January 17, 2013

WinSLAMM Version 10 Runoff Volume, Total Suspended Solids and Other Pollutant Calculations and Regional Calibration Files

WinSLAMM uses the concept of small storm hydrology to calculate runoff volumes and pollutant loadings for urban drainage basins for all rainfall events over a defined time period. All rainfall events are used because, though large events contribute significant amounts of pollutants to urban runoff, many smaller events contribute more runoff volume and total pollutant load over the course of a year than the very few large events.

Drainage Basin Characterization

Drainage basins in WinSLAMM are characterized by defining and describing the land uses that drain to an outfall. The study area could be the land draining to a storm sewer pipe outfall that discharges to a river, stream or lake, or simply a location in the drainage system where runoff volumes and pollutant loads are defined by the user. A drainage basin can be defined as a single lot, a block, subdivision, industrial area, shopping center, school campus, military base, or subbasin draining a large portion of a community.

In WinSLAMM, drainage basins are composed of one or more land uses. These land uses are described as either residential, commercial, institutional, industrial, open space or freeway. These land uses are distinct because the pollutant loading calculated by WinSLAMM will vary depending upon the land use. Each land use is further described by the source areas within the land use. Source areas include rooftops, driveways, streets, parking areas, playgrounds, or landscaped areas (the complete list is included in the WinSLAMM Help File). The type of land use (for example, low density residential vs. high density residential) is characterized by the composition of the source areas within that land use. A low density residential land use will have significantly more landscaped pervious areas than a high density residential area. The high density residential area will have significantly more rooftop, street and paved parking areas than a low density residential area.

Finally, each source area type is characterized by a small group of parameters. For example, the source area parameters for roof areas include if the roof is pitched or flat, and then if the source area is directly connected to the drainage system, and if disconnected, whether the runoff drains to sandy, silty or clayey soils. Other impervious areas (besides roofs and streets) ask if the source area is directly connected to the drainage system, and if disconnected, whether the runoff drains to sandy, silty or clayey soils. If the runoff drains to clayey soils, then two further characterizations are possible for the non-street impervious areas, wither the building density is low, medium or high, and if medium or high, if the source areas include alleys. These impervious area disconnection issues affect the amount of runoff (and associated pollutants) actually make it to the drainage system. The highest yields occur when the areas are directly connected, obviously, while the lowest yields occur when the areas are disconnected in low density land uses having sandy soils, as these would have the longest flow paths over pervious ground having high infiltration rates. The yield factors were determined through extensive monitoring at highly different drainage areas (initially in Milwaukee during the EPA's NURP project and also in

Toronto as part of the TAWMS program conducted in the early 1980s). These have been verified in many other locations and conditions since then.

This list of source area parameters might seem detailed, but it typically is not for two reasons. The first is that these parameters are general. Rooftops are defined as either flat or pitched – it is not necessary to specify a roof pitch. A source area is directly connected if runoff from it flows directly to the drainage system without passing over a significant pervious area. This means that runoff from a rooftop that flows down a driveway to a curb and gutter drainage system before entering the storm sewer is directly connected. Sandy, silty or clayey soils are typically classified by SCS soil types A, B or C and D, respectively.

The second reason source areas need not be thought of as requiring excessive detail is because WinSLAMM provides users with a set of standard land uses (for example, downtown commercial or low density residential) that include specific lists of source areas for each standard land use. These standard land uses are easily accessed (see the Standard Land Use help topic) and can be modified or added to, if necessary, by the user. These were developed through extensive site surveys in Wisconsin in support of their priority watershed program. Supplemental literature describes similar standard land uses for other areas. There is relatively difference across North America for the same land use in different areas. However, the "connectiveness" of the impervious area can be highly varied even in a small area. Therefore, these features should be verified locally.

Typically, WinSLAMM users who are evaluating more than a few drainage basins will divide drainage basins by land use, and then select specific standard land uses for each land use in the drainage basin. Users who are evaluating a small number of drainage basins often measure street areas and lengths, and rooftop, sidewalk, and driveway areas to accurately characterize the drainage area characteristics of the site they are modeling.

Runoff Volume Calculation

Runoff volumes in WinSLAMM are calculated from runoff coefficients (the ratio of runoff to rainfall as a function of rainfall depth) for each of the source areas described in the previous section. These runoff coefficients, which have been determined through extensive field monitoring, are multiplied by the rainfall depth and area of each source area to determine the runoff volume. For example, a drainage basin in a medium density residential area will be composed primarily of street, rooftop, driveway, sidewalk, and pervious source areas. To calculate the runoff volume for each rainfall event in a model run, the program first determines the runoff coefficient for each medium density residential source area, for each rainfall event. This coefficient is calculated from the runoff coefficient (R_v), or RSV file table the user has selected for the model run. Figures 1a and 1b below are examples of a runoff coefficient table from WinSLAMM, and a plot of the data from the table, respectively. As seen, the Rv values increase in magnitude as the rain depth increases, reflecting the increasing yield of rainfall to runoff as the runoff losses become satisfied.

