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Calibration Processes for WinSLAMM

Contents

Introduction

This white paper describes the process for calibrating WinSLAMM, including several examples. Most calibration processes rely on outfall stormwater monitoring data, but the addition of source area sheetflow data increases calibration reliability by helping to better balance sources of the flows and pollutants. Runoff volume and total pollutant mass discharges usually have the best calibration results, with pollutant concentration calibrations being more challenging. The modeled concentrations usually have a narrower overall range of values compared to the observed values. This can be mitigated by using the Monte Carlo option in WinSLAMM that randomly selects concentrations from a probability distribution, varying for each event in the rain series, instead of using a single value for all rains, for each separate source area.

Two appendices are included that illustrate field surveys that can be conducted in the monitored study areas that document development characteristics that affect stormwater quality and used in the modeling process. The first appendix is suitable for neighborhood surveys in typical urban areas, while the second appendix is for industrial or other areas having significant exposures of materials affecting stormwater quality.

Calibration success is usually measured by using several metrics. For a model such as WinSLAMM that relies mostly on laboratory and field measurements and with minimal theoretical processes, it is common that some conditions and situations may not meet all of the calibration goals defined by these metrics. There is much discussion in the literature on the role of models and the consequences of calibration "failure." Wikipedia summarizes some of these issues in the following quote (https://en.wikipedia.org/wiki/All_models_are_wrong#History):

> "The phrase "all models are wrong" was attributed[1] to George Box who used the phrase in a 1976 paper to refer to the limitations of models, arguing that while no model is ever completely accurate, simpler models can still provide valuable insights if applied judiciously.[2] In their 1983 book on generalized linear models, Peter McCullagh and John Nelder stated that while modeling in science is a creative process, some models are better than others, even though none can claim eternal truth.[3 4] In 1996, an Applied Statistician's Creed was proposed by M.R. Nester, which incorporated the aphorism as a central tenet.[1]
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> Although the aphorism is most commonly associated with George Box, the underlying idea has been historically expressed by various thinkers in the past. Alfred Korzybski noted in 1933, "A map is not the territory it represents, but, if correct, it has a similar structure to the territory, which accounts for its usefulness."[5] In 1939, Walter Shewhart discussed the impossibility of constructing a model that fully characterizes a state of statistical control, noting that no model can exactly represent any specific characteristic of such a state.[6] John von Neumann, in 1947, remarked that "truth is much too complicated to allow anything but approximations."[2]"
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> 1. Nester, M. R. (1996), "An applied statistician's creed", Journal of the Royal Statistical Society, Series C, 45 (4): 401–410, doi:10.2307/2986064, JSTOR 2986064.
> 2. Box, George E. P. (1976), "Science and statistics" (PDF), Journal of the American Statistical Association, 71 (356): 791–799, doi:10.1080/01621459.1976.10480949.
> 3. McCullagh, P.; Nelder, J. A. (1983), Generalized Linear Models, Chapman & Hall, §1.1.4.
> 4. McCullagh, P.; Nelder, J. A. (1989), Generalized Linear Models (second ed.), Chapman & Hall, §1.1.4.

5. Korzybski, Alfred (1933). Science and Sanity: An Introduction to Non-Aristotelian Systems and General Semantics (1st ed.). Lancaster, PA: International Non-Aristotelian Library Publishing Company / Science Press Printing Company.
6. The relatedness of Shewhart's quotation with the aphorism "all models are wrong" is noted by Fricker & Woodall (2016).

Murray (2007) also reports that

> "Science consists of models of various sorts, but that virtually all of them are wrong, yet many of those incorrect models are quite useful. Modern physics has shown the existence of solid matter and the conservation of mass to be constructs that are not universally valid. However, these constructs correspond well to aspects of the relatively large and slow world of geomorphology, where quantum and relativistic effects can be neglected. In science generally, we should not ask whether a model is correct, but whether it helps us understand or predict the behavior of the world around us."
>
> "Numerical models can be useful for explaining poorly understood phenomena or for reliable quantitative predictions. When modeling a multi-scale system, a 'top-down' approach—basing models on emergent variables and interactions, rather than explicitly on the much faster and smaller scale processes that give rise to them—facilitates both goals. Parameterizations representing emergent interactions range from highly simplified and abstracted to more quantitatively accurate. Empirically based large-scale parameterizations lead more reliably to accurate large-scale behavior than do parameterizations of much smaller scale processes. Conversely, purposefully simplified representations of model interactions can enhance a model's utility for explanation, clarifying the key feedbacks leading to an enigmatic behavior. For such potential insights to be relevant, the interactions in the model need to correspond to those in the 'real' system in some straightforward way. Such a correspondence usually holds for models constructed for predictive purposes, although this is not a requirement. The goals motivating a modeling endeavor help determine the most appropriate modeling strategies, as well as the most appropriate criteria for judging model usefulness."

When developing WinSLAMM, the goal was to be as "accurate" as possible, but to only incorporate processes that have been measured and quantified during actual field monitoring, with little reliance on theoretical processes that could not be observed. Pitt (1987) found that over-specified models were cumbersome and expensive to calibrate, and may not result in improved predictions. In contrast, very simple models, with few input parameters, may be successfully calibrated for a specific test area, but usually are problematic when used for examining other situations or sites. WinSLAMM was developed to be sufficiently flexible for many purposes, but without the burdens of vague or not observed processes.

As an example, early concerns related to the lack of pavement and landscaping slope effects in the early versions of the model. Special monitoring was therefore conducted to investigate these effects. Landscaped area slopes were observed and incorporated in the grass filter strips and swale calculations. Slope was also found to be important for roof runoff quantification during field measurements. However, pavement slope has a relatively small range in developed areas, and monitoring on steep vs. flat street slopes did not result in significant differences, especially for rougher pavement. In another example, most hydrology models focus on soil moisture affecting infiltration, while our research investigating disturbed urban soils found that soil compaction was just as important, if not more so. Tree cover and interception effects have also been proposed with much greater runoff reduction benefits than observed during field monitoring. Extensive field measurements of interception benefits from different types of urban trees have allowed reasonable calculations of their runoff reduction benefits in urban areas, without relying on the extensive literature of forested areas. Other field studies of evapotranspiration in biofilters and beneficial uses of stormwater were conducted to quantify those benefits, also incorporating literature information. Early field studies of particulate transport identified the significant role of particle size (and later the variation of pollutant strengths associated with the different particle sizes) in stormwater characterization and treatment. It is easy to become overwhelmed by the large number of possible processes affecting urban stormwater quantity and quality. WinSLAMM was developed to focus on those of most importance and that can actually be observed in the field during actual rains. These and many other examples of the processes incorporated in WinSLAMM are described in the papers and research reports available at the WinSLAMM website.

The following sections of this white paper outline, with examples, the calibration processes that have been used for WinSLAMM for a wide range of conditions.

Model Performance Indicators

There are a number of ways to measure the success of model calibration. The HEC-HMS Technical Reference Manual (https://www.hec.usace.army.mil/confluence/hmsdocs/hmstrm/calibration/calibration-summary-statistics) includes a description of model performance evaluations for evaluating streamflow, having continuous flow data at daily and monthly time steps at a watershed scale. It states that acceptable values of the summary statistics will vary depending on the time step, the uncertainty in the observed data, the boundary conditions, and the project scope. The following is a summary from this manual, based on Moriasi, et al. (2007).

PBIAS is the percent bias between the simulated and observed values and is calculated by:

$$PBIAS = \left[\frac{\sum_i^n (Y_i^{sim} - Y_i^{obs}) * (100)}{\sum_i^n (Y_i^{obs})} \right]$$

PBIAS is a measure of the simulated values being on average larger or smaller than the corresponding observed values. Negative PBIAS implies that the model under-estimates observed data, while positive PBIAS means the model over-estimates observed data. HEC-HMS states that their sign notation is opposite of what Moriasi, at al. 2007 used.

NSE is the Nash-Sutcliffe Efficiency factor:

$$NSE = 1 - \left[\frac{\sum_{i=1}^n (Y_i^{obs} - Y_i^{sim})^2}{\sum_{i=1}^n (Y_i^{obs} - \bar{Y}_{obs})^2} \right]$$

NSE evaluates the relative difference between the magnitude of the residual data variance ("noise") and the measured data variance ("information"). It is a measure of how well the plot of observed versus simulated data fits the 1:1 line. Negative NSE values indicate that the mean of the observed values provides a better estimate of the observed data than the model. HEC states this is widely used in hydrology and is considered a good statistic to represent the overall shape of the hydrograph.

R^2 is the coefficient of determination:

$$R^2 = \left[\frac{\sum_i^n (Y_i^{obs} - \bar{Y}_{obs})(Y_i^{sim} - \bar{Y}_{sim})}{\sqrt{\sum_i^n (Y_i^{obs} - \bar{Y}_{obs})^2} * \sqrt{\sum_i^n (Y_i^{sim} - \bar{Y}_{sim})^2}} \right]^2$$

R^2 describes the degree of collinearity between simulated and observed data. R^2 represents the proportion of the variance in measured data explained by the model. R^2 is oversensitive to outliers and insensitive to additive and proportional differences between model predictions and measured data.

HEC-HMS includes the following criteria for evaluating streamflow models, modified from Moriasi, et al. (2007):

Performance Rating	NSE	PBIAS (%)	R^2
Very Good	0.75 to 1.00	<10	>0.85
Good	0.65 to 0.75	10 to 15	0.70 to 0.85
Satisfactory	0.50 to 0.65	15 to 25	0.50 to 0.70
Unsatisfactory	<0.65	>25	<0.50

As noted previously, these are appropriate for typical HEC-RMS model uses, for relatively large undeveloped watersheds with long-term continuous monitoring data. Moriasi, et al. (2015) also provides criteria for sediment and nutrients for watershed and field scale models. The following are example PBIAS criteria for sediment, metals, and other toxicants:

PBIAS evaluations for water quality models	Very Good	Good	Satisfactory	Unsatisfactory
TSS	0 to 20%	20 to 30%	20 to 45%	>45%
Metals	0 to 15	15 to 25	25 to 35	>35
Toxicants	0 to 20	20 to 30	30 to 40	>40

It is difficult for WinSLAMM (or other urban stormwater quality model) to meet these criteria due to the great hydraulic and pollutant source complexity in small, developed areas compared to large watersheds with minimal development and variation. Because of these differences, it is suggested to also use other tools to examine the performance of urban stormwater quality models for relatively small, developed areas. This calibration white paper illustrates a number of these tools that have been used while calibrating WinSLAMM. The following list some of these:

1) Sum of loads (runoff quantity and pollutant discharges) to compare modeled with observed event discharges.
2) Grouped box plots to compare the overlapping loads and other discharge characteristics of the individual events.
3) Paired probability distributions of modeled and observed concentrations (usually log-normal, but verify the distributions) and observe the 95% confidence interval overlapping of the distributions. The Anderson-Darling statistical test also compares the fit of the distributions to

the log-normal distribution. Monte Carlo options in WinSLAMM will probably be needed to better represent the range of concentrations observed.

4) Scatterplot of observed vs. modeled loads and concentrations. Regression with ANOVA is used to test confidence of intercepts and slope terms. The ANOVA results are more robust than the R^2 value alone. Nonparametric statistical tests can be used to compare paired modeled vs. observed values. It's important to evaluate distributions of residuals between observed and modeled terms to identify types of sources or conditions needing modifications during calibration process.

Overview of WinSLAMM

WinSLAMM was developed to evaluate stormwater runoff volume and pollutant loadings in developed areas using small/intermediate storm hydrology concepts (in contrast to conventional drainage design approaches that focus on very large storms). The model determines the runoff based on local rain data and calculates runoff volumes and pollutant loadings from each individual source area within each land use category for each rain. Examples of source areas include: roofs, streets, paved storage and laydown areas, loading docks, small landscaped areas, large landscaped areas, sidewalks, and parking lots. Recent enhancements to WinSLAMM as part of industrial projects include the addition of other source areas that can be configured to describe unique areas for special land uses, such as heavy industrial areas associated with material exposures, and the ability to modify pollutant characteristics for different outfall particle sizes. Other recent additions to the model include the ability to directly use stormwater for beneficial uses, such as toilet flushing, irrigation, and firefighting use. Detailed data from laboratory and field monitoring was also recently used to expand the biofilter treatment media options in the model.

Besides determining the main sources of the stormwater contaminants of concern, the model can apply a wide range of stormwater control practices, including water tanks for stormwater irrigation, pavement and roof disconnections, roof rain gardens, infiltration/biofiltration in paved areas and as curb-cut biofilters, street cleaning, wet detention ponds, grass swales, porous pavement, catchbasins, media filters, hydrodynamic devices, selected proprietary devices, and combinations of these practices located throughout the watersheds and at the outfalls. The model evaluates the practices through engineering calculations of the unit processes based on the actual designs and sizes of the controls and determines how effectively these practices remove runoff volume and pollutants. Another important feature of WinSLAMM is the routing of hydrographs and particle size distributions through series of control practices. Treatment trains therefore are accurately evaluated at many scales in the program, from adjacent small unit processes in a single treatment device to large-scale land use based controls.

WinSLAMM does not use a percent imperviousness or a curve number to generate runoff volume or pollutant loadings. The model applies runoff coefficients to each source area within a land use category. Each source area has a different volumetric runoff coefficient equation based on factors such as: roof slope, type and condition of pavement, soil properties (including compaction), rainfall interception of trees over paved areas, etc., and calculates the runoff expected for each rain. The runoff coefficients in the example parameter files for different locations were developed using monitoring data from typical examples of each site type under a broad range of conditions. These can be modified during the calibration process using local monitoring data.

Each source area also has a unique pollutant concentration (event-mean-concentration, EMC, in addition to a probability distribution used if the Monte Carlo options are selected) assigned to it. The

EMCs for a specific source area usually vary depending on the rain depth. The source area's EMCs in the example parameter files are based on extensive monitoring conducted in North America by the USGS, Wisconsin DNR, University of Alabama, and other groups. These monitoring efforts isolated source areas (roofs, lawns, streets, etc.) for different land uses and examined long term data on the runoff quality. The pollutant concentrations are modified based on local monitoring data as part of the calibration process.

The model can use any length of rainfall record as determined by the user, from single rainfall events to several decades of rain events. More than 2,500 rain files are included with the model for all available 1-hr rain data from throughout the US until 2014 (the last year available from the on-line NOAA websites). These files need to be reviewed by the model user to identify data gaps (according to the included rain file documentation) and modeling dates selected to not include the gaps. When calibrating WinSLAMM, rain files need to be created using locally monitored rain data associated with the monitored runoff data.

For each rainfall event in a data set, WinSLAMM calculates the runoff volume and pollutant load (EMC x runoff volume) for each source area. The model then sums the loads from the source areas to generate a land use or drainage basin subtotal load. The model continues this process for the entire rain series described in the rain file. It is important to note that WinSLAMM does not apply a unit load to a land use. Each rainfall produces a unique load from a modeled area based on the specific characteristics of the source areas in the modeled area. The model routes the resulting loads from the uppermost portion of the modeled areas to the outfall, passing through control practices and with additional flows joining the drainage system. As the flows, particulates, and pollutants are transported through the system, the hydrographs and particle size distributions are modified by the control practices and the different timings of the adjoining flows.

The model replicates the physical processes occurring within each stormwater control practice. For example, for a wet detention pond, the model incorporates the following information for each rain event:

1. Runoff hydrograph, pollution load, and sediment particle size distribution from the drainage basin to the pond,
2. Pond geometry (area for each depth increment),
3. Hydraulics of the outlet structure,
4. Particle settling time and velocity within the pond based on retention time

Stokes Law and Newton's settling equations are used in conjunction with conventional surface overflow rate calculations and modified Puls storage-indication hydraulic routing methods to determine the sediment amounts and characteristics that are trapped in the pond. Again, it is important to note that the model does not apply default percent efficiency values to a control practice. Each rainfall is continuously modeled in short increments (about 6-minute time steps that can be modified). The pollutant control effectiveness will vary based on each rainfall and the pond's antecedent conditions.

The model's output can be customized and typically includes:

1. Runoff volume, pollutant loadings and EMCs for a period of record and/or for each rain event.
2. The above data before and after each stormwater management practice.

3. Removal of particulates and pollutants by particle size from stormwater management practices applying particle settling.
4. Other results can be selected related to flow-duration relationships for the study area, impervious cover model expected biological receiving water conditions, and life-cycle costs of the controls.

A full explanation of the model's capabilities, calibration, functions, and applications can be found at https://www.winslamm.net/. The following calibration discussions also include specific links to specific information sources.

Primary 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). 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 were 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 for the areas associated with the data. For other areas, these calibration conditions need to 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. Over the years, WinSLAMM has been successfully calibrated for many locations, land uses, rainfall, and other conditions.

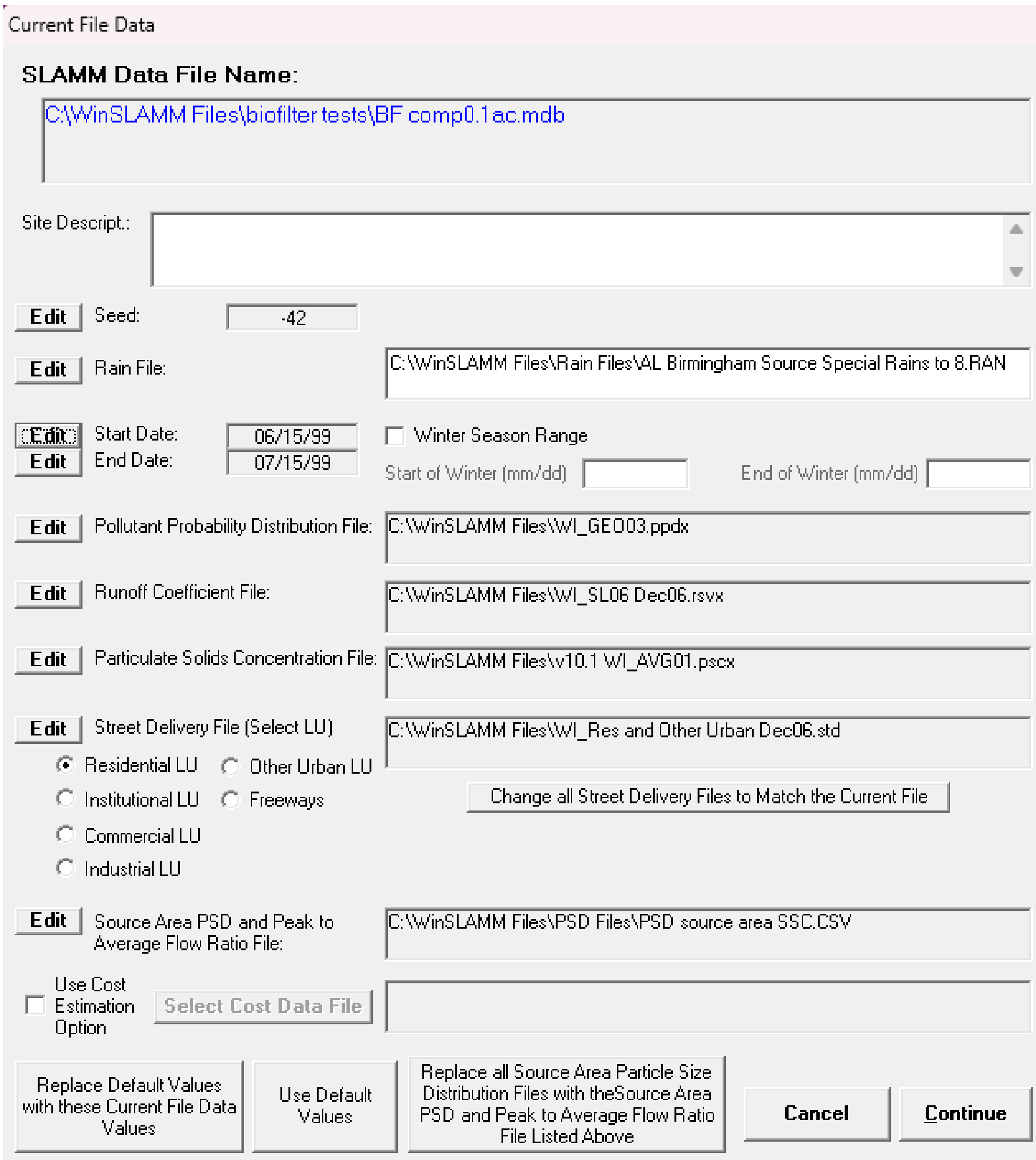
The following describes a general approach to calibrate WinSLAMM and describes some of the data sources for the parameter files used in WinSLAMM. Also described are case studies showing how the model has been calibrated using various types of data. The two appendices also include information for collecting site development characteristics used in the model. Again, the example parameter files included in the WinSLAMM model distribution package need to be calibrated using local data for specific locations and conditions.

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

1) Runoff quantity (the runoff coefficient *.RSVX parameter file)
2) Annual particulate solids loading (and event mean concentrations) (*.PSCX and *.STD parameter files)

3) Annual total pollutant loadings (and event mean concentrations) (*.PPDX parameter file)
4) Partitioning of pollutants between particulate and filtered phases (fine tuning of above file)
5) Variations in pollutant concentrations (adjusting the COV of the pollutants in the *.PPDX file)

The following is the *Current File Data* page in WinSLAMM showing example primary parameter files for a model run:



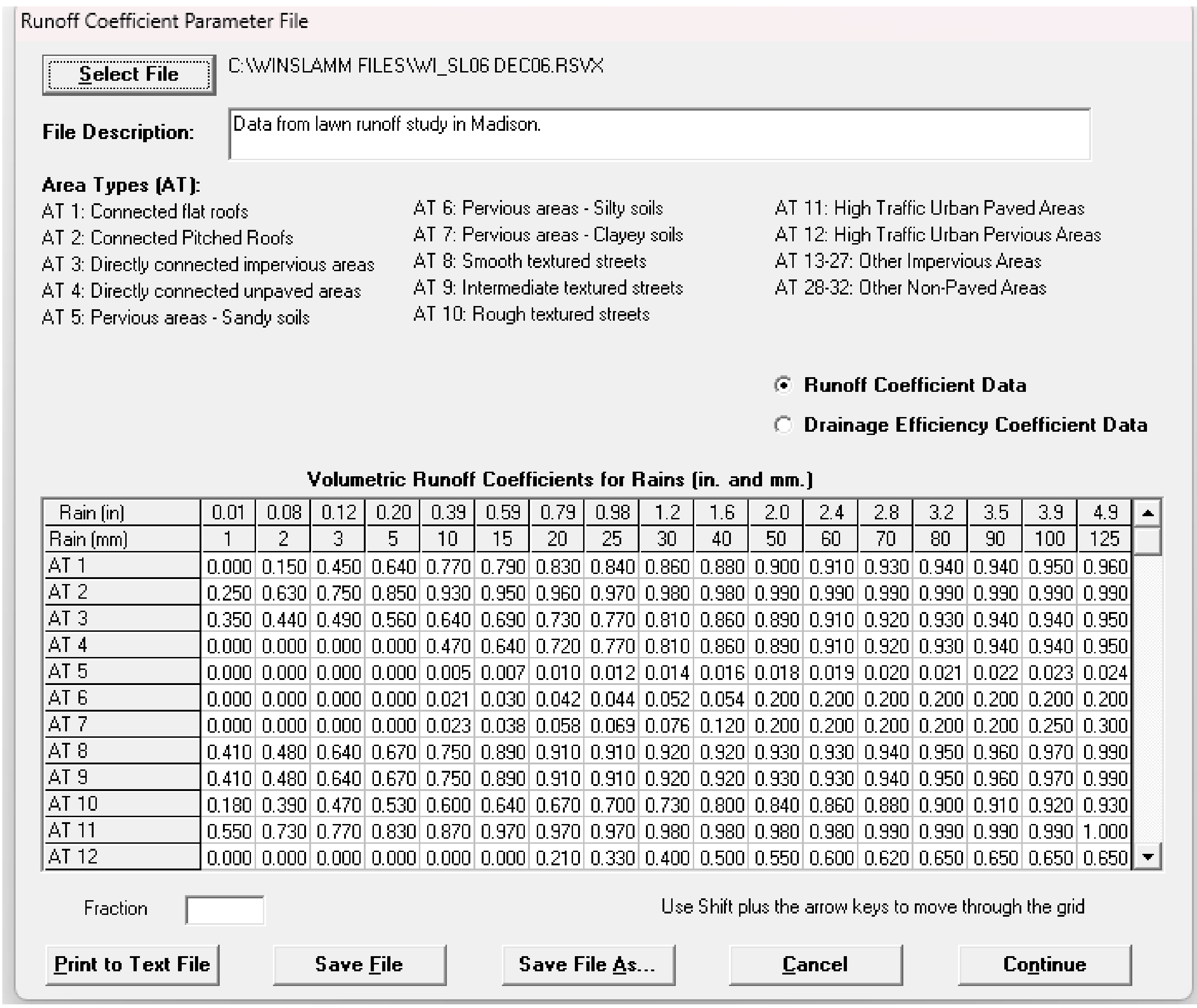
It is very important that the user start with runoff quantity and be completely satisfied with the calibration of each step before proceeding to the next step. Much wasted effort will occur if one skips around in the order of the calibration.

