The Source Loading and Management Model (SLAMM)

A Water Quality Management Planning Model for
Urban Stormwater Runoff

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Abstract

A logical approach to stormwater management requires knowledge of the problems that are to be solved, the sources of the problem pollutants, and the effectiveness of stormwater management practices that can control the problem pollutants at their sources and at outfalls. SLAMM is designed to provide information on these last two aspects of this approach.

The Source Loading and Management Model (SLAMM) was initially developed to identify critical sources stormwater contamination and to more efficiently evaluate stormwater control practices. It soon became evident that in order to accurately evaluate the effectiveness of stormwater controls at an outfall, the sources of the pollutants or problem water flows must be known. SLAMM has evolved to include a variety of source area and end-of-pipe controls and the ability to predict the concentrations and loadings of many different pollutants from a large number of potential source areas. SLAMM calculates mass balances for both particulate and dissolved pollutants and runoff flow volumes for different development characteristics and rainfalls. It was designed to give relatively simple answers (pollutant mass discharges and control measure effects for a very large variety of potential conditions).

SLAMM was developed primarily as a planning level tool, such as to generate information needed to make planning level decisions, while not generating or requiring superfluous information. Its primary capabilities include predicting flow and pollutant discharges that reflect a broad variety of development conditions and the use of many combinations of common urban runoff control practices. Control practices evaluated by SLAMM include detention ponds, infiltration devices, porous pavements, grass swales, catchbasin cleaning, and street cleaning. These controls can be evaluated in many combinations and at many source areas as well as the outfall location. SLAMM also predicts the relative contributions of different source areas (roofs, streets, parking areas, landscaped areas, undeveloped areas, etc.) for each land use investigated. As an aid in designing urban drainage systems, SLAMM also calculates correct NRCS curve numbers that reflect specific development and control characteristics. These curve numbers can then be used in conjunction with available urban drainage procedures to reflect the water quantity reduction benefits of stormwater quality controls.

Special emphasis has been placed on small storm hydrology and particulate washoff in SLAMM, common areas of misuse in the SWMM RUNOFF block. Many currently available urban runoff models have their roots in drainage design where the emphasis is with very large and rare rains. In contrast, stormwater quality problems are mostly associated with common and relatively small rains. The assumptions and simplifications that are legitimately used with drainage design models are not appropriate for water quality models. SLAMM therefore incorporates unique process descriptions to more accurately predict the sources of runoff pollutants and flows for the storms of most interest in stormwater quality analyses. However, SLAMM can be effectively used in conjunction with drainage design models to incorporate the mutual benefits of water quality controls on drainage design. SLAMM is normally used to predict source area contributions and outfall discharges. However, SLAMM has been used in conjunction with a receiving water model (HSPF) to examine the ultimate receiving water effects of urban runoff.

The development of SLAMM began in the mid 1970s, primarily as a data reduction tool for use in early street cleaning and pollutant source identification projects sponsored by the EPA's Storm and Combined Sewer Pollution Control Program. Additional information contained in SLAMM was obtained during the EPA's Nationwide Urban Runoff Program (NURP), especially the Alameda County, California, the Bellevue, Washington, and the Milwaukee projects. The completion of the model was made possible by the

remainder of the NURP projects and additional field studies and programming support sponsored by the Ontario Ministry of the Environment, the Wisconsin Department of Natural Resources, and Region V of the U.S. Environmental Protection Agency. Early users of SLAMM included the Ontario Ministry of the Environment's Toronto Area Watershed Management Strategy (TAWMS) study and the Wisconsin Department of Natural Resources' Priority Watershed Program. SLAMM can now be effectively used as a tool to enable watershed planners to obtain a better understanding of the effectiveness of different control practice programs.

1. The Source Loading and Management Model (WinSLAMM) Introduction and Basic Uses

Introduction

This section examines the Source Loading and Management Model (WinSLAMM), especially as how it can examine combinations of source controls, development options, and outfall treatment. The model will be initially introduced by examining some simple control measure option scenarios. Since the current version of the model is completely written in Visual Basic, the Window's interface allows efficient use, even for new users. This section also describes the WinSLAMM/SWMM Interface Program (SSIP) allowing WinSLAMM to be used in conjunction with EPA's SWMM model by replacing the RUNOFF module.

Source: The most detail on WinSLAMM attributes (especially small storm hydrology and particulate washoff, to be covered in sections 2 and 3) is given in Pitt's dissertation:

Pitt, R. *Small Storm Urban Flow and Particulate Washoff Contributions to Outfall Discharges*, Ph.D. Dissertation, Civil and Environmental Engineering Department, University of Wisconsin, Madison, WI, November 1987.

Much of the material presented here was developed for the Humber River basin in Toronto as part of my dissertation research and was included in the following report prepared for the Ontario Ministry of the Environment:

Pitt, R. and J. McLean. *Humber River Pilot Watershed Project*, Ontario Ministry of the Environment, Toronto, Canada. 483 pgs. June 1986.

Some of the material was presented in Pitt (1986), in a general description of the Wisconsin Nonpoint Source Program:

Pitt, R. "The Incorporation of Urban Runoff Controls in the Wisconsin Priority Watershed Program." In: *Advanced Topics in Urban Runoff Research*, (Edited by B. Urbonas and L.A. Roesner). Engineering Foundation and ASCE, New York. pp. 290-313. 1986.

WINWINSLAMM and its source area treatment capabilities have also been described at EPA Region V/NIPC conferences in Chicago, when some of the examples were prepared:

Pitt, R. and J. Voorhees. "Critical Source Area Controls in the SLAMM Water Quality Model." *A National Symposium: Assessing the Cumulative Impacts of Watershed Developments on Aquatic Ecosystems and Water Quality*. U.S. EPA and Northeastern Illinois Planning Commission. Chicago, Illinois, March 1996.

Pitt, R. and J. Voohees. "The Source Loading and Management Model (SLAMM)." *National Conference on Urban Runoff Management*. U.S. EPA, Chicago, Ill. March 1993.

Various attributes of WinSLAMM have also been published in Volumes 6 through 8 of the proceedings of the stormwater user's conference given annually in Toronto:

Pitt, R. and J. Lantrip. "Infiltration through disturbed urban soils." In: *Advances in Modeling the Management of Stormwater Impacts, Volume 8*. (Edited by W. James). Computational Hydraulics International, Guelph, Ontario. 1999.

Pitt, R. "Small storm hydrology and why it is important for the design of stormwater control practices." In: *Advances in Modeling the Management of Stormwater Impacts, Volume 7*. (Edited by W. James). Computational Hydraulics International, Guelph, Ontario and Lewis Publishers/CRC Press. 1998.

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

The WinSLAMM/SWMM interface program was developed as part of the following EPA research report:

Pitt, R., M. Lilburn, S. Nix, S.R. Durrans, S. Burian, J. Voorhees, and J. Martinson *Guidance Manual for Integrated Wet Weather Flow (WWF) Collection and Treatment Systems for Newly Urbanized Areas (New WWF Systems).* U.S. Environmental Protection Agency. 612 pgs. December 1999.

WinSLAMM was originally developed to better understand the relationships between sources of urban runoff pollutants and runoff quality. It has been continually expanded since the late 1970s and now includes a wide variety of source area and outfall control practices (infiltration practices, wet detention ponds, porous pavement, street cleaning, catchbasin cleaning, and grass swales). WinSLAMM is strongly based on actual field observations, with minimal reliance on pure theoretical processes that have not been adequately documented or confirmed in the field. WinSLAMM is mostly used as a planning tool, to better understand sources of urban runoff pollutants and their control.

Special emphasis has been placed on small storm hydrology and particulate washoff in WinSLAMM, common areas of misuse in the SWMM RUNOFF block. Many currently available urban runoff models have their roots in drainage design where the emphasis is with very large and rare rains. In contrast, stormwater quality problems are mostly associated with common and relatively small rains. The assumptions and simplifications that are legitimately used with drainage design models are not appropriate for water quality models. WinSLAMM therefore incorporates unique process descriptions to more accurately predict the sources of runoff pollutants and flows for the storms of most interest in stormwater quality analyses. However, WinSLAMM can be effectively used in conjunction with drainage design models to incorporate the mutual benefits of water quality controls on drainage design.

WinSLAMM has been used in many areas of North America and has been shown to accurately predict stormwater flows and pollutant characteristics for a broad range of rains, development characteristics, and control practices. As with all stormwater models, WinSLAMM needs to be accurately calibrated and then tested (verified) as part of any local stormwater management effort.

WinSLAMM is unique in many aspects. One of the most important aspects is its ability to consider many stormwater controls (affecting source areas, drainage systems, and outfalls) together, for a long series of rains. Another is its ability to accurately describe a drainage area in sufficient detail for water quality investigations, but without requiring a great deal of superfluous information that field studies have shown to be of little value in accurately predicting discharge results. WinSLAMM also applies stochastic analysis procedures to more accurately represent actual uncertainty in model input parameters in order to better predict the actual range of outfall conditions (especially pollutant concentrations). However, the main reason WinSLAMM was developed was because of errors contained in many existing urban runoff models. These errors were obvious when comparing actual field measurements to the solutions obtained from model algorithms.

In addition to the material presented in this section, a user's guide is included as section 5 to help users with WinSLAMM. Section 4 also contains detailed descriptions for the source area and outfall controls incorporated in WinSLAMM. A supplement users guide gives a detailed example of the use of WinSLAMM for examining biofiltration options in residential areas.

History of WinSLAMM and Typical Uses

The Source Loading and Management Model (WinSLAMM) was initially developed to more efficiently evaluate stormwater control practices. It soon became evident that in order to accurately evaluate the effectiveness of stormwater controls at an outfall, the sources of the pollutants or problem water flows must be known. WinSLAMM has evolved to include a variety of source area and end-of-pipe controls and the ability to predict the concentrations and loadings of many different pollutants from a large number of potential source areas. WinSLAMM calculates mass balances for both particulate and dissolved pollutants and runoff flow volumes for different development characteristics and rainfalls. It was designed to give relatively simple answers (pollutant mass discharges and control measure effects for a very large variety of potential conditions).

WinSLAMM was developed primarily as a planning level tool, such as to generate information needed to make planning level decisions, while not generating or requiring superfluous information. Its primary capabilities include predicting flow and pollutant discharges that reflect a broad variety of development conditions and the use of many combinations of common urban runoff control practices. Control practices evaluated by WinSLAMM include detention ponds, infiltration devices, porous pavements, grass swales, catchbasin cleaning, and street cleaning. These controls can be evaluated in many combinations and at many source areas as well as the outfall location. WinSLAMM also predicts the relative contributions of different source areas (roofs, streets, parking areas, landscaped areas, undeveloped areas, etc.) for each land use investigated. As an aid in designing urban drainage systems, WinSLAMM also calculates correct NRCS curve numbers that reflect specific development and control characteristics. These curve numbers can then be used in conjunction with available urban drainage procedures to reflect the water quantity reduction benefits of stormwater quality controls.

WinSLAMM is normally used to predict source area contributions and outfall discharges. However, WINSLAMM has been used in conjunction with a receiving water model (HSPF) to examine the ultimate receiving water effects of urban runoff (Ontario 1986).

The development of WinSLAMM began in the mid 1970s, primarily as a data reduction tool for use in early street cleaning and pollutant source identification projects sponsored by the EPA's Storm and Combined Sewer Pollution Control Program (Pitt 1979; Pitt and Bozeman 1982; Pitt 1984). Additional information contained in WinSLAMM was obtained during the EPA's Nationwide Urban Runoff Program (NURP) (EPA 1983), especially the Alameda County, California (Pitt and Shawley 1982), the Bellevue, Washington (Pitt and Bissonnette 1984), and the Milwaukee (Bannerman, *et al*. 1983) projects. The completion of the model was made possible by the remainder of the NURP projects and additional field studies and programming support sponsored by the Ontario Ministry of the Environment (Pitt and McLean 1986), the Wisconsin Department of Natural Resources (Pitt 1986; Bannerman, *et al*. 1996; Legg, *et al*. 1996), and Region V of the U.S. Environmental Protection Agency. Early users of WinSLAMM included the Ontario Ministry of the Environment's Toronto Area Watershed Management Strategy (TAWMS) study (Pitt and McLean 1986) and the Wisconsin Department of Natural Resources' Priority Watershed Program (Pitt 1986). Many WinSLAMM user's have incorporated the use of the model with a GIS (Thum, *et al*. 1990; Kim, *et al*. 1993; Kim and Ventura 1993; Ventura and Kim 1993; Bachhuber 1996; Haubner and Joeres 1996). WinSLAMM can now be effectively used as a tool to enable watershed planners to obtain a better understanding of the effectiveness of different control practice programs.

A logical approach to stormwater management requires knowledge of the problems that are to be solved, the sources of the problem pollutants, and the effectiveness of stormwater management practices that can control the problem pollutants at their sources and at outfalls. WinSLAMM is designed to provide information on these last two aspects of this approach.

WinSLAMM Computational Processes

Figure 1-1 illustrates the wide variety of development characteristics that affect stormwater quality and quantity. This figure shows a variety of drainage systems from concrete curb and gutters to grass swales, along with directly connected roof drainage systems and drainage systems that drain to pervious areas. "Development characteristics" define the magnitude of these drainage efficiency attributes, along with the areas associated with each surface type (road surfaces, roofs, landscaped areas, etc.). The use of WinSLAMM shows that these characteristics greatly affect runoff quality and quantity. Land use alone is usually not sufficient to describe these characteristics. The types of the drainage system (curbs and gutters or grass swales) and roof connections (directly connected or draining to pervious area), are probably the most important attributes affecting runoff characteristics. These attributes are not directly related to land use, but some trends are obvious: most roofs in strip commercial and shopping center areas are directly connected, and the roadside is most likely drained by curbs and gutters, for example. Different land uses, of course, are also associated with different levels of pollutant generation. For example, industrial areas usually have the greatest pollutant accumulations due to material transfer and storage, and heavy truck traffic.

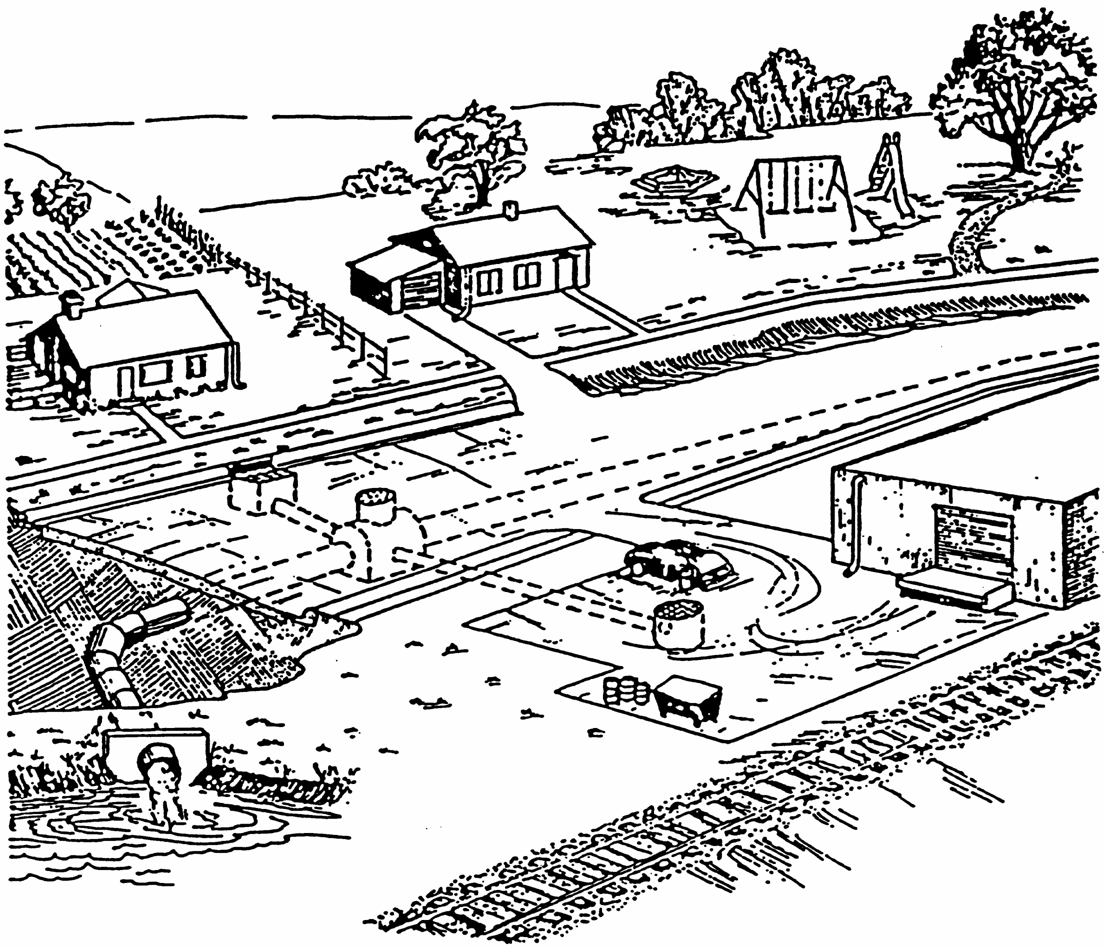


Figure 1-1. Urban runoff source areas and drainage alternatives (Pitt 1986).

Figure 1-2 shows how WinSLAMM considers a variety of pollutant and flow routings that may occur in urban areas. WinSLAMM routes material from unconnected sources to the drainage system directly or to adjacent directly connected or pervious areas which in turn drain to the collection system. Each of these areas has pollutant deposition mechanisms in addition to removal mechanisms associated with them. As an example, unconnected sources, which may include rooftops draining to pervious areas or bare ground and landscaped areas, are affected by regional air pollutant deposition (from point source emissions or from fugitive dust) and other aspects that would affect all surfaces. Pollutant losses from these unconnected sources are caused by wind removal and by rain runoff washoff which flow directly to the drainage system, or to adjacent areas. The drainage system may include curbs and gutters where there is limited deposition, and catch basins and grass swales which may remove substantial participates that are transported in the drainage system. Directly connected impervious areas include paved surfaces that drain directly to the drainage system. These source areas are also affected by regional pollutant deposition, in addition to wind removal and controlled removal processes, such as street cleaning. On-site storage is also important on paved surfaces because of the large amount of participate pollutants that are not washed-off, blown-off, or removed by direct cleaning (Pitt 1979; Pitt and Shawley 1982; Pitt 1984).

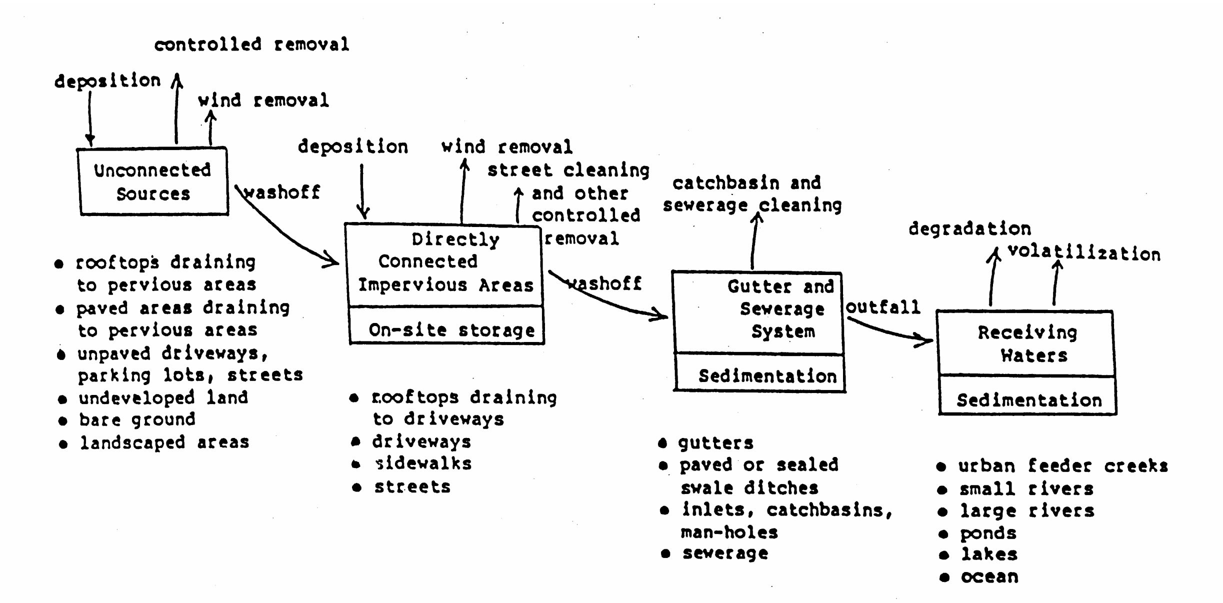


Figure 1-2. Pollutant deposition and removal at source areas (Pitt 1986).

Figure 1-3 shows how WinSLAMM proceeds through the major calculations. There is a double set of nested loops in the analyses where runoff volume and suspended solids (particulate residue) are calculated for each source area and then for each rain. These calculations consider the affects of each source area control, in addition to the runoff pattern between areas. Suspended solids washoff and runoff volume from each individual area for each rain are summed for the entire drainage system. The effects of the drainage system controls (catch basins or grass swales, for example) are then calculated. Finally, the effects of the outfall controls are calculated.

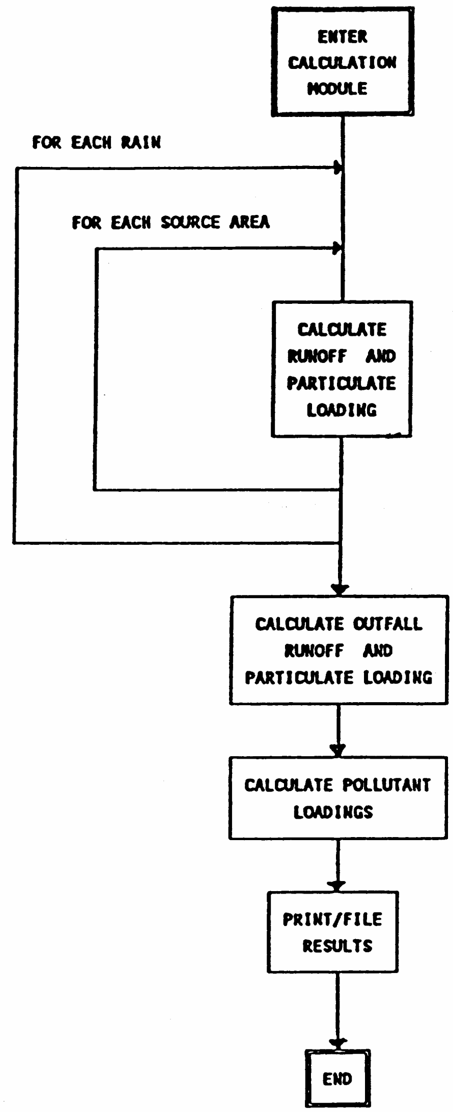


Figure 1-3. WinSLAMM calculation flow chart.

WinSLAMM uses the water volume and suspended solids concentrations at the outfall to calculate the other pollutant concentrations and loadings. WinSLAMM keeps track of the portion of the total outfall suspended solids loading and runoff volume that originated from each source area. The suspended solids fractions are then used to develop weighted loading factors associated with each pollutant. In a similar manner, dissolved pollutant concentrations and loadings are calculated based on the percentage of water volume that originates from each of the source areas within the drainage system.

WinSLAMM predicts urban runoff discharge parameters (total storm runoff flow volume, flow-weighted pollutant concentrations, and total storm pollutant yields) for many individual storms and for the complete study period. It has built-in Monte Carlo sampling procedures to consider many of the uncertainties common in model input values. This enables the model output to be expressed in probabilistic terms that more accurately represent the likely range of results expected.

Monte Carlo Simulation of Pollutants Strengths of Runoff from Various Urban Source Areas

Initial versions of WinSLAMM only used average concentration factors for different land use areas and source areas. This was satisfactory for predicting the event mean concentrations (EMC, as used by NURP, EPA 1983) for an extended period of time and in calculating the unit area loadings for different land uses. Figure 1-4 is a plot of the event mean concentrations at a Toronto test sites (Pitt and McLean 1986). The observed concentrations are compared to the WinSLAMM predicted concentrations for a long term simulation. All of the predicted EMC values are very close to the observed EMC values. However, in order to predict the probability distributions of the concentrations, it was necessary to include probability information for the concentrations found in the different source areas. Statistical analyses of concentration data (attempting to relate concentration trends to rain depths and season, for example) from these different source areas have not been able to explain all of the variation in concentrations that have been observed. The statistical analyses also indicate that most pollutant concentration values from individual source areas are distributed log-normally. Therefore, log-normally distributed random concentration values are used in WinSLAMM for these different areas. The result is much more reasonable predictions for concentration distributions at the outfall when compared to actual observed conditions. This provides more accurate estimates of criteria violations for different stormwater pollutants at an outfall for long continuous simulations.

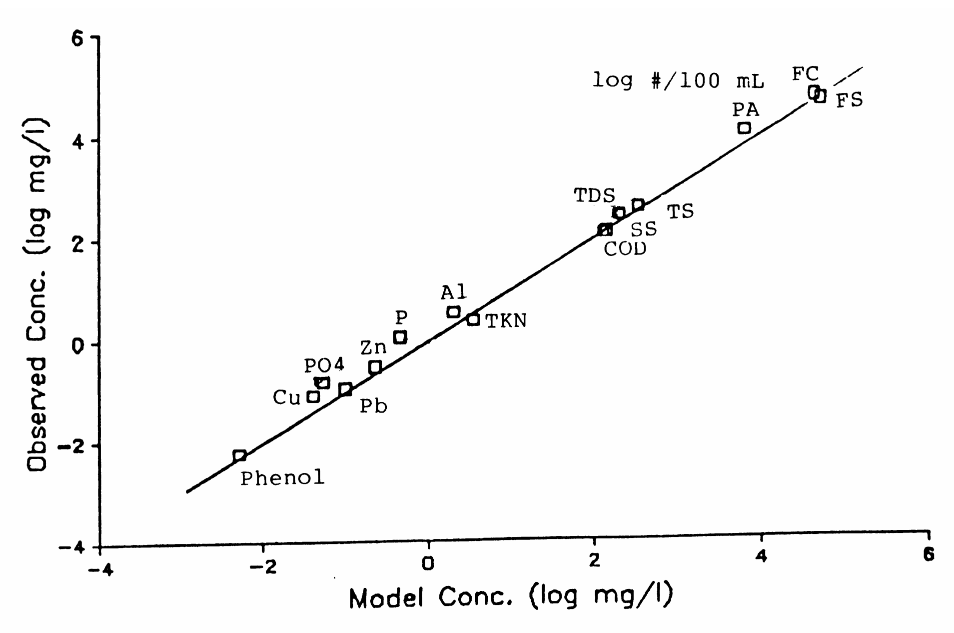


Figure 1-4. Observed and modeled outfall pollutant concentrations – Emery (industrial site) (Pitt 1987).

Use of WinSLAMM to Identify Pollutant Sources and to Evaluate Different Control Programs

Table 1-1 is a field sheet that has been developed to assist users of WinNSLAMM describe test watershed areas. This sheet is mostly used to evaluate stormwater control retrofit practices in existing developed areas, and to examine how different new development standards effect runoff conditions. Much of the information on the sheet is not actually required to operate WinSLAMM, but is very important when considering additional control programs (such as public education and good housekeeping practices) that are not quantified by WinSLAMM. The most important information shown on this sheet is the land use, the type of the gutter or drainage system, and the method of drainage from roofs and large paved areas to the drainage system. The efficiency of drainage in an area, specifically if roof runoff or parking runoff drains across grass surfaces, can be very important when determining the amount of water and pollutants that enter the outfall system. Similarly, the presence of grass swales in an area may substantially reduce the amount of pollutants and water discharged. This information is therefore required to use WinSLAMM.

Table 1-1. Study Area Description Field Sheet

Location: Site number:
Date: Time:
Photo numbers: Roll number:
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:<1930 '30-'50 '51-'70 '71-'80 new
Institutional: school hospital other (type):
Commercial: strip shop. center 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 comp. shingle wood shingle other:
Sediment source nearby? No Yes (describe):
Treated wood near street? No telephone poles fence other:
Landscaping near road:
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: flat (<2%) medium (2-5%) steep (>5%)
Traffic speed: <25 mph 25-40 mph >40 mph
Traffic density: Light moderate heavy
Parking density: none light moderate heavy
Width of street: number of parking lanes:
number of driving lanes:
Condition of street: good fair poor
Texture of street: smooth intermediate 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
Other paved areas (such as alleys and playgrounds), describe:
condition: good fair poor
texture: smooth intermediate rough
Notes:

The areas of the different surfaces in each land use is also very important for WinSLAMM. Figure 1-5 is an example showing the areas of different surfaces for a medium density residential area in Milwaukee. As shown in this example, streets make up between 10 and 20 percent of the total area, while landscaped areas can make up about half of the drainage area. The variation of these different surfaces can be very large within a designated area. The analysis of many candidate areas may therefore be necessary to understand how effective or how consistent the model results may be for a general land use classification.

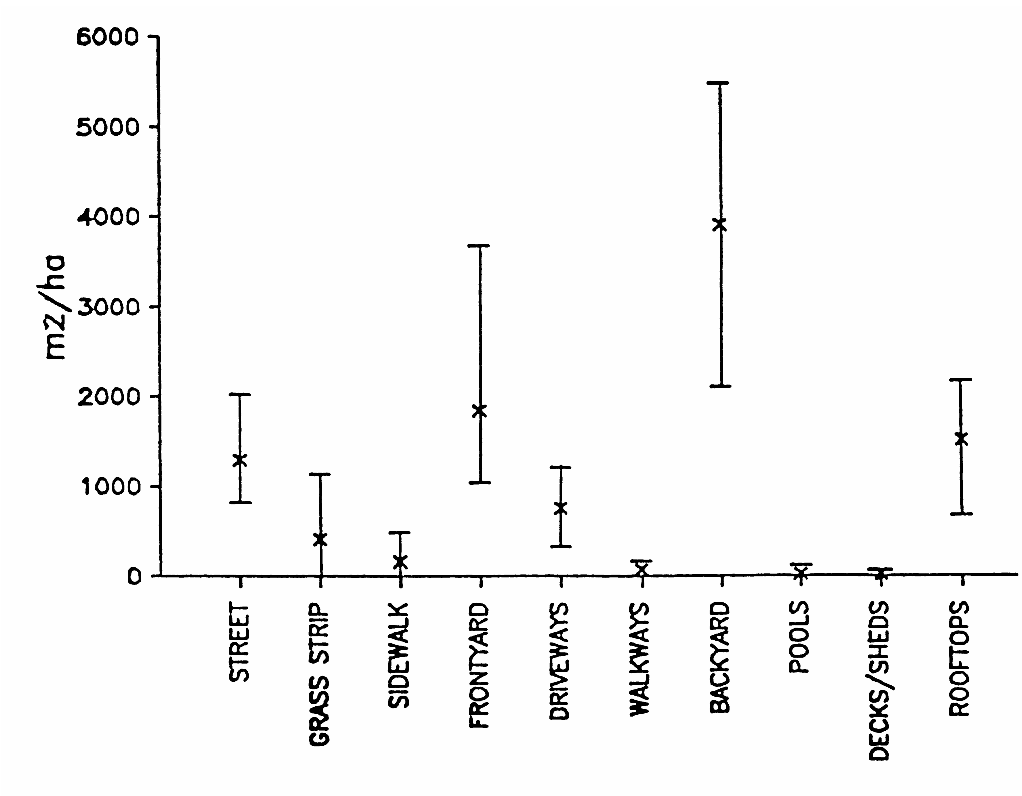


Figure 1-5. Source areas – Milwaukee medium density residential areas (without alleys) (Pitt 1987).

Appendix A contains coding sheets that have been prepared for WinSLAMM users. The information on these sheets is used by WinSLAMM to determine the concentrations and loadings from the different source areas and the effectiveness of different control practices. The first sheets contain general information describing the areas and the characteristics of source areas. More information is required for some source areas than others, based upon responses to questions. Other coding sheets are used to describe the types of control practices that are to be investigated using WinSLAMM in a specific watershed area. Control practices evaluated by WinSLAMM include infiltration trenches, seepage pits, disconnections of directly connected roofs and paved areas, infiltration ponds, street cleaning, porous pavements, catchbasin cleaning, grass swales, cisterns and rain barrels, biofiltration devices including rain gardens, and wet detention ponds. These devices can be used singly or in combination, at source areas or at the outfalls or, in the case of biofiltration, grass swales, and catchbasin controls, within the drainage system. In addition, WinSLAMM provides a great deal of flexibility in describing the sizes and other design aspects for these different practices.

One of the first problems in evaluating an urban area for stormwater controls is the need to understand where the pollutants of concern are originating under different rain conditions. Figures 1-6 through 1-9 are examples for a typical medium density residential area showing the percentage of different pollutants originated from different major sources, as a function of rain depth. As an example, Figure 1-6 shows the areas where water is originating. For storms of up to about 0.1 inch in depth, street surfaces contribute about one-half to the total runoff to the outfall. This contribution decreased to about 20 percent for storms greater than about 0.25 inch in depth. This decrease in the significance of streets as a source of water is associated with an increase of water contributions from landscaped areas (which make up more than 75% of the area and have clayey soils). Similarly, the significance of runoff from driveways and roofs also starts off relatively high and then decreases with increasing storm depth. Figures 1-7, 1-8 and 1-9 are similar plots for suspended solids, phosphorus and lead. These show that streets contribute almost all of these pollutants for the smallest storms up to about 0.1 inch. The contributions from landscaped areas then become dominant. Figure 1-9 shows that the contributions of phosphates are more evenly distributed between streets, driveways, and rooftops for the small storms, but the contributions from landscaped areas completely dominate for storms greater than about 0.25 inch in depth. Obviously, these are just example plots and the source contributions would vary greatly for different land uses/development conditions, rainfall patterns, and the use of different source area controls.

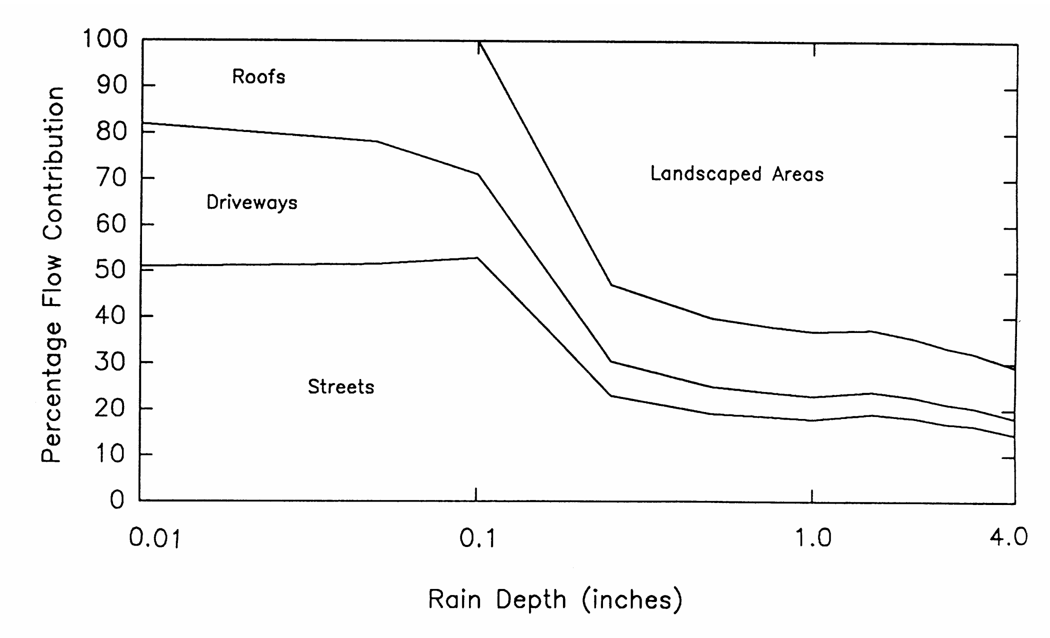


Figure 1-6. Flow sources for example medium density residential area having clayey soils (Pitt and Voorhees 1995).

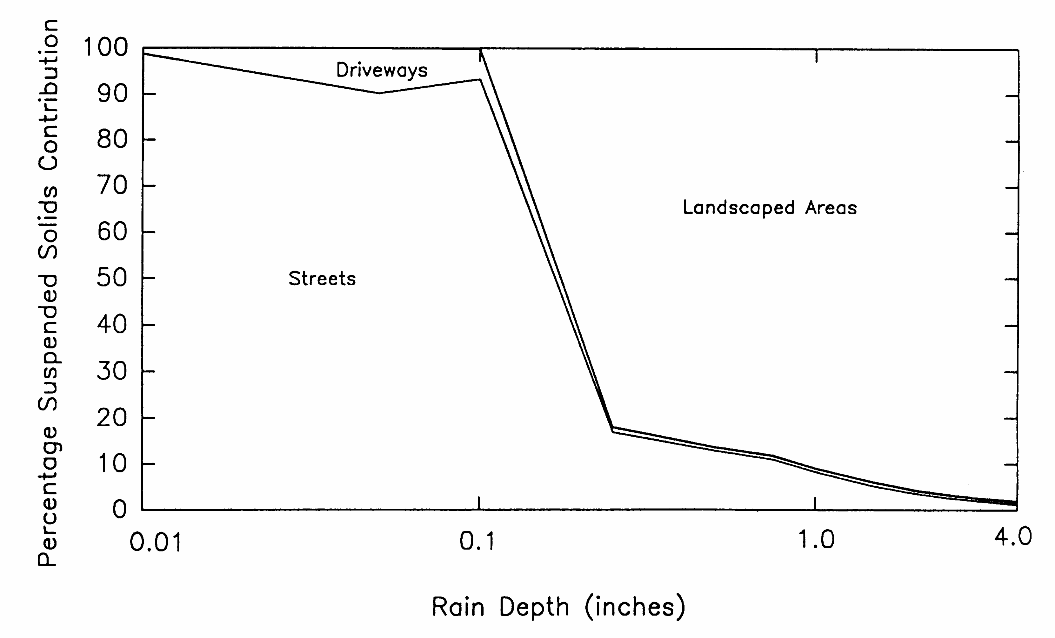


Figure 1-7 Suspended solids sources for example medium density residential area having clayey soils (Pitt and Voorhees 1995).

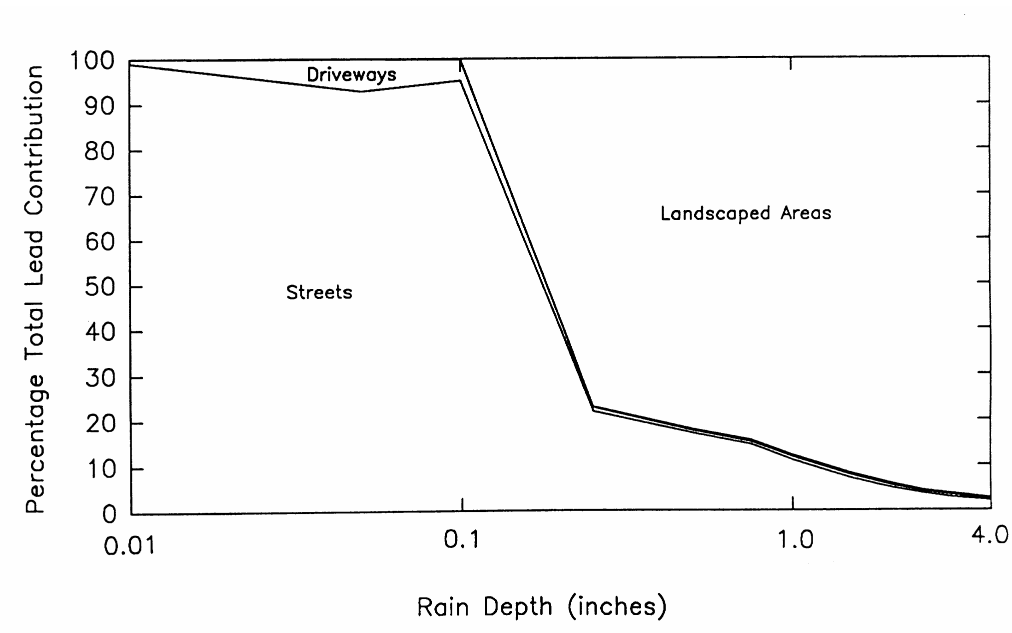


Figure 1-8 Total lead sources for example medium density residential area having clayey soils (Pitt and Voorhees 1995).

