January 17, 2013

WinSLAMM, the Source Loading and Management Model

WinSLAMM, the Source Loading and Management Model, was started in the mid-1970's as part of early EPA sponsored street cleaning and receiving water projects in San Jose (Pitt 1979) and Coyote Creek (CA) (Pitt and Bozeman 1983). The primary purpose of the model is to identify sources of urban stormwater pollutants and to evaluate the efficiency of stormwater control practices. During the mid-1980s, the model was expanded to include more management options beyond street and catchbasin cleaning, including wet detention ponds, infiltration and grass swales. The EPA's Nationwide Urban Runoff Program (NURP) projects (EPA 1983) provided a large data set for the model, especially from Alameda Co. CA (Pitt and Shawley 1983); Bellevue, WA (Pitt and Bissonnette 1983); and Milwaukee, WI (Bannerman, et al 1983). Research funded by the Ontario Ministry of the Environment in Ottawa (Pitt 1987) and the Toronto Area Watershed Management Strategy (TAWMS) study in the Humber River (Pitt and McLean 1986) also provided much information on bacteria sources in urban areas. During the mid-1980s, the model began to be used by the Wisconsin Department of Natural Resources (WDNR) in their Priority Watershed Program (Pitt 1986). The first Windows version of the model was developed in 1995 and the current version is 10.0.1, released in January 2013.

The model is continuously being updated based on user needs and new research (recent and current support from Wisconsin DNR; USGS; US Navy, HydroInternational, and Imbrium, for example). The current version of the program (version 10.0) followed extensive revisions that were several years in development, and includes drag and drop watershed elements and more complete flow and pollutant routing and transport options between control practices and along conveyances to the outfall. Modifications currently being developed for future release include adding proprietary devices and green roofs as directly modeled stormwater control options, and enhancing the routing algorithms.

Over the years, WinSLAMM has been extensively revised and expanded and now includes a wide range of capabilities. The following lists several important model features:

- The model can evaluate a long-series of rain events. One to five years of typical rains are used, but several decades of rains can also be evaluated. The rain series being evaluated normally contain a series of rainfall depths and durations for continuous evaluations. The model can also evaluate high-resolution rain events having several minute rain intensity resolutions for more precise routing calculations, as needed.
- The model is based on actual field data. For example, street dirt accumulation and washoff equations and direct runoff from paved surfaces are based on many thousands of measurements from actual rain events at many locations throughout North America.
- The effects of compacted urban soils are considered.
- Uncertainties of many modeling parameters are represented by built-in Monte Carlo components to better represent random variations that are commonly observed during stormwater monitoring.
- Life-cycle costs (capital, land, financing, and operation/maintenance costs) of control practices can be directly calculated and considered in the model runs.

- Runoff flow-duration probability distributions and associated receiving water biological conditions are calculated based on site conditions and the resulting benefits of the control measures being evaluated.
- The model output can be imported into several other models and Geographical Information Systems for more detailed drainage system and receiving water evaluations and can also be integrated with other local data sources.

Prior descriptions of WinSLAMM have been presented during the Engineering Foundation and in the Urban Water Modeling Conference series, and in other publications (Pitt 1986; 1997; 1999; Pitt and Voorhees 2002 for example). The model web site (http://www.winslamm.com/) also contains further model descriptions and references. The following lists some of the peer-reviewed chapters that have been published over the years in Bill James' comprehensive Urban Water monograph series (published by Computational Hydraulics International) describing various aspects of WinSLAMM:

Pitt, R., J. Voorhees, and C. Burger. "Simple hydrograph shapes for urban stormwater water quality analyses." Monograph 20. ISBN 978-0-9808853-7-8. *Modeling of Urban Water Systems*. James, W., K.N. Irvine, James Y. Li, E.A. McBean, R.E. Pitt, and S.J. Wright (editors). Computational Hydraulics International. http://www.chiwater.com/Publications/Books/index.asp Guelph, Ontario. 2012. pp 279 – 302.

Pitt, R., J. Voorhees, and S.E. Clark. "Continuous long-term simulations for evaluating storage-treatment design options of stormwater filters." Monograph 19. ISBN 978-0-9808853-4-7. *Cognitive Modeling of Urban Water Systems*. James, W., K.N. Irvine, James Y. Li, E.A. McBean, R.E. Pitt, and S.J. Wright (editors). Computational Hydraulics International. Guelph, Ontario. 2011. pp. 121 – 138.

Pitt, R., J. Voorhees. "Modeling green infrastructure components in a combined sewer area." Monograph 19. ISBN 978-0-9808853-4-7. *Modeling Urban Water Systems*. *Cognitive Modeling of Urban Water Systems*. James, W., K.N. Irvine, James Y. Li, E.A. McBean, R.E. Pitt, and S.J. Wright (editors). Computational Hydraulics International. Guelph, Ontario. 2011. pp. 139 – 156.

Avila, H., R. Pitt. "Scour in stormwater catchbasin devices – experimental results form a physical model." In: *Stormwater and Urban Water Systems Modeling*, ISBN-978-0-9808853-2-3, Monograph 17. (edited by W. James, E.A. McBean, R.E. Pitt and S.J. Wright). CHI. Guelph, Ontario, February 2009.

