Modeling Stormwater Control Practices in Series using WinSLAMM

Background

WinSLAMM versions v 9.3.4 and earlier route pollutant loads and runoff volumes on an event-by-event basis, but they do not route an events particle size distribution (psd) or hydrograph from the upstream practices to the downstream practices. For these earlier versions, the model calculates an overall percent reduction based on available research data for that stormwater control practice based on specific design attributes and the calculated influent conditions at that location (SWCP). If a SWCP exists downstream of another SWCP, the runoff volume (and peak flow rates) and pollutant conditions are changed due to the upstream control, but the particle size distribution entering the downstream SWCP from the upstream SWCP is not altered; the percent reduction achieved by the upstream control practice is applied evenly to the particle size distribution entering the downstream practice. WinSLAMM version 9.4 includes particle size and full hydrograph routing for a wet detention pond to a biofilter at the outfall, in transition to version 10, which will have much more complete routing capabilities for hydrographs, particle size distribution, and pollutants.

Research data shows that some SWCPs only remove the relatively larger particles in stormwater. Routing the changes in the particle size distribution is therefore important, because the downstream SWCP would be assumed to be capturing particles already captured by the upstream practice (a practice called double counting). If the downstream practice treats the same particle size distribution, then the amount of total suspended solids (TSS) removed can be overestimated.

Overview

This document describes the types of evaluations that may be conducted for nine common combinations of stormwater control practices in series when using a version of WinSLAMM released prior to WinSLAMM version 9.4. The modeling limitations were derived by reviewing the capabilities of WinSLAMM. The limitations are divided into two groups:

Group 1 – Practices that should not be modeled in series.

The first four combinations should not be modeled in series. For this situation, the user should determine which of the two SWCPs provide the best TSS reduction. The reduction from the SWCP providing the greater reduction should be the TSS reduction assigned to the drainage area. Two of these combinations have warnings in the model about not receiving credit for both SWCPs. However, this is not to say that redundancy should not be considered in order to increase the reliability of pollutant reductions and to possibly reduce maintenance costs. Unfortunately, there will be added capital costs associated with the additional controls, but in some cases, upgradient controls can provide good pre-treatment, resulting in decreased overall maintenance costs.

Group 2 – Practices that can be modeled, with limitations

The remaining five combinations can be modeled in series, but with some limitations. The TSS reductions will be based on some external manipulation of the model output, as described.

These combinations and modeling limitation are suggested and do not necessarily reflect the views of any regulatory agency. The designer or modeler should consult with the appropriate regulatory agency before evaluating these procedures. Many of these combinations offer a treatment train approach where complimentary unit removal processes can increase pollutant removal over a wider range of conditions than if only one control practice was used.

Table1. SWCP Combinations and Modeling Limitations

	Combinations	Modeling Limitations
1	Street cleaning followed by catch basin cleaning	Model practices independently. Select control practice with best TSS reduction.
2	Catch basin cleaning followed by wet detention pond	Model practices independently. Select control practice with best TSS reduction.
3	Street cleaning followed by wet detention pond	Model practices independently. Select control practice with best TSS reduction.
4	Outfall wet detention pond followed by an infiltration basin	Versions earlier than v 9.4: Model practices independently. Select control practice with best TSS reduction.
5	Street cleaning followed by grass swales	Select control practice with best TSS reduction or turn off grass swale filtering.
6	Biofiltration followed by wet detention pond	Select control practice with best TSS reduction or set percent solids reduction due to engineered soil to zero.
7	Grass swales followed by wet detention pond	Select control practice with best TSS reduction or turn off grass swale filtering or select new particle size distribution for wet detention pond.
8	Source area wet detention pond followed by infiltration basin	Select control practice with best TSS reduction or set percent solids reduction due to engineered soil to zero.
9	Wet detention ponds in series	Use model output in a spreadsheet to calculate overall TSS reduction. WinDETPOND also has dual pond features that can be used to help evaluate these conditions.

Analysis

The following is a description of the limitations for each of these combinations of stormwater control practices and the suggested modeling methodology to analyze them.

1. Street Cleaning followed by Catch Basin Cleaning

> Research on the effectiveness of conventional street cleaners and catch basins has shown they both target particles larger than about 50 microns. Since they are both competing for the same particle sizes, the total reduction in TSS would not increase if they were being used in series. To address this, the designer may calculate the TSS reduction for each of the two practices and use the results from the practice with the highest reduction. Also, WinSLAMM v 9.2.0 and later includes the benefits of increased performance from some types of advanced street cleaners. During field tests, these have been shown to be more effective for smaller particles.