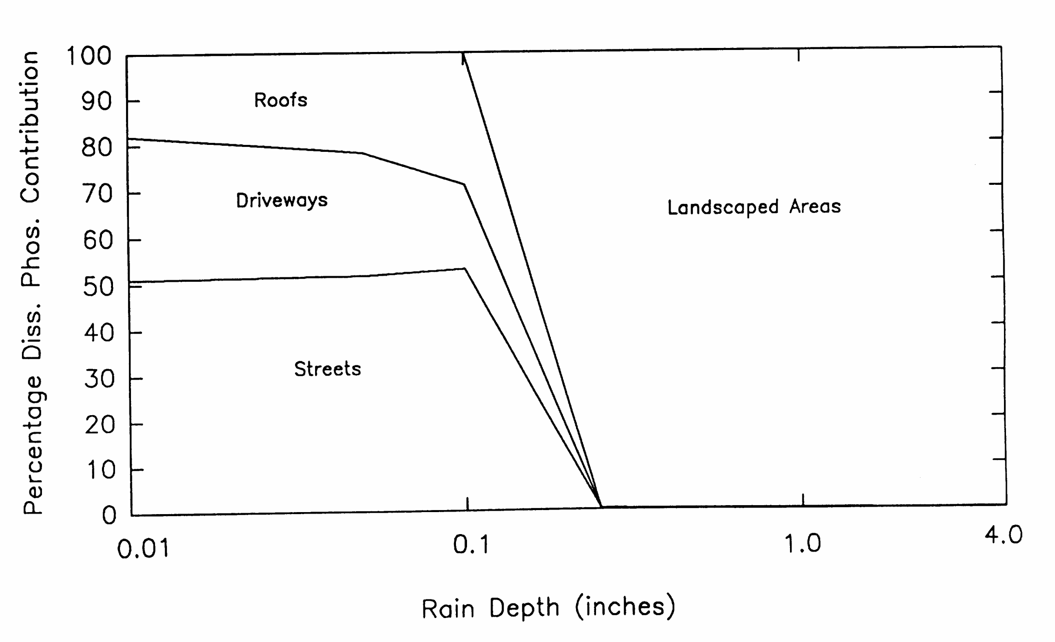


Figure 1-9 Dissolved phosphate sources for example medium density residential area having clayey soils (Pitt and Voorhees 1995).

A major use of WinSLAMM is to better understand the role of different sources of pollutants. As an example, to control suspended solids, street cleaning (or any other method to reduce the washoff of particulates from streets) may be very effective for the smallest storms, but would have very little benefit for storms greater than about 0.25 inches in depth. However, erosion control from landscaped surfaces may be effective over a wider range of storms. The following list shows the different control programs that were investigated in this hypothetical medium density residential area having clayey soils:

- Base level (as built in 1961-1980 with no additional controls)
- Catchbasin cleaning
- Street cleaning
- Grass swales
- Roof disconnections
- Wet detention pond
- Catchbasin and street cleaning combined
- Roof disconnections and grass swales combined
- All of the controls combined

This residential area, which was based upon actual Birmingham, Alabama, field observations for homes built between 1961 to 1980, has no controls, including no street cleaning or catchbasin cleaning. The use of catchbasin cleaning in the area, in addition to street cleaning was evaluated. Grass swale use was also evaluated, but swales are an unlikely retrofit option, and would only be appropriate for newly developing areas. However, it is possible to disconnect some of the roof drainages and divert the roof runoff away from the drainage system and onto grass surfaces for infiltration in existing developments. In addition, wet detention ponds can be retrofitted in different areas and at outfalls. Besides those controls examined individually, catchbasin and street cleaning controls combined were also evaluated, in addition to the combination of disconnecting some of the rooftops and the use of grass swales. Finally, all of the controls together were also examined.

The following list shows a general description of this hypothetical area:

- all curb and gutter drainage (in fair condition)

- 70% of roofs drain to landscaped areas
- 50% of driveways drain to lawns
- 90% of streets are intermediate texture (remaining are rough)
- no street cleaning
- no catchbasins

About one-half of the driveways currently drain to landscaped areas, while the other half drain directly to the pavement or the drainage system. Almost all of the streets are of intermediate texture, and about 10 percent are rough textured. As noted earlier, there currently is no street cleaning or catchbasin cleaning.

The level of catchbasin use that was investigated for this site included 950 ft^3 of total sump volume per 100 acres (typical for this land use), with a cost of about $50 per catchbasin cleaning. Typically, catch basins in this area could be cleaned about twice a year for a total annual cost of about $85 per acre of the watershed.

Street cleaning could also be used with a monthly cleaning effort for about $30 per year per watershed acre. Light parking and no parking restrictions during cleaning is assumed, and the cleaning cost is estimated to be $80 per curb mile.

Grass swale drainage was also investigated, assuming that swales could be used throughout the area, there could be 350 feet of swales per acre (typical for this land use), and the swales were 3.5 ft. wide. Because of the clayey soil conditions, an average infiltration rate of about 0.5 inch per hour was used in this analysis, based on many different double ring infiltrometer tests of typical soil conditions. Swales cost much less than conventional curb and gutter systems, but have an increased maintenance frequency. Again, the use of grass swales is appropriate for new development, but not for retrofitting in this area.

Roof disconnections could also be utilized as a control measure by directing all roof drains to landscaped areas. The objective would be to direct all the roof drains to landscaped areas. Since 70 percent of the roofs already drain to the landscaped areas, only 30 percent could be further disconnected, at a cost of about $125 per household. The estimated total annual cost would be about $10 per watershed acre.

An outfall wet detention pond suitable for 100 acres of this medium density residential area would have a wet pond surface of 0.5% of drainage area to provide about 90% suspended solids control. It would need 3 ft. of dead storage and live storage equal to runoff from 1.25" rain. A 90^o V notch weir and 5 ft. wide emergency spillway could be used. No seepage or evaporation was assumed. The total annual cost was estimated to be about $ 130 per watershed acre.

Table 1-2 summarizes the WinSLAMM results for runoff volume, suspended solids, filterable phosphate, and total lead for 100 acres of this medium density residential area. The only control practices evaluated that would reduce runoff volume are the grass swales and roof disconnections. All of the other control practices evaluated do not infiltrate stormwater. Table 1-2 also shows the total annual average volumetric runoff coefficient (Rv) for these different options. The base level of control has an annual flow-weighted Rv of about 0.3, while the use of swales would reduce the Rv to about 0.1. Only a small reduction of Rv (less than 10 percent) would be associated with complete roof disconnections compared to the existing situation because of the large amount of roof disconnections that already occur. The suspended solids analyses shows that catchbasin cleaning alone could result in about 14 percent suspended solids reductions. Street cleaning would have very little benefit, while the use of grass swales would reduce the suspended solids discharges by about 60 percent. Grass swales would have minimal effect on the reduction of suspended solids concentrations at the outfall (they are primarily an infiltration device, having very little filtering benefits). Wet detention ponds would remove about 90 percent of the mass and concentrations of suspended solids. Similar observations can be made for filterable phosphates and lead.

Table 1-2. WinSLAMM Predicted Runoff and Pollutant Discharge Conditions for Example[1] (Pitt and Voorhees 1995)

Birmingham 1976 rains: (112 rains, 55 in. total 0.01-3.84 in. each)	Runoff Volume annual ft3/acre	Runoff Volume flow-wtg. Rv	CN range	Suspended Solids flow-wtg. mg/L	Suspended Solids annual lbs/acre	Filterable Phosphate flow-wtg. µg/L	Filterable Phosphate annual lbs/acre	Total Lead flow-wtg. µg/L	Total Lead annual lbs/acre
Base (no controls)	59800	0.3	77-100	385	1430	157	0.58	543	2.0
Catchbasin cleaning	59800	0.3	77-100	331	1230	157	0.58	468	1.7
reduction (lbs or ft3)	0				200		0		0.29
reduction (%)	0			14	14	0	0	14	14
cost ($/lb or $/ft3)	N/A				0.43		N/A		293
($85/acre/yr)									
Street cleaning	59800	0.3	77-100	385	1430	157	0.58	543	2.0
reduction (lbs or ft3)	0				0		0		0.01
reduction (%)	0			0	0	0	0	0	0.49
cost ($/lb or $/ft3)	N/A				N/A		N/A		3000
($30/acre/yr)									
Grass swales	23300	0.12	63-100	380	554	151	0.22	513	0.75
reduction (lbs or ft3)	36500				876		0.36		1.28
reduction (%)	61			1	61	4	62	6	63
cost ($/lb or $/ft3)	minimal				minimal		minimal		minimal
($minimal/acre/yr)									
Roof disconnections	56000	0.28	76-100	410	1430	156	0.55	443	1.6
reduction (lbs or ft3)	3800				0		0.03		0.48
reduction (%)	6			-6	0	1	5	18	24
cost ($/lb or $/ft3)	0				N/A		333		21
($10/acre/yr)									
Wet detention pond	59800	0.3	77-100	49	185	157	0.58	69	0.26
reduction (lbs or ft3)	0				1250		0		1.8
reduction (%)	0			87	87	0	0	87	87
cost ($/lb or $/ft3)	N/A				0.10		N/A		73
($130/acre/yr)									
CB & street cleaning	59800	0.3	77-100	331	1230	157	0.58	468	1.7
reduction (lbs or ft3)	0				200		0		0.29
reduction (%)	0			14	14	0	0	14	14
cost ($/lb or $/ft3)	N/A				0.58		N/A		397
($115/acre/yr)									
Roof dis. & swales	20900	0.1	63-100	403	526	139	0.18	352	0.46
reduction (lbs or ft3)	38900				904		0.40		1.6
reduction (%)	65			-5	63	11	69	35	77
cost ($/lb or $/ft3)	0.00026				0.01		25		6.4
($10/acre/yr)									
All above controls	20900	0.1	63-100	42	55	139	0.18	36	0.05
reduction (lbs or ft3)	38900				1375		0.40		1.98
reduction (%)	65			89	96	11	69	93	97
cost ($/lb or $/ft3)	0.0066				0.19		638		129
($255/acre/yr)									

[1] Medium density residential area, developed in 1961-1980, with clayey soils (curbs & gutters); new development controls (not retro-fit)

Figures 1-10 through 1-13 show the maximum percentage reductions in runoff volume and pollutants, along with associated unit removal costs. As an example, Figure 1-10 shows that roof disconnections would have a very small potential maximum benefit for runoff volume reduction and at a very high unit cost compared to the other practices. The use of grass swales could have about a 60 percent reduction at minimal cost. The use of roof disconnection plus swales would slightly increase the maximum benefit to about 65 percent, at a small unit cost. Obviously, the use of roof disconnections alone, or all controlled practices combined, are very inefficient for this example. For suspended solids control, catchbasin cleaning and street cleaning would have minimal benefit at high cost, while the use of grass swales would produce a substantial benefit at very small cost. However, if additional control is necessary, the use of wet detention ponds may be necessary at a higher cost. If close to 95 percent reduction of suspended solids were required, then all of the controls investigated could be used together, but at substantial cost.

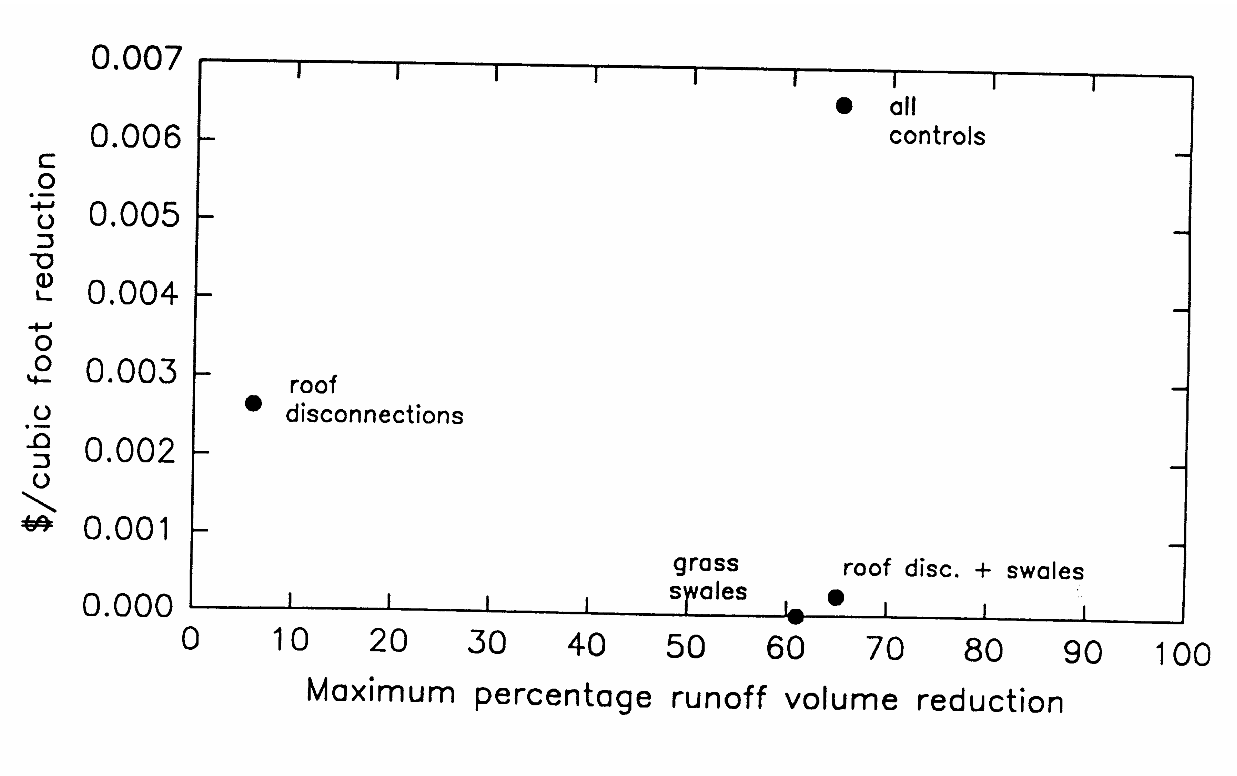


Figure 1-10. Cost-effectiveness data for runoff volume reduction benefits (Pitt and Voorhees 1995).

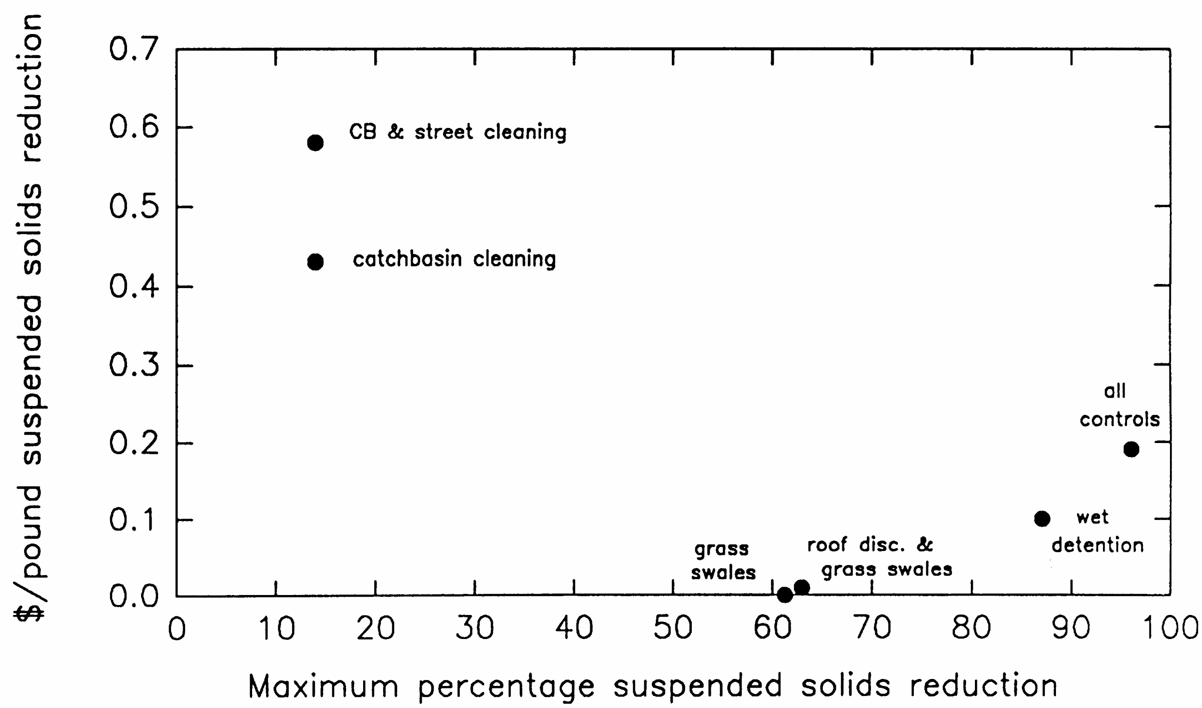


Figure 1-11. Cost-effectiveness data for suspended solids reduction benefits (Pitt and Voorhees 1995).

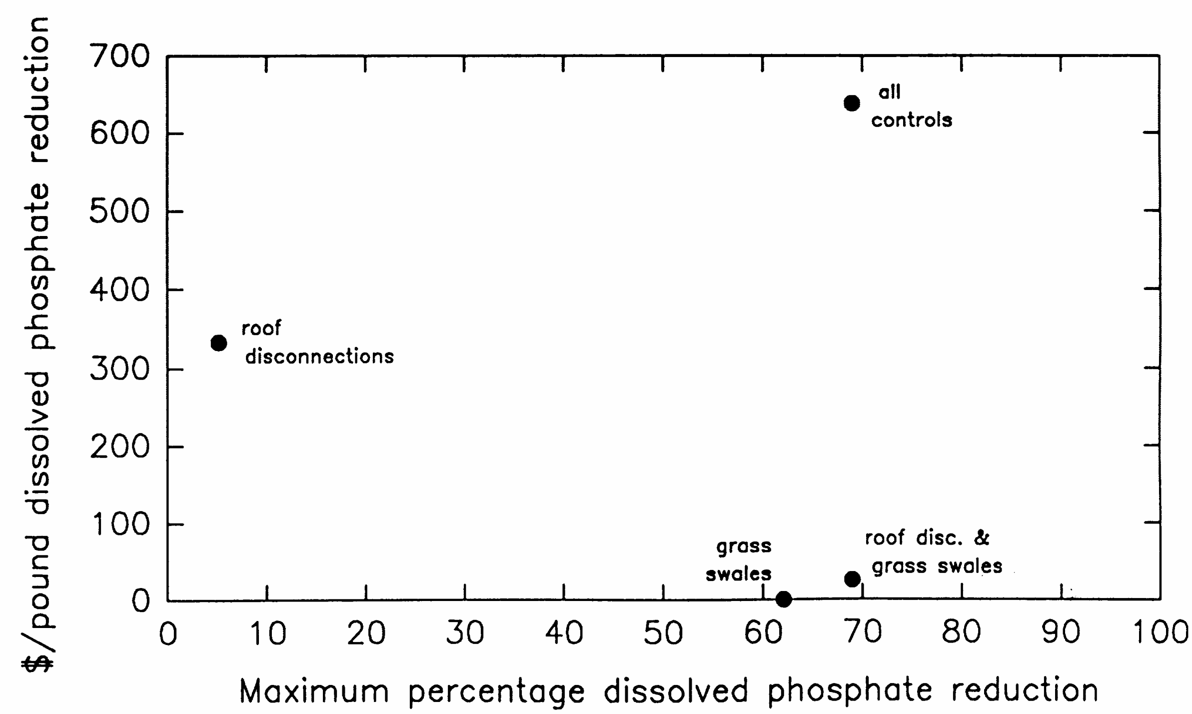


Figure 1-12. Cost-effectiveness data for dissolved phosphate reduction benefits (Pitt and Voorhees 1995).

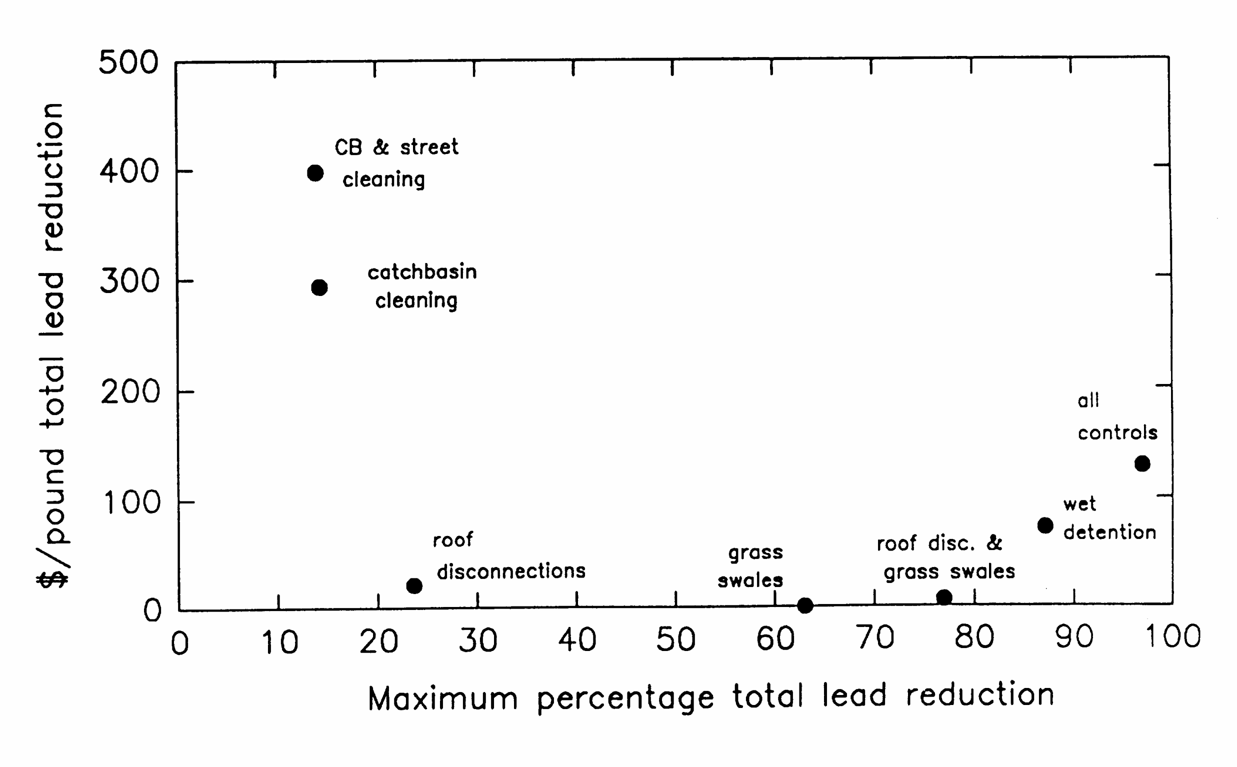


Figure 1-13. Cost-effectiveness data for total lead reduction benefits (Pitt and Voorhees 1995).

WinSLAMM Example

The following is a simple "hello world" WinSLAMM input file example. This will enable the user to become familiar with the input portions of the program, and can form a basis for simple modifications. Table 1-3 is the site characterization sheet for a 100 acre residential area, modeled after actual site surveys. The "acreage" used in the model for each source area is simply the percentage of each area in the surveyed neighborhoods. This enables relatively efficient "unit area" calculations, for annual discharge (ft^3 of runoff/100 acre/study period) and yield (lb of SS/100 acre/study period). The area is relatively simple, comprised of the following areas:

Source Area	% of land use
Roofs (pitched, directly connected)	9.03%
Driveways (directly connected)	2.57%
Streets (smooth texture, mediumparking)	6.80%
Undeveloped areas	1.80%
Small landscaped areas (lawns, silty soils) (backyards)	56.50%
Small landscaped areas (lawns, silty soils) (frontyards)	23.30%

Total directly connected impervious area: 18.40
Pervious areas: 81.60

The filled out coding sheets in Table 1-3 also describe the area and several types of control practices that will be evaluated in the next section.

Table 1-3a. Example WinSLAMM Site Characterization Data Sheet for the "hello world.dat" File

WinSLAMM Site Characterization Data Sheets

1) Site description: Example hello world evaluation with controls

2) Rain file (*.ran) name: source (Edison, after initial review)

3) Starting date for the model run (default is the earliest rain after 1952): (default) or: ________

4) Ending date for the model run (default is the last rain): (default) or: ________

5) Use winter season (removes rain events during this period and begins each spring with elevated street dirt loading after snow melt): Yes/(no), if yes: start of winter (mm/dd):________ and end of winter (mm/dd):______

6) Pollutant probability file (*.ppd) name: poll

7) Seed for random pollutant generator seed (specific value or 0 for random seed; or <0 to disable Monte Carlo routine to use mean pollutant strengths only) (default is -42): (default) or: ________ (will change to 0 for long-term rain file "Edison")

8) Runoff coefficient file (*.rsv) name: runoff

9) Particulate solids concentration file (*.psc) name: part

10) Particulate residue delivery file (*.prr) name (to account for deposition and later resuspension of particulates in drainage system): delivery

11) Street delivery parameter file (*.std) name (to account for decreased energy availability during small rains affecting street washoff along gutters): street

12) Drainage system (enter fraction corresponding to each type) (Total must equal 1.0):

1. grass swales: 1.0
2. undeveloped roadside: _____
3. curb and gutters, valleys, or sealed swales in poor condition, or very flat: _____
4. curb and gutters, valleys, or sealed swales in fair condition: _____
5. curb and gutters, valleys, or sealed swales in good condition, or very steep: _____

13) If entered any swale component:

1. Swale infiltration rate (in/hr). Consider compaction (soil density) or soil amendments. Can select according to soil type: sand (4), loamy sand (1.25), sandy loam (0.5), (loam (0.25)), silt loam (0.15), sandy silt loam (0.1), clay loam (0.05), silty clay loam (0.025), silty clay (0.02), or clay (0.01), or ______

2. Wetted swale width (ft): 4

3. Swale density (ft/acre). Can select according to land use: low density residential (160), medium density residential (350), high density residential (375), strip commercial (630), shopping center (280), industrial (125), freeways (shoulders only: 270 or center and shoulder: 410), or ______

The area served by swales is determined by WinSLAMM after the source areas are described.

14) File name: hello world

15) Output options (under "file" drop down menu):

(1.) Source areas by land use for each rain – complete printout	6. Continuous hydrograph with 6 minute time increments
2. Source area totals and outfall summaries	7. Continuous hydrograph with 15 minute time increments
3. Outfall data only for each rain	8. Continuous hydrograph with 60 minute time increments
4. Outfall summaries only (default)	Save water balance summary of all detention ponds?
5. One line per event runoff and flow summary (will use this option with long-term rain file Edison)	Save outfall runoff and particulate loading for WinDETPOND analyses?

Table 1-3b. Example WinSLAMM Site Characterization Data Sheet for the "hello world.dat" File

WinSLAMM Site Characterization Data Sheet (continued)

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

Source Area	Area (acres)		Directly connected or disconnected to drainage system	Soil	Building density (only needed if clayey soils)	Alleys present? (only needed if high density)	Source area controls*
Roofs 1	9.03	Flat/pitched	Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	I/W/O/B
Roofs 2	____	Flat/pitched	Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	I/W/O/B
Roofs 3	____	Flat/pitched	Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	I/W/O/B
Roofs 4	____	Flat/pitched	Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	I/W/O/B
Roofs 5	____	Flat/pitched	Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	I/W/O/B
Paved parking 1	____		Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	I/W/P/O/B
Paved parking 2	____		Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	I/W/P/O/B
Paved parking 3	____		Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	I/W/P/O/B
Unpaved parking 1	____		Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	I/W/O/B
Unpaved parking 1	____		Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	I/W/O/B
Playground 1	____		Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	I/W/P/O/B
Playground 2	____		Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	I/W/P/O/B
Driveways 1	2.57		Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	P/O/B
Driveways 2	____		Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	P/O/B
Driveways 3	____		Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	P/O/B
Sidewalks 1	____		Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	P/O/B
Sidewalks 2	____		Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	P/O/B
Streets/alleys 1	6.80	3.17 curb-mi (35 ft wide)	Texture: smooth/inter/rough/very rough		Accum: default/other:	Initial load: default/other:	O/S/B
Streets/alleys 2	____	____ curb-mi	Texture: smooth/inter/rough/very rough		Accum: default/other:	Initial load: default/other:	O/S/B
Streets/alleys 3	____	____ curb-mi	Texture: smooth/inter/rough/very rough		Accum: default/other:	Initial load: default/other:	O/S/B
Large landscaped areas 1	____			Sandy/silty/clayey			I/W/O/B
Large landscaped areas 2	____			Sandy/silty/clayey			I/W/O/B
Undeveloped areas	1.80			Sandy/silty/clayey			I/W/O/B
Small landscaped areas 1	56.50			Sandy/silty/clayey			I/O/B
Small landscaped areas 2	23.30			Sandy/silty/clayey			I/O/B
Small landscaped areas 3	____			Sandy/silty/clayey			I/O/B
Isolated areas	____						B
Other Pervious areas	____			Sandy/silty/clayey			I/W/O/B
Other directly connected areas	____						I/W/P/O/B
Other Disconnected areas	____			Sandy/silty/clayey	Low/med/high	Yes/no	I/W/P/O/B
Total:	100.00						

*I: Infiltration trenches; W: Wet detention ponds; P: Porous pavement; O: Other (user designated); B: Bioretention/biofiltration and cisterns/rain barrels; S: Street cleaning

Table 1-3c. Example WinNSLAMM Site Characterization Data Sheet for the "hello world.dat" File

WinSLAMM Site Characterization Data Sheet (continued)

Land Use: Freeways

Source Area	Area (acres)	Texture	Average daily traffic (ADT)	Highway length (miles)	Initial load (lbs)	Source area controls*
Paved lanes/shoulders 1	______	Smooth/inter/rough/very rough	______ vehicles/day	______ miles	Default/______ lbs	I/W/O
Paved lanes/shoulders 2	______	Smooth/inter/rough/very rough	______ vehicles/day	______ miles	Default/______ lbs	I/W/O
Paved lanes/shoulders 3	______	Smooth/inter/rough/very rough	______ vehicles/day	______ miles	Default/______ lbs	I/W/O
Paved lanes/shoulders 4	______	Smooth/inter/rough/very rough	______ vehicles/day	______ miles	Default/______ lbs	I/W/O
Paved lanes/shoulders 5	______	Smooth/inter/rough/very rough	______ vehicles/day	______ miles	Default/______ lbs	I/W/O
Large turf areas	______	Soil: sandy/silty/clayey				I/W/O
Undeveloped areas	______	Soil: sandy/silty/clayey				I/W/O
Other pervious areas	______	Soil: sandy/silty/clayey				I/W/O
Other directly connected areas	______					I/W/P/O/B
Other disconnected areas	______	Soil: sandy/silty/clayey	Density: low/medium/high	Alleys: yes/no		I/W/P/O/B
Total:	______					

*I: Infiltration trenches; W: Wet detention ponds; P: Porous pavement; O: Other (user designated); B: Bioretention/biofiltration and cisterns/rain barrels

Selection of Pollutants for Calculations:

Always calculates runoff volume and suspended solids concentrations and yields. Other pollutants available are dependent on the selected pollutant probability file. This drop down menu shows pollutants available, including particulate, dissolved, and total options:

Pollutant	Particulate	Dissolved	Total
Solids	X		
nitrates		✓	
copper	✓	✓	

Other Control Available (under "land use" drop down menu):

1) Land use biofiltration (enables combined flows from multiple source areas in a single land use to be directed to a bilfiltration or cistern device)

2) Catchbasin or drainage controls: biofiltration/infiltration/catchbasins/drainage controls/other controls

3) Outfall controls: biofiltration/infiltration/wet detention ponds/other controls

Table 1-3d. Example WinSLAMM Site Characterization Data Sheet for the "hello world.dat" File

WinSLAMM Site Characterization Data Sheet (continued)

Infiltration Area or Trench (I):

1) Water percolation rate (in/hr). Can be selected from list based on soil type: sand (8), loamy sand (2.5), sandy loam (1), loam (0. 5), silt loam (0.3), sandy silt loam (0.2), clay loam (0.1), silty clay loam (0.05), silty clay (0.04), or clay (0.02), or ______

2) Area served by device (acres):______

3) Surface area of the device (ft^2): _____

4) Width to depth ratio of the device: ______

Street Cleaning (S): street area 1

Up to 10 street cleaning programs can be specified for the duration of the model run. These programs are described in the following table. The street cleaning program maintains the specified cleaning frequency from the date shown until the program is changed at a later date, or until the final cleaning period ending date. If the model run dates or the rain file are changed, the street cleaning dates may also have to be changed to correspond to the same period.

	Street cleaning date:	Street cleaning frequency: 1) none, 2) 7 passes/week, 3) all weekdays, 4) 4 passes/week, 4) 3 passes/week, 6) 2 passes/week, 7) 1 pass/week, 8) every 2 weeks, 9) every 4 weeks, 10) every 8 weeks, or 11) every 12 weeks.
1	01/01/99	7) 1 pass/week
2	(will change to	
3	01/01/68 when	
4	use Edison, rain)	
5		
6		
7		
8		
9		
10		

Final cleaning period ending date (mm/dd/yy): 12/31/99

Street cleaning productivity: (coefficients based on street texture, parking density, and parking controls, or specified M (<1): ______; B (>1): ________.

Parking densities: 1) none, 2) light, (3) medium,) 4) extensive (short-term), or 5) extensive (long term)

Are parking controls imposed? Yes/(No)

Porous Pavement (P) driveways 1

1) Infiltration rate of pavement, base, or soil, whichever is the least (in/hr): 0.5

2) Porous pavement area (acres): total driveway area (2.57ac)

Other Flow or Pollutant Reduction Control (O)

1) Pollutant concentration reduction (fraction): _____

2) Water volume (flow) reduction (fraction): _____

3) Area served by other control (acres): _____

Table 1-3e. Example WinSLAMM Site Characterization Data Sheet for the "hello world.dat" File

Catchbasin Control Device residential land use

1) Total sump volume in test area (ft^3): 150
2) Area served by catchbasins (acres): total area (100 acres)
3) Percent of sump volume full at beginning of study period (0 to 100%): 0
4) Sump depth below catchbasin outlet (ft). At least one foot is needed to prevent scour: 3 ft
5) Catchbasin cleaning dates. Enter specific dates, or select cleaning frequency from list: monthly, three times per year, semi-annually, annually, every 2 years, every 3 years, every 4 years, or every 5 years. Or enter cleaning dates on the following table:

Catchbasin Cleaning No.	Catchbasin Cleaning Date (mm/dd/yy)
1	
2	
3	
4	
5	

Biofiltration/Bioretention or Rain Barrel/Cistern (B) residential land use

These controls can be located at individual source areas, at a land use receiving flows from multiple source areas, along the drainage system receiving flows from all sources for an area, or at an outfall location. The following information is needed for all devices, irrespective of their location:

Device Geometry

1) top area (ft^2): 60
2) bottom area (ft^2): 50
3) depth (ft): 1
4) rock filled? Yes/no. If yes, fraction of total volume as voids (0-1%): — [currently not available in WinSLAMM]
5) seepage rate (in/hr). Can be selected from list based on soil type: sand (8), loamy sand (2.5), sandy loam (1), loam (0.5), silt loam (0.3), sandy silt loam (0.2), clay loam (0.1), silty clay loam (0.05), silty clay (0.04), clay (0.02), rain barrel/cistern (0), or ______ (-.5 for long periods)

Use random number generator to account for uncertainty in infiltration rate? Yes/no. If yes, seepage rate coefficient of variation (if selected seepage rate from list, a recommended COV is given): _____

6) number of biofiltration control devices (or rain barrels/cisterns) in source area of land use: 197

Outlet/Discharge (must have at least one outlet):

1) sharp crested weir
   1. weir crest length (ft): _____
   2. number of end contractions: 1 or 2
   3: height from datum to bottom of weir opening (ft): ______

2) broad crested weir
   1. weir crest length (ft): 22
   2. weir crest width (ft): 0.25
   3. Height of datum to bottom of weir opening (ft): 0.75
   4. Use default weir coefficients? Yes/no, or enter weir coefficient (English units): ______

3) vertical stand pipe
   1. Pipe diameter (ft): _____
   2. Distance of basin bottom to top of pipe (ft): ______

Table 1-3f. Example WinSLAMM Site Characterization Data Sheet for the "hello world.dat" File

4) evaporation. Enter monthly average evaporation rate (in/hr) for each month:

Month	Monthly average evaporation rate (in/day)
January	
February	
March	
April	
May	
June	
July	
August	
September	
October	
November	
December	

5) rain barrel/cistern. An overflow (such as a sharp-crested weir) must also be designated if using one of these devices. Enter the average monthly water use rate (gallons/day) for each month:

Month	Monthly average water use rate (gallons/day)
January	
February	
March	
April	
May	
June	
July	
August	
September	
October	
November	
December	

Inflow hydrograph peak to average flow ratio. Suggested value is 3.8, or: ______

If a land use device, the source areas that are described for the model are listed. Select those that contribute flow to the device:

Source Areas:	Areas that contribute runoff to biofiltration/cistern:
Roofs 1	
Roofs 2	
Roofs 3	
Roofs 4	
Roofs 5	
Paved parking 1	
Paved parking 2	
Paved parking 3	
Unpaved parking 1	

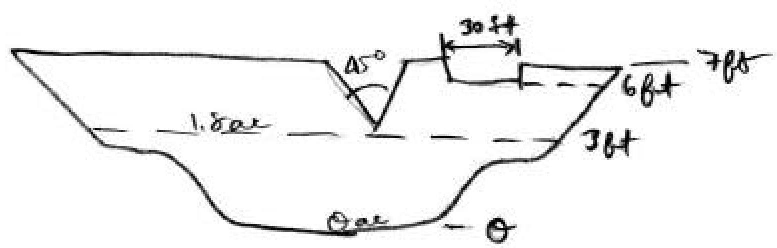
Table 1-3g. Example WinSLAMM Site Characterization Data Sheet for the "hello world.dat" File

Unpaved parking 1
Playground 1
Playground 2
Driveways 1 ✓
Driveways 2
Driveways 3
Sidewalks 1
Sidewalks 2
Streets/alleys 1
Streets/alleys 2
Streets/alleys 3
Large landscaped areas 1
Large landscaped areas 2
Undeveloped areas
Small landscaped areas 1
Small landscaped areas 2
Small landscaped areas 3
Isolated areas
Other Pervious areas
Other directly connected areas
Other Disconnected areas

If land use, drainage, or outfall device, the fraction of runoff directed to the device is: 1.0

Wet Detention Pond (W) outfall

Sketch the pond, showing the important features and measurements:



1) Particle size distribution file (*.cpz): medium

2) Initial stage elevation (ft) (normally the elevation of the lowest invert, unless evaporation has lowered the stage and the value is known): 3.0

3) Inflow hydrograph peak to average flow ratio. Suggested value is 3.8, or: ______

4) Stage area data (at least 5 well spaced values, including the top-most elevation corresponding to the brim of the emergency spillway):

	Stage (ft)	Area (acres)
0	0.00	0.000
1	1	0.6
2	2	1.2
3	3	1.8
4	4	2.4
5	5	3.0
6	6	3.6
7	7	4.2

Table 1-3h. Example WinSLAMM Site Characterization Data Sheet for the “hello world.dat” File

8		
9		
10		
11		
12		
13		
14		

5) Outlet descriptions:
The outlet rates for each device is calculated by the program. If multiple outlets are selected, the individual rates for each stage are summed.