Pitt, R. J. Voorhees, and S. Clark. "Evapotranspiration and related calculations for stormwater biofiltration devices: Proposed calculation scenario and data." In: *Stormwater and Urban Water Systems Modeling*, Monograph 16. (edited by W. James, E.A. McBean, R.E. Pitt and S.J. Wright). CHI. Guelph, Ontario, pp. 309 – 340. 2008.

Bochis, C., R. Pitt, and P. Johnson. "Land development characteristics in Jefferson County, Alabama." In: *Stormwater and Urban Water Systems Modeling*, Monograph 16. (edited by W. James, E.A. McBean, R.E. Pitt and S.J. Wright). CHI. Guelph, Ontario, pp. 249 – 282. 2008.

Pitt, R. and J. Voorhees. "Using decision analyses to select an urban runoff control program" Chapter 4 in: *Contemporary Modeling of Urban Water Systems*, ISBN 0-9736716-3-7, Monograph 15. (edited by W. James, E.A. McBean, R.E. Pitt, and S.J. Wright). CHI. Guelph, Ontario. pp 71 – 107. 2007.

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.

Pitt, R., R. Bannerman, S. Clark, and D. Williamson. "Sources of pollutants in urban areas." 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 – 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.

Pitt, R. E. Shen-En Chen, S. Clark, J. Lantrip, and C.K. Ong. "Infiltration through compacted urban soils and effects on biofiltration design." Stormwater and Urban Water Systems Modeling. In: *Models and Applications to Urban Water Systems*, Vol. 11 (edited by W. James). CHI. Guelph, Ontario, pp. 217 – 252. 2003.

Pitt, R. and M. Lalor. "The role of pollution prevention in stormwater management." In: *Models and Applications to Urban Water Systems*, Vol. 9 (edited by W. James). CHI. Guelph, Ontario, 2001, pp. 1-20.

Pitt, R. and J. Lantrip. "Infiltration through disturbed urban soils." In: *Advances in Modeling the Management of Stormwater Impacts*, Volume 8. (Edited by W. James). Computational Hydraulics International, Guelph, Ontario. 2000. pp. 1 –22.

Pitt, R. "Small storm hydrology and why it is important for the design of stormwater control practices." In: *Advances in Modeling the Management of Stormwater Impacts*, Volume 7. (Edited by W. James). Computational Hydraulics International, Guelph, Ontario and Lewis Publishers/CRC Press. 1999. Pp 61 – 91.

Pitt, R. "Unique Features of the Source Loading and Management Model (SLAMM)." In: *Advances in Modeling the Management of Stormwater Impacts*, Volume 6. (Edited by W. James). Computational Hydraulics International, Guelph, Ontario and Lewis Publishers/CRC Press. pp. 13 – 37. 1997.

WinSLAMM applications include:

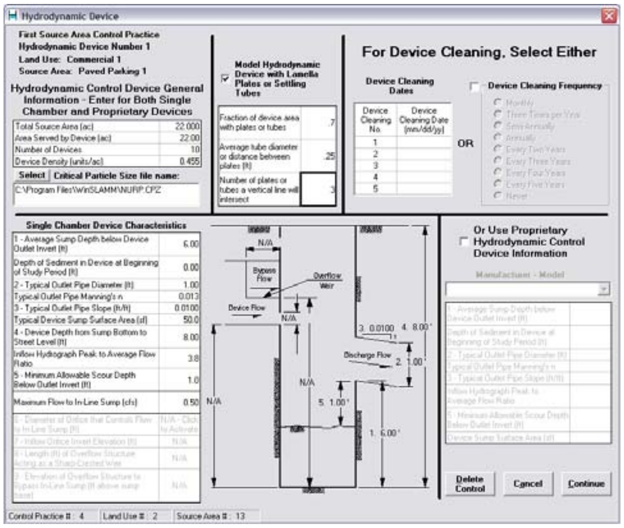
- Permit Compliance – Municipal Pollutant Loadings and Discharge Reductions (NPDES, TMDL)
- Evaluate Alternative Stormwater Controls at Different Scales
    - City-wide
    - Watershed
    - Site Development
- Identify critical drainage areas
    - Identify critical land uses
    - Identify critical source areas
    - Assist with cost-sharing
    - Identify the most cost-effective stormwater control and development scenarios

WinSLAMM is an urban stormwater model (it does not directly address agricultural areas, natural areas, etc.). It is designed to be an effective multi-scale model (individual lots to whole communities), and can calculate annual or seasonal pollutant loads and other stormwater characteristics. It evaluates individual or multiple stormwater control scenarios (located at source areas, land use, drainage system, and outfalls), as shown highlighted in the following table:

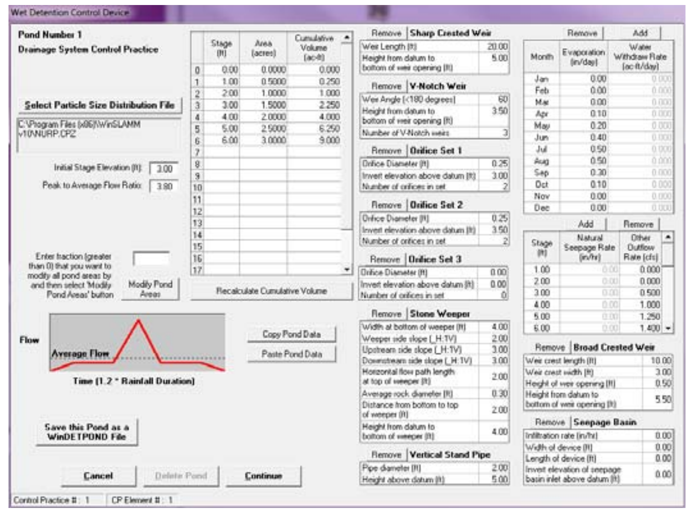
Treatment Area	Hydro-dynamic Devices	Wet Detent-ion Ponds	Street Clean-ing	Biofilt-ration	Porous Pave-ment	Cisterns	Beneficial Uses of Storm-water	Grass Swales	Catch-basin Clean-ing	Filter Strips	Drainage Dis-connect-ions
Roof	■	■		■		■	■	■			■
Paved Parking/Storage	■	■		■	■	■	■	■	■	■	■
Unpaved Parking/Storage	■	■		■		■	■	■		■	■
Playgrounds	■	■		■	■	■	■	■			■
Driveways	■	■		■	■	■	■	■		■	■
Sidewalks/Walks	■	■		■	■	■	■	■		■	■
Streets/Alleys	■		■	■		■	■	■	■	■	
Undeveloped Areas	■	■		■		■	■	■			
Small Landscaped Areas	■	■		■		■	■	■			
Other Pervious Areas	■	■		■		■	■	■			
Other Impervious Areas	■	■		■	■	■	■	■		■	■
High Traffic Urban Roads	■		■	■			■	■			
Large Landscaped Areas	■	■		■		■	■	■			
Drainage System	■	■		■		■	■	■	■		

The effectiveness of the control practices are calculated based on the size and other attributes of the devices, the source area or outfall location characteristics, and the calculated characteristics of the runoff being treated. The model does a complete mass balance and routing of water volume and particulate mass, considering the combined effects of all controls. Hydraulic and particle size routing occurs for each device individually, and serial effects of multiple devices are also calculated in the new version 10 of the model. The effects of the sedimentation controls are calculated using modified Puls hydraulic routing with surface overflow rate particulate routing for particle size bins. The performance of wet ponds has been verified by extensive monitoring of several ponds (WI DNR and USGS, with extensive documentation at: http://unix.eng.ua.edu/~rpitt/SLAMMDETPOND/WinDetpond/WinDETPOND%20user%20guide%20and%20documentation.pdf).

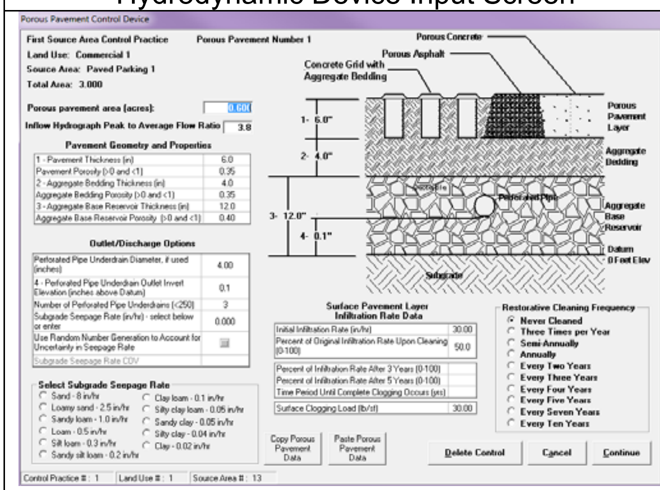
The infiltration and biofiltration devices use a combination of hydraulic routing with infiltration and evaporation/evapotranspiration losses, plus any pumped withdrawals. Underdrain filtering in biofilters is based on extensive tests of media filtration. Grass swale performance is calculated based on extensive laboratory and outdoor testing of particulate trapping of shallow flowing water and infiltration losses (Kirby 2005; Johnson, et al. 2003; Nara and Pitt 2005). Porous pavement performance is calculated based on infiltration losses and clogging effects. Street cleaning and catchbasin benefits are based on extensive EPA research, and newer updated research that has examined modern street cleaning equipment and sediment scour from catchbasins. Hydrodynamic device evaluations use the basic sedimentation processes, but have been verified by tests conducted by the USGS and the DNR, and by tests at the University of Alabama. The following figures show some example screen shots used to enter information for some of the stormwater controls in WinSLAMM.



