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March 30, 2016

Bioretention and Porous Pavement Overflow and Underdrain Flow Conditions

Summary

WinSLAMM was used to evaluate the potential overflow and underdrain flow conditions of the demonstration porous pavement and biofilter (bioretention) sites at NBSD. Site and design information were incorporated into the WinSLAMM model for these devices and evaluated using different underdrains and native soil infiltration rates. The calibrated version of WinSLAMM prepared for NBSD was used, along with San Diego airport January 1999 to December 2005 rains (248 rains from 0.01 to 2.85 inches in depth). WinSLAMM continuously evaluated these controls for these events considering both event and interevent periods.

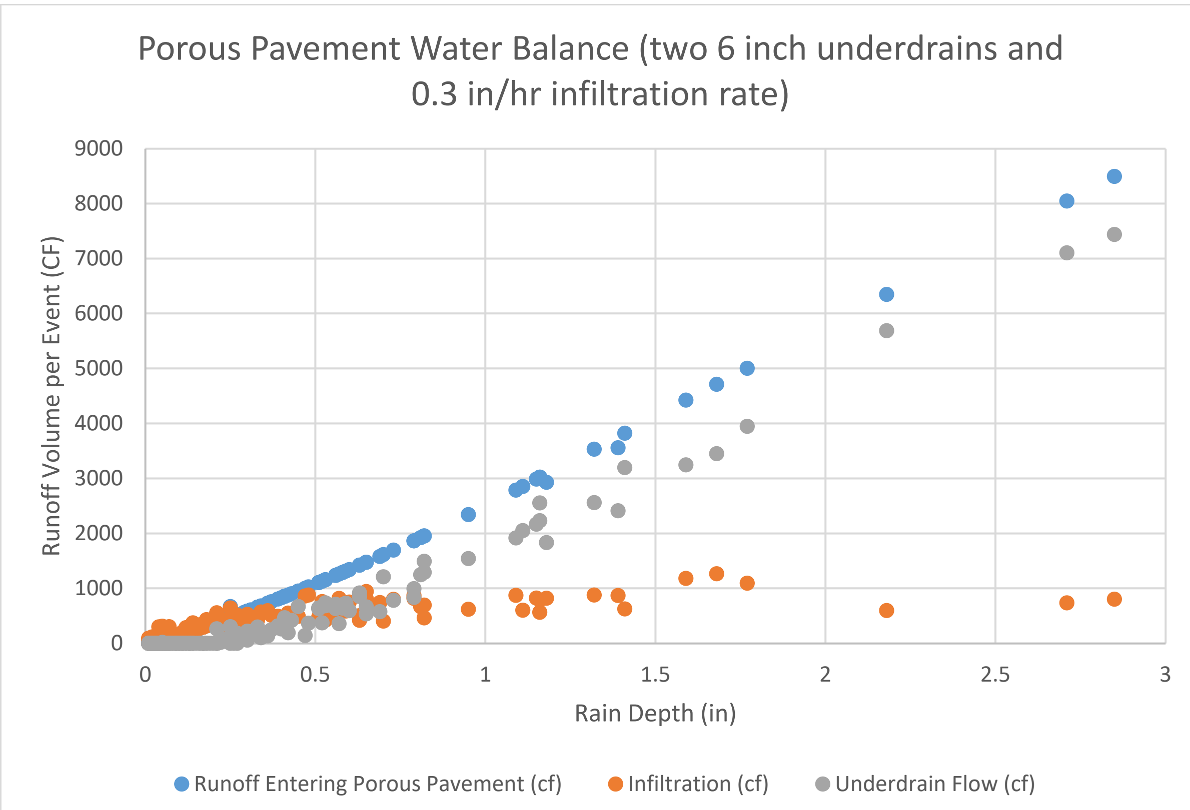
The porous pavement area is about 7% of the total paved drainage area. The model considers both direct rainfall on the porous pavement, plus the runon from the additional area. With very poor infiltrating native soils, underdrains at least 1 in in diameter (3 rows) would be suitable, providing at about 85% particulate solids capture. The use of three 3 inch underdrains would "always" be suitable to discharge any infiltrating water, with no surface overflow. Unless clogged, all rain and runoff would enter the porous pavement, with no surface overflow. However, substantial underdrain flows would occur if the native soil infiltration rates were relatively low. These analyses were therefore used to determine which rains would produce underdrain flows. The performance of the porous pavement varies greatly depending on rain intensity, interevent period, and rain depth, plus the native infiltration rates (the surface infiltration rate through the pavement surface is always high, unless clogged due to poor maintenance). The following table lists the approximate (linearized) maximum rain depths associated with at least 90% runoff reductions and for at least 50% runoff reductions for the porous pavement site. Underdrain flows of at least 10% of the total site runoff would occur for very small rains (0.01 inch rains) for clay soils, increasing to 0.75 inch rains for sandy loam soils. Loamy sand soils would be able to infiltrate all of these rains with no underdrain flows expected.

native infiltration rates (in/hr)	0.02 (clay soil)	0.1 (clay loam soil)	0.5 (loam soil)	1.0 (sandy loam soil)	2.5 (loamy sand soil)
max. rain depth for 90% runoff volume reductions (in)	0.01	0.15	0.23	0.75	all rains
max. rain depth for 50% runoff volume reductions (in)	0.75	1.0	2.0	3.0	all rains
Long-term total runoff reductions (%)	28%	43%	67%	80%	100%

The following figure plots the total runoff entering the porous pavement (for silt loam soils having 0.3 in/hr infiltration rates, the expected site condition), along with the concurrent amount of surface runoff entering the two 6 inch underdrains. Surface bypass runoff is not expected, unless premature clogging of the pavement surface occurs. The percentage fates of incoming water are calculated as:

Infiltration: 43%
Underdrain flow: 57%

Underdrain flow would be expected starting for rains of about 0.5 inches in depth for these infiltration conditions. If the infiltration rates were greater, underdrain flows would be delayed until larger rains.



Anything smaller than two 2 inch underdrains for the porous pavement system (located at the surface of the rock storage layer) would cause surface bypass flows during moderate to small rains. No soil conditions (even clay) would be expected to cause surface bypass flows from this permeable pavement facility for any of the rains in the rain series investigated. However, premature surface clogging of the pavement would cause surface bypass flows.