1) sharp crested weir
   1. weir crest length (ft): _____
   2. number of end contractions: 1 or 2
   3: height from datum to bottom of weir opening (ft): ______

2) V-notch weirs
   Select the weir angle: 1) 11.5°, 2) 30°, 3) 45°, 4) 60°, 5) 90°, 6) 120°
   1) height of bottom weir opening (invert) to the top of the weir (ft): 4
   2) height from datum to bottom of weir opening(ft): 3

3) Orifice
   1) orifice diameter (ft): _____
   2) invert elevation above datum (ft): _____

4) Seepage basin
   1) infiltration fate (in/hr): _____
   2) width of seepage basin (ft): _____
   3) length of seepage basin (ft): _____
   4) invert elevation of seepage basin inlet above datum (ft): _____

5) Natural seepage
Enter the seepage rate (in/hr) for each stage previously entered:

	Stage (ft)	Seepage (in/hr):
0	0.00	
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		

Table 1-3i. Example WinSLAMM Site Characterization Data Sheet for the "hello world.dat" File

6) Evaporation. Enter monthly average evaporation rate (in/hr) for each month:

Month	Monthly average evaporation rate (in/day)
January	
February	
March	
April	
May	
June	
July	
August	
September	
October	
November	
December	

7) Other outflow
Enter the outflow rate (ft^3/sec) (calculated for device not listed) for each stage previously entered:

	Stage (ft)	Outflow (ft^3/sec):
0	0.00	
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		

8) Pumped outlet
Not yet available in WinSLAMM

9) broad crested weir

1. weir crest length (ft): 30
2. weir crest width (ft): 2
3. Use default weir coefficients? Yes/no, or enter weir coefficient (English units): ______
4. Height of weir opening (ft): 1
5. Height of datum to bottom of weir opening (ft): 6

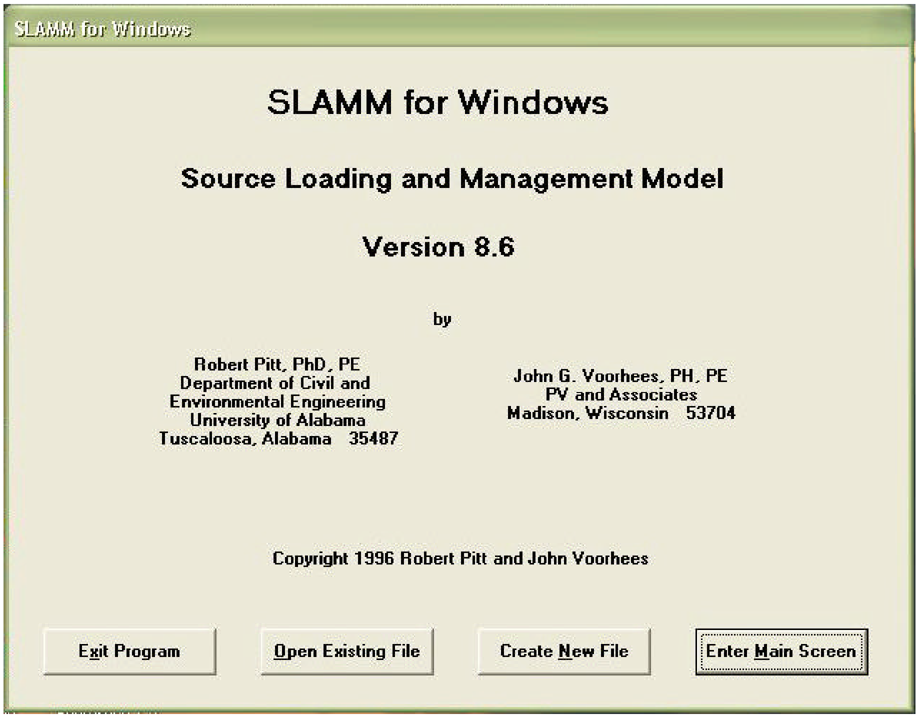
10) vertical stand pipe

1. Pipe diameter (ft): _____
2. Distance of basin bottom to top of pipe (ft): ______

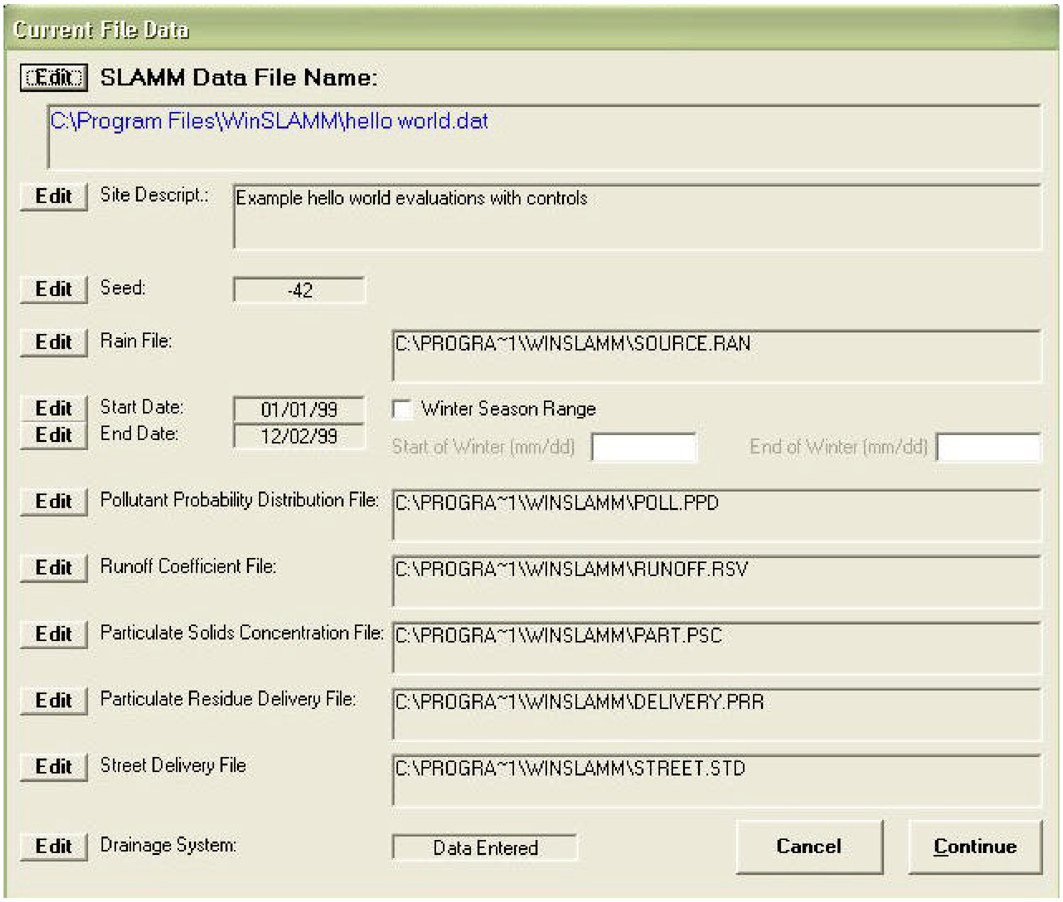
This example illustrates a basic use of WinSLAMM. A simple medium density residential area having street cleaning, catchbasins, grass swales, driveways having porous pavement, stormwater biofiltration controls (a rain garden), and an outfall wet detention pond, are described and evaluated with the model. The following screen dumps illustrate the steps to conduct this analysis.

Program Startup and Basic Data Entry

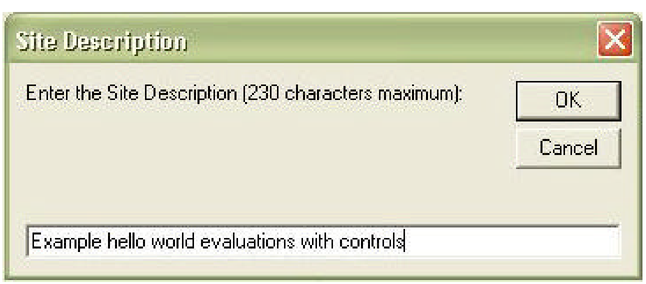
After installation, click on the WinSLAMM icon on the desktop and the following opening screen appears:



This is an example for a new file, so select the "create new file" option. Alternatively, one can select the "enter main screen" and the edit (current file data) screen can be used to enter the information. The edit screen allows more flexibility and maneuvering, but the new file sequence can be much faster. The following screen shows the "current file data" screen. Each main data grouping can be accessed for entering the data or for editing by pressing the "edit" buttons. The following is an example of a filled-out current file data screen for this example:



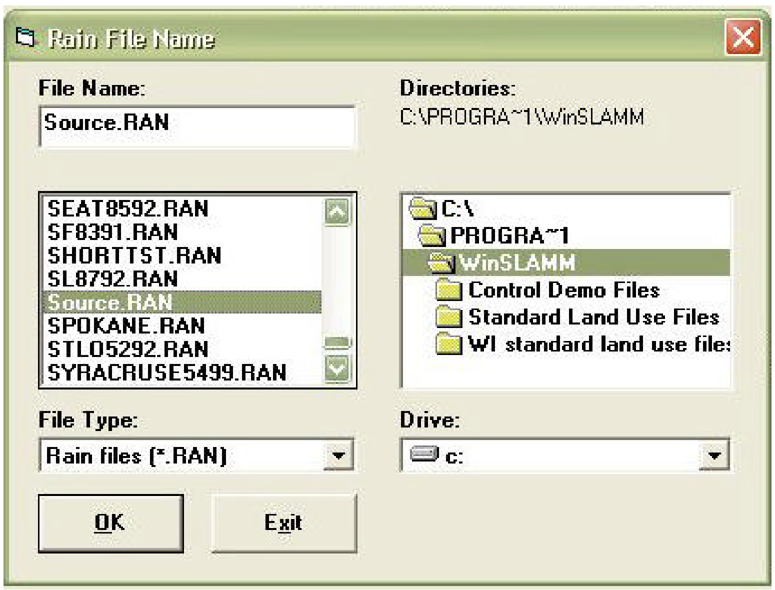
If the “create new file” option is selected, the following screen sequence begins. If an error is made, just continue to the other screens. The current file data screen shown above can be used to verify and edit any entries. The first screen is the site description. This description will be printed with all program output, allowing better tracking of program files.

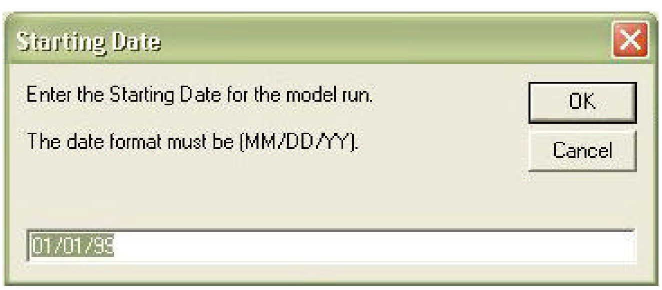


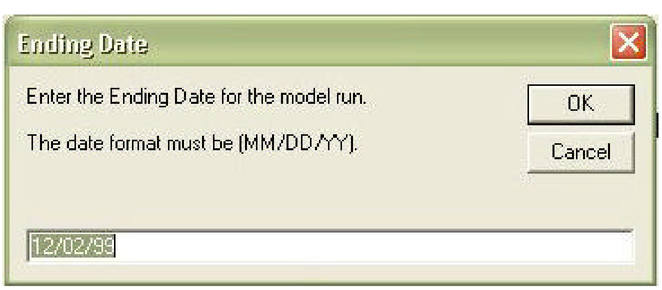
Next, a series of small screens appear, allowing the selection of the program “parameter” files. These files were previously created using either the DOS program MPARA66.EXE, or the “utilities” drop down menu on the main WinSLAMM menu. These files contain much of the information that SLAMM uses in its internal calculations, allowing modifications based on local data, calibration, and verification activities.

The first file to be selected is the rain file. Most of the files listed here were created from EarthInfo CDROMs containing rainfall records from as early as 1948 to the late 1990s. The MPARA66.EXE program contains a utility to semi-automatically create the needed rain files from the CDROMs, after minimal clean-up in a spreadsheet. Other rain information was obtained during stormwater monitoring projects. The files contain the beginning and end dates and times for each ra in, plus the total rain depth for each event. Some of these files contain up to five thousand separate rain events covering several decades of data.

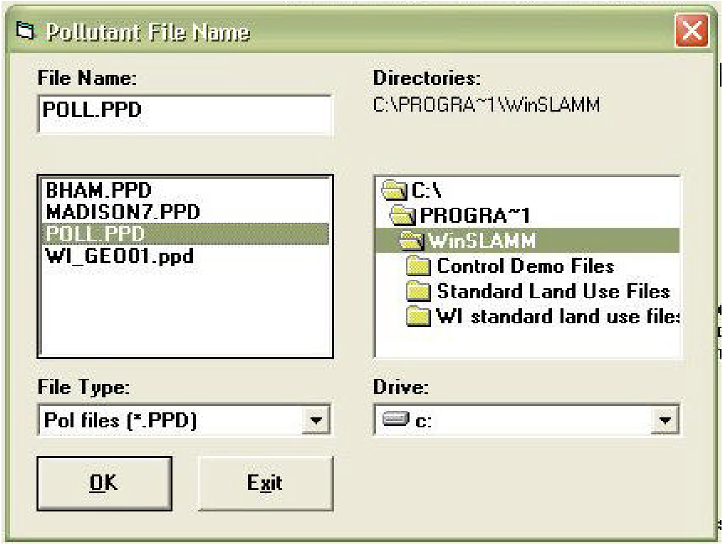
In the following example screen, the SOURCE.RAN file is selected. This file contains data for a short lis t of rains ranging from 0.01 to 4 inches in depth, with appropriate durations corresponding to typical Birmingham, AL, rain conditions. This file is frequently used to quickly visualize the changing sources of flows and pollutants for different rain depths, and to quantify the benefits of source area and outfall controls in reducing stormwater discharges. After this file is used, and any desired modifications in the input file are made (controls, development characteristics, etc.), a long-term rain file can be selected to quantify the stormwater discharges for more typical conditions. In this example, a rain file representing about 31 year of data for Edison, NJ, will also be used.



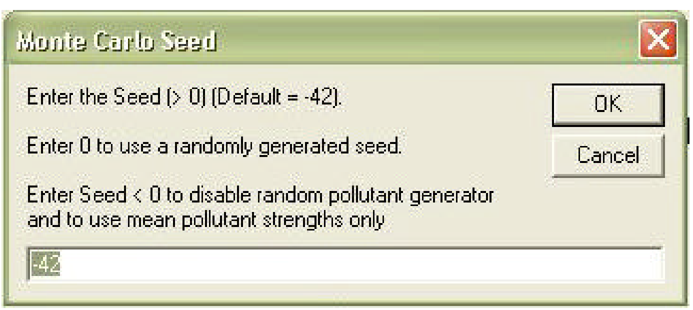




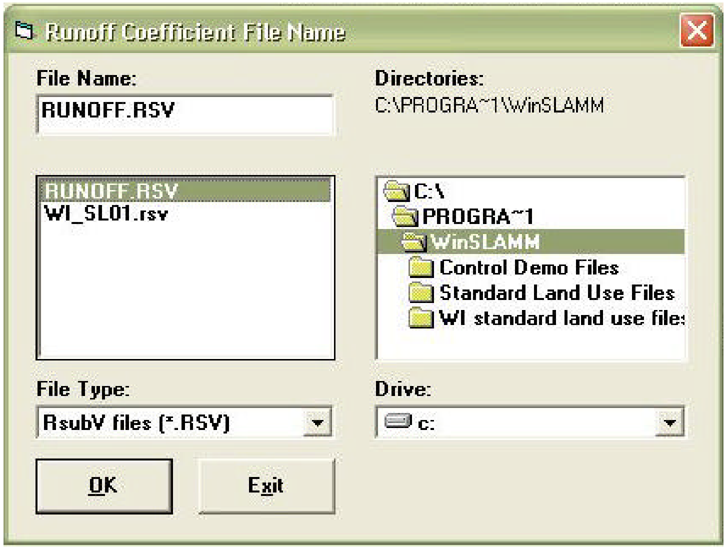
The next file to be selected is the “pollutant probability distribution” file. This file contains the means and variability’s for the pollutants for different source area flows.



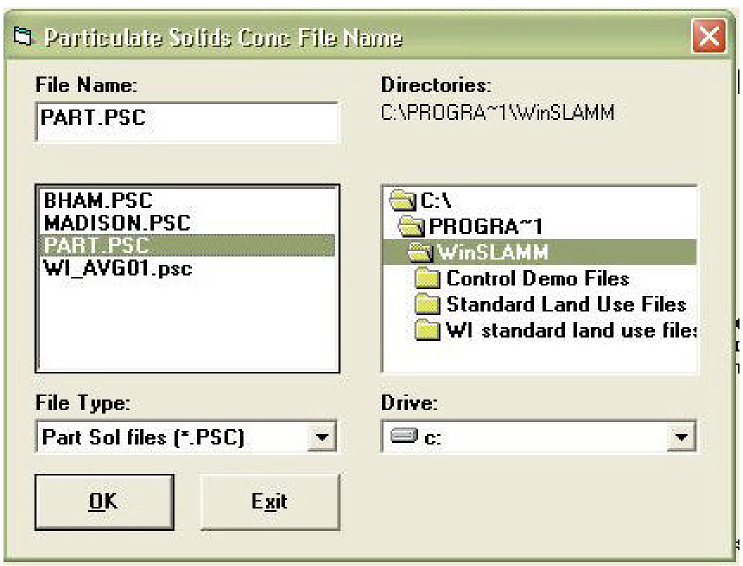
An associated screen then appears requesting a seed value for the Monte Carlo random number distribution calculations (only for pollutants other than suspended solids). Each rain event will use a different set of pollutant characteristics reflecting the naturally occurring large variation observed during field monitoring activities. This seed can be specified so the model will produce identical runs, or a random seed can be selected to more accurately reflect natural conditions. The use of a specified seed (or turning the random number calculations off) is used mostly during program de-bugging operations or for comparing results from short lists of rains (as in this example); in cases where several decades of rains are being evaluated, a value of 0 should be used. In the following example, the default value of -42 is used (with apologies to Douglas Adams).



The next screen selects the runoff coefficient file. These files contain volumetric runoff coefficients for different source areas for different rain depths, plus modifiers describing the benefits of disconnecting impervious source areas. These values can be determined using any model or assumptions desired. The values in the available files here are based on substantial field monitoring in the upper Midwest, the Southeast, and Ontario, and have been verified in many other locations in the US. They can also be easily changed reflecting observed local conditions using the “Utility” dropdown menu in WinSLAMM.

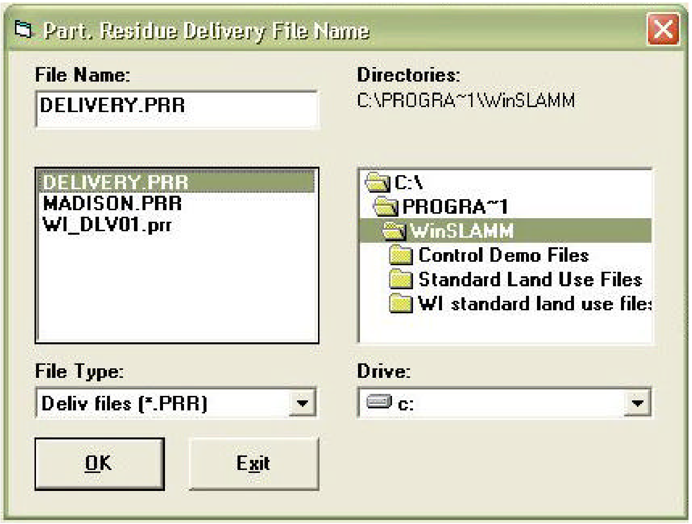


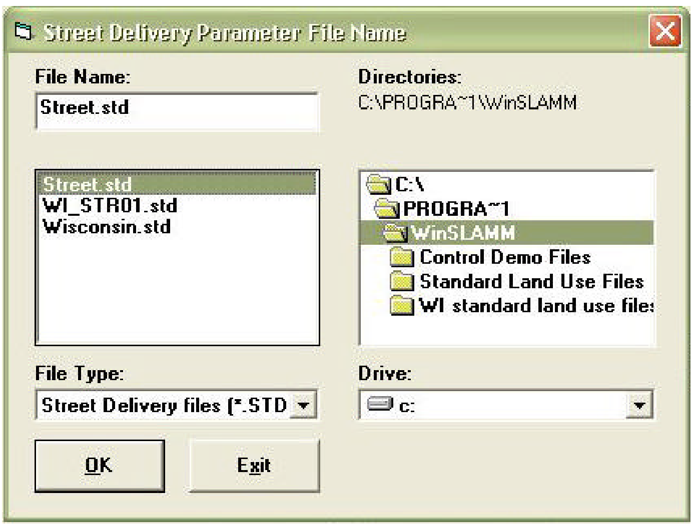
The next file to be selected describes source area first flush characteristics for suspended solids.



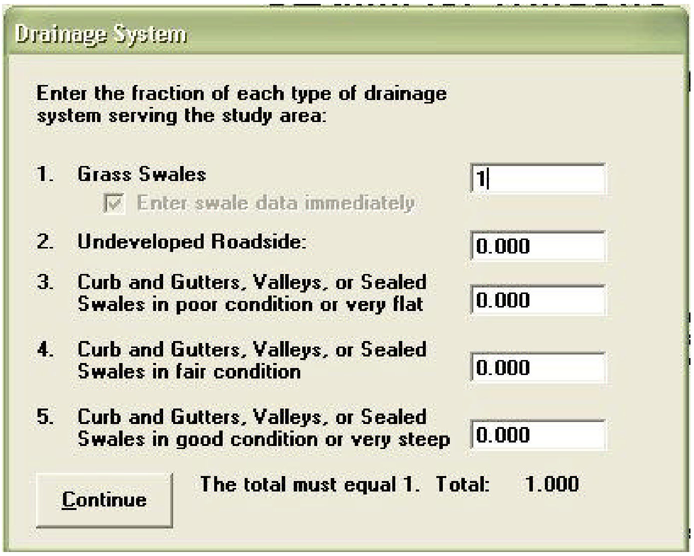
In many cases, high suspended solids concentrations are observed at source areas, but concurrent observations at outfalls from the same areas contain much lower concentrations. Two likely causes for this include independent routing of flows from the different source areas, and deposition of particulates in the drainage system. The following screens allows selection of the “delivery” file that accounts for this reduction in suspended solids concentrations.

Typically, the high “first-flush” suspended solids concentrations observed at parking lots, for example, are substantially reduced before reaching the outfall, while lower concentrations, observed after substantial rain, are less affected. The initial very small flows (having high source area concentrations) have substantially smaller flow energies, while the later flows (having lower concentrations) can have much greater flows. Also, flatter slopes and grass drainages trap much more of the suspended solids than steeper slopes and smooth channels or pipes. WinSLAMM also contains a separate “street delivery” file option that can be modified to account for the maximum rain energy available to wash off street dirt material. In all cases, if suspended solids are not completely moved through the drainage system, the model adds this “wash on” back to the streets for subsequent rain events.

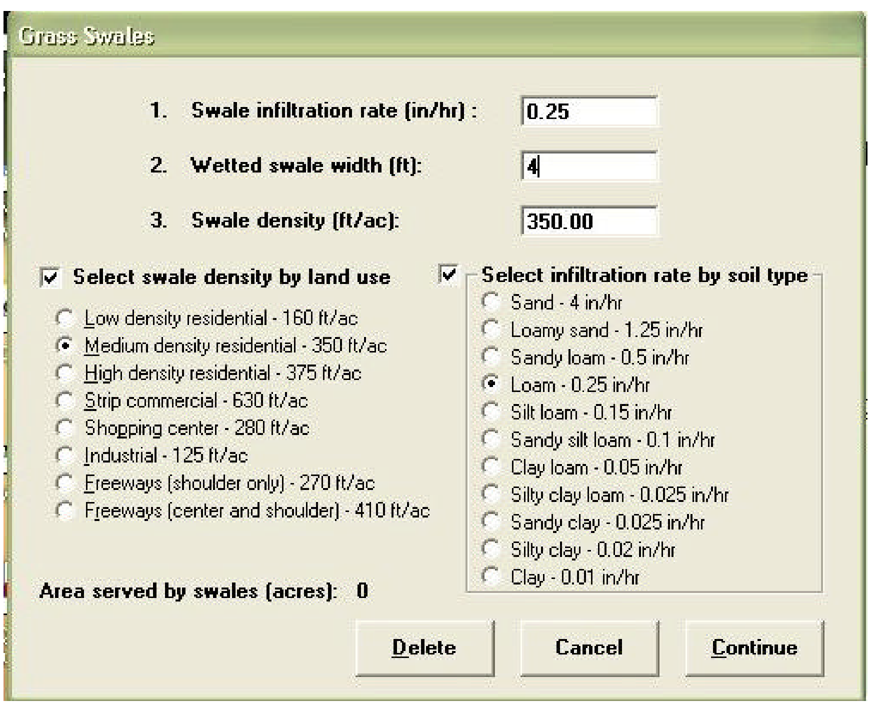




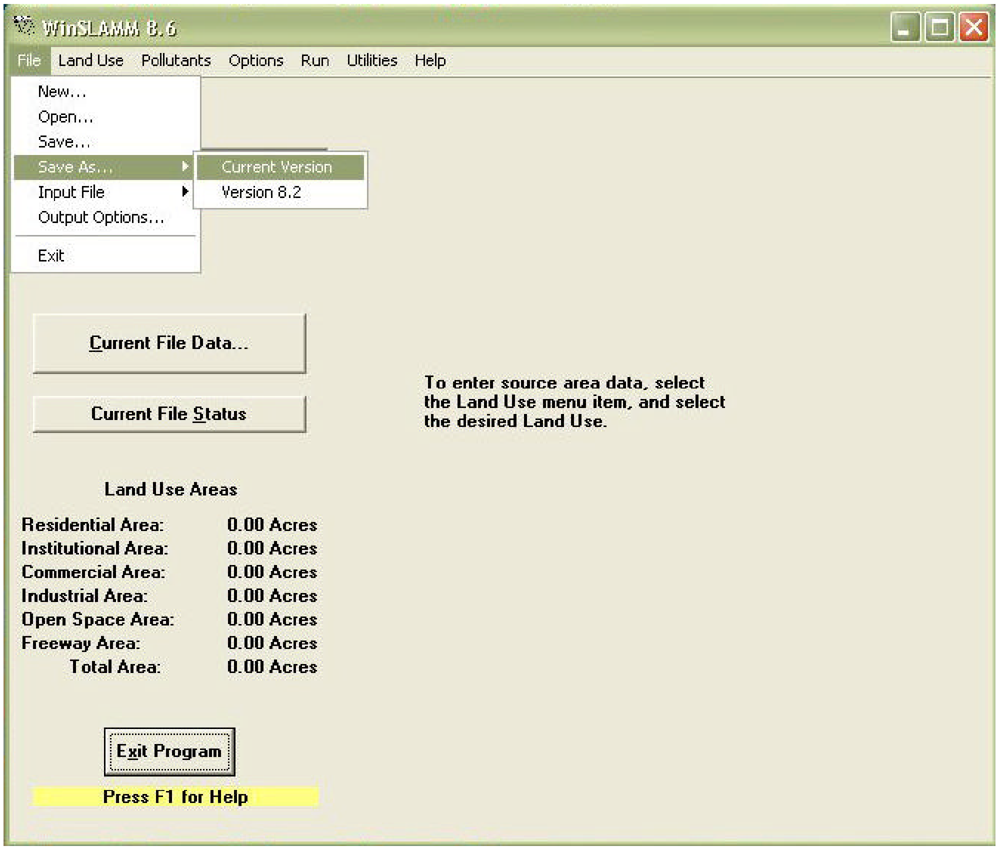
The model needs to know the type of drainage system used. The following screen is used to designate the fraction of each type of drainage in the study area. In this example, grass swales are used throughout the area.

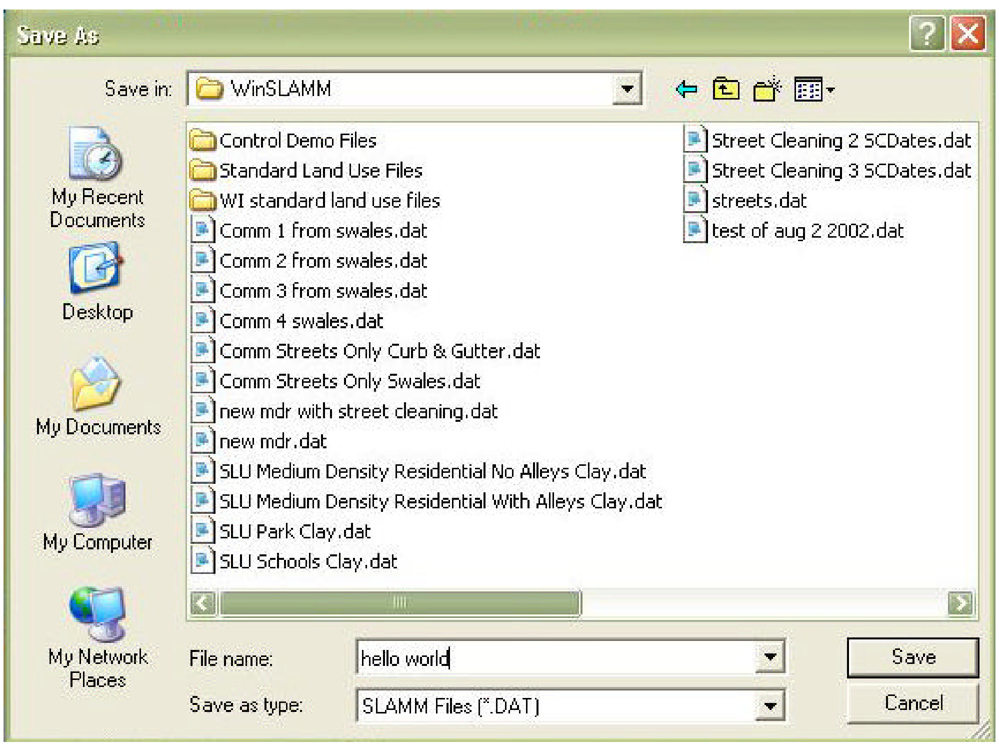


If any grass swales are used in the study area, the following screen is used to enter characteristics describing the swales. The swale density (the linear length of swale per area served) can be directly entered based on site specific measurements, or typical values can be selected based on aerial photograph measurements from many areas. In addition, the infiltration rate for the soil lining the swale can be directly entered, or the general soil type can be selected. The listed infiltration rates are approximately half the values commonly used in ponded situations reflecting the typical measured decrease in infiltration capabilities at flowing water sites. The wetted swale width is used to calculate the area available for infiltration and is assumed to be the relatively flat bottom of the swale.

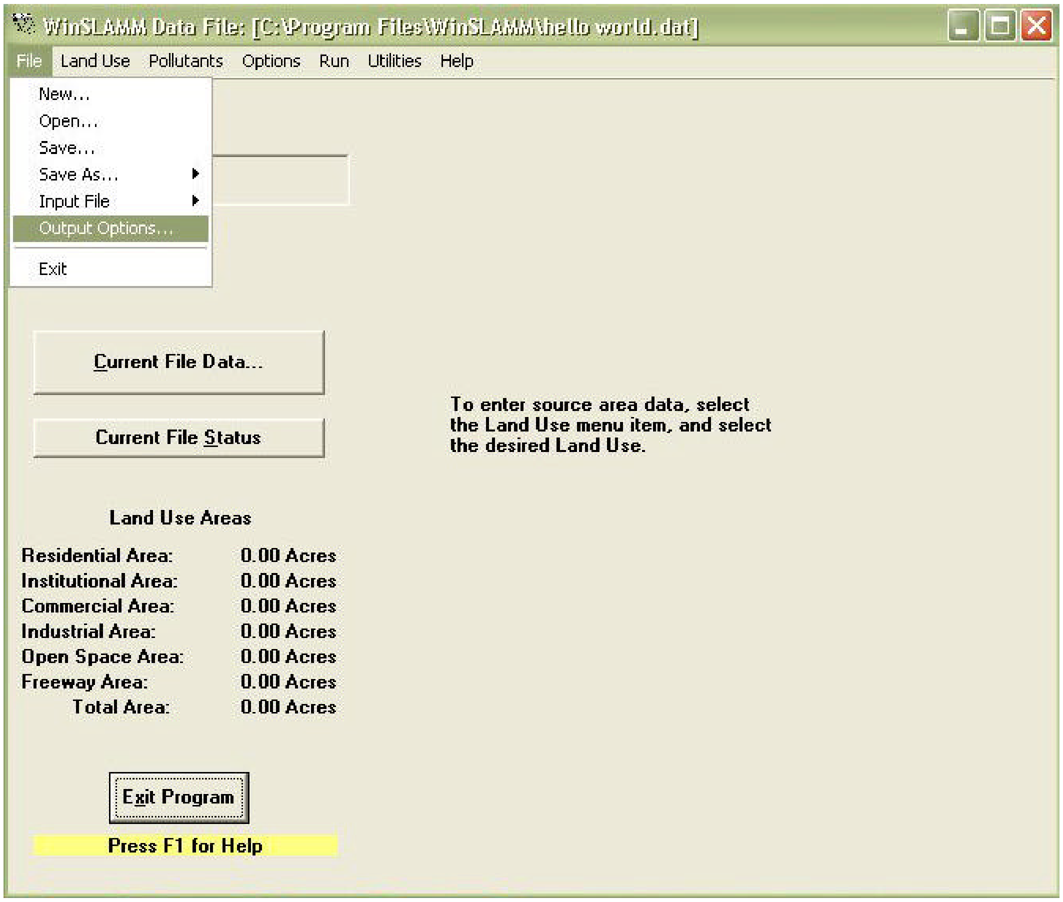


At this point, the file should be named and saved and the output option selected.


WinSLAMM 8.6
File
Land Use
Pollutants
Options
Run
Utilities
Help
New...
Open...
Save...
Save As...
Current Version
Version 8.2
Input File
Output Options...
Exit
Current File Data...
Current File Status
To enter source area data, select the Land Use menu item, and select the desired Land Use.
Land Use Areas
Residential Area: 0.00 Acres
Institutional Area: 0.00 Acres
Commercial Area: 0.00 Acres
Industrial Area: 0.00 Acres
Open Space Area: 0.00 Acres
Freeway Area: 0.00 Acres
Total Area: 0.00 Acres
Exit Program
Press F1 for Help

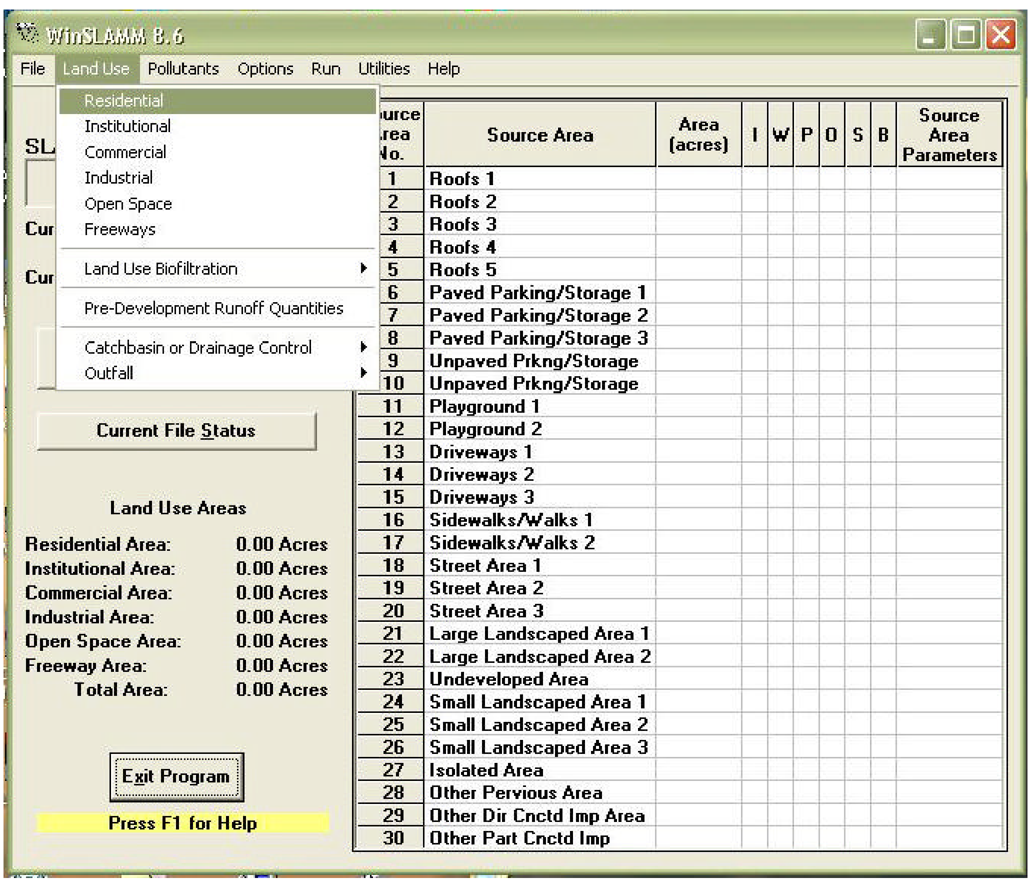

Save As
Save in: WinSLAMM
My Recent Documents
Desktop
My Documents
My Computer
My Network Places
Control Demo Files
Standard Land Use Files
WI standard land use files
Comm 1 from swales.dat
Comm 2 from swales.dat
Comm 3 from swales.dat
Comm 4 swales.dat
Comm Streets Only Curb & Gutter.dat
Comm Streets Only Swales.dat
new mdr with street cleaning.dat
new mdr.dat
SLU Medium Density Residential No Alleys Clay.dat
SLU Medium Density Residential With Alleys Clay.dat
SLU Park Clay.dat
SLU Schools Clay.dat
Street Cleaning 2 SCDates.dat
Street Cleaning 3 SCDates.dat
streets.dat
test of aug 2 2002.dat
File name: hello world
Save as type: SLAMM Files (*.DAT)
Save
Cancel

The form of the output information can be selected by using the “file\output options” dropdown menu. The following screen lists the options. Option 1, the complete printout, is selected here because of the short list of rains in the source.ran file used and that the flow and pollutant sources for each source area are to be compared. Option 4, “Outfall Summaries Only” is the default option. Option 5, “One line per event runoff and flow summary” is the most useful option when a large rain file is being used.



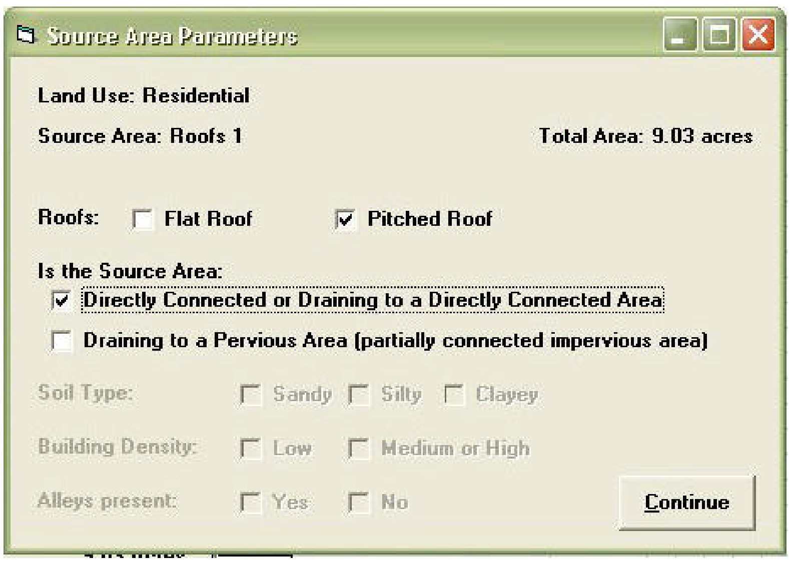
Land Use and Source Area Descriptions

The next step is to select the land use(s) in the study area. The following screen shows the selection of the residential land use and the corresponding source areas.