Runoff Quantity (Runoff Coefficients)

The *.RSVX parameter file contains volumetric runoff coefficients (the ratio of runoff quantity to rain quantity: Rv) for each surface type for various rain depths. The initial runoff coefficients were calculated based on source area impervious and pervious area runoff measurements. These initial coefficients were calibrated based on extensive Milwaukee data and then verified using additional independent Toronto data for a wide variety of land development, soil, and rain conditions (Pitt 1987). However, WinSLAMM was designed to allow the use of alternative runoff calibrations as desired.

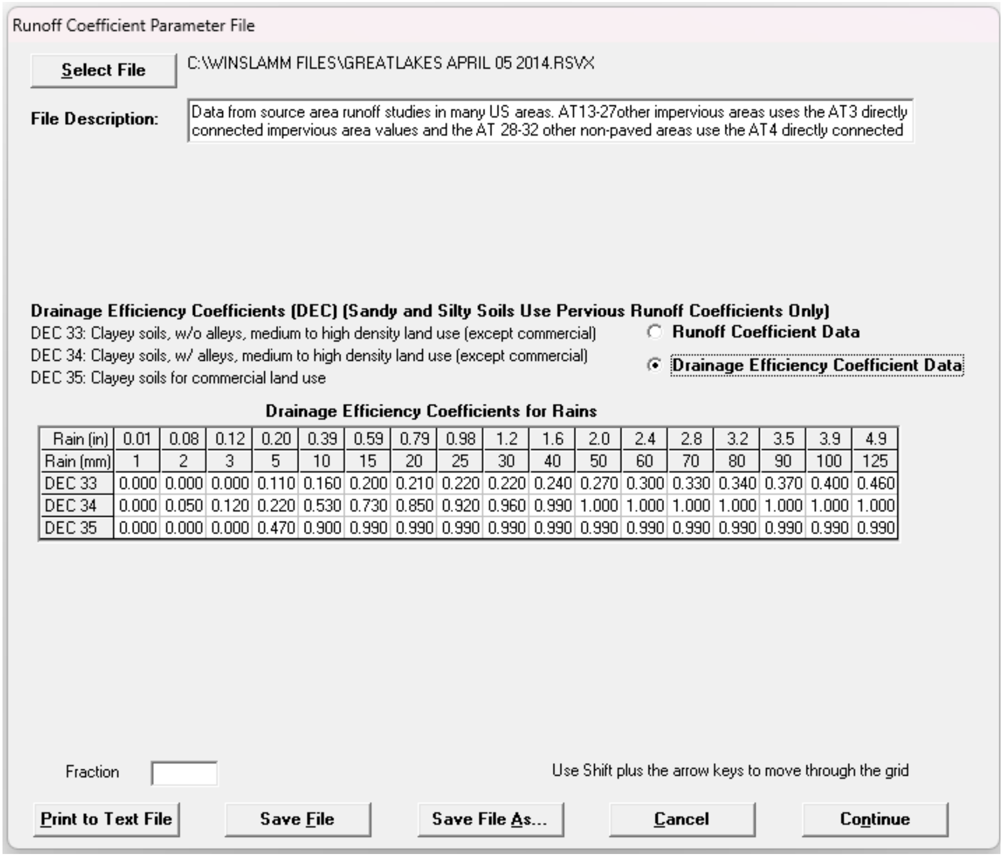
The *.RSVX file must be calibrated before any of the other parameter files are examined. After this file is modified, as needed, the particulate solids files must be calibrated. Finally, the file describing the other pollutants is examined and modified during the last steps.

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



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	0.000	0.150	0.450	0.640	0.770	0.790	0.830	0.840	0.860	0.880	0.900	0.910	0.930	0.940	0.940	0.950	0.960
AT 2	0.250	0.630	0.750	0.850	0.930	0.950	0.960	0.970	0.980	0.980	0.990	0.990	0.990	0.990	0.990	0.990	0.990
AT 3	0.350	0.440	0.490	0.560	0.640	0.690	0.730	0.770	0.810	0.860	0.890	0.910	0.920	0.930	0.940	0.940	0.950
AT 4	0.000	0.000	0.000	0.000	0.470	0.640	0.720	0.770	0.810	0.860	0.890	0.910	0.920	0.930	0.940	0.940	0.950
AT 5	0.000	0.000	0.000	0.000	0.005	0.007	0.010	0.012	0.014	0.016	0.018	0.019	0.020	0.021	0.022	0.023	0.024
AT 6	0.000	0.000	0.000	0.000	0.021	0.030	0.042	0.044	0.052	0.054	0.200	0.200	0.200	0.200	0.200	0.200	0.200
AT 7	0.000	0.000	0.000	0.000	0.023	0.038	0.058	0.069	0.076	0.120	0.200	0.200	0.200	0.200	0.200	0.250	0.300
AT 8	0.410	0.480	0.640	0.670	0.750	0.890	0.910	0.910	0.920	0.920	0.930	0.930	0.940	0.950	0.960	0.970	0.990
AT 9	0.410	0.480	0.640	0.670	0.750	0.890	0.910	0.910	0.920	0.920	0.930	0.930	0.940	0.950	0.960	0.970	0.990
AT 10	0.180	0.390	0.470	0.530	0.600	0.640	0.670	0.700	0.730	0.800	0.840	0.860	0.880	0.900	0.910	0.920	0.930
AT 11	0.550	0.730	0.770	0.830	0.870	0.970	0.970	0.970	0.980	0.980	0.980	0.980	0.990	0.990	0.990	0.990	1.000
AT 12	0.000	0.000	0.000	0.000	0.000	0.000	0.210	0.330	0.400	0.500	0.550	0.600	0.620	0.650	0.650	0.650	0.650

The following screen shows the drainage efficiency coefficients that are used by the model to adjust the runoff amounts from impervious areas when they are disconnected (flowing across soil or landscaped areas).



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
DEC 33	0.000	0.000	0.000	0.110	0.160	0.200	0.210	0.220	0.220	0.240	0.270	0.300	0.330	0.340	0.370	0.400	0.460
DEC 34	0.000	0.050	0.120	0.220	0.530	0.730	0.850	0.920	0.960	0.990	1.000	1.000	1.000	1.000	1.000	1.000	1.000
DEC 35	0.000	0.000	0.000	0.470	0.900	0.990	0.990	0.990	0.990	0.990	0.990	0.990	0.990	0.990	0.990	0.990	0.990

Several summary references on urban hydrology, stressing small-intermediate storm runoff characteristics for urban water quality analyses, are included on the WinSLAMM webpage at: https://www.winslamm.net/dr_pitt_presentations_and_publications.html#UrbanHydrology

Runoff Calibration Steps

The runoff file should be modified as needed based on locally collected rainfall and runoff observations. It is very important that adequate QA/QC procedures be used to ensure the accuracy and suitability of this 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 area, understanding of drainage connection/efficiency, and soil characteristics (including compaction)).

There are inherent errors associated with measuring rainfall and runoff. Most monitoring programs are probably no more than about 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. For these areas, it is not uncommon for large rains to have Rv values greater than 1.0, implying more runoff than rainfall, illustrating normal error variations in the monitoring. Similar errors occur with other sites and smaller rains, but those are not as obvious.

As noted, the first calibration steps are associated with examining the watershed and rainfall - runoff data, followed by changing the *.RSVX file, as necessary:

1. Confirm that the watershed areas and development characteristics are correctly described. Appendix A is a field sheet with descriptions prepared for use by naval base personnel as part of a project examining stormwater sources and discharges at many naval facilities in the U.S. using WinSLAMM. Appendix B is a similar discussion of specialized field surveys used in industrial areas having large amounts of exposed materials and activities that can contribute to stormwater contamination. 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 and associated drainage area as accurately as possible (especially for small areas). 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. Also, 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, playgrounds, 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 include 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 data patterns. Plot rainfall depth vs. runoff depth and plot Rv vs. rainfall depth. The Rv values are normally 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), such as a site with only commercial roofs and parking/storage areas. 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 hydraulically complex.

4. 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 installation package. This file includes several 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 rain events over an extended period of time. 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

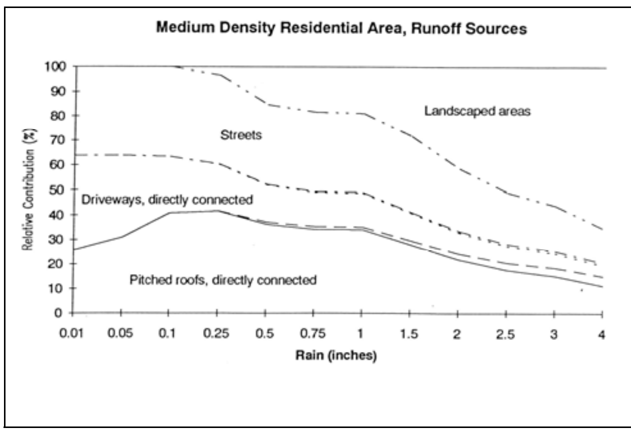
5. Run the created watershed file using the two rain files, without any additional pollutants selected, using the *.RSVX file and using the outfall total (at least) output option for the actual rains and the source area, by rains, output option for the source area rain file. Compare the predicted runoff 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.

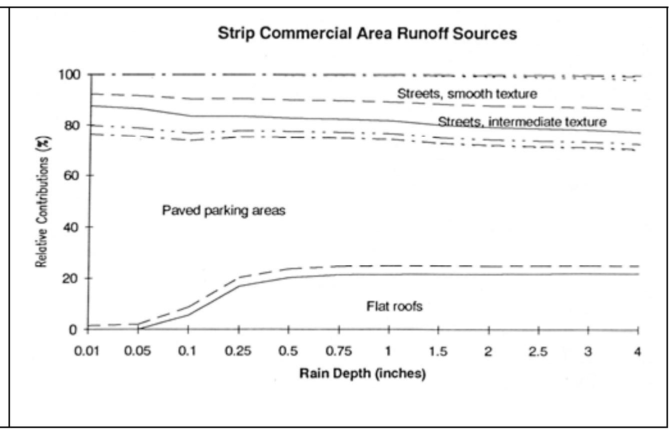
Calculate the percentage runoff depth errors (100 x (observed-predicted)/observed), and plot these against the observed rain depths. The desired pattern for the observed vs. predicted runoff depth plot is a 45-degree line, with minimal deviation. The desired pattern for the residual error plot is an even, narrow band over the range of observed rain depths, centered on the zero residual error horizontal line.

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 need to be made to the *.RSVX file. However, some improvement is usually possible. The overall sum runoff error indicates the general severity of the problem, but other information, described below, 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 rain period. The following are two examples of calculated runoff source area contributions using the SOURCE.RAN file and for typical medium density residential and strip commercial areas. In the residential area file, directly connected roofs and driveways plus 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 file components to modify for the rains that were monitored.





If a constant percentage bias occurs over the range of events monitored, then modify the Rv values in the *.RSVX 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 errors 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 as noted above. 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.

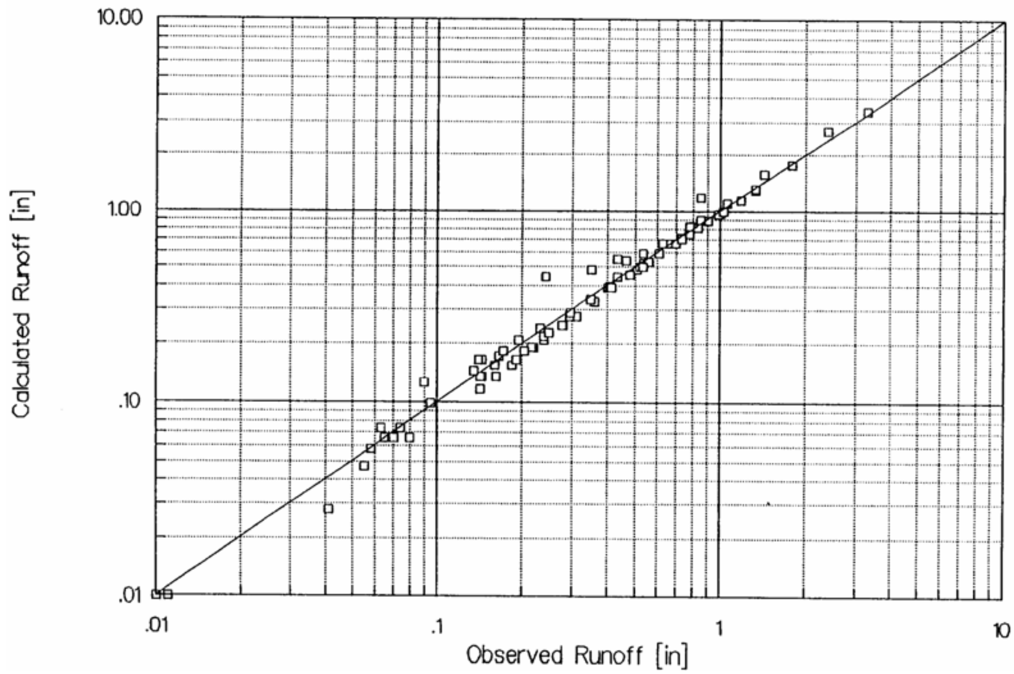
After these smoothing changes are made, re-run the program using the new *.RSVX file and review the results. It may be necessary to repeat this process a few times to become satisfied that no further improvements are possible or necessary.

6. The above process is challenging if only one monitored watershed is available 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 *.RSVX 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 comprehensive approach. Assuming the *.RSVX 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.

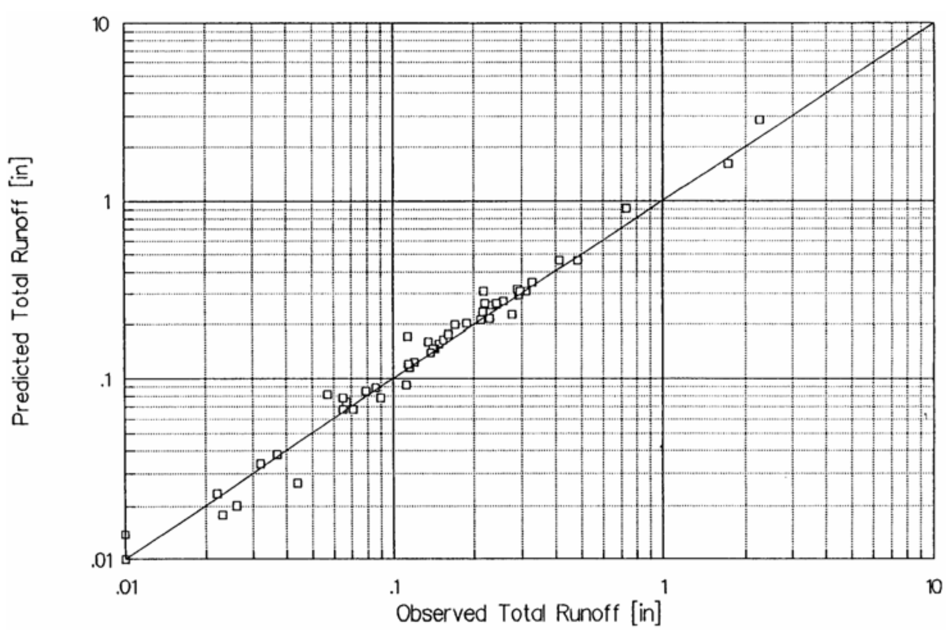
Results of Calibration of Runoff Parameter File (*.RSV)

Over the years, WinSLAMM has been calibrated and verified using available data for many locations. 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 (DNR), in conjunction with the USGS has calibrated WinSLAMM for use in support of the state's MS4 stormwater permit program, and several examples are shown from that work below.

The 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 (Pitt 1987). 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).

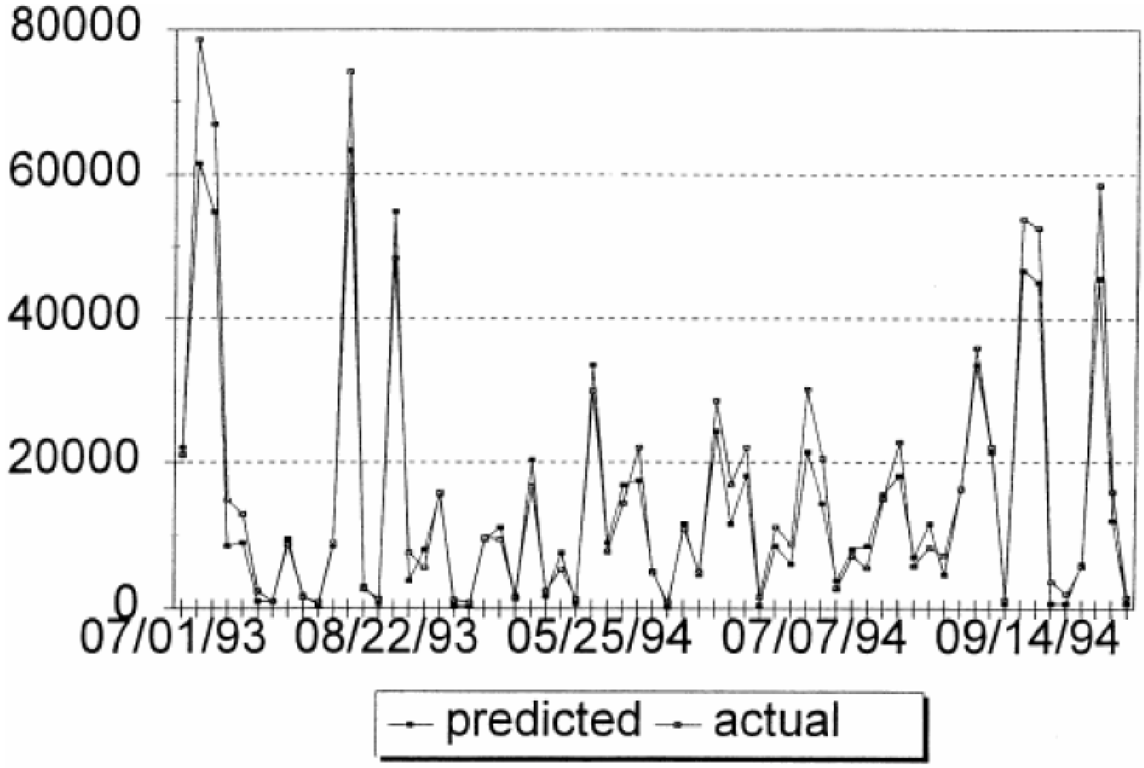


Verification of WinSLAMM hydrology component – Post Office commercial site, Milwaukee, WI (Pitt 1987).

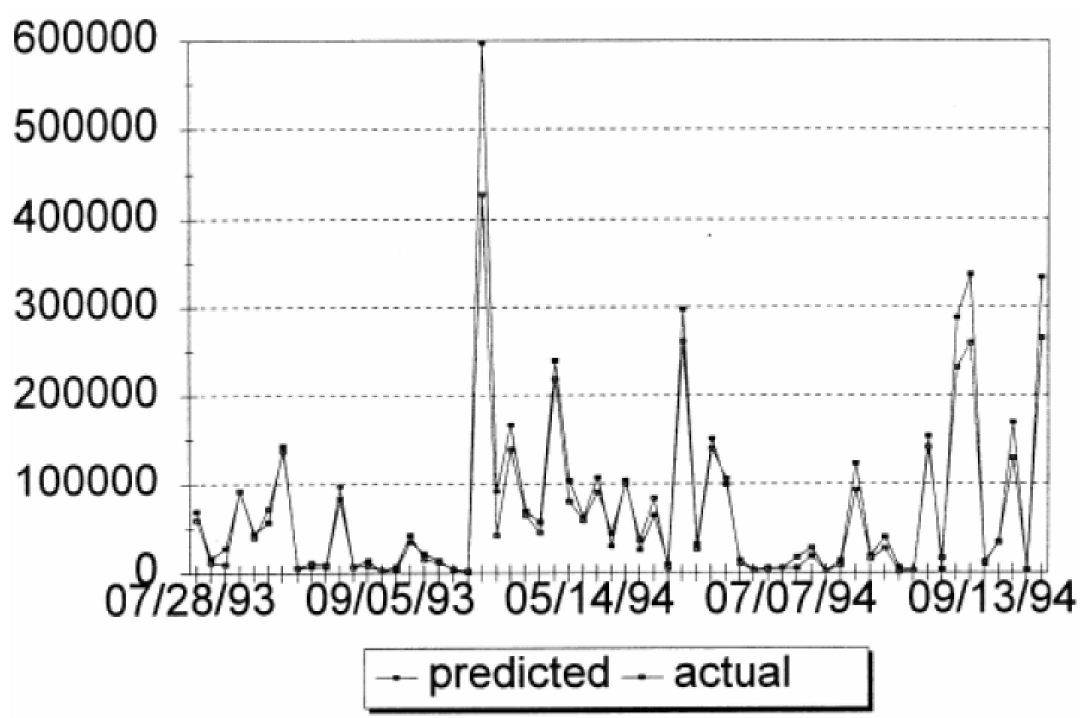


Verification of WinSLAMM hydrology component – Burbank residential site, Milwaukee, WI (Pitt 1987).

