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September 24, 2008

Calibration of WinSLAMM

WinSLAMM Calibration Procedures

The calibration and verification procedures of WinSLAMM are similar to the procedures needed to calibrate and verify any stormwater quality model. Local data should be collected, including stormwater outfall quality and quantity data and watershed information. Several watersheds should be investigated having a variety of relatively homogeneous land uses, if possible. Numerous individual rainfall-runoff events need to be sampled (using flow-weighted composite sampling) from each. The best scenario is to collect all calibration information from one set of watersheds and then verify the model using independent observations from other watersheds. Data from mixed land use watersheds are useful for verifications. Another common approach is to collect calibration information for a series of events from the watersheds, and then verify the calibrated model using additional data from other storms from the same watersheds.

WinSLAMM has typically been calibrated and verified using a combination of approaches. The initial effort for the full implementation of WinSLAMM (as reported by Pitt 1987) used data from three years of monitoring of eight watersheds in Milwaukee and data from one year of monitoring two additional watersheds in Toronto. These data represented a broad range of land uses (residential, commercial, and industrial uses), a wide range of hydraulic complexity (from having mostly connected impervious areas to having much landscaped areas and grass drainages), and widely varying rain conditions (from 0.01 to over 3 inches). The data was supplemented with source area data collected elsewhere (as referenced later) and with small-scale washoff tests conducted in Toronto. These data (from several hundred independent rainfall-runoff events) enabled the basic processes contained within WinSLAMM to be rigorously tested and allowed for a comprehensive set of initial calibration conditions to be developed. With additional site-specific data, these calibration conditions should be modified to consider specific situations not contained in the initial data set. This has been especially important for organic toxicants and for source areas not well represented in the initial data set.

This section describes a general approach to calibrate WinSLAMM and describes the data sources for the additional parameter files used in WinSLAMM. It also includes three case studies showing how the model has been calibrated using various types of data.

The general order for calibrating WinSLAMM (and the associated calibration parameter files) is:

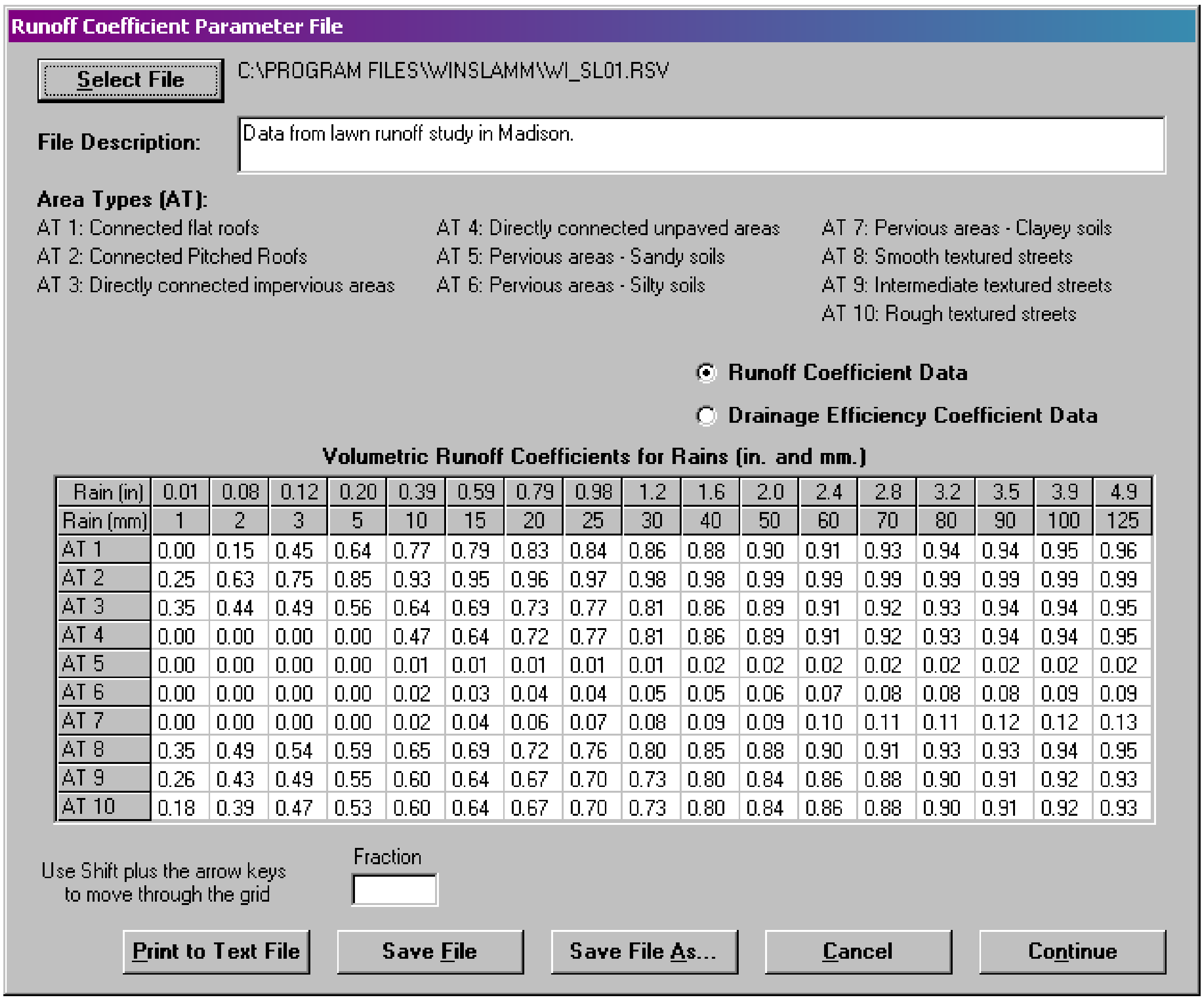
1) Runoff quantity (the runoff coefficient *.RSV parameter file)
2) Annual particulate solids loading (and event mean concentration) (*.PSC, *.PRR, and *.STD parameter files)
3) Event particulate solids loadings and concentrations (fine tuning of above files)
4) Annual total pollutant loadings (and event mean concentrations) (*.PPD parameter file)
5) Partitioning of pollutants between particulate and filterable phases (fine tuning of above file)
6) Variations in pollutant concentrations (adjusting the COV of the pollutants in the *.PPD file)

It is very important that the user start with runoff quantity and be completely satisfied with the calibration of each step before proceeding to the next step. Much wasted effort will occur if one skips around in the order of the calibration.

Runoff Quantity (Runoff Coefficients)

The mandatory *.RSV parameter file contains volumetric runoff coefficients (the ratio of runoff quantity to rain quantity: Rv) for each surface type for various rain depths. The runoff coefficients were calculated using general impervious and pervious area models. These models were then calibrated based on extensive Toronto data and then verified using additional independent Toronto data, along with numerous Milwaukee data for a wide variety of land development and rain conditions by Pitt (1987). However, WinSLAMM was designed to allow the use of alternative runoff models, as desired. Alternative runoff coefficients for each source area type can be calculated using other models and saved under other runoff volume file names.

The *.RSV file must be calibrated before any of the other parameter files are examined. After this file is modified, as needed, the particulate solids files must be calibrated. Finally, the file describing the other pollutants is examined and modified last.


Runoff Coefficient Parameter File

Select File C:\PROGRAM FILES\WINSLAMM\WI_SL01.RSV

File Description: Data from lawn runoff study in Madison.

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

(•) 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	0.15	0.45	0.64	0.77	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	0.35	0.44	0.49	0.56	0.64	0.69	0.73	0.77	0.81	0.86	0.89	0.91	0.92	0.93	0.94	0.94	0.95
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	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
AT 6	0.00	0.00	0.00	0.00	0.02	0.03	0.04	0.04	0.05	0.05	0.06	0.07	0.08	0.08	0.08	0.09	0.09
AT 7	0.00	0.00	0.00	0.00	0.02	0.04	0.06	0.07	0.08	0.09	0.09	0.10	0.11	0.11	0.12	0.12	0.13
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	0.70	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

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Runoff Coefficient Parameter File (*.RSV) Edit and Review Screen in WinSLAMM

Initial Data Sources

The RUNOFF.RSV file contains the verified runoff coefficients, based on the small storm hydrology model described in:

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.

This file was developed using data from eight study sites in Milwaukee (having generally clayey soils) and two study sites in Toronto (having generally sandy soils). The published data are contained in the following reports, and summarized by Pitt (1987):

Bannerman, R., K. Baun, M. Bohn, P.E. Hughes, and D.A. Graczyk. *Evaluation of Urban Nonpoint Source Pollution Management in Milwaukee County, Wisconsin*, Vol. I. Grant No. P005432-01-5, PB 84-114164. US Environmental Protection Agency, Water Planning Division, November 1983.

Pitt, R., and J. McLean. *Humber River Pilot Watershed Project*. Ontario Ministry of the Environment, Toronto, Canada, December 1984.

Calibration Steps

The runoff file should be modified based on correctly collected rainfall and runoff data. It is very important that adequate QA/QC procedures be used to insure the accuracy and suitability of the data. Common problems are associated with unrepresentative rainfall data (too few rain gauges and not correctly located in the watershed), incorrect rain gauge calibrations, poor flow monitoring conditions (surcharged flows, relying on Manning's equation for V and Q, poor conditions at the monitoring location), etc. The use of a calibrated flume or simultaneous use of calibrated velocity and depth sensors is preferred, for example. Other common errors are associated with inaccurate descriptions of the watershed (incorrect area, changing areas based upon different rainfall depths, amount of impervious areas, understanding of drainage efficiency, soil characteristics, etc.).

Few people appreciate the inherent errors associated with measuring rainfall and runoff. Most monitoring programs are probably no more than ± 25% accurate for each event. It is very demanding to obtain rainfall and runoff data that is only 10% in error. This is most evident when highly paved areas (such as shopping centers or strip commercial areas) are monitored and the volumetric runoff coefficients are examined. For these areas, it is not uncommon for many of the events to have Rv values greater than 1.0 (implying more runoff than rainfall). Similar errors occur with other sites, but are not as obvious.

The first calibration steps are associated with examining the watershed and rainfall - runoff data, followed by changing the RUNOFF.RSV file, as necessary:

1. Confirm that the watershed areas and development characteristics are correctly described. Urban drainage areas generally follow the topographic divide, but it is not unusual for storm drainage to cross-over surface topographic divides for a block, or more. If the area is very large (hundreds to thousands of acres), these deviations will tend to cancel out, with minimal detrimental effects. However, for calibration and verification studies, the drainage area should be as precisely defined as possible, especially for small drainage areas (tens to hundreds of acres). Therefore, confirm all storm drainage locations and storm drain inlets affecting the outfall monitoring location. For each inlet, identify the precise watershed divide, if at all possible. This includes examining all buildings located close to the divide and determining where the actual divide is located, including splitting roofs or paved areas, as necessary. Carefully review the location of internal rooftop drainage outfalls.

Another important aspect is correctly identifying the development characteristics for the watershed area. The most important attribute that affects runoff quantity (and quality) is the drainage efficiency of the area. This includes understanding where the paved areas drain. Are they directly connected to the storm drainage system, or do they drain across substantial distances of unpaved areas before reaching the drainage system? Each type of paved area (roofs, parking/storage areas, play grounds, driveways, sidewalks, etc.) needs to be divided into "directly-connected" and "disconnected" portions, usually through site investigations. Streets are assumed to be directly connected, as they are adjacent to the drainage system. Be careful of roof drains that drain to lawns, but only provide a few feet of overland flow before paved areas. These are effectively directly connected areas. Similar problems arise with relatively large paved or roof areas that drain to relatively small unpaved areas (especially in multi-family residential, commercial and industrial areas). Other factors affecting drainage efficiency is the presence of grass swales, or other types of stormwater management devices (dry or wet ponds, porous pavements, infiltration areas, etc.) that may occur in the area. These need to be carefully described and considered in the calibration and verification process.

2. Calculate the Rv for each event and observe the pattern. Plot rainfall depth vs. runoff depth and plot Rv vs. rainfall depth. The Rv values should be small for small rains and steadily increase as the rains increase. The Rv differences will not be great for mostly directly connected impervious areas (either paved or roofed areas), but the trend should be quite dramatic for areas having substantial unpaved areas, if a wide range of rains were monitored. The Rv values should look reasonable for moderate rains (0.25 to 0.5 inch rains): about 0.3 for medium density residential areas, about 0.8+ for commercial areas, etc. If the Rv values all appear to be too small or too large, suspect an error in the drainage area, or an error in the rainfall or flow monitoring data. If several individual events look strange and the others appear to follow a reasonable trend, then investigate specific circumstances for the odd events. Transient problems such as unusual rain intensities, snow/icing problems, debris at flow monitoring station, etc. may periodically occur. If the unusual conditions cannot be explained, then a decision will have to be made concerning eliminating the data, or keeping it in the data set.

3. Hopefully, data from several watersheds are available for the calibration and verification process. If so, start with data from the simplest area (mostly directly connected paved areas and roofs, with little unpaved areas). This area probably represents commercial roofs and parking/storage areas alone. Therefore, these areas should be calibrated first, before moving on to more complex areas. The most complex areas, such as typical residential areas having large expanses of landscaped areas and most of the roofs being disconnected from the drainage areas, should be examined last as they are the most complex hydraulically.

4. Carefully prepare the WinSLAMM input file describing the watershed area and a rain file for the specific rains that occurred during the monitoring period. If rains occurred during the monitoring period that were not monitored, they must also be included in the rain file. It would be a good idea to include rains for about a month preceding the first monitored event because WinSLAMM is a quasi-continuous model and some preceding time is needed to reach the proper conditions before the first monitored event. It will also be helpful to prepare another special rain file to be used in determining the relative sources of runoff (and pollutants) for different rain categories. An example source area rain file, “AL Birmingham Source Special Rains.RAN,” is included with the program. This file includes 12 rains spaced about two weeks apart containing the following rain depths (sorted from small to large rains) and durations. These represent typical durations for these rains for the Birmingham, AL, area. It is easy to prepare a similar source area rain files for any region, after analyzing the long-term rain events. This example contains the following rains:

Rain Depth (inches)	Rain Duration (hours)
0.01	3
0.05	7
0.10	8
0.25	10
0.50	12
0.75	14
1.0	14
1.5	14
2.0	14
2.5	14
3.0	14
4.0	14

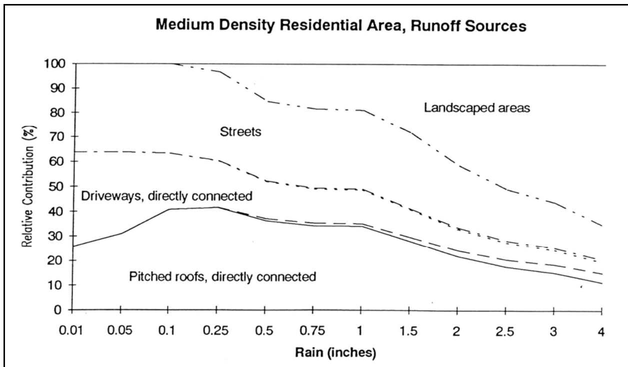
5. Run the created watershed file using the two rain files, without any additional pollutants selected, using the available RUNOFF.RSV file and using the outfall total (at least) output option for the actual rains and the source

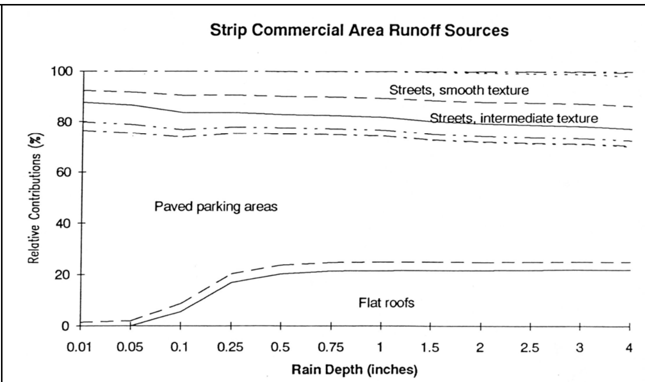
area, by rains, output option for the source area rain file. Compare the predicted runoff depths (in inches) with the measured runoff depths (in inches) for the monitored events by creating a scatter plot of observed vs. predicted runoff values.