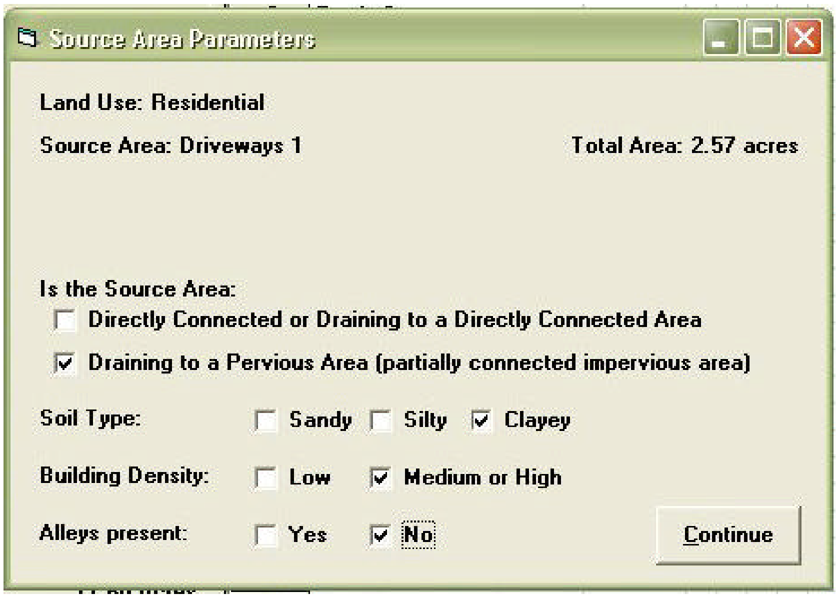


For each source area, double click on the "area" cell and the following screen appears (roof area 1 for this example).

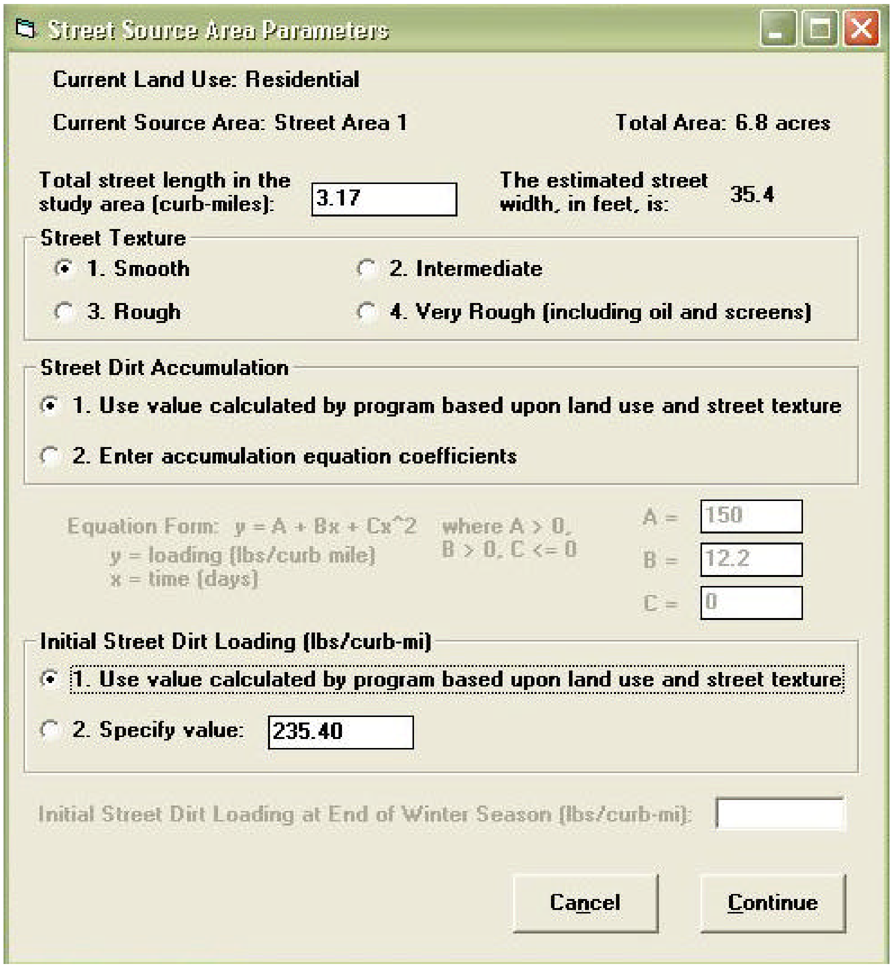
The following screen then appears after the area value is entered. This screen describes the basic roof slope and if the roof drainage is directly connected to the drainage (as in this example), or allowed to drain to the pervious area. If draining to the pervious area, the soil type is needed. If the soil is clayey, then the building density is needed (not needed for sandy or silty soils). If medium or high density, then the model asks about the presence of backyard alleys. Clayey soils, higher building densities, and alleys all decrease the benefits of disconnecting roof runoff.



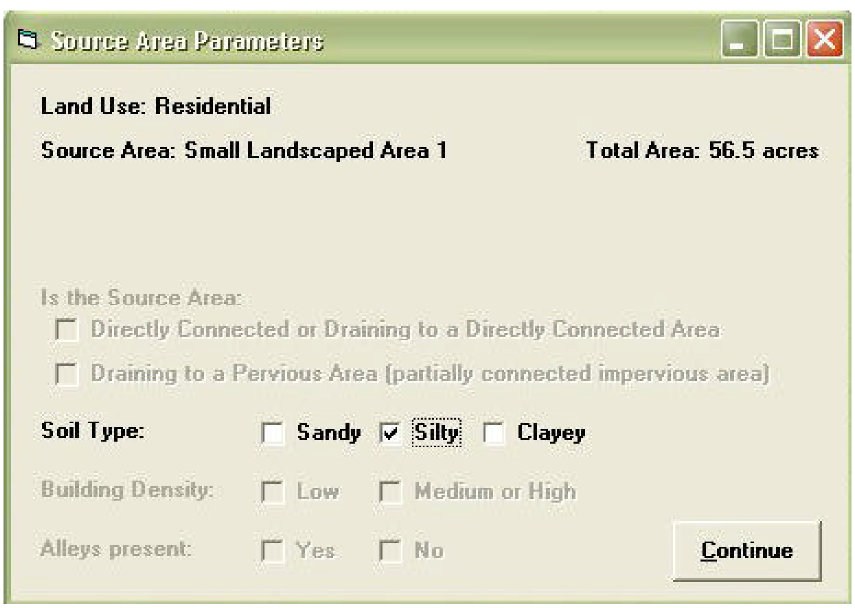
The following is an example screen describing runoff routing for typical paved areas. This example is for driveways, showing that the runoff is disconnected (flowing to the pervious land), and that the ground has a clayey texture, the building density is high, and no alleys are present. High building densities, or the presence of alleys, all decrease the benefits of disconnections of the source areas by effectively decreasing the flow path length before the water enters the drainage system.



The following screen is used to describe street areas. This screen contains information about the street length (the model calculates the corresponding street width as a check) and the street texture. The model can use the built-in street dirt accumulation rates (based on land use) and initial loading values (based on street texture), or the user can enter specific locally measured values. The initial street dirt loading can be increased to reflect the very large values typically found after snowmelt in the spring, for example. One of the options when entering the rain file is to designate a snow season. During that period, all runoff calculations are ceased. If that option is used, the street source area form then requires the user to designate a street dirt loading value corresponding to the high values typically found after the winter season (usually several thousand pounds per curb-mile). This affects the washoff for the early spring rains, along with the effectiveness of the first several street cleaning activities of the year. WinSLAMM does not currently calculate snowmelt.



In this example, the last area to be described is for small landscaped areas. The following screen shows that only the soil type is needed for these areas.

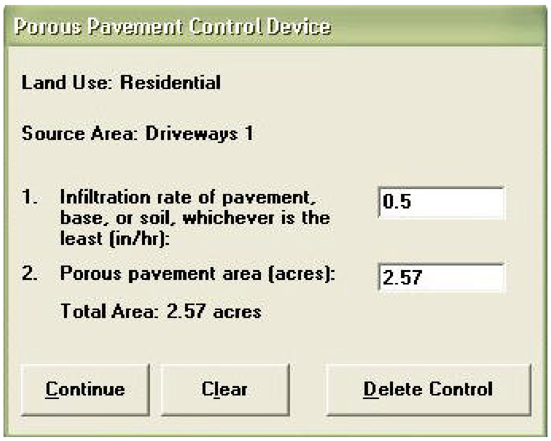


Source Area and Outfall Controls

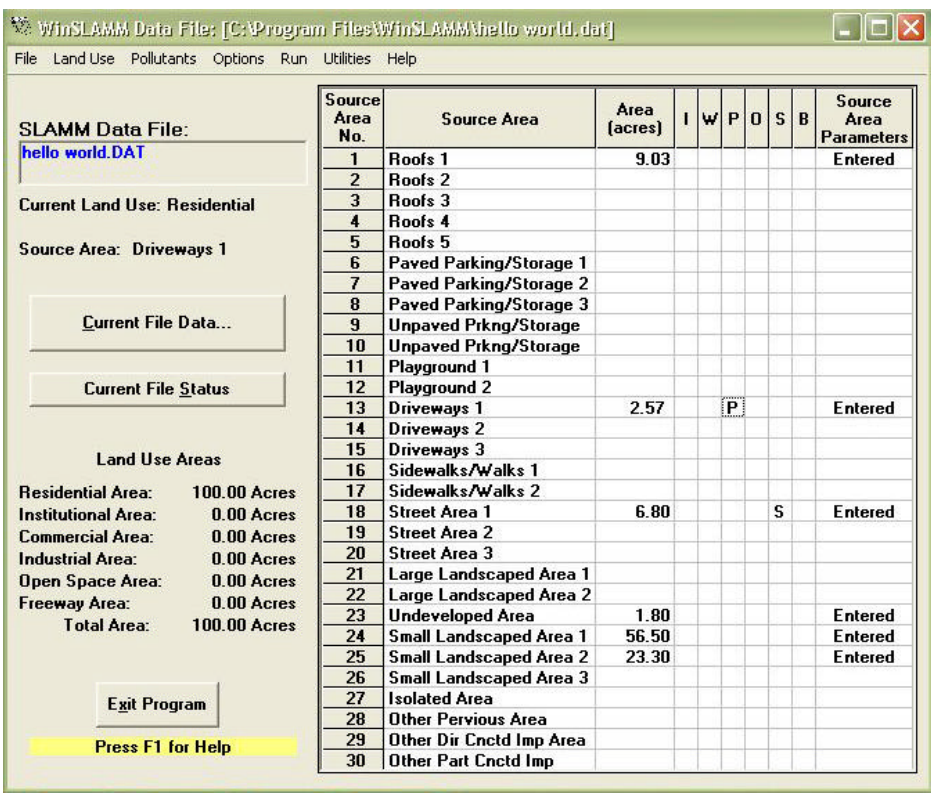
After this information is entered and "continue" is pressed, it is possible to select site specific control options (besides the development characteristics reflected above).

Infiltration Devices and Porous Pavement

Porous pavement is becoming more common for driveways and sidewalks. The cell corresponding to porous pavement (P) and the driveways 1 source area can be selected to bring up the following menu which shows the user entered infiltration rate and the area to be treated by the device:

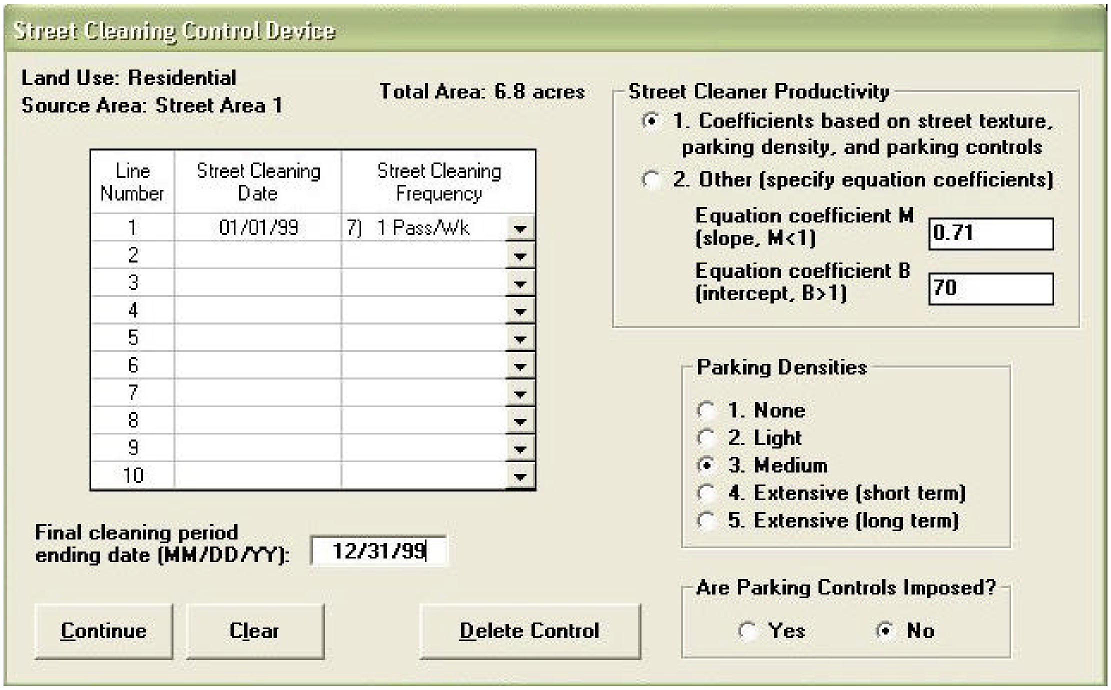


After the information is entered, the letter corresponding to the control appears in the appropriate cell:

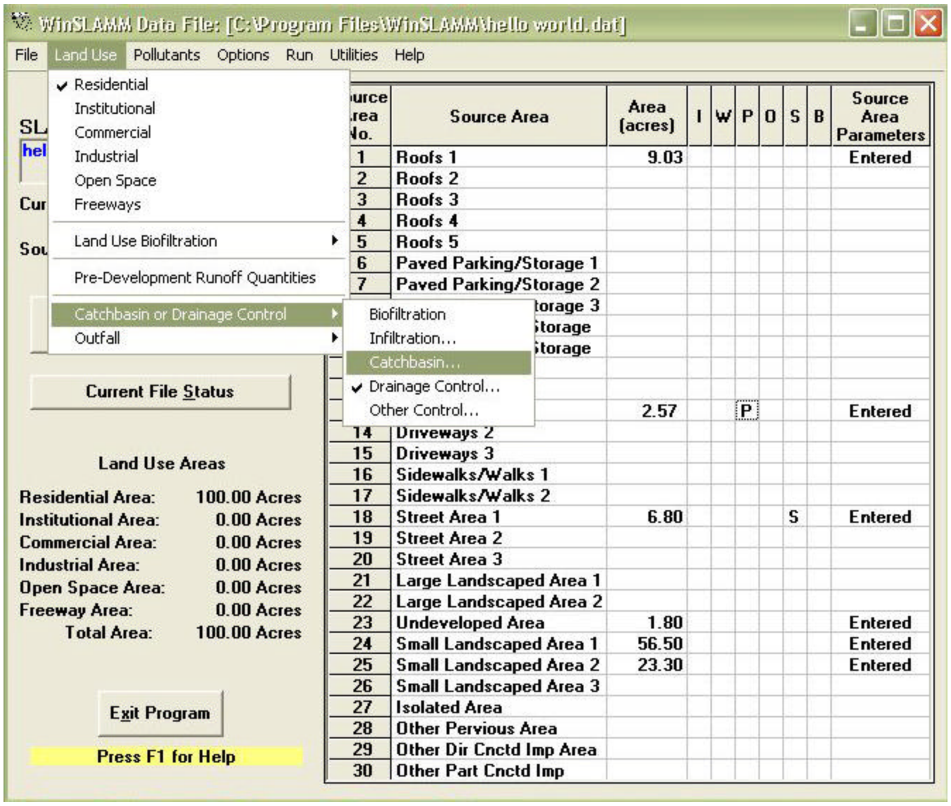


More sophisticated procedures are available in the biofiltration menu option to model infiltration processes.

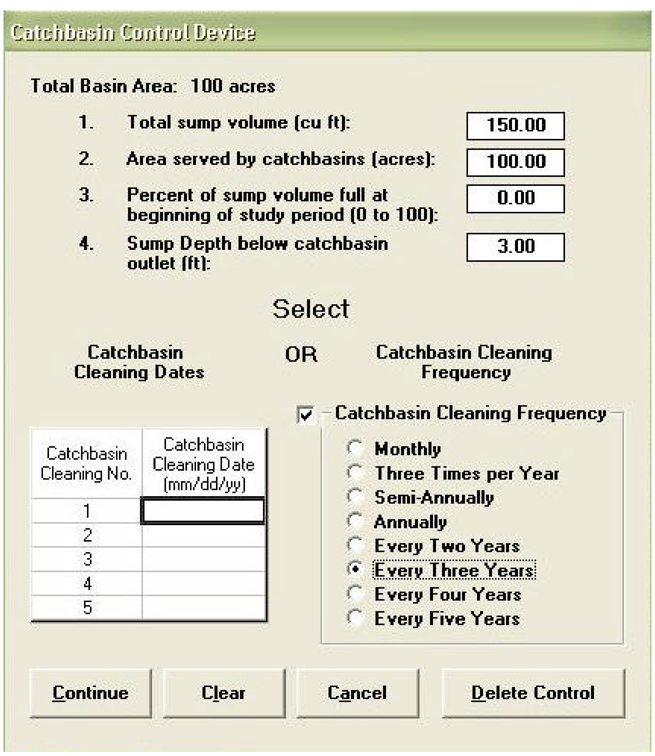
Street Cleaning
Street cleaning can also be simulated with WinSLAMM. The following screen is used to describe the street cleaning program for a specific street area. Up to ten different street cleaning frequencies can be specified for the study area. Each program lasts until the next one starts, or until the final cleaning period ending date. [note: in some cases, the program may require the user to enter the final cleaning period ending date a second time after pressing the continue button, sorry about that].



Catchbasins
Catchbasins can be selected from the “land use\catchbasin or drainage control\catchbasin” dropdown menu:



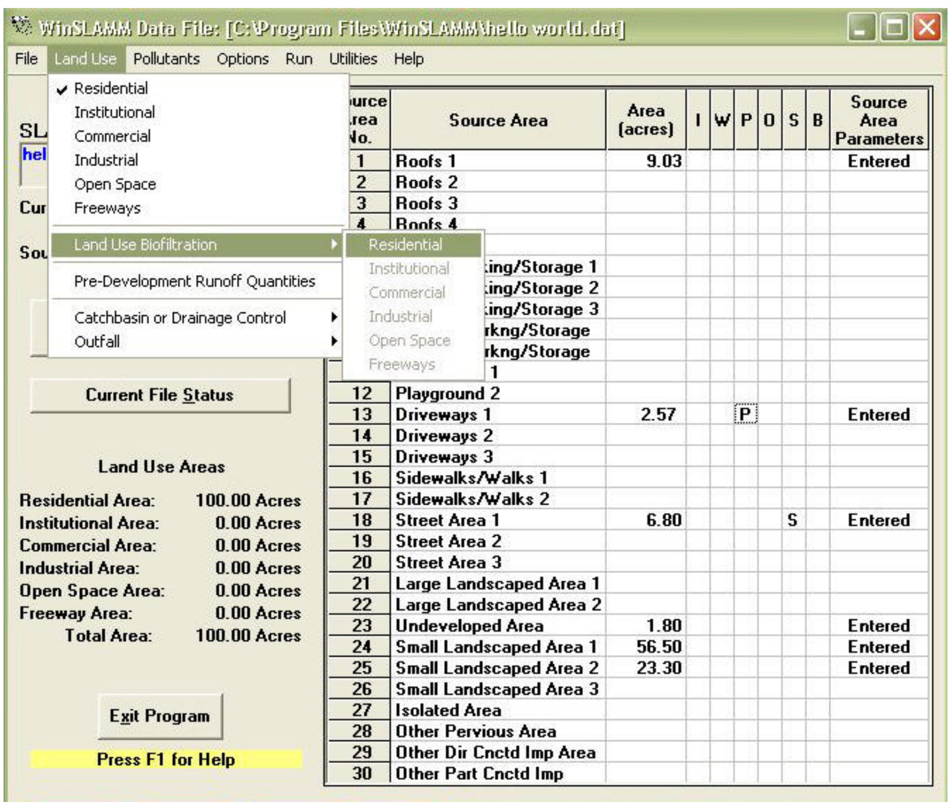
The following screen is used to describe the catchbasins in the study area, and their cleaning frequency:



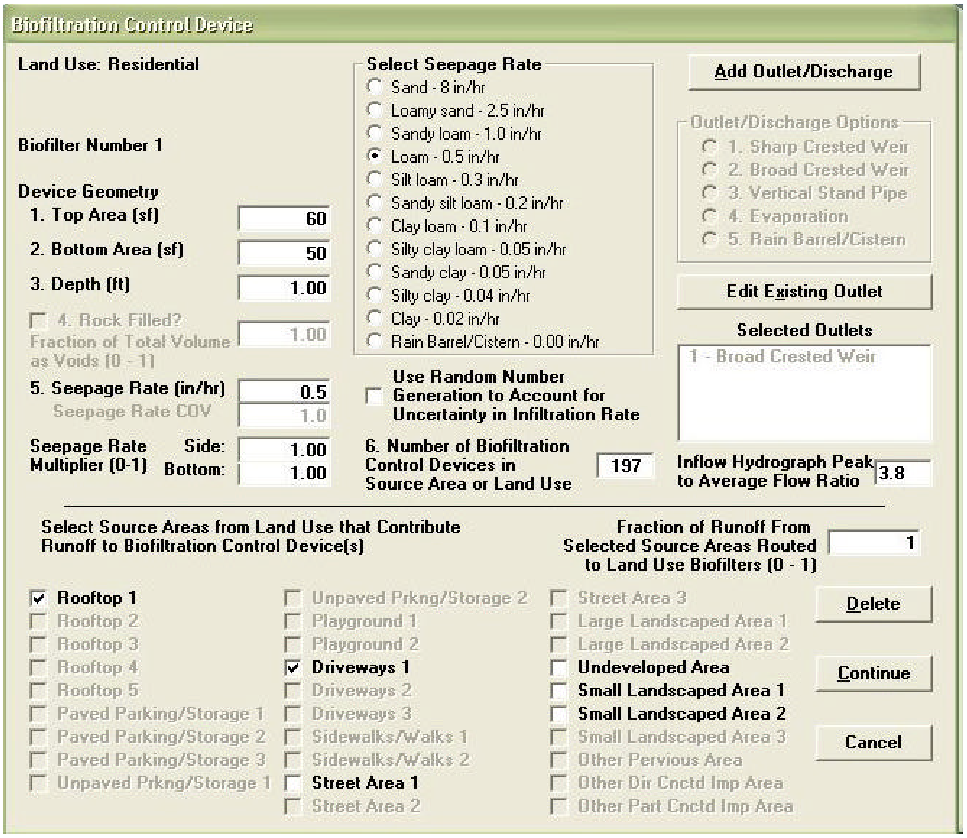
The output forms under particulate solids track the accumulation of solids accumulating in the catchbasins. Catchbasins are only effective in trapping particulates when there is at least a foot of standing water over the trapped sediment. WinSLAMM continues to accumulate solids in catchbasins until this level of sediment is reached. The output forms can be used to estimate how rapidly the catchbasins likely accumulate sediment and when they are likely to become full. The cleaning frequency can then be adjusted to better match the local accumulation rates for the catchbasins in the study area.

Evaluations of concurrent use of catchbasins and street cleaning may be misleading for study areas that are mostly streets, as little field data is available to document the concurrent benefits of this combination of controls. In these cases, extensive street cleaning removes most of the larger particulates that would be trapped in the catchbasins, reducing the predicted effectiveness of the catchbasin. Therefore, WinSLAMM doesn't accumulate solids in catchbasins originating from streets that are being swept. However, the catchbasins do accumulate solids from other areas if there is street cleaning in the study area.

Biofiltration/Bioretention and Rain Gardens/Cisterns
These controls can be located at several locations simultaneously, or individually, in study areas. The most common source areas to be treated by these devices would be roofs, where they can be configured as '"rain gardens." They can also be situated along streets providing infiltration opportunities for street runoff (possibly in conjunction with grass swales, or in median strips of divided roads). They can also be located so they accept flows from several source areas in a land use, as in the following example where 197 units are used in the 100 acres to treat roof runoff and the excess runoff (if any) from driveways paved with porous paver blocks. The land use biofiltration option is selected using the "land use\land use biofiltration" option and selecting the appropriate land use:



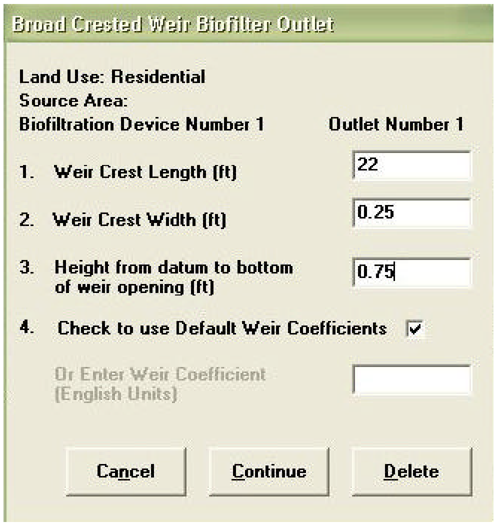
The following form is used to describe the units:



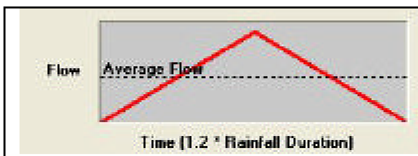
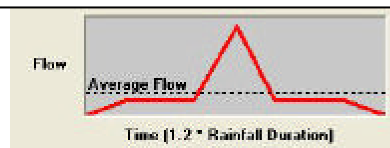
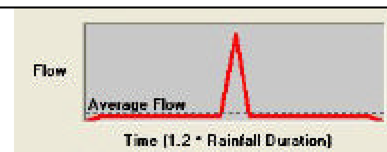
This screen can be used to describe many different types of stormwater control devices. This example is for "rain gardens" located at each of the 197 homes in this 100 acre area. Each rain garden is about 60 ft^2 in area, serving each 2,000 ft^2 of roof, plus driveway runoff. A loam soil having a 0.5 in/hr seepage rate (but with a seepage rate coefficient of variation of 1.0, reflecting typical storm-to-storm variability in soil infiltration rates) is used for each device in this example. The seepage variation is only used for the long-term evaluation having many events, not when the source.ran file is used. The added variation would be confusing when comparing separate rain conditions.

This screen is similar to the source area biofiltration screen, except that it also lists the available source areas in the bottom area of the form. It is therefore possible to combine some of the source areas together for control, such as rooftop and driveway runoff combined. In addition, it is possible to designate only a fraction of the combined flows to the biofiltration areas. As an example, a fraction of the roof runoff and driveway runoff can be directed to a cistern for storage of runoff for later use during dry weather for on-site irrigation (or toilet flushing, etc.). In the rain barrel/cistern "outlet/discharge" option, monthly water uses are entered so the model can track water use and re-filling of the tanks during storms. The similar "drainage system" biofiltration control screen allows infiltration and routing of stormwater as part of the drainage system for the complete area, such as for perforated pipe.

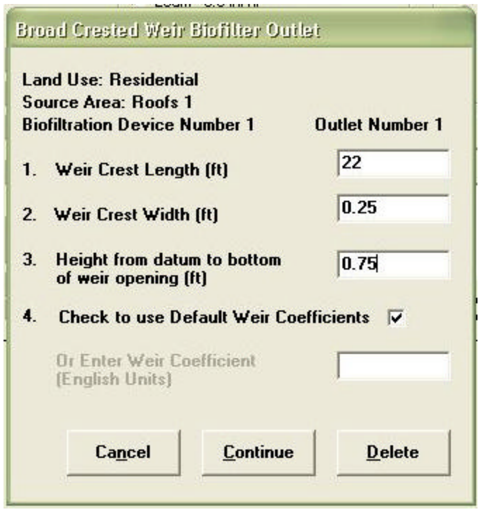
In all cases, the biofiltration devices must have an outlet. In this case, the required outlet is a broad-crested weir (the most likely option for a rain garden):



The ratio of the peak to average flows for the hydrographs for each event is suggested to be 3.8, a typical value based on monitoring. A simple triangular hydrograph corresponds to a ratio of 2.0 and may be representative of large areas during relatively small rains. For small source areas and for moderate to larger rains, higher values than this ratio are appropriate. WinSLAMM can be used to describe the sensitivity of the biofiltration device design to these variable inflow hydrograph shapes. In most cases, large ratios actually result in better performance as most of the runoff then occurs with relatively low flows, while the very high flows occurring during the short periods can usually be stored in the storage “pond” built as part of the biofiltration device. The following are several plots representing different ratios of peak to average flows. In all cases, the same runoff volume calculated for the contributing area is used, but the flow rates are distributed according to the hydrograph shape.

 Ratio = 2.0	 Ratio = 3.8	 Ratio = 10

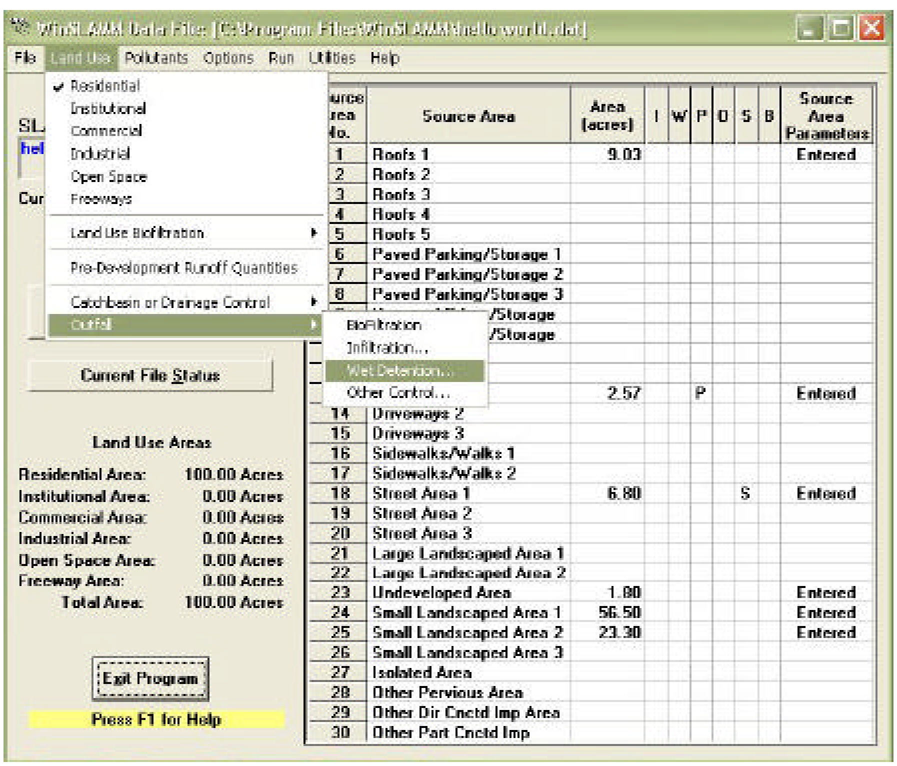
The outlet structures for the biofiltration devices can be simply described as broad-crested weir overflows, with the approximate downstream perimeter as the weir length and several inches for the width. The model routes the flows from the source areas through the biofiltration devices using the modified puls routing procedure (and the above described hydrograph shape), incorporating infiltration, evaporation, and overflows, as described. A rain barrel or cistern is used when calculating the effects of beneficial uses of the runoff water (such as for toilet flushing, irrigation, or other safe use).



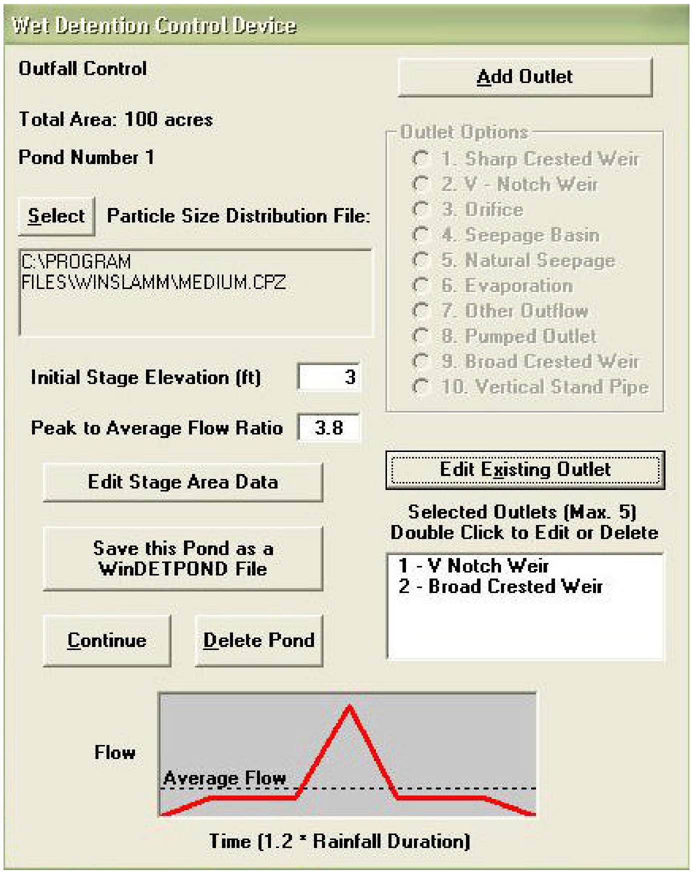
Wet Detention Ponds

The following screens are used to describe wet detention ponds at source areas and at outfalls. The particle size distribution is selected (by selecting from a list of pre-developed parameter files) and the pond geometry is entered. Finally, pond outlets are also described from the list, including weirs, infiltration, evaporation, pumps, and seepage basins located after the pond. The inflow hydrograph is developed based on the total runoff volume entering the pond and using a multiple-triangular hydrograph, as described above for biofiltration devices. Any upland infiltration/biofiltration device located prior to the pond reduces the flow entering the pond. The standard modified-puls method for routing the flows through the ponds are used, in conjunction with the surface overflow rate procedure for routing suspended solids.

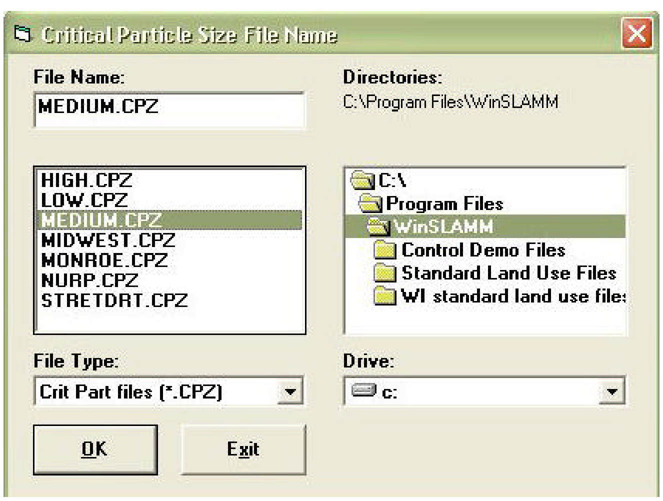
An outfall wet detention pond is selected using the "land use\outfall\wet detention" dropdown menu:



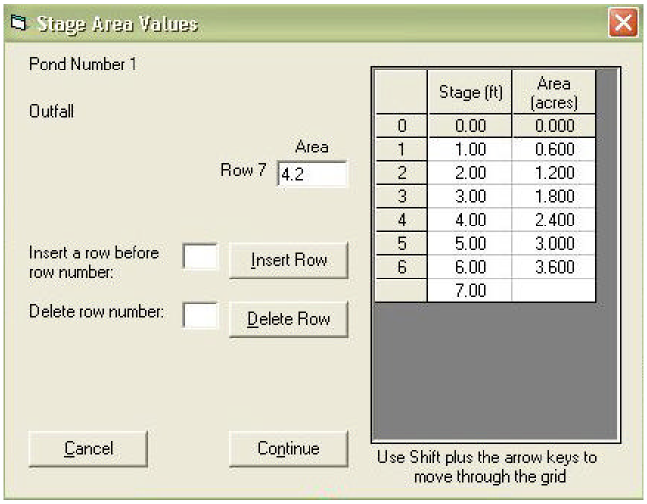
The following screen is then used to describe the pond:



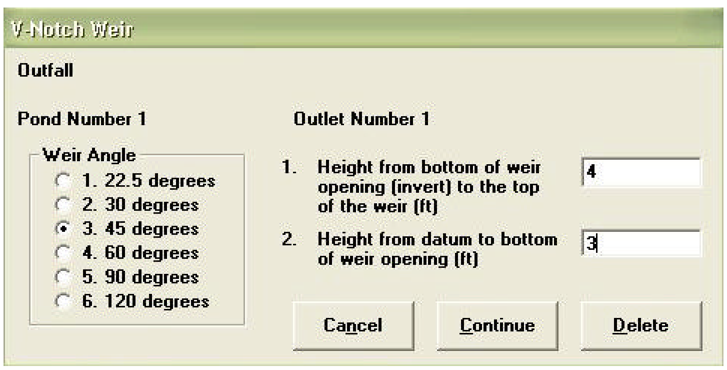
First, the particle size file is selected:



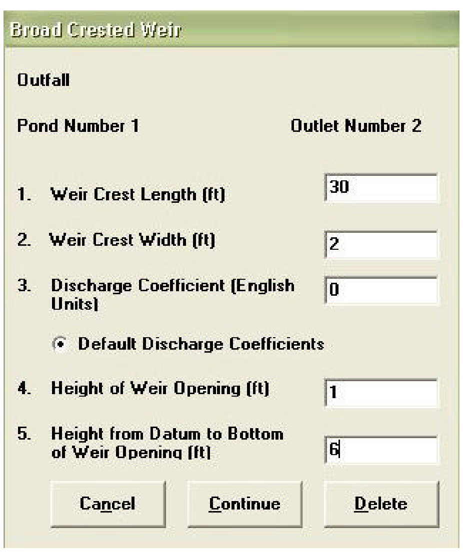
Then the pond shape is entered:



And lastly, the water quality outlet control:

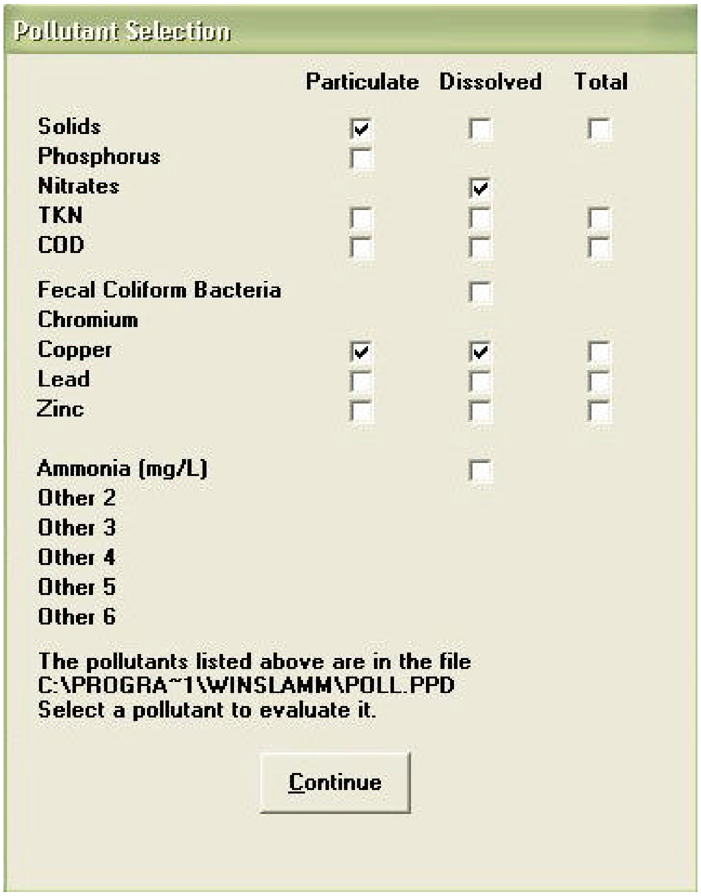


and an emergency spillway are described:



Pollutant Selections

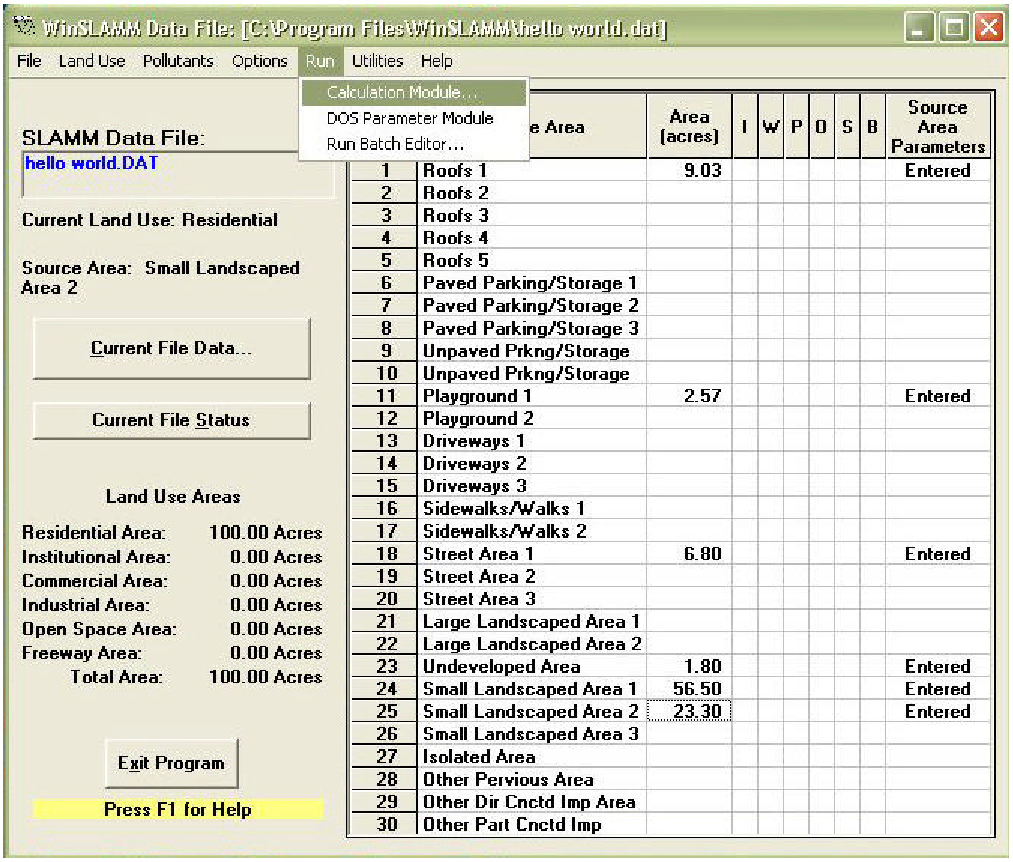
The user can also select the specific pollutants to be analyzed. The following screen shows the pollutants available, based on the previously selected ppd file. The model calculates runoff volume and suspended solids (particulate solids) conditions for all cases. Additional parameters can be selected (or de-selected) by clicking on each available box. The dissolved and particulate-associated forms of the selected pollutants can be evaluated independently from the total forms, if desired. Depending on the Monte Carlo option previously selected, the concentrations of runoff will vary for each rain from each source area.