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 good 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 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.

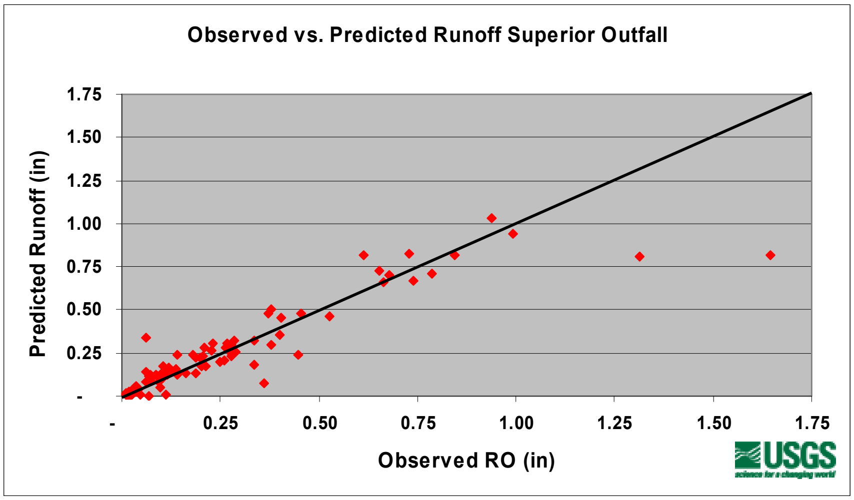


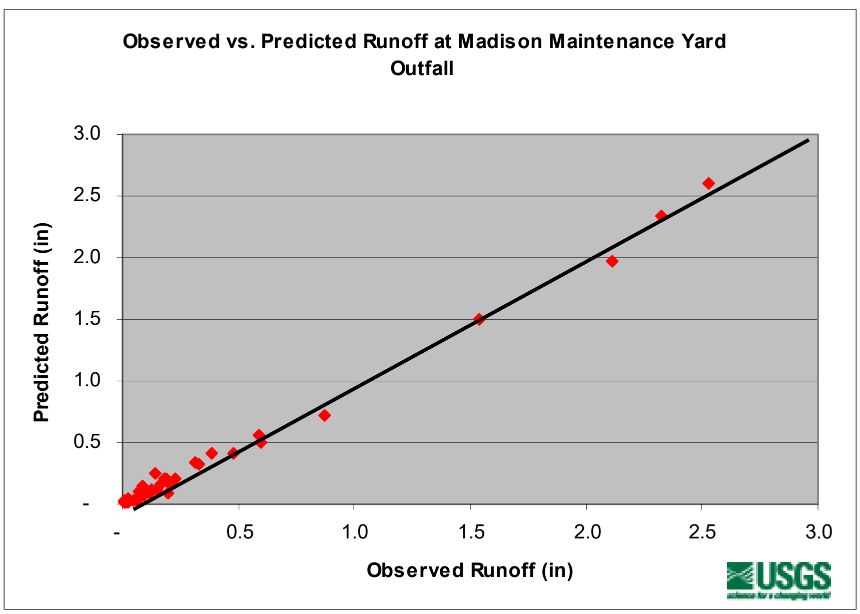
Verification of WinSLAMM hydrology component – Superior, WI, test site.



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 good agreement, except for two large events where the observed runoff quantities were larger than calculated, and which one event caused a surcharge in the storm sewer at the measurement location. 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).





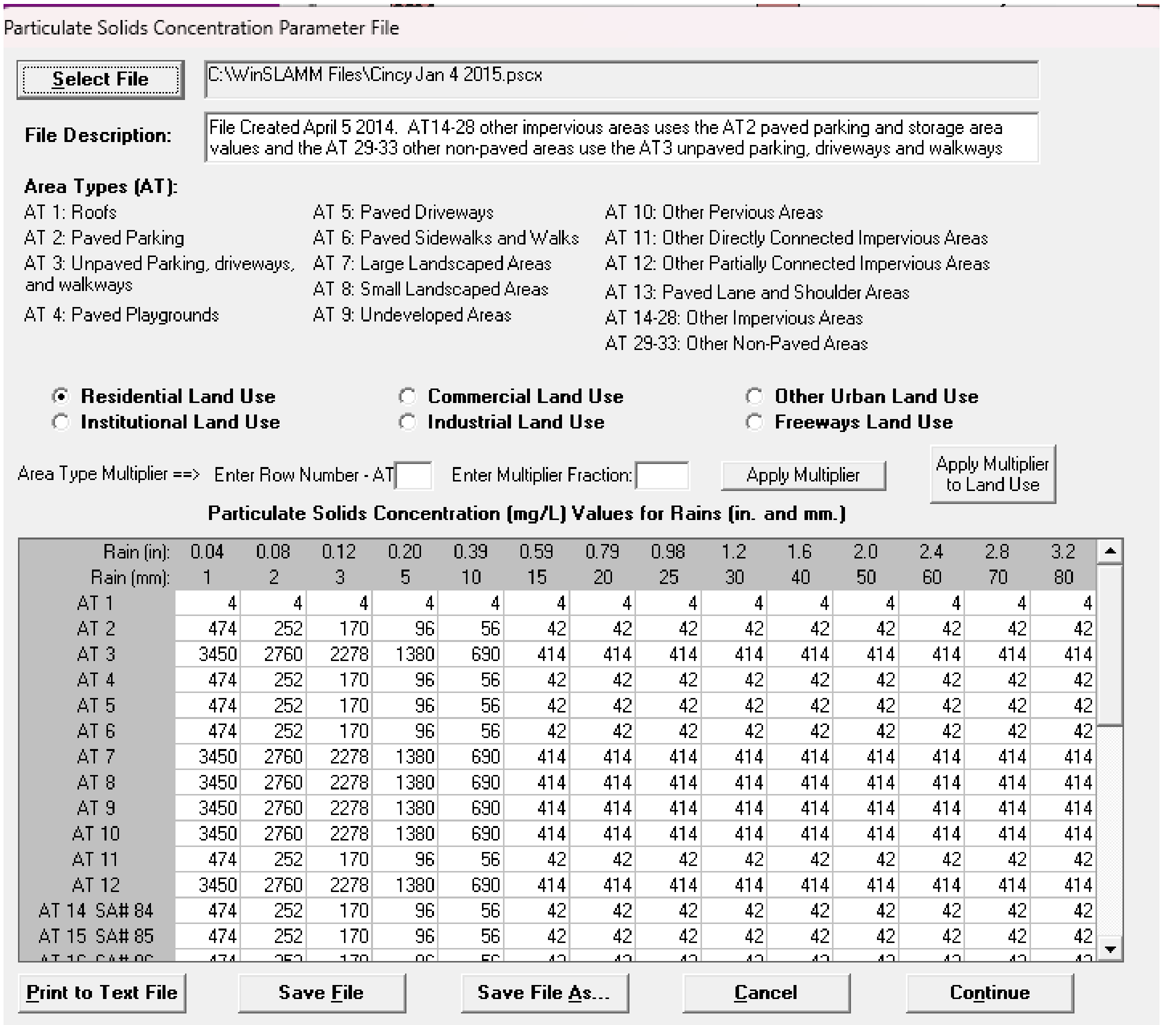
The following table shows the differences in measured and calculated runoff quantities for the monitored events at seven different locations after calibration by the WI DNR. The median difference is about 10%, while the largest difference was 27%.

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 Concentration Files

The *.PSCX 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 original *.PSC file was developed and verified using source area data mostly from Toronto, Milwaukee and Birmingham during specific field tests.

The following is an example Particulate Solids Concentration Parameter File (*.PSCX) Edit and Review Screen in WinSLAMM:


Particulate Solids Concentration Parameter File

Select File | C:\WinSLAMM Files\Cincy Jan 4 2015.pscx

File Description: File Created April 5 2014. AT14-28 other impervious areas uses the AT2 paved parking and storage area values and the AT 29-33 other non-paved areas use the AT3 unpaved parking, driveways and walkways

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 Directly Connected Impervious Areas
AT 12: Other Partially Connected Impervious Areas
AT 13: Paved Lane and Shoulder Areas
AT 14-28: Other Impervious Areas
AT 29-33: Other Non-Paved Areas

Residential Land Use | Commercial Land Use | Other Urban Land Use
Institutional Land Use | Industrial Land Use | Freeways Land Use

Area Type Multiplier ==> Enter Row Number - AT | Enter Multiplier Fraction: | Apply Multiplier | Apply Multiplier to Land Use

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

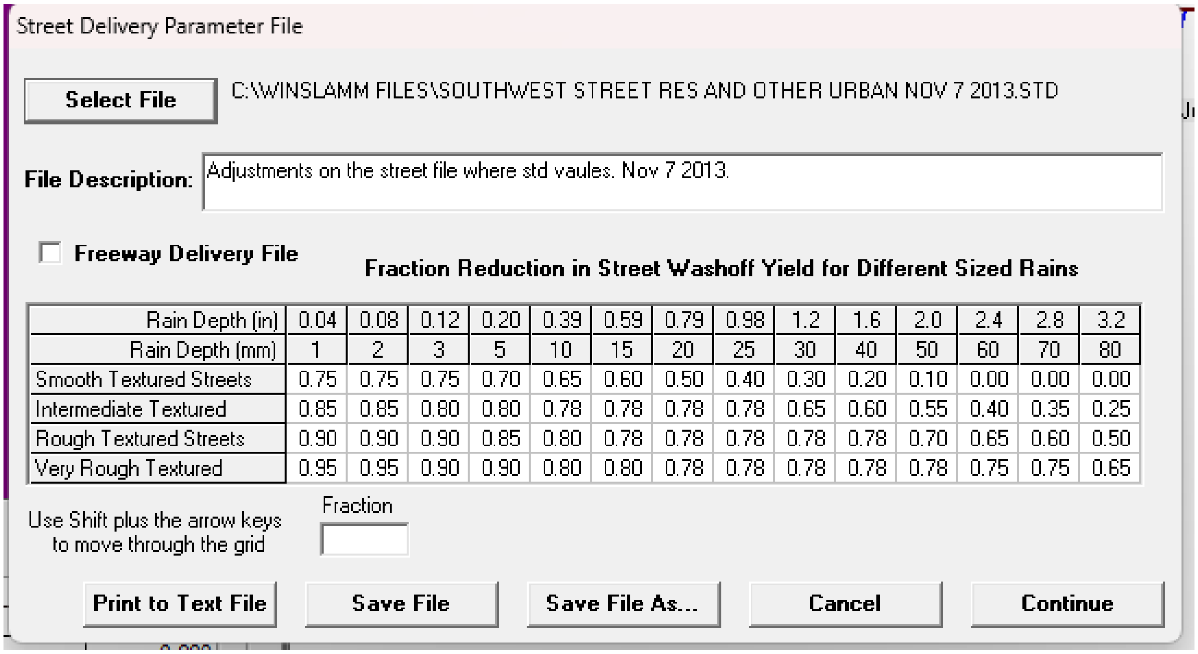
Rain (in):	0.04	0.08	0.12	0.20	0.39	0.59	0.79	0.98	1.2	1.6	2.0	2.4	2.8	3.2
Rain (mm):	1	2	3	5	10	15	20	25	30	40	50	60	70	80
AT 1	4	4	4	4	4	4	4	4	4	4	4	4	4	4
AT 2	474	252	170	96	56	42	42	42	42	42	42	42	42	42
AT 3	3450	2760	2278	1380	690	414	414	414	414	414	414	414	414	414
AT 4	474	252	170	96	56	42	42	42	42	42	42	42	42	42
AT 5	474	252	170	96	56	42	42	42	42	42	42	42	42	42
AT 6	474	252	170	96	56	42	42	42	42	42	42	42	42	42
AT 7	3450	2760	2278	1380	690	414	414	414	414	414	414	414	414	414
AT 8	3450	2760	2278	1380	690	414	414	414	414	414	414	414	414	414
AT 9	3450	2760	2278	1380	690	414	414	414	414	414	414	414	414	414
AT 10	3450	2760	2278	1380	690	414	414	414	414	414	414	414	414	414
AT 11	474	252	170	96	56	42	42	42	42	42	42	42	42	42
AT 12	3450	2760	2278	1380	690	414	414	414	414	414	414	414	414	414
AT 14 SA# 84	474	252	170	96	56	42	42	42	42	42	42	42	42	42
AT 15 SA# 85	474	252	170	96	56	42	42	42	42	42	42	42	42	42

Print to Text File | Save File | Save File As... | Cancel | Continue

A series of articles summarizing sources of pollutants in urban areas are located at:
https://www.winslamm.net/dr_pitt_presentations_and_publications.html#StormwaterPollutantSources

Street Dirt Delivery Files

WinSLAMM uses another file (*.STD) to calibrate the street dirt washoff calculations. The *.STD file accounts for the deposition of particulate pollutants in the storm drainage system, before the outfall, or before outfall controls due to low transport energy for the small rains. The following is an example Street Dirt Delivery Parameter File (*.STD) Edit and Review Screen in WinSLAMM:



Rain Depth (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 Depth (mm)	1	2	3	5	10	15	20	25	30	40	50	60	70	80
Smooth Textured Streets	0.75	0.75	0.75	0.70	0.65	0.60	0.50	0.40	0.30	0.20	0.10	0.00	0.00	0.00
Intermediate Textured	0.85	0.85	0.80	0.80	0.78	0.78	0.78	0.78	0.65	0.60	0.55	0.40	0.35	0.25
Rough Textured Streets	0.90	0.90	0.90	0.85	0.80	0.78	0.78	0.78	0.78	0.78	0.70	0.65	0.60	0.50
Very Rough Textured	0.95	0.95	0.90	0.90	0.80	0.80	0.78	0.78	0.78	0.78	0.78	0.75	0.75	0.65

Summary article of street dust and dirt accumulation and washoff are located at:
https://www.winslamm.net/assets/files/presentations_and_publications/6%20Stormwater%20Pollutant%20Sources/2004%20Pitt%20et%20al%20Street%20dirt%20accum%20and%20washoff%20CHI.pdf

Articles on street dirt washoff processes are located at:
https://www.winslamm.net/assets/files/presentations_and_publications/9%20Urban%20Hydrology/1987%20Pitt%20Urban%20hydrology%20and%20part%20washoff%20dissertation.pdf

Calibration Steps for Particulate Solids

The particulate solids files can only be examined and modified after the runoff file is successfully calibrated. The *.PSCX file contains particulate solids concentrations (SSC, suspended sediment concentrations, or TSS, total suspended solids concentrations, in mg/L, depending on how the samples were collected and processed) for each source area and land use for different rains. The exception is 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 types of 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.

The *.PSC file includes 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 usually greater than later in the same rain. This variation is highly dependent on rain energy. These data included in this file are based on observed conditions at the source areas. Runoff from some source areas (especially roofs and landscaped areas) typically does not show major particulate solids 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 are available. If these data are not available, then start with the *.PSCX file and step 2. The first step is to look at the data and check their reasonableness. 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% range values, then they are generally significantly different at the 95% confidence level for small sample data sets. 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 particulate solids concentrations) and landscaped area runoff (for the high particulate solids concentrations). The other groups (parking areas, 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. This 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 significant 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 log-transformation on the particulate solids data before these statistical tests. These tests will identify differences in sample groupings, but similarities (to combine data) are probably more important. Grouped box plots are usually most helpful, in addition to possibly conducting a cluster analysis to identify natural groupings of the data.

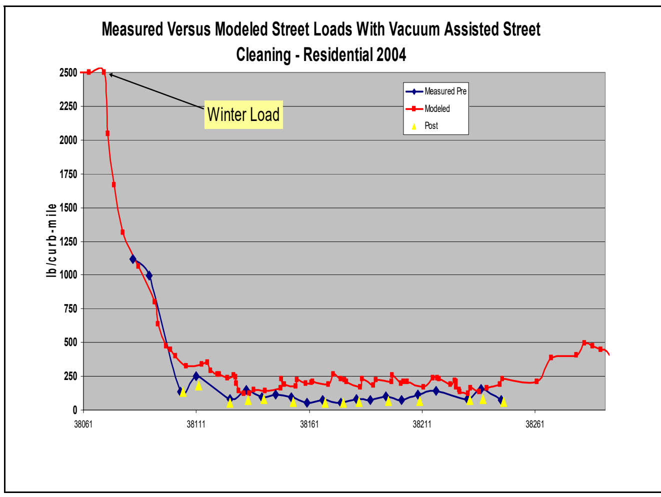
Combine the data into fewer groupings (such as all paved parking areas for commercial and industrial areas, another group for all roofs, regardless of land use, and another for all landscaped area runoff). The data in each of these new groups should be plotted as particulate solids concentrations vs. rain depth. The resulting particulate solids concentrations for each rain depth should be included in the construction of a new *.PSCX 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 from elsewhere (including the example *.PSC files) can be used with caution.

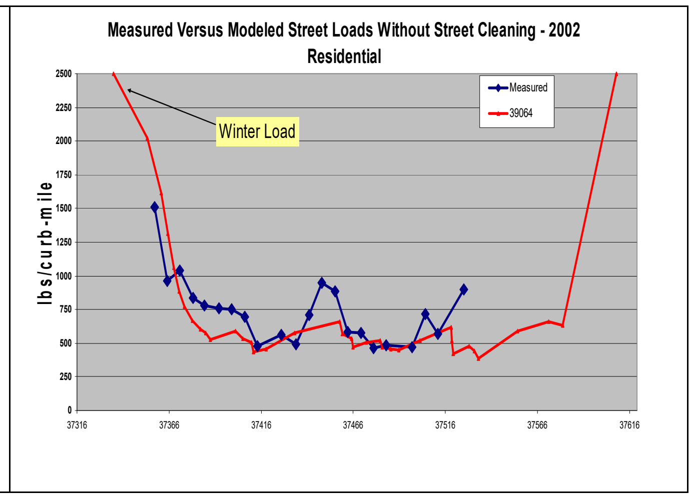
2. Run the watershed description WinSLAMM file prepared previously, using the *PSCX, *.STD, and *.RSVX files and the two rain files (one containing the monitored events and the other being the source.RAN file) without any additional pollutants selected. Select the output option giving results for each 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 particulate solids values. Calculate the percentage 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 percentage discrepancies in particulate solids

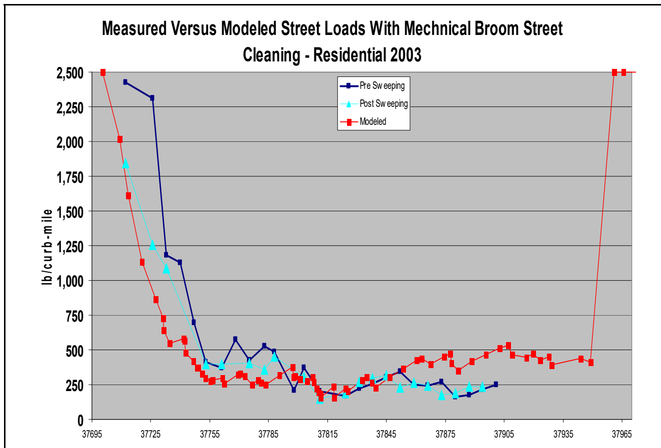
concentrations will be associated with small rain depths (WinSLAMM will probably over-estimate the concentrations), while the differences for the larger rains will be smaller.

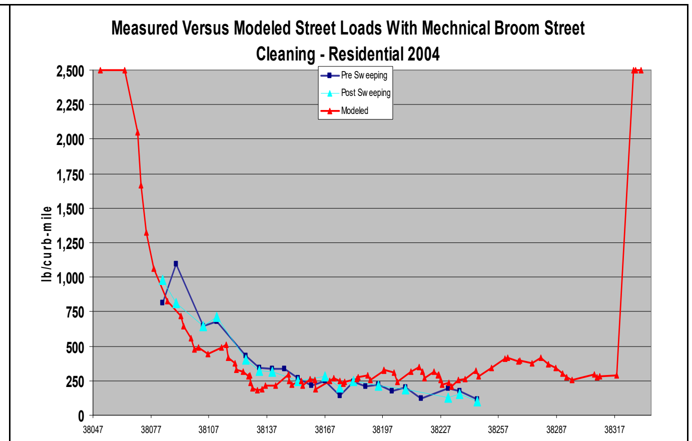
If a constant percentage bias occurs over the range of events monitored, then modify all of the *,PSCX concentrations by the same amount. However, the residual error plot probably will show a bias, with some portions of the rain distribution having greater percentage errors than others. As with the runoff 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 *.PSCX 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 *.PSCX 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.

Results of Calibration of Particulate Solids Parameter Files (*PSCX and *.STD)
The following plots are examples of predicted and measured street dirt loadings from 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 street cleaning.