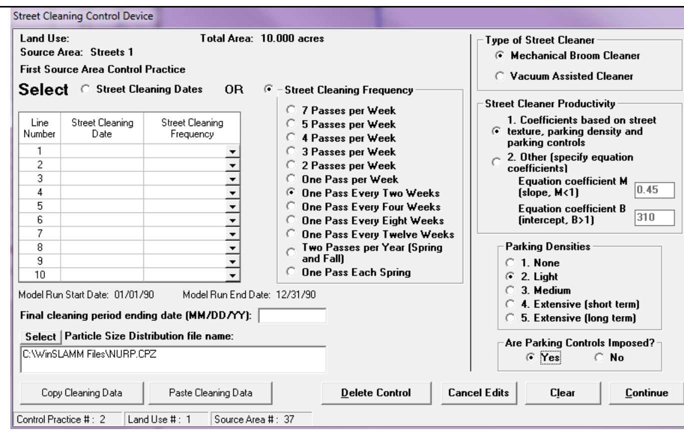
Hydrodynamic Device Input Screen



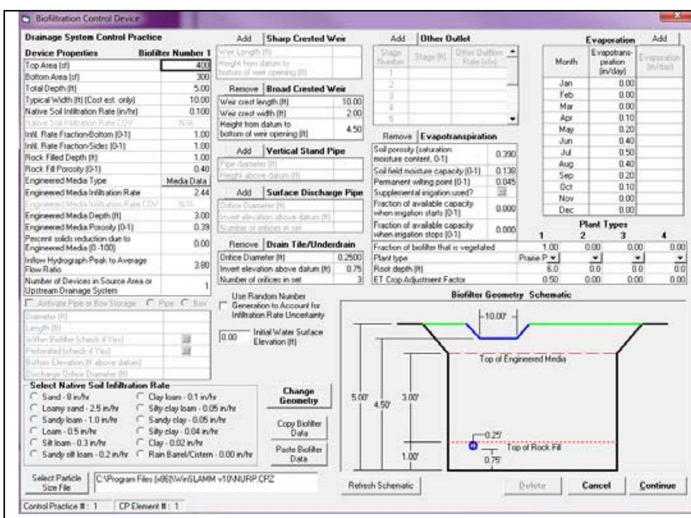
Wet Detention Pond Input Screen



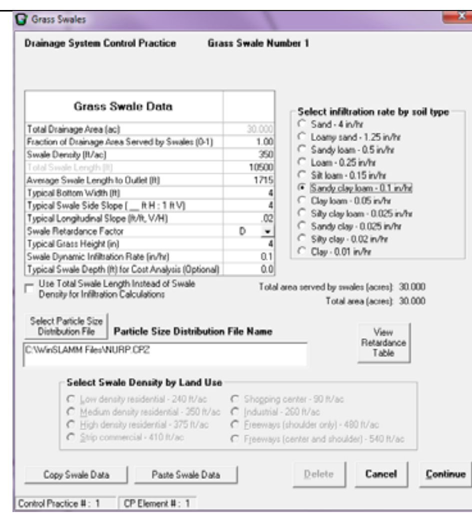
Porous Pavement Input Screen



Street Cleaning Input Screen



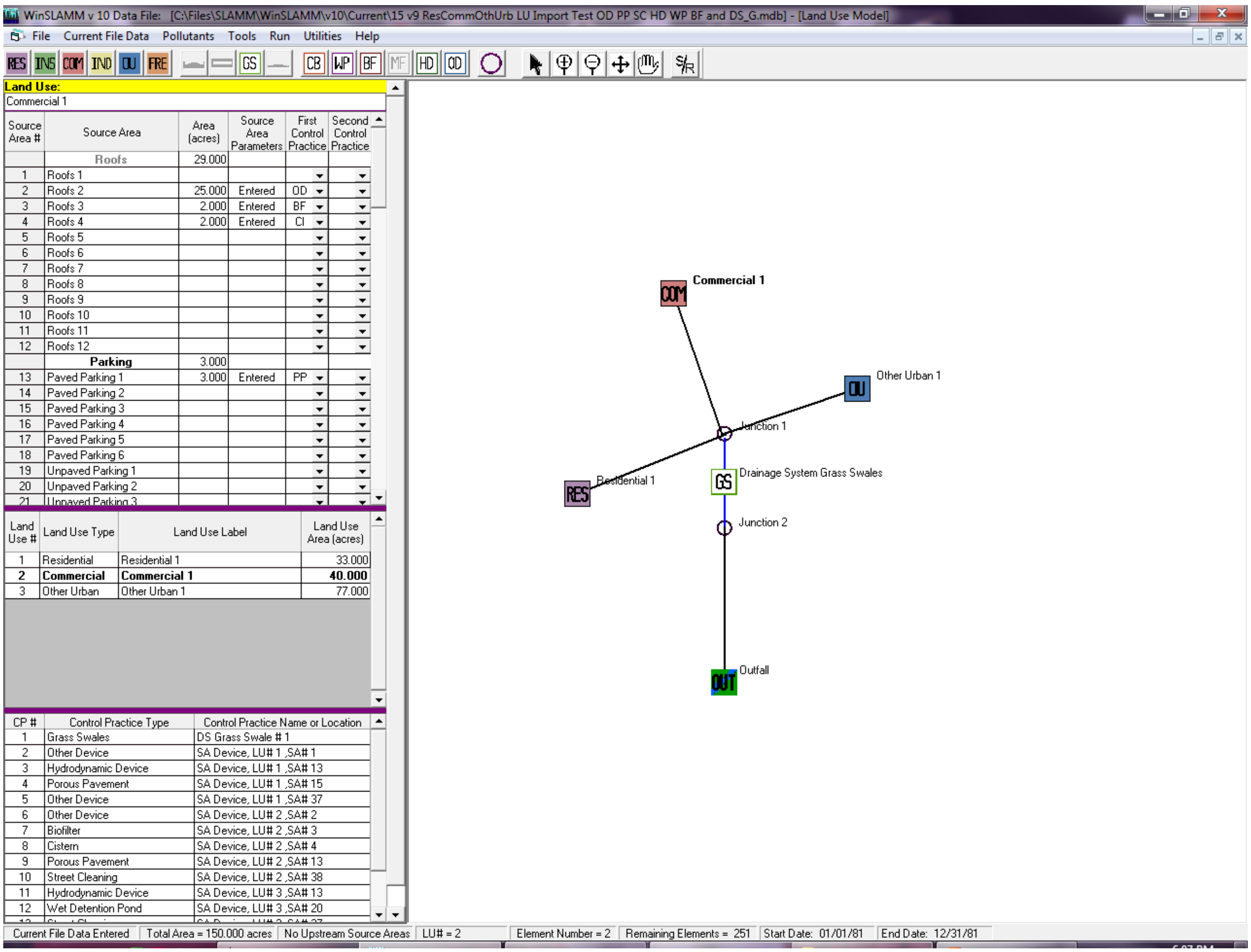
Biofilter Input Screen



Grass Swale Input Screen

Example Control Practice Input Screens for WinSLAMM

Each land use is described by characterizing elements for each source area within the land use, including source area and land use controls and specific characteristics that affect stormwater quality and quantity. Outfall and drainage system controls are described using the drop down menus. The new drag and drop interface allows greater efficiency and flexibility for control placement, and for using multiple land use source areas. The following figure is a screen shot of the WinSLAMM v 10.0 interface.



WinSLAMM Version 10.0 Source Area Screen and Interface