Area Types (AT):

AT 1: Connected flat roofs
AT 2: Connected Pitched Roofs
AT 3: Directly connected impervious areas
AT 4: Directly connected unpaved areas
AT 5: Pervious areas - Sandy soils
AT 6: Pervious areas - Silty soils
AT 7: Pervious areas - Clayey soils
AT 8: Smooth textured streets
AT 9: Intermediate textured streets
AT 10: Rough textured streets
AT 11: High Traffic Urban Paved Areas
AT 12: High Traffic Urban Pervious Areas

(•) **Runoff Coefficient Data**

( ) **Drainage Efficiency Coefficient Data**

Volumetric Runoff Coefficients for Rains (in. and mm.)

Rain (in)	0.01	0.08	0.12	0.20	0.39	0.59	0.79	0.98	1.2	1.6	2.0	2.4	2.8	3.2	3.5	3.9	4.9
Rain (mm)	1	2	3	5	10	15	20	25	30	40	50	60	70	80	90	100	125
AT 1	0.00	0.00	0.30	0.54	0.72	0.79	0.83	0.84	0.86	0.88	0.90	0.91	0.93	0.94	0.94	0.95	0.96
AT 2	0.25	0.63	0.75	0.85	0.93	0.95	0.96	0.97	0.98	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.99
AT 3	0.93	0.96	0.96	0.97	0.97	0.97	0.97	0.97	0.98	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.99
AT 4	0.00	0.00	0.00	0.00	0.47	0.64	0.72	0.77	0.81	0.86	0.89	0.91	0.92	0.93	0.94	0.94	0.95
AT 5	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.02	0.03	0.04	0.07	0.10	0.13	0.15	0.20	0.22	0.25
AT 6	0.00	0.00	0.00	0.05	0.08	0.10	0.11	0.12	0.13	0.14	0.16	0.19	0.22	0.24	0.28	0.30	0.35
AT 7	0.00	0.00	0.00	0.10	0.15	0.19	0.20	0.21	0.22	0.23	0.26	0.29	0.32	0.33	0.36	0.39	0.45
AT 8	0.35	0.49	0.54	0.59	0.65	0.69	0.72	0.76	0.80	0.85	0.88	0.90	0.91	0.93	0.93	0.94	0.95
AT 9	0.26	0.43	0.49	0.55	0.60	0.64	0.67	0.67	0.73	0.80	0.84	0.86	0.88	0.90	0.91	0.92	0.93
AT 10	0.18	0.39	0.47	0.53	0.60	0.64	0.67	0.70	0.73	0.80	0.84	0.86	0.88	0.90	0.91	0.92	0.93
AT 11	0.55	0.73	0.77	0.83	0.87	0.97	0.97	0.97	0.98	0.98	0.98	0.98	0.99	0.99	0.99	0.99	1.00
AT 12	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.33	0.40	0.50	0.55	0.60	0.62	0.65	0.65	0.65	0.65

Figure 1a – Runoff Coefficient Table (v10 Runoff.rsv)

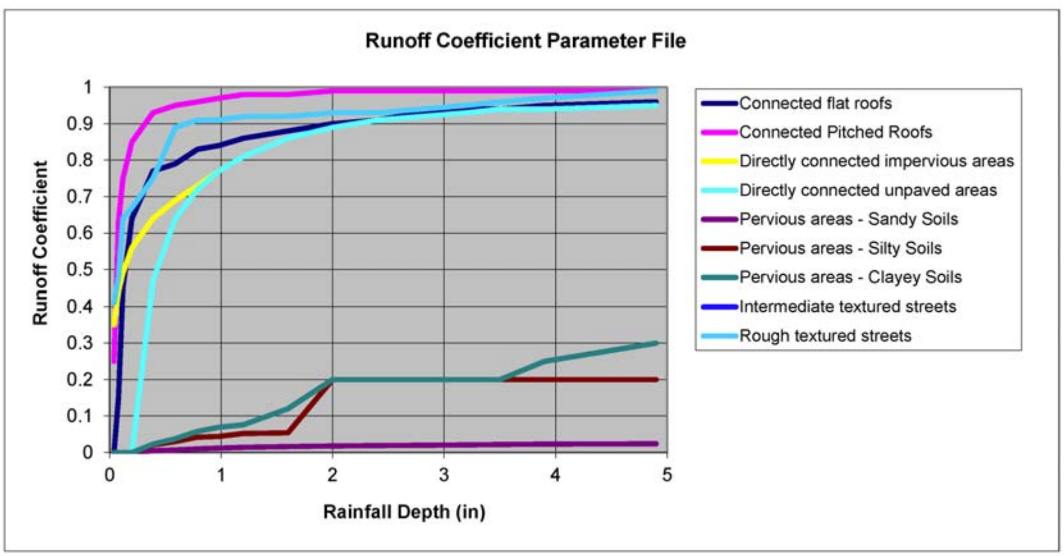


Figure 1b – Runoff Coefficient Plot (v10 Runoff.rsv)

Each runoff coefficient is interpolated from the RSV file for each source area and rainfall depth, and multiplied by the rainfall depth and appropriate source area to determine the runoff volume. Note that based upon monitored data, runoff volume coefficients do not vary by land use, but by surface cover at the source area and rain depth. The runoff volume equation is:

Runoff Volume (ft^3) = Rainfall Depth (in) * Source Area (ac) * Runoff Coefficient * unit conversion

The graphic below (Figure 2) represents a small medium density residential drainage area with connected and disconnected (draining to a pervious area) rooftops, driveways, sidewalks, pervious areas and streets. The R_v value for the first rainfall event is listed with the source area label. Each of these source areas is listed in Table 2, below, along with the runoff coefficient and rainfall volume for each source area for three rainfall events. The main data grid in Table 2 lists the runoff coefficient and volume for each of the source areas, for each of the rainfall events on the table.