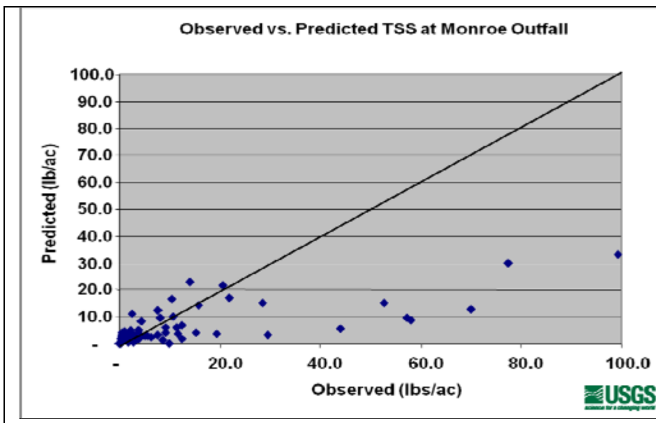




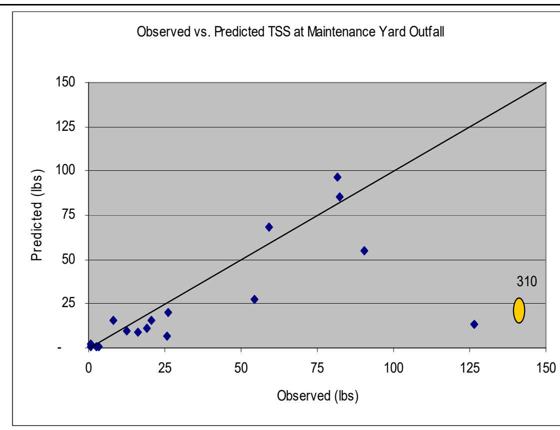


Observed and calculated street dirt loadings for different street cleaning equipment and seasons

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



Effects of bank erosion



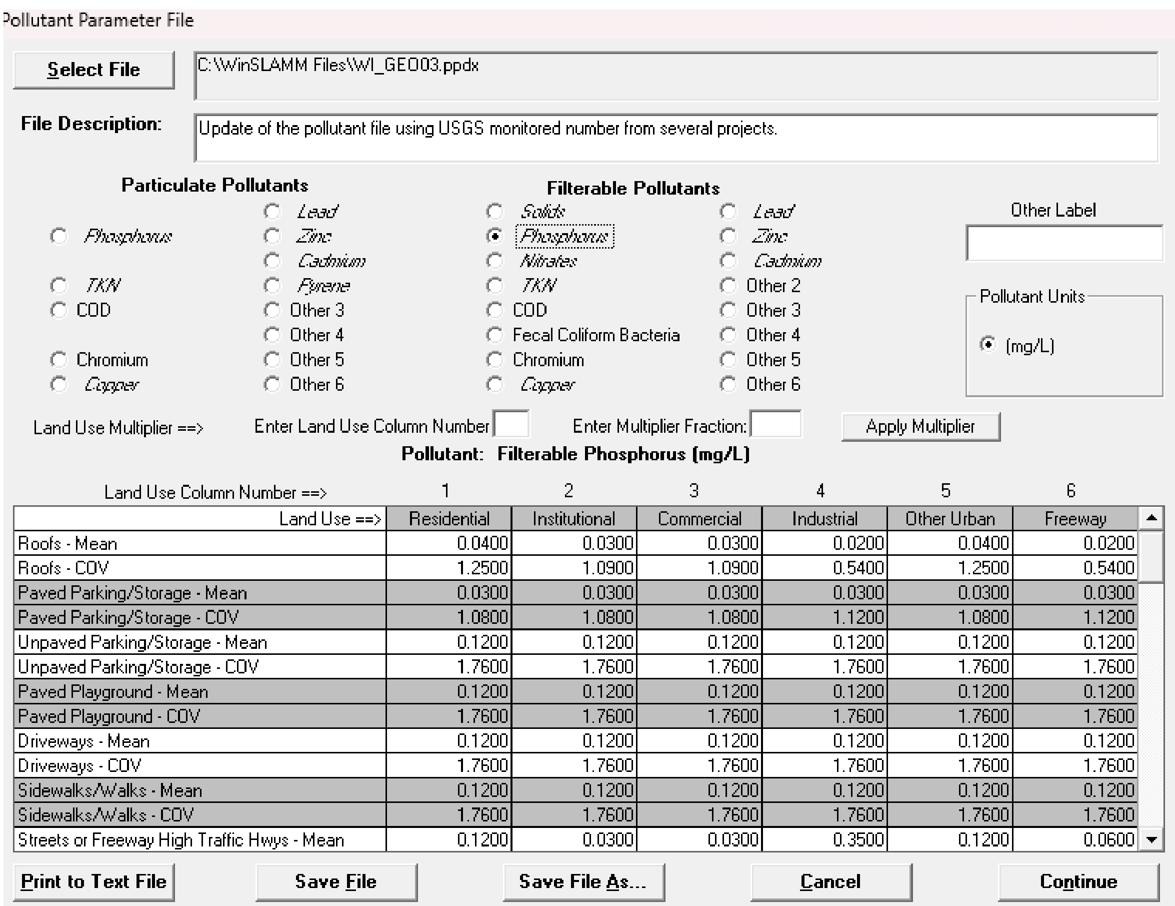
Two large unusual loading observations

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 runoff amounts. Generally, TSS was modeled within about 50% of the observed discharges 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 *.PPDX file describes the particulate pollutant strengths related to particulate solids and the filterable pollutant concentrations for each source area for each land use. This file also contains the coefficient of variation (COV) values for each pollutant for Monte Carlo simulation in WinSLAMM. The following is an example Pollutant Probability Distribution Parameter File (*.PPDX) edit and review screen in WinSLAMM for a portion of the filterable phosphate values:



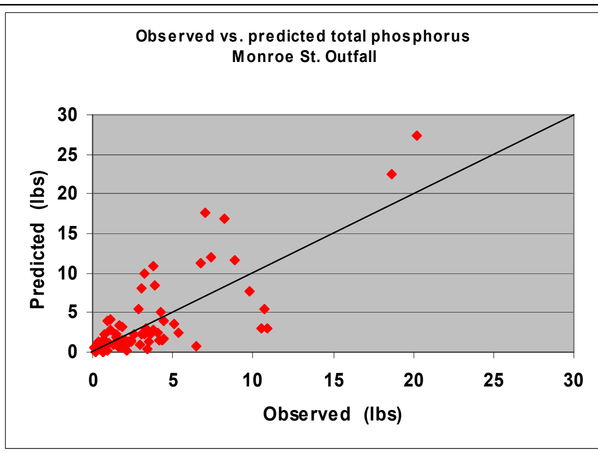
Land Use Column Number ==>	1	2	3	4	5	6
Land Use ==>	Residential	Institutional	Commercial	Industrial	Other Urban	Freeway
Roofs - Mean	0.0400	0.0300	0.0300	0.0200	0.0400	0.0200
Roofs - COV	1.2500	1.0900	1.0900	0.5400	1.2500	0.5400
Paved Parking/Storage - Mean	0.0300	0.0300	0.0300	0.0300	0.0300	0.0300
Paved Parking/Storage - COV	1.0800	1.0800	1.0800	1.1200	1.0800	1.1200
Unpaved Parking/Storage - Mean	0.1200	0.1200	0.1200	0.1200	0.1200	0.1200
Unpaved Parking/Storage - COV	1.7600	1.7600	1.7600	1.7600	1.7600	1.7600
Paved Playground - Mean	0.1200	0.1200	0.1200	0.1200	0.1200	0.1200
Paved Playground - COV	1.7600	1.7600	1.7600	1.7600	1.7600	1.7600
Driveways - Mean	0.1200	0.1200	0.1200	0.1200	0.1200	0.1200
Driveways - COV	1.7600	1.7600	1.7600	1.7600	1.7600	1.7600
Sidewalks/Walks - Mean	0.1200	0.1200	0.1200	0.1200	0.1200	0.1200
Sidewalks/Walks - COV	1.7600	1.7600	1.7600	1.7600	1.7600	1.7600
Streets or Freeway High Traffic Hwys - Mean	0.1200	0.0300	0.0300	0.3500	0.1200	0.0600

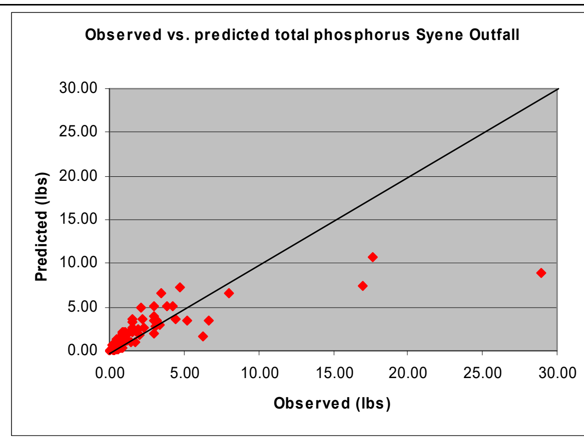
A series of articles summarizing sources of pollutants in urban areas are located at:
https://www.winslamm.net/dr_pitt_presentations_and_publications.html#StormwaterPollutantSources

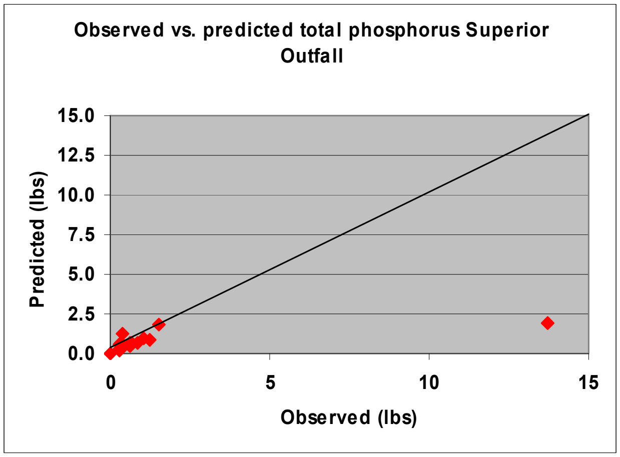
Calibration Steps for Pollutants
After the flow and particulate solids calibration steps have been completed to satisfaction, calibration of the pollutants can be undertaken. One can start with an existing *.PPDX file, or a new one can be created using local source area sheetflow data. The yield of the 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 can then be adjusted by the fraction representing the differences between the observed and calculated yields. After re-running the model using the adjusted *.PPDX 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.

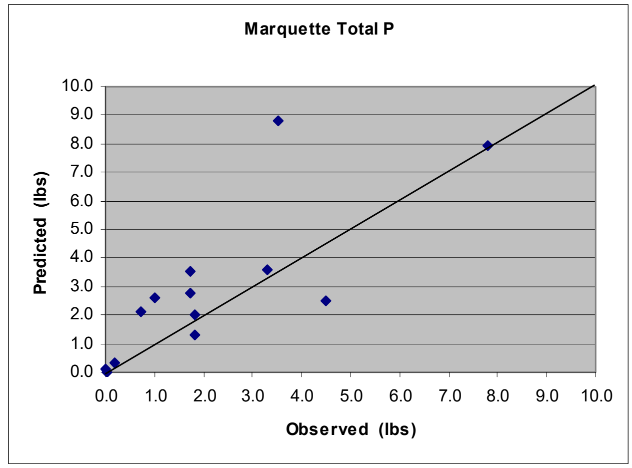
The next step is to examine the filtered vs. particulate fractions for the pollutants. Examine the monitoring data to see if there are any statistically significant trends of this ratio for different rain categories. Adjust the particulate and filterable values to balance the calculated concentration 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. It is nearly impossible to obtain similar concentration probability plots of modeled vs. observed values without using the Monte Carlo option.

Example Results of Calibration of Pollutant Parameter Files (*PPDX)
The following plots are examples of predicted and measured phosphorus and zinc loadings prepared during WI DNR WinSLAMM calibration efforts.





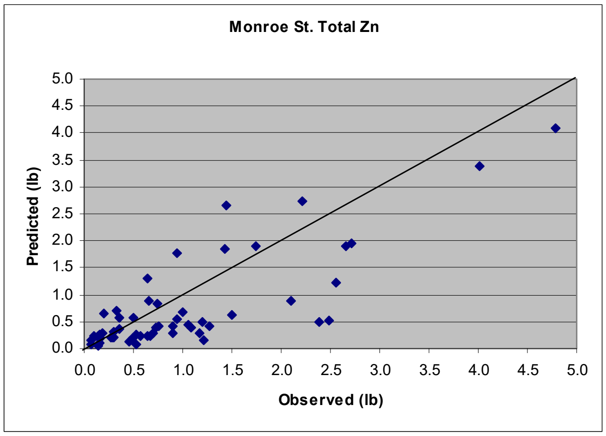


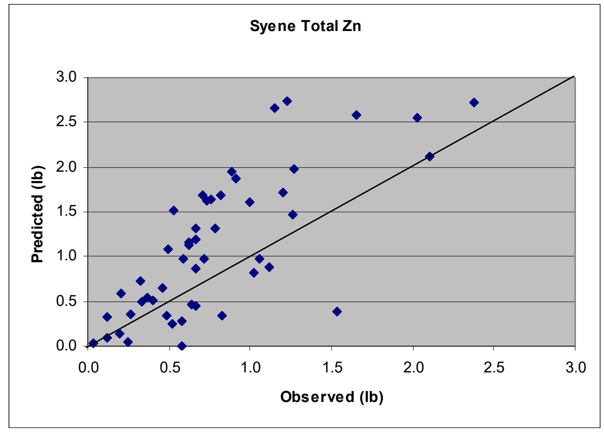


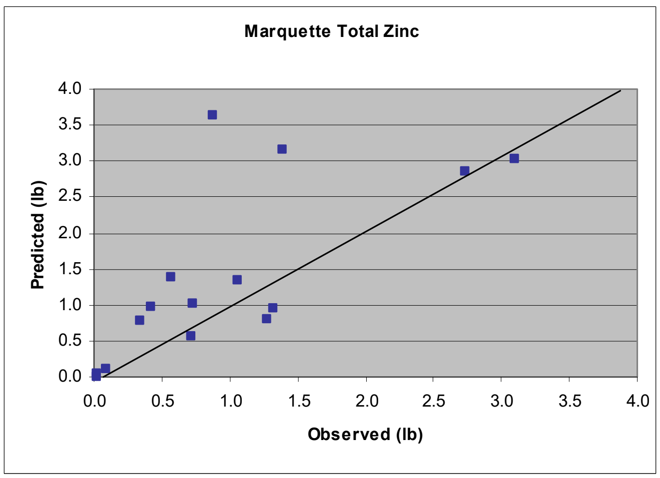
The sum of loading errors are shown on the following table, and indicate the effect that a few unusual events can have on model performance. The errors for phosphorus were about the same as observed for particulate solids, with about half of the total phosphorus load associated with filtered phosphorus 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%

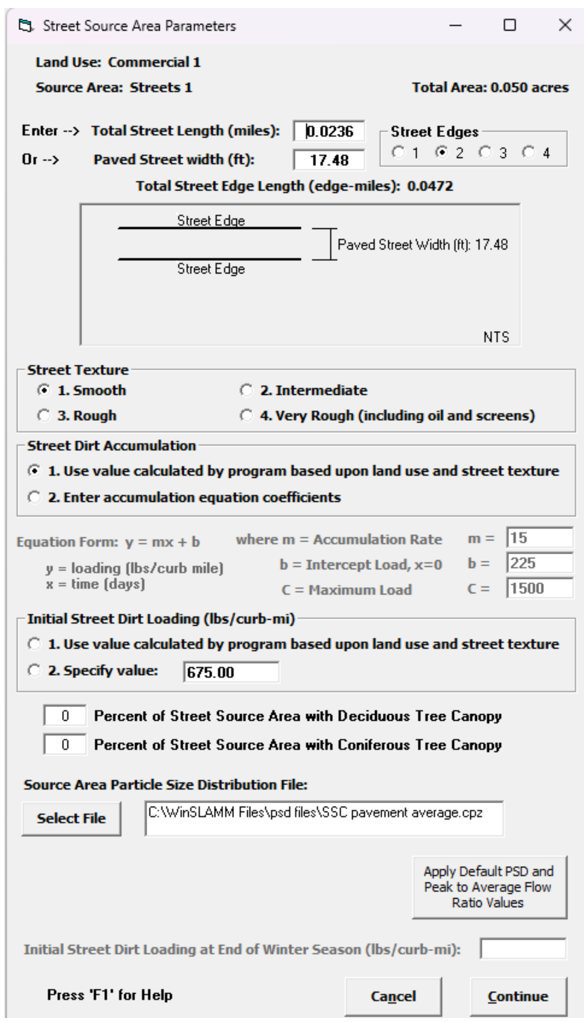
Overall, WinSLAMM can predict runoff volumes for each individual event with sum of load errors ranging from about 10 to 30%. Particulate solids modeling performance has greater variability, generally with some biases associated with unusual site conditions that are not considered in the model (such as 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%. The event-to-event calibrations for the pollutants also show greater variability.

Secondary WinSLAMM Calibration

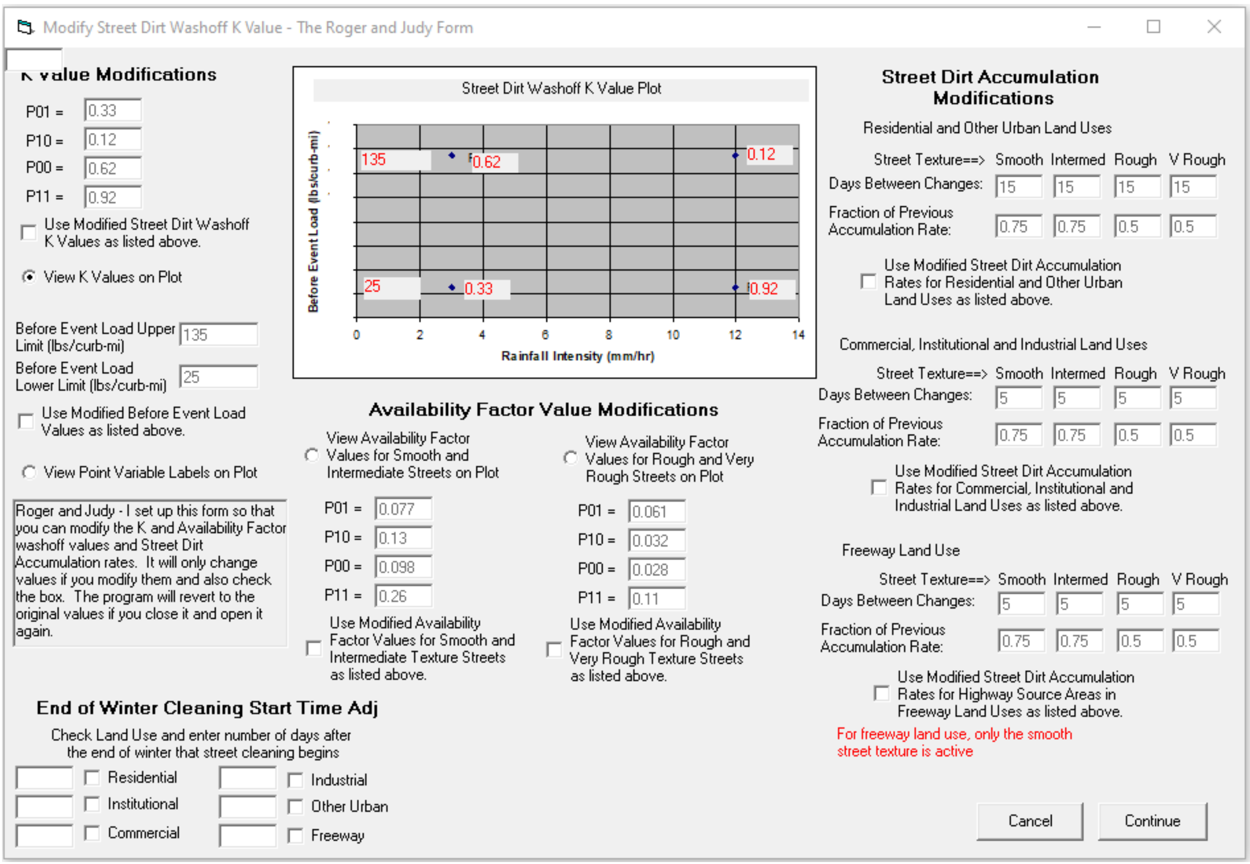
There are a number of other locations in WinSLAMM where parameters can be changed as part of the calibration process. Some of these are shown below.

Street Dirt Accumulation and Initial Load Values

The street source area screen (example shown below) includes options to use the street dirt accumulation rates calculated by the model (based on land use and street texture) or to enter alternative equation coefficients. The form also allows one to enter a specific initial street dirt loading value for the start of the modeling period after the end of the winter period (if selected in the initial rain file selection screen), or to use the value determined by the model. These changes can be used to modify the street dirt contributions, based on locally monitored values and as part of the calibration process. The following screen shows an example where the street dirt accumulation rates and initial load after winter can be modified. The street dirt accumulation rates are default values. The calibration process begins with modifying the accumulation rate based upon local data. Further modifications to the model are discussed below.



The street dirt washoff K values for various street conditions are hard-coded into the model because the calibration process, performed by the Wisconsin DNR and the USGS, requires a significant amount of data. To assist the DNR and USGS with the development of these washoff values, PVA developed a form titled: Modify Street Dirt Washoff K Value – The Roger and Judy Form. This form was developed for Roger Bannerman (DNR) and Judy Horwatich (USGS) to assist with performing the street dirt calibration using the extensive USGS street dirt accumulation and washoff database. A screen shot of the form is shown below. This form can be made available to users who have street dirt washoff data and an understanding of how the accumulation and washoff process works. If you are performing a calibration and have the data to make modifications, please contact PVA to discuss this activities.



Tree Rainfall Interception over Impervious Areas

The above street source area screen also includes the ability to show the amount of street cover over the street. This option is also available for other impervious areas. The urban tree rainfall interception white paper summary is located at: https://www.winslamm.net/assets/files/presentations_and_publications/13%20Stormwater%20Management%20and%20Modeling/2020%20Pitt%20Tree%20rainfall%20interception%20in%20WinSLAMM.pdf

Particle Size Distributions for Source Areas

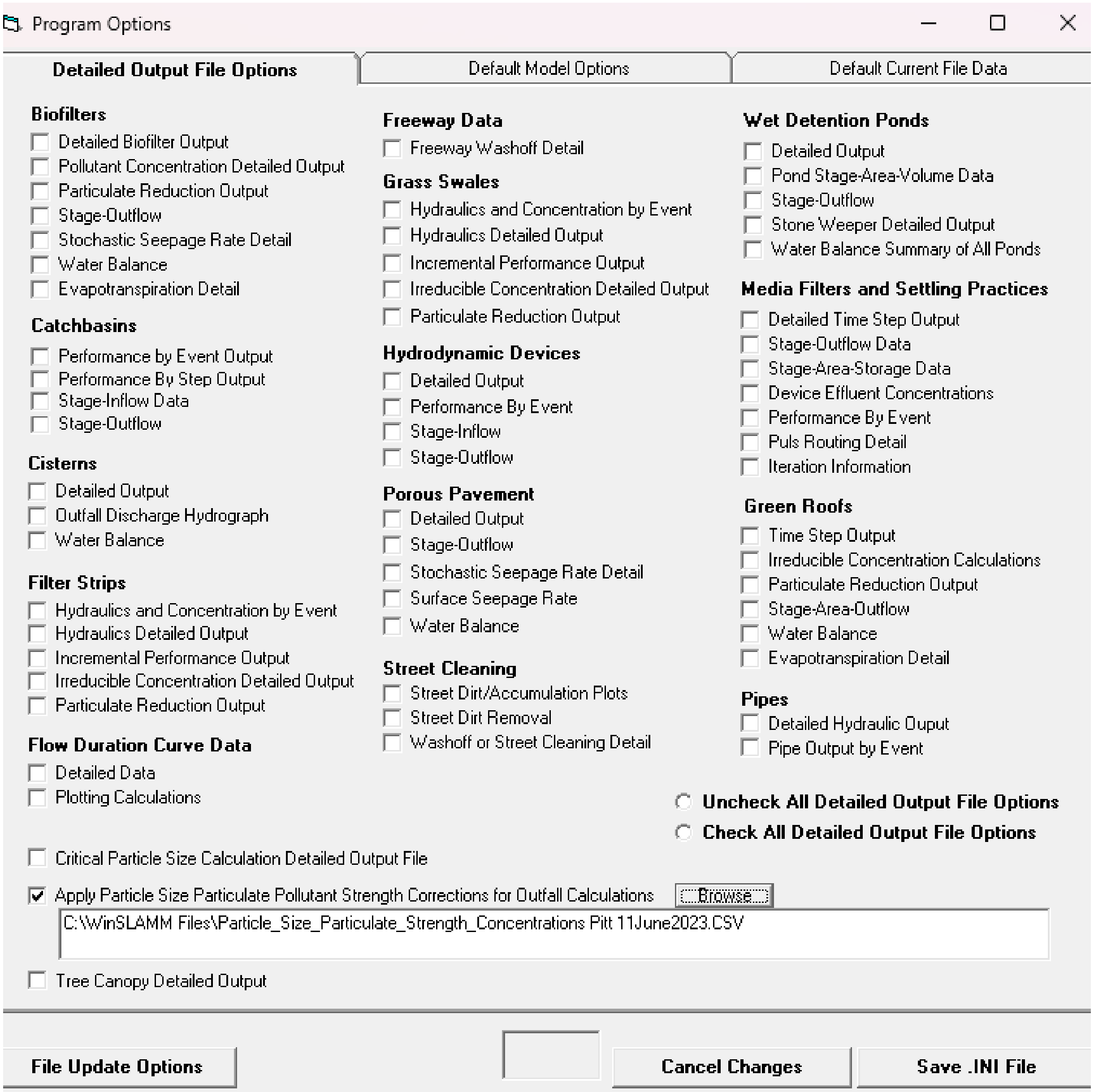
A recommended secondary modeling calibration option is to select the set of particle size distribution (*.psd) files for different source areas and land uses, instead of using the same particle size distribution for all areas. An example spreadsheet file (as a *.csv file) that can be selected in the model lists the *.cpz files, as shown below:

	A	B	C	D	E
1	C:\WinSLAMM Files\psd files\				
2		Residential Land Use	Institutional Land Use	Commercial Land Use	Industrial Land Use
3	Roofs	SSC roof average.cpz	SSC roof average.cpz	SSC roof average.cpz	SSC roof average.cpz
4	Paved Parking	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average
5	Unpaved Parking	SSC landscaped average.cpz	SSC landscaped average.cpz	SSC landscaped average.cpz	SSC landscaped avera
6	Driveways	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average
7	Sidewalks	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average
8	Streets	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average
9	Sandy Pervious Areas	SSC landscaped average.cpz	SSC landscaped average.cpz	SSC landscaped average.cpz	SSC landscaped avera
10	Silty Pervious Areas	SSC landscaped average.cpz	SSC landscaped average.cpz	SSC landscaped average.cpz	SSC landscaped avera
11	Clayey Pervious Areas	SSC landscaped average.cpz	SSC landscaped average.cpz	SSC landscaped average.cpz	SSC landscaped avera
12	Paved Playgrounds	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average
13	Other Pervious Areas	SSC landscaped average.cpz	SSC landscaped average.cpz	SSC landscaped average.cpz	SSC landscaped avera
14	Other Direct Con Imp Areas	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average
15	Other Part Con Imp Areas	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average
16	Other Imp Area 1	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average
17	Other Imp Area 2	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average
18	Other Imp Area 3	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average
19	Other Imp Area 4	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average
20	Other Imp Area 5	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average
21	Other Imp Area 6	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average
22	Other Imp Area 7	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average
23	Other Imp Area 8	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average
24	Other Imp Area 9	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average
25	Other Imp Area 10	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average
26	Other Imp Area 11	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average
27	Other Imp Area 12	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average
28	Other Imp Area 13	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average
29	Other Imp Area 14	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average
30	Other Imp Area 15	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average
31	Other Non-Paved Area 1	SSC landscaped average.cpz	SSC landscaped average.cpz	SSC landscaped average.cpz	SSC landscaped avera
32	Other Non-Paved Area 2	SSC landscaped average.cpz	SSC landscaped average.cpz	SSC landscaped average.cpz	SSC landscaped avera
33	Other Non-Paved Area 3	SSC landscaped average.cpz	SSC landscaped average.cpz	SSC landscaped average.cpz	SSC landscaped avera
34	Other Non-Paved Area 4	SSC landscaped average.cpz	SSC landscaped average.cpz	SSC landscaped average.cpz	SSC landscaped avera
35	Other Non-Paved Area 5	SSC landscaped average.cpz	SSC landscaped average.cpz	SSC landscaped average.cpz	SSC landscaped avera
36	Paved Lane/Shldr	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average
37	High Traffic Urban	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average
38	High Traf Urban Perv	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average.cpz	SSC pavement average
39	Large Turf Areas	SSC landscaped average.cpz	SSC landscaped average.cpz	SSC landscaped average.cpz	SSC landscaped avera

A summary white paper describing source area particle sizes is available at:
https://www.chijournal.org/C416

Particulate Pollutant Strengths for Outfall Particle Sizes

Another feature (added as part of a recent industrial area project) is the ability to modify the pollutant particulate strengths for different particle sizes at the outfall. The following program option screen allows the selection of the appropriate *.csv file containing this information:



The following spreadsheet shows the format for this file, showing multiplier factors for the mean pollutant strengths included in the *.PSCX file for each particle size range used in WinSLAMM:

bin#	range	Phosphorus	Nitrates	TKN	COD	Fecal Coliform Bacteria	Chromium	Copper	Lead	Zinc	1 Cadmium	2 Pyrene
1	0.45 to < 2	1.68	n/a	1	1.2	n/a	0.68	0.61	0.69	1.56	1.23	1.64
2	2 to < 3	0.71	n/a	1	0.66	n/a	0.68	0.61	0.69	1.56	1.23	1.64
3	3 to < 4	0.71	n/a	1	0.66	n/a	0.68	0.61	0.69	1.56	1.23	1.64
4	4 to < 5	0.71	n/a	1	0.66	n/a	0.68	0.61	0.69	1.56	1.23	1.64
5	5 to < 6	0.71	n/a	1	0.66	n/a	0.66	1.16	1.09	0.47	0.75	0.48
6	6 to < 7	0.71	n/a	1	0.66	n/a	0.66	1.16	1.09	0.47	0.75	0.48
7	7 to < 8	0.71	n/a	1	0.66	n/a	0.66	1.16	1.09	0.47	0.75	0.48
8	8 to < 9	0.71	n/a	1	0.66	n/a	0.66	1.16	1.09	0.47	0.75	0.48
9	9 to < 10	0.71	n/a	1	0.66	n/a	0.66	1.16	1.09	0.47	0.75	0.48
10	10 to < 11	0.81	n/a	1	0.67	n/a	0.66	1.16	1.09	0.47	0.75	0.48
11	11 to < 12	0.81	n/a	1	0.67	n/a	0.66	1.16	1.09	0.47	0.75	0.48
12	12 to < 13	0.81	n/a	1	0.67	n/a	0.66	1.16	1.09	0.47	0.75	0.48
13	13 to < 14	0.81	n/a	1	0.67	n/a	0.66	1.16	1.09	0.47	0.75	0.48
14	14 to < 15	0.81	n/a	1	0.67	n/a	0.66	1.16	1.09	0.47	0.75	0.48
15	15 to < 20	0.81	n/a	1	0.67	n/a	0.66	1.16	1.09	0.47	0.75	0.48
16	20 to < 25	0.81	n/a	1	0.67	n/a	0.73	0.7	0.75	0.56	0.79	0.43
17	25 to < 30	0.81	n/a	1	0.67	n/a	0.73	0.7	0.75	0.56	0.79	0.43
18	30 to < 35	0.81	n/a	1	0.67	n/a	0.73	0.7	0.75	0.56	0.79	0.43
19	35 to < 40	0.81	n/a	1	0.67	n/a	0.73	0.7	0.75	0.56	0.79	0.43
20	40 to < 50	0.78	n/a	1.29	1.15	n/a	0.73	0.7	0.75	0.56	0.79	0.43
21	50 to < 60	1	n/a	1.07	1.09	n/a	0.73	0.7	0.75	0.56	0.79	0.43
22	60 to < 80	1.16	n/a	0.89	1.2	n/a	1.92	1.47	1.43	1.57	1.26	1.44
23	80 to < 100	0.71	n/a	0.93	0.9	n/a	1.92	1.47	1.43	1.57	1.26	1.44
24	100 to < 150	0.68	n/a	0.93	0.96	n/a	1.92	1.47	1.43	1.57	1.26	1.44
25	150 to < 200	0.53	n/a	0.79	0.54	n/a	1.92	1.47	1.43	1.57	1.26	1.44
26	200 to < 300	0.52	n/a	0.49	0.66	n/a	1.92	1.47	1.43	1.57	1.26	1.44
27	300 to < 500	0.7	n/a	0.56	0.68	n/a	1.92	1.47	1.43	1.57	1.26	1.44
28	500 to < 800	0.7	n/a	0.56	0.7	n/a	1.92	1.47	1.43	1.57	1.26	1.44
29	800 to < 1000	0.69	n/a	0.83	0.86	n/a	1.92	1.47	1.43	1.57	1.26	1.44
30	1000 to < 2000	0.88	n/a	1.23	1.15	n/a	1.92	1.47	1.43	1.57	1.26	1.44
31	=> 2000	0.9	n/a	1.18	1.43	n/a	1.92	1.47	1.43	1.57	1.26	1.44

Particle_Size_Particulate_Stren

Ready Accessibility: Unavailable

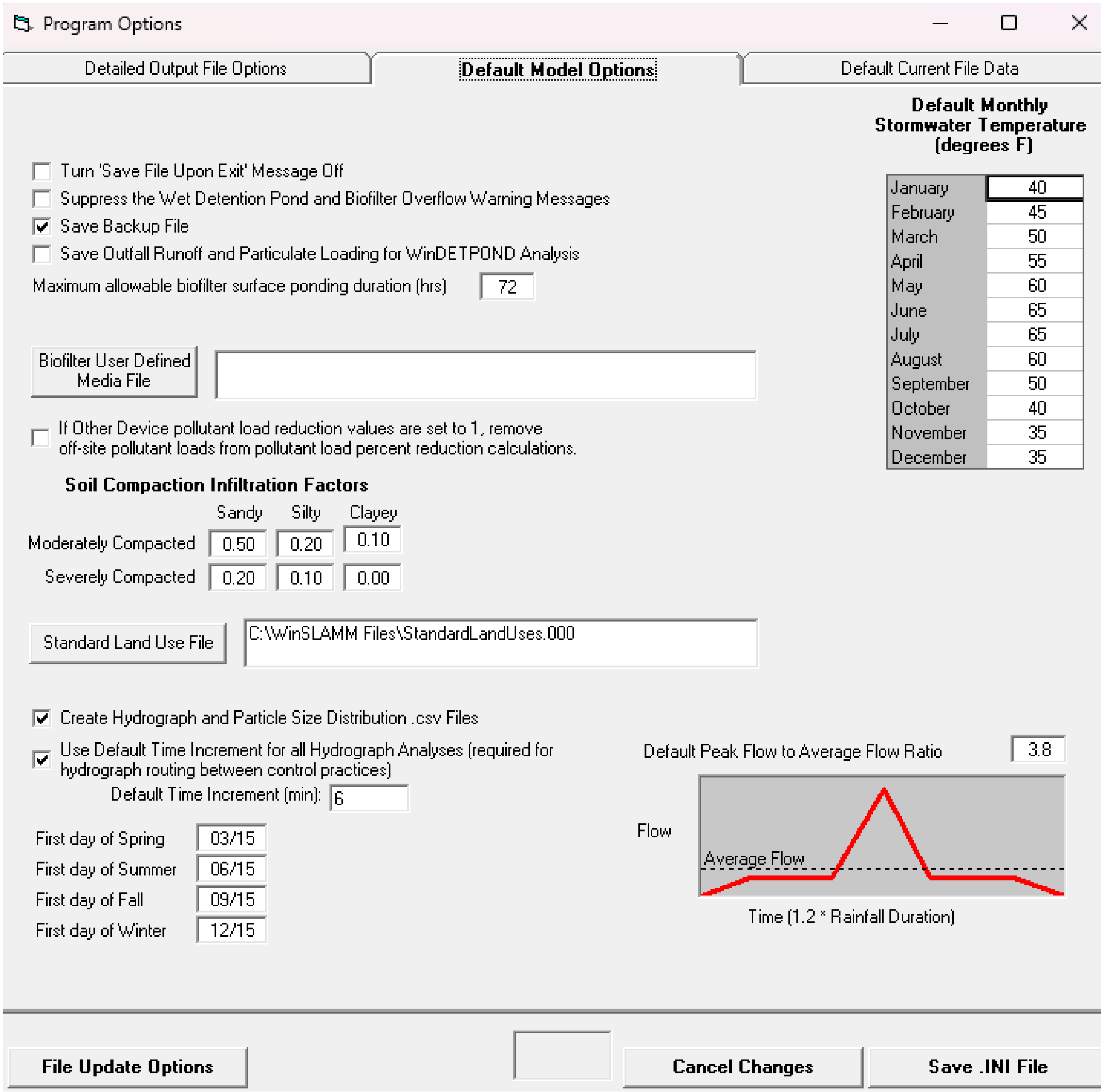
A white paper on stormwater particulate strengths by particle size is available at: https://www.winslamm.net/assets/files/presentations_and_publications/13%20Stormwater%20Management%20and%20Modeling/2022%20Pitt%20Particulate%20strgth%20by%20size%20in%20WinSLAMM.pdf

Soil Compaction Factors, Water Temperatures, Hydrograph Shapes, and Seasons

The *Program Options* page also includes opportunities to change several factors that also affect program performance, including:

- Monthly water temperatures that are used in settling equations for stormwater controls incorporating Stoke's Law.
- Soil compaction factors for sandy, silty, and clayey soils for moderately and severely compacted soils. These factors modify the normal urban soil infiltration rates for these compaction and texture conditions.
- Seasonal periods of the year used when model calculations change for different times of the year, such as the tree rainfall interception values. Future program additions will also enable source area pollutant concentrations to change by season (especially phosphorus).
- Initial hydrograph shapes at source areas before routing through the drainage system and stormwater controls. Future model options will enable these to vary for different source areas.

The following is an example program option screen:



Summary papers on compacted urban soils are located at:
https://www.winslamm.net/dr_pitt_presentations_and_publications.html#CompactedUrbanSoils

A summary paper on urban hydrograph shapes is located at:
https://www.winslamm.net/assets/files/presentations_and_publications/9%20Urban%20Hydrology/2011%20Pitt%20et%20al%20Hydrograph%20shapes%20in%20urban%20areas%20CHI.pdf

Evapotranspiration and Pond Water Evaporation

Several stormwater control options also include other factors that can be changed that affect the model calibration. As an example, the detention pond and biofilter controls include the ability to add pond evaporation rates applied to open water bodies, and the biofilter controls include the option to use

vegetation and associated evapotranspiration. Evapotranspiration and pond evaporation summary papers are located at:
https://www.winslamm.net/assets/files/presentations_and_publications/13%20Stormwater%20Management%20and%20Modeling/2022%20Pitt%20ET%20and%20evap%20data%20for%20WinSLAMM.pdf

https://www.winslamm.net/assets/files/presentations_and_publications/13%20Stormwater%20Management%20and%20Modeling/pan%20evap%20data%20554363%20NOAA%20NWS%2034.pdf

Large-scale Case Studies of WinSLAMM Calibration and Verification

The following discussions illustrate source area and outfall monitoring used to calibrate and verify WinSLAMM at several locations. Outfall data alone, while useful, can be misleading without the additional source area sheetflow data. The source area information is important for parameter file adjustments and decreases the likelihood of over-adjusting some source areas to balance under-adjustments for other areas.

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

The following subsection describes some of the monitoring efforts conducted by the WI DNR and the USGS to obtain extensive data for calibration of WinSLAMM (and other models). 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 for 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 (NSQD) for example regional parameter files.

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 summarized by Pitt, *et al.* (2005a, 2005b, and 2005c).

1. Madison, WI, runoff samples were collected during three months of 1991 (Bannerman, *et al.* 1996) 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 collected in below ground bottles by gravity flow. 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, filtered phosphorus, filtered 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.

2. Milwaukee and additional Madison, WI, runoff samples were 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.

3. 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, filtered phosphorus, hardness, total recoverable and filtered 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 simultaneously measured at the stormwater outfall for the study area.

4. 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, filtered phosphorus, and total phosphorus. Flow and water quality were measured at the stormwater outfalls for both study areas.

5. Additional Madison, WI, runoff samples (Waschbusch, et al. 1999) were further evaluated for 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 filtered cadmium, lead, copper, zinc, and phosphorus.

6. 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 was 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.

7. 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 (1.7-ha) city maintenance yard. Inlet and outlet runoff samples were collected for 45 runoff events. Samples were analyzed for total solids, suspended solids, total and filtered phosphorus, nitrate plus nitrite, ammonia N, chloride, hardness, alkalinity, organic carbon, particle sizes, PAHs, and total and filtered 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.

8. 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 a 0.10-acre 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 filtered phosphorus, total and filtered 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 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 those 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.

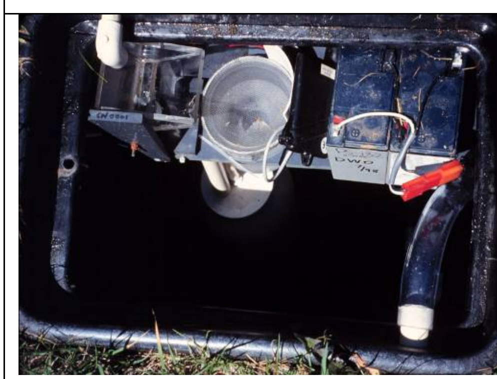
Although loads from a source area are greatly influenced by the volume of runoff, the large differences in some of the source area concentrations can decrease the importance of volume when comparing the loads from different source areas. For example, the volume of runoff from lawns is expected to be 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). Similarly, PAH concentrations from commercial parking lots can be 10 to 100 times higher than from other source areas. While commercial parking lots represent only 3% of an urban drainage area, they 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.	Maintenance Yard	4	40


Street sheetflow sampler installation


Roof runoff sampler


Sheetflow sampler and flow meter


Sheetflow sampling installation in lawn

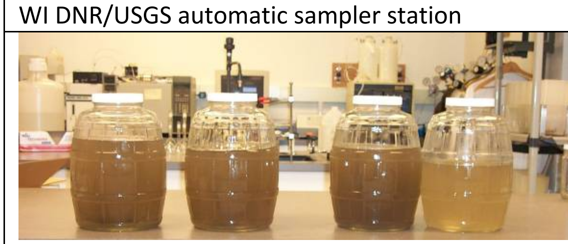
Source area sampling in Wisconsin (WI DNR and USGS)

Number of Source Area Samples Obtained

Source Area	Total Suspended Solids	Particulate & Filtered Phosphorus	Particulate & Filtered 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

The National Stormwater Quality Database (NSQD) is an urban stormwater runoff characterization database developed under the direction of Dr. Robert Pitt, P.E., of the University of Alabama and the Center for Watershed Protection under support from the U.S. Environmental Protection Agency. Originally released in 2001, followed by several updates by Dr. Pitt and Dr. Alexander Maestre (also while at the University of Alabama), it has recently moved to a new long-term home as a companion project to the International Stormwater BMP Database. The NSQD is being maintained as a separate stand-alone database, serving as an important resource for municipal stormwater managers and researchers who are seeking urban runoff characterization data. The NSQD can be searched for water quality data based on land use, state, and EPA Rain Zone, along with several other criteria. The NSQD can be downloaded from the website, and a new web application has been developed to accommodate custom data extraction queries. The NSQD Version 4.02 (last updated January 2015) can be downloaded in two formats containing the same information (http://www.bmpdatabase.org/nsqd.html).

The following table lists the constituents included in version 4.02 of the NSQD, and the number of observations (in some cases, most of the observations are below the reported detection limits).

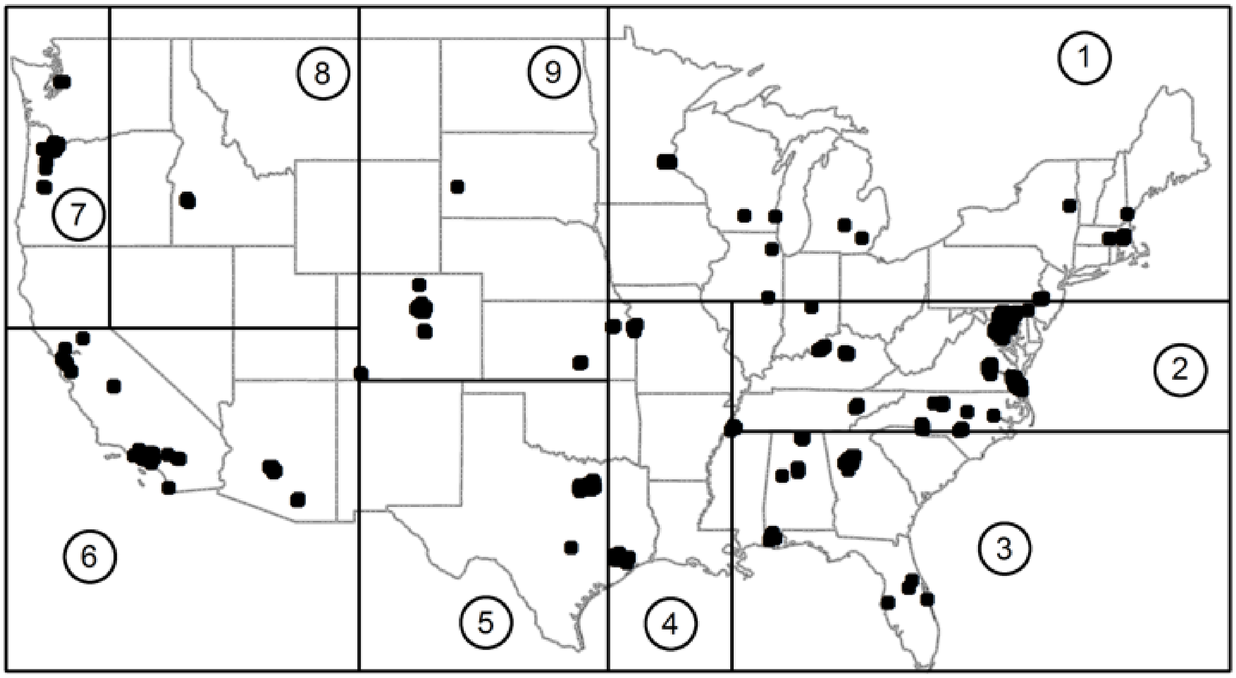
Constituents and Numbers of Observations Included in NSQD, version 4.02 (having at least 50 observations)

Total events: 9,130 Precipitation depth: 5,172 Runoff depth: 2,591 Hardness: 1,670 Alkalinity: 525 pH: 3,253 Temperature: 1,251 TDS, 4,158 Conductivity: 1,517 Chloride: 869 Total solids: 100 Total suspended solids: 7,713 Turbidity: 936 BOD5: 5,227 COD: 5,290 DO: 192 Fecal coliforms: 2,223 Fecal streptococcus: 1,317 Total coliforms: 282	Total nitrogen: 1,213 Total Kjeldahl N: 7,044 Total organic N: 66 Ammonia: 3,020 Nitrate N: 1,028 Nitrite N: 714 Nitrite + nitrate: 5,748 Total phosphorus: 8,019 Filtered P: 4,051 Ortho phosphate: 746 Filtered ortho P: 244 Total antimony: 1,584 Filtered antimony: 641 Total arsenic: 2,441 Filtered arsenic: 770 Total barium: 582 Total beryllium: 1,509 Filtered beryllium: 578 Total cadmium: 4,105 Filtered cadmium: 961	Total chromium: 2,328 Filtered chromium: 821 Total copper: 5,915 Filtered copper: 1,002 Cyanide: 1,338 Total iron: 608 Filtered iron: 556 Total lead: 363 (before 1984) Total lead: 5,032 (since 1984) Filtered lead: 1,016 (since 1984) Total mercury: 1,702 Filtered mercury: 706 Total nickel: 2,164 Filtered nickel: 807 Total selenium: 1,737 Filtered selenium: 682 Total silver: 1,880 Filtered silver: 766 Total thallium: 1,423 Filtered thallium: 653 Total zinc: 6,638 Filtered zinc: 984