The calculated outputs from WinSLAMM are organized in several tiers of information. The first output the model shows is a summary table with the results of the most commonly analyzed pollutants (runoff volume and particulate solids, and any pollutants that were selected). The data in the summary table includes the following information:

Runoff Volume (ft^3, percent reduction; and R_v, runoff coefficient) and Particulate Solids (lbs and mg/L) for:

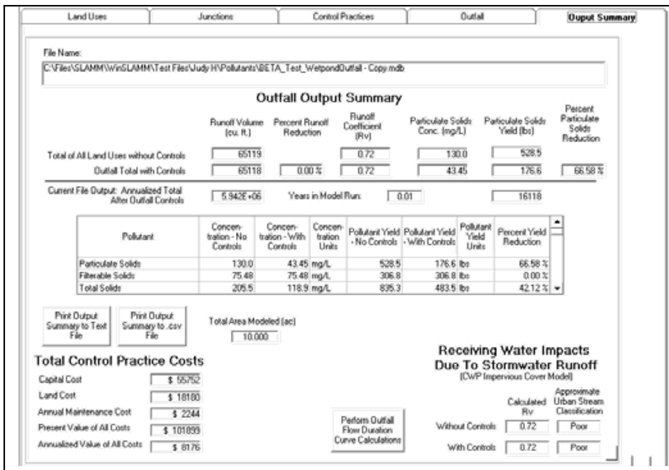
- Source area total without controls

- Total before drainage system
- Total after drainage system
- Total after outfall controls
- Annualized discharges

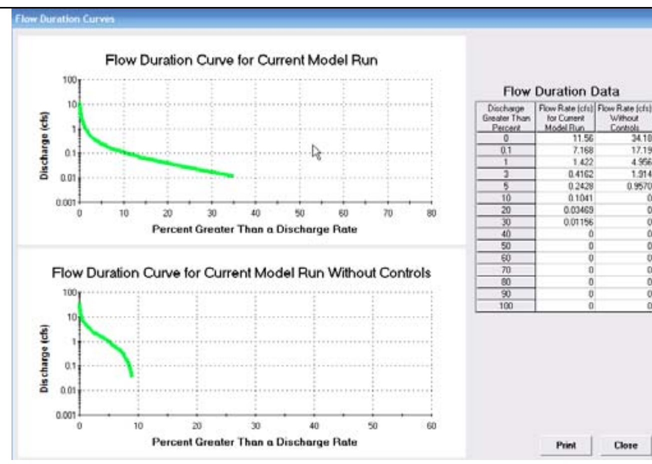
Total control practice costs:
- Capital costs
- Land cost
- Annual maintenance cost
- Present value of all costs
- Annualized value of all costs

Receiving water impacts due to stormwater runoff:
- Calculated R_v with and without controls
- Approximate biological condition of receiving water (good, fair, or poor, based on the Center for Watershed Protection's Impervious Cover Model)
- Flow duration curves (probabilities of flow rates for current model run with and without controls)

The flow duration curves are included on an optional second page, as shown on the following figure.