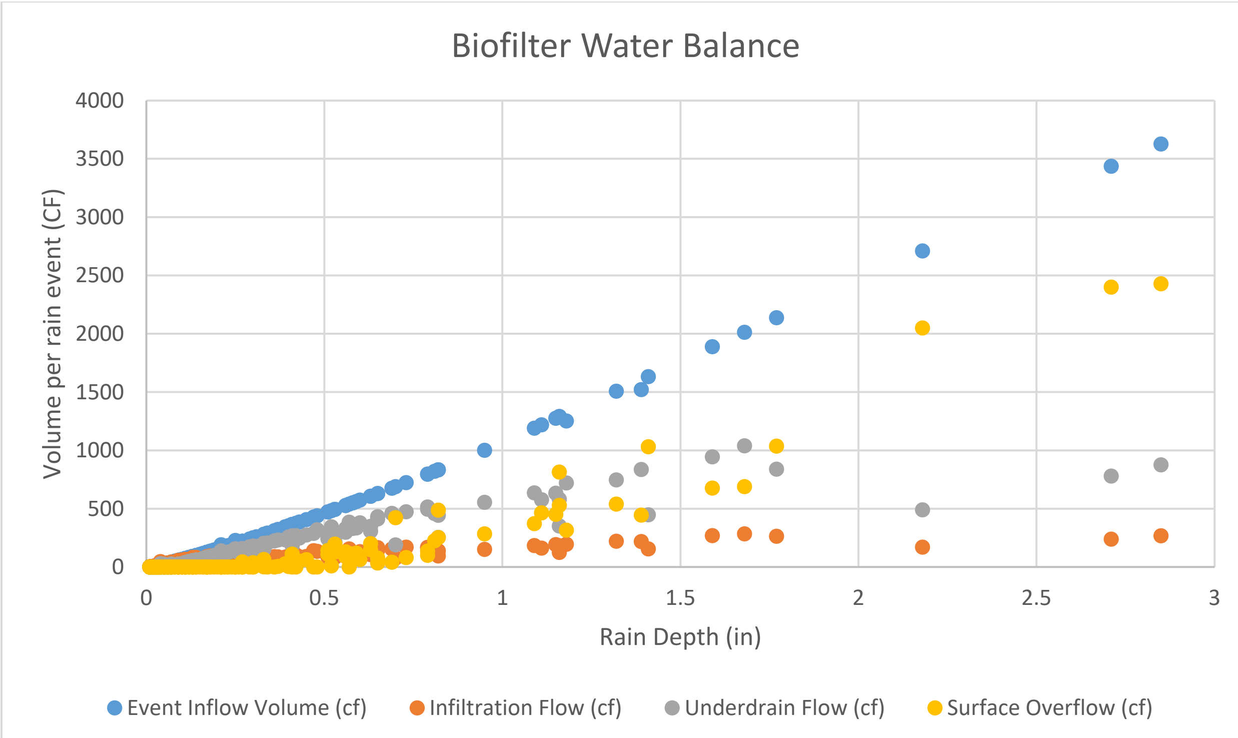
The biofilter is about 2% of the paved drainage area. With any if the soil conditions, the three 3 inch underdrains would not be restrictive, so these analyses indicate the rain conditions likely to produce underdrain flows for the different soil conditions. The overall runoff reductions are less than 10% with poor infiltration conditions. For 0.3 and 1 in/hr native soil infiltration rates, no underdrain could be used for the highest level of runoff volume control (about 50 or 70%, respectively, for the two infiltration rates). The underdrains would cause short-circuiting of the stormwater before it could be infiltrated, with 10 to 15% decreased runoff volume capture performance. There are less flow-duration benefits with the biofilter compared to the porous pavement site, but clogging should not be an issue (several decades of use before silting of media). The following table lists the approximate (linearized) maximum rain depths associated with at least 90% runoff reductions and for at least 50% runoff reductions for the biofilter site. Underdrain flows of at least 10% of the total site runoff would occur for very small rains (0.05 inch rains) for clay soils, increasing to 0.3 inch rains for sandy loam soils. Loamy sand soils would produce underdrain flows for rains larger than about 1.8 inches in depth.

native infiltration rates (in/hr)	0.02 (clay soil)	0.1 (clay loam soil)	0.5 (loam soil)	1.0 (sandy loam soil)	2.5 (loamy sand soil)
max. rain depth for 90% runoff volume reductions (in)	max reduction of 65%	max reduction of 80%	0.05	0.3	1.8
max. rain depth for 50% runoff volume reductions (in)	0.3	0.6	0.75	1	all rains
Long-term total runoff reductions (%)	7%	14	34	53	93

The following figure plots the total runoff entering the biofilter (for silt loam soils having 0.3 in/hr infiltration rates, the expected site condition), along with the concurrent amount of surface runoff bypassing the biofilter due to excessive ponding. Surface bypass runoff would start to occur with rains of about 0.5 inches in depth, although smaller rains may produce bypass flows depending on other rainfall characteristics and antecedent water stored in the biofilter at the start of the rain. The percentage fates of incoming water are calculated as:

Infiltration: 22% (total runoff volume reduction)
Underdrain flow: 47%
Surface overflow: 31%

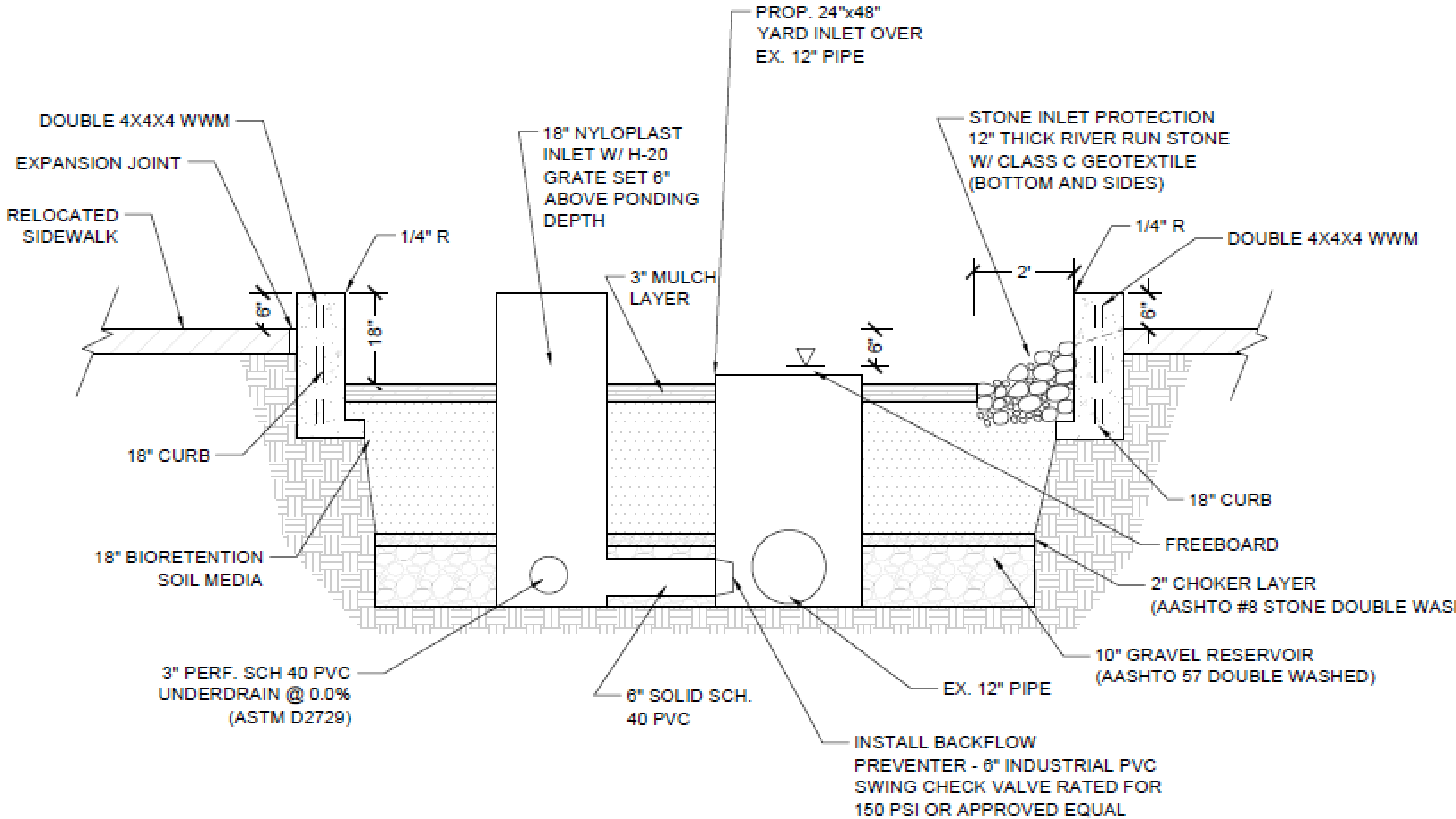
Substantial surface runoff occurs (about 25 to 50% of the total runoff volume) with 1 inch rains. Saturated conditions occur with very little additional infiltration possible after about 0.5 in rains. If the site soil infiltration conditions were greater than 0.3 in/hr, the surface bypass flows would be less and start with larger rains.