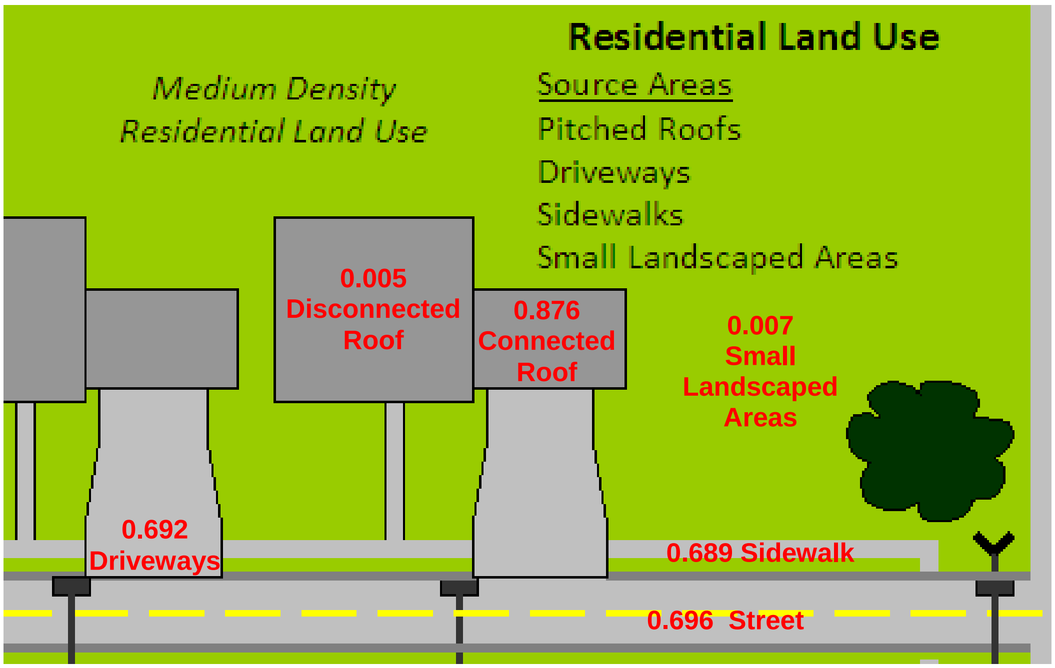


Figure 2 – Medium Density Residential Drainage Area with Runoff Coefficients for the First Rainfall Event Listed in Table 2

Table 2 – Medium Density Runoff Coefficient Example for Three Rainfall Events

Rainfall Depth (in) ==>		0.26		0.71		0.41	
Source Area	Area (ac)	Rv	Runoff (cf)	Rv	Runoff (cf)	Rv	Runoff (cf)
Residential Land Use							
Roof - Connected	0.15	0.876	124	0.957	370	0.932	208
Roof - Disconnected	0.20	0.005	1	0.037	19	0.020	6
Driveway	0.15	0.692	98	0.903	349	0.761	170
Sidewalk	0.04	0.689	26	0.902	93	0.756	45
Small Landscape Area	1.25	0.007	8	0.037	120	0.022	40
Street	0.30	0.696	197	0.903	698	0.761	340
Total	2.09		454		1649		809