Summary Table with Detailed Output Tabs

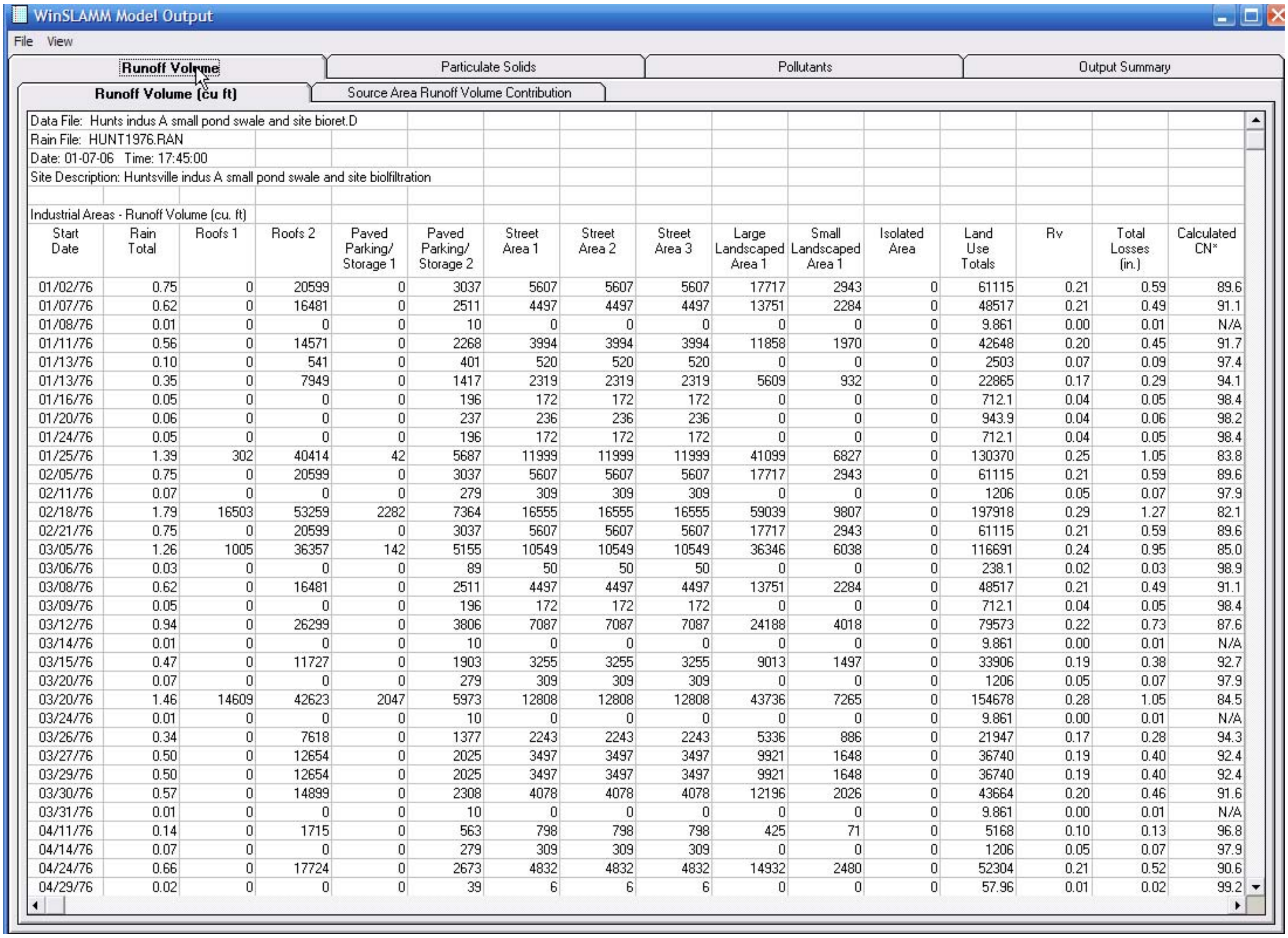


Flow-Duration Summary Output Option

The tabs along the top of the summary table display additional results for runoff volume (ft^3), particulate solids (lbs and mg/L), and the analyzed pollutants (lbs and mg/L). Results are shown:

- By source area for each rain event
- Land use total
- Summary for all rains
- Total for land use and for each event
- Outfall summary, before and after drainage system and before and after outfall controls

A tab is also available that summarizes many performance attributes of all stormwater controls used in the model run. If more detail is needed, other tabs lead the user to extensive model outputs. An example of the detailed data for runoff volume is shown in the following figure:



WinSLAMM Model Output

File View

Runoff Volume | Particulate Solids | Pollutants | Output Summary

Runoff Volume (cu ft) | Source Area Runoff Volume Contribution

Data File: Hunts indus A small pond swale and site bioret.D
Rain File: HUNT1976.RAN
Date: 01-07-06 Time: 17:45:00
Site Description: Huntsville indus A small pond swale and site biolfiltration

Industrial Areas - Runoff Volume (cu. ft)