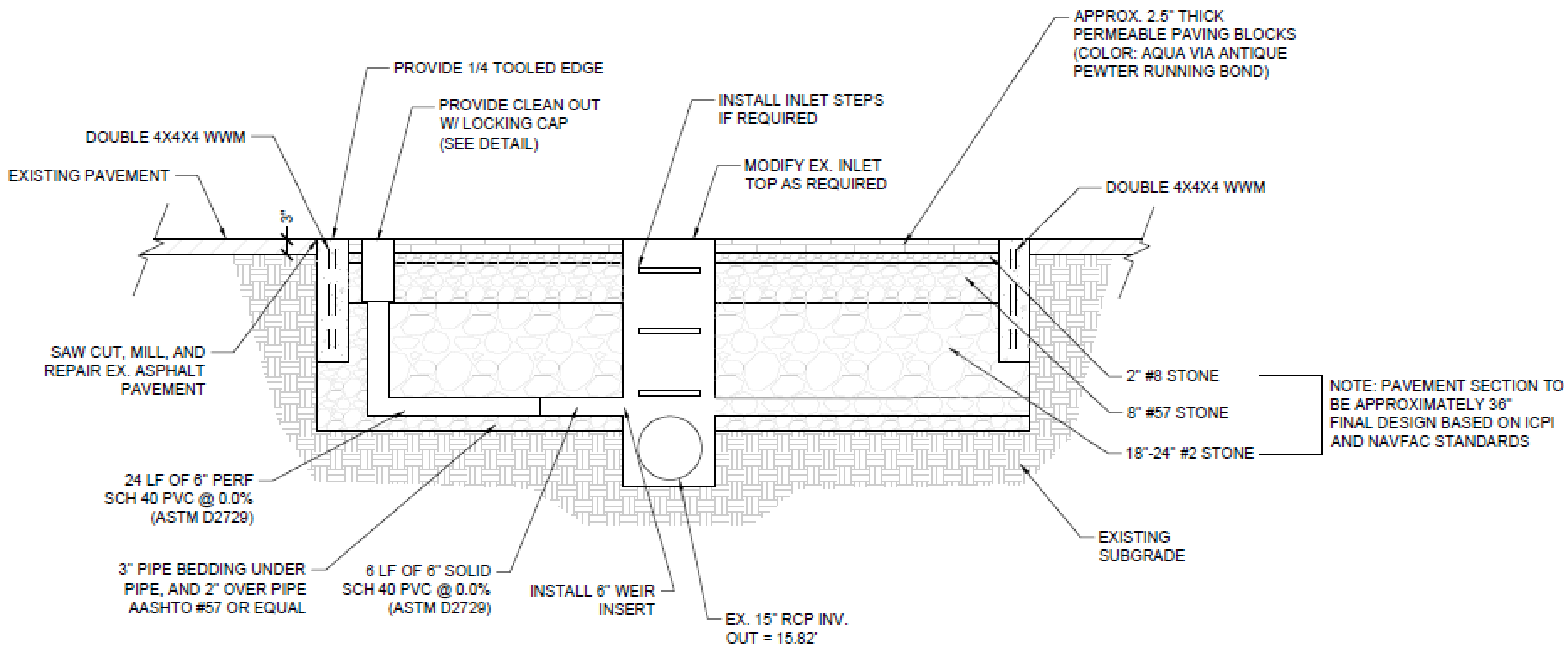
Site Information

The following table and figures were provided by the Low Impact Development Center to describe the drainage areas and treatment system characteristics. These were used to prepare the WinSLAMM input files that were analyzed to examine the effects of the different underdrain options for the porous pavement and biofilter stormwater controls.