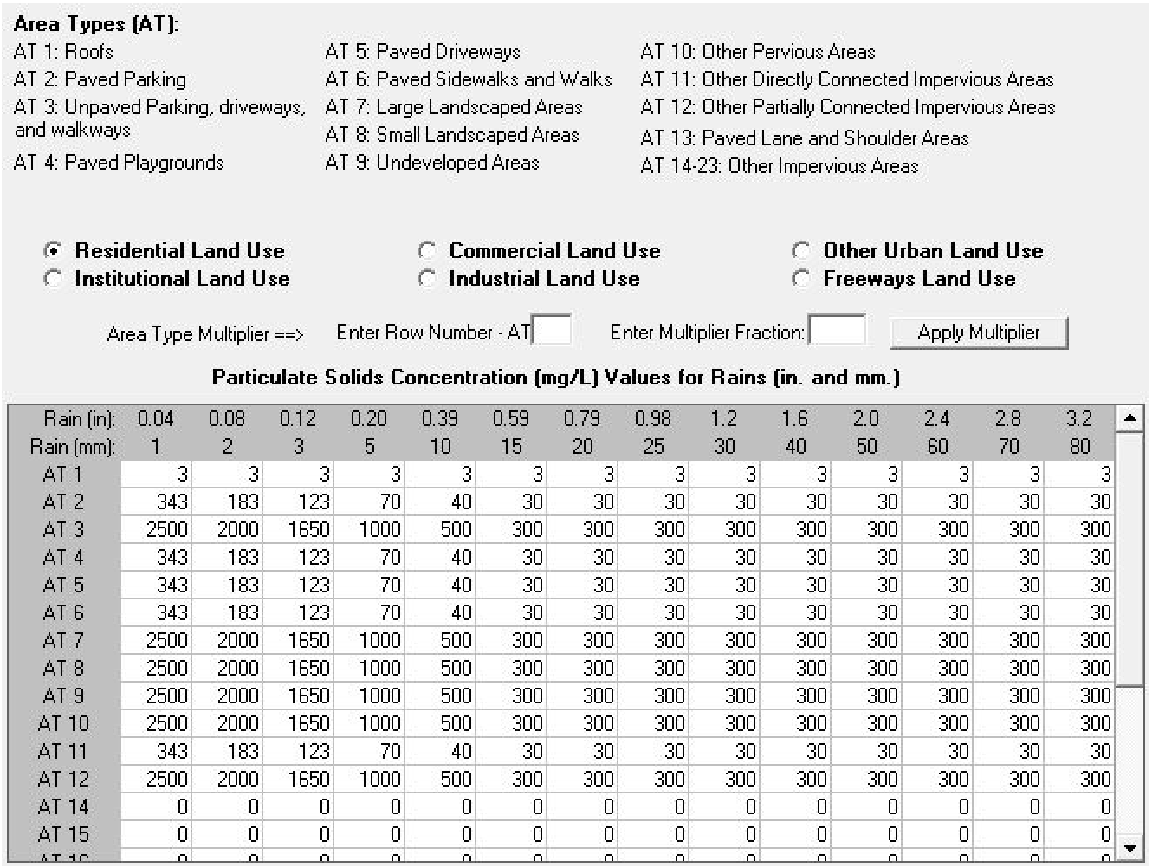
WinSLAMM calculates the runoff volume for each source area and for each rainfall event, in the model run as a base model condition. This is without stormwater control practices and is listed as the 'Base' condition on the WinSLAMM output summary. Stormwater control practices affecting runoff from source areas and/or the drainage system are added to the model run to evaluate the effectiveness of the control practices for comparison.

Total Suspended Solids Calculation

Total suspended solids pollutant values are determined in a similar manner. The program determines the particulate solids concentration for each source area in each land use, for each rainfall event. This coefficient is calculated from the particulate solids concentration, or PSC file (Figure 3) table you select for the model run. Each particulate solids concentration value is interpolated from the PSC file for each land use, source area and rainfall depth, and multiplied by the runoff volume to determine the particulate solids loading. The equation is:

Particulate Solids Loading (lbs) = Runoff Volume (ft^3) * Particulate Solids Concentration (mg/L) * unit conversion

The particulate solids concentration values in Table 3 are examples for residential land uses, and are calibrated from monitored data from the Birmingham, Alabama area. This file contains a similar set of data for the other land uses. The values are varied as a function of the rainfall depth.



Rain (in):	0.04	0.08	0.12	0.20	0.39	0.59	0.79	0.98	1.2	1.6	2.0	2.4	2.8	3.2
Rain (mm):	1	2	3	5	10	15	20	25	30	40	50	60	70	80
AT 1	3	3	3	3	3	3	3	3	3	3	3	3	3	3
AT 2	343	183	123	70	40	30	30	30	30	30	30	30	30	30
AT 3	2500	2000	1650	1000	500	300	300	300	300	300	300	300	300	300
AT 4	343	183	123	70	40	30	30	30	30	30	30	30	30	30
AT 5	343	183	123	70	40	30	30	30	30	30	30	30	30	30
AT 6	343	183	123	70	40	30	30	30	30	30	30	30	30	30
AT 7	2500	2000	1650	1000	500	300	300	300	300	300	300	300	300	300
AT 8	2500	2000	1650	1000	500	300	300	300	300	300	300	300	300	300
AT 9	2500	2000	1650	1000	500	300	300	300	300	300	300	300	300	300
AT 10	2500	2000	1650	1000	500	300	300	300	300	300	300	300	300	300
AT 11	343	183	123	70	40	30	30	30	30	30	30	30	30	30
AT 12	2500	2000	1650	1000	500	300	300	300	300	300	300	300	300	300
AT 14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AT 15	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 3 – Particulate Solids Concentration Table (BHAM_PPD_CALIB_June07.ppdx)

Other Pollutant Calculations

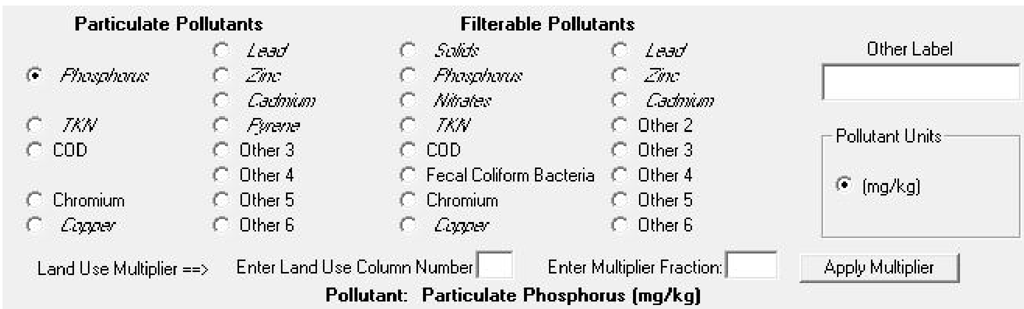
Particulate and filterable pollutants are determined in a similar manner. WinSLAMM has a set of pollutants available for analysis associated with each pollutant probability distribution (.PPD) file. These files are calibrated based upon monitored data and are available for different areas of the country, as described below. Figure 4 shows an example set of available pollutants (note that Cadmium and Pyrene are not standard pollutants, but have been added to the illustrated pollutant file).