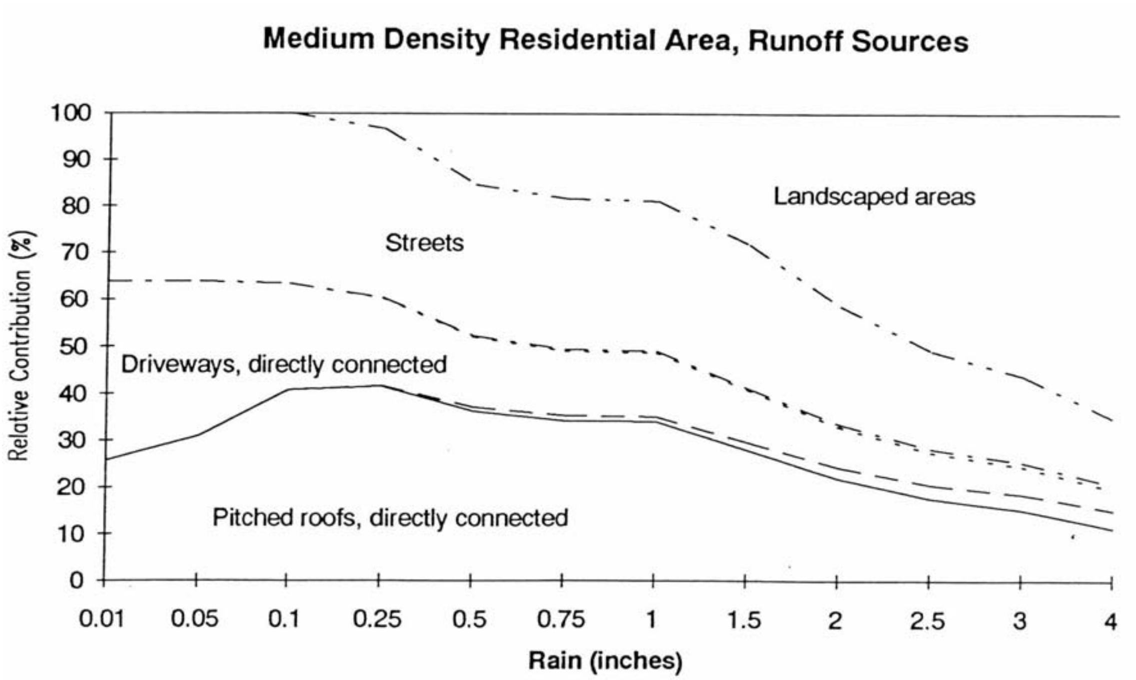
Start Date	Rain Total	Roofs 1	Roofs 2	Paved Parking/ Storage 1	Paved Parking/ Storage 2	Street Area 1	Street Area 2	Street Area 3	Large Landscaped Area 1	Small Landscaped Area 1	Isolated Area	Land Use Totals	Rv	Total Losses (in.)	Calculated CN*
01/02/76	0.75	0	20599	0	3037	5607	5607	5607	17717	2943	0	61115	0.21	0.59	89.6
01/07/76	0.62	0	16481	0	2511	4497	4497	4497	13751	2284	0	48517	0.21	0.49	91.1
01/08/76	0.01	0	0	0	10	0	0	0	0	0	0	9.861	0.00	0.01	N/A
01/11/76	0.56	0	14571	0	2268	3994	3994	3994	11858	1970	0	42648	0.20	0.45	91.7
01/13/76	0.10	0	541	0	401	520	520	520	0	0	0	2503	0.07	0.09	97.4
01/13/76	0.35	0	7949	0	1417	2319	2319	2319	5609	932	0	22865	0.17	0.29	94.1
01/16/76	0.05	0	0	0	196	172	172	172	0	0	0	712.1	0.04	0.05	98.4
01/20/76	0.06	0	0	0	237	236	236	236	0	0	0	943.9	0.04	0.06	98.2
01/24/76	0.05	0	0	0	196	172	172	172	0	0	0	712.1	0.04	0.05	98.4
01/25/76	1.39	302	40414	42	5687	11999	11999	11999	41099	6827	0	130370	0.25	1.05	83.8
02/05/76	0.75	0	20599	0	3037	5607	5607	5607	17717	2943	0	61115	0.21	0.59	89.6
02/11/76	0.07	0	0	0	279	309	309	309	0	0	0	1206	0.05	0.07	97.9
02/18/76	1.79	16503	53259	2282	7364	16555	16555	16555	59039	9807	0	197918	0.29	1.27	82.1
02/21/76	0.75	0	20599	0	3037	5607	5607	5607	17717	2943	0	61115	0.21	0.59	89.6
03/05/76	1.26	1005	36357	142	5155	10549	10549	10549	36346	6038	0	116691	0.24	0.95	85.0
03/06/76	0.03	0	0	0	89	50	50	50	0	0	0	238.1	0.02	0.03	98.9
03/08/76	0.62	0	16481	0	2511	4497	4497	4497	13751	2284	0	48517	0.21	0.49	91.1
03/09/76	0.05	0	0	0	196	172	172	172	0	0	0	712.1	0.04	0.05	98.4
03/12/76	0.94	0	26299	0	3806	7087	7087	7087	24188	4018	0	79573	0.22	0.73	87.6
03/14/76	0.01	0	0	0	10	0	0	0	0	0	0	9.861	0.00	0.01	N/A
03/15/76	0.47	0	11727	0	1903	3255	3255	3255	9013	1497	0	33906	0.19	0.38	92.7
03/20/76	0.07	0	0	0	279	309	309	309	0	0	0	1206	0.05	0.07	97.9
03/20/76	1.46	14609	42623	2047	5973	12808	12808	12808	43736	7265	0	154678	0.28	1.05	84.5
03/24/76	0.01	0	0	0	10	0	0	0	0	0	0	9.861	0.00	0.01	N/A
03/26/76	0.34	0	7618	0	1377	2243	2243	2243	5336	886	0	21947	0.17	0.28	94.3
03/27/76	0.50	0	12654	0	2025	3497	3497	3497	9921	1648	0	36740	0.19	0.40	92.4
03/29/76	0.50	0	12654	0	2025	3497	3497	3497	9921	1648	0	36740	0.19	0.40	92.4
03/30/76	0.57	0	14899	0	2308	4078	4078	4078	12196	2026	0	43664	0.20	0.46	91.6
03/31/76	0.01	0	0	0	10	0	0	0	0	0	0	9.861	0.00	0.01	N/A
04/11/76	0.14	0	1715	0	563	798	798	798	425	71	0	5168	0.10	0.13	96.8
04/14/76	0.07	0	0	0	279	309	309	309	0	0	0	1206	0.05	0.07	97.9
04/24/76	0.66	0	17724	0	2673	4832	4832	4832	14932	2480	0	52304	0.21	0.52	90.6
04/29/76	0.02	0	0	0	39	6	6	6	0	0	0	57.96	0.01	0.02	99.2