Oil and grease: 2,330 Total petroleum hydrocarbons: 295 Acrolein: 464* Acrylonitrile: 205* Benzene: 213 Bromoform: 189* Carbon tetrachloride: 189* Chlorobenzene: 213* Chlorodibrimo methane: 189* Chloroethane: 213* Chloroethylvinylether: 624 Chloroform: 499 Dichlorobro methane: 116 1,1-Dichloroethane: 258* 1,2-Dichloroethane: 247 1,1-Dichloroethylene: 71*	1,2-Dichloropropane: 212* Trans-1,3-Dichloropropene: 150* 1,3-Dichloropropylene: 42* Ethyl benzene: 575 Methyl bromide: 207* Methyl chloride: 321 Methylene chloride: 457 1,1,2,2-Tetachloroethane: 222* Tetrachloroethylene: 99 Trichloroflourormethane: 156* Toluene: 573 1,2-Transdichloroethylene: 82* 1,1,1-Trichloroethane: 226 1,1,2-Trichloroethane: 222* Trichloroethylene: 83* Vinyl chloride: 222*

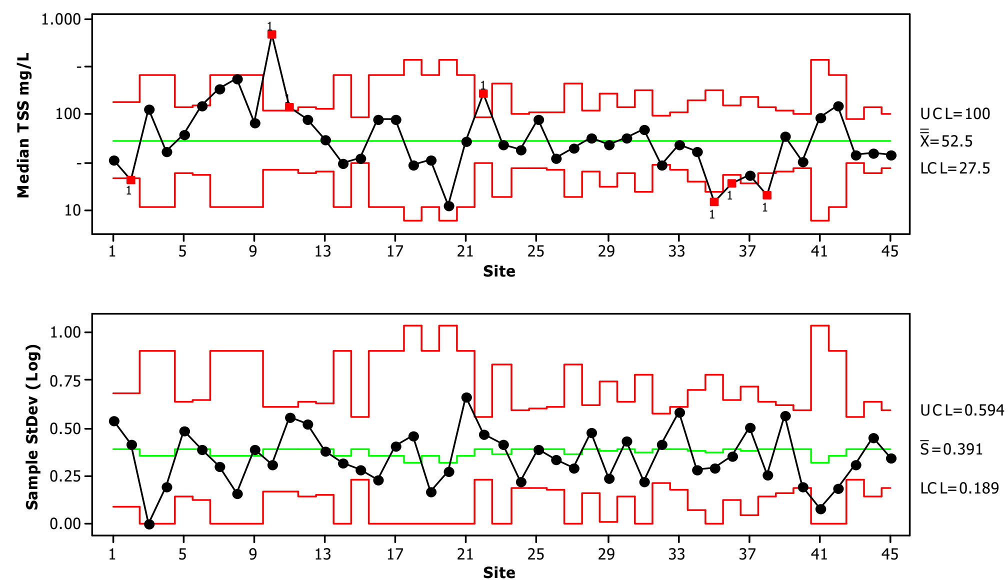
* All, or almost all, non-detected (about 13 organic compounds had the highest detection frequency)

The NSQD contains data from about 9,500 runoff events at 600 outfall sampling locations, with a median of 10 samples per site (maximum 115). Most of the data in version 4 was obtained from Phase I NPDES municipal monitoring programs, along with several other sources (USGS, BMP database outfall data before controls, special state and academic research programs, NURP, etc.). Most of the effort associated with the NSQD during its development included QA/QC processes to verify the data, especially for unusual conditions. The following map shows the locations of the data within EPA rainfall zones (not the same as EPA administrative regions).



Distributions of NSQD data sources per EPA rainfall zones.

Maestre (many publications, including his Ph.D. dissertation, Maestre 2005) was one of the primary researchers who helped develop and evaluate the NSQD. He investigated first-flush factors, examined distributions of the values and explored various data substitution options for handling non-detectable values, amongst many other interesting stormwater and data analysis issues. The following figures are an example of Xbar-S charts he prepared for each constituent to identify sites within a land use group that did not appear to fall within expected data distributions. He then reviewed those sites, including examining aerial photographs.



Xbar-S chart of Total Suspended Solids in commercial land use sites indicating unusually high values at some locations (Maestre and Pitt 2006 and 2007).

The following figure is an example from one of the questionable sites that had high suspended solids concentrations. This photograph shows evidence of sediment tracking from an adjacent sand and gravel operation affecting an adjacent monitored commercial site.

Aerial photograph of a monitored commercial area having unusually high TSS concentrations showing proximity to quarry operation.

It is well known that stormwater characteristics vary considerably. Geographical area and land use have been identified as important factors affecting base flow and stormwater runoff quality, for example. Many graduate students and other stormwater researchers have used earlier versions of the NSQD to explore potential relationships of factors that may affect stormwater quality. As an example, Bochis (2010) during her PhD research using an earlier version of the NSQD calculated the main factors and interactions affecting stormwater quality, as shown on the following table. Yellow and green cells note statistically significant relationships ($p<0.05$); yellow should be used for predictive purposes as they contain the highest order interaction terms.

Main Factors and Interactions Affecting Stormwater Quality (Bochis 2010)

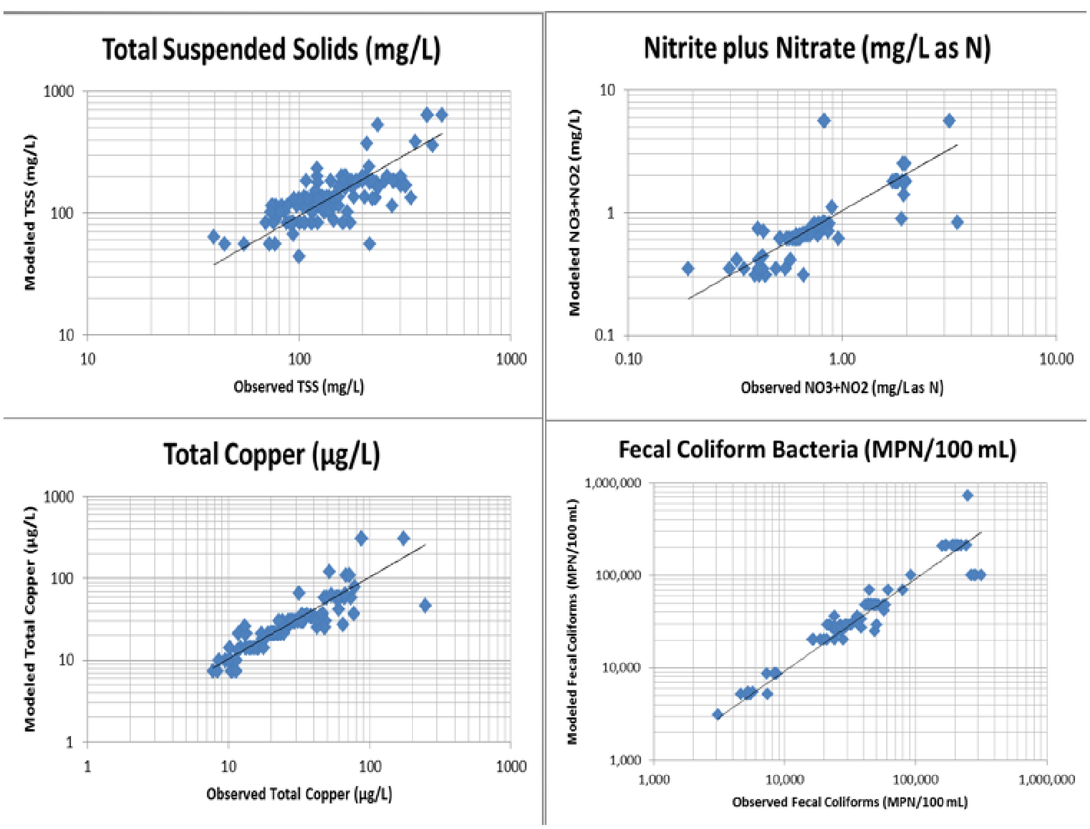
Constituent	Land Use (LU)	Season (SN)	EPA Rain Zone (EPA)	LU*SN	LU*EPA	SN*EPA	LU*EPA*SN
TSS mg/L	<0.0001	0.74	<0.0001	0.017	<0.0001	0.18	<0.0001
BOD_5 mg/L	<0.0001	0.16	<0.0001	0.0008	<0.0001	0.0011	0.22
COD mg/L	<0.0001	0.13	<0.0001	0.034	<0.0001	0.014	0.0085
TP mg/L	<0.0001	0.69	<0.0001	0.055	<0.0001	0.0004	<0.0001
$NO_2 + NO_3$ mg/L	<0.0001	0.11	<0.0001	0.052	<0.0001	0.034	0.057
TKN mg/L	0.0026	0.024	<0.0001	0.99	<0.0001	<0.0001	0.17
Cu mg/L	<0.0001	0.11	<0.0001	0.62	<0.0001	0.038	0.14
Pb mg/L	<0.0001	0.76	<0.0001	0.42	<0.0001	0.29	0.011
Zn mg/L	<0.0001	0.91	<0.0001	0.94	<0.0001	0.014	<0.0001

Land use is a consistent factor affecting the observed variation in stormwater quality, while location (EPA rain zones) are also very important, while season alone had little effect. An example use of these data to calibrate WinSLAMM for different regions in the US is shown by Pitt (2011). The following table shows the land use and location distribution of 114 locations that had detailed development characteristics available to supplement the NSQD water quality data.

Number of Locations by Geographical Area and Land Use for WinSLAMM Regional Calibration Examples

	Commercial	Industrial	Institutional	Open Space	Resid.	Freeways/ Highways	Total by Region
Central	4	2	4	1	5	3	19
East Coast	3	1	1	1	2	3	11
Great Lakes (the USGS/DNR files)	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

These areas were described in WinSLAMM using the best available site data. The long-term average modeled concentrations were compared to the observed concentrations for each location. Example comparison scatterplots are shown below. Obviously, some constituents had better matches than others, but the lines of equal values were all significant. It should be noted that all models require calibration and verification. The NSQD is a good place to start for preliminary analyses, but additional locally collected information is necessary for the greatest reliability.



WinSLAMM modeled and observed concentrations for selected NSQD locations.

Example use of NSQD Data for Local WinSLAMM Calibration ++++++

The recommended strategy for using WinSLAMM is to start with supplied example parameter and rain files. The most important element will be to prepare a site file based on accurate site descriptions and measurements. It is possible to prepare a site-specific rain file using local data (needed for the specific rains included in a local monitoring effort), or download data from NOAA. Collection of local or regional outfall monitoring data is also strongly recommended in order to modify the parameter files, as needed. The NSQD (available at: http://www.bmpdatabase.org/nsqd.html) can be used to locate regional data that may be suitable for preliminary calibration. Again, detailed site investigations to be able to obtain an accurate file of all locations will be needed. This white paper presents an outline, with examples, of how the parameter files can be modified using regional data.

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-examine the prior calibration of WinSLAMM for local conditions. The model was originally calibrated in the mid-1990s using locally obtained sheetflow data (Pitt, *et al.* 2005a, b, and c).

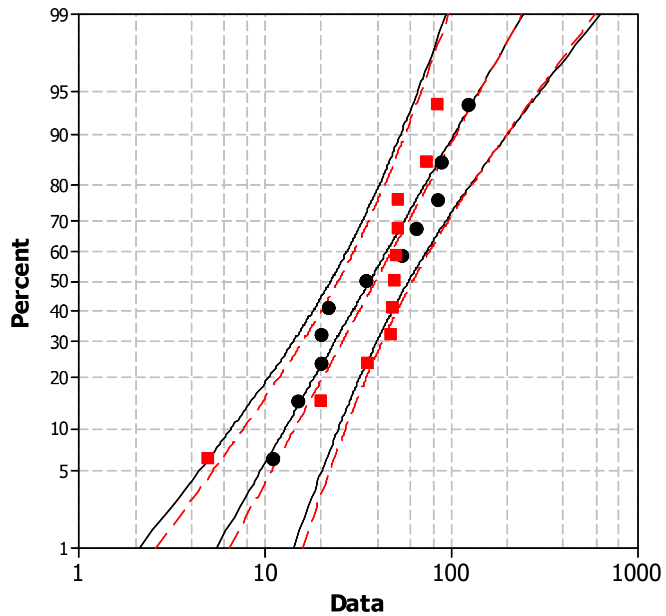
In order to construct WinSLAMM files, several types of information about the site is needed, such as descriptions of the drainage system (grass swales, curb and gutter in good/fair/poor condition, undeveloped roadside) and the fraction of each type of drainage system serving the study area; the soil type (sandy, silty, clayey, and compaction levels); 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.

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.

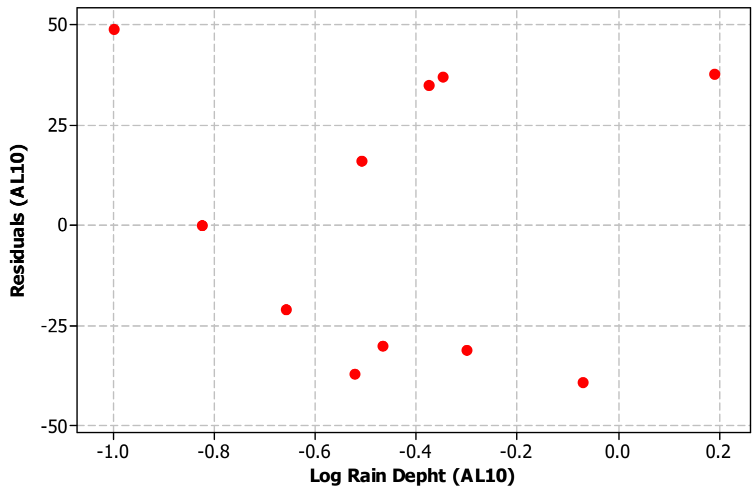
Data from five drainage areas are available for the re-calibration and verification process. Therefore, the calibration process started with data from the simplest and most uniform drainage area (one that has only a single land use); these areas were calibrated first before moving on to more complex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

One data file 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.

The re-calibration process was started by running the WinSLAMM files for the monitored drainage areas using their own rain file, and the particulate file 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, as shown below. The data was plotted using a log- normal distribution. The data and model values should form approximately a straight line, as most stormwater pollutants are log-normally distributed. Departures from this straight line indicate departures from the specified 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, also shown below. Also, the sum of the observed and predicted particulate solids concentration (mg/L) for all monitored events was calculated. The percentage difference in the sum of concentrations should be small, indicating small changes needed. The largest percentage differences in the particulate solids concentrations are associated with small rain depths (WinSLAMM will probably over-estimate the concentrations), while the differences for the larger rains are smaller. WinSLAMM calibration for particulate solids concentrations and loadings was accomplished by modifying the STREET.STD and BHAM.PSC files.



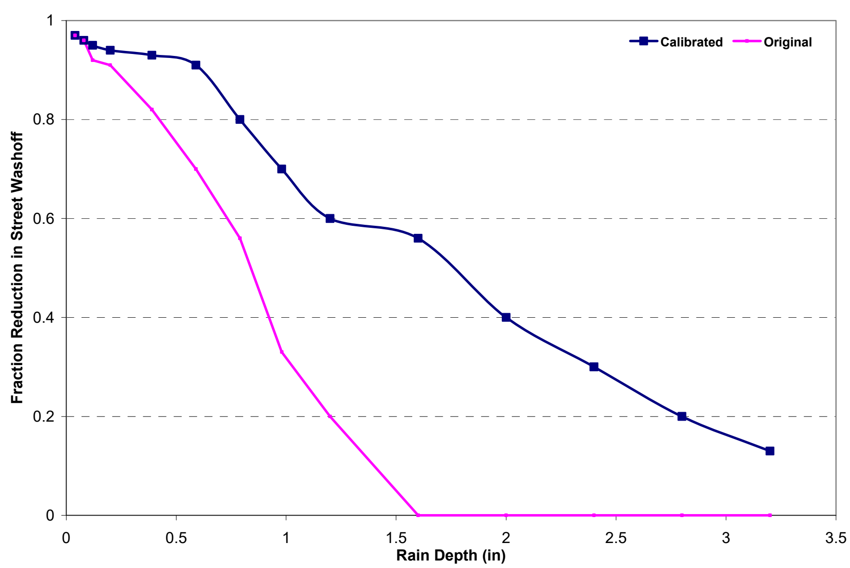
Example of Log-Normal Probability Plot for Site ALJC010 Particulate Solids (Residential Land Use) (red squares are modeled values and black dots are observed values).



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

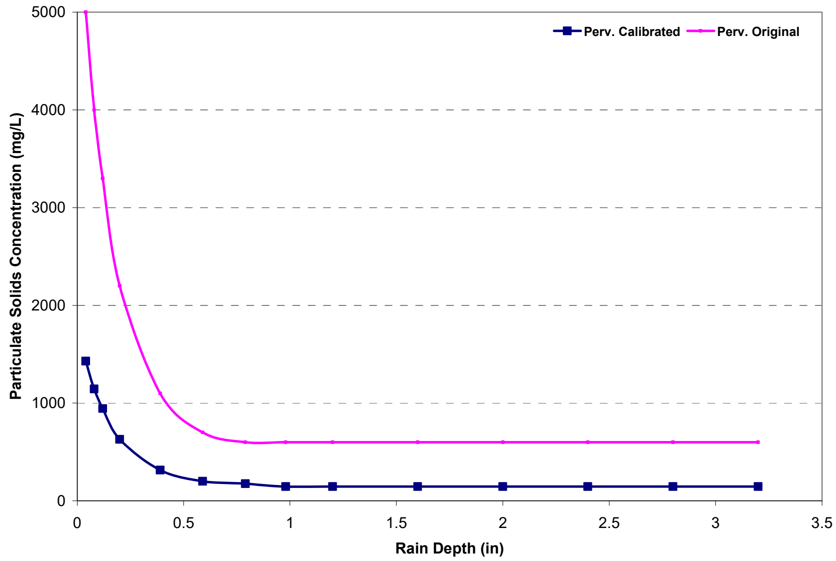
Grass swales, undeveloped roadsides, and flat curbs and gutters have slow runoff velocities and lower carrying capacities of sediment than flows in steeper areas or smoother gutters. The grass swale drainage model component calculates the delivery of the sediment along the swale, considering deposition of the particulates and infiltration of the runoff.

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, with an example shown below.



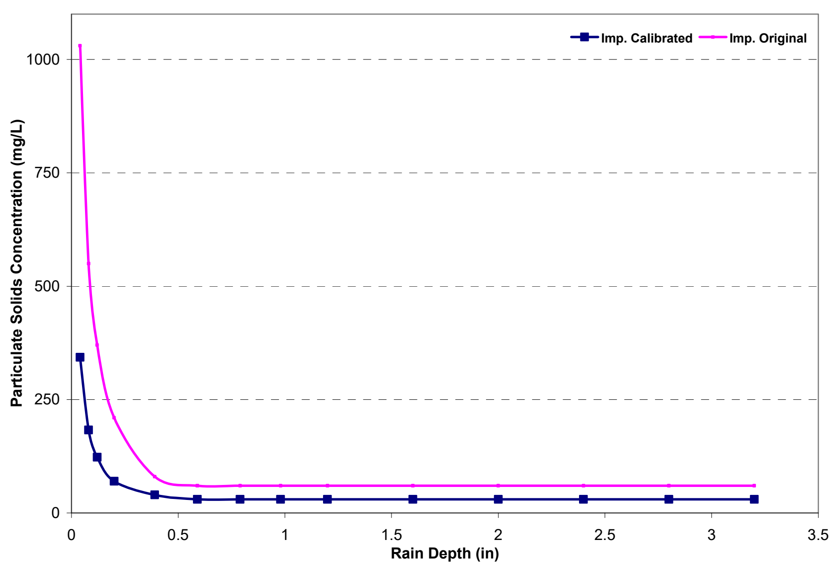
Example of Street Delivery File. *.STD (for Residential Land Uses)

The *.PSCX 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 *.PSCX 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, the percentage PSC values were modified more for the larger storms than for the smaller storms, as shown below.



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

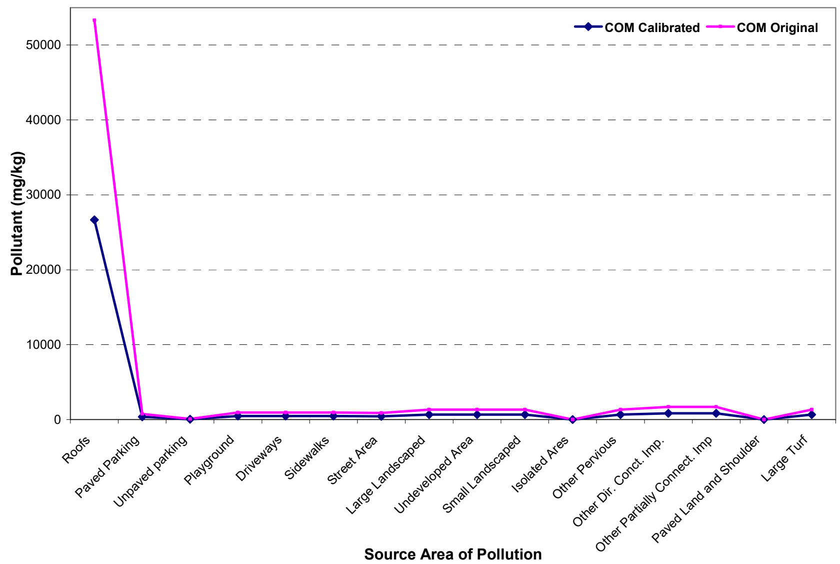
After each change was made, the program was re-run using the new parameter file and the results were reviewed. It was necessary to repeat this process a few times to become satisfied that no further improvements were possible.



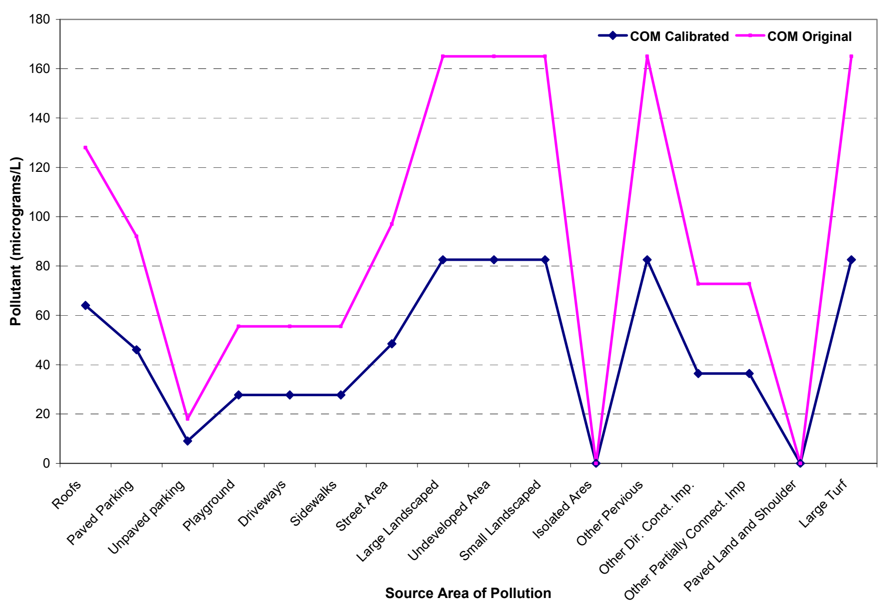
Example of Particulate Solids Concentration File for Residential Land Use - Impervious Surfaces

The pollutant file BHAM.PPDX 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 *.PSCX 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, as shown below.