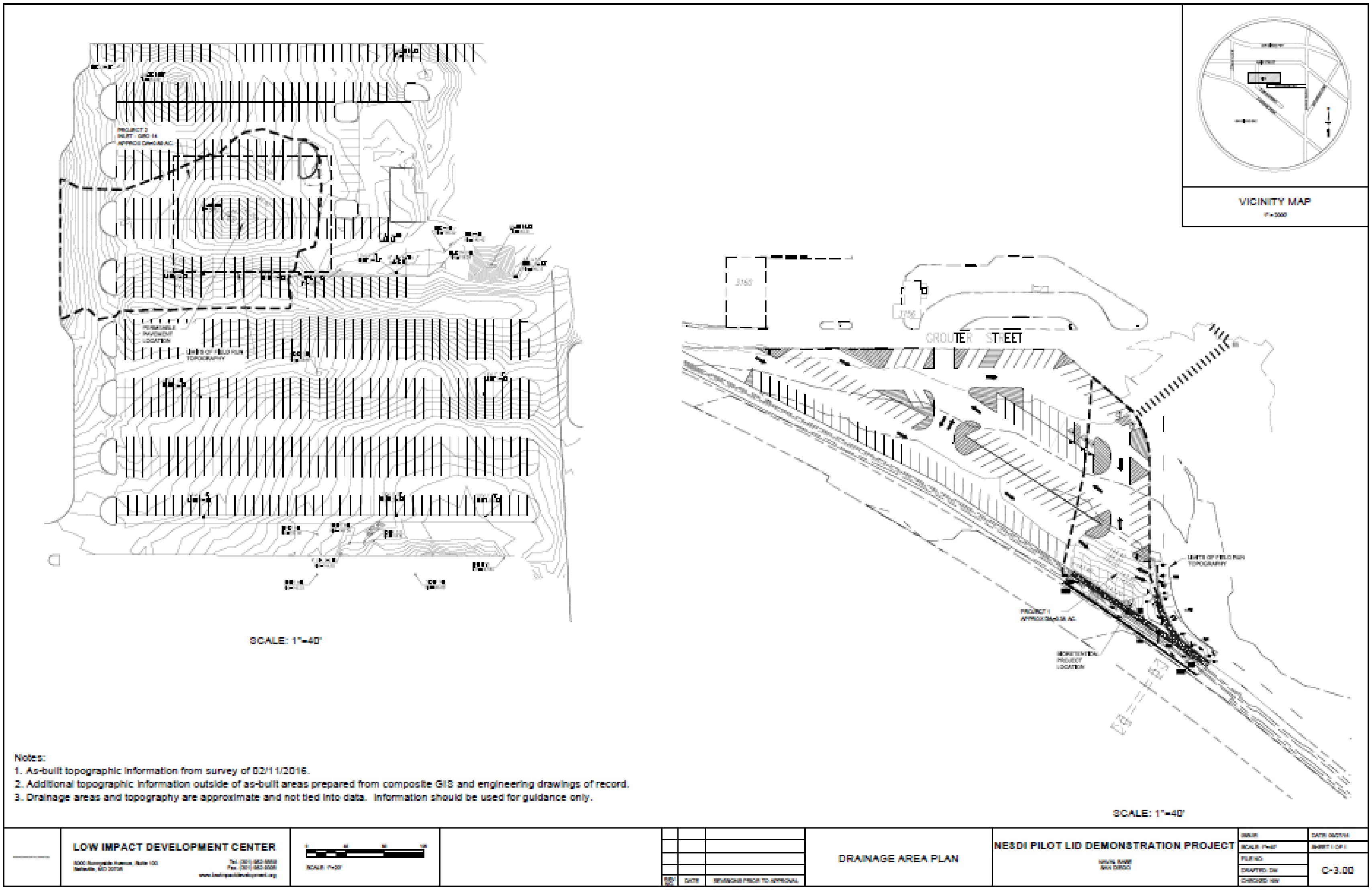
Stormwater Control	Drainage Area (ac)	Drainage Area (sf)	Surface Area (sf)	Ponding Depth (ft)	Ponding Storage (cf)	Mulch Depth (ft)	Mulch Storage (cf)	Media Depth (ft)	Media Storage (cf)	Gravel Depth (ft)	Gravel Storage (cf)	Total Storage (cf)
Bioretention	0.38	16,550	400	0.5	200	0.17	27	1.5	240	0.83	133	600
Permeable Pavement	0.89	38,750	2,800	0	0	0	0	0	0	3	3,360	3,360



Biofilter Details (Low Impact Development Center).



Permeable Pavement Details (Low Impact Development Center).

