WinSLAMM Model Algorithms

Grass Swale Infiltration and Filtering Functions

Grass swale performance is determined by routing a complex triangular hydrograph through the swales entered described in the model by the user. Runoff volume reductions are determined by infiltration losses, and particulate losses are determined through particle trapping.

The runoff volume is reduced using the area affected by the wetted perimeter and the dynamic infiltration rate of the swales for each six-minute time step of the hydrograph. The calculated flow and the swale geometry are used to iteratively determine the Mannings n and the depth of flow in the swale for each time step, using traditional VR-n curves based upon retardance measurements that were extended 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) to cover the smaller flows found in roadside 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 dynamic infiltration rate is one-half the static infiltration rate as measured using double ring infiltrometer devices. For relatively flat swale gradients (<0.5 %), the static infiltration is used without modification. The dynamic infiltration rate is used for steeper swales (>2.0 %) based on field mass balance measurements of swale infiltration during swale research by Wanielista (19XX) in Florida, as described later.

Particulate filtering is calculated for each time step using the average swale length to the outlet and the calculated depth of flow for each 6-minute time step of the hydrograph. The depth of grass also affects the particulate trapping in the swale. The depth of flow and swale geometry are used to calculate the flow velocity, which in turn is used to determine the travel time, and particulate settling frequency for the average swale length in the study area for each particle size increment. Particulate trapping is based on the settling frequency: how many times would a particle be able to completely settle during the length of the swale. Particles that may settle many times in the swale (the large particles) are much more likely to remain trapped in the swale, while particles that settle less frequently have a greater probability of moving through the swale. Taller grass is also more effective in trapping the particles than shorter grass, though grasses greater than four inches in height will not increase filtering performance in the model at this time because of current data limitations.

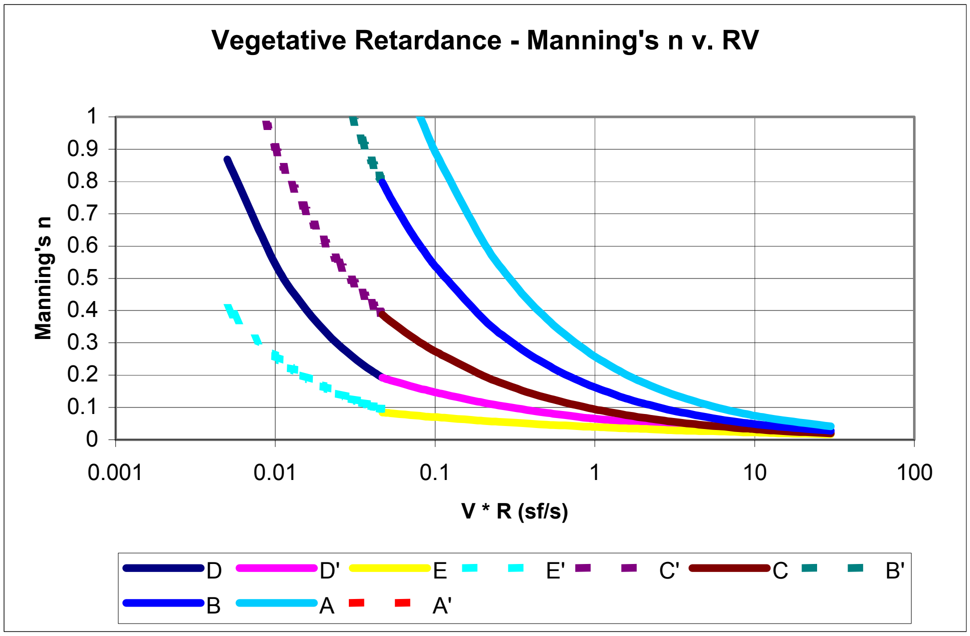
The flow, particulate, and swale geometry information is used to determine the flow depth to grass height ratio and the settling frequency that are used to calculate particulate trapping, adapted from Nara and Pitt (Nara, Y., R. Pitt, S.R. Durrans, and J. Kirby. “Sediment transport in grass swales.” In: *Stormwater and Urban Water Systems Modeling.* Monograph 14, edited by W. James, K.N. Irvine, E.A. McBean, and R.E. Pitt. CHI. Guelph, Ontario, pp. 379 - 402. 2006). 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 broader groups of particle sizes and evaluated to determine if they are 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. No particles smaller than 50 microns are trapped in grass swales due to turbulent resuspension of these small particles.

The outline of the swale infiltration and filtering functions is as follows:

1. **Swale Properties**. The average swale length is the length of the typical swale in the drainage area before it discharges into the drainage system (either inlet or outfall). For a square drainage area, this average length is assumed to be the width of the area, plus one-half the height of the area, corresponding to a swale going thru the center of the area and draining to a corner of the area. The user can enter their own average swale length of the modeled area. This would be important if a single commercial site is being investigated and the actual swale lengths are known and are different from the above calculated value, for example.
   Determine the swale system properties.
   a. For Infiltration: The entire swale length, as represented by the product of the swale density and the area served by swales, is used in the infiltration calculation.
   b. For Filtering: The average grass swale length is reduced by 25 feet times the number of acres of impervious surface in the area served by the swales to account for the initial turbulent zone as the water enters the swale.
      The average swale length (either entered by the user or 1.5 times the square root of the area served by swales, as described above) is reduced based upon either or both of the flow velocity and longitudinal slope. This is needed to ensure that a minimum swale length is used for all calculations.