Calculate the percentage runoff depth errors: 100 x (observed-predicted)/observed, and plot these against the observed rain depths. The desired pattern for the observed vs. predicted runoff depth plot is a 45 degree line, with little deviation. The desired pattern for the residual error plot is an even, narrow band over the range of observed rain depths, centered on the zero residual error horizontal line. Also calculate the sum of the observed and predicted runoff depths for all monitored events. The percentage difference in the sum of depths should be small.

If you are satisfied with these analyses, then no changes are to be made to the RUNOFF.RSV file. However, some improvement is usually possible. The overall sum runoff error indicates the general severity of the problem, but other information [such as what?] needs to be used to identify which source areas for which rains need to have their Rv values modified.

The model run using the SOURCE.RAN file is important in directing where the changes should be made. This run contains the percentage contribution of runoff for each rain, for each source area. This shows where WinSLAMM is generating the runoff for the different rain depths. It is doubtful if the monitored events cover the wide range of rains contained in this special rain file. Therefore, only look at the range of predicted data covering the actual monitored rains. The following are two examples of calculated runoff source area contributions using the SOURCE.RAN file and the local land use files for medium density residential areas and strip commercial areas. In the residential area file, directly connected roofs and driveways and the streets are the major runoff sources for the small events (<0.3 inches), while landscaped areas become important for larger events; at about 2 inches or rainfall, the landscaped areas contribute about half of the area runoff. The strip commercial area changes less due to the absence of significant landscaped areas. Using figures like these allows the model user to identify which parameter filter components to modify for the rains that area monitored.





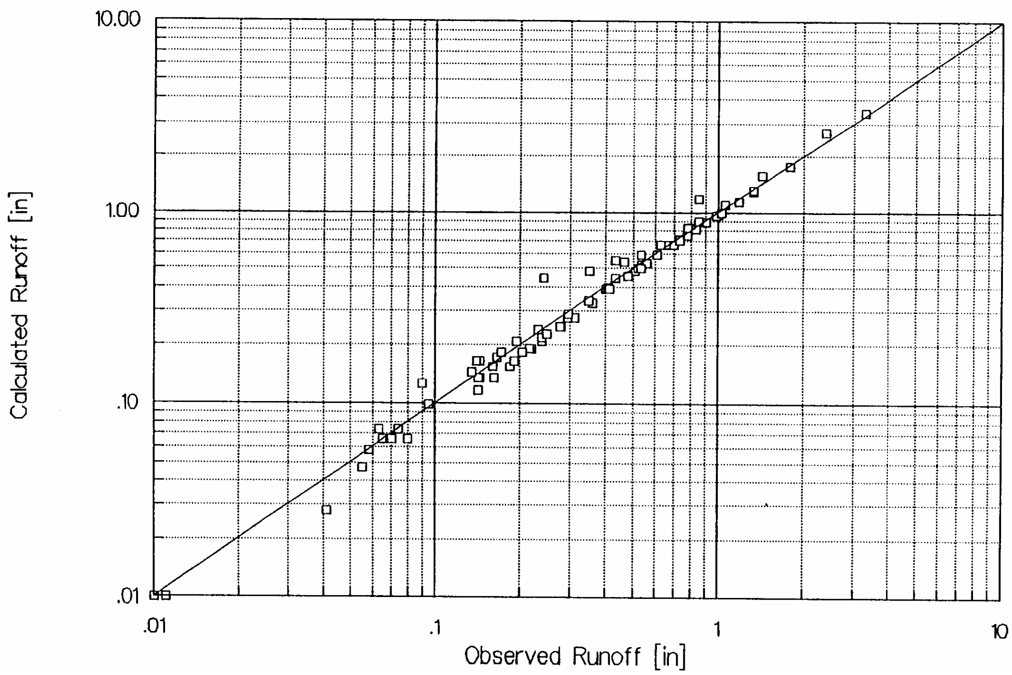
If a constant percentage bias occurs (unlikely) over the range of events monitored, then modify the Rv values in the RUNOFF.RSV file for the contributing source areas for the range of rains monitored. However, the residual error plot probably shows a bias, with some portions of the rain distribution having greater problems than others. It is therefore possible to divide the residual error plot into different rain depth ranges, corresponding to different amounts of correction needed. Each rain depth range also has different source contributions. Therefore, Rv corrections can be made to each source area for different rain ranges. It is probably best to start with the smallest rains where the directly connected impervious areas have the greatest influence, then go to the largest rains where runoff from the soil dominates (re-running the program using the partially corrected file). It is possible to create a simple series of simultaneous equations to solve for the changes to be concurrently made, but manual changes are typically adequate. After the changes are made, it is necessary to plot the new Rv values for each source area against rain depth and to smooth the resulting relationships to remove any discontinuities. After these smoothing changes are made, re-run the program using the new *.RSV file and review the results. It may be necessary to repeat this process a few times to become satisfied that no further improvements are possible or necessary.

6. The above process is difficult if only one watershed is available for study and if the watershed area has much disconnected paved/roof areas. The preferred approach would be to start by evaluating an area having all directly connected impervious areas and making the basic changes in the Rv values for each source area and rain, as needed. Another area (preferably similar in character) having disconnected impervious areas would then be used to verify (or change) the coefficients in the RUNOFF.RSV that reduces the Rv values if the impervious areas are disconnected. The ten different watersheds used in preparing the initial RUNOFF.RSV file allowed this more rigorous approach. Assuming the RUNOFF.RSV file Rv values are acceptable, the disconnection coefficients can be adjusted in a similar manner using the above described residual analysis: the runoff residual errors are plotted against rain depth and changes are made to the disconnection coefficients to minimize the total and individual errors.

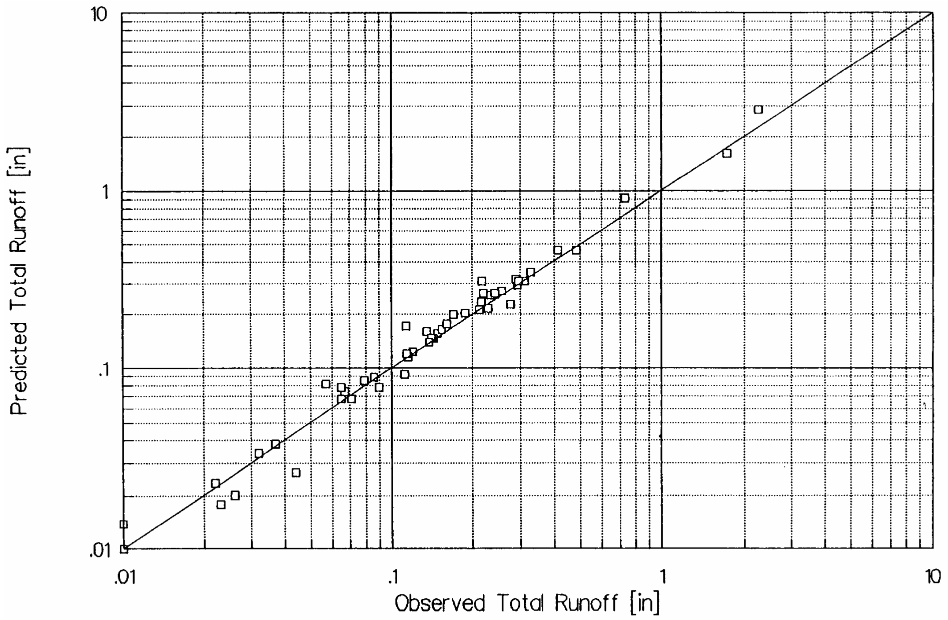
Results of Calibration of Runoff Parameter File (.RSV)*

Over the years, WinSLAMM has been calibrated and verified using available data. The initial calibration conducted in the mid-1980s used data from several Milwaukee Nationwide Urban Runoff Project (NURP) (Bannerman, *et al.* 1983) monitoring locations and two from Toronto monitored as part of the Toronto Area Wastewater Management Strategy Study (TAWMS) (Pitt and McLean 1986) and was extensively described by Pitt (1987). The WI Department of Natural Resources (NDR), in conjunction with the USGS is calibrating the model for use in support of the state's MS4 stormwater permit program, and several examples are shown from that work.

The final runoff coefficients used in the first version of RUNOFF.RSV were verified using additional runoff data from the same monitored areas (that were not used in the calibration efforts) and from areas located elsewhere. The following figures show how well the small storm hydrology model works over a wide range of rain depths and for two very different land uses. The "Post Office" site was a commercial shopping center, while the "Burbank" site was a medium density residential area (both monitored as part of the EPA's NURP project in Milwaukee, as reported by Bannerman, *et al.* 1983).

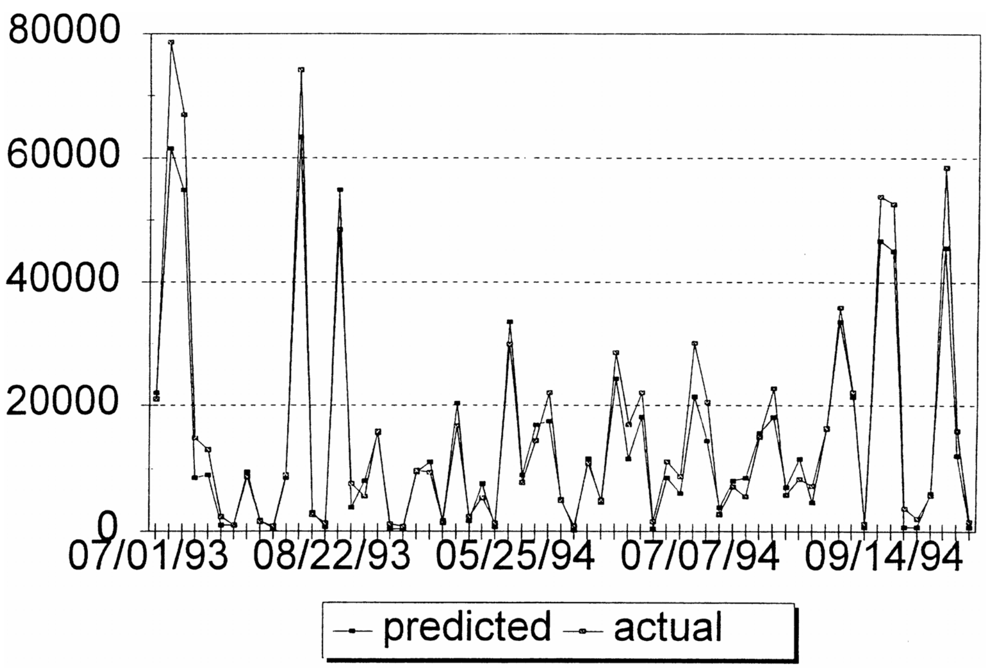


Verification of WinSLAMM hydrology component – Post Office commercial site, Milwaukee, WI (Pitt 1987).

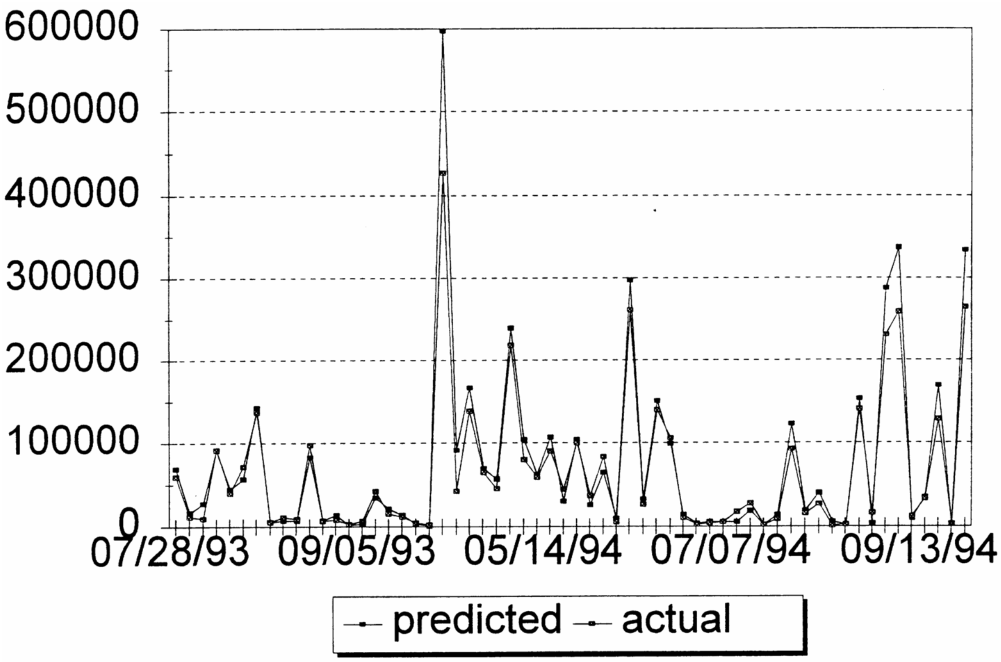


Verification of WinSLAMM hydrology component – Burbank residential site, Milwaukee, WI (Pitt 1987).

The following two plots are for two residential sites monitored by the WI DNR in Superior, WI, and in Marquette, MI, during 1993 and 1994. These two sites were used to verify the small storm hydrology component of WinSLAMM, with no local calibration, demonstrating the excellent fit of observed and predicted flows. The model was subsequently re-calibrated for these two sites to enable better fits for the larger events. It was originally expected that this model would not work very well for very large storms, especially in areas having appreciable pervious areas, where rain intensity was expected to have a more significant effect on infiltration than for small rains.