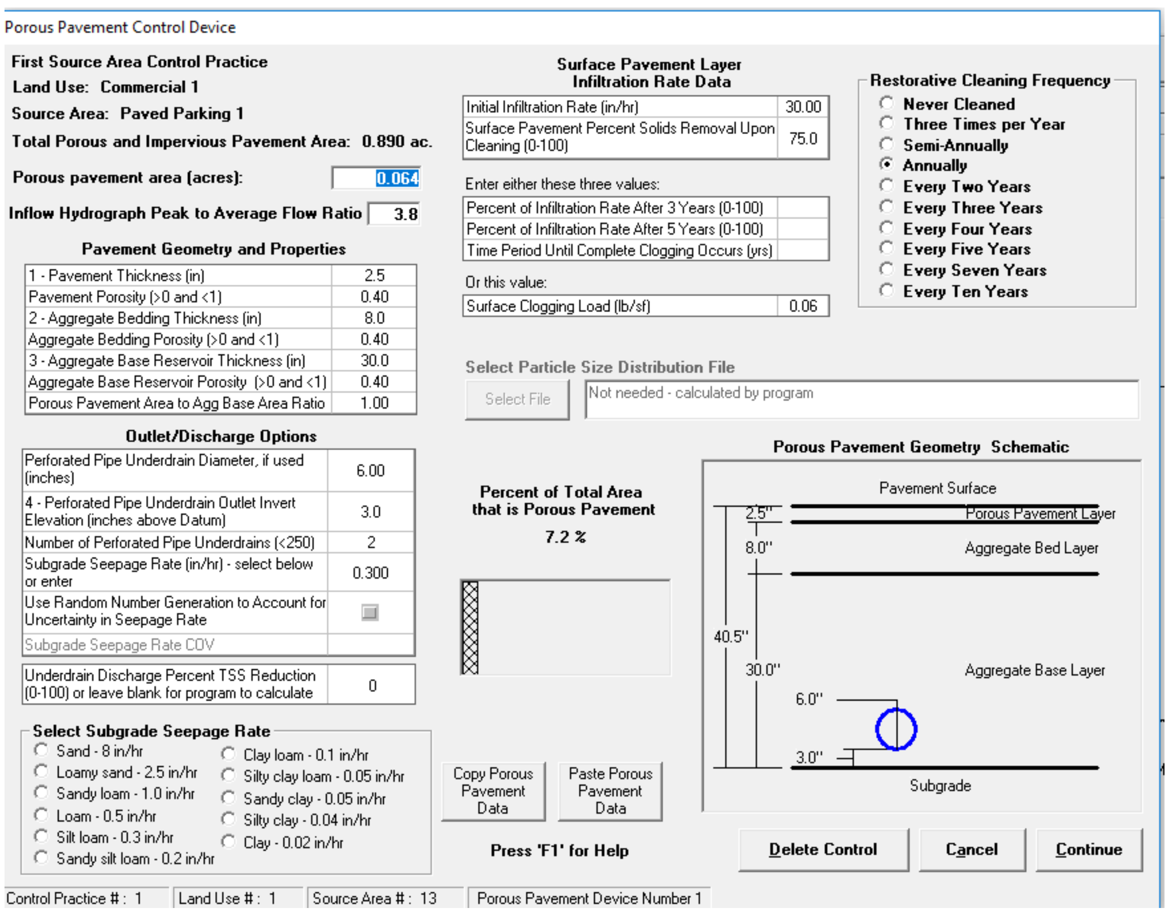


Bioretention and Porous Pavement Drainage Areas

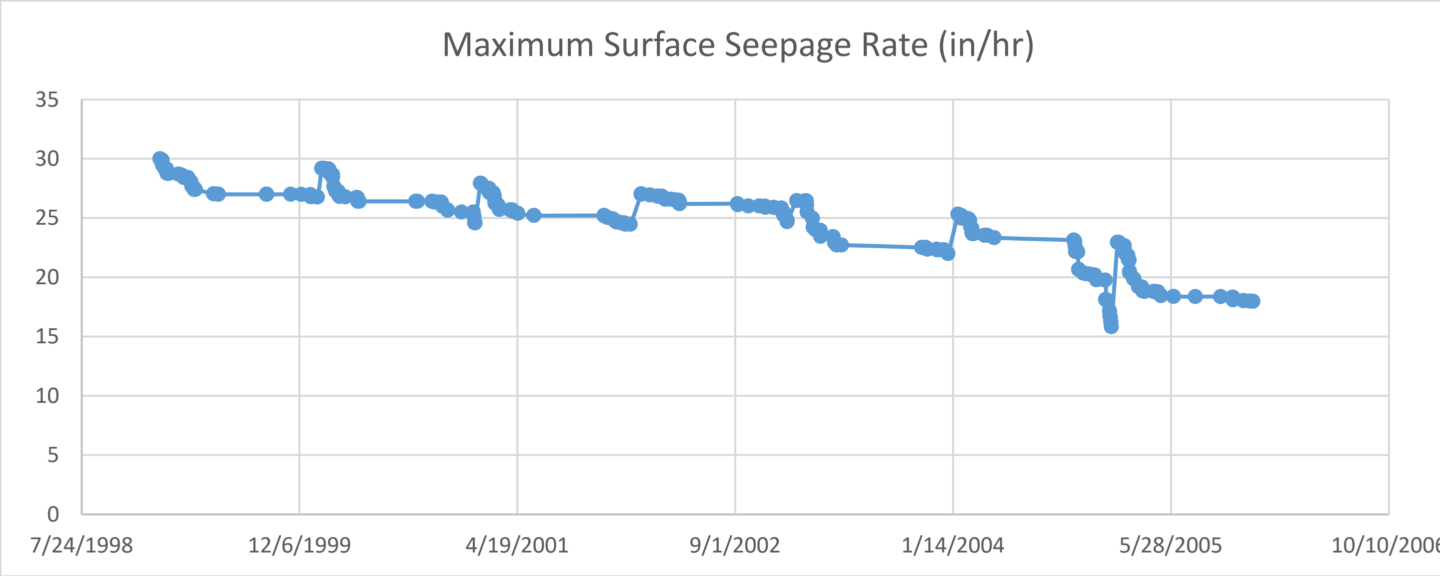
Porous Pavement Analyses

The WinSLAMM porous pavement control in version 10 has full routing calculations associated with subsurface pond storage, and it allows runon from adjacent paved areas that do not have porous pavement. The outlet options for porous pavements include subgrade seepage and an optional underdrain, which is modeled as an orifice. The porous pavement control device has a surface seepage rate that limits the amount of runoff that can enter the storage system. The seepage rate is usually much greater than the rain intensity, so this would be unusual, except if it is significantly reduced by clogging or if substantial runon occurs from adjacent paved areas. This surface seepage rate is reduced to account for clogging with time, while the surface seepage rate can be partially restored with cleaning at a stated cleaning frequency. The runoff volume reaching the porous pavement surface is equal to the rainfall volume directly falling on the porous pavement, plus runoff volume from any runon from the adjacent paved areas. The porous pavement surface can be paver blocks, porous concrete, porous asphalt, or any other porous surface, including reinforced turf. Porous pavements are usually installed over a subsurface storage layer that can dramatically increase the infiltration performance of the device.

It is necessary to describe the geometry and other characteristics of a typical porous pavement surface, as shown in the following input screen figures. The model computes the runoff volume, equal to the rainfall volume plus any runon, and then creates a complex triangular hydrograph (the flow duration equals the rain duration) that it routes through that porous pavement system.



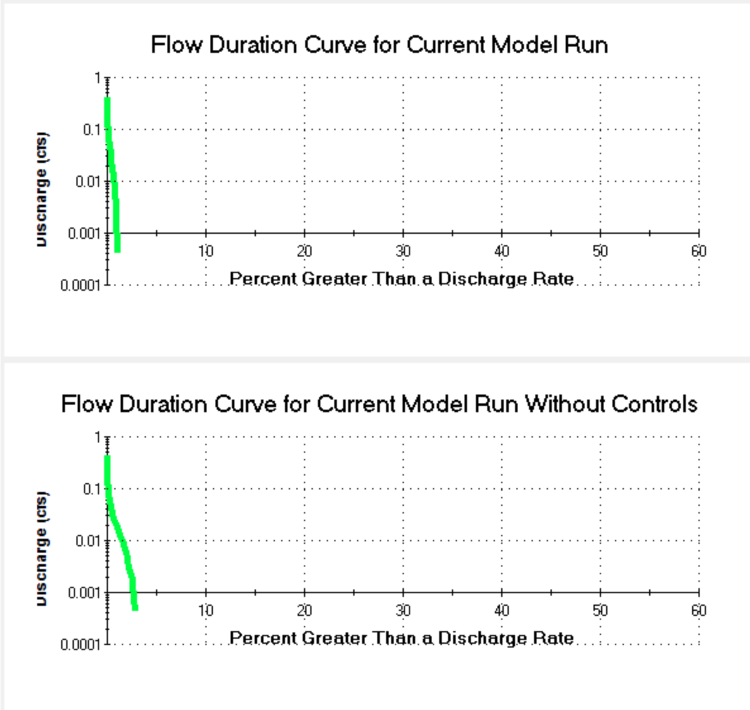
The initial pavement infiltration rate was assumed to be about 30 in/hr. With annual cleaning that can restore about 75% of the infiltration capacity (typical), the infiltration capacities decrease in time for this site, losing about 1/3 to ½ of the initial capacity after the 7 years of this model analysis. It is expected that failure may occur after 15 or 20 years, requiring replacement of the porous pavement facility (surface material and media to be replaced). Premature failure may occur due to tracking of material on the porous pavement, or other unusual conditions.



Porous Pavement Surface Infiltration Rate with Time (Annual cleaning; initial rate of 30 in/hr).

The flow-duration distributions shown below will be significantly moderated with the porous pavement. The duration of flow will decrease by about 90% (for this example for 0.3 in/hr infiltration rate and two 6 in underdrains).