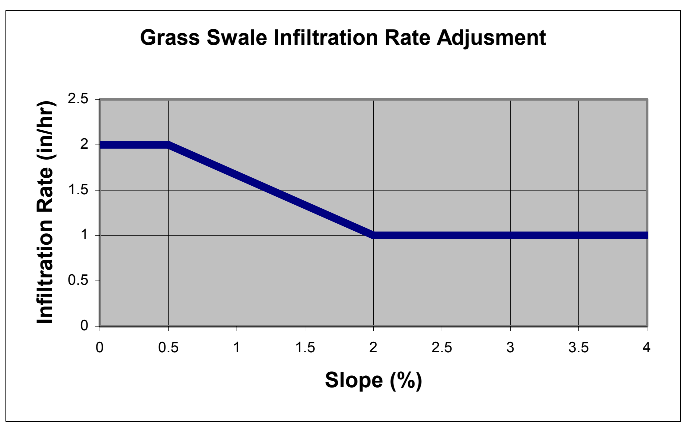
Flow Velocity (inches/sec)		Longitudinal Slope	Swale Length Reduction (ft)
< 0.5	And	< 0.02	3
< 1	Or	> 0.02 and <= 0.05	6
>= 1	Or	> 0.05	10

2. **Swale Hydraulic Properties**. After the appropriate swale length is determined, the program will calculate the incremental flow rate for each time step, in six minute increments. The flow in the swale system at each time step is half the flow from the time step, assumed to be the average flow. This is an iterative process, where
   a. Assume a depth of flow in the swale
   b. Calculate the VR (Velocity times Hydraulic Radius) based upon that depth
   c. Determine the Mannings n value based upon VR using the plot shown below, based upon the Stillwater data (solid lines with VR > 0.05 and Kirby data (solid D retardance.
   d. Calculate the flow based upon the Mannings n and assumed depth
   e. Determine the difference between the calculated flow and the modeled incremental flow entering the swale. If the difference between the two flows is greater than 0.0001 cfs, re-estimate the flow depth, and begin the process again.



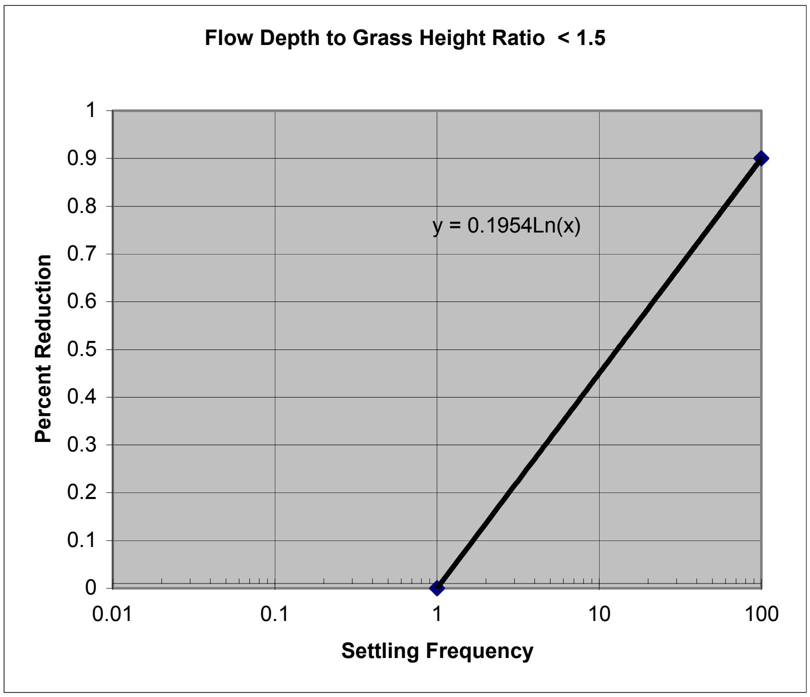
The Stillwater data (solid lines with VR > 0.05) and the vegetative retardance D value from the Kirby data (solid dark blue line) were used to interpolate the remaining n v. RV retardance lines. However, since virtually none of the data from either the Stillwater or Kirby studies ever had a Mannings n value above 1.0, that is taken as the maximum allowable n value.

3. **Swale Filtering Process**. After determining the flow properties of the swale, for each time step -



   a. Adjust the infiltration rate based upon the swale slope, as illustrated in the adjacent plot where the measured double ring static infiltration rate was determined to be 2 in/hr, so the dynamic infiltration rate is calculated to be half that, or 1 in/hr..
   b. Calculate the runoff volume infiltrated by the swale using the adjusted infiltration rate and the calculated wetted perimeter for each time step.
   c. Adjust the average swale length as described above in 1b., Average Swale Properties.
   d. Determine the average travel time (swale length/flow velocity) in the average swale
   e. Determine the flow depth to grass height ratio
   f. For each particle size increment, determine the:

i. Average settling velocity for the range of particles in the narrow size increment
ii. Settling duration (depth of flow/settling velocity)
iii. Setting frequency (travel time/settling duration)
iv. Determine the percent particulate reduction based upon the settling frequency and the flow depth to grass height ratio, as shown on the example plot below for a flow depth to grass height ratio < 1.5. Other graphs are used for flow depth to grass height ratios of 1.5 to 4 and >4, based on the research by Nara and Pitt.(2006).
v. If the particle size is less than 50 microns, the settling frequency is assumed to be zero as no settling of these small particles is expected.



g. Combine the results from the 31 narrow particle classes into a particle size distribution having eight wider groups.
    i. Calculate the effluent concentration for each group.
    ii. Check to make sure the treated particulate solids concentration for each group is not less than the irreducible concentration for that group. The groups and irreducible concentrations are listed below.

Particle Size Range Number	Particle Size Range	Irreducible Conc. for Size Range (mg/L)
1	0.45 to 2 µm	5
2	2 to 5 µm	4
3	5 to 10 µm	3
4	10 to 30 µm	2
5	30 to 60 µm	1
6	60 to 106 µm	0
7	106 to 425 µm	0
8	> 425 µm	0