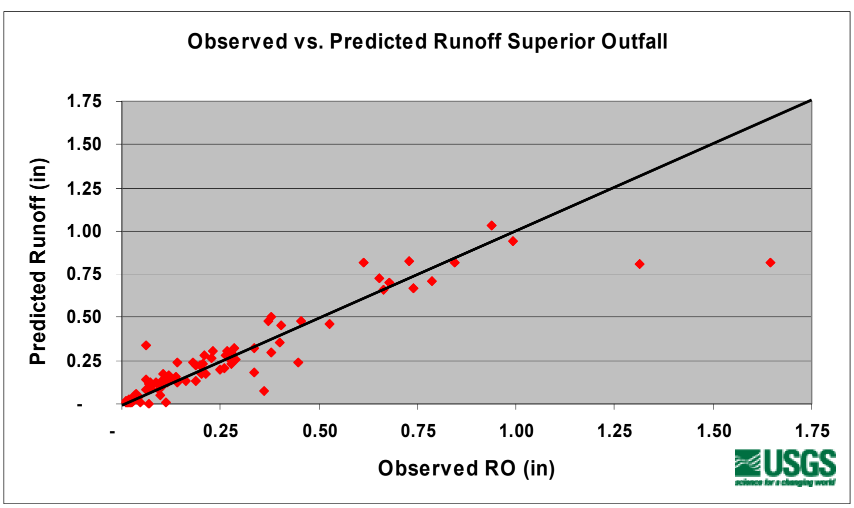


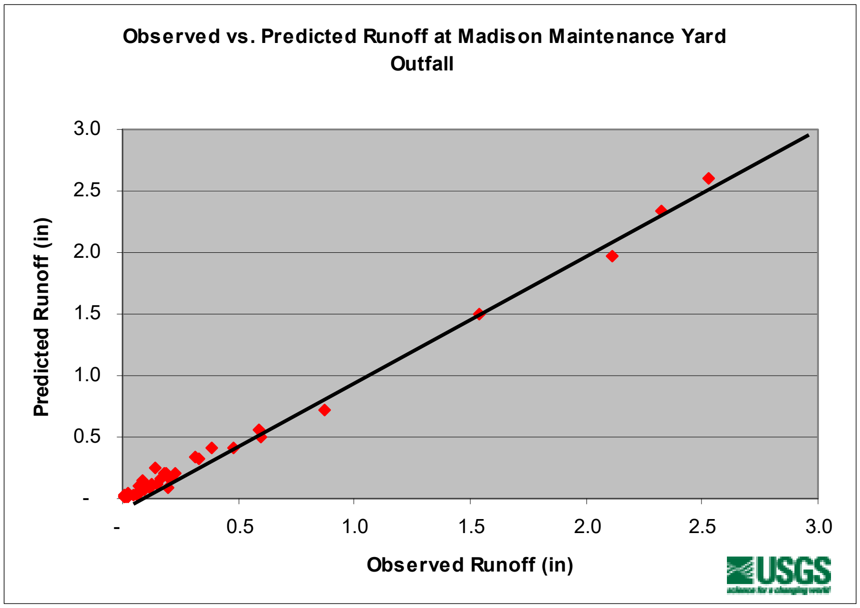
Verification of WinSLAMM hydrology component – Superior, WI, test site.



Verification of WinSLAMM hydrology component – Marquette, MI, test site.

The following graphs illustrate observed and calculated runoff quantities conducted by the WI DNR. The Superior, WI, plot shows very good agreement, except for two large events where the observed runoff quantities were larger than calculated. The Madison maintenance yard plot is much more consistent over a much wider range of conditions, likely because of the simpler source areas (large paved areas and directly connected roofs).





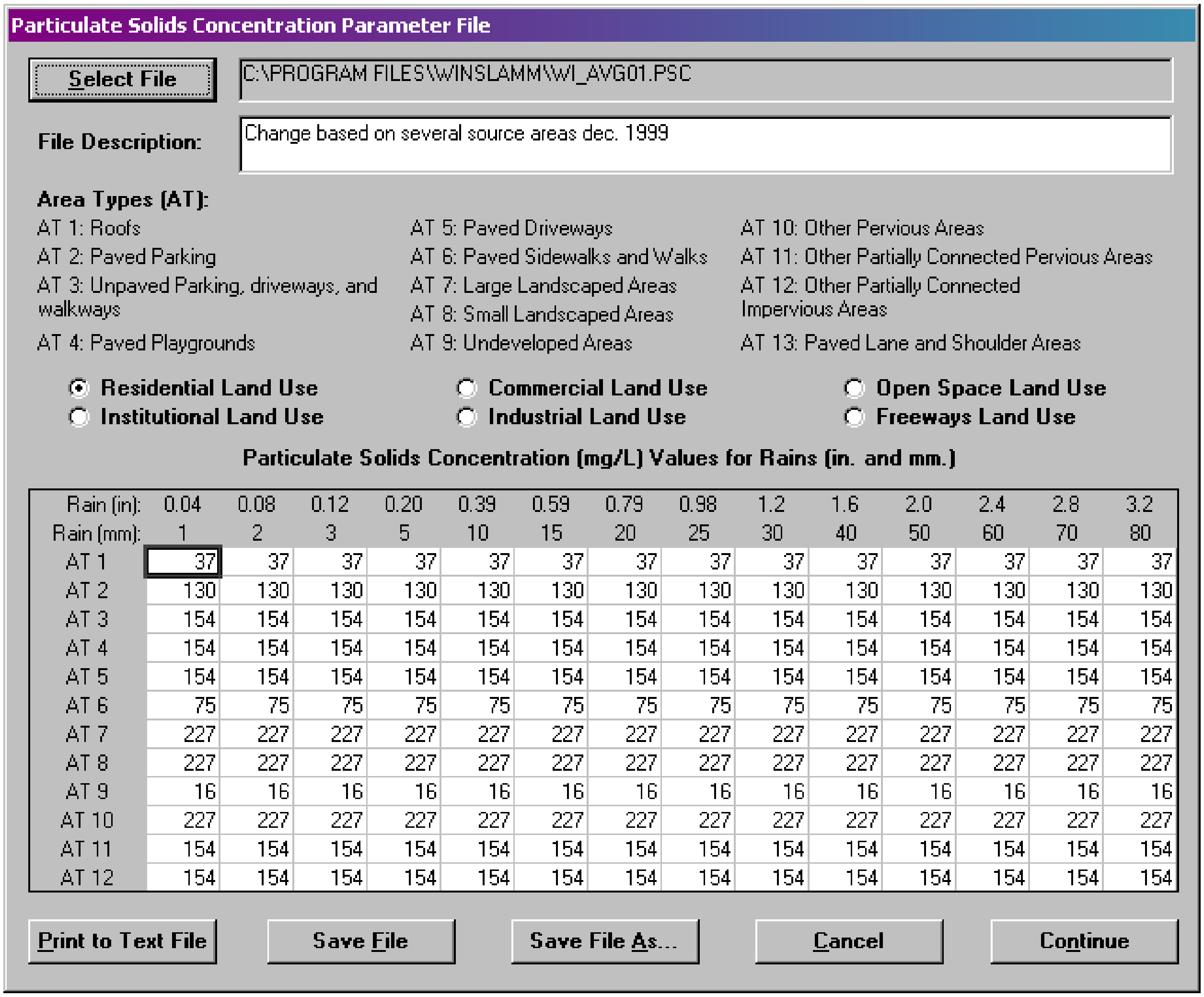
The following table shows the differences in measured and calculated runoff quantities for the monitored events at seven different locations after calibration by the WI DNR. The median difference is about 10%, while the largest difference was 27%.

Location	**Total Rain During Monitoring Period**	**Measured Runoff for Monitoring Period**	**Modeled Runoff for Monitoring Period**	**Difference, %**
Harper	27.9	7.3	5.3	-27%
Monroe	46.4	8.2	8.8	7%
Canterbury	14.5	5.4	5.9	10%
Marquette	22.1	3.8	4.5	19%
Superior	41.8	22.8	21.8	-4%
Syene	70.5	36.2	33.4	-8%
Badger	17.2	14.9	14.3	-4%

Particulate Solids Concentrations

Particulate Solids Concentration Files

The mandatory *.PSC file describes the particulate residue (suspended solids) concentrations for each source area (except for roads and freeway lanes, which are included in the build-up and washoff algorithms of WinSLAMM) and land use, for several rain categories. The PART.PSC file was developed and verified using source area data mostly from Toronto, Milwaukee and Birmingham during specific field tests.



Particulate Solids Concentration Parameter File

Select File C:\PROGRAM FILES\WINSLAMM\WI_AVG01.PSC

File Description: Change based on several source areas dec. 1999

Area Types (AT):

AT 1: Roofs
AT 2: Paved Parking
AT 3: Unpaved Parking, driveways, and walkways
AT 4: Paved Playgrounds
AT 5: Paved Driveways
AT 6: Paved Sidewalks and Walks
AT 7: Large Landscaped Areas
AT 8: Small Landscaped Areas
AT 9: Undeveloped Areas
AT 10: Other Pervious Areas
AT 11: Other Partially Connected Pervious Areas
AT 12: Other Partially Connected Impervious Areas
AT 13: Paved Lane and Shoulder Areas

Residential Land Use / Institutional Land Use / Commercial Land Use / Industrial Land Use / Open Space Land Use / Freeways Land Use

Particulate Solids Concentration (mg/L) Values for Rains (in. and mm.)

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	37	37	37	37	37	37	37	37	37	37	37	37	37	37
AT 2	130	130	130	130	130	130	130	130	130	130	130	130	130	130
AT 3	154	154	154	154	154	154	154	154	154	154	154	154	154	154
AT 4	154	154	154	154	154	154	154	154	154	154	154	154	154	154
AT 5	154	154	154	154	154	154	154	154	154	154	154	154	154	154
AT 6	75	75	75	75	75	75	75	75	75	75	75	75	75	75
AT 7	227	227	227	227	227	227	227	227	227	227	227	227	227	227
AT 8	227	227	227	227	227	227	227	227	227	227	227	227	227	227
AT 9	16	16	16	16	16	16	16	16	16	16	16	16	16	16
AT 10	227	227	227	227	227	227	227	227	227	227	227	227	227	227
AT 11	154	154	154	154	154	154	154	154	154	154	154	154	154	154
AT 12	154	154	154	154	154	154	154	154	154	154	154	154	154	154

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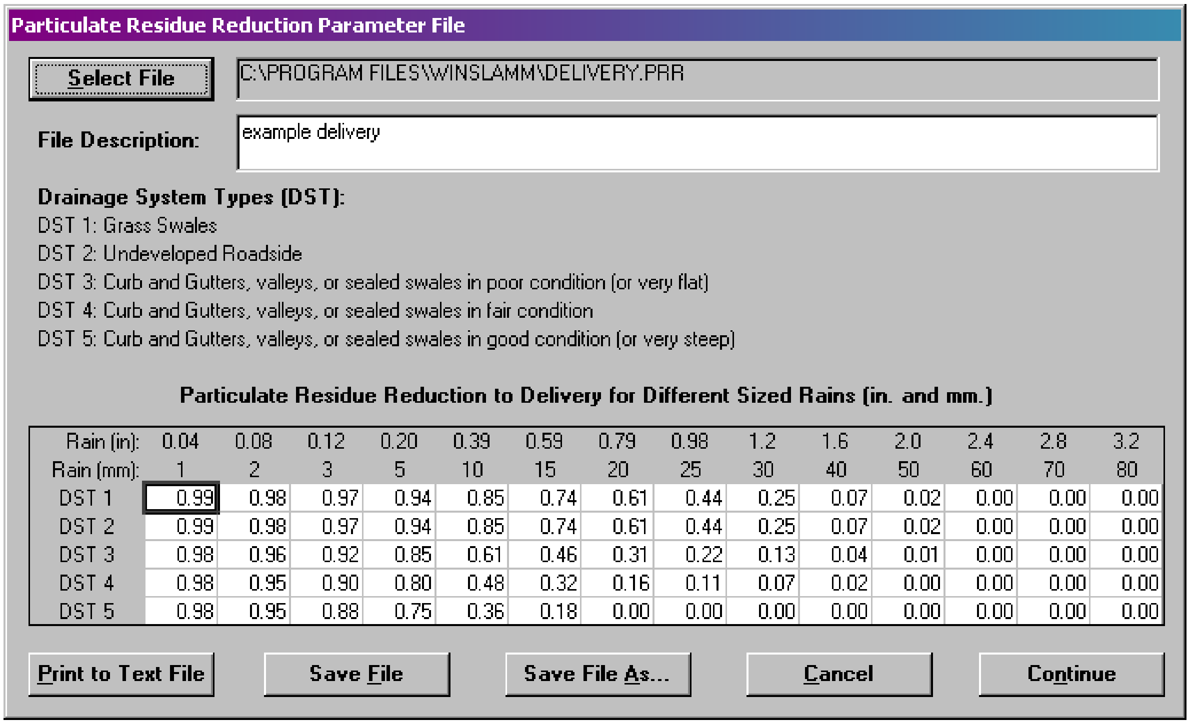
Particulate Solids Concentration Parameter File (*.PSC) Edit and Review Screen in WinSLAMM

Delivery Files

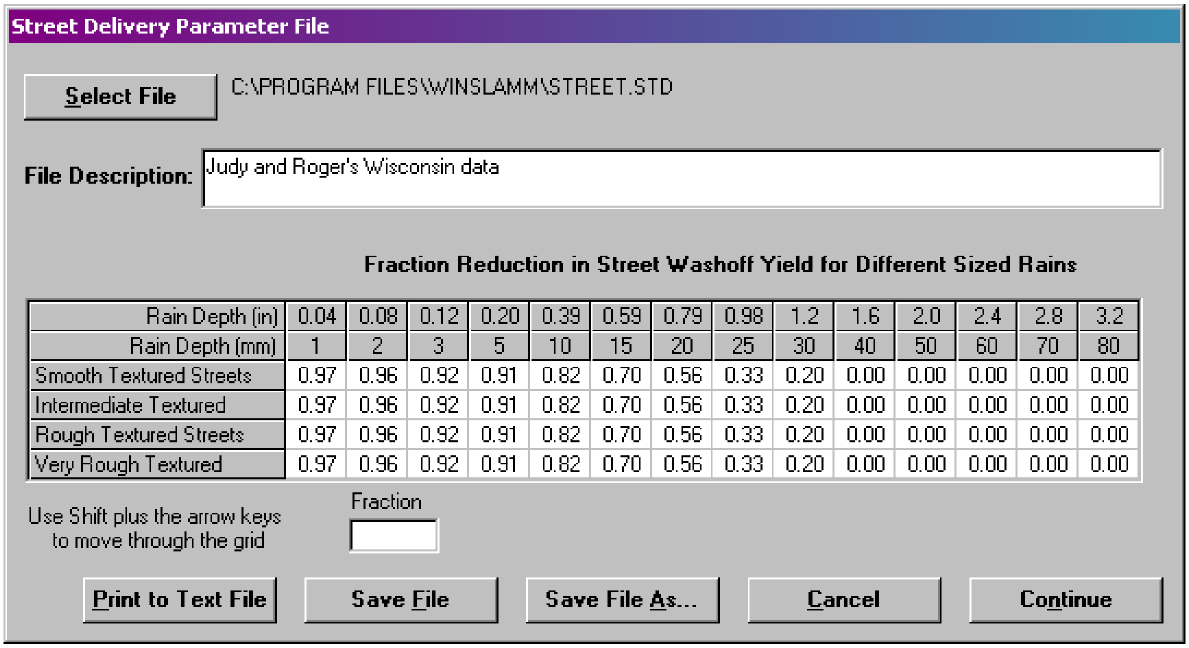
SLAMM uses another file (*.PRR) to calibrate the source predictions to outfall observations because the *.PSC file contains particulate solids data for only some of the source areas, while the streets and highway lanes are directly predicted. The mandatory.PRR file accounts for the deposition of particulate pollutants in the storm drainage system, before the outfall, or before outfall controls. The DELIVERY.PRR file was originally calibrated for swales, curb and gutters, undeveloped roadsides, or combinations of drainage conditions. The current version of WinSLAMM directly calculates the deposition of particulates in grass swales, so this is no longer part of this parameter file. Planned program modifications will also allow the direct calculation of particulate deposition in the other drainage system components, eventually making this parameter file obsolete.