Flow Duration Curves



Flow Duration Data

Discharge Greater Than Percent	Flow Rate (cfs) for Current Model Run	Flow Rate (cfs) Without Controls
0	0.4071	0.4293
0.1	0.08793	0.09830
1	0	0.01803
3	0	0
5	0	0
10	0	0
20	0	0
30	0	0
40	0	0
50	0	0
60	0	0
70	0	0
80	0	0
90	0	0
100	0	0

Print Close

The performance of the porous pavement varies greatly depending on rain intensity, interevent period, and rain depth, plus the native infiltration rates (the surface infiltration rate through the pavement surface is always high, unless clogged due to poor maintenance). The following table lists the approximate (linearized) maximum rain depths associated with at least 90% runoff reductions and for at least 50% runoff reductions.

native infiltration rates (in/hr)	0.02 (clay soil)	0.1 (clay loam soil)	0.5 (loam soil)	1.0 (sandy loam soil)	2.5 (loamy sand soil)
max. rain depth for 90% runoff volume reductions (in)	0.01	0.15	0.23	0.75	all rains
max. rain depth for 50% runoff volume reductions (in)	0.75	1.0	2.0	3.0	all rains
Long-term total runoff reductions (%)	28%	43%	67%	80%	100%

Bioretention Facility Analysis

Biofilters are similar in function to rain gardens but have more complex cross-sections with increased water volume storage that enhances their performance. They are excavations to collect runoff and allow infiltration. They are usually filled with a rock storage layer, and treatment layer, and most have underdrains to prevent excessive ponding for extended times. Because of the increased amount of storage compared to a simple rain garden, biofilters can better handle short periods of increased runoff and larger amounts of runoff.

Biofilter performance is based on the characteristics of the flow entering the device, the infiltration rate into the native soil, the filtering capacity and infiltration rate of the engineered media fill if used, the amount of rock fill storage, the size of the device and the outlet structures for the device. Pollutant filtering by the engineered media (usually containing amendments) is based on the engineered media type and the particle size distribution of the particulates in the inflowing water. If the engineered media flow rate is lower than the flow rates entering the device, the engineered media will affect the device performance by forcing the excess water to bypass the device through surface discharges, if the storage capacity above the engineered media is inadequate.

The device operation is modeled using the Modified Puls Storage-Indication method and is analyzed differently depending on whether a rock and engineered media layer is in the model. The model simulates the inflow and outflow hydrographs using a time interval selected by the user (typically 6 minutes), although this interval is reduced automatically by the program if the simulation calculations approach becoming unstable.

The inflow hydrograph is divided into the selected time intervals, which are routed to the surface of the biofilter. The biofilter is evaluated in two basic sections: the aboveground section (or above the engineered media) and the belowground section (below the surface of the engineered media). If there is a rock layer and an engineered media layer, separate details are entered for each. The available surface outflow devices include broad crested weirs (required to have at least one as the surface overflow outlet), and optional crested weirs, vertical stand pipes, and evaporation/ET. An underdrain is also optional that discharges back to the drainage system (but with “filtered” water).

As water enters the device, the water infiltrates through the media to the belowground section if the engineered media infiltration rate is greater than the inflowing water rate. If the inflow rate increases to be greater than the media infiltration rate, the aboveground storage begins to fill. If the inflowing rate is high enough and the excess runoff volume exceeds the available storage, the water discharges from the device through the aboveground surface broad crested weir outflow, and any other surface outlet. As water enters the belowground section of the device, it passes through the native soil and, as the bottom section fills, it may enter an underdrain (if used). All water that flows through the underdrain is assumed to be filtered by the engineered media. The filtering performance changes based on the type of engineered media and varies by the particle size of the particulates in the water. If the water level in the belowground section of the device reaches the top of the engineered media layer, infiltration from the surface layer into the belowground layer stops until the water level in the belowground section is below the top of the engineered media layer. If there are no rock and engineered media layers, flow into the native soil is considered to be an outflow: there is no belowground section, and all treatment by the device is assumed to be through volume loss by infiltration into the native soil (this is the typical way rain gardens operate, since they have no media or underdrain, but do have surface storage).

The following figures are the data entry forms used for biofilters and related stormwater controls. To model biofilters, the geometry and other characteristics of the biofilter are described, or of a typical biofilter if modeling a set of biofilters for, say, roofs or parking lot source areas. The number of biofilters to be modeled in the source area is also entered on the form. The model divides the total source area runoff volume 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. It then multiplies the resulting runoff pollutant and flow reductions by the number of biofilters for the total source area effects.

Device Geometry:

Top Area (square feet): Enter the top area of the biofilter

Bottom Area (square feet): Enter the bottom area of the biofilter

Total Depth (feet): Enter the depth of the biofilter.

Typical Width (ft): If you intend to perform a cost analysis of the biofilter practices listed in the .mdb file, you must enter the typical biofilter width (ft) of a biofilter system you are modeling. This value is not used for a hydraulic or water quality analysis; it is relevant only for the cost analysis.

Native Soil Infiltration Rate (in/hr): Enter the infiltration rate or select a typical infiltration rate based on soil type from the provided list in the lower left-hand corner of the window. The native soil infiltration rate value is supplied if you select the typical seepage rate provided by the model.

Native Soil Infiltration Rate COV (Coefficient of Variation): If you want to consider the typical variabilities in the infiltration rates, select the "Use Random Number Generation to Account for Uncertainty in Infiltration Rate" checkbox and then accept or enter another seepage rate COV value in the cell below the native soil infiltration rate. This is optional and uses a Monte Carlo simulation built into the model. If selected, the infiltration rates are randomly varied for each event based on a log-normal probability distribution of actual measured infiltration rate variabilities.

Infiltration Rate Fraction - Bottom (0-1): Enter the seepage rate multiplier for bottom flow (from 0 to 1) to reduce the seepage rate through the bottom of the biofilter. This option can be useful if you want to evaluate the effects of complete clogging on the bottom of the device.

Infiltration Rate Fraction - Side (0-1): Enter the seepage rate multiplier for side flow (from 0 to 1) to reduce the seepage rate through either the sides of the biofilter. This option can be useful if you want to ignore the benefits of seepage out of the sides of the device, as required by some regulatory agencies.

Rock Filled Depth (ft): This is the depth of biofilter that is rock filled. This must be less than or equal to the biofilter depth, and may be zero if there is no rock fill. Water is assumed to flow through the rock storage layer very quickly.

Rock Fill Porosity: Enter the fraction of rock fill that is voids as a value from zero to one. If you have both rock fill and engineered soil, the model sums the total pore volume available in the biofilter. If you are using an underdrain, a rock storage layer will be required (and the underdrain is usually located near the top of this storage layer, but can be at the bottom if there is no natural infiltration, or for a sealed system).

Engineered Media Type. If the device has an engineered soil layer, the program uses an infiltration rate depending on the type of engineered media, based on extensive media tests in laboratory columns and in the field. Select the 'Media Data' button to enter media type information including the media porosity, infiltration rate, field moisture capacity and permanent wilting point.

Engineered Media Infiltration Rate (in/hr): If you have selected a specific engineered media type, the program uses an infiltration rate for that media type, or if you selected a user defined media type, you may enter your own engineered media infiltration rate.

Engineered Media Depth (ft). This must be less than or equal to the biofilter depth, and may be zero if there is no engineered media fill.

Engineered Media Porosity (0-1): This is the fraction of engineered media that is voids - enter the porosity of the engineered media as a value from zero to one. If you have both rock fill and engineered media, the model sums the total pore volume from all layers.