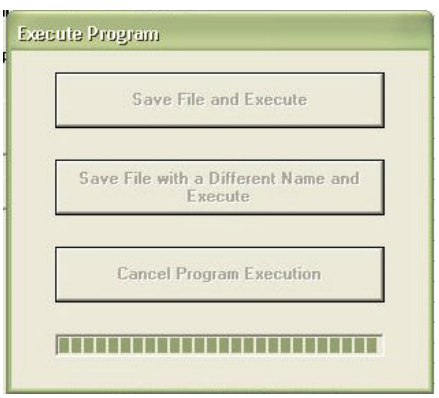
The file can be saved at any time by selecting the "file\save", or "file\save as" dropdown menu options.

Program Calculation and Output

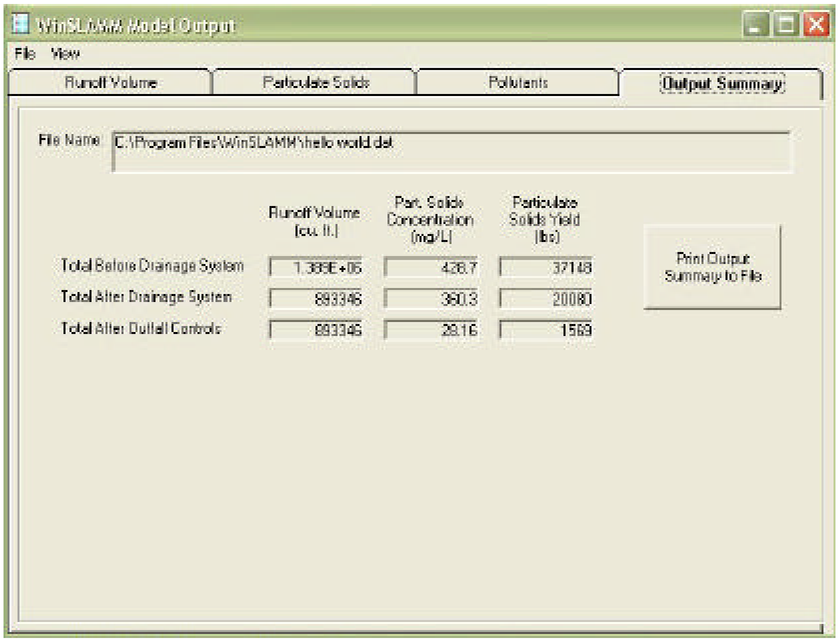
WinSLAMM evaluates the file after selecting the "run\Windows Calculation Module" dropdown menu, as shown below.



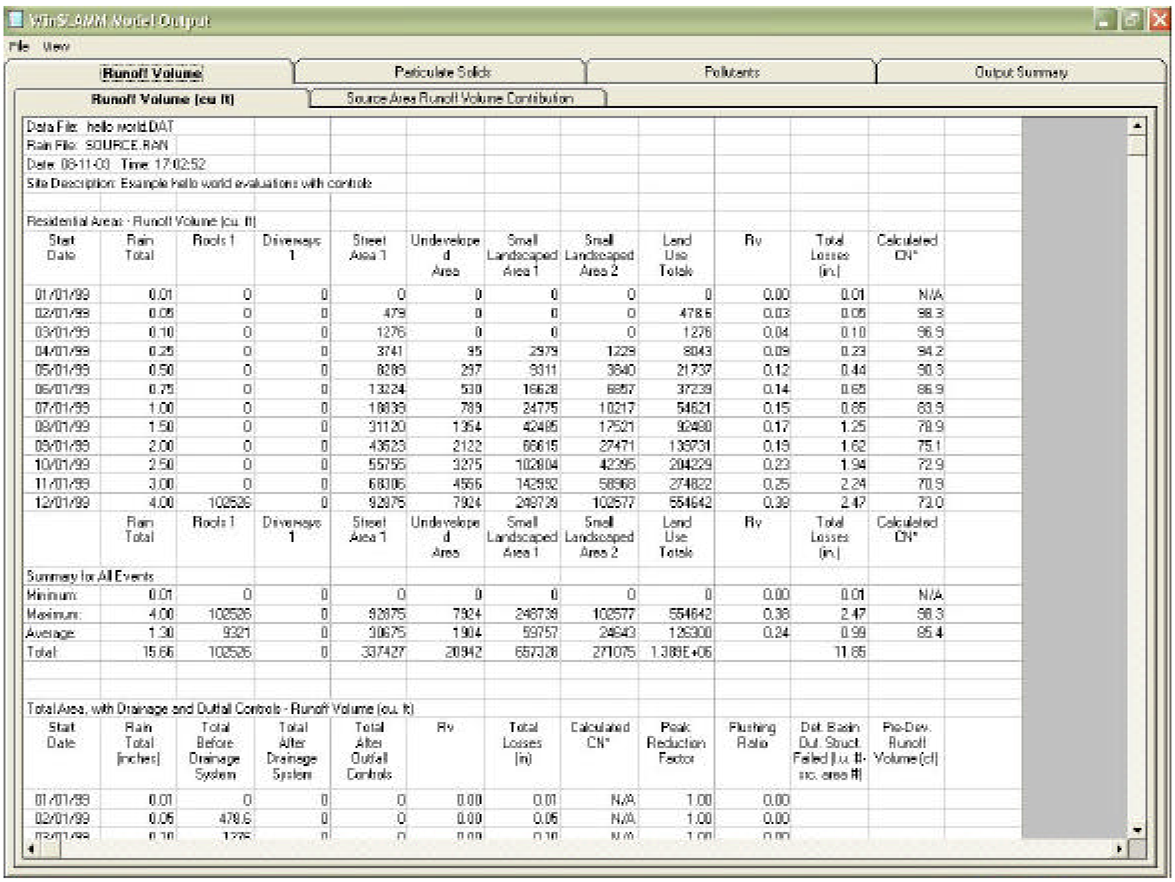
Select the “Save File and Execute” option. The model has finished execution when the progress bar is filled:



Upon completion, the output is summarized in a series of user selectable tables for output options 1 through 4. The opening screen displays a summary of the runoff volume, suspended solids concentrations and suspended solids yields before the drainage system (before grass swales, or other drainage system features and catchbasins affect the discharges), after the drainage system (so the effects of the drainage system can be directly examined), and after any outfall controls reflecting the calculated discharged amounts (allowing the effects of any outfall controls, such as wet detention ponds, to be directly examined).



Selecting the tabs across the top displays detailed information for runoff volume, particulate solids, and the pollutants.



Data File: hello world.DAT
Rain File: SOURCE.RAN
Date: 08-11-03 Time: 17:02:52
Site Description: Example hello world evaluations with controls

Residential Areas - Runoff Volume (cu. ft)

Start Date	Rain Total	Roofs 1	Driveways 1	Street Area 1	Undeveloped Area	Small Landscaped Area 1	Small Landscaped Area 2	Land Use Totals	Rv	Total Losses (in.)	Calculated CN*
01/01/99	0.01	0	0	0	0	0	0	0	0.00	0.01	N/A
02/01/99	0.05	0	0	479	0	0	0	478.6	0.03	0.05	98.3
03/01/99	0.10	0	0	1276	0	0	0	1276	0.04	0.10	96.9
04/01/99	0.25	0	0	3741	95	2979	1229	8043	0.09	0.23	94.2
05/01/99	0.50	0	0	8289	297	9311	3840	21737	0.12	0.44	90.3
06/01/99	0.75	0	0	13224	530	16628	6857	37239	0.14	0.65	86.9
07/01/99	1.00	0	0	18839	789	24775	10217	54621	0.15	0.85	83.9
08/01/99	1.50	0	0	31120	1354	42485	17521	92480	0.17	1.25	78.9
09/01/99	2.00	0	0	43623	2122	66615	27471	139731	0.19	1.62	75.1
10/01/99	2.50	0	0	55755	3275	102804	42395	204229	0.23	1.94	72.9
11/01/99	3.00	0	0	68306	4556	142992	58968	274822	0.25	2.24	70.9
12/01/99	4.00	102526	0	92875	7924	248739	102577	554642	0.38	2.47	73.0

Summary for All Events

	Rain Total	Roofs 1	Driveways 1	Street Area 1	Undeveloped Area	Small Landscaped Area 1	Small Landscaped Area 2	Land Use Totals	Rv	Total Losses (in.)	Calculated CN*
Minimum:	0.01	0	0	0	0	0	0	0	0.00	0.01	N/A
Maximum:	4.00	102526	0	92875	7924	248739	102577	554642	0.38	2.47	98.3
Average:	1.30	9321	0	30675	1904	59757	24643	126300	0.24	0.99	85.4
Total:	15.66	102526	0	337427	20942	657328	271075	1.389E+06		11.65	

Total Area, with Drainage and Outfall Controls - Runoff Volume (cu. ft)

Start Date	Rain Total (inches)	Total Before Drainage System	Total After Drainage System	Total After Outfall Controls	Rv	Total Losses (in)	Calculated CN*	Peak Reduction Factor	Flushing Ratio	Det. Basin Out. Struct. Failed (Lu. #- src. area #)	Pre-Dev. Runoff Volume (cf)
01/01/99	0.01	0	0	0	0.00	0.01	N/A	1.00	0.00		
02/01/99	0.05	478.6	0	0	0.00	0.05	N/A	1.00	0.00		
03/01/99	0.10	1276	0	0	0.00	0.10	N/A	1.00	0.00		

The above sheet shows the runoff volume contributions from each source area for each rain. This rain file (source.ran) is a special rain file that only contains 12 events ranging in depth from 0.01 to 4 inches, and spaced about a month apart. This allows direct evaluations of the effectiveness of source area, drainage system, and outfall controls. In this example, the biofiltration device (a rain garden collecting the roof runoff plus the excess runoff from the driveways not infiltrated by the porous pavement) completely infiltrates all runoff from the driveways for all rains and all runoff from the roofs for all but the largest rain. Obviously, these controls may be over-sized for this situation, but this does illustrate how this information can be evaluated. The following screen (scrolled down from the prior screen) summarizes the drainage system and outfall controls for this site:

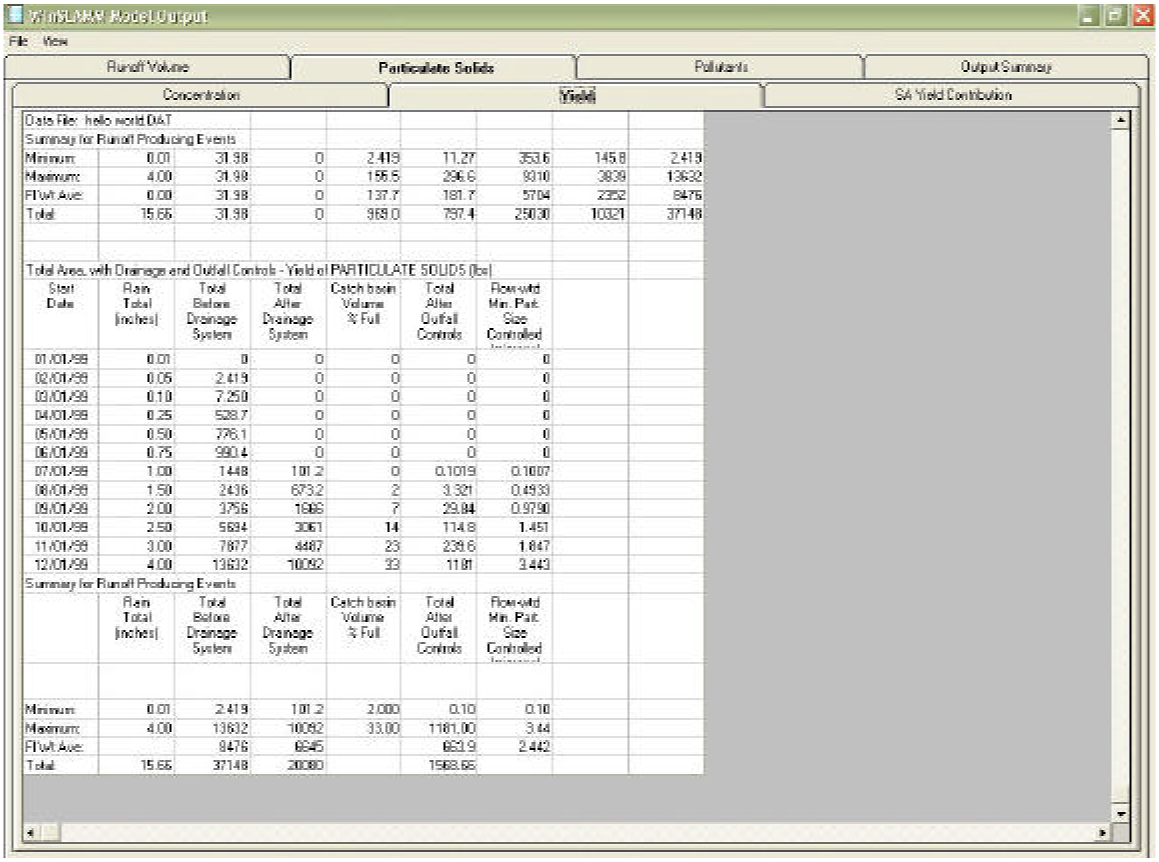
File View

Runoff Volume | Particulate Solids | Pollutants | Output Summary

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

Data File: hello world.DAT											
Summary for All Events											
Minimum:	0.01	0	0	0	0	0	0	0	0.00	0.01	N/A
Maximum:	4.00	102526	0	92675	7924	248739	102577	554642	0.38	2.47	98.3
Average:	1.30	9321	0	30675	1904	59757	24643	126300	0.24	0.99	85.4
Total:	15.66	102526	0	337427	20942	657328	271075	1.389E+06		11.85	
Total Area, with Drainage and Outfall Controls - Runoff Volume (cu. ft)											
Start Date	Rain Total (inches)	Total Before Drainage System	Total After Drainage System	Total After Outfall Controls	Rv	Total Losses (in)	Calculated CN*	Peak Reduction Factor	Flushing Ratio	Det. Basin Out. Struct. Failed (i.e. #- inc. area #)	Pre-Dev. Runoff Volume (cf)
01/01/99	0.01	0	0	0	0.00	0.01	N/A	1.00	0.00		
02/01/99	0.05	478.6	0	0	0.00	0.05	N/A	1.00	0.00		
03/01/99	0.10	1276	0	0	0.00	0.10	N/A	1.00	0.00		
04/01/99	0.25	8043	0	0	0.00	0.25	N/A	1.00	0.00		
05/01/99	0.50	21737	0	0	0.00	0.50	N/A	1.00	0.00		
06/01/99	0.75	37239	0	0	0.00	0.75	N/A	1.00	0.00		
07/01/99	1.00	54621	6282	6282	0.02	0.98	73.0	0.99	0.05		
08/01/99	1.50	92480	38426	38426	0.07	1.39	71.5	0.93	0.32		
09/01/99	2.00	139731	79963	79963	0.11	1.78	69.1	0.86	0.66		
10/01/99	2.50	204229	133033	133033	0.15	2.13	67.3	0.78	1.09		
11/01/99	3.00	274822	186482	186482	0.17	2.49	65.2	0.67	1.54		
12/01/99	4.00	554642	449160	449160	0.31	2.76	68.5	0.46	3.71		
Summary for All Events *Note: NRCS does not recommend using CN method for rains < 0.5 in. See 'PreDevelopment Areas and CN' Help for more info.											
	Rain Total (inches)	Total Before Drainage System	Total After Drainage System	Total After Outfall Controls	Rv	Total Losses (in)	Calculated CN*	Peak Reduction Factor	Flushing Ratio		Pre-Dev. Runoff Volume (cf)
Number of Rains:		11	11	11							
Minimum:	0.01	0	0	0	0.00	0.01	N/A	0.46	0.00		
Maximum:	4.00	554642	449160	449160	0.31	2.76	73.0	1.00	3.71		
Average:	1.42	126300	81213	81213	0.16	1.10	80.4	0.89	0.61		
Total:	15.66	1.389E+06	893346	893346		13.19					

In this table, the drainage system control (grass swales) are able to completely infiltrate the runoff for all events up to about the one inch rain. The outfall wet detention pond obviously has no effect on runoff volume (no pond evaporation or seepage was included in this evaluation). The following is the table for particulate solids and illustrates how the drainage system and outfall controls significantly reduce these discharges for each rain event.



WinSLAMM Model Output

File View

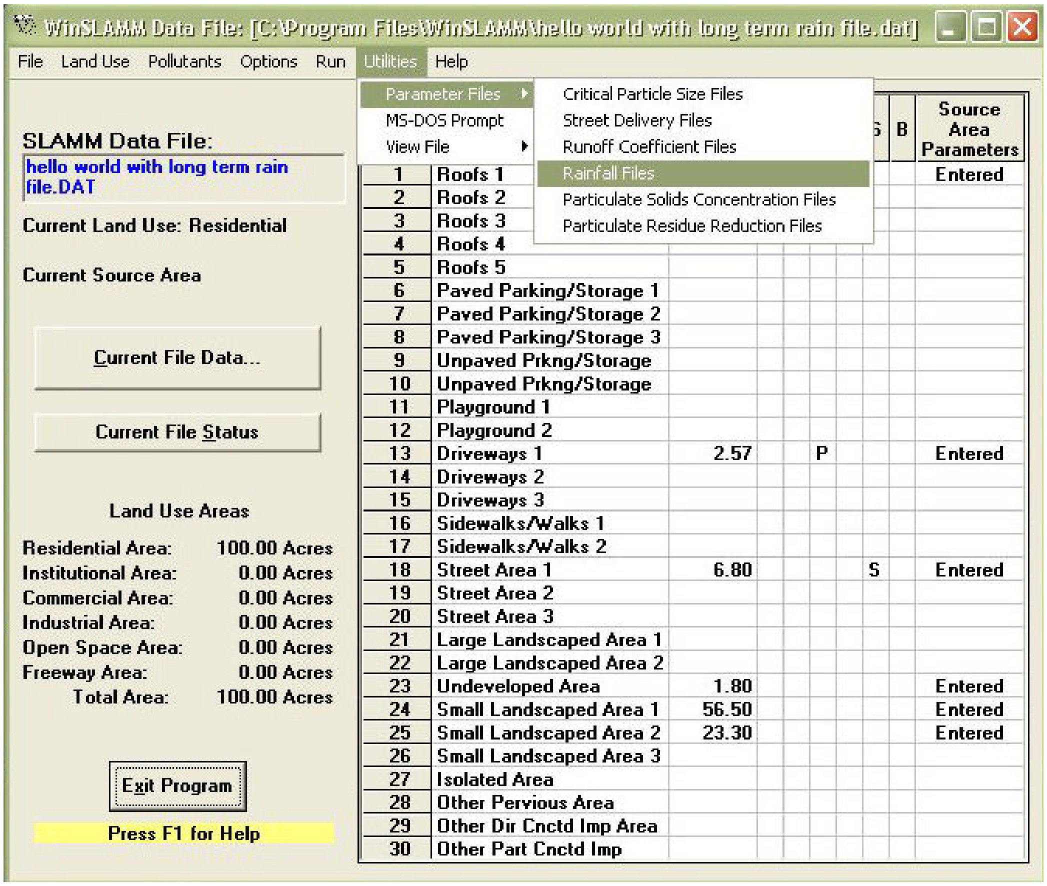
Runoff Volume | Particulate Solids | Pollutants | Output Summary

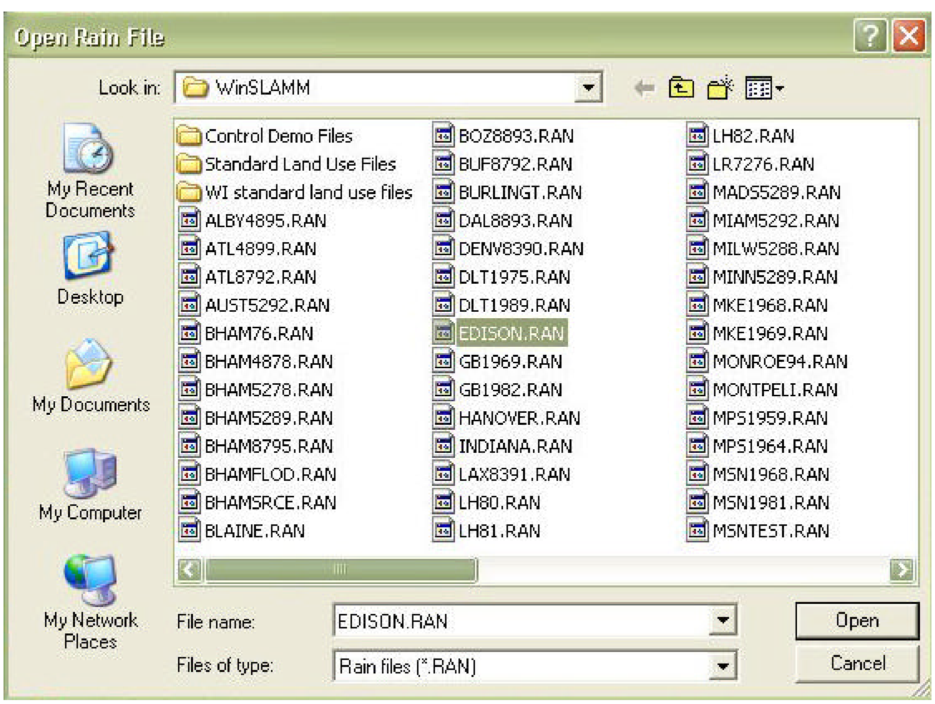
Concentration | Yield | SA Yield Contribution

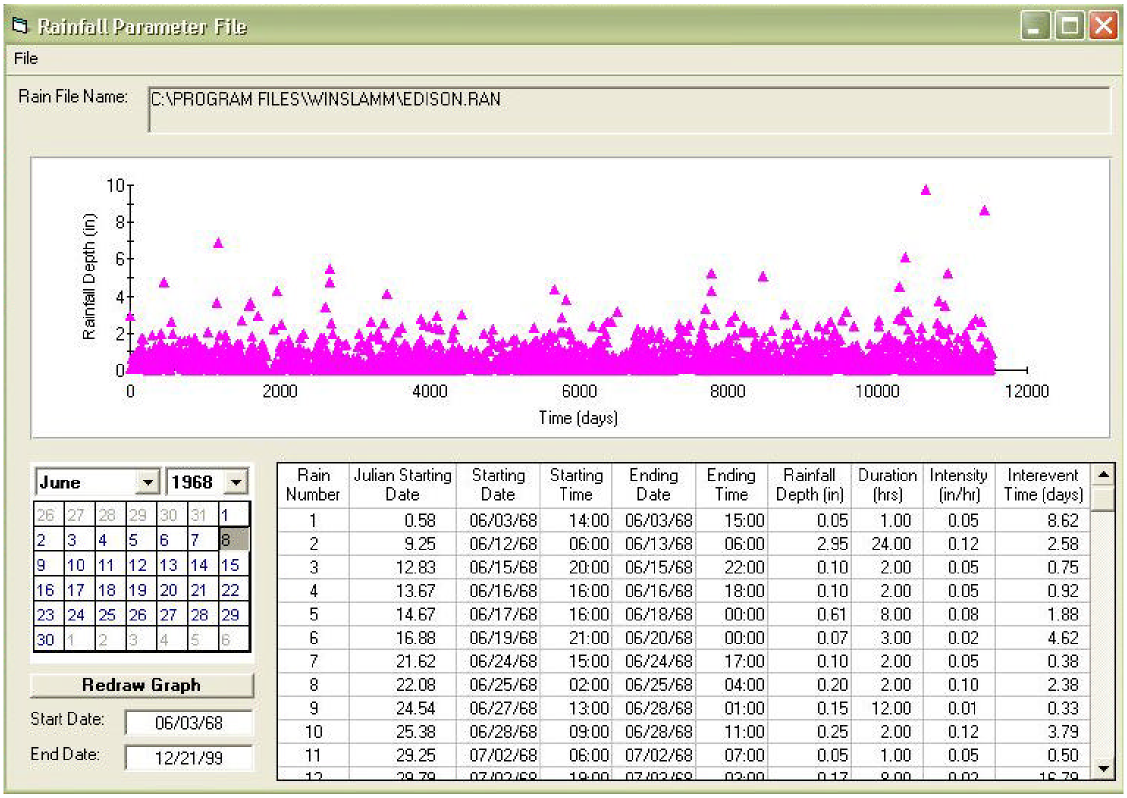
Data File: hello world.DAT								
Summary for Runoff Producing Events								
Minimum:	0.01	31.98	0	2.419	11.27	353.6	145.8	2.419
Maximum:	4.00	31.98	0	155.5	296.6	9310	3839	13632
Fl Wt Ave:	0.00	31.98	0	137.7	181.7	5704	2352	8476
Total:	15.66	31.98	0	969.0	797.4	25030	10321	37148
Total Area, with Drainage and Outfall Controls - Yield of PARTICULATE SOLIDS (lbs)								
Start Date	Rain Total (inches)	Total Before Drainage System	Total After Drainage System	Catch basin Volume % Full	Total After Outfall Controls	Flow-wtd Min. Part. Size Controlled		
01/01/99	0.01	0	0	0	0	0		
02/01/99	0.05	2.419	0	0	0	0		
03/01/99	0.10	7.250	0	0	0	0		
04/01/99	0.25	528.7	0	0	0	0		
05/01/99	0.50	776.1	0	0	0	0		
06/01/99	0.75	990.4	0	0	0	0		
07/01/99	1.00	1448	101.2	0	0.1019	0.1007		
08/01/99	1.50	2436	673.2	2	3.321	0.4933		
09/01/99	2.00	3756	1986	7	29.84	0.9790		
10/01/99	2.50	5694	3061	14	114.8	1.451		
11/01/99	3.00	7877	4487	23	239.6	1.847		
12/01/99	4.00	13632	10092	33	1181	3.443		
Summary for Runoff Producing Events								
	Rain Total (inches)	Total Before Drainage System	Total After Drainage System	Catch basin Volume % Full	Total After Outfall Controls	Flow-wtd Min. Part. Size Controlled		
Minimum:	0.01	2.419	101.2	2.000	0.10	0.10		
Maximum:	4.00	13632	10092	33.00	1181.00	3.44		
Fl Wt Ave:		8476	6645		663.9	2.442		
Total:	15.66	37148	20080		1568.66			

The wet pond is more than 90% effective, for even the largest rains. This is due to the large amount of runoff that was infiltrated before the pond. This example illustrates how these different controls can be evaluated and how they interact for different sized events. Source area controls can be easily evaluated by conducting special model runs having parallel source areas, one with the control (such as street cleaning, or disconnected drainage) and the other without the control, and directly comparing the results using the source.ran file and output option 1.

After the initial evaluations are conducted using this simple rain file and output option, it is recommended that long-term continuous simulations be used to compare alternative stormwater control programs. In this example, the Edison.ran file (Edison, New Jersey) was used for a period from June 1968 to December 1999, a period of about 31.6 years. This period had 2,751 rains up to 9.8 inches in depth, but with a median of 0.26 inches. The rain file can be viewed using the "utilities\parameter files\rainfall files" dropdown menu, and then selecting the rain file from the program directory:


WinSLAMM Data File: [C:\Program Files\WinSLAMM\hello world with long term rain file.dat]
File Land Use Pollutants Options Run Utilities Help
Parameter Files
MS-DOS Prompt
View File
Critical Particle Size Files
Street Delivery Files
Runoff Coefficient Files
Rainfall Files
Particulate Solids Concentration Files
Particulate Residue Reduction Files
SLAMM Data File:
hello world with long term rain file.DAT
Current Land Use: Residential
Current Source Area
Current File Data...
Current File Status
Land Use Areas
Residential Area: 100.00 Acres
Institutional Area: 0.00 Acres
Commercial Area: 0.00 Acres
Industrial Area: 0.00 Acres
Open Space Area: 0.00 Acres
Freeway Area: 0.00 Acres
Total Area: 100.00 Acres
Exit Program
Press F1 for Help
B
Source Area Parameters
1 Roofs 1 Entered
2 Roofs 2
3 Roofs 3
4 Roofs 4
5 Roofs 5
6 Paved Parking/Storage 1
7 Paved Parking/Storage 2
8 Paved Parking/Storage 3
9 Unpaved Prkng/Storage
10 Unpaved Prkng/Storage
11 Playground 1
12 Playground 2
13 Driveways 1 2.57 P Entered
14 Driveways 2
15 Driveways 3
16 Sidewalks/Walks 1
17 Sidewalks/Walks 2
18 Street Area 1 6.80 S Entered
19 Street Area 2
20 Street Area 3
21 Large Landscaped Area 1
22 Large Landscaped Area 2
23 Undeveloped Area 1.80 Entered
24 Small Landscaped Area 1 56.50 Entered
25 Small Landscaped Area 2 23.30 Entered
26 Small Landscaped Area 3
27 Isolated Area
28 Other Pervious Area
29 Other Dir Cnctd Imp Area
30 Other Part Cnctd Imp

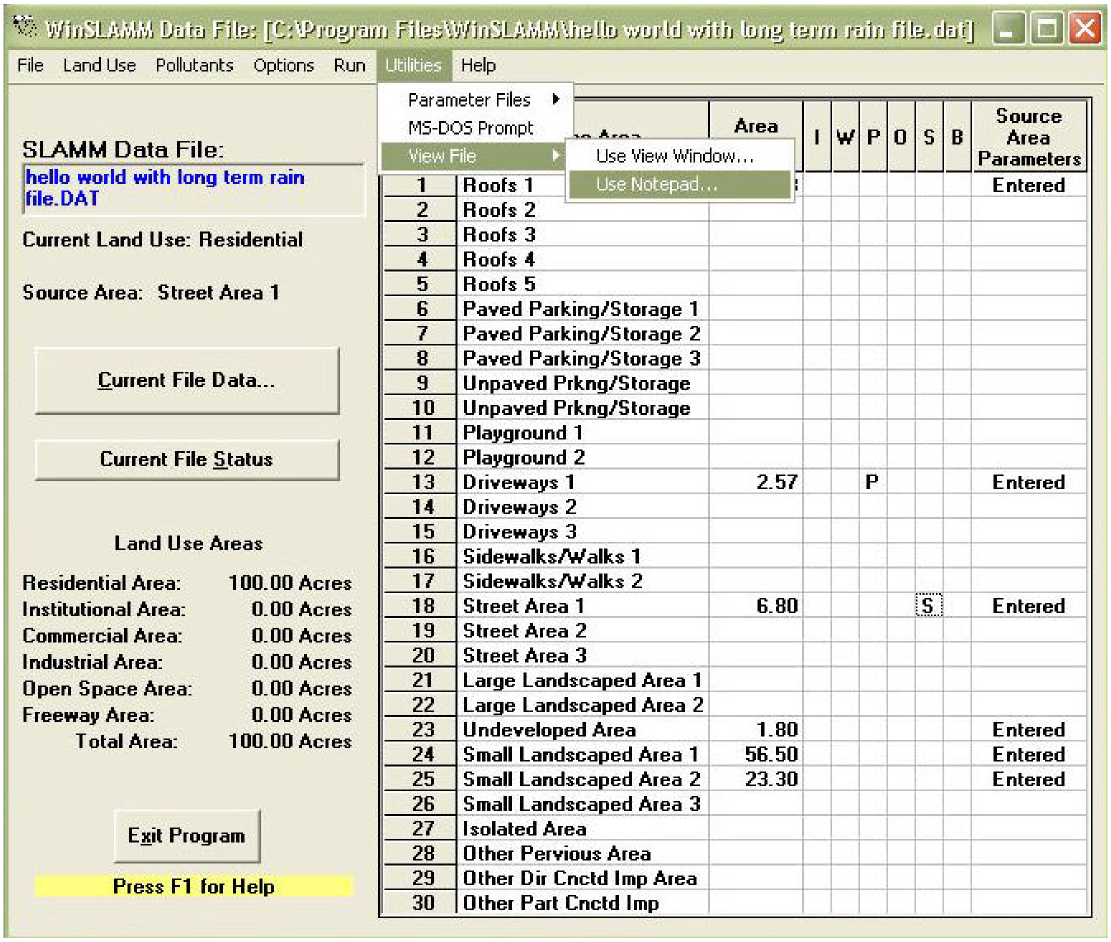

Open Rain File
Look in: WinSLAMM
My Recent Documents
Desktop
My Documents
My Computer
My Network Places
Control Demo Files
Standard Land Use Files
WI standard land use files
ALBY4895.RAN
ATL4899.RAN
ATL8792.RAN
AUST5292.RAN
BHAM76.RAN
BHAM4878.RAN
BHAM5278.RAN
BHAM5289.RAN
BHAM8795.RAN
BHAMFLOD.RAN
BHAMSRCE.RAN
BLAINE.RAN
BOZ8893.RAN
BUF8792.RAN
BURLINGT.RAN
DAL8893.RAN
DENV8390.RAN
DLT1975.RAN
DLT1989.RAN
EDISON.RAN
GB1969.RAN
GB1982.RAN
HANOVER.RAN
INDIANA.RAN
LAX8391.RAN
LH80.RAN
LH81.RAN
LH82.RAN
LR7276.RAN
MADS5289.RAN
MIAM5292.RAN
MILW5288.RAN
MINN5289.RAN
MKE1968.RAN
MKE1969.RAN
MONROE94.RAN
MONTPELI.RAN
MPS1959.RAN
MPS1964.RAN
MSN1968.RAN
MSN1981.RAN
MSNTEST.RAN
File name: EDISON.RAN
Files of type: Rain files (*.RAN)
Open
Cancel

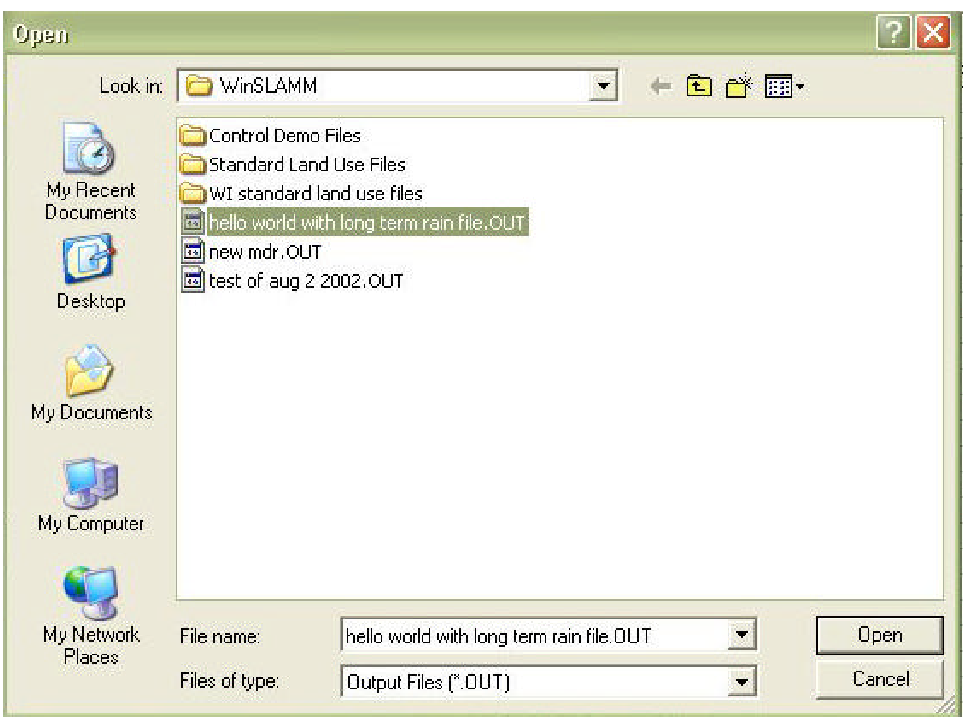


Rain Number	Julian Starting Date	Starting Date	Starting Time	Ending Date	Ending Time	Rainfall Depth (in)	Duration (hrs)	Intensity (in/hr)	Interevent Time (days)
1	0.58	06/03/68	14:00	06/03/68	15:00	0.05	1.00	0.05	8.62
2	9.25	06/12/68	06:00	06/13/68	06:00	2.95	24.00	0.12	2.58
3	12.83	06/15/68	20:00	06/15/68	22:00	0.10	2.00	0.05	0.75
4	13.67	06/16/68	16:00	06/16/68	18:00	0.10	2.00	0.05	0.92
5	14.67	06/17/68	16:00	06/18/68	00:00	0.61	8.00	0.08	1.88
6	16.88	06/19/68	21:00	06/20/68	00:00	0.07	3.00	0.02	4.62
7	21.62	06/24/68	15:00	06/24/68	17:00	0.10	2.00	0.05	0.38
8	22.08	06/25/68	02:00	06/25/68	04:00	0.20	2.00	0.10	2.38
9	24.54	06/27/68	13:00	06/28/68	01:00	0.15	12.00	0.01	0.33
10	25.38	06/28/68	09:00	06/28/68	11:00	0.25	2.00	0.12	3.79
11	29.25	07/02/68	06:00	07/02/68	07:00	0.05	1.00	0.05	0.50

This screen shows the individual rains plotted by time and a scroll window displays the characteristics of the individual rains.