Runoff volume detailed WinSLAMM output.

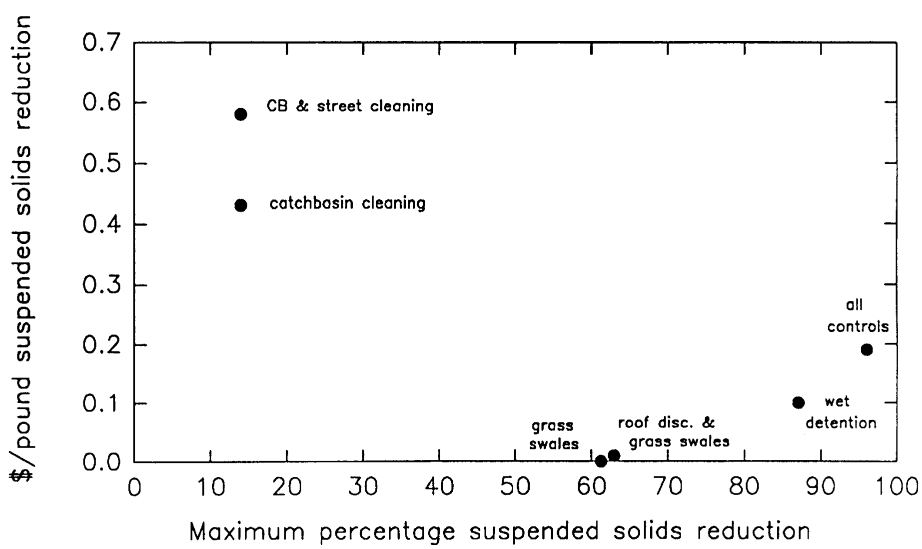
Another group of output options are "one-line per event" data sets. This data is saved in a *.csv file format that can be opened in a spreadsheet for viewing and further data manipulation. These files can also be examined by selecting the "utilities/view file/use notepad or use Windows view" pull down menu option from the main WinSLAMM page. The data presented in these files includes "One-Line per Event Runoff Details," with data for each event and statistical summaries for all events (number of events, total, equivalent annual total, minimum, maximum, average of all events, median, standard deviation, and coefficient of variation). The available data includes:

- Rain duration (hours)
- Rain interevent period (days)
- Runoff duration (hours)
- Rain depth (inches)
- Runoff volume (ft^3)
- R_v
- Average flow (cfs)
- Peak flow (cfs)
- Suspended solids (lbs and mg/L)

One of the main features of WinSLAMM is to identify the sources of pollutants for different rain conditions for a specific development. The following example plot shows how runoff volume originates from different sources in a medium density residential area for different categories of rains. This type of plot is very useful when determining the most likely effective locations for stormwater controls, or for changes in development characteristics. This plot was created in Excel using the exported detailed *.csv runoff volume file, for example:



A powerful feature of WinSLAMM is the batch processor that enables many control options to be quickly compared for an area. The batch processor can analyze runoff volume and pollutants and also combine unit cost data to evaluate the cost effectiveness of control options. The following plot of the cost-performance data for one study site shows the unit costs associated with preventing particulate solids from being discharged from an area and was created using the tabular output from the batch processor:



WinSLAMM was developed originally as a research tool to evaluate monitoring results. Early stormwater models, which were developed to focus on large drainage design events, were not doing a good job describing what was occurring during the monitoring programs for typical runoff conditions. Numerous research projects over the years examined these urban runoff processes in detail to be able to accurately quantify stormwater during the smaller and more common rains. Over the years, WinSLAMM (originally SLAMM) was expanded to include a wide range of stormwater controls and other features. It is also periodically modified at the request of stormwater managers, regulators, and researchers, to provide additional information or features.

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