Percent Solids Reduction Due to Engineered Media. If you want to enter a percent solids reduction value from engineered media if permitted to do so by the regulatory agency or because you have suitable data, select "User-Defined" as the engineered media type in the Detailed Soil Characteristics form. If you select any other engineered media type, the program calculates the particulate solids reductions based on the media type and stormwater characteristics.

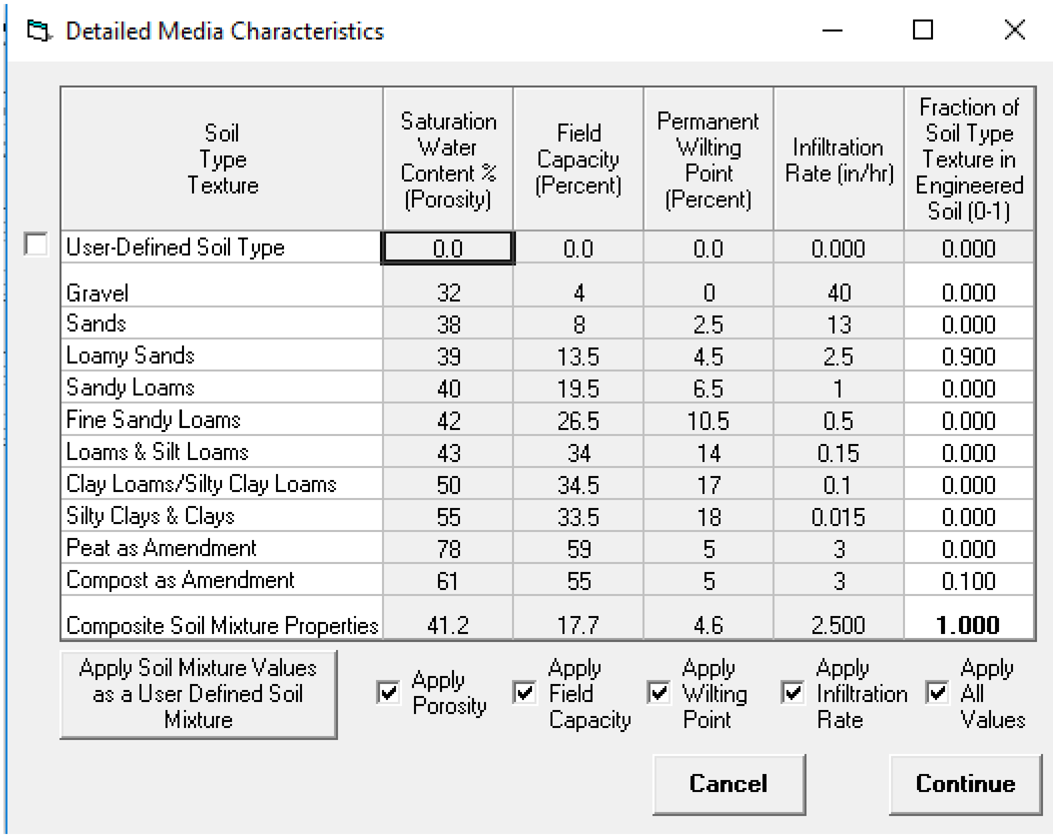
Inflow Hydrograph Peak Flow to Average Flow Ratio. This value is used to determine the shape of the complex triangular unit hydrograph that is routed through the device. A typical value of the peak to average flow ratio is 3.8. However, short duration events in small areas may have larger ratios and similarly, long duration events in large areas may have smaller ratios. In version 10, it is recommended that the option to use the routed hydrograph from upgradient areas and controls be selected instead of setting this value to 3.8.

Number of Devices in the Source Area or Upstream Drainage System (all assumed to be similar with similar drainage areas, otherwise enter them separately). The model divides the runoff volume by the number of biofilters in the source area or land use, creates a complex triangular hydrograph that it routes through that biofilter, and then multiplies the resulting losses by the number of biofilters to apply the results to the source area.

Particle Size Distribution File. The particle size distribution of the particulates in the runoff affects the percent solids reduction of the engineered media layer. If you select the 'Route Hydrographs and Particle Sizes between Control Devices' checkbox in Program Options/Default Model Options (recommended), the program uses the routed particle size distributions from upgradient source areas. The particle size distribution entering the control device is modified by whatever practices are upstream of the control practice. If the practice is the most upstream practice, the initial particle size distribution is used.

Pipe or Box Storage is not activated in this model version.

The following figure is a screen shot used to select the engineered media mixture. The model calculated the porosity, field capacity, wilting point, and infiltration rates for many combinations based on laboratory and field tests. The model also calculates the removal of different sized particles in the runoff based on the media mixture and stormwater characteristics.