Particulate Solids Delivery Parameter File (*.PRR) Edit and Review Screen in WinSLAMM

Street Delivery Files

In addition, another delivery file was created specifically focusing on street dirt delivery during washoff events. The washoff tests used in the initial calibration of WinSLAMM were relatively small in scale (usually about 10 X 30 ft in area). The washoff of street dirt is accurately calculated by WinSLAMM (as shown later in the WI calibration example), but the transport of the washed-off particulates along the street gutters was found to vary greatly, depending on storm size. This *.STD file was therefore created to more accurately account for this deposition of street dirt washoff material.



Street Dirt Delivery Parameter File (*.STD) Edit and Review Screen in WinSLAMM

Initial Data Sources for Particulate Solids

The following list shows the major published sources of the particulate residue (suspended solids) data used in developing the original PART.PSC and DELIVERY.PRR files:

Bannerman, R., K. Baun, M. Bohn, P.E. Hughes, and D.A. Graczyk. *Evaluation of Urban Nonpoint Source Pollution Management in Milwaukee County, Wisconsin*, Vol. I. Grant No. P005432-01-5, PB 84-114164. US Environmental Protection Agency, Water Planning Division, November 1983. SS and pollutants from streets, commercial roofs and parking areas - Milwaukee

Pitt, R. and G. Shawley. *Demonstration of Nonpoint Pollution Management on Castro Valley Creek*. Environmental Protection Agency, Water Planning Division, Washington, D.C., June 1981. SS and pollutants from many source areas - Castro Valley, CA

Pitt, R. *Urban Bacteria Sources and Control in the Lower Rideau River Watershed*, Ottawa, Ontario. Ontario Ministry of the Environment, May 1982. SS and some pollutants from some source areas- Ottawa

Pitt, R. and M. Bozeman. *Sources of Urban Runoff Pollution and Its Effects on an Urban Creek*. EPA-600/S2-82-090, U.S. Environmental Protection Agency, Cincinnati, Ohio, December 1982. SS and pollutants from many source areas - San Jose, CA

Pitt, R. and J. McLean. *Humber River Pilot Watershed Project*. Ontario Ministry of the Environment, Toronto, Canada, December 1984. SS and pollutants from many source areas - Toronto

Shelley, P.E. and D.R. Gaboury. "Estimation of Pollution from Highway Runoff - Initial Results," *Conference on Urban Runoff Quality - Impact and Quality Enhancement Technology*, Henniker, New Hampshire, Edited by B. Urbonas and L.A. Roesner, Proceedings published by the American Society of Civil Engineering, New York, June 1986. SS and pollutants from highways – nationwide

Calibration Steps for Particulate Solids

The particulate solids files can only be examined and modified after the runoff file is acceptable. The *.PSC file contains particulate solids concentrations (currently termed SSC, suspended sediment concentrations) (in mg/L) for each source area and land use for different rains, except for the street areas that use explicit accumulation and washoff algorithms based on land use, street texture, and rain conditions. Highway paved lane and shoulder areas also have explicit algorithms that calculate accumulation and washoff of particulate solids based on traffic volume and rains. Both of these areas have a great deal of research information available, allowing these direct calculations. Unfortunately, other source areas have little research data available to allow direct predictions of particulate solids runoff concentrations.

This file is therefore used to account for the "first-flush" effects observed at specific source areas. Concentrations of particulate solids at the very beginning of rains at some paved areas (especially small paved parking areas) are much greater than later in the same rain. This variation is highly dependent on rain energy and WinSLAMM uses a similar relationship to describe particulate solids variations for different rain depths. These data are based on observed conditions at the source areas. Runoff from some source areas (especially roofs and landscaped areas) typically does not indicate major concentration changes for different rains.

The first calibration steps are associated with QA/QC checks and observing trends in predicted vs. observed outfall particulate solids concentrations, and then making needed changes:

1. This step is used if local source area data for particulate solids is available. If this data is not available, then start with the PART.PSC file and step 2.

The first step is to look at the data and see if it seems reasonable. The collected source area particulate solids concentrations need to be divided into separate categories for each source area and land use. These categories should be tested to determine if the categories are significantly different from each other. The easiest way to visualize these relationships is by using grouped boxed plots, sorted by median concentrations. If the boxes are offset by at least the 25% and 75% values, then they are generally significantly different at the 95% confidence level. What is likely, however, is that the groups show a gradual trend, with extreme groups different from each other and the other central groups showing generally overlapping distributions. The extreme groups may be roof runoff (for the low concentrations) and landscaped area runoff (for the high concentrations). The other groups (parking areas, streets, walks, etc.) probably have more closely related particulate solids concentrations.

A two-way ANOVA test can be conducted to determine if there are any significant differences between the source area categories or between the land use categories. The test also determines if the combination of source area and land use combined affects the categories. ANOVA doesn't specifically identify which sets of data are different from any other. A multiple comparison procedure (such as the Bonferroni *t*-test) can be used to identify significant differences between all cells in the 2-way matrix if the ANOVA finds that a significance difference exists. Both of these tests are parametric tests and require that the data be normally distributed. It may therefore be necessary to perform a logtransformation on the raw particulate solids data. These tests will identify differences in sample groupings, but similarities (to combine data) are probably more important to know. The grouped box plots, again, will be most helpful, in addition to possibly conducting a cluster analysis to identify natural groupings of the data.

Combine the data into fewer groupings (such as all paved parking areas for commercial and industrial areas, another group for all roofs, regardless of land use, and another for all landscaped area runoff). The data in each of these new groups should be plotted as particulate solids concentrations vs. rain depth. The resulting particulate solids concentrations for each rain depth should be included in the construction of a new *.PSC file, duplicating values for all land uses and source areas that were combined based on the statistical tests. If all land uses and source areas are not included in the local monitoring data, then data (unmodified) from elsewhere (including the existing PART.PSC file) can be used with caution.

2. Run the watershed description WinSLAMM file prepared previously, using the DELIVERY.PRR file, the calibrated *.RSV file and the two rain files (one containing the monitored events and the other being the source.RAN file) without any additional pollutants selected. Select the output option giving results for each rain, by source area.

Compare the predicted to the observed particulate solids concentrations for the monitored events by creating a scatter plot of observed vs. predicted runoff values. Calculate the percentage particulate solids concentration errors: 100 x (observed-predicted)/observed, and plot these against the observed particulate solids concentrations and against rain depth for the monitored events. The residual patterns desired are as described above for the runoff calibration. Also calculate the sum of the observed and predicted particulate solids loadings (in lbs) for all monitored events. The percentage difference in the sum of loadings should be small and will indicate the general magnitude of the changes needed. It is likely that the largest discrepancies in particulate solids concentrations will be associated with small rain depths (WinSLAMM will probably over-estimate the concentrations), while the differences for the larger rains will be smaller.

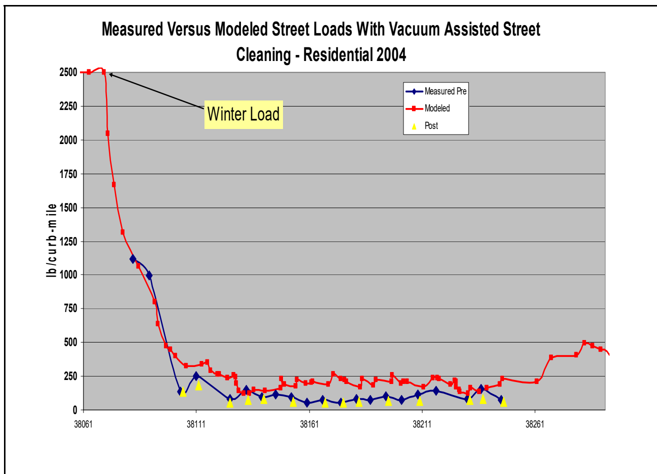
The calibration of WinSLAMM for the particulate solids concentrations and loadings will mostly be accomplished by modifying the DELIVERY.PRR file. This file accounts for the reduction of particulate solids concentrations for small rains because of deposition of these solids along the drainage path, from the source area (where the *.PSC associated concentrations were measured) to the outfall. Grass swales, undeveloped roadsides, and flat curbs and gutters have relatively slow runoff velocities and lower carrying capacities of sediment than flows in steeper areas and smoother gutters. The differences are most pronounced for the smaller rains than for larger rains where the velocities are all much greater, corresponding to much greater sediment carrying capacities.

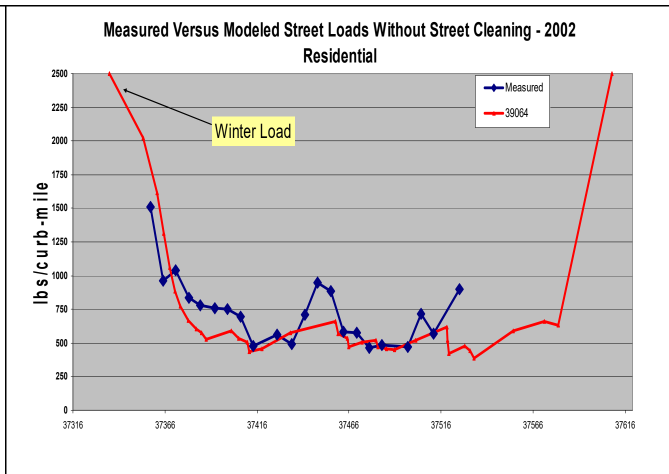
Since the *.PRR file adjusts the delivery of the particulate solids for the whole watershed combined (for the drainage system type) the SOURCE.RAN file results won't be helpful in making changes to this files. However, if changes need to be made to the *.PSC file, the results from the model run using this rain file will be very helpful. This run contains the percentage contribution of particulate solids for each rain, for each source area. This shows where WinSLAMM is generating the particulate solids for the different rain depths. Again, only look at the range of predicted data covering the actual monitored rains.

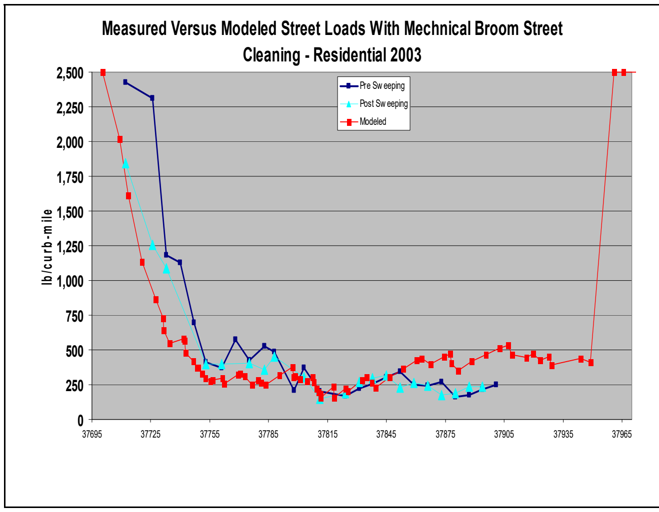
If a constant percentage bias occurs (unlikely) over the range of events monitored, then modify all of the delivery fractions by the same amount. However, the residual error plot probably will show a bias, with some portions of the rain distribution having greater problems than others. As with the runoff calibration, it is possible to divide the residual error plot into different rain depth ranges, corresponding to different amounts of correction needed for particulate solids loads. Each rain depth range also has different source contributions. Therefore, the delivery corrections can be made to each source area for different rain ranges. The street dirt delivery file (*.STD) can also be used to modify the contributions from the streets, especially for the smaller rain events. After the changes are made, it is necessary to plot the new delivery values for each rain depth and to smooth the resulting relationships to remove any discontinuities. After these smoothing changes are made, re-run the program using the new *.PRR and *.STD files and review the results. It may be necessary to repeat this process a few times to become satisfied that no further improvements are possible. Although both of these delivery files are needed, their effects can be removed simply by using delivery files that contain all zeros (the WI DNR recommended files uses a delivery file having all zeros, for example, but their street dirt delivery files are different for different land uses).

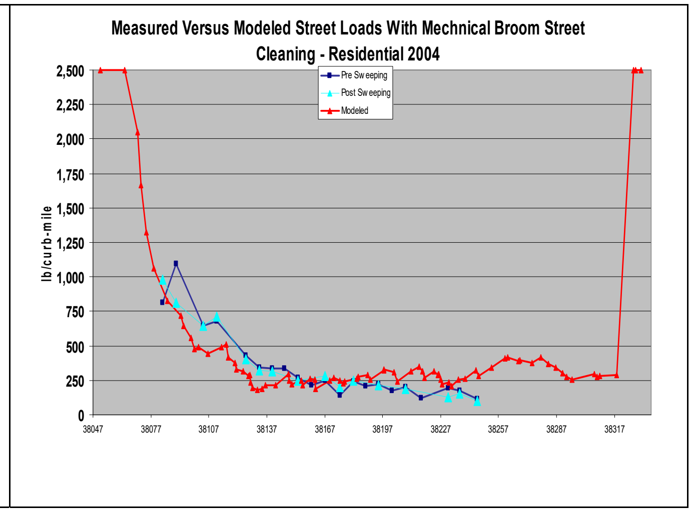
*Results of Calibration of Particulate Solids Parameter Files (*PSC, *.PRR, and *.STD)*

The following plots are examples of predicted and measured street dirt loadings from recent street cleaning projects conducted in Madison, WI, by the WI DNR and the USGS. The calibrated files result in accurate representations of available street dirt loadings throughout the year, including the very large loadings in the early spring after snowmelt, and the subsequent reductions in loading associated with the street cleaning.