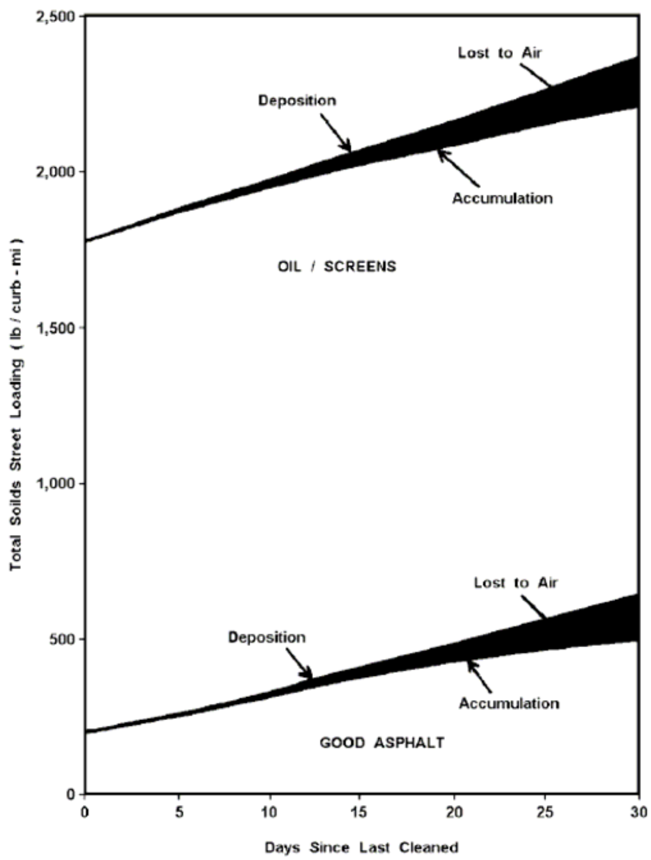
h. Sum the concentration values for each particle size group to determine the final concentration in the effluent discharged from the swale system for each time step.

Street Dirt Accumulation, Washoff and Street Cleaning Functions

Street Dirt Accumulation

Street dirt accumulation is expressed in WinSLAMM as a function of the initial deposition rate, time since the time series started (after a rain event or street cleaning event), and a decrease function. The street dirt loading equation uses a higher initial street dirt loading rate immediately after a rainfall or street cleaning event (the deposition rate); the rate of accumulation of material on the street decreases over time, until the maximum street dirt loading is reached.

The following figure from EPA-sponsored research conducted in San Jose, CA (Pitt 1979) shows the relationship between the deposition rate, the accumulation rate, and the amount of street dirt lost to the air as fugitive dust (determined by the decrease function) for two different streets in the same study area: the only difference is the street texture. Very rough streets have a larger initial load after an event compared to smooth streets, but the accumulation rate of street dirt is the same, resulting in much greater street dirt loadings for rough textured streets. The amount of street dirt lost as fugitive dust (due to traffic turbulence or high winds) increases with time, as the amount of material increases on the street (more exposed to these fugitive dust losses compared to the street dirt being protected in the street texture). Eventually, the street dirt loading levels off, reaching a steady load (after an extended period).



Source: Pitt 1979

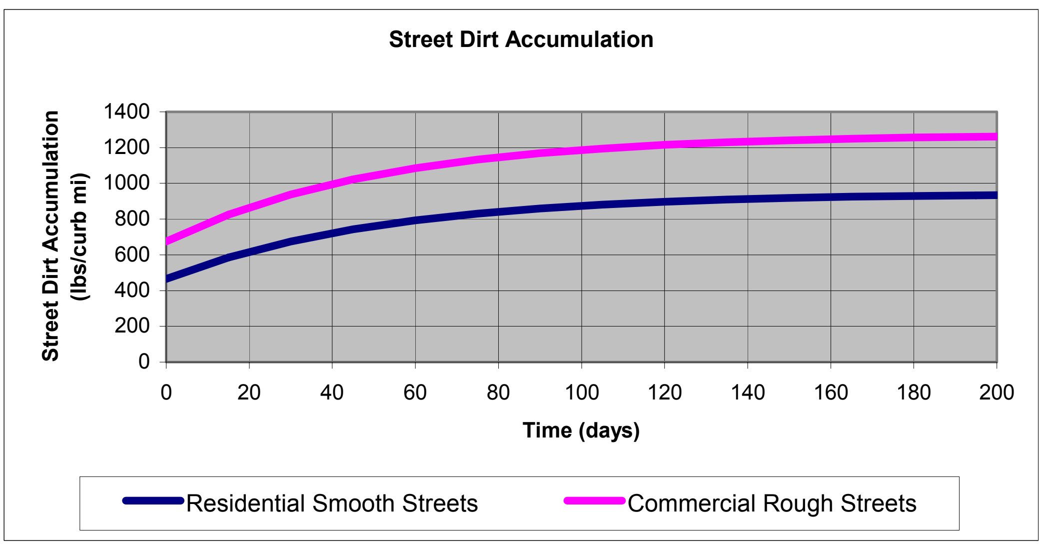
The following equation is used in WinSLAMM to calculate the street dirt load at any time.

$SDLoad_i = SDLoad_{i-1} + SDDepRate * AccRateReducFrac^{(i-1)} * (PerNum-1) * NumDays$

Where

$SDLoad_i$ = Street dirt load at the end of a given time period (lbs/curb-mi)
$SDLoad_{i-1}$ = Street dirt load at the end of the previous time period (lbs/curb-mi)
i = The time period number that a given street dirt accumulation rate is applied
SDDepRate = Street dirt deposition rate (lbs/curb-mi/day)
DepRateReducFrac = The fraction that the deposition rate is reduced by, for each time period due to fugitive dust losses
PerNum = The time period number
NumDays = The number of days per time period

To determine the street dirt loading at a given time period after the end of a washoff or street cleaning event, the program divides the accumulation curve into even time periods. The accumulation rate is progressively reduced for each time period by the accumulation rate reduction fraction, and this fraction is multiplied by the accumulation rate for each time period. The street dirt load from this time period is added to the load from the previous time period. The Street Dirt Accumulation plot illustrates two curves – one for smooth residential streets, and one for rough commercial streets.