Example of Particulate Zinc for Commercial Land Use, *.PPDX



Example of Filterable Zinc Concentration for Commercial Land Use, *.PPDX

Once again, after each change was made to the pollutant file, the program was re-run using the new *.PPDX 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.

WinSLAMM Uses at Heavy Industrial Sites

Use of WinSLAMM at US Navy Installations

WinSLAMM has also been modified to incorporate features for use at industrial sites and other locations where exposed materials can contribute stormwater contamination. One case study example includes a series of projects conducted for the US Navy and several navy installations from 2014 through 2018. Case studies of WinSLAMM use at these navy industrial areas are located at: https://www.winslamm.net/dr_pitt_presentations_and_publications.html#NavyStormwatermonitoringandmodelingreports2010to2017

These studies collected site data for calibrating WinSLAMM for several stormwater drainage areas at Naval Base San Diego comprising residential, commercial, and institutional land uses, along with the industrial Sierra Pier at Subase San Diego. Two sites at Norfolk, VA, naval facilities were also investigated (Little Creek and St. Juliennes Creek Annex) which included an industrial facility and a scrapyard and storage area. Three areas were also investigated in the Puget Sound area of Washington (at the Bangor, Bremerton, and Everett naval bases) including industrial areas and piers.

Data collected at these sites described soil, weather, and land development conditions. Available stormwater quality data were also summarized and used to calibrate WinSLAMM for each site. Additional analyses were also conducted investigating first flush vs. composite water quality and seasonal first flush conditions. After WinSLAMM calibration using the available data, the model was used to calculate the sources of the flows, TSS, copper, and zinc at these naval bases. The site variations of these bases represent a wide range of conditions.

The first calibration activities focused on the TSS data at each location and land use. Calibration started using the regional NSQD calibration files for the southwest for all land uses besides the industrial areas (which used the navy calibrated files from a prior study). Model runs were conducted using truncated rain files that had the best rain data available corresponding to the events monitored at the site. The TSS concentrations and mass loadings were examined for patterns and other relationships to indicate where adjustments were needed. As an example, if the loads for the small events were low, the directly connected impervious areas (locations that generated flows during the small events) were adjusted to closely match the observed loads. Then the complete rain series available was examined and adjustments were then made to the non-paved areas to closely match the observed loads. When multiple sites of the same land use occurred at one area, all of the land use areas were examined and adjusted together to obtain the least sum of squares of the residuals. Basically, the sum of all the event loads for all sites were compared and the ratio of the observed to the calculated load sum was then used as a factor to modify the calibration file data (the industrial parameter files were not changed from the prior calibrations).

Besides the particle concentration file data, changes were also simultaneously made to the street TSS washoff delivery file (as the street runoff TSS load is calculated by the model and does not use a calibration file directly). Therefore, matching the sum of loads for the observed and calculated data sets was the primary calibration objective. When a satisfactory overall match was obtained, further analyses were conducted examining individual event loads and concentration values. Further adjustments were made in an attempt to best represent the overall range and variation in loads and concentrations.

After the TSS calibrations were completed, copper and zinc calibrations were next conducted for both particulate and filtered conditions, starting with mass discharges and then concentrations. After these calibrations were made for the residential, commercial, and institutional land uses, the prior industrial calibration files were used for newer industrial areas for the California and Washington sites. The Virginia industrial calibrations only reflected the current data as prior naval facility data were not available for that area.

The performances of the calibrations were good for the load calculations, but not as good for some of the concentration data. While the average concentrations matched well, the calculated concentration values for individual events sometimes were less variable than observed. This is mostly associated with various uncertainties of the monitored data, such as the periodic monitored events over long periods of time resulting in artificially long interevent periods (partially compensated by using special street delivery factors), varying amounts of observations from the different sites for the different constituents, and unknown site activities in the past that do not correspond to currently observed site conditions.

Observed and Calculated TSS Loads and Average Concentrations

			TSS sum of loads, total (lbs)		TSS conc., average (mg/L)	
		Number of monitored events	observed	calculated	observed	calculated
All San Diego resid/commer sites combined		32	4,822	4,759	149	78
Virginia, St. Juliennes OF 40&41	scrapyard	7	384	458	19	21
Washington, Bangor OF 02	Large industrial area with swales	4	808	670	5	61 (w/o swale effects)

Observed and Calculated Total Copper Loads and Average Concentrations

			Total copper, sum of total loads (lbs)		Total copper conc., average (µg/L)	
		Number of monitored events	observed	calculated	observed	calculated
All San Diego resid/commer sites combined		23	2.33	2.48	90	81
Virginia, St. Juliennes OF 40&41	scrapyard	7	0.62	0.60	24	30
Washington, Bremerton OF15	Large mixed land use area	11	1.02	1.03	10	9.8
Washington, Bangor OF 02	Large industrial area with swales	14	0.079	0.17	8.2	14
Washington, Everett, OFA	Industrial piers	13	0.37*	0.08	142*	37

* several very high concentrations observed

Observed and Calculated Total Zinc Loads and Average Concentrations

			Total zinc, sum of total loads (lbs)		Total zinc conc., average (µg/L)	
		Number of monitored events	observed	calculated	observed	calculated
All San Diego resid/commer sites combined		17	13.0	15.7	766	480
Virginia, St. Juliennes OF 40&41	scrapyard	7	1.9	3.1	91**	158
Washington, Bremerton OF15	Large mixed land use area	11	6.3	6.3	61	60
Washington, Bangor OF 02	Large industrial area with swales	14	0.42	0.49	44	46
Washington, Everett, OFA	Industrial piers	13	0.23	0.26	102	122

* several very high concentrations observed

** filterable concentrations greater than total concentrations when both sites examined

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Appendix A: Neighborhood Surveys in Urban Land Use Areas

An “Area Description” field sheet is used to record important characteristics of the homogeneous land use areas during the field surveys. In addition, aerial photographs, such as from GoogleEarth https://maps.google.com/maps?hl=en&tab=nl or other high resolution satellite images or drone surveys are used to measure the actual coverage of each type of surface in each neighborhood studied. This appendix describes the field sheet and the information requested. Several reports describing the use of these sheets and land development characteristics are located at: https://www.winslamm.net/dr_pitt_presentations_and_publications.html#LandDevelopmentCharacteristics.

Location: Site number:
Date: Time:
Photo numbers:
Land-use and industrial activity:
Residential: low medium high density single family
multiple family
trailer parks
high rise apartments
Income level: low medium high
Age of development: <1960 1960-1990 1990-2010 >2010
Institutional: school church hospital other (type):
Commercial: strip shopping center/mall downtown hotel offices
Industrial: light medium heavy (manufacturing) describe:
Open space: undeveloped park golf cemetery
Other: freeway utility ROW railroad ROW other:
Maintenance of building: excellent moderate poor
Heights of buildings: 1 2 3 4+ stories
Roof drains: % underground % gutter % impervious % pervious
Roof types: flat composition shingle wood shingle galvanized metal other metal other:
Sediment source nearby? No Yes (describe):
Treated wood near drainage system or directly connected pavement? No telephone poles fence other:
Landscaping near road or directly connected impervious surfaces:
Quantity: none some much
Type: deciduous evergreen lawn
Maintenance: excessive adequate poor
Leafs on street: none some much
Topography:
Street slope: flat (<2%) medium (2-5%) steep (>5%)
Land slope (next to street): flat (<2%) medium (2-5%) steep (>5%)
Traffic speed: <25mph 25-40mph >40mph
Traffic density: light moderate heavy
Parking density: none light (20 to 50%) moderate (50 to 80%) heavy (>80%)
Width of street: number of parking lanes:
number of driving lanes:
Condition of street: good fair poor
Texture of street: smooth intermediate rough very rough
Pavement material: asphalt concrete unpaved
Driveways: paved unpaved
Condition: good fair poor
Texture: smooth intermediate rough
Gutter material: grass swale lined ditch concrete asphalt
Condition: good fair poor
Street/gutter interface: smooth fair uneven
Litter loadings near street: clean fair dirty
Parking/storage areas (describe):
Condition of pavement: good fair poor
Texture of pavement: smooth intermediate rough unpaved
Directly connected to drainage: yes no
Other paved areas (such as alleys and playgrounds), describe:
Condition: good fair poor
Texture: smooth intermediate rough
Directly connected to drainage: yes no
Other notes/comments:


Example of sub meter color satellite image (Google).

Instructions for Basic Field Inventory Sheet
Each homogeneous area to be investigated in each survey sheet usually covers about 4 blocks (can be along a street or more commonly, an enclosed area a block on a side). The areas are identified before going into the field from aerial photographs based on similar visual characteristics. For shopping malls, hospitals, and other single land uses, each field sheet is for one location. Large industrial areas (especially) that contain a variety of critical source areas need more detailed site surveys that are discussed in Appendix B.

• *Location*:
The block address number range and the street name are noted. A sub-area name can also be used to describe the drainage area, or portion of town. A field sheet is filled out for each homogeneous land use sampling area being investigated in the study area. Specific blocks to be surveyed are selected based on maps and aerial photographs before the survey is conducted. Each site needs at least two photographs taken: one is a general scene, and the other is a close-up showing about 25 by 40 centimeters of pavement. Additional photographs are usually taken to record unusual conditions. A photograph is also taken of the completed field sheet at the end of each neighborhood survey to separate and label the images. These photographs are very important to confirm the descriptions recorded on the data sheets and to verify the consistency of information for the different areas within each category. The photographs are also very important when additional site information is needed, but not specifically recorded on the data sheets. Google street view can also be used to supplement the site surveys, but

they cannot replace going into the field (especially for off-street features such as roof drain disconnections).

• *Land-use*:
The land-use type that best describe the block is circled. These definitions may need to be modified based on local practice and information. Also, some of the homogeneous areas may need to be re-categorized after the data is obtained. As an example, the housing density initial estimates may be incorrect for some areas and the surveyed areas may need to be moved to another category after the accurate measurements are available. If more than one land-use is present in an area being studied (would happen if conducting a survey in a monitored area), then a separate form should be used for each homogeneous land use subarea. The approximate income level for the residential areas is also circled. The specific types of industrial activities (warehouses, metal plating, bottling, electronics, gas station, etc.) for industrial and commercial areas are also noted on the form, but more detailed information, discussed later, should also be obtained. Also, the approximate age of development is circled.

• *Roof drainage*:
The discharge locations of the roof drains are also noted on the form. The approximate distribution of the discharge locations is noted if more than one location is evident. This is determined by driving around the complete area and tallying the roof drain locations (on the back of the field sheet, for example). It is assumed that all backyard drains are disconnected, unless alleys are present. In that case, drive the alleys and note the back drain connections. Obviously, do not trespass to view all the drains. The "underground" location may be to storm sewers, sanitary sewers, or dry wells. Some areas have roof drains apparently directed underground but are actually discharged to the roadside gutter or drainage ditch. If they lead to the gutter (discharge locations are usually seen along the gutter), then the "to gutter" category is circled. Additionally, if the flow path length is less than about five feet (flat, shorter if steep) over pervious ground for a typical house, it is functionally directly connected to impervious areas, requiring circling the "to impervious" category. The roof types and building heights are also indicated (again, the approximate distributions are noted if more than one type is present in the "homogeneous" subarea). It is necessary to take an inventory of all visible roof drains in the substudy inventory area by keeping tallies of each type of drain connection. The distribution of the percentage per connection type is put on the inventory sheet. If other categories of characteristics vary in the study block (paved or unpaved driveway categories is another common variation), then these are also tallied for the area and the results shown on the sheet.

A directly connected roof drain	A disconnected roof drain (drains to pervious area)
 Pitched metal roof	 Flat commercial roofs
 Underground roof drain (not clear where it is connected)	 “Underground” roof drain (showing perforations to allow release if water backs up, possibly draining to underground dry well or french drain)

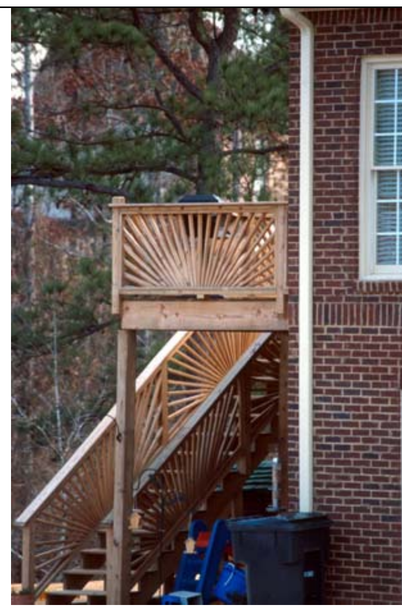
• *Sediment sources*:

Sediment sources near the drainage (street, drainage way, or gutter), such as construction sites, unpaved driveways, unpaved parking areas or storage lots, or eroding vacant land, are described and photographed.

 Soil erosion from landscaped areas having fine-grained soils during periods of high rain intensities	 Scoured drain pathway from paved area.
 Utility work near street.	 Unprotected slope.

Erosion source (bare soil near pavement)

• *Treated wood near drainage system or directly connected impervious area:*
Circle or describe any treated wood that is located near any directly connected impervious area. Most wood treatment chemicals (heavy metals or organic compounds) are effectively captured if drained to landscaped areas. If these areas drain to pavement, much of the toxicants can directly enter the drainage system. Also describe the type of wood preservative, if possible (Copper-chromium-arsenic, CCA, creosote, etc.).

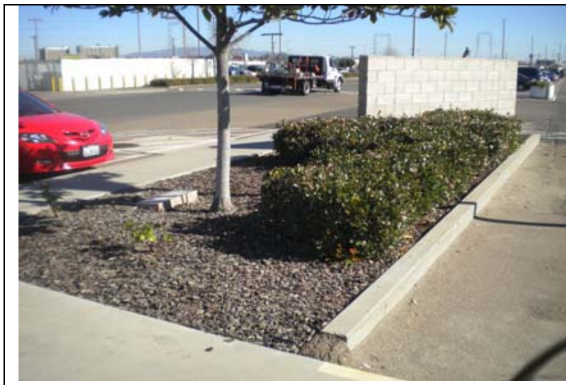


Treated wood near drainage system or directly connected impervious areas can contribute toxicants to the storm drainage system.

• *Landscaping near road or directly connected impervious surfaces:*
Describe the type of landscaping near the road and other directly connected impervious surfaces. Large amounts of trees near these areas can add nutrients to the stormwater. Deciduous vegetation can add large amounts of leaf litter in the fall that requires special cleanup operations to prevent clogging of the drainage system. Excessive maintenance (total absence of weeds, for example) implies an excess amount of chemical use (fertilizers, herbicides, and pesticides) that also contribute to stormwater degradation.

Wide arterial street with little roadside vegetation.

Narrow residential street with substantial adjacent vegetation.

 Parking lot island (raised bed is not a biofilter area, but could be easilty converted)	

• *Parking density:*
Vehicles parked along a street cleaning route reduce the length of curb that may be cleaned by municipal street cleaning operations. Since most of the street surface pollutants are found close to the curb on smooth streets with little parking, parked vehicles can significantly reduce the cleaning effectiveness of normal cleaning programs on these streets. Extensively parked cars block the migration of particulates towards the curb, resulting in higher “middle of the street" loading values than for streets with little or no parking. The percentage of curb length occupied by parked vehicles is close to the percentage of parking spaces occupied, but is usually smaller due to parking restrictions such as driveways and fire hydrants. As the number of parked cars increase, the percentage of' curb left uncleaned by street cleaning operations increases proportionally, especially as the street cleaning equipment must also maneuver around the parked cars.

If a smooth street has extensive on-street parking 24 hours a day (such as in a high-density residential neighborhood), most of the street surface particulates would not be within the 8 ft. strip next to the curb that is usually cleaned by street cleaning equipment. If the percentage of curb length occupied by parked cars exceeds about 80 percent for extensive 24-hour parking conditions, it would be best if the parked cars remained and the street cleaner swept around the cars (in the 8 to 16 ft. strip from the curb). Of course, all of the cars should be removed periodically to allow the street cleaner to operate next to the curb to remove litter caught under the cars. In an area with extensive daytime parking only (such as in downtown commercial areas), the parked cars should remain parked during cleaning (daytime cleaning) if the percentage of curb length occupied exceeds about 95 percent.

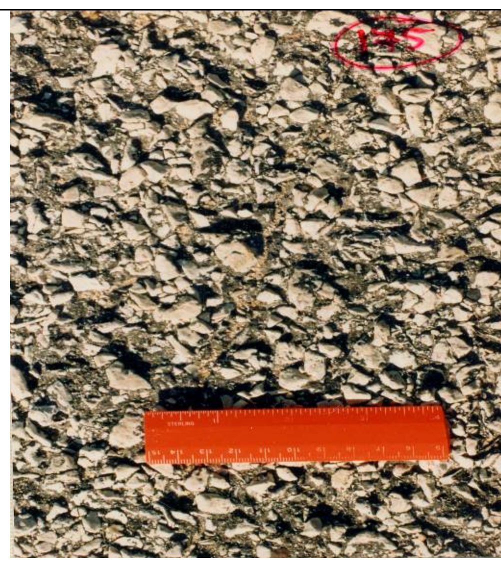
• *Street and Pavement*:
The numbers of traffic and parking lanes are also noted on the field sheet. Pavement condition and texture are different characteristics and are noted separately. Condition implies the state of repair, specifically relating to cracks and potholes in the pavement. Texture implies roughness. A rough street may be in excellent condition: many new street overlays result in very rough streets. Some much worn streets may also be quite smooth, but with many cracks. Rough or streets in poor condition have much greater street dirt loadings and are much more difficult to clean with street cleaning equipment. They also produce less washoff of the street dirt during rains. Smooth streets are cleaned by both street cleaning equipment and rains more effectively.

A close-up photograph of the street surface is used to make final determinations of street texture by comparing with reference photographs. An overview photograph of the street is also taken to make the final determination of the street condition. The gutter/street interface condition is an indication of how well the street pavement and the gutter material join. Many new pavement overlay jobs result in uneven pavement near the gutter, resulting in a several centimeter ridge along the gutter/street interface. If the street interface is in poor condition or is uneven, an additional photograph is taken to show the interface close-up. The litter perception is also indicated on the field sheet and another photograph is taken of heavily littered areas.


Smooth textured street.


Intermediate textured street.


Rough textured street


Very rough textured street.

 Paver blocks (these appear to be grouted and don't allow infiltration, but substantial detention storage during smaller rains).	 Rough textured pavement
 Concrete in poor condition (large numbers of large cracks)	 Very rough pavement (worn)
 Dirty asphalt parking lot	

Basic Aerial Photographic Measurements of Source Areas

Measurements of the source areas from aerial photographs are also needed to quantify the areas associated with each area description (areas of roofs that are directly connected, areas of parking areas that are disconnected, areas of rough textured streets, etc.). After the field data description sheets are filled out during each neighborhood survey, the corresponding aerial photographs and/or GIS maps are examined, and the individual elements (roofs, parking areas, street areas, sidewalks, landscaping, etc.) are measured. This can be done manually or by using automated tools, such as GIS Tools. The aerial photograph area measurements are usually tabulated and summarized in Excel spreadsheets. These data are then used to build the WinSLAMM files to describe each land use area. This information can be manually measured from aerial photographs and recorded on data sheets, using one sheet for each site surveyed. An example of this manual measurement data sheet is shown below, but most current measurements are done with GIS systems.

Little Shades Creek Stormwater Study - Site Characteristics

Site #: 66 Land use: Single-Family Zoning: R-1 Govt: Vest.

Description: High density buildings

Location: Chestnut Road

Total area: 11.6 ha.

Total number of units in area: 31 Density: 2.67 /ha

Streets: Total street length: 992.2 m Street length density: 85.53 m/ha

Average street width: 6.05 m Street area: 6002.8 m²

Street area density: 517.48 m²/ha

Grass area between sidewalk and street: width: ___ m length: ___ m

area: ___ m² density: X m²/ha

Sidewalk: width: ___ m length: ___ m area: ___ m² density: X m²/ha

Front landscaping: average per unit 2350 m² x 31 # units = 72838 m²

density: 6279 m²/ha

Driveways: avg. per unit 78.65 m² x 31 # units = 2438.15 m² density: 210.19 m²/ha

100 % paved; 210.19 m²/ha

0 % unpaved; 0 m²/ha

Parking areas: ___ m² density: X m²/ha 5459.8

___ % paved; X m²/ha

___ % unpaved; X m²/ha

Storage areas: ___ m² density: X m²/ha

___ % paved; X m²/ha

___ % unpaved; X m²/ha

Playgrounds: ___ m² density: X m²/ha

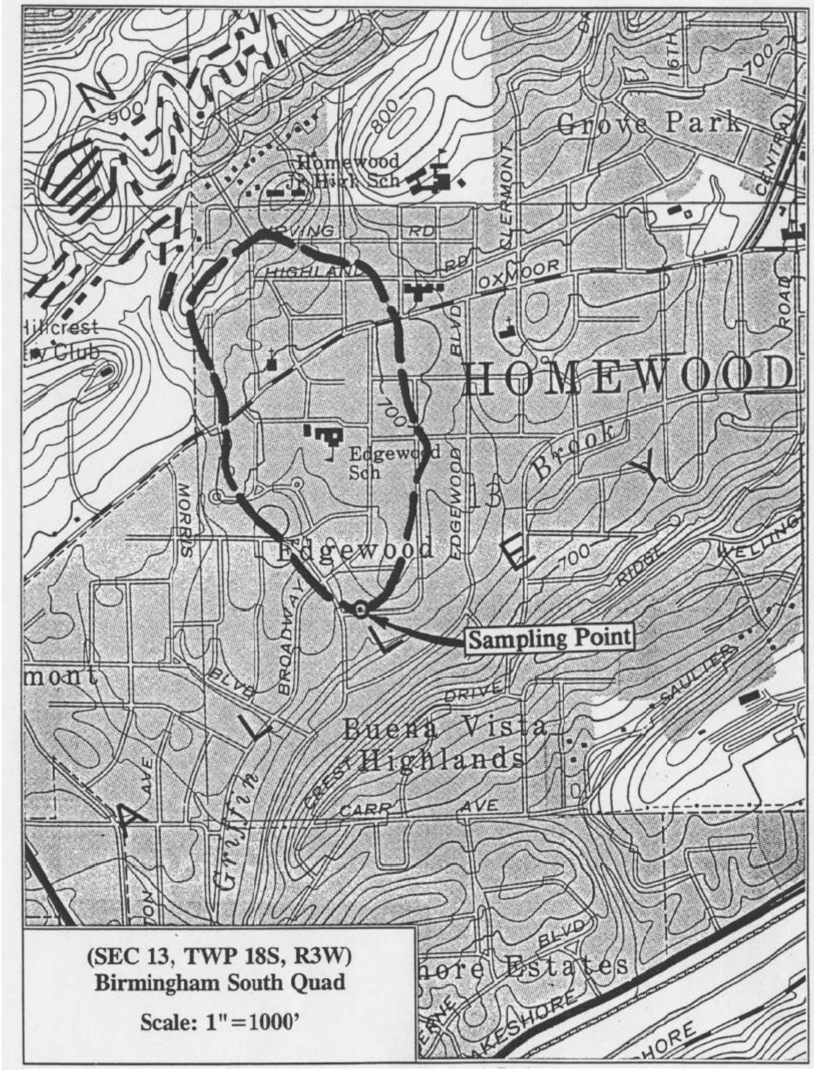
___ % paved; X m²/ha

___ % unpaved; X m²/ha

Bochis (2007) examined several different approaches using automated methods to acquire the source area data as part of a stormwater study in Jefferson County, AL. The first step was to obtain satellite imagery taken during 2001 and 2003, plus watersheds paper maps from the Storm Water Management

Authority of Jefferson County (SWMA). All images were originally purchased from Space Imaging and acquired by IKONOS Satellite imagery which is a high-resolution satellite operated by Space Imaging LLC. IKONOS produces 1-meter black-and-white (panchromatic) and 4-meter multi-spectral (red, blue, green, near infrared) imagery that can be combined in a variety of ways to accommodate a wide range of high-resolution imagery applications. The satellite was launched on September 24, 1999, and has been delivering commercial data since early 2000. Google maps now can provide higher resolution aerial photographs and Lidar systems on drones can collect very detailed cm scale maps.