2. Catch Basin Cleaning followed by a Wet Detention Pond

Research on the effectiveness of catch basins and wet detention ponds has shown that wet detention ponds will trap much smaller particle sizes than those retained in a catch basin. Catch basins tend to accumulate particles larger than about 50 microns to varying amounts and a wet detention pond can retain a significant percentage of the particles down to about 4 microns. To address this, the designer may calculate the TSS reduction for each of the two practices and use the results from the practice with the highest reduction. Unless the wet detention pond is greatly undersized, the pond should have much higher pollutant reduction values. Note that catch basin cleaning in a drainage area served by a properly sized wet detention pond will help to minimize the accumulation of debris in the storm sewer pipes and reduce the maintenance frequency of a downstream pond.

3. Street Cleaning followed by a Wet Detention Pond

Research on the effectiveness of street cleaning and wet detention ponds has shown that ponds will trap the same particles that are likely picked up by a street cleaner, plus others. Street cleaners tend to target particles greater than about 50 microns, while a wet detention pond can retain a significant percentage of the particles down to about 4 microns. To address this, the designer may calculate the TSS reduction for each of the two practices and use the results from the practice with the highest reduction. Unless the wet detention pond is greatly undersized, it should have much higher pollutant reduction values. However, street cleaning in a drainage area served by a wet detention pond will reduce debris on the streets and possibly reduce the maintenance needs of a downstream pond.

4. Outfall Wet Detention Pond followed by an Infiltration Basin

The infiltration device does not remove pollutants by sedimentation, but by infiltrating the carrier water and therefore stranding the associated pollutants in the infiltration basin. The particle size in the bypassing stormwater is not affected by this process in the model. However, modifying the hydrograph in the up-gradient pond will benefit the infiltration basin because it will attenuate the flow and so reduce or eliminate the volume of water bypassed by the infiltration device. Version 9.4 allows a pond before the infiltration device to account for this benefit. Versions earlier than v 9.4 do not include the hydrograph modification before infiltration and therefore under-predict expected performance.

Since the wet detention pond can be a pre-treatment system for an infiltration basin, it is important to calculate the TSS reduction to provide adequate pre-treatment to reduce the chance of infiltration basin failure. If the wet detention pond acts as a pre-treatment system for the infiltration basin, the TSS reduction for the drainage area will be based on the model results for the infiltration basin. If the infiltration basin is designed to treat a large percentage of the runoff from all of the drainage area, the basin will trap even the smaller particles in the pond effluent. In the absence of the pond, the infiltration basin would trap all the particles that would be deposited in the pond. Therefore, in general, the infiltration basin would provide the greater TSS reduction.

If version 9.3 or earlier is being used, the model cannot simulate two practices at the outfall. To address this, the designer may calculate the TSS reduction for each of the two practices as if the other practice was not present, and use the results from the practice with the highest reduction.

If version 9.4 or later is being used, the designer may model the two practices in series at the outfall. An algorithm was added to version 9.4 and later that routes the resultant particle size distribution and hydrograph for each rainfall event from the wet detention pond to the infiltration basin.

5. Street Cleaning followed by Grass Swales

Research on the effectiveness of these two control practices has shown that grass swales can capture particles greater than about 50 microns and that street cleaning also tends to target particles larger than about 50 microns. If grass swales were used in series with street cleaning in the model, the modeled grass swales would be credited with removing much of the particles already captured by street cleaning.

Also, street cleaning is only effective for streets with curbs and gutters. Streets with grass swales usually do not have curbs and gutters. These two practices can be used in the same drainage area if part of the drainage area has curbs and gutters without grass swales, or if the inlets in the curb drain directly to the swales.

If WinSLAMM version 9.2 or earlier is used, the two practices may be modeled in series. This is because these earlier versions did not calculate the solids capture that grass swales provide. If WinSLAMM version 9.3 or later is used, then the user can either model the two practices separately and use the results from the practice with the highest reduction, OR turn off the filtering provided by grass swales. To turn off filtering, set the grass height to zero. This would still enable the infiltration benefits of the grass swales to be calculated. However, unless the grass swales are very inefficient and the street cleaning program is very aggressive, it is likely that the grass swales will be more efficient in removing particulates. Therefore, it may be best to always check these two practices separately, and then turn off the grass swale filtering only if the street cleaning was found to be more effective.