Street Land Use and Texture	Accumulation Rate Reduction Period (days)	Street Dirt Base Load (lbs/curb-mi)	Street Dirt Deposition Rate (lbs/curb-mi/day)
Residential Smooth	15	225	8
Commercial Rough	5	375	10

The accumulation rate reduction periods, accumulation rate reduction fractions and deposition rates used in SLAMM are listed in the tables below. The minimum available load for street cleaning or washoff is B/(1-M)

Accumulation Rate Reduction Fraction

Land Use	Street Texture: Smooth and Intermediate	Street Texture: Rough and Very Rough
Residential and Other Urban	0.75	0.5
Commercial, Institutional and Industrial	0.75	0.5

Accumulation Rate Reduction Period (days)

Land Use	Street Texture: Smooth and Intermediate	Street Texture: Rough and Very Rough
Residential and Other Urban	15	15
Commercial, Institutional and Industrial	5	5

Street Dirt Base Load and Maximum Accumulation Load

Street Texture	Base Load (lbs/curb-mi)	Maximum Accumulation Load (lbs/curb-mi)
Smooth and Intermediate	225	1500
Rough	375	1750
Very Rough	375	2000

Deposition Rate (lbs/curb-mi/day)

Residential Land Use	8
Institutional Land Use	10
Commercial Land Use	10
Industrial Land Use	25
Other Urban Land Use	10

Washoff

Street dirt washoff is based upon modified relationships and equations that were initially developed by Sarter and Boyd (1972). Sartor and Boyd fitted their data to an exponential curve, assuming that the rate of particle removal of a given size is proportional to the street dirt loading and the constant rain intensity:

$$dN/dt = k\ r\ N$$

where:

dN/dt = the change in street dirt loading per unit time
k = proportionality constant
r = rain intensity (in/h)
N = street dirt loading (lb/curb-mile)

This equation, upon integration, becomes:

$$N = N_o\ e^{-krt}$$

where:

N = residual street dirt load (after the rain)

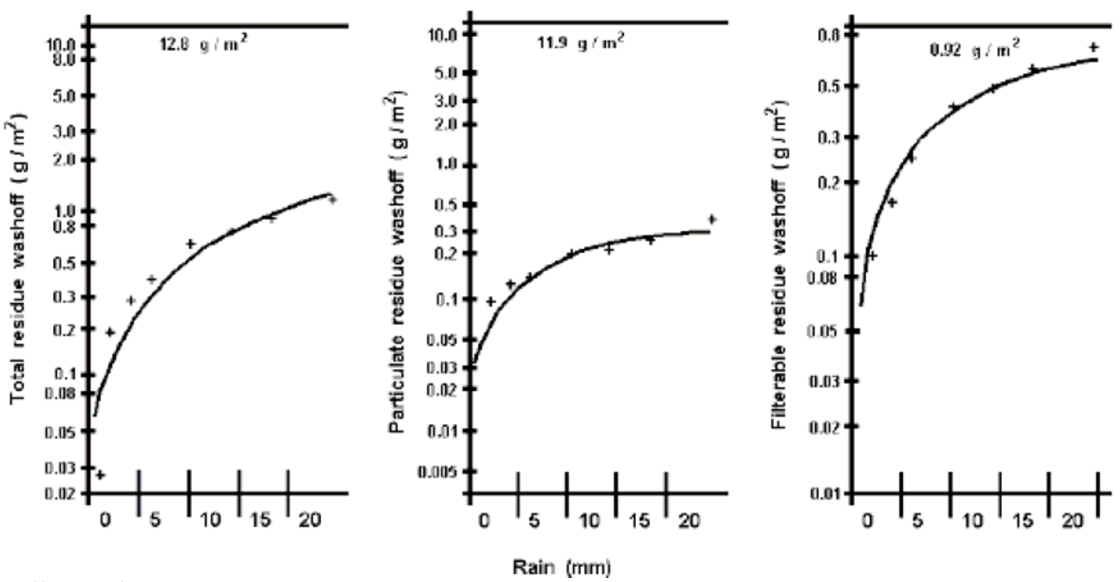
N_o = initial street dirt load
t = rain duration

Street dirt washoff is therefore equal to N_o - N. The variable combination rt, or rain intensity times rain duration, is equal to total rain volume (R). This equation therefore further reduces to:

$$N = N_o e^{-kR}$$

Therefore, this equation is only sensitive to total rain, and not rain intensity. The proportionality constant, k, was found by Sartor and Boyd to be slightly dependent on street texture and condition, but was independent of rain intensity and particle size. The N_o factor is only the portion of the total street load available for washoff (the maximum asymptotic washoff load observed during the washoff tests). It is not the total initial street loading assumed by many models. WinSLAMM uses an availability factor for total solids on the street based on extensive field monitoring to reduce the washoff quantity to what is available for washoff. WinSLAMM also uses a street delivery fraction as an additional calibration tool to adjust the initial calculated washoff fraction to determine the final washoff load.

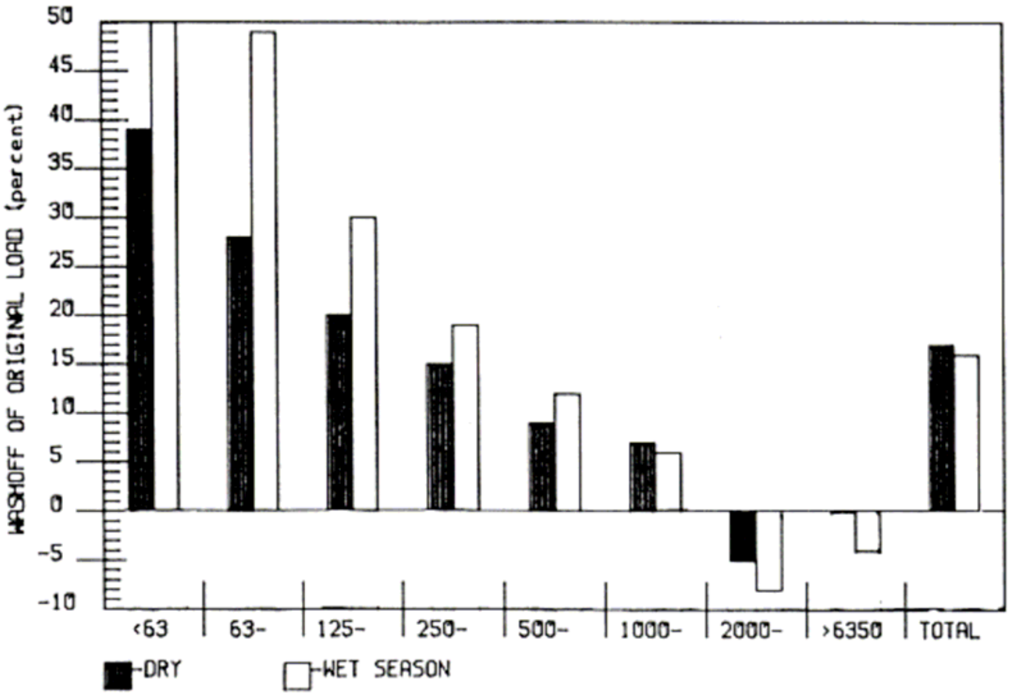
The following washoff plots are from field research conducted by Pitt (1987) and shows the accumulative washoff as a function of rain depth for particulates <0.45 µm (TDS), >0.45 µm (SS) and for total solids. The maximum washoff for the SS data is about 0.3 g/m^2, while the total loading on the street was about 12 g/m^2, an availability factor of about 1/35 for this test. Many controlled washoff tests were conducted to obtain these parameters.