For each selected pollutant, the program determines the particulate pollutant concentration for each source area in each land use. The particulate pollutant strength units in the PPD file are either milligrams or micrograms of pollutant per kilograms of the calculated particulate solids loading for each source area. Particulate pollutant strengths are multiplied by the calculated particulate solids loading for each source area in each land use to determine the particulate pollutant loading for that source area. The equation is:

Particulate Pollutant Loading (lbs) = Particulate Solids Loading (lbs) * Particulate Pollutant strength (mg/kg) * unit conversion

WinSLAMM determines the filterable pollutant concentration for each source area in each land use in a similar manner. The filterable pollutant concentration units are either milligrams, micrograms, or a Count (for bacteria) of pollutant per Liter of the calculated runoff volume. This coefficient is obtaind from the table used in the model run for each land use and source area. Filterable pollutant concentrations are multiplied by the runoff volume to determine the filterable pollutant loading. The equation is:

Filterable Pollutant Loading (lbs) = Runoff Volume (ft^3) * Filterable Pollutant Concentration (mg/L) * unit conversion



Land Use ==>	1 Residential	2 Institutional	3 Commercial	4 Industrial	5 Other Urban	6 Freeway
Roofs - Mean	3293.00	5573.00	5573.00	2226.00	3293.00	2226.00
Roofs - COV	1.11	1.24	1.24	1.41	1.11	1.41
Paved Parking/Storage - Mean	1423.00	1423.00	1423.00	1017.00	1423.00	1017.00
Paved Parking/Storage - COV	0.89	0.89	0.89	0.38	0.89	0.38
Unpaved Parking/Storage - Mean	2434.00	2434.00	2434.00	2434.00	2434.00	2434.00
Unpaved Parking/Storage - COV	0.79	0.79	0.79	0.79	0.79	0.79
Paved Playground - Mean	2434.00	2434.00	2434.00	2434.00	2434.00	2434.00
Paved Playground - COV	0.79	0.79	0.79	0.79	0.79	0.79
Driveways - Mean	2434.00	2434.00	2434.00	2434.00	2434.00	2434.00
Driveways - COV	0.79	0.79	0.79	0.79	0.79	0.79
Sidewalks/Walks - Mean	2434.00	2434.00	2434.00	2434.00	2434.00	2434.00
Sidewalks/Walks - COV	0.79	0.79	0.79	0.79	0.79	0.79
Streets or Freeway High Traffic Hwys - Mean	2305.00	1558.00	1558.00	1153.00	2305.00	1121.00

Figure 4 – Particulate Solids Concentration Table (BHAM_PPD_CALIB_June07.ppdx)

Sets of Regional Calibration Files Distributed with WinSLAMM

Detailed land use characteristics and concurrent monitoring data are available from several older and current stormwater research projects. The projects and locations used in developing the regional calibration files include:

• Jefferson County, AL (high density residential; medium density residential <1960, 1960 to 1980 and >1980; low density residential; apartments; multi-family; offices; shopping center; schools; churches; light industrial; parks; cemeteries; golf courses; and vacant land). These areas were inventoried as part of regional stormwater research and included about 10 single land use neighborhoods for each land use category. Local NPDES data were available to calibrate WinSLAMM for regional conditions using the specific monitored areas. The sites are described in several publications, including:

- 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.

• Bellevue, WA (medium density residential <1960). These data were from test and control watersheds that were extensively monitored as part of the Bellevue project of the EPA's Nationwide Urban Runoff Program (NURP). Much monitoring data from these sites are available for calibration of WinSLAMM. These areas are described in:

- Pitt, R. and P. Bissonnette. *Bellevue Urban Runoff Program Summary Report*, U.S. Environmental Protection Agency, Water Planning Division. PB84 237213. Washington, D.C. 173 pgs. 1984.
- Pitt, R. *Characterizing and Controlling Urban Runoff through Street and Sewerage Cleaning*. U.S. Environmental Protection Agency, Storm and Combined Sewer Program, Risk Reduction Engineering Laboratory. EPA/600/S2-85/038. PB 85-186500. Cincinnati, Ohio. 467 pgs. June 1985.

• Kansas City, MO (medium density residential <1960). These descriptions are from the test watershed in the EPA green infrastructure demonstration project conducted in Kansas City. Detailed inventories were made of each of the approximately 600 homes in the area. These are summarized in the following:

- 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.
- Pitt, R. and J. Voorhees. "Green infrastructure performance modeling with WinSLAMM." *2009 World Environmental and Water Resources Congress* Proceedings, Kansas City, MO, May 18 - 22, 2009.

• Downtown Central Business Districts (Atlanta, GA; Chicago, IL; Los Angeles, CA; New York, NY; and San Francisco, CA). These were not monitored locations, but were selected to represent a land use category for land development characteristics that are not well represented in the available research projects. Five example areas in the high density downtown areas of each of these five cities were examined in detail using Google maps. The areas associated with each land cover in a several block area were manually measured and described. No runoff quality or quantity data are available for these areas.