For the “one line per event output option” the “utilities\view file\use notepad” dropdown menu can be used to select the output file for viewing, as shown below:


WinSLAMM Data File: [C:\Program Files\WinSLAMM\hello world with long term rain file.dat]
File
Land Use
Pollutants
Options
Run
Utilities
Help
Parameter Files
MS-DOS Prompt
View File
Use View Window...
Use Notepad...
SLAMM Data File:
hello world with long term rain file.DAT
Current Land Use: Residential
Source Area: Street Area 1
Current File Data...
Current File Status
Land Use Areas
Residential Area: 100.00 Acres
Institutional Area: 0.00 Acres
Commercial Area: 0.00 Acres
Industrial Area: 0.00 Acres
Open Space Area: 0.00 Acres
Freeway Area: 0.00 Acres
Total Area: 100.00 Acres
Exit Program
Press F1 for Help
Area
I W P O S B
Source Area Parameters
1 Roofs 1 Entered
2 Roofs 2
3 Roofs 3
4 Roofs 4
5 Roofs 5
6 Paved Parking/Storage 1
7 Paved Parking/Storage 2
8 Paved Parking/Storage 3
9 Unpaved Prkng/Storage
10 Unpaved Prkng/Storage
11 Playground 1
12 Playground 2
13 Driveways 1 2.57 P Entered
14 Driveways 2
15 Driveways 3
16 Sidewalks/Walks 1
17 Sidewalks/Walks 2
18 Street Area 1 6.80 S Entered
19 Street Area 2
20 Street Area 3
21 Large Landscaped Area 1
22 Large Landscaped Area 2
23 Undeveloped Area 1.80 Entered
24 Small Landscaped Area 1 56.50 Entered
25 Small Landscaped Area 2 23.30 Entered
26 Small Landscaped Area 3
27 Isolated Area
28 Other Pervious Area
29 Other Dir Cnctd Imp Area
30 Other Part Cnctd Imp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Look in: WinSLAMM
Control Demo Files
Standard Land Use Files
WI standard land use files
hello world with long term rain file.OUT
new mdr.OUT
test of aug 2 2002.OUT
My Recent Documents
Desktop
My Documents
My Computer
My Network Places
File name: hello world with long term rain file.OUT
Files of type: Output Files (*.OUT)
Open
Cancel

The following is a partial screen dump of this output file. There are 15 columns of data generated, and, as the name implies, each line represents an individual event. When scrolled to the bottom, column statistics are given, as shown below.

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Event Number	Rain Start Start Date	Rain Start Start Time	Julian Start Date & Time	Rain Duration (hrs)	Rain Interevent Period(days)	Runoff Duration (hrs)	Rain Depth (in)	Runoff Volume (cf)	R sub v
1	06/03/68	14:00	5,998.58	1.00	8.62	1.20	0.05	0	0.00
2	06/12/68	06:00	6,007.25	24.00	2.58	28.80	2.95	196,640	0.18
3	06/15/68	20:00	6,010.83	2.00	0.75	2.40	0.10	0	0.00
4	06/16/68	16:00	6,011.67	2.00	0.92	2.40	0.10	0	0.00
5	06/17/68	16:00	6,012.67	8.00	1.88	9.60	0.61	3,189	0.01
6	06/19/68	21:00	6,014.88	3.00	4.62	3.60	0.07	0	0.00
7	06/24/68	15:00	6,019.62	2.00	0.38	2.40	0.10	0	0.00
8	06/25/68	02:00	6,020.08	2.00	2.37	2.40	0.20	0	0.00
9	06/27/68	13:00	6,022.54	12.00	0.33	14.40	0.15	0	0.00
10	06/28/68	09:00	6,023.38	2.00	3.79	2.40	0.25	0	0.00
11	07/02/68	06:00	6,027.25	1.00	0.50	1.20	0.05	0	0.00
12	07/02/68	19:00	6,027.79	8.00	16.79	9.60	0.17	0	0.00
13	07/19/68	22:00	6,044.92	1.00	4.58	1.20	0.12	0	0.00
14	07/24/68	13:00	6,049.54	7.00	8.04	8.40	0.54	1,599	0.01
15	08/01/68	21:00	6,057.88	8.00	0.79	9.60	0.60	2,617	0.01
16	08/03/68	00:00	6,059.00	6.00	4.21	7.20	0.55	5,109	0.03
17	08/07/68	11:00	6,063.46	2.00	9.00	2.40	0.83	49,702	0.16
18	08/16/68	13:00	6,072.54	1.00	0.33	1.20	0.05	0	0.00
19	08/16/68	22:00	6,072.92	3.00	0.46	3.60	0.06	0	0.00
20	08/17/68	12:00	6,073.50	2.00	1.21	2.40	0.80	46,171	0.16
21	08/18/68	19:00	6,074.79	1.00	14.79	1.20	0.05	0	0.00
22	09/02/68	15:00	6,089.62	1.00	3.58	1.20	1.05	79,950	0.21
23	09/06/68	06:00	6,093.25	9.00	4.00	10.80	0.33	0	0.00
24	09/10/68	15:00	6,097.62	13.00	25.67	15.60	0.98	13,168	0.04
25	10/06/68	20:00	6,123.83	12.00	17.50	14.40	0.88	9,049	0.03
26	10/24/68	20:00	6,141.83	11.00	3.46	13.20	0.38	0	0.00
27	10/28/68	18:00	6,145.75	2.00	6.50	2.40	0.04	0	0.00
28	11/04/68	08:00	6,152.33	2.00	2.58	2.40	0.04	0	0.00
29	11/07/68	00:00	6,155.00	30.00	1.58	36.00	1.27	0	0.00
30	11/09/68	20:00	6,157.83	15.00	1.50	18.00	0.93	4,021	0.01
31	11/11/68	23:00	6,159.96	23.00	4.25	27.60	1.75	46,150	0.07
32	11/17/68	04:00	6,165.17	2.00	0.79	2.40	0.04	0	0.00
33	11/18/68	01:00	6,166.04	23.00	5.88	27.60	0.85	0	0.00
34	11/24/68	21:00	6,172.88	7.00	3.42	8.40	0.25	0	0.00
35	11/28/68	14:00	6,176.58	3.00	0.25	3.60	0.05	0	0.00
36	11/28/68	23:00	6,176.96	7.00	2.62	8.40	0.18	0	0.00
37	12/01/68	21:00	6,179.88	8.00	1.79	9.60	0.35	0	0.00
38	12/04/68	00:00	6,182.00	17.00	9.38	20.40	1.70	58,573	0.09
39	12/14/68	02:00	6,192.08	33.00	7.25	39.60	0.83	0	0.00
40	12/22/68	17:00	6,200.71	14.00	4.04	16.80	0.65	0	0.00
41	12/27/68	08:00	6,205.33	7.00	0.88	8.40	0.12	0	0.00
42	12/28/68	12:00	6,206.50	11.00	2.83	13.20	0.20	0	0.00
43	12/31/68	19:00	6,209.79	9.00	5.75	10.80	0.10	0	0.00
44	01/06/69	22:00	6,215.92	11.00	11.04	13.20	0.15	0	0.00
45	01/18/69	10:00	6,227.42	7.00	4.29	8.40	0.04	0	0.00
46	01/23/69	00:00	6,232.00	6.00	1.12	7.20	0.18	0	0.00
47	01/24/69	09:00	6,233.38	2.00	4.71	2.40	0.03	0	0.00
48	01/29/69	04:00	6,238.17	13.00	0.33	15.60	0.08	0	0.00
49	01/30/69	01:00	6,239.04	20.00	1.21	24.00	0.43	0	0.00
50	02/01/69	02:00	6,241.08	10.00	1.54	12.00	0.11	0	0.00
51	02/03/69	01:00	6,243.04	19.00	6.33	22.80	0.31	0	0.00
52	02/10/69	04:00	6,250.17	1.00	13.25	1.20	1.05	80,116	0.21
53	02/23/69	11:00	6,263.46	20.00	5.75	24.00	0.80	0	0.00
54	03/02/69	01:00	6,270.04	6.00	0.37	7.20	0.10	0	0.00
55	03/02/69	16:00	6,270.67	13.00	4.25	15.60	0.20	0	0.00
56	03/07/69	11:00	6,275.46	1.00	13.50	1.20	0.31	5,483	0.05

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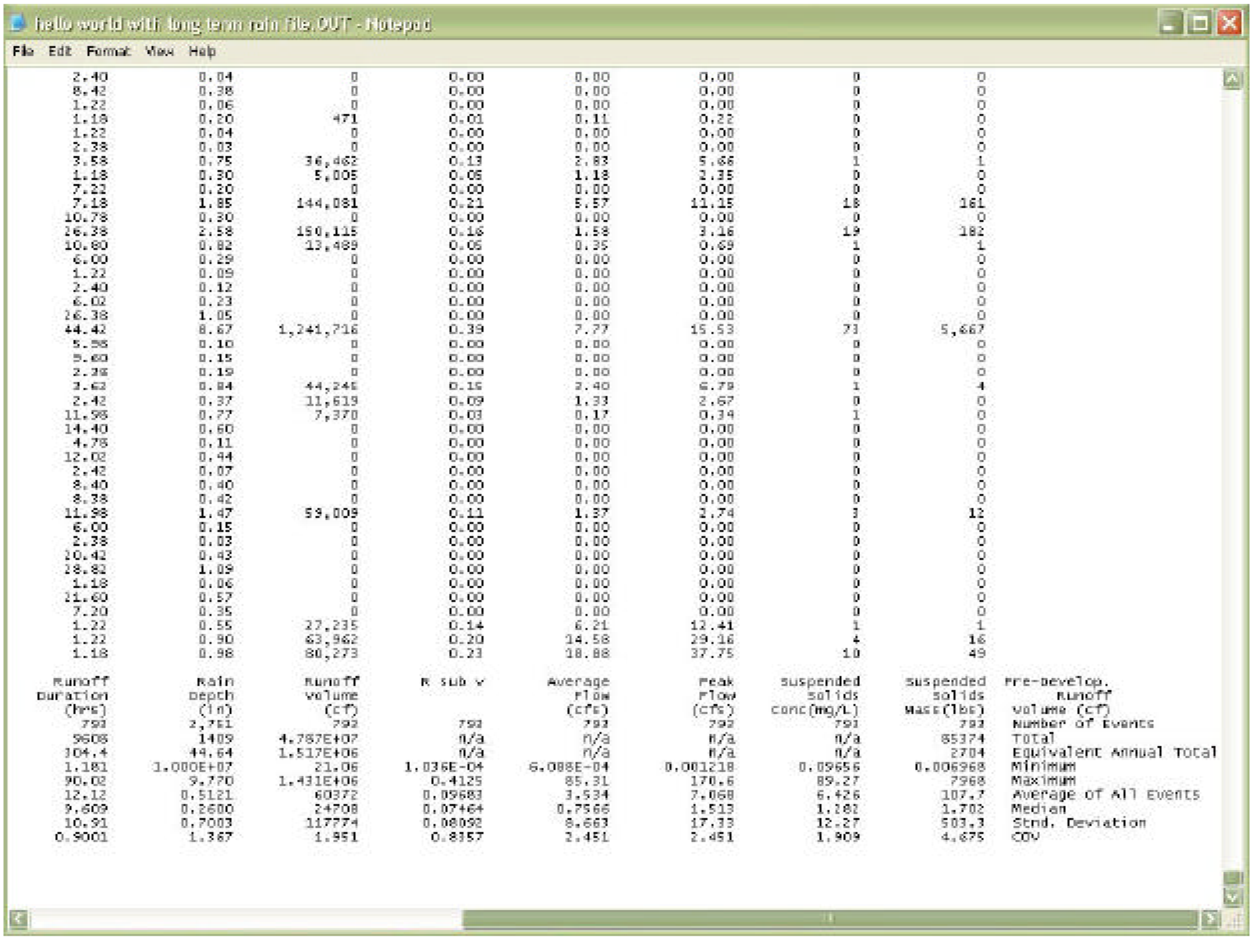
2,711	06/17/99	18:00	17,334.75	2.00	3.21	2.40	0.04	0	0.00
2,712	06/21/99	01:00	17,338.04	7.02	0.83	8.42	0.38	0	0.00
2,713	06/22/99	04:00	17,339.17	1.02	6.75	1.22	0.06	0	0.00
2,714	06/28/99	23:00	17,345.96	0.98	0.54	1.18	0.20	471	0.01
2,715	06/29/99	13:00	17,346.54	1.02	13.25	1.22	0.04	0	0.00
2,716	07/12/99	20:00	17,359.83	1.98	9.67	2.38	0.03	0	0.00
2,717	07/22/99	14:00	17,369.58	2.98	13.88	3.58	0.75	36,462	0.13
2,718	08/05/99	14:00	17,383.58	0.98	2.67	1.18	0.30	5,005	0.05
2,719	08/08/99	07:00	17,386.29	6.02	1.42	7.22	0.20	0	0.00
2,720	08/09/99	23:00	17,387.96	5.98	4.50	7.18	1.85	144,081	0.21
2,721	08/14/99	17:00	17,392.71	8.98	5.38	10.78	0.30	0	0.00
2,722	08/20/99	11:00	17,398.46	21.98	5.38	26.38	2.58	150,115	0.16
2,723	08/26/99	18:00	17,404.75	9.00	9.75	10.80	0.82	13,489	0.05
2,724	09/05/99	21:00	17,414.88	5.00	1.21	6.00	0.29	0	0.00
2,725	09/07/99	07:00	17,416.29	1.02	0.29	1.22	0.09	0	0.00
2,726	09/07/99	15:00	17,416.62	2.00	0.83	2.40	0.12	0	0.00
2,727	09/08/99	13:00	17,417.54	5.02	0.83	6.02	0.23	0	0.00
2,728	09/09/99	14:00	17,418.58	21.98	4.79	26.38	1.05	0	0.00
2,729	09/15/99	07:00	17,424.29	37.02	3.50	44.42	8.67	1,241,716	0.39
2,730	09/20/99	08:00	17,429.33	4.98	0.71	5.98	0.10	0	0.00
2,731	09/21/99	06:00	17,430.25	8.00	0.63	9.60	0.15	0	0.00
2,732	09/22/99	05:00	17,431.21	1.98	7.87	2.38	0.19	0	0.00
2,733	09/30/99	04:00	17,439.17	3.02	4.00	3.62	0.84	44,245	0.15
2,734	10/04/99	07:00	17,443.29	2.02	0.33	2.42	0.37	11,619	0.09
2,735	10/04/99	17:00	17,443.71	9.98	5.00	11.98	0.77	7,370	0.03
2,736	10/10/99	02:00	17,449.12	12.00	3.33	14.40	0.60	0	0.00
2,737	10/13/99	23:00	17,452.96	3.98	3.67	4.78	0.11	0	0.00
2,738	10/17/99	19:00	17,456.79	10.02	1.08	12.02	0.44	0	0.00
2,739	10/19/99	07:00	17,458.29	2.02	0.88	2.42	0.07	0	0.00
2,740	10/20/99	06:00	17,459.25	7.00	2.29	8.40	0.40	0	0.00
2,741	10/22/99	20:00	17,461.83	6.98	10.33	8.38	0.42	0	0.00
2,742	11/02/99	11:00	17,472.46	9.98	16.88	11.98	1.47	59,009	0.11
2,743	11/19/99	18:00	17,489.75	5.00	3.75	6.00	0.15	0	0.00
2,744	11/23/99	17:00	17,493.71	1.98	1.12	2.38	0.03	0	0.00
2,745	11/24/99	22:00	17,494.92	17.02	0.67	20.42	0.43	0	0.00
2,746	11/26/99	07:00	17,496.29	24.02	6.17	28.82	1.09	0	0.00
2,747	12/03/99	11:00	17,503.46	0.98	2.75	1.18	0.06	0	0.00
2,748	12/06/99	06:00	17,506.25	18.00	3.50	21.60	0.57	0	0.00
2,749	12/10/99	12:00	17,510.50	6.00	3.54	7.20	0.35	0	0.00
2,750	12/14/99	07:00	17,514.29	1.02	0.96	1.22	0.55	27,235	0.14
2,751	12/15/99	07:00	17,515.29	1.02	6.00	1.22	0.90	63,962	0.20
2,752	12/21/99	08:00	17,521.33	0.98	0.00	1.18	0.98	80,273	0.23

Summary Statistics	Rain Duration (hrs)	Rain Interevent Period(days)	Runoff Duration (hrs)	Rain Depth (in)	Runoff Volume (cf)	R sub v
Number of Events	2,751	2,751	793	2,751	793	793
Total	22146	10600	9608	1409	4.787E+07	N/A
Equivalent Annual Total	701.5	335.8	304.4	44.64	1.517E+06	N/A
Minimum	0.9844	0	1.181	1.000E+07	21.06	1.036E-04
Maximum	75.02	98.46	90.02	9.770	1.431E+06	0.4125
Average of All Events	8.047	3.852	12.12	0.5121	60372	0.09083
Median	5.992	2.792	9.609	0.2600	24708	0.07464
Stnd. Deviation	7.712	4.586	10.91	0.7002	117774	0.08092
COV	0.9586	1.190	0.9001	1.367	1.951	0.8357

First Rain Date: 06/03/68
Last Rain Date: 12/21/99
Total Time Period (yrs): 31.56918



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Runoff Duration (hrs)	Rain Depth (in)	Runoff Volume (cf)	R sub v	Average Flow (cfs)	Peak Flow (cfs)	Suspended Solids Conc(mg/L)	Suspended Solids Mass(lbs)	Pre-develop. Runoff Volume (cf)
2.40	0.04	0	0.00	0.00	0.00	0	0	
8.42	0.38	0	0.00	0.00	0.00	0	0	
1.22	0.06	0	0.00	0.00	0.00	0	0	
1.18	0.20	471	0.01	0.11	0.22	0	0	
1.22	0.04	0	0.00	0.00	0.00	0	0	
2.38	0.03	0	0.00	0.00	0.00	0	0	
3.58	0.75	36,462	0.13	2.83	5.66	1	1	
1.18	0.30	5,005	0.06	1.18	2.35	0	0	
7.22	0.20	0	0.00	0.00	0.00	0	0	
7.18	1.85	144,081	0.21	5.57	11.15	18	161	
10.78	0.30	0	0.00	0.00	0.00	0	0	
26.38	2.58	150,115	0.16	1.58	3.16	19	182	
10.80	0.82	13,489	0.06	0.35	0.69	1	1	
6.00	0.29	0	0.00	0.00	0.00	0	0	
1.22	0.09	0	0.00	0.00	0.00	0	0	
2.40	0.12	0	0.00	0.00	0.00	0	0	
6.02	0.23	0	0.00	0.00	0.00	0	0	
26.38	1.05	0	0.00	0.00	0.00	0	0	
44.42	8.67	1,241,716	0.39	7.77	15.53	71	5,667	
5.98	0.10	0	0.00	0.00	0.00	0	0	
5.60	0.15	0	0.00	0.00	0.00	0	0	
2.38	0.19	0	0.00	0.00	0.00	0	0	
3.62	0.84	44,246	0.15	2.40	6.79	1	4	
2.42	0.37	11,619	0.09	1.33	2.67	0	0	
11.98	0.77	7,370	0.03	0.17	0.34	1	0	
14.40	0.60	0	0.00	0.00	0.00	0	0	
4.78	0.11	0	0.00	0.00	0.00	0	0	
12.02	0.44	0	0.00	0.00	0.00	0	0	
2.42	0.07	0	0.00	0.00	0.00	0	0	
8.40	0.40	0	0.00	0.00	0.00	0	0	
8.38	0.42	0	0.00	0.00	0.00	0	0	
11.98	1.47	59,009	0.11	1.37	2.74	3	12	
6.00	0.15	0	0.00	0.00	0.00	0	0	
2.38	0.03	0	0.00	0.00	0.00	0	0	
20.42	0.43	0	0.00	0.00	0.00	0	0	
28.82	1.09	0	0.00	0.00	0.00	0	0	
1.18	0.06	0	0.00	0.00	0.00	0	0	
21.60	0.57	0	0.00	0.00	0.00	0	0	
7.20	0.35	0	0.00	0.00	0.00	0	0	
1.22	0.55	27,235	0.14	6.21	12.41	1	1	
1.22	0.90	63,962	0.20	14.58	29.16	4	16	
1.18	0.98	80,273	0.23	18.88	37.75	10	49	
793	2,751	792	792	793	792	791	793	Number of Events
9608	1409	4.787E+07	n/a	n/a	n/a	n/a	85374	Total
304.4	44.64	1.517E+06	n/a	n/a	n/a	n/a	2704	Equivalent Annual Total
1.181	1.000E+07	21.06	1.036E-04	6.088E-04	0.001218	0.09656	0.006968	Minimum
90.02	9.770	1.431E+06	0.4125	85.31	170.6	89.27	7968	Maximum
12.12	0.5121	60372	0.09683	3.534	7.068	6.426	107.7	Average of All Events
9.609	0.2600	24708	0.07464	0.7566	1.513	1.282	1.702	Median
10.91	0.7003	117774	0.08092	8.663	17.33	12.27	503.3	Stnd. Deviation
0.9001	1.367	1.951	0.8357	2.451	2.451	1.909	4.675	COV

Normally, the "equivalent annual total" discharges are used for comparison. These are the summed values fro m each column divided by the total time period.

Case Study for Source Area Controls in the Birmingham, AL, Area

Tables 1-4 and 1-5 illustrate the outputs for a typical analysis, comparing source area biofiltration controls to a similar analysis having no controls and all paved and roof areas being connected. Runoff occurs during all rains, even during the smallest 0.01 inch event (although the Rv for this event is only 0.01), when all areas are directly connected to the drainage system and no infiltration or biofiltration controls are used. When the infiltration devices are used, runoff only occurs for rains greater than about 0.5 inches. The runoff volume is even reduced during the largest 4 inch rain by about 10 percent when using these controls. The control benefits for suspended solids mass discharges are similar. They are greater than the benefits for runoff volume for the moderate rains (0.50 to 1.50 inches), but the suspended solids reductions are actually slightly less than the volume reductions for the larger rains. This is likely because of the infiltration of relatively clean roof runoff in the "rain gardens" compared to infiltration of runoff from other areas, and the significantly increased suspended solids discharges from landscaped areas during these large rains. It is therefore reasonable to expect about 80%, or greater, runoff and suspended solids reductions for all rains up to about 0.75 inches in depth with this example control scenario.

Table 1-4. Summary of Runoff and Suspended Solids Control for Different Rain Depths

Rain depth (inches)	Rv with no controls and all pavement and roofs are directly connected	Rv with biofiltration controls and with disconnected pavement and roofs	% runoff volume reductions with controls	Suspended solids with no controls and all pavement and roofs are directly connected (lbs/ac)	Suspended solids with biofiltration controls and with disconnected pavement and roofs (lbs/acre)	% suspended solids reductions with controls
0.01	0.01	0.00	100%	<0.1	0	100%
0.05	0.06	0.00	100%	<0.1	0	100%
0.10	0.11	0.00	100%	0.15	0	100%
0.25	0.22	0.00	100%	3.6	0	100%
0.50	0.28	0.01	96%	10	0.12	99%
0.75	0.31	0.08	74%	16	2.5	84%
1.00	0.32	0.16	50%	23	8.6	63%
1.50	0.35	0.24	31%	40	27	33%
2.00	0.38	0.28	26%	61	49	20%
2.50	0.42	0.34	19%	87	76	13%
3.00	0.44	0.37	16%	110	100	10%
4.00	0.50	0.45	10%	180	170	6%

This area was further evaluated using a continuous series of rains over a 37 year period (1953 through 1989) that contained 4,011 separate rains ranging from 0.01 to 13.58 inches in depth. The minimum rain duration was 1 hour (by definition), while the maximum duration was 93 hours (the median was 4 hours). The interevent times ranged from 6 hours (used to define separate rain events) to 44 days (the median was 1.9 days).

Table 1-5 summarizes these results for several alternatives. The “as-built” condition is based on actual conditions in the Birmingham, AL, area derived from neighborhood surveys and aerial photographic measurements. The “totally connected” condition is this same area, but assuming that all roofs and driveways are directly connected to the drainage system, while the “totally disconnected” condition assumes that these paved and roof areas all drain to the clayey soils. The “skinny street” option reduces the measured street widths from 35 to 20 ft, keeping the same street lengths, and increasing the landscaped areas by the reduction in street area. The swales and roof garden option is similar to the above evaluation, but the last option shown also had amended soils in the swales and roof gardens to increase the infiltration rates to about 0.5 in/hr (loamy soil conditions).

Table 1-5. Runoff and Suspended Solids Annual Discharges for Different Control Options

	Flow-weighted Rv	Suspended solids discharges (lb/ac/yr)
Totally connected	0.34	1390
As built and surveyed	0.31	1380
% reduction	9%	0%
As built, but with “skinny” streets	0.30	1430
% reduction	13%	3% increase
Totally disconnected	0.27	1380
% reduction	21%	<1%
Totally disconnected with swales	0.25	1060
% reduction	26%	24%
Totally disconnected, swales, roof rain gardens, and amended soils	0.12	590
% reduction	65%	58%

The current (partially connected) conditions produce about 10% less runoff and about the same amount of suspended solids compared to totally connected conditions. If the current conditions were built with skinny streets, the runoff reductions would slightly improve to about 13%. Substantial runoff and suspended solids reductions (about 60 to 65%) would occur for totally disconnected conditions, plus the use of rain gardens to improve roof runoff and the use of amended soils in both the rain gardens and swales to improve infiltration in the clayey soils.

Obviously, these are only predictions for a single area and the specific results would vary substantially for other areas having different rains, soils, and development characteristics. However, this example does illustrate how WinSLAMM can be used to calculated expected benefits of different types of biofiltration controls in a typical medium density residential area.

WinSLAMM/SWMM Interface Program

Introduction. The purpose of the WinSLAMM-SWMM Interface Program (SSIP) is to allow the user to replace SWMM's RUNOFF Block with WinSLAMM. This allows WinSLAMM to provide the runoff and pollutant loads for input into the TRANSPORT or EXTRAN Blocks of SWMM, instead of using results from the RUNOFF Block. Using WinSLAMM better accounts for small storm processes and adds greater flexibility in evaluating source area flow and pollutant controls. The interface program manipulates the output from WinSLAMM so that it is acceptable for SWMM. The principal manipulation is to convert the event volumes and loads into event hydrographs and pollutographs.

The version of the WinSLAMM-SWMM Interface Program presented here is Version 1. 1. This version has not reached the full potential envisioned for the program. This is discussed later. It is assumed that the reader is familiar with both WinSLAMM and SWMM and has the appropriate documentation.

SSIP Version 1.0. An early version of the WinSLAMM-SWMM Integration Program was developed to work with SWMM Windows provided by the US Environmental Protection Agency (based on SWMM Version 4.3). This was used to create SSIP Version 1.1, which is deigned for use with all SWMM 4 sub-versions.

SSIP Version 1.1. SSIP Version 1.1 takes hydrographs and pollutographs from WinSLAMM and partially prepares input hydrographs for use in the SWMM EXTRAN Block and input hydrographs and pollutographs for the SWMM TRANSPORT Block. *However, at this time SSIP has only been tested in the preparation of hydrographs for SWMM EXTRAN.*

WINSLAMM currently has the option of producing source area hydrographs and pollutographs over continuous periods. Each location is produced as a separate file. The format for these files is as follows:

- First Line = subcatchment number (defined in WinSLAMM)
- Second Line = labels for each column in "quotation marks", separated by commas
- Third Line = Values separated by commas, no spaces (e.g., time,flow,pollutant,pollutant,)
- NOTE: The time increments used in each file must be identical (e.g., 1, 1.5, 2, … must be the same for each file).

These files are converted into files appropriate for SWMM. However, at this time, the user must manually manipulate some of these converted files for actual use in SWMM. The WinSLAMM/SWMM Interface Program Version 1.1 is Windows-based and is programmed in Visual Basic. A new version is currently being prepared that will further minimize the needed user manipulation.

How SSIP Works.
1. SSIP goes through each WinSLAMM hydrograph/pollutograph file, one at a time, in the directory chosen by the user. These files have the extension *.hyd.

2. SSIP then creates the files for SWMM (*.hp1, *.hp2, and*.hp3 for TRANSPORT and *.hp4 for EXTRAN).

3. Next, it reads the second hydrograph/pollutograph file and appends the information to the first files that were created. This will be done for all files with the extension *.hyd. So it is important that only the files desired are located in the directory.

4. When there are no more WinSLAMM files left, the user gets a message that the file conversions are completed.

Interface Program Instructions. The instructions below are illustrated with a series of files provided with the disk that accompanies this report. These files are referred to throughout this section in order to illustrate the process for executing SSIP and creating useable hydrograph files for SWMM EXTRAN. (Recall that this is the only application of SSIP that has been tested to date.) All of the needed WinSLAMM and SSIE files are installed in a single directory when the files are installed (from the attached disks having zipped filed).

1 . The user begins by opening the file "Interface1.exe" provided on the disk. A series of dialog boxes will then appear. Instructions for each dialog box appear with that box. The dialog boxes are discussed below:

- A start-up box. This box starts the program.
- A file location box (to identify where the WinSLAMM files are and where the SWMM files are to be placed.) At this time, SSIP seems to work best if all file operations (including the execution of SIPP) are carried out under the same directory. Set the WinSLAMM file locator to the directory to which you placed the contents of the supplied disk (this is where the WinSLAMM files are located). For this application there are three files, associated with each of three locations for which WinSLAMM produced hydrographs and pollutographs. These three locations will be input to SWMM. Set the SWMM file locator to the same directory.
- A SWMM Block selection box (i.e. for which SWMM Block files are to be produced). The TRANSPORT option has not been tested. Use only the EXTRAN option at this time. Select the EXTRAN option.
- A "process complete" box informing the user that the SWMM files have been created.

2. Once the processing is complete, as many as four files (*.hp 1, *.hp2, and *.hp3 for TRANSPORT and *.hp4 for EXTRAN) will have been produced. These files need to be manually placed in a SWMM system input file produced by the user. (The term "system input file" is meant to describe the file that describes the drainage system.) An example system input file is included on the disk as "extrn001.run". This file is associated with Example 1 in the SWMM EXTRAN Block users manual (Roesner, *et al*. 1988). Be sure it is on the directory you created on your hard drive.

The SWMM system input file will need to be modified before SWMM can be executed. For the most part, this requires the user to modify and then merge the file created by SSIP with the SWMM system input file. Open the file named "usehp001.hp4" with any text editor. (The "001" indicates that this is the first time a file was created. If you repeated this operation, a file called "usehp002.hp4" would be produced.) Then do the following:

- Remove the first line that simply says "3".
- On the line labeled "K2", replace the three alphanumeric labels (in quotes) with 82309, 80408, and 81009 (no quotes), respectively. These are the three locations in SWMM to which the WinSLAMM produced flows are being directed (see Example 1 in the SWMM EXTRAN users manual).
- Resave this file.

Open the example SWMM system input file "extrn001.run" with any text editor. Then do the following:

- Optional: change the value 1440 to some other appropriate value. This is the number of time steps. The number of time steps multiplied by the computational time step length (the value 20 to the right of the number of time steps), in seconds, must be equal to or shorter than the time represented by the flow history provided by WinSLAMM. In this case, the example WinSLAMM files covers 365 hours, or 1,314,000 seconds. The hydrograph time step is 2.5 minutes. (The computational time step and the flow time step do not have to be the same.)
- Replace the lines labeled "K3" with the file "usehp001.hp4". Be sure that the "$ENDPROGRAM" line is the last line in the resulting file. The K3 lines in EXTRAN are the hydrographs to input to the sewer system, with each line representing a different point in time.
- Resave this file.

3. Execute SWMM with the modified “extrn001.run” file. You can follow this process with any sub-version of SWMM Version 4.

Limitations and Caveats. SSIP takes all the WinSLAMM files from the directory chosen by the user and converts them. If there are WinSLAMM files (i.e., those with the extension *.HYD) in the directory chosen by the user that are not to be included in the conversion, it is suggested that the user delete or move these files before running the Interface Program.

SSIP does not run on Windows NT because of file permissions. It is designed to run under Windows 95 or Windows 98. SSIP may work under other operating systems, but these have not been tested or supported.

Future Versions. Work is continuing on making SSIP much more user friendly and efficient. In its present form, the user is far too involved in file manipulation. Future versions will also transfer information through the more efficient and automated interface mechanisms found in SWMM (see Section 2 of the SWMM user's manual, Huber, *et al*. 1988) rather than through the user-prepared system input files. Location matching will also be part of SSIP (as opposed to the manual matching done now). These changes will make the interface effort much more seamless for the user.

References

Bachhuber, J.A. “A decision making approach for stormwater management measures: A case example in the City of Waukesha, Wisconsin.” *North American Water and Environment Congress*. American Society of Civil Engineers. Reston, VA. C-184-1. 1996.

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

Bannerman, R.T., A.D. Legg, and S.R. Greb. *Quality of Wisconsin Stormwater, 1989-94*. U.S. Geological Survey. Open-file report 96-458. Madison, WI. 26 pgs. 1996.

EPA (U.S. Environmental Protection Agency). *Final Report for the Nationwide Urban Runoff Program*. Water Planning Division, Washington, D.C., December 1983.

Haubner, S.M. and E.F. Joeres. “Using a GIS for estimating input parameters in urban stormwater quality modeling.” *Water Resources Bulletin*. Vol. 32, no. 6, pp. 1341 – 1351. December 1996.

Huber, W.C and R.E. Dickinson, *Storm Water Management Model, Version 4, User’s Manual*, EPA-600/3-88-001a, U.S. Environmental Protection Agency, Athens, Georgia, 1988.

Kim, K., P.G. Thum, and J. Prey. “Urban non-point source pollution assessment using a geographical information system.” *Journal of Environmental Management*. Vol. 39., no. 39, pp. 157 – 170. 1993.

Kim, K. and S. Ventura. “Large-scale modeling of urban nonpoint source pollution using a geographical information system.” *Photogrammetric Engineering & Remote Sensing*. Vol. 59, no. 10, pp. 1539 – 1544. October 1993.

Legg, A.D., R.T. Bannerman, and J. Panuska. Variation in the Relation of Rainfall to Runoff from Residential Lawns in Madison, Wisconsin, July and August 1995. U.S. Geological Survey. Water-resources investigations report 96-4194. Madison, Wisconsin. 11 pgs. 1996.

Ontario Ministry of the Environment. *Humber River Water Quality Management Plan*, Toronto Area Watershed Management Strategy. Toronto, Ontario, 1986.

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

Pitt, R. and M. Bozeman. *Sources of Urban Runoff Pollution and Its Effects on an Urban Creek*. EPA-600/S2-82-090, U.S. Environmental Protection Agency, Cincinnati, Ohio, December 1982.

Pitt, R. and G. Shawley. *A Demonstration of Non-Point Source Pollution Management on Castro Valley Creek*. Alameda County Flood Control and Water Conservation District (Hayward, CA) for the Nationwide Urban Runoff Program, U.S. Environmental Protection Agency, Water Planning Division, Washington, D.C., June 1982.

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

Pitt, R. and P. Bissonnette. *Bellevue Urban Runoff Program, Summary Report*. Storm and Surface Water Utility, Bellevue, Washington, November 1984.

Pitt, R. and J. McLean. *Toronto Area Watershed Management Strategy Study - Humber River Pilot Watershed Project*. Ontario Ministry of the Environment, Toronto, Ontario, June 1986.

Pitt, R. "Runoff controls in Wisconsin's priority watersheds," *Conference on Urban Runoff Quality - Impact and Quality Enhancement Technology*, Henniker, New Hampshire, Edited by B. Urbonas and L.A. Roesner, Proceedings published by the American Society of Civil Engineering, New York, June 1986.

Pitt, R. *Small Storm Flow and Particulate Washoff Contributions to Outfall Discharges*. Ph.D. dissertation, Department of Civil and Environmental Engineering, the University of Wisconsin - Madison, November 1987.

Pitt, R. and J. Voorhees. "Source loading and management model (WINSLAMM)." *Seminar Publication: National Conference on Urban Runoff Management: Enhancing Urban Watershed Management at the Local, County, and State Levels*. March 30 – April 2, 1993. Center for Environmental Research Information, U.S. Environmental Protection Agency. EPA/625/R-95/003. Cincinnati. Ohio. pp. 225-243. April 1995.

Roesner, L.A., J.A. Aldrich, and R.E. Dickinson, *Storm Water Management Model, User's Manual, Version 4: Addendum I, EXTRAN*, EPA-600/3-88-001b, U.S. Environmental Protection Agency, Cincinnati, Ohio, August, 1988.

Thum, P.G., S.R. Pickett, B.J. Niemann, Jr., and S.J. Ventura. "LIS/GIS: Integrating nonpoint pollution assessment with land development planning." *Wisconsin Land Information Newsletter*. University of Wisconsin – Madison. Vol., no. 2, pp. 1 – 11. 1990.

Ventura, S.J. and K. Kim. "Modeling urban nonpoint source pollution with a geographical information system." *Water Resources Bulletin*. Vol. 29, no. 2, pp. 189 – 198. April 1993.

Appendix A. Blank Site Characterization Data Sheets

WinSLAMM Site Characterization Data Sheets

1) Site description: ____

2) Rain file (*.ran) name:___________________

3) Starting date for the model run (default is the earliest rain after 1952): default or: ____________________

4) Ending date for the model run (default is the last rain): default or: _____________________

5) Use winter season (removes rain events during this period and begins each spring with elevated street dirt loading after snow melt): Yes/no, if yes: start of winter (mm/dd):________ and end of winter (mm/dd):______

6) Pollutant probability file (*.ppd) name:_________________________

7) Seed for random pollutant generator seed (specific value or 0 for random seed; or <0 to disable Monte Carlo routine to use mean pollutant strengths only) (default is -42): default or: _________________

8) Runoff coefficient file (*.rsv) name: ________________________

9) Particulate solids concentration file (*.psc) name:_________________________

10) Particulate residue delivery file (*.prr) name (to account for deposition and later resuspension of particulates in drainage system): __________________________

11) Street delivery parameter file (*.std) name (to account for decreased energy availability during small rains affecting street washoff along gutters): _________________________

12) Drainage system (enter fraction corresponding to each type) (Total must equal 1.0):

1. grass swales:_____
2. undeveloped roadside: _____
3. curb and gutters, valleys, or sealed swales in poor condition, or very flat: _____
4. curb and gutters, valleys, or sealed swales in fair condition: _____
5. curb and gutters, valleys, or sealed swales in good condition, or very steep: _____

13) If entered any swale component:

1. Swale infiltration rate (in/hr). Consider compaction (soil density) or soil amendments. Can select according to soil type: sand (4), loamy sand (1.25), sandy loam (0.5), loam (0.25), silt loam (0.15), sandy silt loam (0.1), clay loam (0.05), silty clay loam (0.025), silty clay (0.02), or clay (0.01), or ______

2. Wetted swale width (ft): ________

3. Swale density (ft/acre). Can select according to land use: low density residential (160), medium density residential (350), high density residential (375), strip commercial (630), shopping center (280), industrial (125), freeways (shoulders only: 270 or center and shoulder: 410), or ______

The area served by swales is determined by WinSLAMM after the source areas are described.

14) File name:_____________________________________

15) Output options (under “file” drop down menu):

1. Source areas by land use for each rain – complete printout	6. Continuous hydrograph with 6 minute time increments
2. Source area totals and outfall summaries	7. Continuous hydrograph with 15 minute time increments
3. Outfall data only for each rain	8. Continuous hydrograph with 60 minute time increments
4. Outfall summaries only (default)	Save water balance summary of all detention ponds?
5. One line per event runoff and flow summary	Save outfall runoff and particulate loading for WinDETPOND analyses?