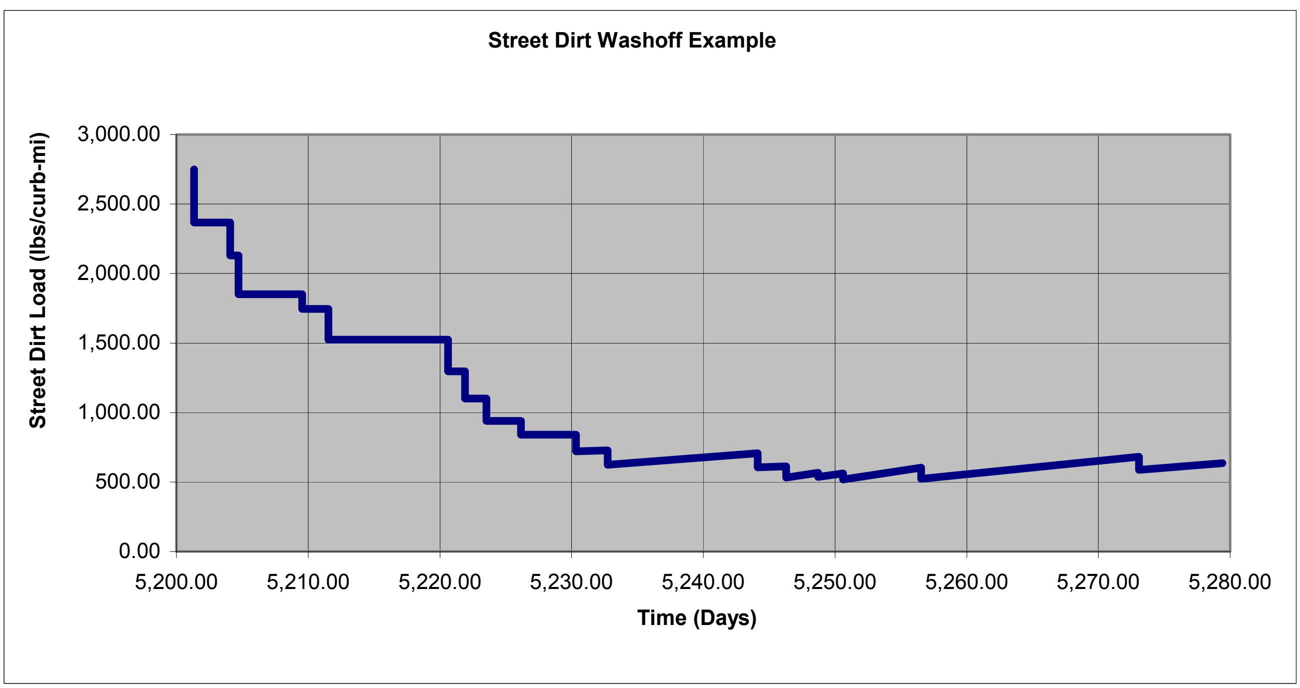
Washoff plots for HDR test (high rain intensity, dirty, and rough street) (Pitt 1987).

Both the availability factor and the proportionality constant, k, in WinSLAMM are a function of street texture, the before event load and rainfall intensity. The value of k varies from 0.12 to 0.92, and the availability factor varies from 0.09 to 0.18. To view these values for each event, select the detailed output option ‘Washoff or Street Cleaning Detail File’.

The following plot shows the washoff amounts for different particle sizes during many rains in Bellevue, WA, obtained during another EPA project (Pitt 1985). Note that the rains more effectively remove the smaller particles than the larger particles. In fact, large particles may actually increase in loading during a rain due to large particulates not being able to be transported along the gutter during the rain. WinSLAMM therefore also includes a street dirt delivery function that addresses this deposition of street dirt in the gutters.



Observed washoff of street dirt during tests in Bellevue, WA (Pitt 1985).



The above example plot shows how washoff decreases with each rainfall event after the end of the winter season. The initial load of 2750 lbs/curb-mi is the street dirt load at the end of the winter season. The load decreases with each washoff event until the load after the washoff event plus the load accumulated before the next event is less than the load from the street dirt accumulation curve. Once the load reaches this level (in the above example, at about 720 lb/curb-mile), the street dirt load will begin to increase until the next washoff event.

Street Cleaning

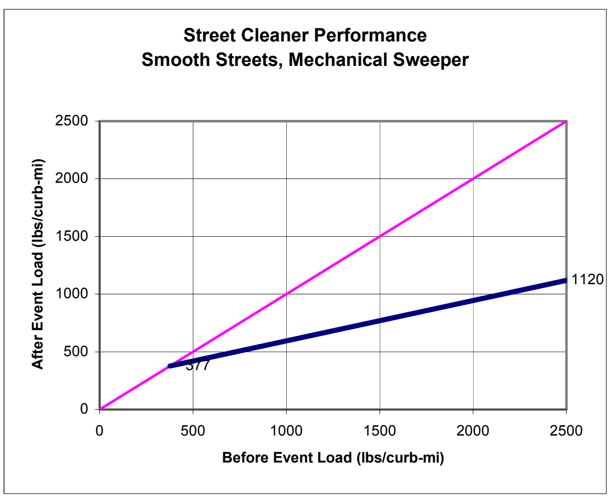
The street cleaning equation is a linear function with a slope and a constant term. Both terms are a function of the type of cleaning equipment (mechanical broom or vacuum assisted cleaner), the street texture, the parking density and whether or not parking controls are imposed. The slope must be less than one and the intercept must be greater than one. Note that the program will not calculate an AfterEventLoad that is greater than the BeforeEventLoad. The street cleaning equation is:

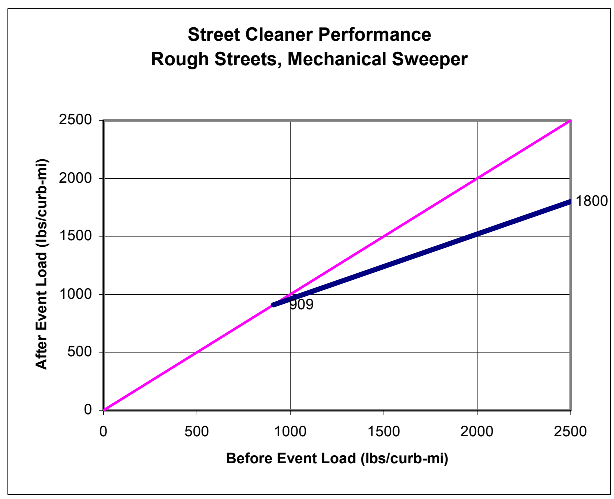
AfterEventLoad = M * BeforeEventLoad + B

where

AfterEventLoad = Street dirt load after the cleaning event
M = Maximum cleaner efficiency (less than 1.0, no units)
BeforeEventLoad = Street dirt load before the cleaning event (lbs/curb-mile)
B = Slope intercept term, (greater than 1, lbs/curb-mile)

Below is an example of how a mechanical sweeper will perform on smooth and rough streets if there is no parking allowed on the streets (Parking Density = None). The table below the plot lists the equation coefficients for these two conditions.





Street Cleaning Coefficients for the above Plots

	Slope Coefficient, M	Intercept Coefficient, B
Smooth Streets	0.35	245 lbs/curb-mi
Rough Streets	0.56	400 lbs/curb-mi

Freeway Accumulation and Washoff

Freeway Accumulation

Freeway accumulation is expressed in WinSLAMM as available particulate residue, which is a function of average daily traffic, freeway length and the accumulation duration, which can be no greater than twenty days.

The following equation is used in WinSLAMM to calculate the available total residue at any time.

AvailTtlRes = 0.007 * ADT^0.89 * FreewayLength * AccumDur + CurLoad

Where

AvailTtlRes = Available Total Residue (lbs)
ADT = Average Daily Traffic (vehicles/day)
FreewayLength = Freeway Length (miles)
AccumDur = Length of time from the last washoff event (days)
CurLoad = The freeway load after the end of the washoff event (lbs)

Washoff

Freeway washoff is based upon modified relationships and equations that were initially developed by Sarter and Boyd (1972). Rexnord, Inc. (1985) conducted a series of monitoring projects for the USDOT in the early 1980s to measure the discharge of pollutants from limited access roads. They monitored several freeways in different cities throughout the country. They related runoff quality to traffic loads, and rain factors, and directly calibrated the Sartor and Boyd washoff equations. Sartor and Boyd fitted their data to an exponential curve, assuming that the rate of particle removal of a given size is proportional to the freeway loading and the constant rain intensity:

$$dN/dt = k\ r\ N$$

where:

dN/dt = the change in freeway loading per unit time
k = proportionality constant
r = rain intensity (in/h)
N = freeway loading (lb/curb-mile)

This equation, upon integration, becomes:

$$N = N_o\ e^{-krt}$$

where:

N = residual freeway load (after the rain)
N_o = initial freeway load
t = rain duration

Freeway washoff is therefore equal to N_o - N. The variable combination rt, or rain intensity times rain duration, is equal to total rain volume (R). This equation therefore further reduces to:

$$N = N_o e^{-kR}$$

Therefore, this equation is only sensitive to total rain, and not rain intensity. The proportionality constant, k, was adjusted to reflect freeway conditions, based upon the Rexnord data [1985], but was independent of rain intensity and particle size. The N_o factor is only the portion of the total freeway load available for washoff (the maximum asymptotic washoff load observed during the washoff tests). Because the Rexnord only monitored actual runoff (and not street dirt loads), WinSLAMM uses a lumped approach for highway runoff, directly predicting runoff from traffic volumes and the rain characteristics. As such, the benefits of street cleaning cannot be directly determined, as street cleaning affects the total street dirt load, which is much larger than the "available" street dirt loading. WinSLAMM also uses a freeway delivery fraction, which is a function of drainage system type and rainfall depth, as an additional calibration tool to adjust the initial calculated washoff fraction to determine the final washoff load to account for limiting effects of rain energy.

Rexnord, Inc. Effects of Highway Runoff on Receiving Waters. Volume 4. Procedural Guidelines for Environmental Assessments. PB86-228228/XAB. Federal Highway Administration. July 1985.

Biofiltration Infiltration and Filtering Functions

General Description

The biofiltration control option is a multi-featured control device that uses full routing calculations associated with pond storage along with a variety of outlet(s) and soil treatment options. The “outlet” devices include:

- natural soil infiltration (you can consider the wide range of variability in infiltration rates in disturbed urban soils by selecting the built-in Monte Carlo option),
- evaporation,
- surface discharges through overflows (a stand pipe or weirs),
- subsurface discharges through underdrains, or
- to set up the device as a rain barrel or a cistern with controlled withdrawals for beneficial uses of the captured stormwater.

This is a very flexible control device, and as such can be used to evaluate the following types of control practices:

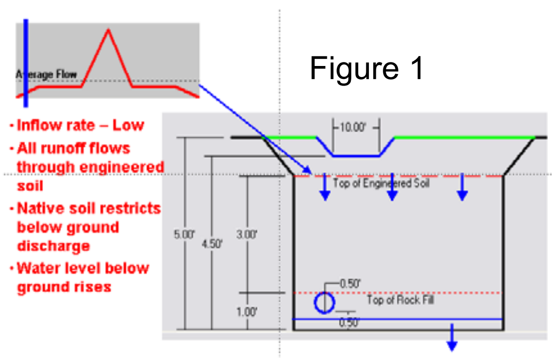
- Biofilters
- Rain Gardens
- Infiltration Basins
- Infiltration Trenches
- Cisterns and Rain Barrels
- Infiltration Pits
- Rock-filled Trenches
- Percolation Ponds
- Perforated Pipes
- Bottomless Inlets

Biofiltration controls are usually numerous in an area and can be represented in the model individually or in multiples (by specifying how many of each unit is treating the flow from an individual or combination of source areas).