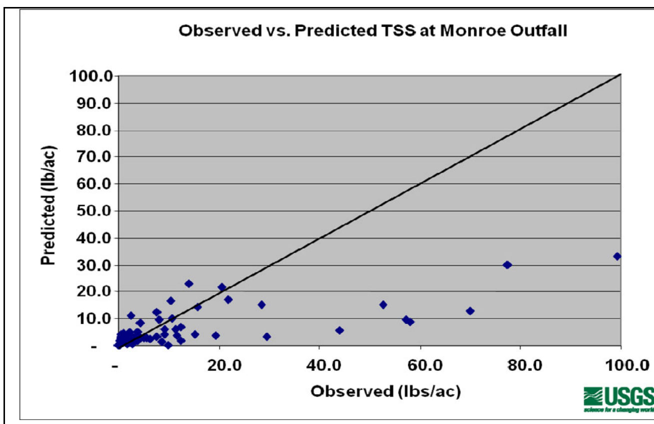




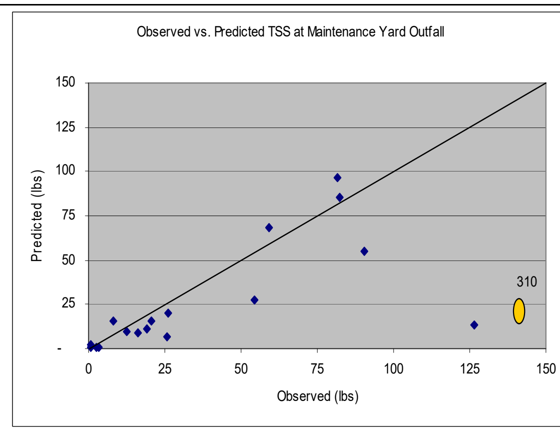


Observed and calculated street dirt loadings for different street cleaning equipment and seasons

The following plots show the predicted and monitored TSS outfall concentrations at two Wisconsin sites. The first plot shows a poor comparison of observed and monitored TSS data. When the watershed was more thoroughly investigated, areas of bank erosion were found up from the monitoring station that were not included in the model. The second plot shows a reasonable comparison, except for two unusually high observed loads.



Effects of bank erosion



Two large unusual loading observations

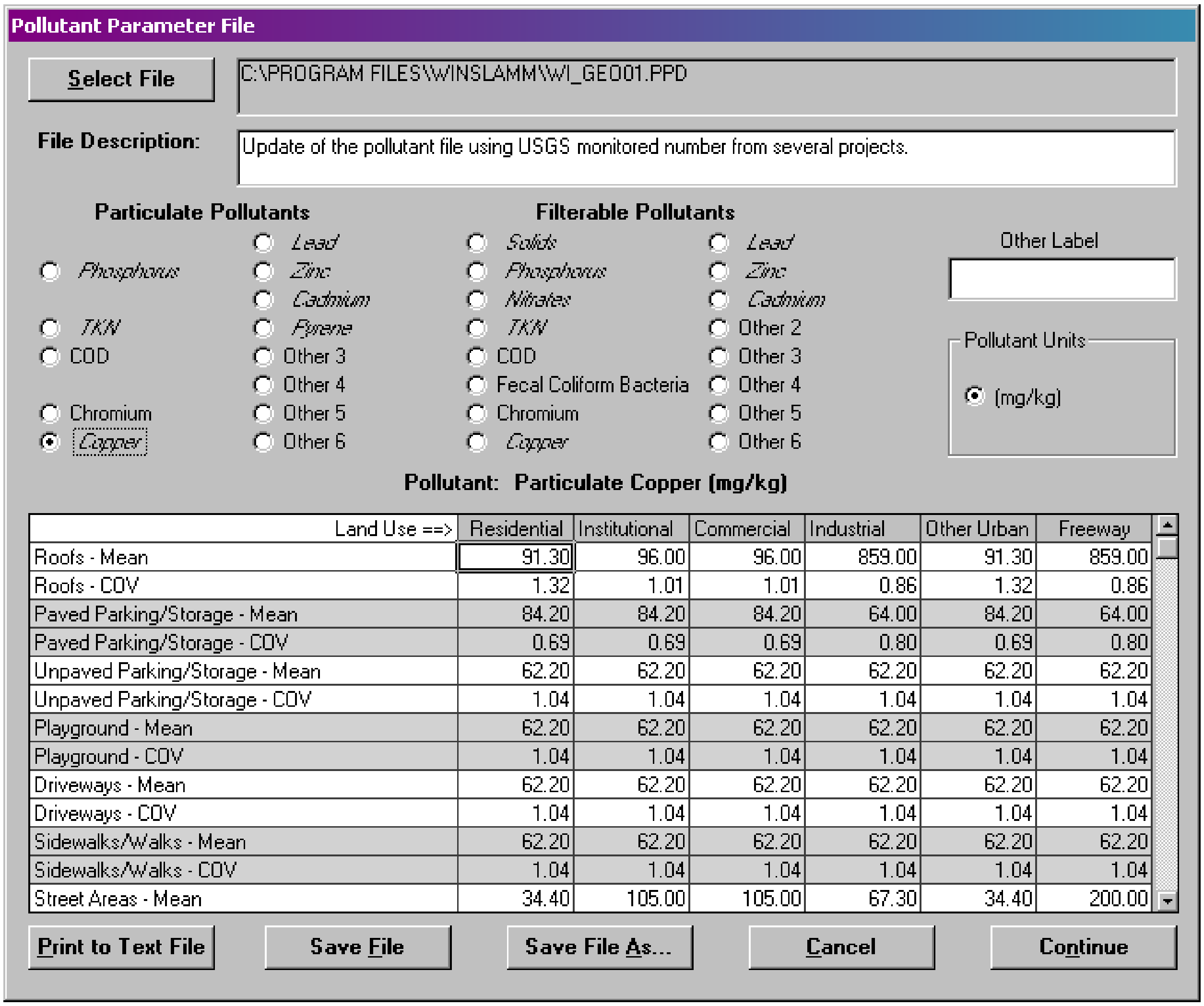
The differences in the sum of loads for monitored vs. modeled TSS loads are shown in the following table. These indicate the larger variation that may be expected when monitoring TSS, compared to flows. Generally, TSS was modeled within about 50% of the observed conditions, over the wide range of conditions represented by these sites.

Site	**Land Use**	**Percent Difference in TSS Annual Loads**
Harper	Residential	11%

Monroe	Resid./Comm.	-52%
Marquette	Resid./Comm.	- 29%
Canterbury	Resid./Comm.	12%
Superior	Commercial	-66%
Syene	Light Industrial	19%
Badger Rd.	Light Industrial	-40%

Pollutant Concentrations

The optional pollutant.PPD file describes the particulate pollutant strengths related to particulate solids and describes the filterable pollutant concentrations for each source area for each land use. This file is not needed if only runoff volume and particulate residue calculations are desired. This file also contains the coefficient of variation (COV) values for each pollutant for Monte Carlo simulation in WinSLAMM. The original *.PPD files were developed and verified using source area data from Toronto, Milwaukee and Birmingham during specific field tests. The following list shows the major published sources of the pollutant characteristic data used in developing this file. Recently, Pitt, *et al.* (2005) summarized available source area sheet flow data collected from a large number of studies and that have been used in calibrating WinSLAMM.



Land Use ==>	Residential	Institutional	Commercial	Industrial	Other Urban	Freeway
Roofs - Mean	91.30	96.00	96.00	859.00	91.30	859.00
Roofs - COV	1.32	1.01	1.01	0.86	1.32	0.86
Paved Parking/Storage - Mean	84.20	84.20	84.20	64.00	84.20	64.00
Paved Parking/Storage - COV	0.69	0.69	0.69	0.80	0.69	0.80
Unpaved Parking/Storage - Mean	62.20	62.20	62.20	62.20	62.20	62.20
Unpaved Parking/Storage - COV	1.04	1.04	1.04	1.04	1.04	1.04
Playground - Mean	62.20	62.20	62.20	62.20	62.20	62.20
Playground - COV	1.04	1.04	1.04	1.04	1.04	1.04
Driveways - Mean	62.20	62.20	62.20	62.20	62.20	62.20
Driveways - COV	1.04	1.04	1.04	1.04	1.04	1.04
Sidewalks/Walks - Mean	62.20	62.20	62.20	62.20	62.20	62.20
Sidewalks/Walks - COV	1.04	1.04	1.04	1.04	1.04	1.04
Street Areas - Mean	34.40	105.00	105.00	67.30	34.40	200.00

Pollutant Probability Distribution Parameter File (*.PPD) Edit and Review Screen in WinSLAMM

Initial Pollutant Concentration Data Sources

The following references contain stormwater source area sheetflow and particulate concentrations that have been used during past WinSLAMM calibration efforts. Recently, a compilation of these data was published by Pitt, *et al.* (2005a, 2005b, and 2005c):

Bannerman, R., K. Baun, M. Bohn, P.E. Hughes, and D.A. Graczyk. *Evaluation of Urban Nonpoint Source Pollution Management in Milwaukee County, Wisconsin*, Vol. I. Grant No. P005432-01-5, PB 84-114164. US Environmental Protection Agency, Water Planning Division, November 1983. SS and pollutants from streets, commercial roofs and parking areas – Milwaukee

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. 2005a.

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. 2005b.

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. 2005c.

Pitt, R. and G. Amy. *Toxic Materials Analysis of Street Surface Contaminants*. EPA-R2-73-283, U.S. Environmental Protection Agency, Washington, D.C., August 1973. SS quality from street dirt - nationwide

Pitt, R. *Demonstration of Nonpoint Pollution Abatement Through Improved Street Cleaning Practices*. EPA-600/2-79-161, U.S. Environmental Protection Agency, Cincinnati, Ohio, August 1979. SS and pollutants from streets – San Jose, CA

Pitt, R. and G. Shawley. *Demonstration of Nonpoint Pollution Management on Castro Valley Creek*. Environmental Protection Agency, Water Planning Division, Washington, D.C., June 1981. SS and pollutants from many source areas - Castro Valley, CA

Pitt, R. *Urban Bacteria Sources and Control in the Lower Rideau River Watershed*, Ottawa, Ontario. Ontario Ministry of the Environment, May 1982. SS and some pollutants from some source areas- Ottawa

Pitt, R. and R. Sutherland. *Washoe County Urban Stormwater Management Program; Volume 2, Street Particulate Data Collection and Analyses*. Washoe Council of Governments, Reno, Nevada, August 1982. SS and pollutants from streets - Reno, NV

Pitt, R. and M. Bozeman. *Sources of Urban Runoff Pollution and Its Effects on an Urban Creek*. EPA-600/S2-82-090, U.S. Environmental Protection Agency, Cincinnati, Ohio, December 1982. SS and pollutants from many source areas - San Jose, CA

Pitt, R. *Characterization, Sources, and Control of Urban Runoff by Street and Sewerage Cleaning*. Contract No. R-80597012, U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, Ohio, 1984. SS and pollutants from streets - Bellevue, WA

Pitt, R. and J. McLean. *Humber River Pilot Watershed Project*. Ontario Ministry of the Environment, Toronto, Canada, December 1984. SS and pollutants from many source areas - Toronto

Sartor, J.D. and G.B. Boyd. *Water Pollution Aspects of Street Surface Contaminants*. EPA-R2-72-081, U.S. Environmental Protection Agency, November 1972. SS and pollutants from streets - nationwide

Shaheen, D.G. *Contributions of Urban Roadway Usage to Water Pollution*. 600/2-75-004, U.S. Environmental Protection Agency, April 1975. SS and pollutants from streets - Washington, D.C.

Shelley, P.E. and D.R. Gaboury. "Estimation of Pollution from Highway Runoff - Initial Results," *Conference on Urban Runoff Quality - Impact and Quality Enhancement Technology*, Henniker, New Hampshire, Edited by B. Urbonas and L.A. Roesner, Proceedings published by the American Society of Civil Engineering, New York, June 1986. SS and pollutants from highways - nationwide

Terstriep, M.L., G.M. Bender, and D.C. Noel. *Final Report - NURP Project, Champaign, Illinois: Evaluation of the Effectiveness of Municipal Street Sweeping in the Control of Urban Storm Runoff Pollution*. State Water Survey Division, Illinois Dept. of Energy and Natural Resources, Champaign-Urbana, Illinois, December 1982. SS and pollutants from streets - Champaign, IL

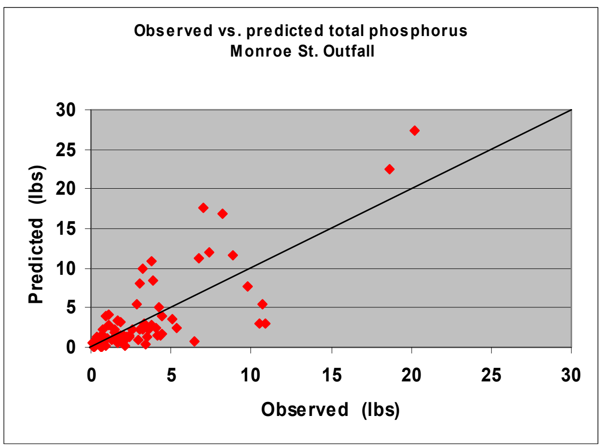
Calibration Steps for Pollutants

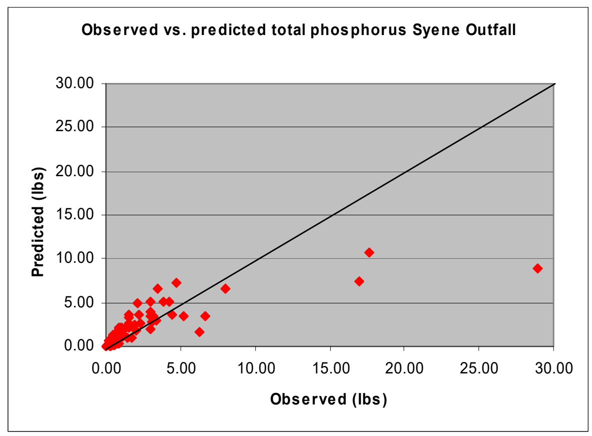
After the flow and particulate solids calibration steps have been completed to satisfaction, calibration of the pollutants of concern can be undertaken. Start with an existing *.PPD file, or create a new one using local sheetflow data. The yield of the total forms of the pollutants (particulate fraction plus filtered fraction) for the sum of the monitored events should first be compared to the sum of the yield for the same events as calculated by WinSLAMM. The individual concentration values for each of the source areas for the monitored land use should be adjusted by the fraction representing the differences between the observed and calculated yields. After re-running the model using the adjusted *.PPD file, plot the individual concentrations in a scatterplot of measured vs. calculated values. It would be useful to study the calculated results from the Source.RAN file to determine which events are associated with the smallest rains, and adjust those first, then re-run the program and examine the next set of events that include sheetflow contributions from the next increment of source areas, repeating until adjustments have been made for all events, as necessary.