The second step was the electronic delineation of the study watersheds using map digitizing and GIS tools. The multi-spectral image of Jefferson County and the paper maps of the watersheds were used to manually digitize and then cut each of the watersheds using ArcGIS 9 (ArcMap). Each watershed was saved separately as a shape file (.SHP). The following are examples of a high-density residential shape file, showing the location on the USGS quad map and the cut out shape aerial image. Since these were monitored watersheds, they included a mixture of land uses, although each was predominately a single land use. Therefore, several homogeneous land use neighborhoods were inventoried in each watershed to represent each of the land uses present. The areas of these land uses were also determined and the characteristics of the complete watershed were therefore known.



ALJC009: HIGH DENSITY RESIDENTIAL- SHADES CREEK BASIN

Mixed High Density Residential Area - Site Satellite Image (Bochis 2007).

The multi-spectral Jefferson.sid aerial images were obtained from the National Aerial Photography Program (NAPP) which were further processed by SWMA. Film negatives were purchased by SWMA from the USGS and were scanned and saved into digital format, orthorectified and sid'ed into USGS quad arrangements (one singular layer). They were not scanned by a metric scanner (which would have resulted in sharper and more precise output images).

The National Aerial Photography Program was initiated in 1980 and coordinated by the USGS. The purpose is to acquire aerial photography of each of the 48 lower states every five years. They are acquired at 20,000 feet elevation and centered on 1:24,000 scale USGS maps, with eight frames making up one USGS quadrangle map. Each frame represents 32.3 sq.mi. at 2-ft pixels. Final output are digital ortho quarter quads (DOQQ) and revised approximately every five years. For more information about NAPP, see: http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/NAPP. The next step used the two 1-meter panchromatic satellite images ("Leafoff.img" flown December 2000 and "Leaffon.img", flown summer 2001; raster format "ERDAS IMAGE", number of raster bands: 1) of Jefferson County.

These images were purchased by SWMA from Space Imaging and were assembled into mosaics using a PLSS-Township arrangements. It is complete for the entire county area, but with cloud obstructions in some areas. The overlapping/cutting process made use of GIS Tools: ArcInfo, ArcToolbox and ArcMap 8.9. Each image was saved separately (.IMG extension) having the equivalent name of the watershed.

The satellite image measurement process was initially used to describe the different land uses within the watersheds. For residential land uses, the most visible neighborhoods (having minimal cloud cover) were selected, and their individual elements were electronically measured. However, for industrial, commercial, and institutional areas, it was necessary to take account of all the elements incorporated in the land use due to greater variabilities of the different surface cover areas. The areas of the individual elements were calculated using ArcGIS and stored in the shape file attribute table.

Data measurement storage and processing

The older Little Shades Creek area measurements were obtained manually from aerial photographs and then transferred to Excel worksheets. The individual elements of the six Jefferson County watersheds were measured in square feet units and recorded directly in an electronic format (.dBASE IV). For easier handling of these data, the files were later converted into Excel worksheet files. Data normalizing was also performed to account for rounding errors.

In order to construct WinSLAMM files, several types of information about the sites are needed: 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); some of the field information (roof type, street texture, etc.), and the area measurements normalized data. All of the information was obtained during the field surveys, or during the aerial photograph measurements. A number of communities have incorporated direct connections between their GIS systems and WinSLAMM, automating the development of the source description files. In other areas, regional agencies have created standard land use files based on extensive regional surveys for direct use by stormwater managers in their areas. However, for more variable areas, site specific surveys for the drainage areas for the outfalls of interest are needed.

Appendix B: Field Surveys at Industrial Source Areas Having Material Exposures Affecting Stormwater Quality

Besides the above listed basic source area categories, ten "other impervious areas" are available for each land use. For the Navy calibrated WinSLAMM model, they were identified in the industrial area and represent unique naval facility site activities. Several of the modeling reports are located at: https://www.winslamm.net/dr_pitt_presentations_and_publications.html#NavyStormwatermonitoringandmodelingreports2010to2017. These are listed in the following table which is used to summarize the field surveys and aerial photographic analyses:

Specialized Critical Source Areas ("other impervious areas")

Source Area Categories for Location: ______________________________ **Land Use: _____________ Date Surveyed: ___________ Surveyed by: _____________**	**Total Area in Category (acres)**
OIA1 - airfield apron/runway paved areas - directly connected	
OIA1 - airfield apron/runway paved areas- disconnected sandy	
OIA1 - airfield apron/runway paved areas - disconnected silty or clayey	
OIA2 - other airfield paved areas- directly connected	
OIA2 - other airfield paved areas- disconnected sandy soils	
OIA2 - other airfield paved areas- - disconnected silty or clayey soils	
OIA3 - light pier/laydown/storage/loading dock concrete areas- directly connected	
OIA3 - light pier/laydown/storage/loading dock concrete areas - disconnected sandy soils	
OIA3 - light pier/laydown/storage/loading dock concrete areas - disconnected silty or clayey soils	
OIA4 - moderate pier/laydown/storage/loading dock concrete areas - directly connected	
OIA4 - moderate pier/laydown/storage/loading dock concrete areas - disconnected sandy soils	
OIA4 - moderate pier/laydown/storage/loading dock concrete areas - disconnected silty or clayey soils	
OIA5 - heavy pier/laydown/storage/loading dock and scrapyard concrete areas- directly connected	
OIA5 - heavy pier/laydown/storage/loading dock and scrapyard concrete areas - disconnected sandy soils	
OIA5 - heavy pier/laydown/storage/loading dock and scrapyard concrete areas- disconnected silty or clayey soils	
OIA6 - light pier/laydown/storage/loading dock asphalt areas - directly connected	
OIA6 - light pier/laydown/storage/loading dock asphalt areas- disconnected sandy soils	
OIA6 - light pier/laydown/storage/loading dock asphalt areas- disconnected silty or clayey soils	
OIA7 - moderate pier/laydown/storage/loading dock asphalt areas- directly connected	
OIA7 - moderate pier/laydown/storage/loading dock asphalt areas- disconnected sandy soils	
OIA7 - moderate pier/laydown/storage/loading dock asphalt areas- disconnected silty or clayey soils	
OIA8 - heavy pier/laydown/storage/loading dock and scrapyard asphalt areas - directly connected	
OIA8 - heavy pier/laydown/storage/loading dock and scrapyard asphalt areas - disconnected sandy soils	
OIA8 - heavy pier/laydown/storage/loading dock and scrapyard asphalt areas - disconnected silty or clayey soils	
OIA9 - galvanized metal roofs, directly connected- directly connected	
OIA9 - galvanized metal roofs - disconnected sandy soils	
OIA9 - galvanized metal roofs- disconnected silty or clayey soils	
OIA10 - other impervious areas with galvanized materials- directly connected	
OIA10 - other impervious areas with galvanized materials - disconnected sandy soils	
OIA10 - other impervious areas with galvanized materials - disconnected silty or clayey soils	

The site surveys should be based on aerial photographs to allow identifying each source area in the study area. Facility managers usually have the buildings numbered that make this easier, while surrounding paved parking or landscaped areas can be identified by their proximity to the numbered buildings. Storage and laydown areas will likely require unique labeling for identification. The following tables (shortened for this appendix) can be used for the site surveys in small watershed areas. All of these areas should be clearly defined on aerial photographs and maps. The "other impervious area #10" for impervious areas with galvanized materials should be carefully identified as having a footprint only reflecting the area affected by the galvanized material. If contained on a larger paved area, the remaining area should be appropriately designated (most likely storage or laydown area). Descriptions of the basic sources listed below are included previously in Appendix A.

Roofs, pitched **Land Use: ____________ Date Surveyed: ____________ Surveyed by: ______________________________**			
Location and description, including roofing material (galvanized metal roofs are "other impervious areas #9") (and photo numbers)	**Directly connected (acres)**	**Disconnected to sandy soils (acres)**	**Disconnected to silty or clayey soils (acres)**
Total areas in subcategory:			

Roofs, flat **Land Use: ____________ Date Surveyed: ____________ Surveyed by: ______________________________**			
Location and description, including roofing material (galvanized metal roofs are "other impervious areas #9") (and photo numbers)	**Directly connected (acres)**	**Disconnected to sandy soils (acres)**	**Disconnected to silty or clayey soils (acres)**
Total areas in subcategory:			

Paved parking areas **Land Use: ____________ Date Surveyed: ____________ Surveyed by: ______________________________**			
Location and description (and photo numbers)	**Directly connected (acres)**	**Disconnected to sandy soils (acres)**	**Disconnected to silty or clayey soils (acres)**
Total areas in subcategory:			

Unpaved parking areas **Land Use: ____________ Date Surveyed: ____________ Surveyed by: ________________________________**			
Location and description (and photo numbers)	**Directly connected (acres)**	**Disconnected to sandy soils (acres)**	**Disconnected to silty or clayey soils (acres)**
Total areas in subcategory:			

Driveways **Land Use: ____________ Date Surveyed: ____________ Surveyed by: ________________________________**			
Location and description (and photo numbers)	**Directly connected (acres)**	**Disconnected to sandy soils (acres)**	**Disconnected to silty or clayey soils (acres)**
Total areas in subcategory:			

Streets with curbs and gutters **Land Use: ____________ Date Surveyed: ____________ Surveyed by: _________________________________**			
Location and description, including street widths (and photo numbers)	**Smooth pavement (acres)**	**Intermediate pavement (acres)**	**Rough pavement (acres)**
Total areas in subcategory:			

Streets with roadside grass swales **Land Use: ____________ Date Surveyed: ____________ Surveyed by: _________________________________**			
Location and description, including street widths (and photo numbers)	**Smooth pavement (acres)**	**Intermediate pavement (acres)**	**Rough pavement (acres)**
Total areas in subcategory:			

Landscaped areas and undeveloped areas Land Use: ____________ Date Surveyed: ____________ Surveyed by: _______________________________		
Location and description (and photo numbers)	Sandy soils (acres)	Silty or clayey soils (acres)
Total areas in subcategory:		

OIA1 - airfield apron/runway paved areas Land Use: ____________ Date Surveyed: ____________ Surveyed by: _______________________________			
Location and description (and photo numbers)	Directly connected (acres)	Disconnected to sandy soils (acres)	Disconnected to silty or clayey soils (acres)
Total areas in subcategory:			

OIA2 - other airfield paved areas Land Use: ____________ Date Surveyed: ____________ Surveyed by: _______________________________			
Location and description (and photo numbers)	Directly connected (acres)	Disconnected to sandy soils (acres)	Disconnected to silty or clayey soils (acres)
Total areas in subcategory:			

OIA3 - light pier/laydown/storage/loading dock concrete areas Land Use: ____________ Date Surveyed: ____________ Surveyed by: _______________________________			
Location and description (and photo numbers)	Directly connected (acres)	Disconnected to sandy soils (acres)	Disconnected to silty or clayey soils (acres)
Total areas in subcategory:			

OIA4 - moderate pier/laydown/storage/loading dock concrete areas Land Use: ____________ Date Surveyed: ____________ Surveyed by: ______________________________			
Location and description (and photo numbers)	**Directly connected (acres)**	**Disconnected to sandy soils (acres)**	**Disconnected to silty or clayey soils (acres)**
Total areas in subcategory:			

OIA5 - heavy pier/laydown/storage/loading dock and scrapyard concrete areas Land Use: ____________ Date Surveyed: ____________ Surveyed by: ______________________________			
Location and description (and photo numbers)	**Directly connected (acres)**	**Disconnected to sandy soils (acres)**	**Disconnected to silty or clayey soils (acres)**
Total areas in subcategory:			

OIA6 - light pier/laydown/storage/loading dock asphalt areas Land Use: ____________ Date Surveyed: ____________ Surveyed by: ______________________________			
Location and description (and photo numbers)	**Directly connected (acres)**	**Disconnected to sandy soils (acres)**	**Disconnected to silty or clayey soils (acres)**
Total areas in subcategory:			

OIA7 - moderate pier/laydown/storage/loading dock asphalt areas Land Use: ____________ Date Surveyed: ____________ Surveyed by: ______________________________			
Location and description (and photo numbers)	**Directly connected (acres)**	**Disconnected to sandy soils (acres)**	**Disconnected to silty or clayey soils (acres)**

Total areas in subcategory:			

OIA8 - heavy pier/laydown/storage/loading dock and scrapyard asphalt areas **Land Use: ____________ Date Surveyed: ____________ Surveyed by: ______________________________**			
Location and description (and photo numbers)	**Directly connected (acres)**	**Disconnected to sandy soils (acres)**	**Disconnected to silty or clayey soils (acres)**
Total areas in subcategory:			

OIA9 - galvanized metal roofs **Land Use: ____________ Date Surveyed: ____________ Surveyed by: ______________________________**			
Location and description (and photo numbers)	**Directly connected (acres)**	**Disconnected to sandy soils (acres)**	**Disconnected to silty or clayey soils (acres)**
Total areas in subcategory:			

OIA10 - other impervious areas with galvanized materials **Land Use: ____________ Date Surveyed: ____________ Surveyed by: ______________________________**			
Location and description, including galvanized material areas exposed, such as fence length and height (and photo numbers)	**Directly connected (acres)**	**Disconnected to sandy soils (acres)**	**Disconnected to silty or clayey soils (acres)**
Total areas in subcategory:			

The above list of specialized source areas identified for naval facilities include four major categories (airfield aprons, runways and other paved areas; pier, laydown, or storage areas; galvanized roofs; and paved areas with galvanized materials). Each of these categories is described below. Each category is separated into directed connected impervious areas or impervious areas that drain to sandy soils or drain to silty or clayey soils. The largest category (the piers, laydown areas, storage areas, plus loading docks) are also separated in light, moderate, or heavy industrial activity, and if paved with asphalt or concrete. The following are example photographs for each of these major source areas.

Airfield Apron, Runway, and Other Paved Areas
These areas are located at naval air stations and other aircraft operations areas. The active runway and associated aprons are noted separately from other adjacent paved areas.

Asphalt area adjacent to runway

Pier, Laydown, Storage, or Loading Dock Areas (concrete or asphalt) (light, moderate, or heavy use)
Most of the active areas on the naval bases likely are included in these laydown, pier, and storage areas. These are separated into three categories corresponding to the amount of activity and materials stored, and further noted if asphalt or concrete. The light laydown, pier, or storage areas have little industrial activity and few materials stored. Examples include little used areas such as ceremonial piers, or inactive storage areas. No obvious contaminating materials are stored in these areas, but some aluminum, untreated wood, hoses, and painted steel may be stored in these areas. Medium industrial activity laydown, piers, and storage areas include long-term material and equipment storage and small areas of frequently moved materials. Heavy industrial activity occurs on piers when ships are being actively prepared for deployment, large amounts of materials being stored (including treated wood, rusty metals, open debris containers, paint yards, etc.).

Light Laydown, Pier, or Storage Areas

 Light laydown area, electrical cables, (on concrete)	 Light laydown area, aluminum ramp, (on concrete)

Medium Laydown, Pier, or Storage Areas

 Medium storage area, with containers (on concrete)	 Medium storage area, vehicles (on asphalt and semi pervious steet mats)

Medium storage and laydown area (on asphalt)

Medium storage and laydown area (on asphalt)

Medium storage area, mic steel parts, pallets, and shipping crates (on asphalt)

Medium industrial storage/laydown area (on asphalt)

Medium industrial storage/laydown area, crane tracks, industrial equip. and trailer (on asphalt)

Medium storage area, rubber (on concrete)

Medium industrial storage/laydown area, mobile offices, electical cable on gangplank, note crane tracks (on asphalt)

Medium industrial storage/laydown area, scrap metal and garbage bins (on asphalt)


Medium industrial storage/laydown area, laydown area adjacent to truck yard (on asphalt)


Medium industrial storage/laydown area, loading area and laydown of pervious grassy area. (on asphalt, grass in foreground)


Medium laydown area, metal cube supports (on concrete)


Medium laydown area, painted metal barge support stands, treated wood, and barge (on concrete)

Medium laydown area, painted metal platform supports with rubber (on concrete)

Medium storage/laydown area (on asphalt)

Heavy Laydown and Storage Areas

Heavy storage/laydown area (on asphalt)

Heavy storage/laydown area (on asphalt)

Heavy storage/laydown area, rubber bumpers, aluminum stairs/walkways, some galvanized materials, conex and hoses (on asphalt)

Heavy industrial storage/laydown area, treated (copper?) wood (on asphalt)

Heavy industrial storage/laydown area, electrical cables on gangplank with large crane on track in background, misc. laydown (on asphalt)

Heavy industrial storage/laydown area, deck plating (on asphalt)

Heavy storage area, gas cylinders (on asphalt)

Heavy storage area, tires and pipes (on concrete)

Heavy industrial storage/laydown area, cable laydown area (on asphalt)

Heavy industrial storage/laydown area, wooden boxes with steel reinforced edges (on asphlt)


Heavy storage area, mixed metals (on concrete)


Heavy storage area/laydown area, mixed metals


Heavy laydown area, pipes (on concrete)


Heavy laydown area, cables and steel matting

 Heavy storage area, rusty metal (on dirty asphalt)	

Galvanized Metal Roofs
Galvanized metal roofs are in a separate category from other building roofs due to the large zinc content of the roof runoff.

Galvanized metal roofs, painted galvanized w/significant paint peeling of wall. Note broken drainage, connected.

Galvanized metal roofs, galvanized storage sheds, drains to ground.

Other Impervious Areas with Galvanized Materials
Other impervious areas with galvanized materials are usually small areas where galvanized steel pipes are stored, galvanized utility boxes are located, galvanized stairways, and sacrificial zinc anodes are stored. If the galvanized metal is painted, the conditions of the coating should be noted on the survey form. Also, these are usually small areas within larger paved storage or laydown areas. The areas affected by the galvanized materials should be estimated on the survey forms, and the surrounding paved area also included in the appropriate category. Building siding and chain anchor fencing of galvanized steel also needs to be indicated; the areas of the buildings noted and the length and height of the fencing.

Galvanized metal circuit breaker boxes

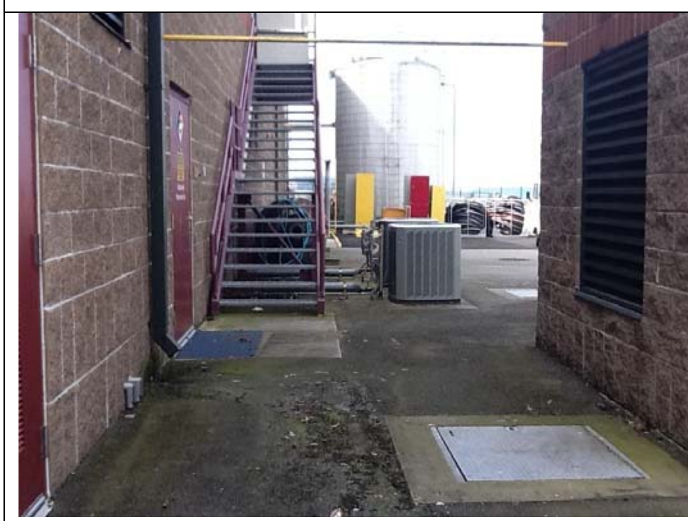

Galvanized and copper piping


Galvanized steel fencing


Galvanized metal drying rack at paint shop

Galvanized metal pipe parking barrier

Painted galvanized frame with galvanized and copper pipes



Galvanized metal stairway (painted)

Galvanized metal stairway (painted)

Other galvanized material areas, galvanized utility box, 40 boxes on site

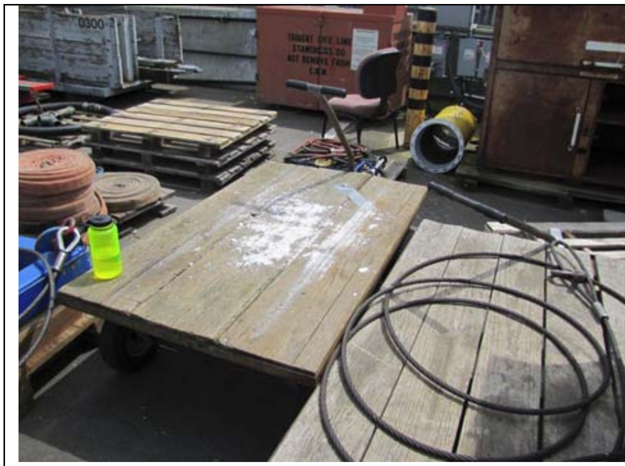

Other galvanized material areas, galvanized stairway structure


Other galvanized material areas, galvanized stairway structure

Other galvanized material areas small dumpster with zinc waste. Note zinc particles on asphalt surface


Other galvanized material areas zinc anodes in dumpster

Other galvanized material areas galvanized shed, lead waste, Hazardous Waste Accumulation Area

 Other galvanized material areas laydown area with miscellaneous items (note zinc debris on table)	 Other galvanized material areas cable reel, note zinc particles from corroded anodes
 Other galvanized material areas storage and laydown including zinc anodes (note corroded anode material on ground)	 Other galvanized material areas, residue on asphalt is zinc
 Other galvanized material areas, laydown and storage area, baskets are uncoated galvanized steel construction	