6. Biofiltration (eg. rain gardens or biofilters) followed by Wet Detention Pond

Research on the effectiveness of these two control practices has shown that biofiltration systems will remove particulates over a wide range of particle sizes before the filtered water is returned to the surface drainage through an underdrain. Rain gardens (without underdrains) will also trap particulates at the surface and in the first few inches of soil. A wet detention pond, however, is not only capable of removing many of the same particles sizes, but it is typically designed to provide that control for the entire drainage area. Usually, the biofiltration systems or rain gardens are treating a relatively small percentage of the drainage area (such as roof runoff). If the downstream pond has been designed to treat the entire drainage area, sediment removal in the biofilters may be redundant. However, source area biofilters and rain gardens can significantly reduce the runoff volume reaching a downstream pond, which would enhance the pond pollutant removal performance.

If WinSLAMM version 9.3 or earlier is used, the two practices may not be modeled in series because the particle size will be modified by the biofiltration control, which these versions of the model do not consider. To address this, the designer may calculate the TSS reduction for both practices and use the results from the practice with the greatest reduction. The wet detention pond serving the complete area will likely achieve the highest TSS reduction, unless a very large number of biofiltration systems have been installed in the drainage area.

If WinSLAMM version 9.3 or later is being used, then the designer may model the two practices in series. However, the designer must set the percent solids reduction due to the engineered soil to zero to prevent double counting of particulate removal. This approach will still consider the water runoff volume reduction benefits of the two practices in series.

7. Grass Swales followed by Wet Detention Pond

According to recent stormwater research, properly designed and maintained grass swales can capture most of the particles present in the stormwater that are greater than about 50 microns. Therefore, the particle size distribution reaching the wet detention pond will be dominated by particles less than 50 microns.

If WinSLAMM version 9.2, or earlier, is being used, the two practices may be modeled in series. This is because these earlier versions did not account for solids capturing in grass swales, but did consider the runoff volume and the associated solids reductions.

If WinSLAMM version 9.3, or later, is being used, the designer has a few choices. The first choice is to model the two practices separately and use the results from the practice with the highest reduction. The second choice is to turn off the filtering provided by grass swales, which still will allow the model to consider runoff volume and associated solids reductions. To turn off filtering, set the grass height to zero.

The third choice is to adjust the particle size distribution based on the reduction provided by the grass swales. Although the model will determine how much the grass swales reduce the volume of runoff to the wet detention pond, it will not calculate the effect of the grass swales on the particle size distribution entering the pond. The wet detention pond particles size distribution must be adjusted to have no particle sizes larger than 50 microns. The adjusted NURP particle size distribution provided in Table 2 is an example of a particle size distribution that is modified for a wet detention pond in series with grass swales.

Table 2. Adjusted NURP Particle Size Distribution for
Grass Swales followed by a Wet Detention Pond.

Critical Particle Size (microns)	**Percent Less Than (%)**
2	17
4	35
6	49
8	61
10	67
30	93
50	100

(WinSLAMM requires more data for particle size distributions. Interpolate the above data to fulfill the WinSLAMM data requirements)

8. Source Area Wet Detention Pond followed by Infiltration Basin

WinSLAMM can simulate a wet detention pond at the source area followed by an infiltration practice at the land use, drainage, or outfall level. The wet detention pond algorithm will simulate the efficiency of the wet detention pond by removing particulates from the system. The runoff volume entering the infiltration basin will be the same as the runoff volume exiting the up-gradient wet detention basin. The runoff exiting the wet detention pond (and entering the infiltration basin) will have reduced particulate pollutant concentrations due to the removal of particulates in the up-gradient wet detention pond.

The runoff volume and concentration values exiting the wet detention pond is passed to the infiltration basin (which is assumed to have no underdrain). The infiltration basin algorithm calculates the amount of runoff infiltrated. The associated particulate (and other pollutant) loadings will be removed from the system based on the amount of runoff volume infiltrated times the concentration, which does not change unless the sediment basin is larger than the detention pond. The concentration entering the infiltration basin will be equivalent to the concentration exiting the infiltration basin in any overflow discharge.

If version 9.2 or earlier is being used, the designer may model the two practices in series. The designer should model the infiltration basin with no engineered soil and set the infiltration rate equal to the native soil infiltration rate.

If version 9.3 or later is being used, the designer may model the two practices in series. If using an engineered soil, the designer should set the percent solids reduction due to the engineered soil to zero. This will enable the model to calculate the water volume reduction of the infiltration basin.

9. Wet Detention Ponds in Series

Research shows that the particle size distribution in urban runoff is greatly modified after treatment in a wet detention pond. Therefore, the particle size distribution in a downstream pond in series with an upstream pond will treat stormwater having a significantly different influent psd compared to the psd that entered the up-gradient pond.