Hydraulic Algorithm

The device operation is modeled using the Modified Puls Storage-Indication method, and is analyzed differently depending upon the use of rock and/or engineered soil layers. The complex triangular inflow hydrograph is divided into six-minute time steps that are routed to the surface of the biofilter. The biofilter is evaluated in two sections, or cells: the above ground section (or above the engineered soil) and the below ground section (including the engineered soil and/or other fill material). The series of graphics below illustrates a number of different flow configurations.

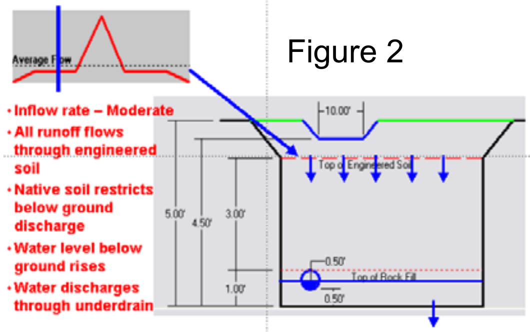
Figure 1



As water enters the device, all flow is routed from the surface to the below ground section of the device. This continues to occur as long as the engineered soil infiltration rate for the biofilter area is greater than the water inflow rate, and, if the antecedent soil conditions allow for infiltration. All runoff flows through the engineered soil and is infiltrated into the native soil. The runoff that is infiltrated into the native soil is considered completely (100 %) treated. See Figure 1.

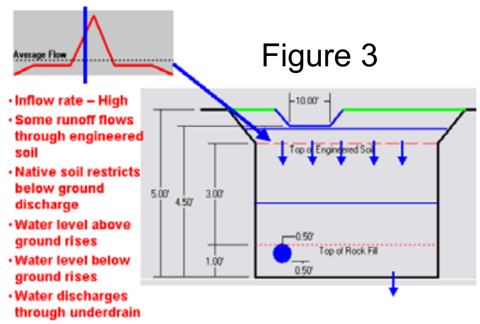
As the inflow rate increases, the below ground water level increases to the point where water begins to flow out the orifice. At this point all runoff is treated by the engineered soil. But since some runoff flows through the orifice/drain tile, some treated runoff is discharged from the system. (Figure 2)

Figure 2



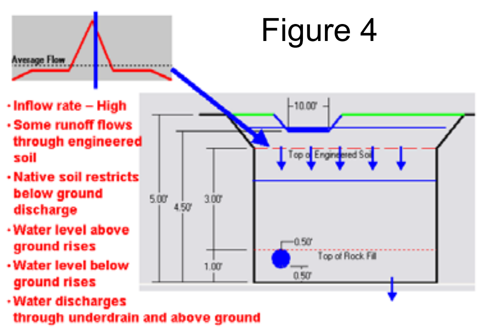
The above ground storage begins to fill up once the inflow rate exceeds the engineered soil infiltration rate. Water levels in the below ground cell continue to rise. This will occur as long as the inflow rate to the below ground cell is greater than the outflow rate from the orifice/drain tile plus the infiltration into the native soil. Some treated runoff is discharged from the system. (Figure 3)

Figure 3



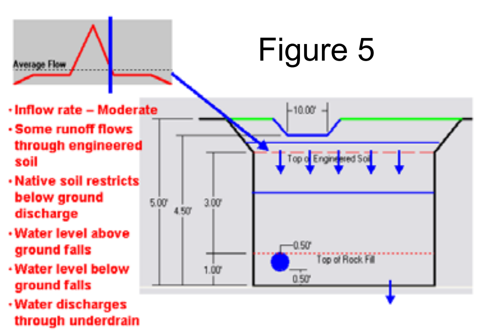
In Figure 4, the above ground storage exceeds the elevation of the overflow weir. At this point, untreated runoff is discharged into the system. Water levels in the below ground cell continue to rise as the inflow rate to the below ground cell is greater than the outflow rate from the drain tile plus the infiltration into the native soil. Some treated runoff is also discharged from the system. If the water level in the below ground section of the device reaches the top of the engineered soil layer, then infiltration from the surface layer into the below ground layer is turned off. Infiltration into the below ground layer is turned off until the water level in the below ground section is below the top of the engineered soil layer.

Figure 4



As the inflow rate decreases, the surface water level also decreases. No more untreated water is discharged, but treated water, which flowed through the engineered soil, is still discharged through the orifice/drain tile. (Figure 5)

Figure 5



As the inflow rate continues to decrease, surface water vanishes and the water level below ground decreases. This will occur because the inflow rate through the engineered soil is less than the sum of the discharge rate through the orifice/drain tile and infiltration into the native soil. At this point all runoff is treated by the engineered soil, but since some runoff flows through the orifice, some treated runoff is discharged from the system. (Figure 6)

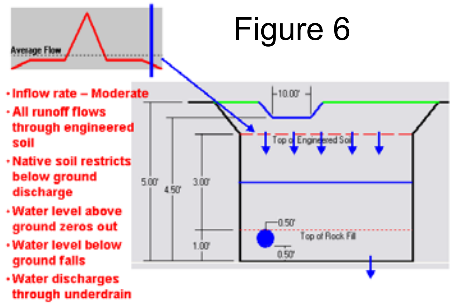


Figure 6

As the inflow rate approaches zero, the water level below ground continues to decrease. Once the water level is below the orifice/drain tile, then all water is treated because all water is infiltrated into native soil. (Figure 7)

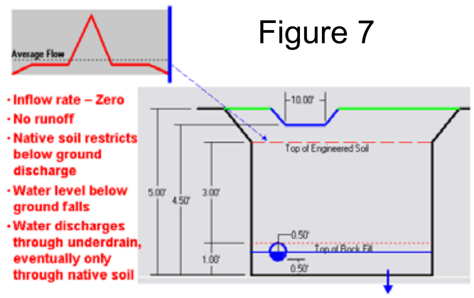


Figure 7

If there are no rock and engineered soil layers, then:

- flow into the native soil is considered to be an outflow,
- there is no below ground section, and
- all treatment by the device is assumed to be through volume loss by infiltration into the native soil.