• Millburn, NJ (medium density residential 1961-80). Nine homes were monitored during this EPA research project investigating the effects of dry-well disposal of stormwater from individual homes, and the potential for irrigation use of this water. Google map aerial photographs and site surveys were conducted at each home to determine the land covers and characteristics. Data were presented at the following technical conferences:

- Talebi, L. and R. Pitt. "Stormwater Non-potable Beneficial Uses: Modeling Groundwater Recharge at a Stormwater Drywell Installation." ASCE/EWRI World Environment and Water Resources Congress. Palm Springs, CA, May 22-26, 2011.
- Talebi, L. and R. Pitt. "Stormwater Non-potable Beneficial Uses and Effects on Urban Infrastructure." 84th Annual Water Environment Federation Technical Exhibition and Conference (WEFTEC), Los Angeles, CA, October 15–19, 2011.

• San Jose, CA (medium density residential 1961-80; downtown central business district). Two residential and one downtown area were characterized as part of this early stormwater research project. Stormwater characterization data are available for these areas. These are described in the following report:

- Pitt, R. *Demonstration of Nonpoint Pollution Abatement Through Improved Street Cleaning Practices*, EPA-600/2-79-161, U.S. Environmental Protection Agency, Cincinnati, Ohio. 270 pgs. 1979.

• Toronto, Ontario (medium density residential 1961-80; medium industrial). These two areas were characterized and monitored as part of a research project conducted for the Toronto Area Wastewater Management Strategy Study (TAWMS). Stormwater characterization data are also available for these areas. These are described in the following reports:

- Pitt, R. and J. McLean*. Humber River Pilot Watershed Project*, Ontario Ministry of the Environment, Toronto, Canada. 483 pgs. June 1986.
- Pitt, R. *Small Storm Urban Flow and Particulate Washoff Contributions to Outfall Discharges*, Ph.D. Dissertation, Civil and Environmental Engineering Department, University of Wisconsin, Madison, WI, November 1987.

• Tuscaloosa, AL (parking lots at city park and at the city hall). These two sites were characterized and monitored as part of the pilot-scale and full-scale monitoring projects of the Up-Flo™ filter. The pilot-scale tests were conducted as part of an EPA SBIR project and were conducted at the Tuscaloosa City Hall. The full-scale tests were conducted at the Riverwalk parking lot. Stormwater quality and quantity data are available from both of these sites for model calibration. These sites are described in the following reports:

- Pitt, R. and U. Khambhammettu. *Field Verification Tests of the UpFlow™ Filter. Small Business Innovative Research, Phase 2 (SBIR2) Report*. U.S. Environmental Protection Agency, Edison, NJ. 275 pages. March 2006.
- Khambhammettu. U., R. Pitt, R. Andoh, and S. Clark "UpFlow filtration for the treatment of stormwater at critical source areas." Chapter 9 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 185 – 204. 2007.
- Togawa, N., R. Pitt. R. Andoh, and K. Osei. "Field Performance Results of UpFlow Stormwater Treatment Device." ASCE/EWRI World Environment and Water Resources Congress. Palm Springs, CA, May 22-26, 2011. Conference CD.

• Wisconsin (downtown central business district; duplex residential; high density residential with alleys; high density residential without alleys; high rise residential; hospital; fairgrounds; light industry; low density residential; medium density residential; medium industry; mobile homes; multi-family residential; open space; schools; shopping center; strip commercial; and suburban residential). These areas are the standard land use areas studied and described by the Wisconsin Department of Natural Resources and the USGS to support WinSLAMM modeling in the state. These area descriptions are based on locations studied throughout the main urban areas in Wisconsin, including Milwaukee, Madison, Green Bay, etc. Generally, about 10 homogeneous areas representing each land use category were examined in each study area to develop these characteristic descriptions. Much stormwater characterization data are available for these areas and calibrated versions of the WinSLAMM parameter files are maintained by the USGS for use by state stormwater managers and regulators. Descriptions of these projects and the source water quality data are summarized in the following:

- Pitt, R., R. Bannerman, S. Clark, and D. Williamson. "Sources of pollutants in urban areas (Part 1) – Older monitoring projects." In: *Effective Modeling of Urban Water Systems*, Monograph 13. (edited by W. James, K.N. Irvine, E.A. McBean, and R.E. Pitt). CHI. Guelph, Ontario, pp. 465 – 484 and 507 – 530. 2005.

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

• Lincoln, NE (low density residential; medium density residential <1960; 1960-80; >1980; light industry; strip malls; shopping centers; schools; churches; hospitals). These site descriptions are for a stormwater management project in Lincoln, NE that examined pollutant sources and controls. About ten homogeneous examples representing each land use were studied to develop these land use descriptions. Regional NPDES stormwater data are available for this area.

There are many land uses described from many locations throughout the country. The Wisconsin standard land use files represent the broadest range of land uses and the most observations. The Birmingham, AL and Lincoln, NE areas also have data representing a broad range of land uses. Several other study areas are also available that represent other geographical areas of the county. The individual data were initially grouped into six major land use categories: commercial, industrial, institutional, open space, residential, and freeway/highway land uses. Table 3 summarizes the breakdown of these categories into directly connected impervious areas (DCIA), partially connected impervious areas, and pervious areas.