Currently, WinSLAMM can only evaluate the TSS reduction for a single pond; it will not accurately model ponds in series. The model output for each pond must be used, external to the model, to determine the TSS reduction for ponds in series. DETPOND can model two ponds in series, with particle size distribution and hydrograph routing, but with no additional flows entering the system between the ponds. This modification was made to allow the use of forebays and pre-treatment ponds to be evaluated.

To address two ponds in series, the designer can conduct the following analysis to determine the overall effectiveness of multiple wet detention ponds in series. The methodology assumes the results are based on the TSS loads and percent TSS reductions estimated with a continuous simulation model for each drainage area. The TSS efficiencies for each pond are determined using the runoff water from the entire upstream area as if the upstream ponds are not present.

No attempt is made to route the hydrographs between ponds or to track changes in the particle size distribution as the water moves from one pond to another. This methodology assumes each pond will be treating the same particle size distribution. The following are the steps in the calculation. An example is provided following the methodology.

A. Calculate TSS loads and % reduction for each pond

1. Create a WinSLAMM data file for the drainage area for each pond. This must include the entire drainage area for the pond (even if upstream ponds are present).
2. Using the average rainfall year for the region and the appropriate particle size distribution, calculate the TSS load to each pond and the percent reduction achieved by each pond. This will result in a separate model run for each pond. Do not include the TSS reduction calculated for any upstream pond(s).
3. After each model run, record the TSS load for each pond's drainage area and the percent reduction achieved by each pond in a table.

B. Compare Percent TSS Reductions for Ponds

1. If the last pond in the series has the highest TSS reduction, or if all the ponds have the same TSS reduction, then the last pond will be the value of the TSS reduction for the entire drainage area. No more calculations are necessary.
2. If the last pond in the series does not have the highest TSS reduction, more calculations are necessary, as described below.

C. Calculate the TSS Reduction for a Series Where the Pond with the Highest Percent Reduction is NOT the Last Pond in the Series

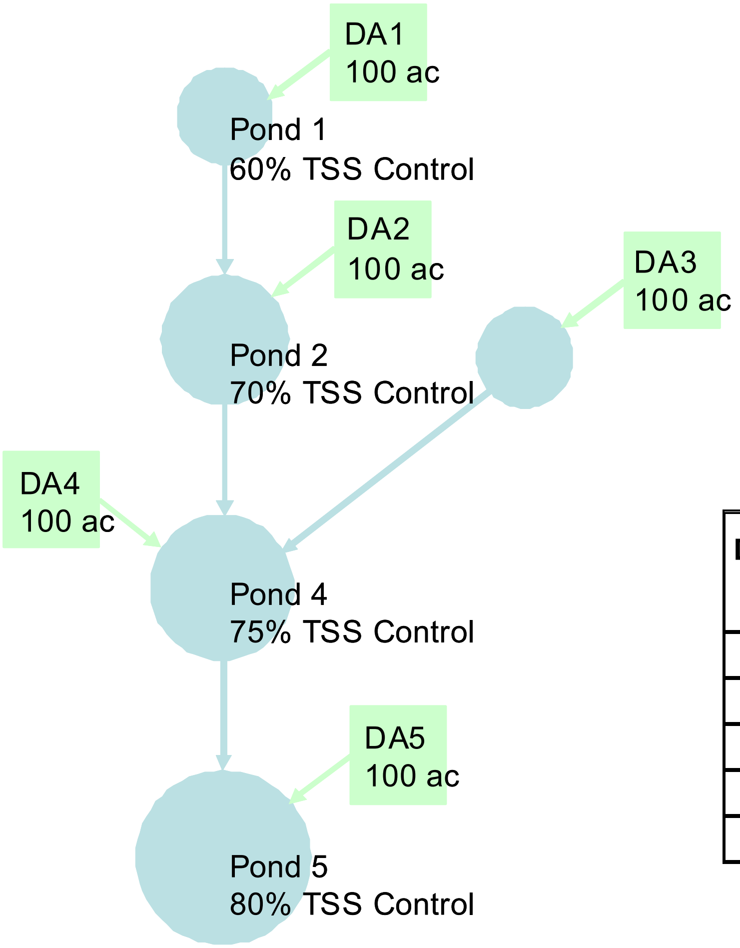
1. Find the pond with the highest TSS reduction. Multiply the percent reduction times the TSS load coming into the pond. This TSS load includes the drainage area for any ponds upstream of this pond. Make a table listing the pounds of TSS coming into the pond and the pounds of TSS trapped by the pond.
2. Starting at the last pond in the series, find the drainage area with the second highest percent TSS reduction. Do not include any pond in the drainage area above the pond with the highest percent TSS reduction.
3. Create a new land use file for the areas above the pond with the second highest TSS reduction, but below the pond with the highest TSS reduction.
4. Determine and record the TSS load for this new drainage area.
5. Multiply the new TSS load times the original percent TSS reduction calculated for this pond in Step C.1. Record the pounds TSS reduced.
6. Repeat this process until all the drainage areas have a pounds TSS reduced value.