WinSLAMM Site Characterization Data Sheet (continued)

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

Source Area	Area (acres)		Directly connected or disconnected to drainage system	Soil	Building density (only needed if clayey soils)	Alleys present? (only needed if high density)	Source area controls*
Roofs 1	______	Flat/pitched	Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	I/W/O/B
Roofs 2	______	Flat/pitched	Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	I/W/O/B
Roofs 3	______	Flat/pitched	Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	I/W/O/B
Roofs 4	______	Flat/pitched	Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	I/W/O/B
Roofs 5	______	Flat/pitched	Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	I/W/O/B
Paved parking 1	______		Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	I/W/P/O/B
Paved parking 2	______		Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	I/W/P/O/B
Paved parking 3	______		Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	I/W/P/O/B
Unpaved parking 1	______		Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	I/W/O/B
Unpaved parking 1	______		Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	I/W/O/B
Playground 1	______		Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	I/W/P/O/B
Playground 2	______		Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	I/W/P/O/B
Driveways 1	______		Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	P/O/B
Driveways 2	______		Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	P/O/B
Driveways 3	______		Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	P/O/B
Sidewalks 1	______		Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	P/O/B
Sidewalks 2	______		Dir con/discon	Sandy/silty/clayey	Low/med/high	Yes/no	P/O/B
Streets/alleys 1	______	____ curb-mi	Texture: smooth/inter/rough/very rough		Accum: default/other:	Initial load: default/other:	O/S/B
Streets/alleys 2	______	____ curb-mi	Texture: smooth/inter/rough/very rough		Accum: default/other:	Initial load: default/other:	O/S/B
Streets/alleys 3	______	____ curb-mi	Texture: smooth/inter/rough/very rough		Accum: default/other:	Initial load: default/other:	O/S/B
Large landscaped areas 1	______			Sandy/silty/clayey			I/W/O/B
Large landscaped areas 2	______			Sandy/silty/clayey			I/W/O/B
Undeveloped areas	______			Sandy/silty/clayey			I/W/O/B
Small landscaped areas 1	______			Sandy/silty/clayey			I/O/B
Small landscaped areas 2	______			Sandy/silty/clayey			I/O/B
Small landscaped areas 3	______			Sandy/silty/clayey			I/O/B
Isolated areas	______						B
Other Pervious areas	______			Sandy/silty/clayey			I/W/O/B
Other directly connected areas	______						I/W/P/O/B
Other Disconnected areas	______			Sandy/silty/clayey	Low/med/high	Yes/no	I/W/P/O/B
Total:	______						

*I: Infiltration trenches; W: Wet detention ponds; P: Porous pavement; O: Other (user designated); B: Bioretention/biofiltration and cisterns/rain barrels; S: Street cleaning

WinSLAMM Site Characterization Data Sheet (continued)

Land Use: Freeways

Source Area	Area (acres)	Texture	Average daily traffic (ADT)	Highway length (miles)	Initial load (lbs)	Source area controls*
Paved lanes/shoulders 1	________	Smooth/inter/rough/very rough	______ vehicles/day	______ miles	Default/_____ lbs	I/W/O
Paved lanes/shoulders 2	________	Smooth/inter/rough/very rough	______ vehicles/day	______ miles	Default/_____ lbs	I/W/O
Paved lanes/shoulders 3	________	Smooth/inter/rough/very rough	______ vehicles/day	______ miles	Default/_____ lbs	I/W/O
Paved lanes/shoulders 4	________	Smooth/inter/rough/very rough	______ vehicles/day	______ miles	Default/_____ lbs	I/W/O
Paved lanes/shoulders 5	________	Smooth/inter/rough/very rough	______ vehicles/day	______ miles	Default/_____ lbs	I/W/O
Large turf areas	________	Soil: sandy/silty/clayey				I/W/O
Undeveloped areas	________	Soil: sandy/silty/clayey				I/W/O
Other pervious areas	________	Soil: sandy/silty/clayey				I/W/O
Other directly connected areas	________					I/W/P/O/B
Other disconnected areas	________	Soil: sandy/silty/clayey	Density: low/medium/high	Alleys: yes/no		I/W/P/O/B
Total:	________					

*I: Infiltration trenches; W: Wet detention ponds; P: Porous pavement; O: Other (user designated); B: Bioretention/biofiltration and cisterns/rain barrels

Selection of Pollutants for Calculations:

Always calculates runoff volume and suspended solids concentrations and yields. Other pollutants available are dependent on the selected pollutant probability file. This drop down menu shows pollutants available, including particulate, dissolved, and total options:

Pollutant	Particulate	Dissolved	Total
Solids	X		

Other Control Available (under "land use" drop down menu):

1) Land use biofiltration (enables combined flows from multiple source areas in a single land use to be directed to a bilfiltration or cistern device)

2) Catchbasin or drainage controls: biofiltration/infiltration/catchbasins/drainage controls/other controls

3) Outfall controls: biofiltration/infiltration/wet detention ponds/other controls

Infiltration Area or Trench (I):

1) Water percolation rate (in/hr). Can be selected from list based on soil type: sand (8), loamy sand (2.5), sandy loam (1), loam (0. 5), silt loam (0.3), sandy silt loam (0.2), clay loam (0.1), silty clay loam (0.05), silty clay (0.04), or clay (0.02), or ______
2) Area served by device (acres):______
3) Surface area of the device (ft^2): _____
4) Width to depth ratio of the device: ______

Street Cleaning (S):

Up to 10 street cleaning programs can be specified for the duration of the model run. These programs are described in the following table. The street cleaning program maintains the specified cleaning frequency from the date shown until the program is changed at a later date, or until the final cleaning period ending date. If the model run dates or the rain file are changed, the street cleaning dates may also have to be changed to correspond to the same period.

	Street cleaning date:	Street cleaning frequency: 1) none, 2) 7 passes/week, 3) all weekdays, 4) 4 passes/week, 4) 3 passes/week, 6) 2 passes/week, 7) 1 pass/week, 8) every 2 weeks, 9) every 4 weeks, 10) every 8 weeks, or 11) every 12 weeks.
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Final cleaning period ending date (mm/dd/yy): __________

Street cleaning productivity: coefficients based on street texture, parking density, and parking controls, or specified M (<1): ______; B (>1): ________.

Parking densities: 1) none, 2) light, 3) medium, 4) extensive (short-term), or 5) extensive (long term)

Are parking controls imposed? Yes/No

Porous Pavement (P)

1) Infiltration rate of pavement, base, or soil, whichever is the least (in/hr): _____
2) Porous pavement area (acres): ______

Other Flow or Pollutant Reduction Control (O)

1) Pollutant concentration reduction (fraction): _____
2) Water volume (flow) reduction (fraction): _____
3) Area served by other control (acres): _____

Catchbasin Control Device

1) Total sump volume in test area (ft^3): _____

2) Area served by catchbasins (acres): _____

3) Percent of sump volume full at beginning of study period (0 to 100%): _____

4) Sump depth below catchbasin outlet (ft). At least one foot is needed to prevent scour: _____

5) Catchbasin cleaning dates. Enter specific dates, or select cleaning frequency from list: monthly, three times per year, semi-annually, annually, every 2 years, every 3 years, every 4 years, or every 5 years. Or enter cleaning dates on the following table:

Catchbasin Cleaning No.	Catchbasin Cleaning Date (mm/dd/yy)
1	
2	
3	
4	
5	

Biofiltration/Bioretention or Rain Barrel/Cistern (B)

These controls can be located at individual source areas, at a land use receiving flows from multiple source areas, along the drainage system receiving flows from all sources for an area, or at an outfall location. The following information is needed for all devices, irrespective of their location:

Device Geometry

1) top area (ft^2): _____

2) bottom area (ft^2): _____

3) depth (ft): _____

4) rock filled? Yes/no. If yes, fraction of total volume as voids (0-1%): _____ [currently not available in WinSLAMM]

5) seepage rate (in/hr). Can be selected from list based on soil type: sand (8), loamy sand (2.5), sandy loam (1), loam (0. 5), silt loam (0.3), sandy silt loam (0.2), clay loam (0.1), silty clay loam (0.05), silty clay (0.04), clay (0.02), rain barrel/cistern (0), or ______

Use random number generator to account for uncertainty in infiltration rate? Yes/no. If yes, seepage rate coefficient of variation (if selected seepage rate from list, a recommended COV is given): _____

6) number of biofiltration control devices (or rain barrels/cisterns) in source area of land use: _____

Outlet/Discharge (must have at least one outlet):

1) sharp crested weir

1. weir crest length (ft): _____
2. number of end contractions: 1 or 2
3: height from datum to bottom of weir opening (ft): ______

2) broad crested weir

1. weir crest length (ft): _____
2. weir crest width (ft): _____
3. Height of datum to bottom of weir opening (ft): ______
4. Use default weir coefficients? Yes/no, or enter weir coefficient (English units): ______

3) vertical stand pipe

1. Pipe diameter (ft): _____
2. Distance of basin bottom to top of pipe (ft): ______

4) evaporation. Enter monthly average evaporation rate (in/hr) for each month:

Month	Monthly average evaporation rate (in/day)
January	
February	
March	
April	
May	
June	
July	
August	
September	
October	
November	
December	

5) rain barrel/cistern. An overflow (such as a sharp-crested weir) must also be designated if using one of these devices. Enter the average monthly water use rate (gallons/day) for each month:

Month	Monthly average water use rate (gallons/day)
January	
February	
March	
April	
May	
June	
July	
August	
September	
October	
November	
December	

Inflow hydrograph peak to average flow ratio. Suggested value is 3.8, or: ______

If a land use device, the source areas that are described for the model are listed. Select those that contribute flow to the device:

Source Areas:	Areas that contribute runoff to biofiltration/cistern:
Roofs 1	
Roofs 2	
Roofs 3	
Roofs 4	
Roofs 5	
Paved parking 1	
Paved parking 2	
Paved parking 3	
Unpaved parking 1	
Unpaved parking 1	
Playground 1	
Playground 2	
Driveways 1	
Driveways 2	
Driveways 3	
Sidewalks 1	
Sidewalks 2	
Streets/alleys 1	
Streets/alleys 2	
Streets/alleys 3	
Large landscaped areas 1	
Large landscaped areas 2	
Undeveloped areas	
Small landscaped areas 1	
Small landscaped areas 2	
Small landscaped areas 3	
Isolated areas	
Other Pervious areas	
Other directly connected areas	
Other Disconnected areas	

If land use, drainage, or outfall device, the fraction of runoff directed to the device is: ______

Wet Detention Pond (W)

Sketch the pond, showing the important features and measurements:

1) Particle size distribution file (*.cpz): ______________________

2) Initial stage elevation (ft) (normally the elevation of the lowest invert, unless evaporation has lowered the stage and the value is known): _____

3) Inflow hydrograph peak to average flow ratio. Suggested value is 3.8, or: ______

4) Stage area data (at least 5 well spaced values, including the top-most elevation corresponding to the brim of the emergency spillway):

	Stage (ft)	Area (acres)
0	0.00	0.000
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		

5) Outlet descriptions:
The outlet rates for each device is calculated by the program. If multiple outlets are selected, the individual rates for each stage are summed.

1) sharp crested weir
  1. weir crest length (ft): _____
  2. number of end contractions: 1 or 2
  3: height from datum to bottom of weir opening (ft): ______

2) V-notch weirs
  Select the weir angle: 1) 11.5^o, 2) 30^o, 3) 45^o, 4) 60^o, 5) 90^o, 6) 120^o
  1) height of bottom weir opening (invert) to the top of the weir (ft): _____
  2) height from datum to bottom of weir opening(ft): _____

3) Orifice
  1) orifice diameter (ft): _____
  2) invert elevation above datum (ft): _____

4) Seepage basin
  1) infiltration fate (in/hr): _____
  2) width of seepage basin (ft): _____
  3) length of seepage basin (ft): _____
  4) invert elevation of seepage basin inlet above datum (ft): _____

5) Natural seepage
Enter the seepage rate (in/hr) for each stage previously entered:

	Stage (ft)	Seepage (in/hr):
0	0.00	
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		

6) Evaporation. Enter monthly average evaporation rate (in/hr) for each month:

Month	Monthly average evaporation rate (in/day)
January	
February	
March	
April	
May	
June	
July	
August	
September	
October	
November	
December	

7) Other outflow
Enter the outflow rate (ft^3/sec) (calculated for device not listed) for each stage previously entered:

	Stage (ft)	Outflow (ft^3/sec):
0	0.00	
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		

8) Pumped outlet
Not yet available in WinSLAMM

9) broad crested weir

1. weir crest length (ft): _____
2. weir crest width (ft): _____
3. Use default weir coefficients? Yes/no, or enter weir coefficient (English units): ______
4. Height of weir opening (ft): ______
5. Height of datum to bottom of weir opening (ft): ______

10) vertical stand pipe

1. Pipe diameter (ft): _____
2. Distance of basin bottom to top of pipe (ft): ______

August 12, 2003

2. The Integration of Water Quality and Drainage Design Objectives

Introduction

Different drainage design criteria and receiving water use objectives often require the examination of different types of rains for the design of urban drainage systems. These different (and often conflicting) objectives of a stormwater drainage system can be addressed by using distinct portions of the long-term rainfall record. Several historical examinations (including Heaney, *et al*. 1977) have also considered the need for the examination of a wide range of rain events for drainage design. However, the lack of efficient computer resources severely restricted long-term analyses in the past. Currently, computer resources are much more available and are capable of much more comprehensive investigations (Gregory and James 1996). In addition to having more efficient computational resources, it is also necessary to re-examine some of the fundamental urban hydrology modeling assumptions (Pitt 1987). Most of the urban hydrology methods currently used for drainage design have been successfully used for large “design” storms. Obviously, this approach (providing urban areas safe from excessive flooding and associated flood related damages) is the most critical objective of urban drainage. However, it is now possible (and legally required in many areas) to provide urban drainage systems that also minimizes other problems associated with urban stormwater. This broader set of urban drainage objectives requires a broader approach to drainage design, and the use of hydrology methods with different assumptions and simplifications.

Runoff volume is usually the most important hydrology parameter in water quality studies, while peak flow rate and time of concentration are usually the most important hydrologic parameters for flooding and drainage studies. The relationships between these different hydrologic parameters and rain parameters are significantly different for different classes of rains. Runoff models for water quality investigations should therefore be different than the runoff models for flooding and drainage investigations. Similarly, flooding and drainage investigations should normally not use a hydrology model developed for water quality investigations.

The importance of different areas in a watershed as pollutant sources is dependent on accurate hydrology predictions. One also need to know the variations of each source area’s importance for different rains. Many control practice designs also depend on inflow hydrology. If one incorrectly predicts the sources of pollutants or flows, then one will not get expected stormwater control benefits. This section briefly describes a method to accurately predict the sources of urban runoff source flows during important small rains. This method is fundamental to the Source Loading and Management Model (WinSLAMM) that can be used in conjunction with the SWMM model.

Most existing stormwater models incorrectly predict flows associated with small rains in urban areas. This is important because common small storms are responsible for most of the annual urban runoff discharge quantities throughout North America (EPA 1983, Pitt 1987). Most existing urban runoff models originated from drainage and flooding evaluation procedures that emphasized very large rains (several inches in depth). These large storms only contribute very small portions of the annual average discharges. Obviously, the pollutant shock loadings and habitat destruction caused by a large storm may create significant receiving water use impairments, but a number of years will be available for recovery before another massive rain occurs. However, moderate storms, occurring several times a year, are responsible for the majority of the pollutant discharges. The effects caused by these frequent discharges are mostly chronic in nature (such as contaminated sediment and frequent high flow rates) and the interevent periods are not long enough to allow the receiving water conditions to recover (Pitt and Bozeman 1982).

Simplifying the assumptions concerning runoff losses for impervious and pervious areas for small rains has little significance on the accuracy of the predictions of runoff volumes for large rains. These same assumptions, however, cause dramatically large errors when predicting runoff associated with small rains, the rains of most importance for water pollutant discharges. The significance of small rains as important pollutant generators is then missed and controls are then designed for wrong storms and wrong source areas. The hydrology prediction method described here is a simplified procedure used to predict runoff volumes from individual homogeneous areas for a wide variety of rains. It requires knowledge of certain development characteristics of the urban area.

Rainfall and Runoff Characteristics for Urban Areas

Actual stormwater characteristics that can be used to evaluate design procedures were evaluated by Pitt, et al. (1999), and is summarized in this section. That evaluation examined data obtained from the EPA’s Nationwide Urban Runoff Program (EPA 1983), the EPA’s Urban- Rainfall-Runoff-Quality Data Base (Heaney, *et al*. 1982), and from the Humber River portion of the Toronto Area Watershed Management Study (Pitt and McLean 1986). The Toronto area data were from two extensively monitored watersheds, a residential/commercial area and an industrial area. Most of the EPA’s “Data Base” data is from 2 locations in Broward County, FL; 1 site in Dade County, FL; 2 sites in Salt Lake City, UT; and 2 sites in Seattle, WA. Most of the data were obtained during the 1970s. These sites had the best representation of data of interest for these analyses and the sites were well described. Parameters examined included simultaneous rainfall and runoff depths, plus peak rain and flow rates. The following plots were prepared using this data:

- runoff depth versus rainfall,
- volumetric runoff coefficient (Rv) versus rainfall,
- NRCS curve number (CN) versus rainfall, and
- ratio of reported peak flow/peak rainfall versus rainfall.

In a similar manner, information from the EPA's NURP program (EPA 1983) was also investigated. A wider variety of information was collected during NURP, enabling additional relationships examining stormwater quality. Most of the data is from 5 sites in Champaign, IL; 2 sites in Austin, TX; 5 sites in Irondequoit Bay, NY; 1 site in Rapid City, SD; plus additional observations from Tampa, FL, Winston Salem, NC, and Eugene and Springfield, OR. Most of this data were obtained during the early 1980s and was subjected to rigorous quality control. Besides the four plots listed above, the following plots were also constructed examining potential water quality concentration relationships:

- total suspended solids concentration versus rainfall,
- COD concentration versus rainfall,
- phosphorous concentration versus rainfall,
- lead concentration versus rainfall,
- peak flow/peak rain versus rainfall, and
- peak flow rate versus peak rain intensity.

These plots were constructed to examine stormwater design methods using actual monitored data. These data can be used to examine many typical assumptions concerning stormwater drainage design and stormwater quality. Figures 2-1 through 2-9 show example plots for the John South Basin, a single family residential area, monitored during the EPA's NURP project in Champaign-Urbana, IL. The basic rainfall versus runoff plots (Figure 2-1) were made to indicate the smoothness of this basic relationship. A large scatter instead of a smooth curve may indicate measurement errors or uneven rainfalls over the catchment, or highly variable infiltration characteristics (due to changing soil moisture before the different rains). As shown on these plots, the runoff depth increases with increasing rain. However, several plots do show substantial scatter, mostly for sites having relatively small runoff yields. In addition, in some cases, more runoff was observed than could be accounted for by the rain. Errors in these measurements may be significant and would vary for the different sites. The senior authors of this report were involved in several of the monitoring projects that are included in these analyses, and also served on EPA technical committees overseeing others. In addition, we have many years experience in monitoring these parameters in many locations and recognize many of the past problems and current attempts to correct them. The following list therefore shows possible measurement errors that may have affected this data:

- variable rainfall over a large test catchment that was not well represented by enough rain gages (Although several of the test catchments had multiple rain gages, most did not, and few were probably frequently re-calibrated in the field.),
- poorly calibrated monitoring equipment (Many flow monitoring equipment relied on using the Manning's equation in pipes, with assumed roughness coefficients, without independent calibration, while other monitoring locations used calibrated insert weirs.)
- transcription errors (Many of these older monitoring activities required manual transfer from field equipment recorders to computers for analysis. In many cases, obvious "factor of ten" errors were made, for example.),
- newly developed equipment that has not been adequately tested, and
- difficult locations in the sewerage or streams that were monitored.

It is expected that the measurement errors were probably no less than about 25% during these monitoring activities. The effects of actual influencing factors can only be determined after the effects of these errors are considered.

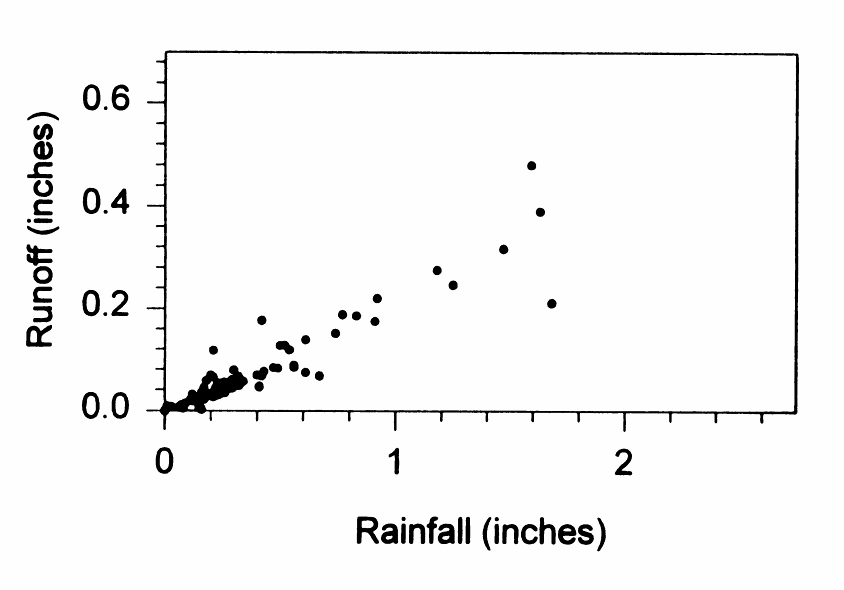


Figure 2-1. Runoff vs. rainfall.

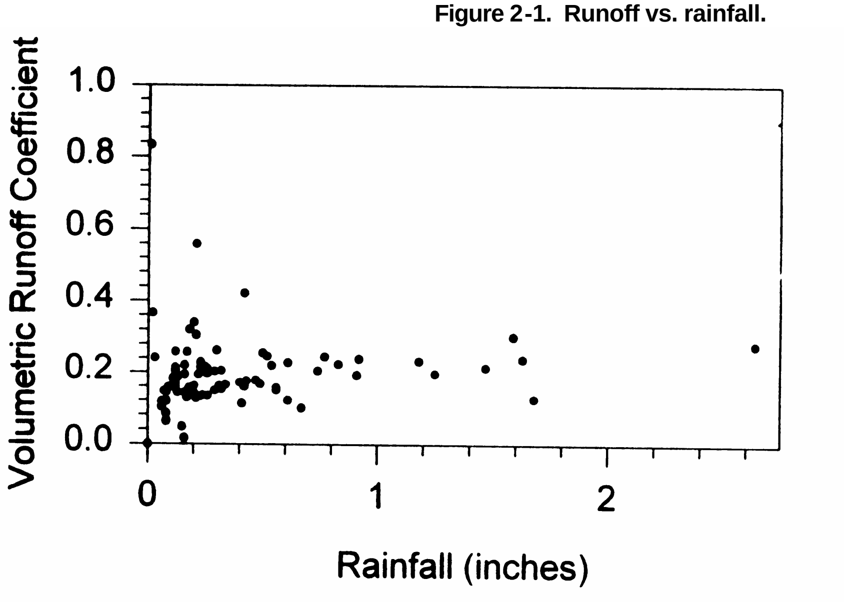


Figure 2-2. Rv vs. rainfall.

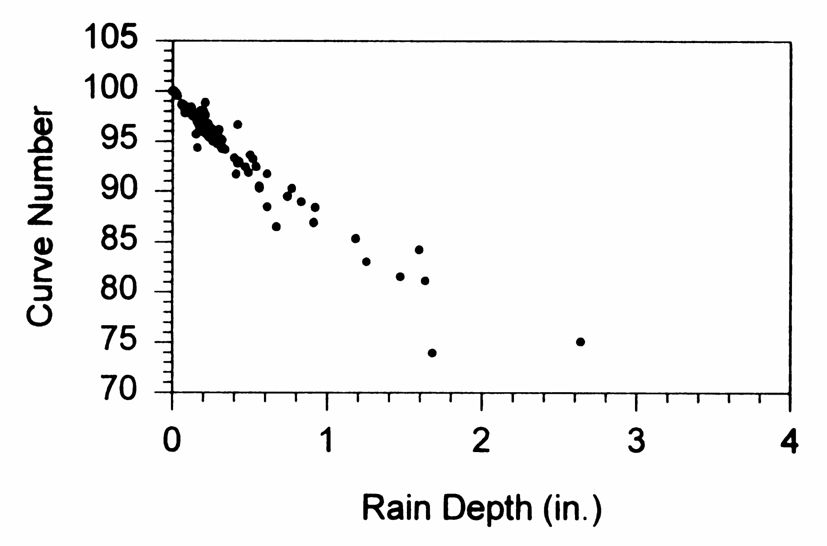


Figure 2-3. Curve number vs. rain depth.

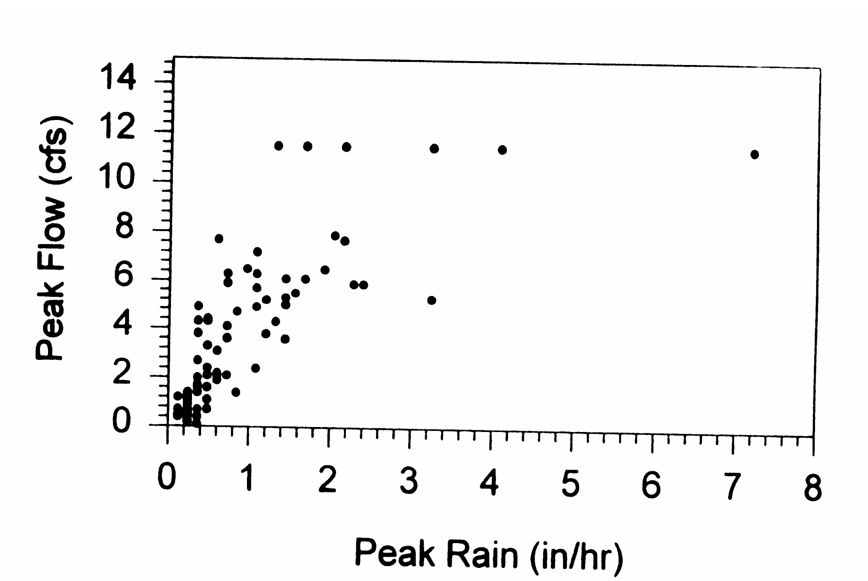


Figure 2-4. Peak flow vs. peak rain.

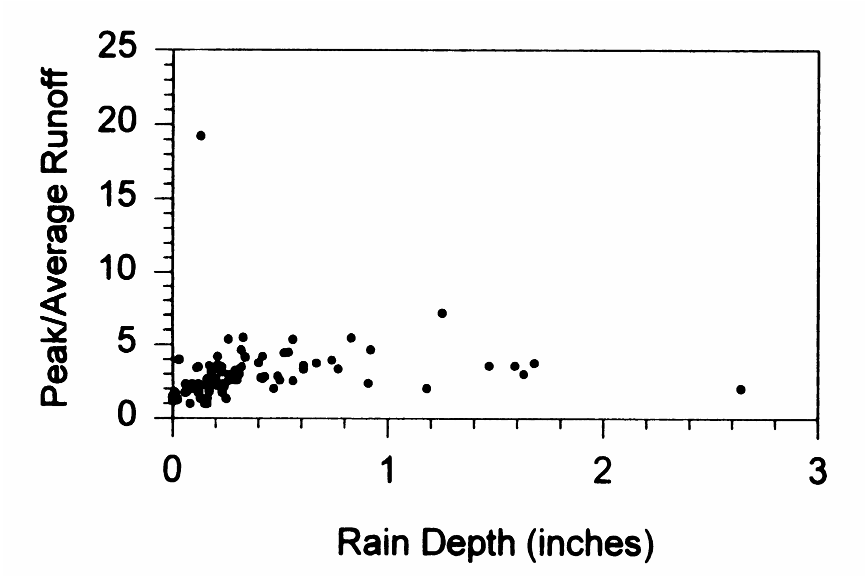


Figure 2-5. Peak/avg. runoff vs. rain depth.

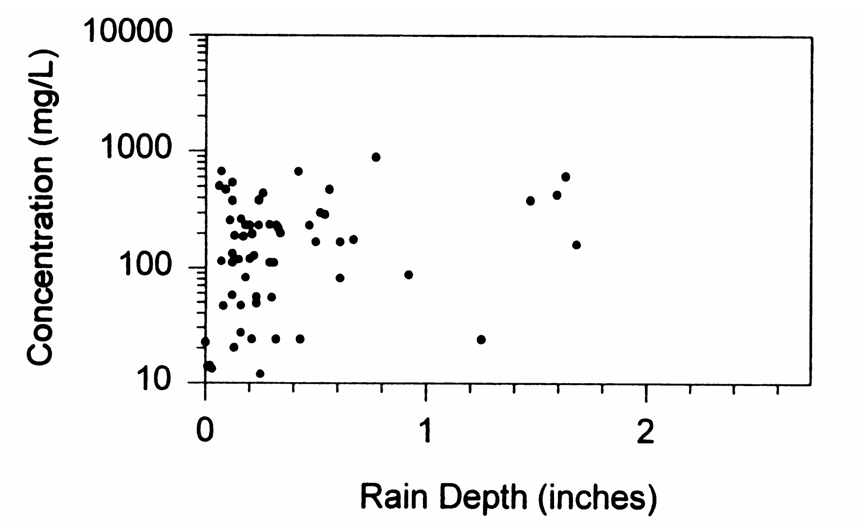


Figure 2-6. SS vs. rain depth.

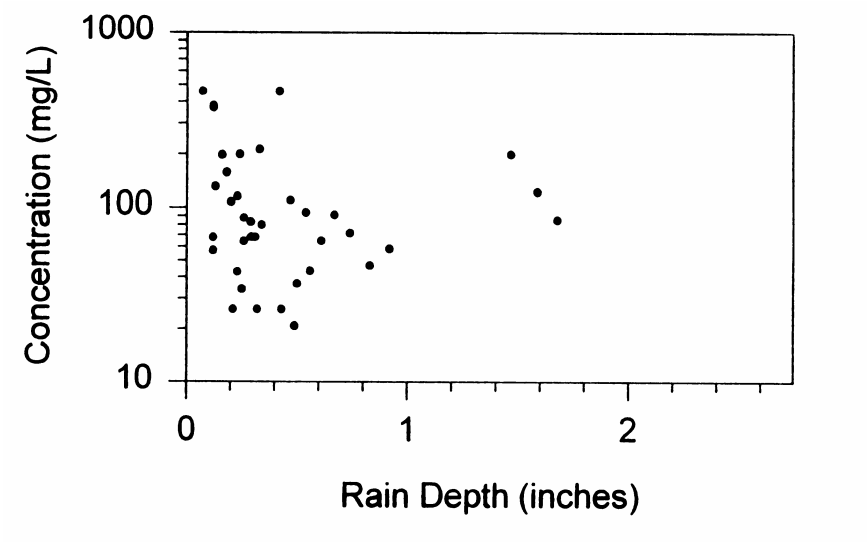


Figure 2-7. COD vs. rain depth.

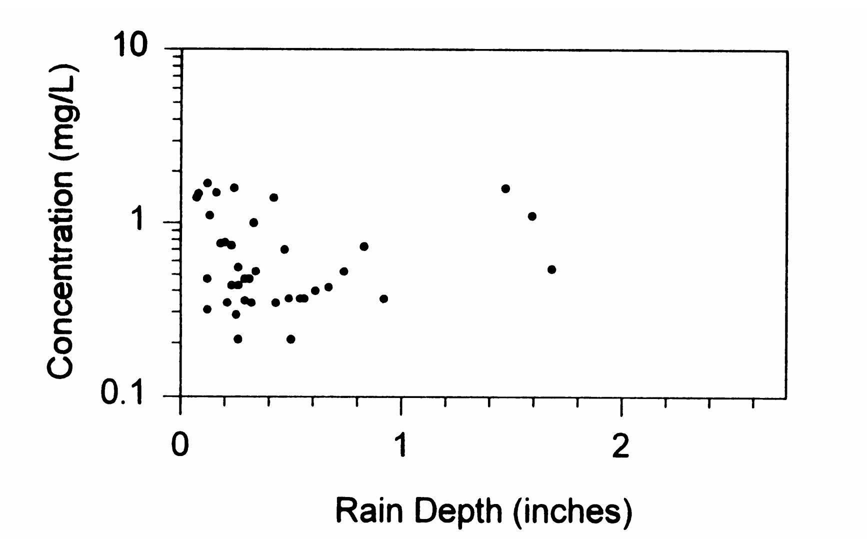


Figure 2-8. Phosphorus vs. rain depth.

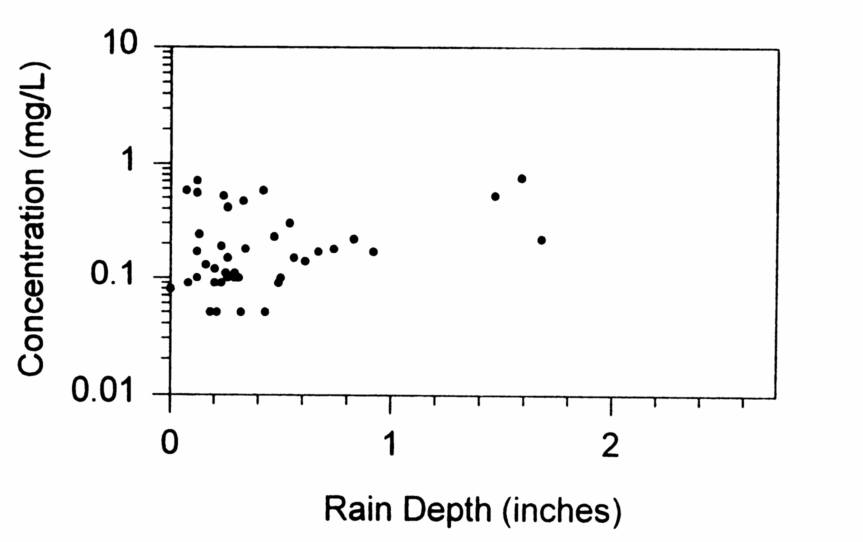


Figure 2-9. Lead vs. rain depth.

The plots of rainfall versus the volumetric runoff coefficient plot (Figure 2-2) shows the ratio of the runoff volume, expressed as depth for the watershed, to rain depth, or the Rv, for different rain depths. This is a related plot to the one described above. If the Rv ratio was constant for all events, the rainfall versus runoff depth plot described above, would indicate a straight diagonal line, with no scatter. It is typically assumed that the above described relationship would indicate increasing Rv values as the rain depth increased. Figure 2-1 shows a slight upwards curve with increasing rain depths. This is due to the rainfall losses making up smaller and smaller portions of the total rainfall as the rainfall increases, with a larger fraction of the rainfall occurring as runoff. The plot of Rv versus rainfall (Figure 2-2) would therefore show an increasing trend with increasing rain depth. In most cases, the plots of actual data indicate a large (random?) scatter, making the identification of a trend problematic. The use of a constant Rv for all rains may also be a problem because of the large scatter. In many cases, the long-term average Rv for a residential area may be close to the typically used value. In Figure 2-2, the values appear to center about 0.2 (somewhat smaller than the typically used value of about 0.3 for medium density residential areas), but the observed Rv values may range from lows of less than 0.04 to highs of greater than 0.5, especially for the smallest rains. The small rains probably have the greatest measurement errors, as the rainfall is much more variable for small rains than for larger rains, plus very low flows are difficult to accurately measure. Obviously, understanding what may be causing this scatter is of great interest, but is difficult because of measurement errors masking trends that may be present. In many cases, using a probability distribution to describe this variation may be the best approach.

Figure 2-3 is a plot of the NRCS curve number (CN) versus rainfall depth (SCS 1986). The NRCS assumes that the CN is constant for all rain depths for a specific site. However, they specify several limitations, including:

- the CN method is less accurate when the runoff is less than 0.5 inch. It is suggested that an independent procedure be used for confirmation,
- the CN needs to be modified according to antecedent conditions, especially soil moisture before an event, and
- the effects of impervious modifications (especially if they are not directly connected to the drainage path) needs to be reflected in the CN.

Few of these warnings are considered by most storm drainage designers, or by users of NRCS CN procedures for stormwater quality analyses. Figure 2-3 shows the typical pattern obtained when plotting CN against rain depth. The CN for small rain depths is always very large (approaching 100), then it decreases as the rain depth increases. At some point, the observed CN values equal the NRCS published recommended CN. During rains smaller than this matching point, the actual CN is greater than the NRCS CN. Predicted runoff depths would therefore be much less than the observed depths during these rains. Very large differences in runoff depths are associated with small differences in CN values, making this variation very important.

Figure 2-4 shows the observed peak runoff flow rate versus the peak rain intensity. If the averaging period for the peak flows and peak rain intensities were close to the catchment time of concentration (t_c), the slope of this relationship would be comparable to the Rational coefficient (C). The averaging times for the peak values probably ranged from 5 minutes to 1 hour for the different projects. Unfortunately, this averaging time period was rarely specified in the data documentation. Most urban area t_c values probably range from about 5 to 15 minutes. As indicated in this figure, the relationship between these two parameters shows a general upward trend, but it would be difficult to fit a statistically valid straight line through the data. As noted above for the other two drainage design procedures, actual real-world variations (coupled to measurement errors) add a lot of variation to the predicted runoff flow and volume estimates. Most drainage designers do not consider the actual variations that may occur.

Figure 2-5 shows an example plot of the ratio of the peak runoff flow rate to the average runoff flow rate versus rain depth. These values can be used to help describe the shape of simple urban area hydrographs. If the hydrograph can be represented by a simple triangular hydrograph, then the peak flow to average flow ratio must be close to 2. As shown on these figures, this ratio is typically substantially larger than 2 (it can never be less than 1 obviously), indicating the need to use a somewhat more sophisticated hydrograph shape (such as a double triangular hydrograph that can consider greater flows). These plots indicate if this ratio can be predicted as a function of rain depth. In most cases, values close to 2 are seen for the smallest rains, but they ratio increases to 5, or more, fairly quickly, but with much variability.

Example plots for total suspended solids, COD, phosphorous, and lead are shown on Figures 2-6 through 2-9 for each NURP site. It is commonly assumed that runoff pollutant concentrations are high for small rains (and at the beginning of all rains) and then taper off (the "first-flush" effect). As indicated on these plots, concentration has a generally random pattern. In many cases, the highest concentrations observed will occur for small events, but there is a large variation in observed concentrations at all rain depths. The upper limits of observed concentrations may show a declining curve with increasing rain depths, but the concentrations may best be described with random probability distributions. Analyses of concentrations versus antecedent dry periods can reduce some of this variability, as can analyses of runoff concentrations from isolated source areas.

Small Storm Hydrology

Stormwater Receiving Water Problems

Reviews of numerous urban receiving water studies from throughout the U.S. have identified the following diverse list of receiving water problems that may be caused by stormwater (Pitt 1995):

- Sedimentation damage in stormwater conveyance systems and in receiving waters.
- Nuisance algae growths from nutrient discharges into quiescent waters.
- Inedible fish and undrinkable water caused by toxic pollutant discharges.
- Shifts to less sensitive aquatic organisms caused by contaminated sediments and habitat destruction.
- Property damage from increased drainage system failures.
- Swimming beach closures from pathogenic microorganisms.
- Water quality violations, especially for bacteria and total recoverable heavy metals.

The first four problem areas are mostly associated with slug (mass) discharges (not instantaneous concentrations or rates), while the last three are mostly associated with instantaneous concentrations and high flow rates.

In order to predict receiving water problems caused by stormwater, accurate flow estimates and pollutant mass discharges must be known. Knowing where the potentially problem pollutants originate in the watershed is also valuable in order to select appropriate stormwater control candidates. Accurate knowledge of runoff volumes during different storms has been shown to be necessary when predicting pollutant discharges.