Detailed Media Characteristics

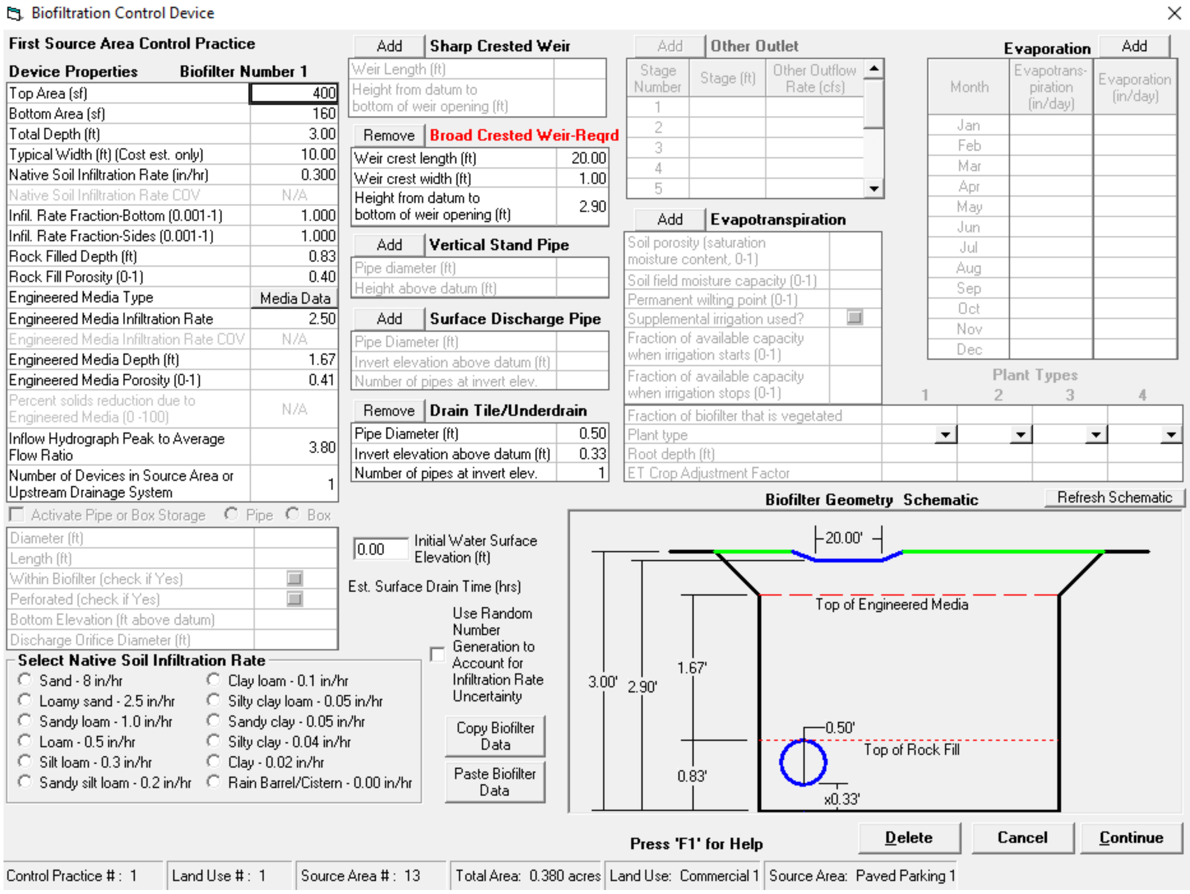
Soil Type Texture	Saturation Water Content % (Porosity)	Field Capacity (Percent)	Permanent Wilting Point (Percent)	Infiltration Rate (in/hr)	Fraction of Soil Type Texture in Engineered Soil (0-1)
User-Defined Soil Type	0.0	0.0	0.0	0.000	0.000
Gravel	32	4	0	40	0.000
Sands	38	8	2.5	13	0.000
Loamy Sands	39	13.5	4.5	2.5	0.900
Sandy Loams	40	19.5	6.5	1	0.000
Fine Sandy Loams	42	26.5	10.5	0.5	0.000
Loams & Silt Loams	43	34	14	0.15	0.000
Clay Loams/Silty Clay Loams	50	34.5	17	0.1	0.000
Silty Clays & Clays	55	33.5	18	0.015	0.000
Peat as Amendment	78	59	5	3	0.000
Compost as Amendment	61	55	5	3	0.100
Composite Soil Mixture Properties	41.2	17.7	4.6	2.500	**1.000**

Apply Soil Mixture Values as a User Defined Soil Mixture | Apply Porosity | Apply Field Capacity | Apply Wilting Point | Apply Infiltration Rate | Apply All Values

Cancel | Continue

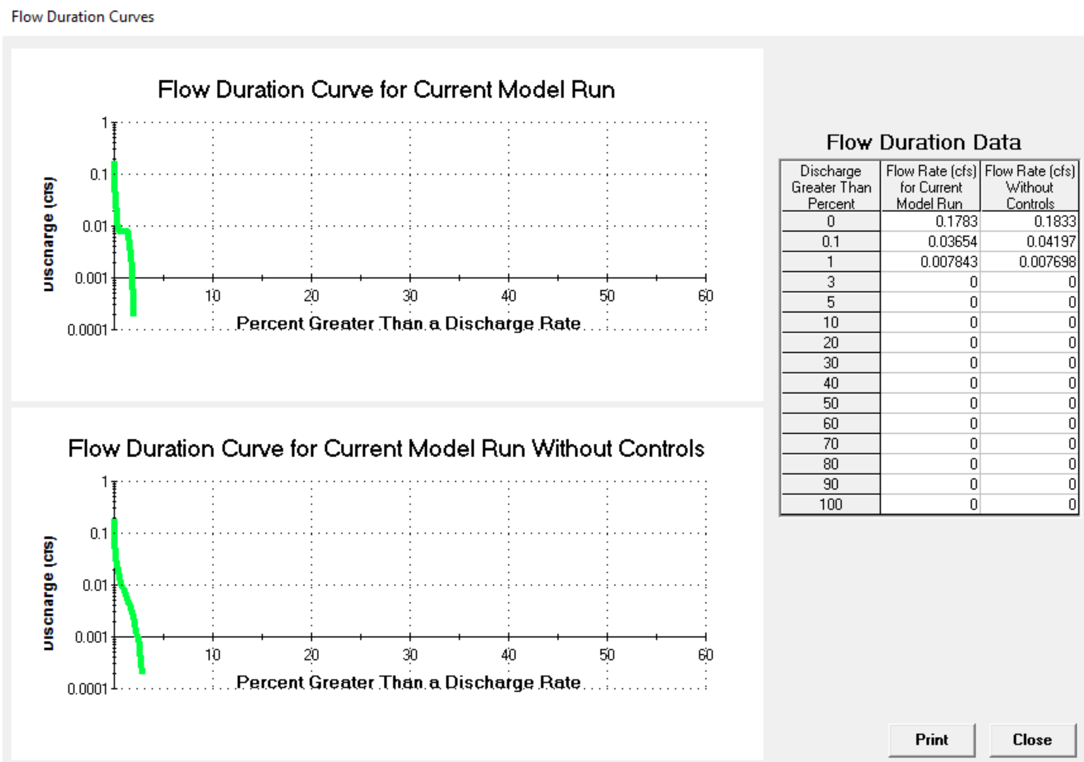
Screen shot of bioretention media screen showing mixture assumed for site (10% compost and 90% loam soil).

The resulting media infiltration rate is estimated to be about 2.5 in/hr, and the porosity is estimated to be about 0.4. No plants were used in this analysis so the wilting point value was not used in the media moisture calculations.



Bioretention System Input Screen (0.3 in/hr native soil infiltration rate and 6 inch underdrain)

The shape of the flow-duration graphs below for with and without treatment (1X6 in underdrains and 0.3 in/hr native soil infiltration rate) are quite different, but the actual flows for peak, 0.1% and 1% durations are similar. Even though the peak discharge rate are similar, the flows drop quickly to moderate flows.



Discharge Greater Than Percent	Flow Rate (cfs) for Current Model Run	Flow Rate (cfs) Without Controls
0	0.1783	0.1833
0.1	0.03654	0.04197
1	0.007843	0.007698
3	0	0
5	0	0
10	0	0
20	0	0
30	0	0
40	0	0
50	0	0
60	0	0
70	0	0
80	0	0
90	0	0
100	0	0

The calculated particulate solids loading rate for this biofilter is about 0.2 kg/m^2/yr. It would therefore require many decades of use before the total accumulative loading reached the expected clogging load of 10 to 25kg/m^2. Therefore, even with minimal plants to help incorporate the particulates into the biofilter's media, this system should not prematurely fail.

The performance of the biofilter varies greatly depending on rain intensity, interevent period, and rain depth, plus the native infiltration rates. The following table lists the approximate (linearized) maximum rain depths associated with at least 90% runoff reductions and for at least 50% runoff reductions.

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