Table 3. Summary of Major Land Use Characteristics (average and COV)

Land Use Category (# of example areas)	**Total directly connected impervious areas (DCIA)**	**total partially connected impervious areas**	**Total pervious areas**
Commercial (16)	79.5 (0.3)	1.8 (2.8)	18.6 (1.0)
Industrial (5)	54.3 (0.3)	21.4 (0.4)	24.3 (0.5)
Institutional (8)	50.0 (0.4)	9.1 (0.9)	40.8 (0.3)
Open Space (5)	10.2 (1.2)	10.6 (1.3)	79.1 (0.3)
Residential (25)	24.0 (0.6)	12.1 (0.5)	63.8 (0.2)
Freeway and Highway (4)	31.9 (1.2)	27.4 (1.2)	40.7 (0.3)

The directly connected impervious areas are most closely related to the runoff quantities. The partially connected impervious areas contribute runoff at later portions of larger rains, while the pervious areas may only contribute flows after substantial rain has occurred. As expected, most of the data represent residential areas, with commercial areas next, and the other areas having fewer than 10 detailed area descriptions each.

In order to examine geographical variations in stormwater characteristics, these land uses were sorted into six areas: Northwest; Southwest; Central; Southeast; Great Lakes; and East Coast. Model calibration was performed in each of these six geographical areas for all of the land uses in each area. If a land use was not represented in an area, the overall average land use characteristics were used. Stormwater quality data from the National Stormwater Quality Database (NSQD) was sorted into groups representing major land use and geographical categories. Figure 5 shows the EPA Rain Zones (not to be confused with the EPA administrative regions), the locations for the NSQD stormwater data, and the general calibration set regions. The modeled concentrations were compared to the observed concentrations, as described in the following section.

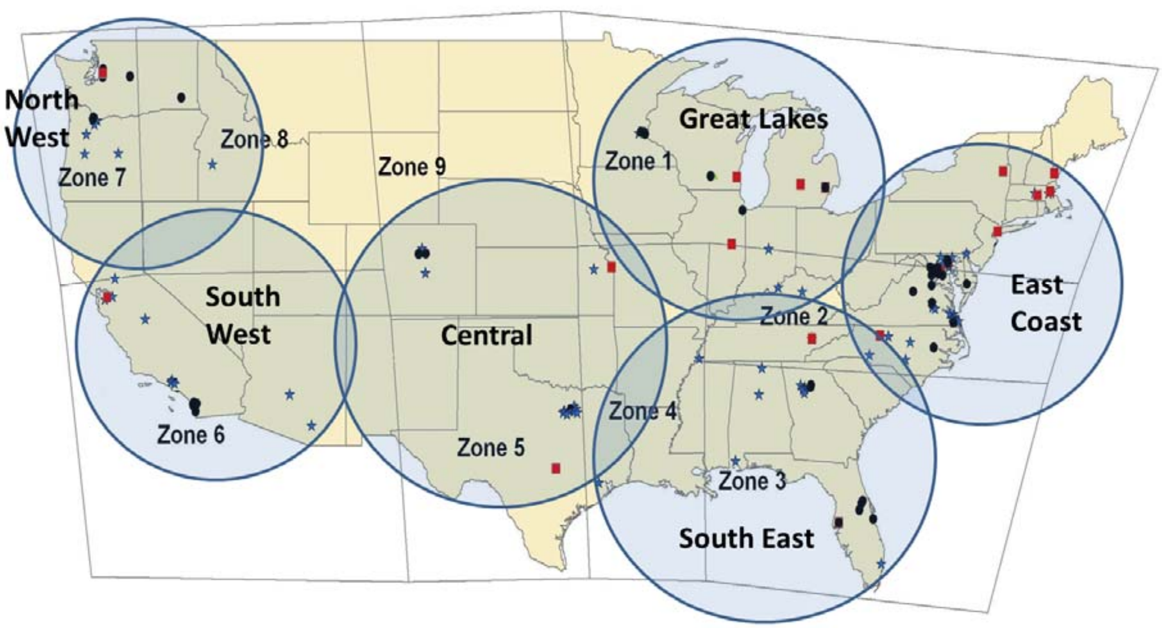


Figure 5. Sampling locations for data contained in the National Stormwater Quality Database (NSQD), version 3, showing EPA Rain Zones and general calibration set regions.

Modeled Stormwater Characteristics Compared to Observed Data

As noted above, the land use characteristics were used to create a range of standard land use files for evaluation with WinSLAMM. Six geographical areas with six major land use categories in each geographical area were examined. Many of the locations where the site characteristics were available also had stormwater monitoring data available that were used for regional calibration. If sites did not have site-specific data, NSQD regional data were used instead.

The first task was to sort all of the land use files into these six major land use categories. Table 4 lists the number of sites that were available for each group. As noted, most of the data were available for residential, then commercial areas, with less data available for institutional, industrial, open space, and highway/freeway areas. Overall site characteristics (averaged) were determined for each of these six categories. These six overall averaged files were then used in each of the six geographical areas, to complement available data for each location and land use data set. Some of the area and land use combinations only had this one file available, if no areas were monitored. A total of 114 files were used, with most in the residential and commercial areas, as previously noted, and with most of the files located in the Great Lakes region (due to the large number of Wisconsin observations) and in the Southeast (due to the large number of Birmingham, AL area observations).