Pollutant Removal

Biofilter performance is based upon the:

- flow entering the device,
- the infiltration rate into the native soil,
- the filtering capacity and infiltration rate of the engineered soil fill,
- the amount of rock fill storage,
- the size of the device, and
- the outlet structures for the device.

Pollutant filtering by the engineered soil (usually containing amendments) is based upon the engineered soil type and the particle size distribution of the inflowing water. The user can also directly enter the percent reduction due to filtering that is allowed by a regulatory agency.

Scenarios include:

1. Biofilter with Engineered Soil. Particulate solids (and associated particulate-bound pollutants) are removed based upon the influent particle size distribution and the engineered soil type, as described in Table 1. The fractional removal rate for each particle size range is applied to the influent concentration, for each event. For example, 18% of the particles in the NURP.CPZ particle size distribution fall within the range of 12 to 30 microns. If the engineered soil media were peat and sand, then eighteen percent of the influent concentration for each event would be reduced by 85% for that particle size range. This reduction is applied to all runoff that flows through the engineered soil. If the

engineered soil flow rate is lower than the flow rates entering the device, then the engineered soil will affect the device performance by forcing the excess water to bypass the device through surface discharge if the storage capacity above the engineered soil in inadequate. This bypass water is considered, in the model, to be untreated. There is also an "irreducible" concentration that is considered below which the filtration media cannot remove the particulate solids concentration.

2. Biofilter with User-Defined Engineered Soil. The particulate solids reduction of all runoff that flows through the engineered soil will be reduced by the user-defined reduction value. The overall effluent concentration reduction for each event will be proportional to the runoff that bypasses the device. For example, if 75% of the runoff from a rainfall event flows through a device that is to get a 50% reduction, as defined by the user, then the total percent reduction for that event would be 37.5%.

3. Biofilter with No Engineered Soil. The particulate solids reduction is calculated by the volume of runoff that infiltrates into the native soil. If, for a given event, 40% of the runoff is infiltrated into the native soil, then there will be a 40% reduction in particulate solids.

Table 1 - Particulate Treatment in Stormwater Infiltration and Filter Control Devices

Fractional Removal of Stormwater Particulates

Media	Applicable Stormwater Controls	0.45 to 3µm	3 to 12µm	12 to 30µm	30 to 60µm	60 to 120µm	120 to 250µm	>250µm	Minimum Effluent TSS Concentration
Porous pavement surface (asphalt or concrete)	Porous pavement	0.00	0.00	0.00	0.00	0.25	0.50	1.00	n/a
Coarse gravel	Porous pavement and biofilter underdrain and storage layer	0.00	0.00	0.00	0.00	0.00	0.00	0.10	n/a
Sand	Porous pavement, biofilter, and filter	0.10	0.33	0.85	0.90	1.00	1.00	1.00	10 mg/L
Loam soil	Engineered soil/biofilter	0.10	0.33	0.85	0.90	1.00	1.00	1.00	25 mg/L
Peat – sand	Filter	0.10	0.33	0.85	1.00	1.00	1.00	1.00	5 mg/L
Compost – sand	Filter	0.10	0.33	0.85	0.90	1.00	1.00	1.00	10 mg/L
Peat	Filter	0.10	0.33	0.80	1.00	1.00	1.00	1.00	5 mg/L
Compost	Filter	0.00	0.10	0.20	0.50	0.75	1.00	1.00	10 mg/L

Notes:

1. If the calculated effluent concentration is greater than the allowable minimum concentration, then the model reports the calculated effluent concentration.
2. If the calculated effluent concentration is less that the allowable minimum concentration, then the model reports that value, but only if it is greater than the influent concentration.
3. If the minimum concentration is greater than the influent concentration, then the model reports the influent concentration (can't create a larger concentration!), but only if the calculated effluent concentration is less than the minimum allowable concentration.

Table 2 below lists, for each biofilter configuration, which biofilter outlet devices are applicable. There are either one or two cells for any biofilter configuration. The above ground cell is the cell where water initially enters the biofilter, and is the storage space above the ground surface/engineered soil. If there is no engineered soil or rock fill, then there is only the one cell, which is the above ground cell. If there is engineered soil and/or rock fill, then the second cell is the below ground cell containing the engineered soil and/or rock fill. For example, for a biofilter with rock fill (Biofilter Configuration 2), the underdrain is the only hydraulic outlet possible for the below ground cell.

Table 2 - Biofilter Outlet Device Operation Criteria

Biofilter Configuration	Cell Location	Broad Crested Weir	Sharp Crested Weir	Under-drain	Vertical Stand Pipe	Evapora-tion	Evapotrans-piration	Native Soil Infiltration	Engineered Soil Infiltration
1 - No Fill	Above Ground	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A
2 - Rock Fill	Above Ground	Yes	Yes	Yes	Yes	Yes	No	No	N/A
	Below Ground	No	No	Yes	No	No	No	Yes	N/A
3 - Engineered Soil Fill	Above Ground	Yes	Yes	Yes	Yes	Yes	No	No	Yes
	Below Ground	No	No	Yes	No	No	Yes	Yes	No
4 - Rock and Engineered Soil Fill	Above Ground	Yes	Yes	Yes	Yes	Yes	No	No	Yes
	Below Ground	No	No	Yes	No	No	Yes	Yes	No

Output Options

There are six different output options available to view the performance of the biofilter. The output summary, which appears after an individual model run, will display the biofilter's performance on the entire modeled system. The user can also select detailed output. The detailed output options include:

- Stage-Outflow File
- Detailed Biofilter Output File
- Stochastic Seepage Rate Detail File
- Water Balance File
- Particulate Reduction Output File
- Irreducible Concentration Detailed Output

The description of each of these files can be found elsewhere in the Help File.