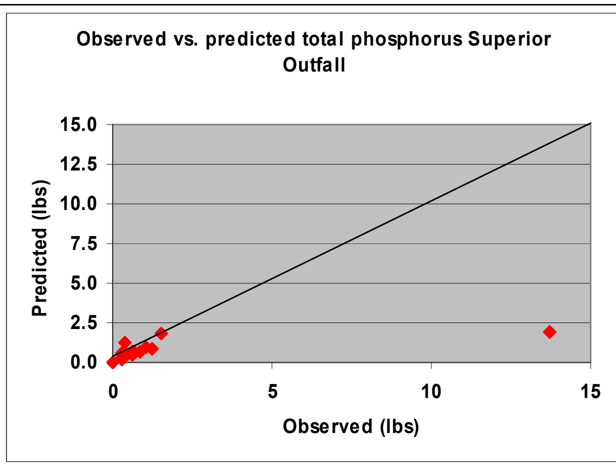
The next step is to examine the filtered vs. particulate fractions for the pollutants. Examine the monitoring data to see if there are any statistically significant trends of this ratio for different rain categories (not very likely). Adjust the particulate (mg/kg) and filterable (mg/L) values to balance the calculated concentration ratio to reflect the measured ratio. Finally, examine the probability distributions of the calculated and measured concentrations (particulate and filterable separately) and adjust the COV values to obtain similar slopes on the probability distribution plots.

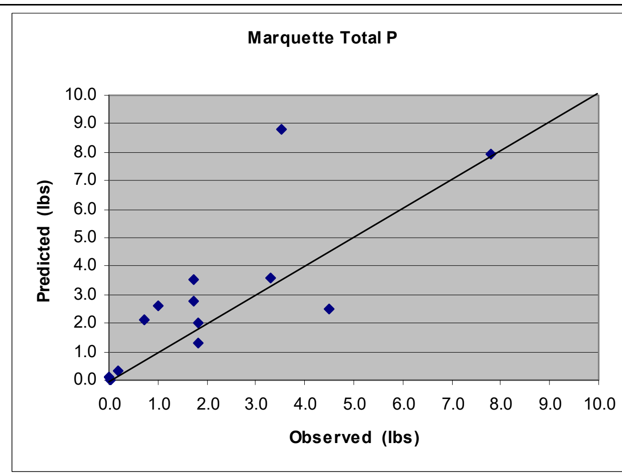
*Results of Calibration of Pollutant Parameter Files (*PPD)*

The following plots are examples of predicted and measured phosphorus and zinc loadings prepared during WI DNR WinSLAMM calibration efforts.





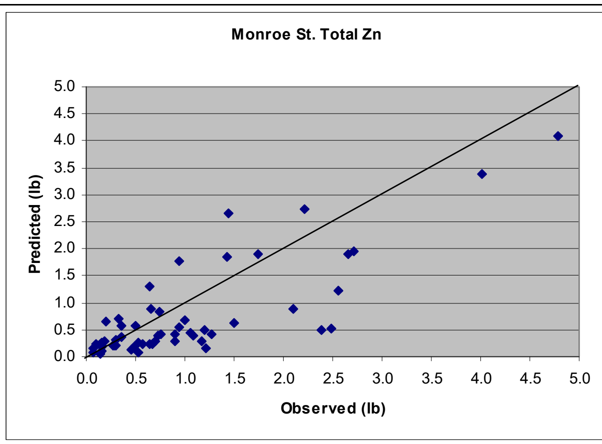


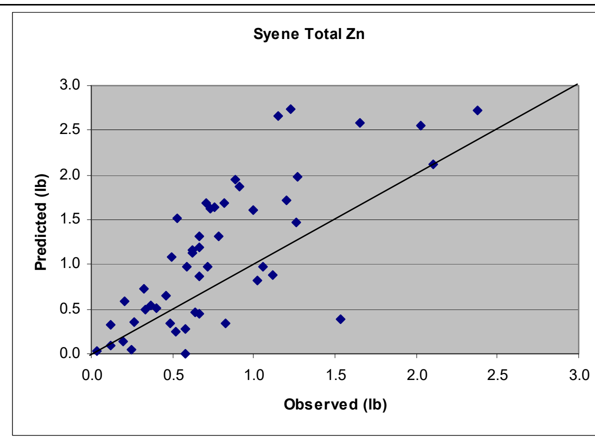


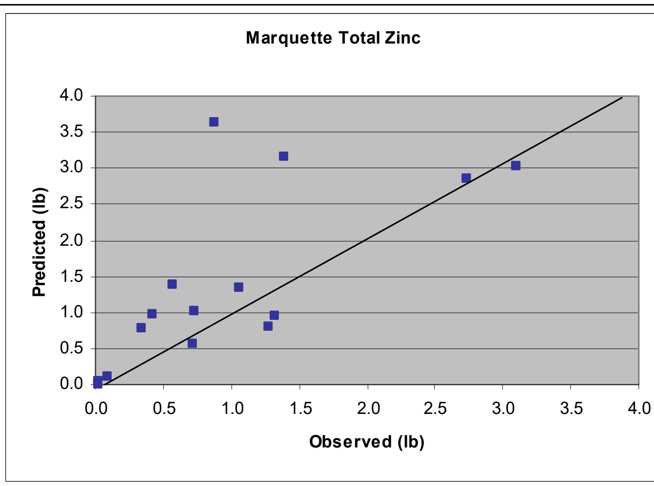
The sum of loading errors are shown on the following table, and indicate the effect that a few unusual events can have on model performance when minimal data is collected. The larger amounts of data usually results in better fits. The errors for phosphorus were about the same as observed for particulate solids, although about half of the total phosphorus load is associated with dissolved phosphorus forms.

Site	Number of Events	Measured TP Load	Modeled TP Load	Percent Difference
Harper	33	12	16	33%
Monroe	71	250	305	22%
Cantebury	24	406	472	16%
Marquette	16	49	80	65%
Superior	19	24	8	-68%
Syene	77	182	204	12%

The following plots show the observed and calculated zinc loads, and similar levels of sum of load errors as noted above for phosphorus and particulate solids.







Site	Landuse	Percent Difference in Total Zn Predicted and Observed Loads
Marquette	Residential	54%
Monroe	Resid./Comm.	-18%
Canterbury	Resid./Comm.	35%
Syene	Light Industrial	37%
Superior	Commercial	20%

Overall, WinSLAMM can accurately predict runoff volumes for each individual event quite well, and with sum of load errors ranging from about 10 to 30%. Particulate solids performance is degraded somewhat, with some biases associated with unusual site conditions that are not considered in the model (such as excessive eroding areas), with sum of load errors of up to 50% (median of about 30%). Pollutant prediction errors are somewhat larger for some sites, with sum or load errors up to about 70% (median of about 25% for phosphorus and about 40% for zinc). The event to event calibrations for the pollutants also show greater variability. However, the model can accurately predict probability distributions of the pollutant concentrations, as discussed in a later section where the NSQD data was used to calibrate the model.

The following subsection describes some of the monitoring efforts conducted by the WI DNR and the USGS over the past several years to obtain extensive data for calibration of WinSLAMM (and other models). Much of this data is summarized in the above noted references. The State of Wisconsin has developed a set of calibrated parameter files that are used by modelers in the state to prepare city-wide stormwater plans to their local NPDES stormwater permits. These calibrated files are also used by engineers to evaluate new development plans and to show the performance of expected control practice scenarios. These files can be downloaded at the USGS website at: http://wi.water.usgs.gov/slamm/. Many other model users have used these files successfully elsewhere, although it is always best to verify model performance with locally obtained stormwaters data. A later section shows how this was accomplished using data from the National Stormwater Quality Database.

Wisconsin Monitoring Efforts to Obtain Data to Support the Calibration of WinSLAMM

This section describes the field monitoring efforts that the Wisconsin Department of Natural Resources (DNR) has been conducting to calibration and verification WinSLAMM, and other models for their area. The following describes the source area sheetflow monitoring activities conducted in seven monitoring projects in Wisconsin, and one in Michigan. The monitoring was conducted by the United States Geological Survey (USGS) in cooperation with the DNR. All of these monitoring projects were conducted between 1991 and 1997. The source area data were recently summarized by Pitt, *et al.* (2005a, 2005b, and 2005c).

Early Madison, WI, runoff samples were collected during three months of 1991 (Bannerman, *et al.* 1993) to identify the relative pollutant loads from the most common source areas in two study areas. One study area was mostly residential with some commercial land use, while the second area was all light industrial land use. Sheetflow samples were collected from 46 sites representing roofs, streets, driveways, parking lots, and lawns in the residential, commercial, and light industrial land uses. The sheetflow samplers were simple in design and were positioned to isolate the runoff from each type of source area. Runoff was delivered to the sample bottles by gravity and the bottles for most of the source areas were installed below the surface of the ground. An effort was made in all the projects to use sample collection methods and equipment that prevented the sample bottles from over-filling before the end of the runoff event. To a large extent, the source area concentrations represented a composite of the runoff occurring during the entire sampled events. Automated flow meters and water samplers were installed at the storm sewer outfalls for each study area for outfall verification. The sheetflow samples were analyzed for total suspended solids, total solids, total phosphorus, dissolved phosphorus, dissolved and total recoverable zinc, copper, cadmium, chromium, and lead, hardness, and fecal coliform bacteria. Between 7 and 10 runoff samples were collected from each site, except for the lawns and commercial parking areas where fewer samples were collected.

Milwaukee and Madison, WI, runoff samples were further collected during 1993 (Roa-Espinosa and Bannerman 1994) to evaluate different methods for collecting source area runoff samples at industrial sites. As part of this evaluation, a total of 50 sampling locations at roofs, paved areas, and lawns were sampled at five industrial facilities. The sheetflow samplers were simple in design and they were located to isolate the runoff from each type of source area. Runoff was delivered to the sample bottles by gravity and the bottles for most of the source areas were installed below the surface of the ground. The samples were analyzed for chemical oxygen demand, suspended solids, total solids, total recoverable zinc, lead, nickel, and copper, and hardness. Depending on the location, samples were collected during 5 to 7 runoff events.

Marquette, MI, runoff samples were collected during 1993 and 1994 (Steuer, *et al.* 1997) to characterize contaminant concentrations for eight sources in one study area. The study area (297 acres) contained a mixture of land uses including residential, open space, commercial and institutional. A total of 33 sheetflow sampling sites were located at streets, parking lots, driveways, rooftops, and grass areas. Samples were analyzed for total solids, suspended solids, ammonia N, nitrate plus nitrite, total Kjeldahl nitrogen, total phosphorus, dissolved phosphorus, hardness, total recoverable and dissolved zinc, lead, cadmium, and copper, fecal coliform, BOD_5, COD, and PAHs. Sheetflow samples were collected for 12 runoff events at each site. Flow and water quality were measured at the storm sewer outfall for the study area.

Madison, WI, runoff samples were collected during 1994 and 1995 (Waschbusch, *et al.* 1999) to estimate the sources of phosphorus in two residential areas for further detailed calibration of WinSLAMM. All the source areas were in two drainage areas. One was 232 acres, with mostly residential and some commercial land uses, while the other was 41 residential acres. Sheetflow samples were collected from roofs, streets, driveways, parking lots, and lawns in residential and commercial land uses. Twenty five storms were sampled in both basins. The sheetflow samples were analyzed for total suspended solids, total solids, dissolved phosphorus, and total phosphorus. Flow and water quality were measured at the storm sewer outfalls for both study areas.

Madison, WI, runoff samples were collected during 1994 and 1995 (Waschbusch, et al. XXX) to evaluate the effects of various environmental factors on the yields of pollutants washed off city streets. The environmental factors included average daily traffic count, antecedent dry time, rainfall intensity, rainfall depth, season, and tree canopy. Street pollutant concentrations were also used to calibrate WinSLAMM. Sheetflow samples were collected from five streets with different daily traffic counts. The street samplers were grouted into the street approximately 5 ft (1.5m) from the curb. The sample bottles were covered with a 6 inch (150mm) concave polycarbonate cap, set flush with the street surface. A drain hole in the cap could be constricted to control the flow into the bottle. At total of 11 or 12 runoff samples were collected at each site. Samples were analyzed for suspended solids, PAHs, hardness, and total and dissolved cadmium, lead, copper, zinc, and phosphorus.

Superior, WI, runoff samples were collected during 1995 and 1996 (Holstrom, *et al*. 1995 and 1996) to measure flow rates and water quality for runoff from an undeveloped site. The drainage area of the wooded lot is 76.2 acres. Flow was measured with a Parshall flume and runoff samples were collected with a volume activated water quality sampler. Sixteen storm-composite samples were analyzed for suspended solids, total solids, and total phosphorus. Samples were less frequently analyzed for COD, BOD_5, sulfate, chloride, nitrogen compounds, and total copper, lead, and zinc.

Madison, WI, runoff samples were collected during 1996 and 1997 (Waschbusch, *et al.* 1999) to verify the pollutant removal efficiency of a stormwater treatment device (Stormceptor). The device was located to treat the runoff from a 4.3 acre (1.7ha) city maintenance yard. Inlet and outlet runoff samples were collected for 45 runoff events. Samples were analyzed for total solids, suspended solids, total and dissolved phosphorus, nitrate plus nitrite, ammonia N, chloride, hardness, alkalinity, organic carbon, particle sizes, PAHs, and total and dissolved copper, cadmium, lead, and zinc. Automated sampling equipment was used to measure flow and collect flow–weighted composite samples. The inlet pollutant concentrations were used to calibrate WinSLAMM for industrial paved storage and parking areas.

Milwaukee, WI, runoff samples were collected during 1996 (Corsi, *et al.* 1999) to measure the pollutant removal efficiency of a stormwater treatment device (the MCTT, Multi-Chamber Treatment Train). The device was located to treat the runoff from 0.10 acres of paved equipment storage area at a city maintenance facility. Inlet and outlet samples were collected for 15 runoff events. Flow meters and automatic water samplers were used to measure flow rates and collect flow-weighted composite water samples in the inlet and outlet pipes. Samples were analyzed for total solids, suspended solids, alkalinity, BOD_5, COD, volatile particulate solids, ammonia as N, nitrate plus nitrite as N, chloride, sulfate, hardness, PAHs, TOC, total and dissolved phosphorus, total and dissolved zinc, cadmium, lead, chromium, and copper. The inlet pollutant concentrations were used to calibrate WinSLAMM for paved industrial storage and parking areas.