Table 4. Number of Land Use Files Used for Each Category

	Commercial	Industrial	Institutional	Open Space	Residential	Freeways/ Highways	Total by Location
Central	4	2	4	1	5	3	19
East Coast	3	1	1	1	2	3	11
Great Lakes	6	4	4	2	11	4	31
Northwest	2	1	1	1	3	3	11
Southeast	7	2	3	5	8	4	29
Southwest	5	1	1	1	2	3	13
Total by Land Use	27	11	14	11	31	20	114

Each of these 114 files was associated with stormwater characteristic data, with preference given to site-specific monitoring data. If local observations were not available, then NSQD data was used. As noted in the earlier NSQD project memo, those observations were separated into land use and regional EPA rain zone categories. The NSQD data associated with the land use-area category were used if at least 30 events were monitored; if not, then the overall land use values for the constituent were used. Infrequently, the overall land use data did not have at least 30 event observations, so the overall average concentration was used.

The characteristics and constituents examined and calibrated included: Rv (the volumetric runoff coefficient, the ratio of runoff depth to rain depth), TSS, TDS, COD, TP, filtered P, TKN, NO_3+NO_2, Cu, Pb, Zn, and fecal coliforms. The bacteria data was not available for the WI locations, so the NSQD was used for the Great Lakes locations. In addition, calculated peak flow (CFS/100 acres) was also examined.

Initially, each of the 114 standard land use files were used in WinSLAMM using the original calibrated parameter files. The source area concentration data used in these files are described and summarized in the following publications (previously listed as the sources of the WI data, but these also include data from most of the source areas examined):

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

Area rain files were selected for each of the regions. The averaged land use files were evaluated using the following rain data for 4 or 5 years (1995 through 1999, except for Lincoln, NE that started in 1996 due to missing rain records): Great Lakes: Madison, WI; East Coast: Newark, NJ; Central: Lincoln, NE; Northwest: Seattle, WA; Southeast: Birmingham, AL; and Southwest: Los Angeles, CA. The sites having site-specific observations used the rain records associated with the sites and for the period of record. The Great Lakes region recognized a winter period (Dec 3 to March 12) as did the Central region (Dec 20 to Feb 10). During these winter periods, no stormwater calculations were made.

The calculated long-term averaged modeled concentrations were compared to the monitored concentrations for each site and for the land use category combined. Factors were applied uniformly to each land use-area pollutant parameter file to adjust the long-term modeled concentrations to best match the monitored/observed values. The WI and AL location files were not changed as they were associated with previously calibrated conditions (except for the constituents that were not measured locally). In addition, the runoff parameter files were not modified as they have been shown to compare well to observed conditions under a wide range of situations throughout the country.

Table 5 summarizes the results of the comparisons of the modeled to the observed values for all of the 114 files (91 for Rv, as some areas did not have suitable comparison flow data) for each constituent. As noted in this summary table, the regression statistics were all excellent (the P-values of the regression equations and for the slope terms were all highly significant), and the regression slope terms were all close to 1.0, with a few exceptions. The residual behaviors were all very good, except for total and filtered phosphorus that showed a strong bias, with modeled concentrations being too high for small observed concentrations. All of the other constituents had random variations about the best fit lines with small variabilities.

Table 5. Summary of Observed vs. Modeled Concentrations

	Regression Slope (intercept = 0) and 95% CI	P-value of slope term	P-value of regression	Adjusted R^2	Number of Observations	Residual Behavior Comments
Volumetric Runoff Coefficients	0.93 (0.87, 0.99)	<0.0001	<0.0001	0.90	91	Some modeled values high for small observed RV
Total Suspended Solids	0.90 (0.83, 0.97)	<0.0001	<0.0001	0.85	114	Good
Total Dissolved Solids	0.62 (0.53, 0.70)	<0.0001	<0.0001	0.63	114	Good
Chemical Oxygen Demand	1.00 (0.92, 1.04)	<0.0001	<0.0001	0.93	114	Good
Total Phosphorus	0.88 (0.68, 1.08)	<0.0001	<0.0001	0.40	114	Most modeled values high for small observed TP concentrations
Filterable Phosphorus	0.95 (0.81, 1.09)	<0.0001	<0.0001	0.61	114	Most modeled values high for small observed filterable P concentrations
Total Kjeldahl Nitrogen	1.06 (0.96, 1.15)	<0.0001	<0.0001	0.80	114	Good
Nitrites plus Nitrates	0.70 (0.62, 0.78)	<0.0001	<0.0001	0.71	114	Good
Total Copper	0.59 (0.50, 0.67)	<0.0001	<0.0001	0.60	114	Good
Total Lead	0.99 (0.93, 1.05)	<0.0001	<0.0001	0.90	114	Good
Total Zinc	0.96 (0.92, 1.00)	<0.0001	<0.0001	0.95	114	Good
Fecal Coliform Bacteria	0.74 (0.65, 0.83)	<0.0001	<0.0001	0.68	114	Good