D. Calculation of TSS reduction for entire watershed

1. Add together the pounds of TSS reduced.
2. Divide this total by the TSS load for the entire watershed without controls to determine the percent reduction for the watershed.

Below are two different scenarios that illustrate how to perform these calculations. The first scenario assumes that the downstream pond provides the most TSS reduction. The second one demonstrates how to calculate the overall pond performance when the downstream pond does not provide the most TSS reduction, by dividing the sum of the TSS reduction from all the ponds by the sum of all the TSS to the ponds.

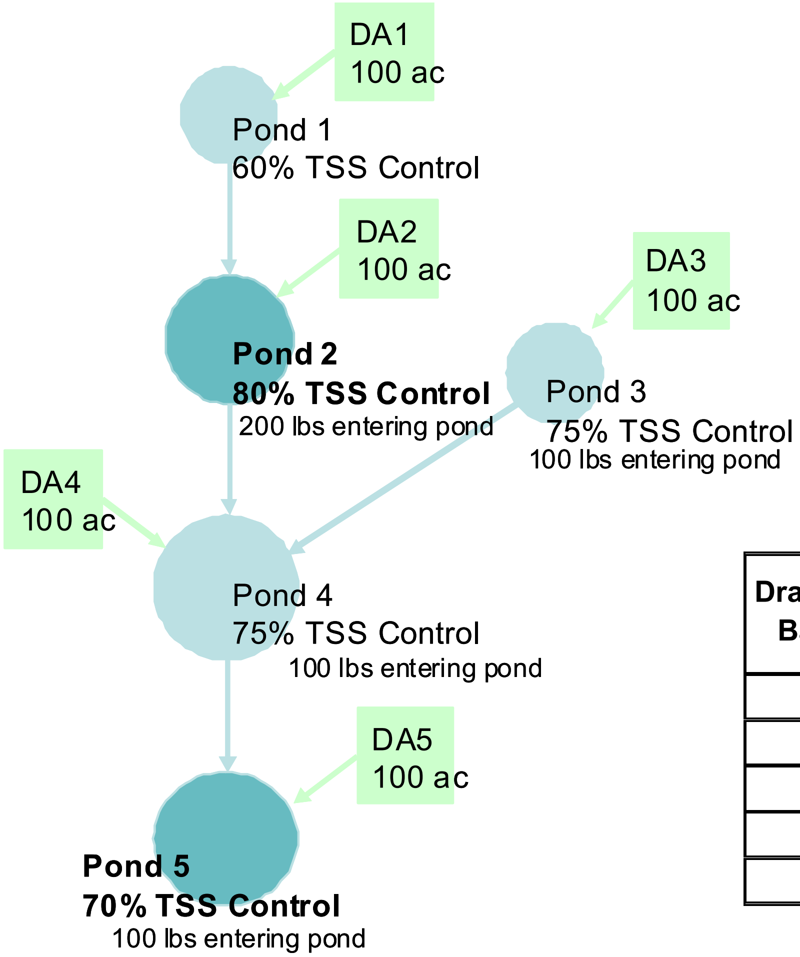
Scenario A – Downstream-most pond has highest TSS reduction efficiency



Drainage Basin	Total Drainage Area (ac)	Percent Reduction
1	100	60%
2	200	70%
3	100	75%
4	400	75%
5	500	80%

Calculation Order	Pond	Contributing Drainage Area	TSS Control	TSS to Pond	TSS Reduction
			(%)	(tons)	(tons)
Pond with Highest TSS Reduction =	Pond 5	DA1, DA2, DA3, DA4, DA5	80	500	400
Total			80	500	400

Scenario B – Downstream-most pond does not have highest TSS reduction efficiency



Drainage Basin	Total Drainage Area (ac)	Percent Reduction
1	100	60%
2	200	80%
3	100	75%
4	400	75%
5	500	70%

Calculation Order	Pond	Contributing Drainage Area	TSS Control	TSS to Pond	TSS Reduction
			(%)	(tons)	(tons)
Pond with Highest TSS Reduction =	Pond 2	DA1, DA2	80	200	160
Pond with next Highest TSS Reduction =	Pond 3, 4	DA3, DA4	75	200	150
Pond with next Highest TSS Reduction =	Pond 5	DA5	70	100	70
Total			**76**	**500**	**380**