Results from the eight Wisconsin studies were combined to create an average concentration and COV for each source area and land use. Almost all of the average concentration values represent the results from more than one study. Because the constituent list was different for each study, the sample count varies considerably between the types of source areas. Sample counts are high for suspended solids and phosphorus, since they were analyzed during all the studies. Only one project (Marquette, MI) analyzed COD and PAHs for all the source areas, so these constituents have a low sample count. Censored values (samples having less than the detection limit) are included as one-half the detection limit for some of the constituents having low sample counts.

Although loads from a source area are greatly influenced by the volume of runoff, the large differences in some of the source area concentrations can decrease the importance of volume when comparing the loads from different source areas. For example, the volume of runoff from lawns is expected to be relatively low, but concentrations of phosphorus in lawn runoff are 2 to 10 times higher than for other source areas. Because of these relatively high concentrations, lawns can contribute as much as 50% of the annual total phosphorus load in a residential area (Washbusch, *et al.* 1999). With PAH levels from commercial parking lots 10 to 100 times higher than from any other source area, commercial parking lots, representing only 3% of an urban drainage area, can contribute 60% of the annual PAH load (Steuer, *et al*. 1997.

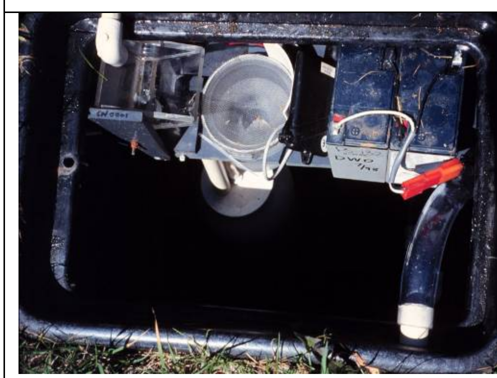
Size and Number of Outfall Samples Obtained at Seven WI DNR Study Locations

SITE	LAND USE	ACRES	# EVENTS
Harper	Residential	41	55
Monroe	Residential	232	75
Canterbury	Residential	964	55

Marquette	Resid/Com.	288	64
Superior	Commercial	22	91
Syene Rd.	Industrial	114	108
Badger Rd.	Maint. Yard	4	40


Street sheetflow sampler installation


Roof runoff sampler


Sheetflow sampler and flow meter


Sheetflow sampling installation in lawn

Source area sampling in Wisconsin (WI DNR and USGS)

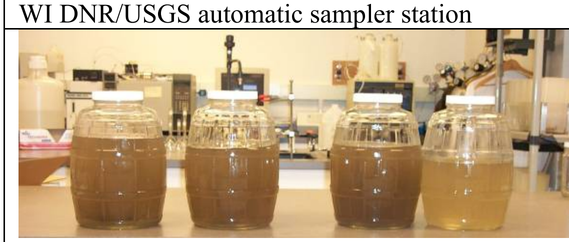
Number of Source Area Samples Obtained

Source Area	Total Suspended Solids	Particulate & Dissolved Phosphorus	Particulate & Dissolved Zinc
Res. Roof	81	76	29
Com. Roof	34	29	13
Ind. Roof	42	9	41
Com. Parking Lot	44	36	65

Ind. Parking Lot	75	21	65
Driveway	69	66	19
Lawns	40	39	48

WI DNR/USGS automatic sampler station


Area-velocity sensor


Large volume composite samples


Water sample intake

Bed load sampler installation

Three bed load samplers in a row

Use of MS4 Data Contained in the National Stormwater Quality Database (NSQD) to Calibrate WinSLAMM

WinSLAMM Data Files

Bochis (2007) used data from the NSQD (National Stormwater Quality Database) MS4 (municipal separate storm sewer system) database (Maestre and Pitt 2005) for Jefferson County, Alabama to re-validate WinSLAMM for local conditions. The model was originally calibrated in the mid-1990s using locally obtained sheetflow data (Pitt, *et al.* 2005).

In order to construct WinSLAMM files, several types of information about the site is needed, such as descriptions of the drainage system (grass swales, curb and gutter in good/fair/poor condition, undeveloped roadside) and the fraction of each type of drainage system serving the study area; the soil type (sandy, silty, clayey); site development characteristics (such as the roof type, street texture, etc.); and measurements of the different source areas. Except for the soil type, all of the other information was obtained for the monitored areas during field surveys, or using measurements from aerial photographs.

The site's general soil types were obtained from the field maps showing the exact site locations were used in conjunction with Alabama topographic maps (scale 1:24000, published by US Geological Survey in 1988) and the *Soil Survey of Jefferson County*, Alabama, maps (scale 1:24000, published by US Department of Agriculture Soil Conservation Service in 1975) to identify the site locations on the county soil maps.

The information necessary to perform a WinSLAMM model run is stored in a WinSLAMM data file and its associated parameter files. This information includes a description of land uses and source areas, the time period and corresponding rainfall events, the pollutant control devices applied to the site, and the pollutants to be analyzed.

Several parameter files are needed when conducting a WinSLAMM analysis. The most important file used with the model is the rain file (*.RAN) which describes the rain series during the study period. To better evaluate the conditions in the five different Jefferson County drainage areas, a separate rain file was created for each area based on the nearest rain gage data. Each file described the rains that occurred during the field sampling, including several rains before and after the sampling period started and ended. Separate rain files were used for each watershed in order to best represent the actual rains that occurred at each site, as there was substantial variability in the rain characteristics (depth and duration) over the entire area. The rain files contain the start and end dates and times for each rain, and the total rain depth for the rain. A six hour dry period separated each rain event. The model calculated the antecedent rain period before each event, and the average rain intensity.

For the Little Shades Creek watershed analyses, the typical Birmingham area rain file (BHAM76.RAN) was used. This file includes the rains for the entire 1976 year which has been previously determined to be a representative rain year for the area, based on comparisons with long term (about 45 year) rain records. Birmingham's rains are reasonably well distributed throughout the year. However, some of the wetter winter months, plus March and July, have twice the rainfall of October, the driest month. Summer rainfall is almost entirely from scattered afternoon and early evening thunderstorms. Serious droughts are rare and most dry spells are not severe.

There are mandatory and optional parameter files required to run WinSLAMM. The runoff file (*.RSV), a required file, contains volumetric runoff coefficients for each surface type that generates surface runoff for the rains. For this study, the RUNOFF.RSV file supplied with the model was used for all runs. The file was developed based on extensive monitoring data collected in Toronto and Milwaukee (as reported by Pitt 1987). It has been verified using additional independent data representing a wide range of land development and rain conditions. The current NSQD MS4 database for Jefferson County Alabama does not include runoff data, so it was not possible to re-verify this file for local conditions.

Four additional files were previously created based on Birmingham area regional research and include:

1. The particulate solids concentration file (BHAM.PSC) that describes the particulate residue (particulate solids) concentrations for each source area (except for roads) and land use, for several rain categories;

2. The particulate residue reduction file (DELIVERY.PRR) that accounts for the deposition of particulate pollutants in the storm drainage system, before the outfall, or before outfall controls (the delivery file is calibrated for swales, curb and gutters, undeveloped roadsides, or combinations of drainage conditions);

3. The pollutant file (BHAM.PPD) is needed when examining pollutants besides particulate solids, and is used to describe the particulate pollutant strengths related to particulate residue (in units such as mg pollutant / kg particulate solids) and the filterable pollutant concentrations (in units such as mg/L) for each source area for each land use (this file also contains the coefficient of variation (COV) values for each pollutant for Monte Carlo simulations in WinSLAMM in order to account for the random nature of stormwater pollutants); and

4. The street delivery file (STREET.STD) is used to define the limits of the street dirt washoff routines in the model based on rain characteristics (energy limitations).

These four files (*.PSC, *.PRR, *.PPD, *.STD) were re-validated using the NSQD MS4 monitoring information for Jefferson County prior to their use in examining the Little Shades Creek data. The Jefferson County MS4 data were not affected by any stormwater source area or outfall control measures.

Rain File Construction

The first step in the construction of the rain files was the collection of hourly rainfall data for the Birmingham, AL, area for the same rains that were monitored for the stormwater permit data. The local rain data for the Birmingham Municipal Airport Weather Observation Station was obtained through its internet site maintained by NCDC (National Climatic Data Center).
http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwDI~StnSrch~StnID~20000236.
The hourly precipitation data (measured in hundredths of inches, stored and observed to the same accuracy) from January 01, 2001 to April 11, 2005 were downloaded as a text file (.TXT) and used to create the MASTER.RAN file, covering the same time period as the local MS4 data collection.

This rain file, which served as the basic rain file for all of the individual rain files for each of the five monitoring locations, had some missing data. Periods of missing data were added manually and labeled “no record” for the start/end date and time of the rain and rain depth. The “no record” rain depth values were replaced using estimated values obtained by averaging the values from four Birmingham Water Works (BWW) Rainfall Stations (Lake Purdy, Putnam, Shades and Western) for that particular day. Carson and Inland Lake stations (also part of the BWW network) were not used due to their remote location from the study watersheds. The BHAMSRCE.RAN rain file, supplied with WinSLAMM, was used as a reference to estimate the durations of the rain events. BHAMSRCE.RAN was created using long-term rainfall records. It includes 12 rain events from 0.01 to 4 inches and corresponding typical rain durations. A rain file was created for each MS4 station using this master rain file. The rain files include the start/end date and time of the rain event, along with the total rain depth. The final individual rain files start and end approximately 1 month before and after the monitoring dates.

WinSLAMM Re-Calibration Process

The verification and calibration procedures for WinSLAMM are the same as for any other stormwater quality model: local data needs to be collected to check the accuracy of the calculated results produced by the model. The data that is needed include outfall quality and quantity measurements and watershed information.

A good approach to calibrate a model is to collect all the necessary information from one watershed and to use that data to adjust the necessary parameters to obtain the best agreement between the calculated and observed conditions. Verification then uses independent data from another watershed to compare the calculated and observed conditions. Another common method used to calibrate and verify a model is to collect information for a series of events and use that data for adjusting the model parameters to obtain the best fit. Verification is accomplished using additional data from the same watershed that was not used for the calibration. During this re-calibration and re-verification of WinSLAMM, we used the first approach due to the fact that we had monitoring data from five independent drainage areas.

The process of calibrating WinSLAMM for this project used the following order:

- Runoff quantity (*.rsv file)
- Particulate solids loading (*psc and delivery files)
- Total pollutant loading (*.ppd file)

The runoff quantity file has to be calibrated before any of the additional parameter files are examined. After this file is calibrated, the particulate solids files must be calibrated, followed by the other pollutants. It is very important to be completely satisfied with the calibration at each step before proceeding to the next one. As already mentioned, the NSQD MS4 Jefferson County monitoring information does not include runoff data, so the RUNOFF.RSV could not be re-validated, therefore the re-calibration process started with particulate solids and delivery files.

Data from five drainage areas are available for the re-calibration and verification process. Therefore, the calibration process started with data from the simplest and most uniform drainage area (one that has only a single land use); these areas were calibrated first before moving on to more complex areas, such as areas having a mixture of land uses and areas having both connected and disconnected roofs.

One single data file (*.dat) that stores the information necessary to perform a WinSLAMM model run was created for each drainage area based on the field data and the surface areas measured from the aerial photographs. Each data file was modeled twice, once using the rain file for the specific monitoring event, and again using the BHAMSRCE rain file. The model output included the percentage contribution of runoff volume and pollutants of interest for each rain and for each source area, indicating the main source areas that generate runoff for the different rain depths. The use of BHAMSRCE rain file (containing only 12 sorted rains) was important because it revealed the rain depth at which each source area generated runoff and pollutants, and helped focus on certain areas that needed to have their parameters modified. The monitored rain events covered a smaller range of rain depths.

Re-validation of particulate solids concentration (*.PSC) file

WinSLAMM uses the mandatory PARTICULATE.PSC file to describe particulate solids concentrations for each source area (except for streets) and all land uses (except freeway), for several rain categories. The model also uses the DELIVERY.PRR file to adjust the source predictions for outfall conditions because the larger particulates will accumulate in the storm drainage system during the smaller rains. This file is used for swales, curb and gutters, undeveloped roadsides, or combinations of drainage components.

The washoff of particulates from streets is directly calculated using explicit accumulation and washoff algorithms based on land use, street texture, and rain conditions. Freeway paved lane and shoulder areas are also directly predicted and have explicit algorithms that calculates the washoff of particulate solids based on traffic volumes and rain conditions. The street and highway predictions for particulate solids are modified by the STREET.STD file to account for reduced rainfall energy during the smaller rains. Concentrations of particulate solids at the beginning of the rains at some source area (especially paved parking areas) are much greater than later in the same rain ("first flush" conditions). This variation is highly dependent on rain energy and WinSLAMM uses a similar relationship to describe particulate solids variations for different rain depths.

The re-calibration process was started by running the WinSLAMM files for the monitored drainage areas using their own rain file, and the delivery, street and particulate files without any additional pollutants selected. The predicted and observed particulate solids concentrations for the monitored events were compared by creating a double probability plot of observed and predicted values (Figure A1). The data is plotted using a log- normal distribution. The data and model values should form approximately a straight line. Departures from this straight line indicate departures from the specified normal distribution. The desired pattern for the observed and modeled particulate solids concentration plots is to have two overlapping lines of points with minimal deviation. The desired pattern for the residual error plot is an even, narrow band over the range of observed rain depths, centered on the zero residual error horizontal line (Figure A2). Also, the sum of the observed and predicted particulate solids concentration (mg/L) for all monitored events has to be calculated. The percentage difference in the sum of concentrations should be small, indicating small changes needed. It is likely that the largest difference in the particulate solids concentrations are associated with small rain depths (WinSLAMM will probably over-estimates the concentrations, unless the delivery files are correctly used), while the differences for the larger rains will be smaller. WinSLAMM calibration for particulate solids concentrations and loadings was accomplished by modifying the DELIVERY.PRR, STREET.STD and BHAM.PSC files.

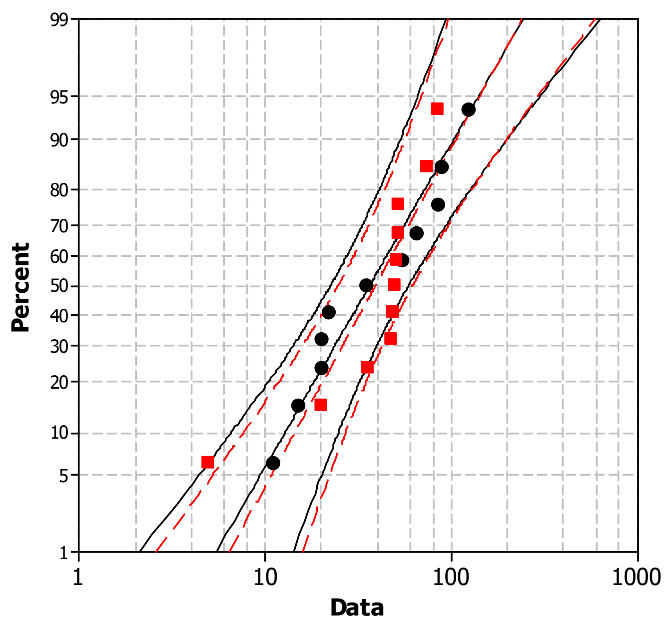


Fig. A1. Example of Log-Normal Probability Plot for Site ALJC010 Particulate Solids (Residential Land Use) (red squares are modeled values and black dots are observed values).

