somewhat additional reductions expected.

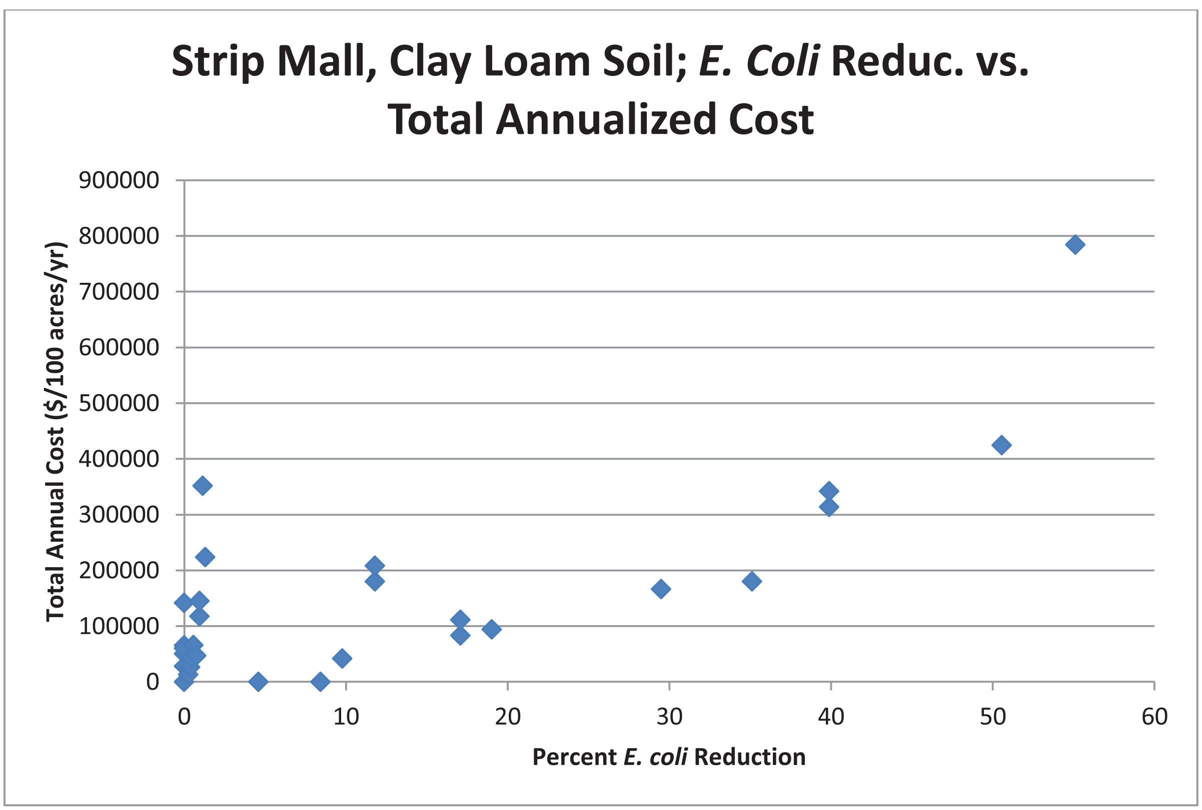
When examining the performance options, it is seen that the mass discharges always decrease, unless a control program option is very inefficient, or for filterable pollutant concentrations for an option that only affect particulate-bound pollutants (such as street cleaning). However, the resulting concentrations after control by some options may actually be seen to increase. An example is for a roof runoff volume reducing control (such as rain gardens) for a pollutant that has low concentrations in roof runoff compared to other source areas. As that cleaner water is infiltrated (always a good idea to minimize groundwater contamination issues), the remaining load of that constituent from all areas is transported with less water, resulting in a higher concentration, even if the water volume reduction is large. However, the load reduction should still decrease, corresponding to the pollutant content of the infiltrating roof runoff.

Commercial: Strip Mall Land Use

Clay Loam Soil Conditions




Strip Mall, Clay Loam Soil; TSS Reduc. vs. Total Annualized Cost
Total Annual Cost ($/100 acres/yr)
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
0
10
20
30
40
50
60
70
80
90
100
Percent TSS Mass Reduction


Strip Mall, Clay Loam Soil; *E. Coli* Reduc. vs. Total Annualized Cost
Total Annual Cost ($/100 acres/yr)
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
0
10
20
30
40
50
60
Percent *E. coli* Reduction

Commercial Strip Mall Land Use, Clay Loam Soil, Sorted by *E. coli* Removal (costs are per 100 acres)