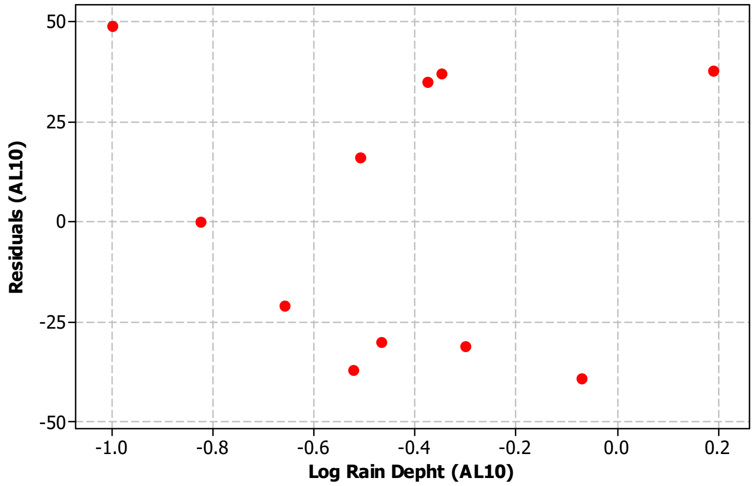


Fig. A2. Example of Residual Plot for Site ALJC010 (Residential Land Use)

The *.PRR file adjusts the delivery of the particulate solids for the whole watershed (based on the drainage system type) and usually has a greater effect on small rains, with minimum effects on large rains. The DELIVERY.PRR file data was smoothened by modifying almost all of the delivery fractions by the same amount (Figure A3). Grass swales, undeveloped roadsides, and flat curbs and gutters have slow runoff velocities and lower carrying capacities of sediment than flows in steeper areas or smoother gutters.

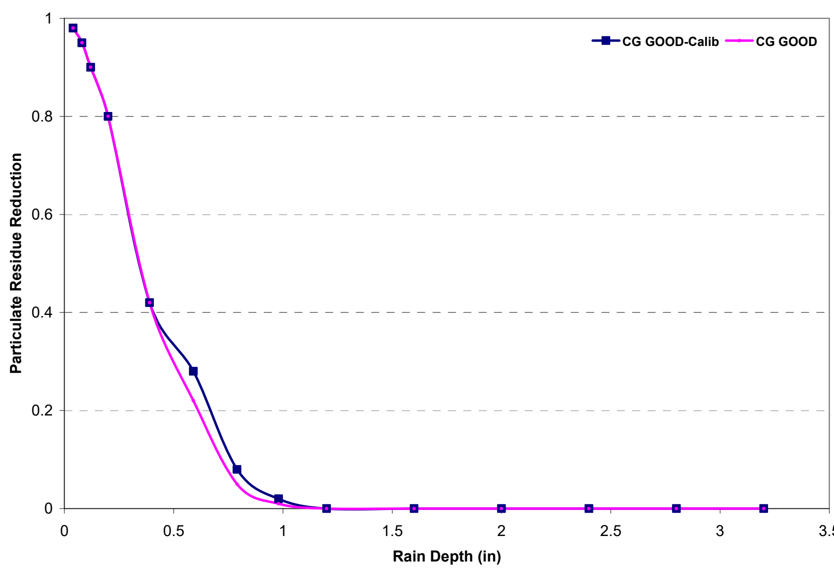


Fig. A3. Example of Smoothed Delivery File, *.PRR (for Curbs and Gutters in Good Conditions or Very Steep Drainage System)

The street delivery file (*.STD) only affects solids originating from the street areas, and was the next file to be calibrated. Separate street delivery files were created for each land use (Figure A4).

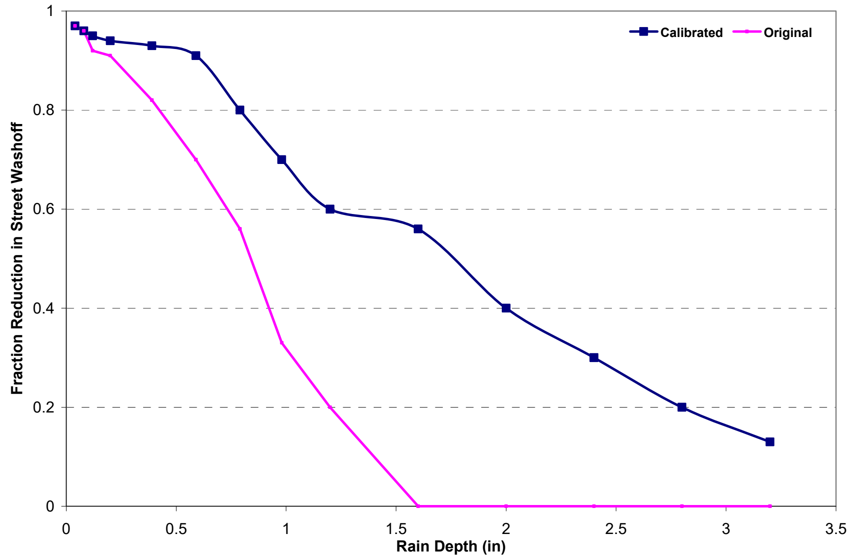


Fig. A4. Example of Street Delivery File. *.STD (for Residential Land Uses)

The *.PSC file describes the particulate solids concentrations (mg/L) for each rain for each source area, showing where WinSLAMM is generating the particulate solids for different rain depths. The calibration process for the *.PSC file began by first focusing on the larger storms, trying to bring the medians of the observed and calculated values close together. For some land uses, we ended up changing the PSC values more for the larger storms than for the smaller storms (Figure A5 and A6).

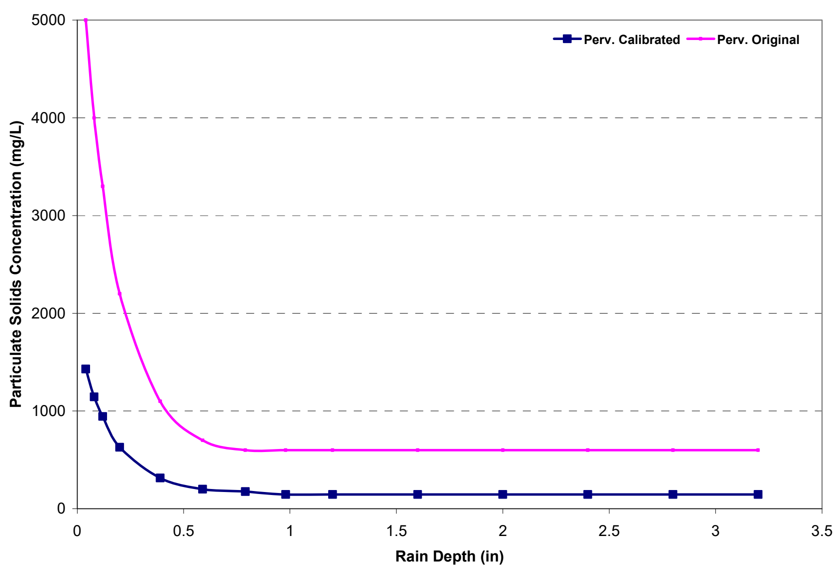


Fig. A5. Example of Particulate Solids Concentration File for Residential Land Use - Pervious Surfaces, *.PSC

After each change was made, the program was re-run using the new parameter file and the results were reviewed. It was necessary to repeat this process a few times to become satisfied that no further improvements were possible.

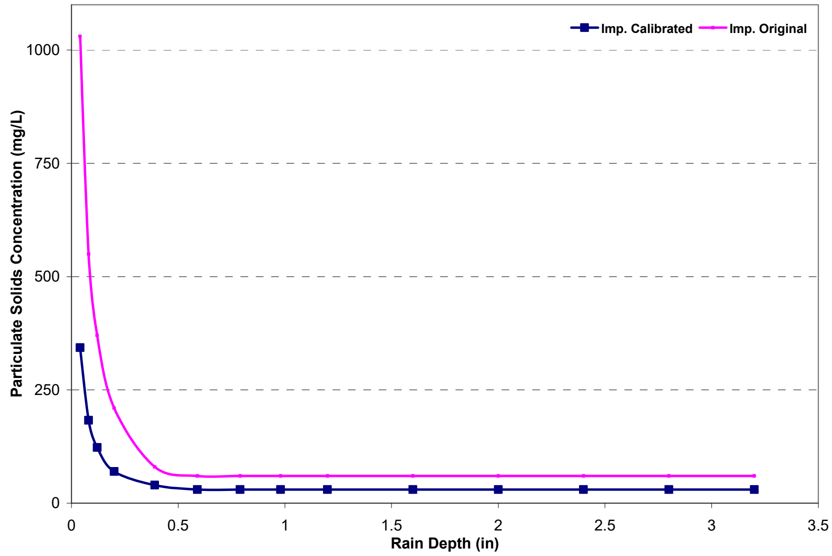


Fig. A6. Example of Particulate Solids Concentration File for Residential Land Use - Impervious Surfaces

Re-validation of pollutants concentration (*.PPD) file
The pollutant file BHAM.PPD describes the particulate pollutant strengths associated with the particulate solids (mg pollutant/kg particulate solids) and the filterable pollutant concentrations (mg/L) for each land use for each source area. This file is not needed if the watershed analysis includes only runoff volume and particulate solids calculations. This file also contains the COV values for each pollutant for Monte Carlo simulations in WinSLAMM, an option which is turned off by the default (seed of -42).

For this study, only phosphorus, COD, copper, and zinc from the pollutants list were calibrated. The procedure for calibrating the total pollutants followed the same pattern as for calibrating the *.PSC file, with one exception: the total pollutant value is the sum of the particulate and filterable pollutant values. Therefore, the calibration was performed for particulate and filterable pollutants by increasing and decreasing the values by the same amount for one particular pollutant (Figure A7 and A8).

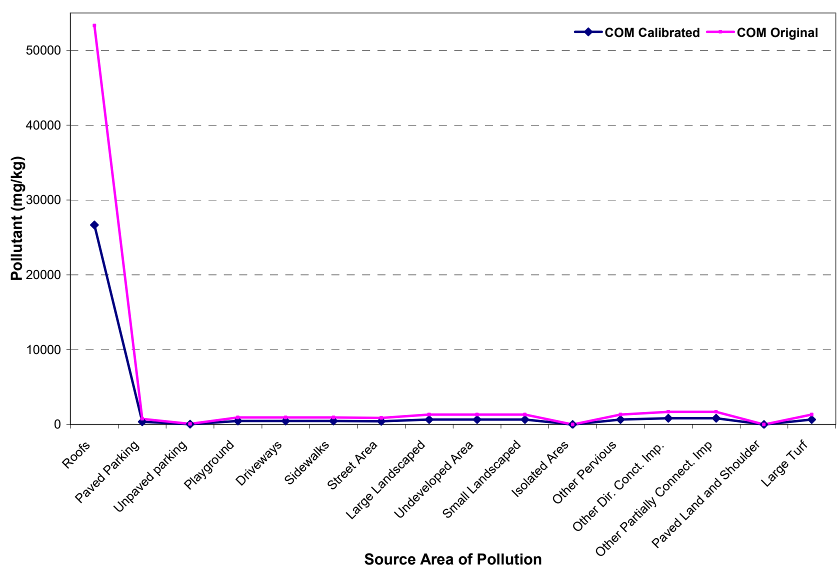


Fig. A7. Example of Particulate Zinc for Commercial Land Use, *.PPD

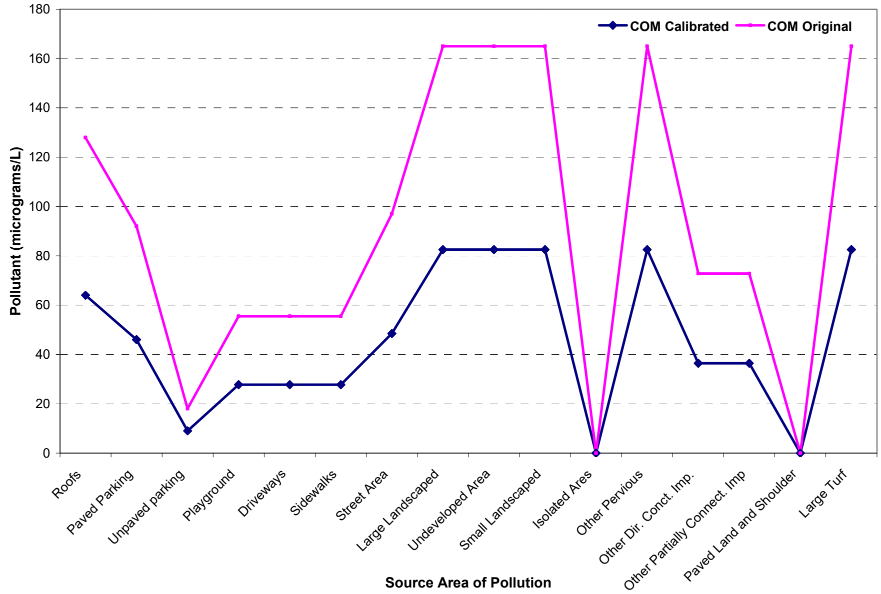


Fig. A8. Example of Filterable Zinc Concentration for Commercial Land Use, *.PPD

Once again, after each change was made to the pollutant file, the program was re-run using the new *.PPD parameter file and the already calibrated particulate solids concentrations files. The results were reviewed and the process was repeated multiple times until satisfied that no further improvements were possible.

Recommended Strategy for Local Use of WinSLAMM

The recommended strategy for using WinSLAMM is to start with the supplied parameter file set and rain files. The most important element will be to prepare an accurate site file based on a correct site description. It is also easy to prepare a site specific rain file using local data, or download data from NOAA CD ROMS (such as those supplied from EarthInfo, Golden, CO). Collection of local or regional outfall monitoring data is also strongly recommended in order to modify the parameter files, as needed. Detailed site files will be needed for each site where data are available. The NSQD (available at: http://unix.eng.ua.edu/~rpitt/Research/ms4/mainms4.shtml) can also be used to locate regional data that may be suitable data for calibration. Again, detailed site investigations to be able to obtain an accurate file of all locations will be needed. This discussion presented an outline, with examples, of how the parameter files can be modified using regional data. Without regional calibration, one will have to accept larger calculation errors than if local calibration was conducted. Even so, the model will still be useful for comparative purposes, especially if accurate rain and site files are used. In most cases, the runoff file needs very little change in order to accurately predict runoff volumes, for example.

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