File Name	Rv	Biological Condition	Runoff Volume Percent Reduction	Particulate Solids Yield Percent Reduction	*E. coli* Yield Percent Reduction	Particulate Solids Concentration (mg/L)	Capital Cost	Land Cost	Maintenance Cost	Total Annual Cost	Total Present Value Cost	Cost per cubic foot Runoff Volume Reduced ($/cf)	Cost per pound Particulate Solids Reduced ($/lb)
01 strip mall Linc base	0.64	Poor	n/a	n/a	n/a	410	n/a	n/a	n/a	n/a	n/a	n/a	n/a
01 strip mall Linc CB	0.64	Poor	0	16	0	346	566,626	0	19,620	65,088	811,134	-	2.52
01 strip mall Linc pond 085 perct	0.64	Poor	0	65	0	145	251,151	9,938	6,907	27,857	347,165	-	0.26
01 strip mall Linc pond 17 perct	0.64	Poor	0	80	0	83	463,123	19,875	11,783	50,540	629,841	-	0.38
01 strip mall Linc pond 34 perct	0.64	Poor	0	92	0	34	535,234	39,750	14,170	60,308	751,573	-	0.40
01 strip mall Linc street cleaning daily	0.64	Poor	0	2	0	400	26,560	0	139,412	141,543	1,763,935	-	35.42
01 strip mall Linc rain barrels few	0.61	Poor	5	3	0	418	88,474	10,000	5,270	13,172	164,154	0.05	2.99
01 strip mall Linc rain barrels	0.60	Poor	6	4	0	422	176,948	20,000	10,541	26,344	328,308	0.06	4.39
01 strip mall Linc roof rain garden 3 perct clay loam	0.60	Poor	7	4	0	422	266,024	75,069	17,432	44,802	558,331	0.10	6.59
01 strip mall Linc rain barrels many	0.58	Poor	10	5	1	430	442,371	50,000	26,352	65,861	820,770	0.10	7.75
01 strip mall Linc rain tanks small	0.56	Poor	13	6	1	440	294,581	41,667	19,942	46,923	584,766	0.06	4.39
01 strip mall Linc rain tanks	0.54	Poor	16	8	1	451	736,452	104,167	49,854	117,308	1,461,915	0.11	9.18
01 strip mall Linc sml pnd and rain tanks	0.54	Poor	16	70	1	148	987,603	114,104	56,761	145,165	1,809,080	0.14	1.25
01 strip mall Linc rain tanks large	0.52	Poor	20	9	1	463	2,209,356	312,500	149,563	351,924	4,385,745	0.28	23.60
01 strip mall Linc roof rain garden 15 perct clay loam	0.50	Poor	22	11	1	472	1,330,119	375,344	87,159	224,010	2,791,656	0.15	12.82
01 strip mall Linc half disconnected	0.61	Poor	4	8	5	395	0	0	0	0	0	0.00	0.00
01 strip mall Linc disconnected	0.59	Poor	8	15	8	379	0	0	0	0	0	0.00	0.00
01 strip mall Linc curb biofilters 20 clay loam	0.58	Poor	9	21	10	358	283,417	3,444	18,601	41,619	518,670	0.07	1.21
01 strip mall Linc swale clay loam	0.57	Poor	11	24	12	351	1,613,577	0	50,678	180,156	2,245,143	0.24	4.51
01 strip mall Linc sml pond	0.57	Poor	11	73	12	125	1,864,728	9,938	57,586	208,014	2,592,308	0.28	1.72

and swale clay loam													
01 strip mall Linc curb biofilters 40 clay loam	0.53	Poor	17	33	17	328	566,833	6,887	37,202	83,239	1,037,339	0.08	1.51
01 strip mall Linc sml pnd and curb biofilters 40 clay loam	0.53	Poor	17	74	17	129	817,984	16,825	44,109	111,096	1,384,504	0.10	0.91
01 strip mall Linc biofilt parking 3 perct clay loam	0.55	Poor	14	38	19	295	572,422	137,126	37,181	94,117	1,172,910	0.11	1.51
01 strip mall Linc curb biofilters 80 clay loam	0.45	Poor	29	51	30	283	1,133,666	13,774	74,404	166,478	2,074,678	0.09	1.96
01 strip mall Linc porous pvt parking half clay loam	0.48	Poor	25	41	35	325	2,158,148	0	7,223	180,398	2,248,161	0.11	2.68
01 strip mall Linc biofilt parking 10 perct clay loam	0.46	Poor	29	64	40	204	1,909,465	457,420	124,029	313,954	3,912,554	0.17	2.94
01 strip mall Linc sml pnd and biofilt parking 10 perct clay loam	0.46	Poor	29	87	40	72	2,160,616	467,357	130,936	341,811	4,259,720	0.18	2.36
01 strip mall Linc sml pnd and park biofilt 10 perc and curb biofilters 40 clay loam	0.37	Poor	43	91	51	67	2,721,929	474,244	168,138	424,607	5,291,539	0.15	2.82
01 strip mall Linc biofilt parking 25 perct clay loam	0.39	Poor	40	74	55	175	4,771,573	1,143,049	309,936	784,540	9,777,105	0.31	6.38