Typical Problems with Assumptions Commonly Used in Urban Hydrology Analyses

Most of the Annual Rain is Associated With Many Small Individual Events

This discussion reviews actual monitored rainfall and runoff distributions for Milwaukee, WI (data from Bannerman, *et al*. 1983), and examines long-term rainfall histories and predicted runoff from 24 locations throughout the U.S. The Milwaukee observations show that southeastern Wisconsin rainfall distributions can be divided into the following categories, with possible management approaches relevant for each category of rain:

- Common rains having relatively low pollutant discharges are associated with rains less than about 0.5 in. (12 mm) in depth. These are key rains when runoff-associated water quality violations, such as for bacteria, are of concern. In most areas, runoff from these rains should be totally captured and either re-used for on-site beneficial uses or infiltrated in upland areas. For most areas, the runoff from these rains can be relatively easily removed from the surface drainage system.

- Rains between 0.5 and 1.5 in. (12 and 38 mm) are responsible for about 75% of the runoff pollutant discharges and are key rains when addressing mass pollutant discharges. The small rains in this category can also be removed from the drainage system and the runoff re-used on site for beneficial uses or infiltrated to replenish the lost groundwater infiltration associated with urbanization. The runoff from the larger rains should be treated to prevent pollutant discharges from entering the receiving waters.

- Rains greater than 1.5 in. (38 mm) are associated with drainage design and are only responsible for relatively small portions of the annual pollutant discharges. Typical storm drainage design events fall in the upper portion of this category. Extensive pollution control designed for these events would be very costly, especially considering the relatively small portion of the annual runoff associated with the events. However, discharge rate reductions are important to reduce habitat problems in the receiving waters. The infiltration and other treatment controls used to handle the smaller storms in the above categories would have some benefit in reducing pollutant discharges during these larger, rarer storms.

- In addition, extremely large rains also infrequently occur that exceed the capacity of the drainage system and cause local flooding. Two of these extreme events were monitored in Milwaukee during the Nationwide Urban Runoff Program (NURP) project (EPA 1983). These storms, while very destructive, are sufficiently rare that the resulting environmental problems do not justify the massive stormwater quality controls that would be necessary for their reduction. The problem during these events is massive property damage and possible loss of life. These rains typically greatly exceed the capacities of the storm drainage systems, causing extensive flooding. It is critical that these excessive flows be conveyed in “secondary” drainage systems. These secondary systems would normally be graded large depressions between buildings that would direct the water away from the buildings and critical transportation routes and to possible infrequent/temporary detention areas (such as large playing fields or parking lots). Because these events are so rare, institutional memory often fails and development is allowed in areas that are not indicated on conventional flood maps, but would suffer critical flood damage.

Obviously, the critical values defining these rain categories are highly dependent on local rain and development conditions. Computer modeling analyses from several representative urban locations from throughout the U.S. are presented in this paper. These modeled plots indicate how these rainfall and runoff probability distributions can be used for more effective storm drainage design in the future. In all cases, better integration of stormwater quality and drainage design objectives will require the use of long-term continuous simulations of alternative drainage designs in conjunction with upland and end-of-pipe stormwater quality controls. The complexity of most receiving water quality problems prevents a simple analysis. The use of simple design storms, which was a major breakthrough in effective drainage design more than 100 years ago, is not adequate when receiving water quality issues must also be addressed.

This discussion also reviews typical urban hydrology methods and discusses common problems in their use in predicting flows from these important small and moderate sized storms. A general model is then described, and validation data presented, showing better runoff volume predictions possible for a wide range of rain conditions.

Figure 2-10 includes cumulative probability density functions (CDFs) of measured rain and runoff distributions for Milwaukee during the 1981 NURP monitored rain year (data from Bannerman, *et al*. 1983). CDFs are used for plotting because they clearly show the ranges of rain depths responsible for most of the runoff. Rains between 0.05 and 5 in. were monitored during this period, with two very large events (greater than 3 inches) occurred during this monitoring period which greatly distort these curves, compared to typical rain years. The following observations are evident:

- The median rain depth was about 0.3 in.
- 66% of all Milwaukee rains are less than 0.5 in. in depth.
- For medium density residential areas, 50% of runoff was associated with rains less than 0.75 in.
- A 100-yr., 24-hr rain of 5.6 in. for Milwaukee could produce about 15% of the typical annual runoff volume, but it only contributes about 0.15% of the average annual runoff volume, when amortized over 100 yrs.
- Similarly, a 25-yr., 24-hr rain of 4.4 in. for Milwaukee could produce about 12.5% of the typical annual runoff volume, but it only contributes about 0.5% of the average annual runoff volume, when amortized over 25 yrs.

Figure 2-11 shows CDFs of measured Milwaukee pollutant loads associated with different rain depths for a medium density residential area. Suspended solids, COD, lead, and phosphate loads are seen to closely follow the runoff volume CDF shown in Figure 2-10, as expected. Since load is the product of concentration and runoff volume, some of the high correlation shown between load and rain depth is obviously spurious. However, these overlays illustrate the range of rains associated with the greatest pollutant discharges.

The monitored rainfall and runoff distributions for Milwaukee show the following distinct rain categories:

- <0.5 inch. These rains account for most of the events, but little of the runoff volume, and are therefore easiest to control. They produce much less pollutant mass discharges and probably have less receiving water effects than other rains. However, the runoff pollutant concentrations likely exceed regulatory standards for several categories of critical pollutants, especially bacteria and some total recoverable metals. They also cause large numbers of overflow events in uncontrolled combined sewers. These rains are very common, occurring once or twice a week (accounting for about 60% of the total rainfall events and about 45% of the total runoff events that occurred), but they only account for about 20% of the annual runoff and pollutant discharges. Rains less than about 0.05 inches did not produce noticeable runoff.

- 0.5 to 1.5 inches. These rains account for the majority of the runoff volume (about 50% of the annual volume for this Milwaukee example) and produce moderate to high flows. They account for about 35% of the annual rain events, and about 20% of the annual runoff events. These rains occur on the average about every two weeks during the spring to fall seasons and subject the receiving waters to frequent high pollutant loads and moderate to high flows.

- 1.5 to 3 inches. These rains produce the most damaging flows, from a habitat destruction standpoint, and occur every several months (at least once or twice a year). These recurring high flows, which were historically associated with much less frequent rains, establish the energy gradient of the stream and cause unstable streambanks. Only about 2 percent of the rains are in this category and they are responsible for about 10 percent of the annual runoff and pollutant discharges.

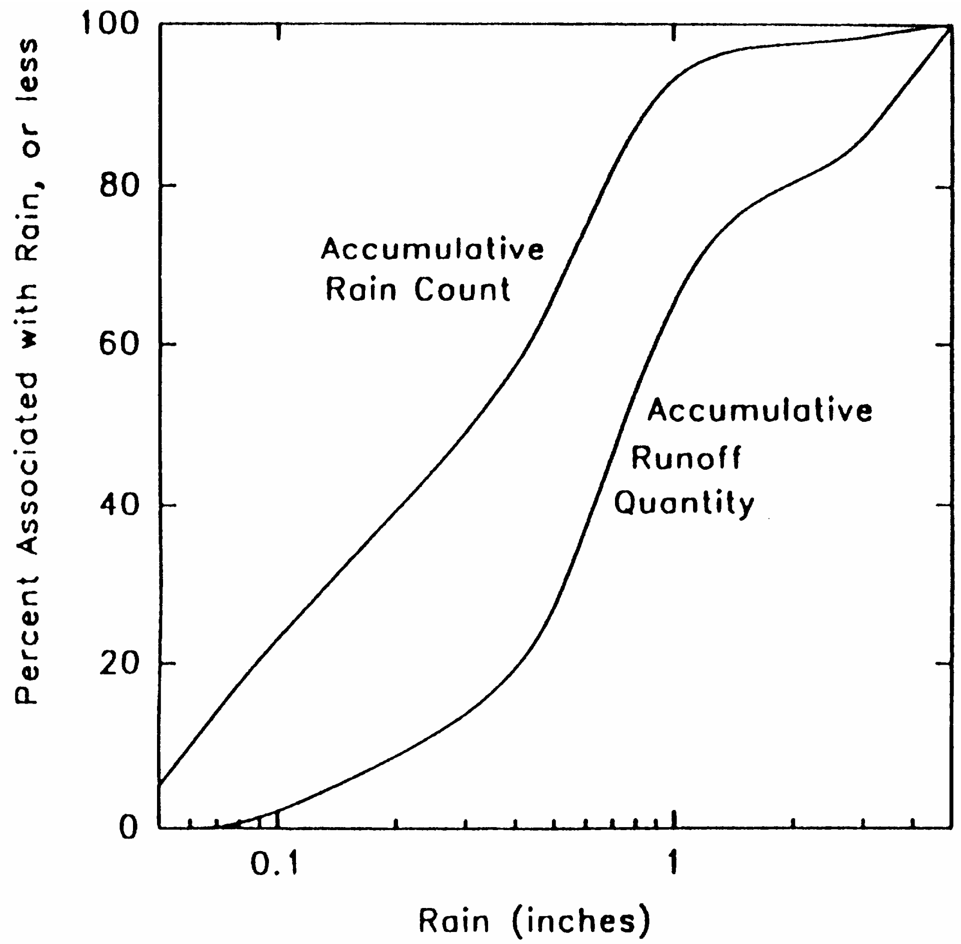


Figure 2-10. Milwaukee rain and runoff distributions.

• >3 inches. This category is rarely represented in field studies due to the rarity of these large events and the typically short duration of most field observations. The smallest rains in this category are included in design storms used for drainage systems in Milwaukee. These rains occur only rarely (once every several years to once every several decades, or less frequently) and produce extremely large flows. The 3-year monitoring period during the Milwaukee NURP program (1980 through 1983) was unusual in that two of these events occurred. Less than 2 percent of the rains were in this category (typically <<1% would be), and they produced about 15% of the annual runoff quantity and pollutant discharges. During a "normal" period, these rains would only produce a very small fraction of the annual average discharges. However, when they do occur, great property and receiving water damage results. The receiving water damage (mostly associated with habitat destruction, sediment scouring, and the flushing of organisms great distances downstream and out of the system) can conceivably naturally recover to before-storm conditions within a few years.

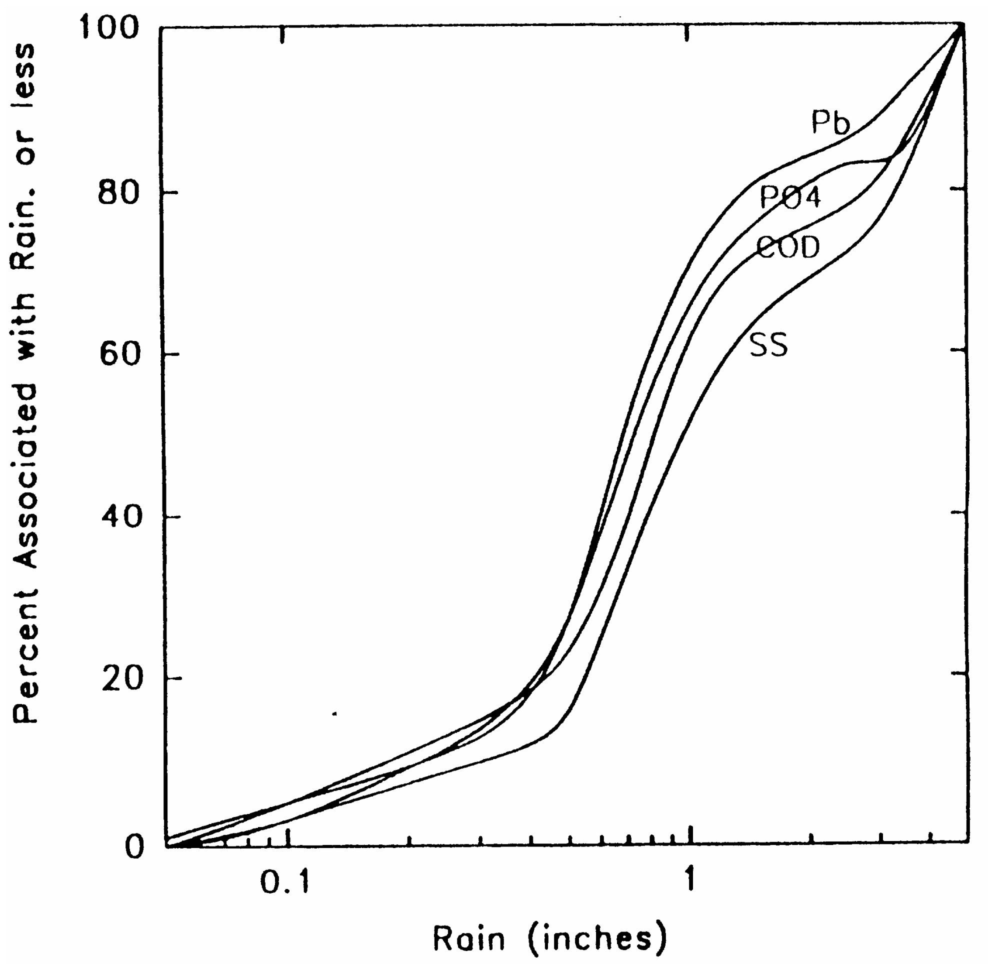


Figure 2-11. Milwaukee pollutant discharge distributions.

These rainfall and pollutant mass distributions are not unique for Milwaukee. Long-term continuous simulations were made using WinSLAMM (incorporating the small storm hydrology components described in this report section) for 22 representative locations from throughout the U.S. (Figure 2-12). These locations represent most of the major river basins and much of the rainfall variations in the country. These analyses are only intended to show the importance of these smaller rains for many different regions and conditions. They are not intended to be used for design purposes. As noted earlier, the recommended approach for design is to continuously model long rain records for site specific conditions. These locally derived runoff distributions, reflecting site conditions and actual rains, can then used for evaluating alternative drainage and water quality designs.

These simulations were based on 5 to 10 years of rainfall records, usually containing about 500 individual rains. The rainfall records were from certified NOAA weather stations and were obtained from CD-ROMs distributed by EarthInfo of Boulder, CO. Hourly rainfall depths for the indicated periods were downloaded from the CD-ROMs into an Excel spreadsheet. The files were slightly modified (by eliminating the daily total rainfall column) and saved as a comma delineated file. This file was then read by an utility program included in the WinSLAMM package. This rainfall file utility combined adjacent hourly rainfall values into individual rains, based on user selections (at least 6 hrs of no rain was used to separate adjacent rain events and all rain depths were used, with the exception of the "trace" values). These rain files for each city were then used in WinSLAMM for typical medium density and strip commercial developments. The outputs of these computer runs were then plotted as shown on Figure 2-13.

Figure 2-12. U.S. major river basins and modeled cities.

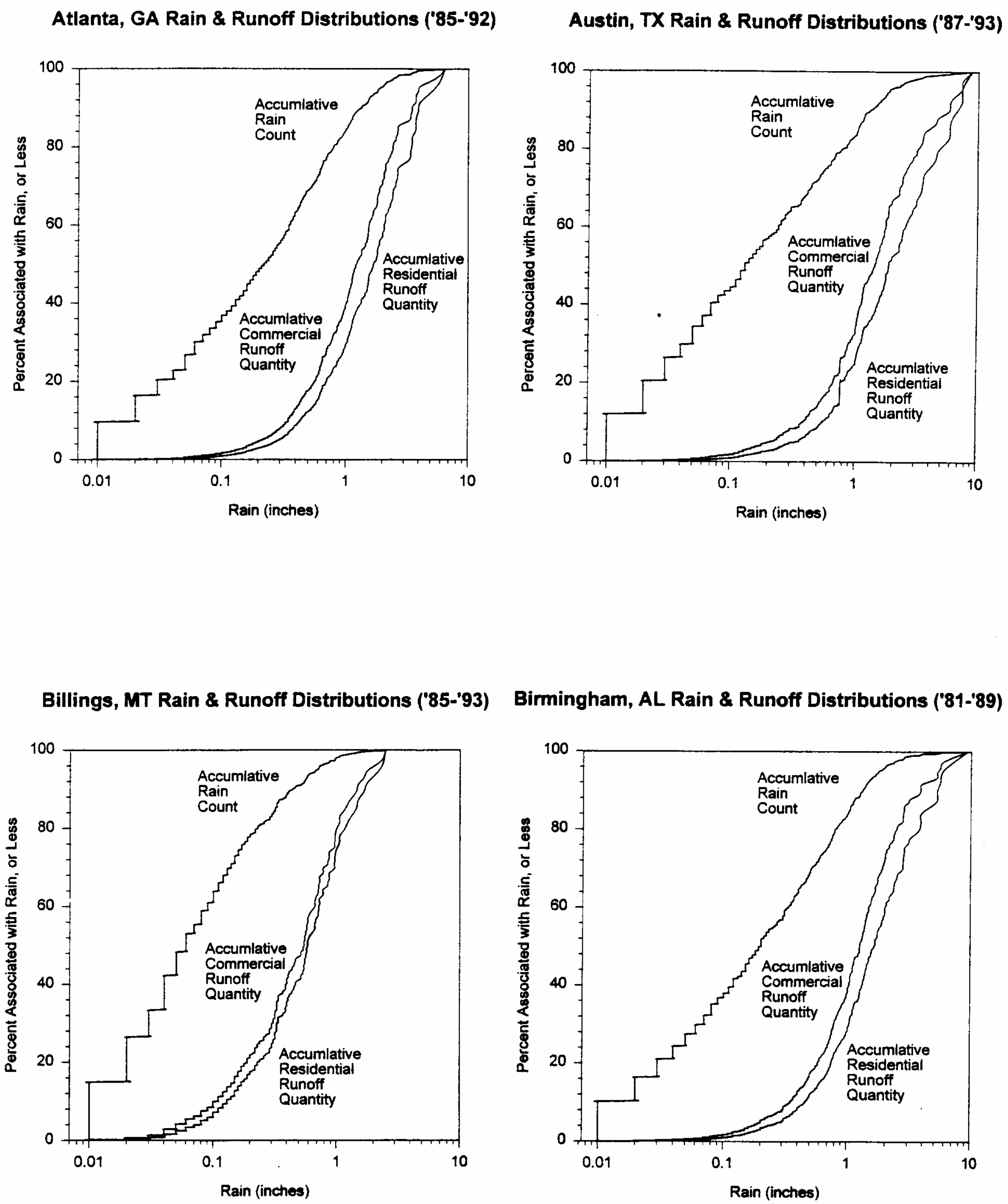


Figure 2-13a. Modeled rain, runoff, and pollutant distributions.

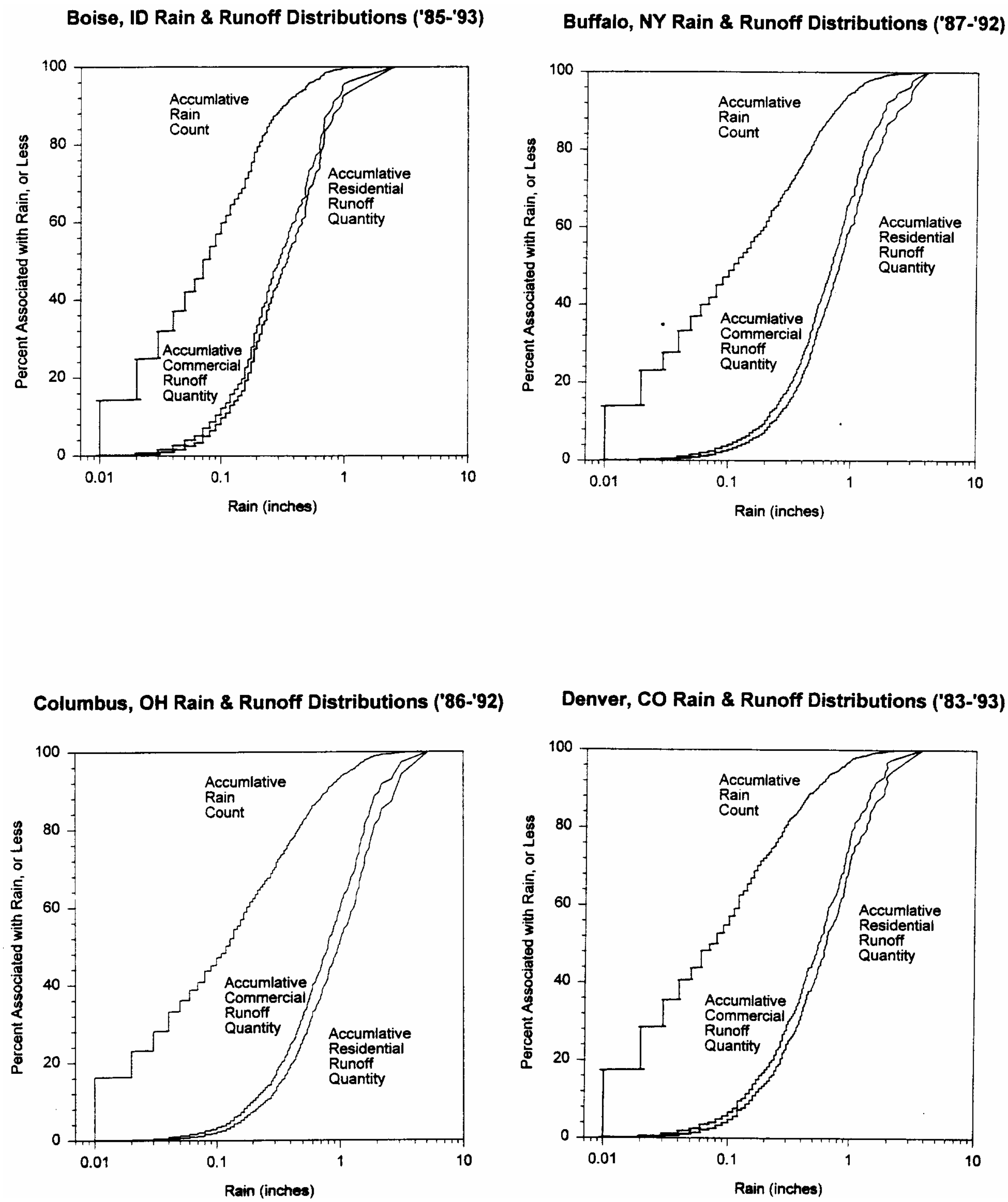


Figure 2-13b. Modeled rain, runoff, and pollutant distributions (cont.).

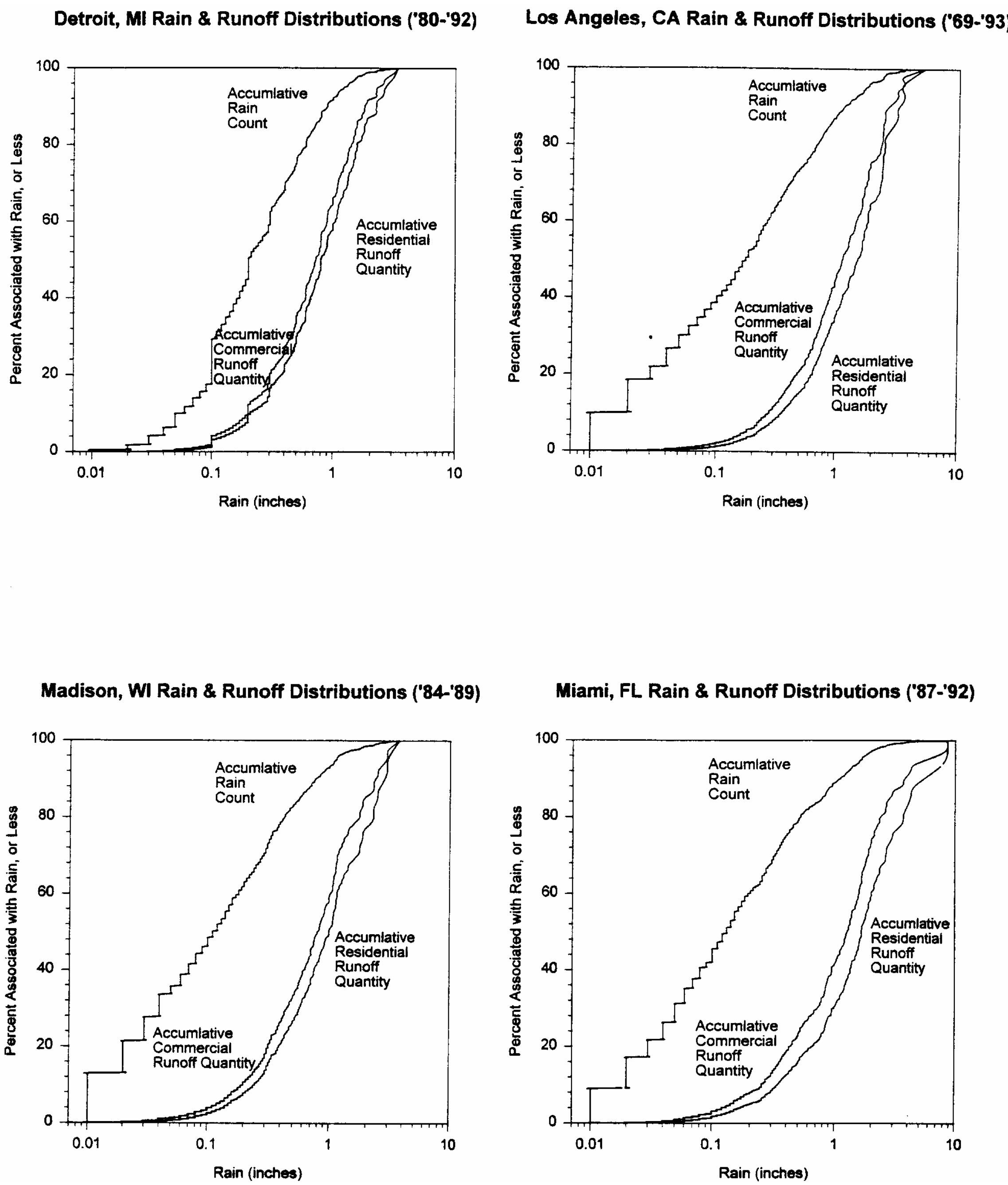


Figure 2-13c. Modeled rain, runoff, and pollutant distributions (cont.).

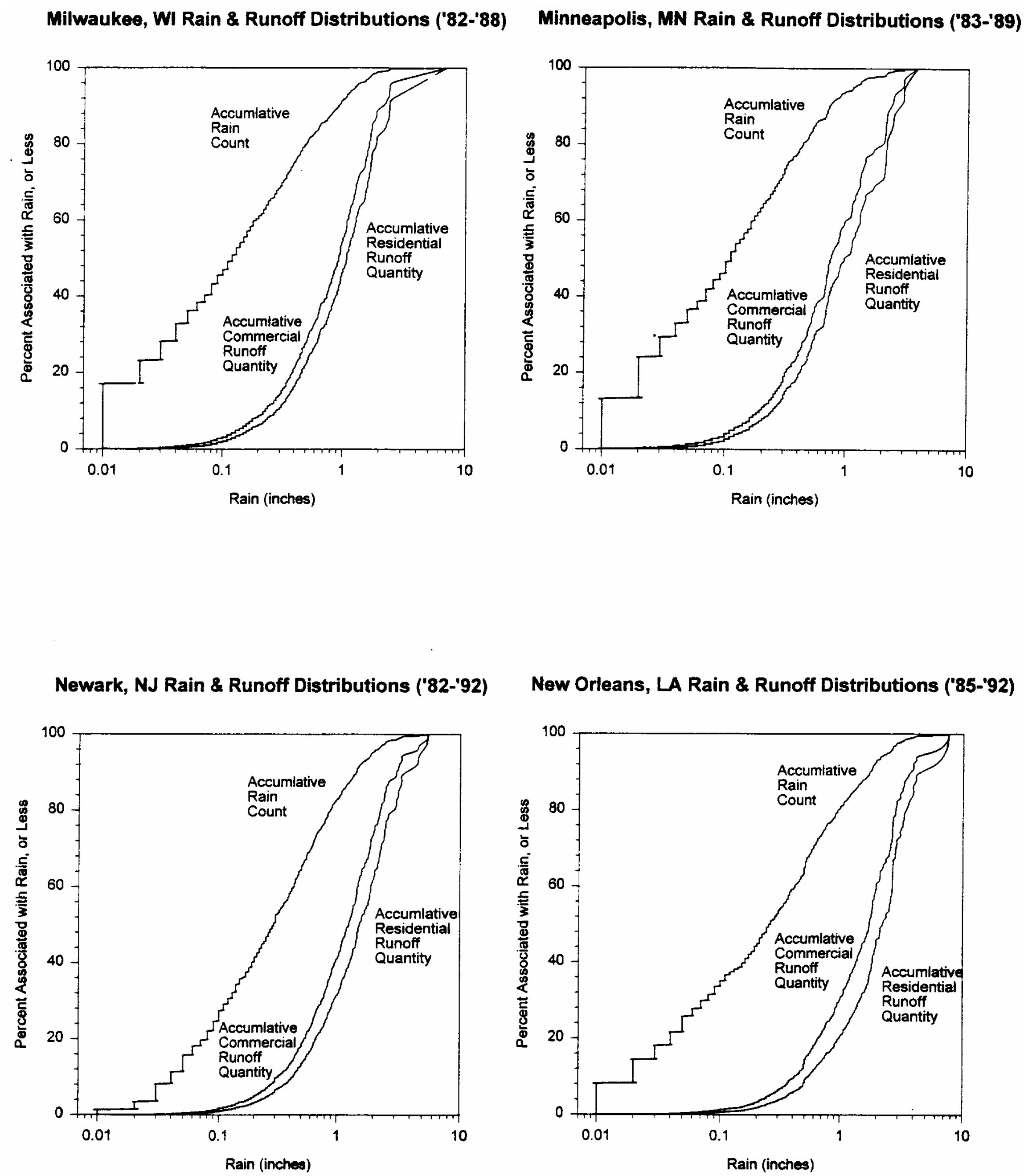


Figure 2-13d. Modeled rain, runoff, and pollutant distributions (cont.).

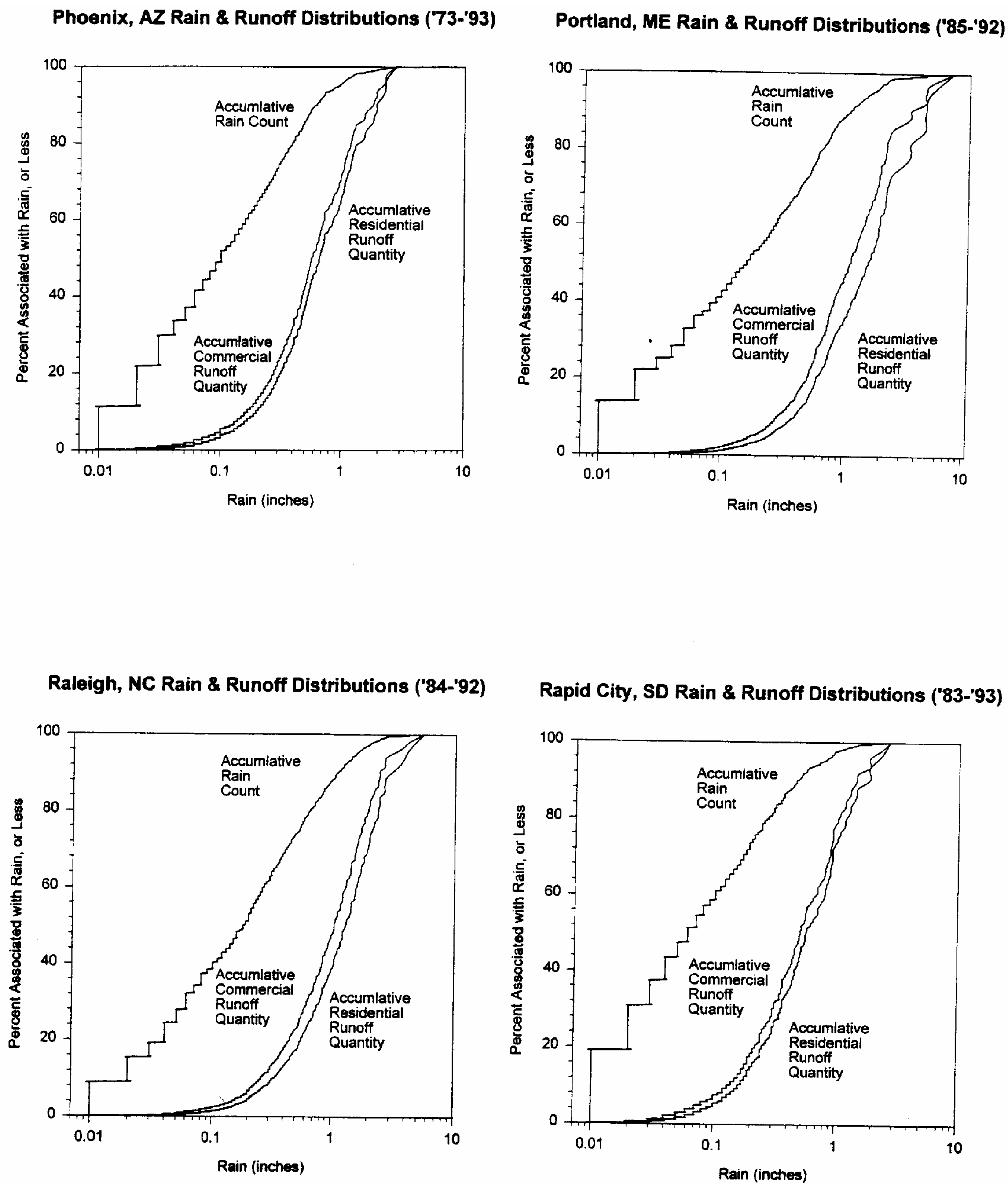


Figure 2-13e. Modeled rain, runoff, and pollutant distributions (cont.).

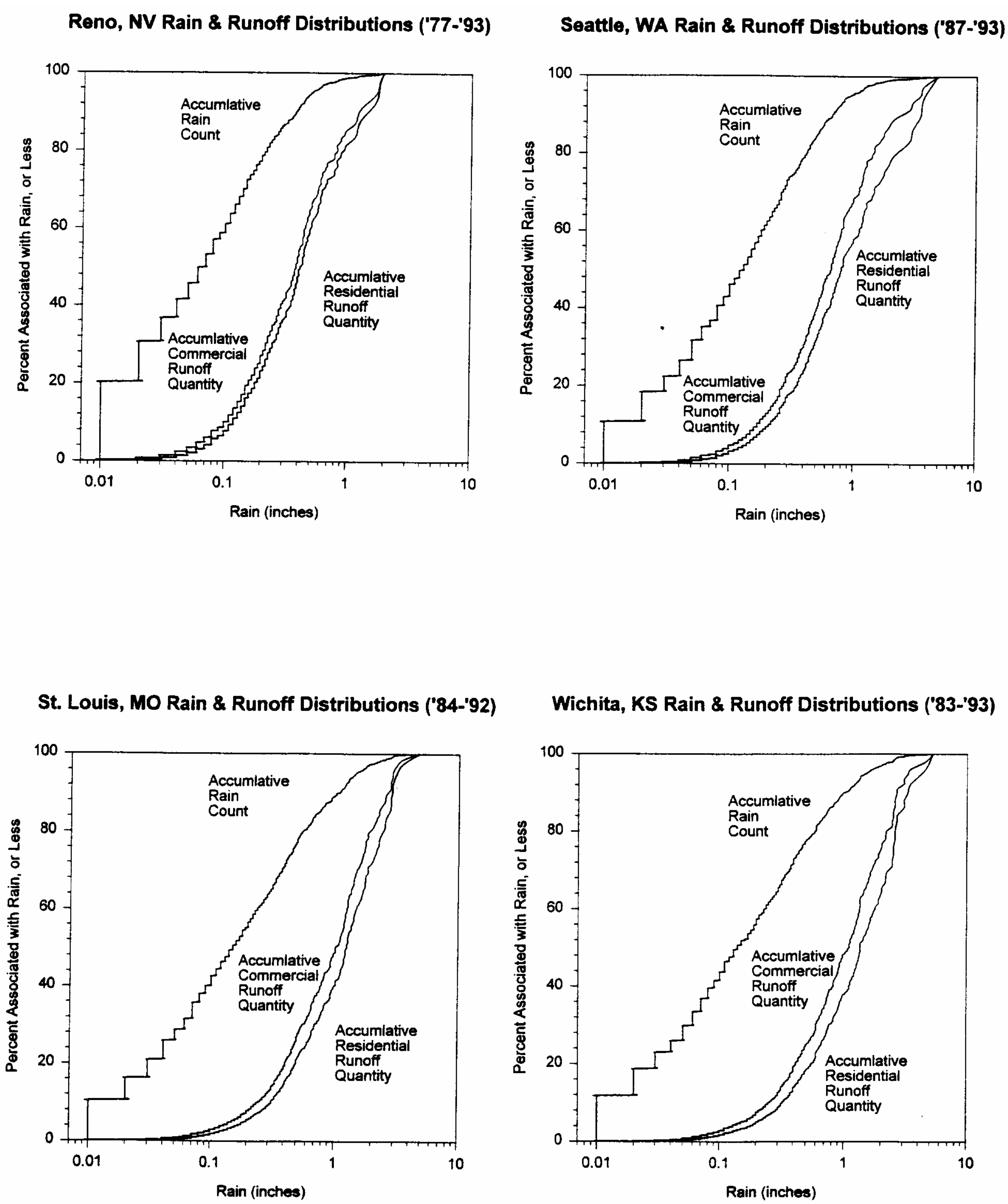


Figure 2-13f. Modeled rain, runoff, and pollutant distributions (cont.).

Table 2-1 summarizes these rain and runoff distributions for different U.S. locations, while Figures 2-14 through 2-19 plot some of the important values on a U.S. map. Lower and upper runoff distribution breakpoints were identified on all of the individual distributions. The breakpoints separate the distributions into the following three general categories:

- less than lower breakpoint: small, but frequent rains. These generally account for 50 to 70 percent of all rain events (by number), but only produce about 10 to 20 percent of the runoff volume. Figure 2-15 shows that the rain depth for this breakpoint ranges from about 0.10 in. in the Southwest arid regions of the country, to about 0.5 in. in the wet Southeast. These events are most important because of their frequencies, not because of their mass discharges. These rains are therefore of great interest where water quality violations associated with urban stormwater occur. This would be most common for bacteria (especially fecal coliforms) and for total recoverable heavy metals which typically exceed receiving water numeric criteria during practically every rain event in heavily urbanized drainages having separate stormwater drainage systems.

- between the lower and upper breakpoint: moderate rains. These rains generally account for 30 to 50 percent of all rains events (by number), but produce 75 to 90 percent of all of the runoff volume (Figure 2-19). Figure 2-17 shows that the rain depths associated with the upper breakpoint range from about 1 to 2 in. in the arid parts of the U.S. to up to 5 or 6 in. in wetter areas. As shown earlier for actual monitored events in Milwaukee and elsewhere, these runoff volume distributions are approximately the same as the pollutant distributions. Therefore, these intermediate rains also account for most of the pollutant mass discharges and much of the actual receiving water problems associated with stormwater discharges.

- above the upper breakpoint: large, but rare rains. These rains include the typical drainage design events and are therefore quite rare. During the period analyzed, many of the sites only had one or two, if any, events above this breakpoint. These rare events do account for about 5 to 10 percent of the runoff on an annual basis, as shown on Figure 2-18. Obviously, these events must be evaluated to ensure adequate drainage.

Because of the importance of these small and moderate rains, it is important to review typically used urban hydrology methods that have been commonly used to predict runoff from urban areas. These tools have been reasonably successful when evaluating drainage capacity for large "design storm" events. However, the following paragraphs will indicate their short-comings when used for evaluating the common smaller events. A general urban runoff model is also presented that has been shown to be useful to predict runoff volumes for a wide range of rain events, especially the small and moderate rains of greatest interest in water quality evaluations.

The Rainfall-Runoff Inter-Relationships for Different Urban Areas are Surprisingly Similar

Figure 2-20 shows a dendogram from a cluster analysis (using SYSTAT) of rainfall and runoff data from two areas: an industrial area and a residential and commercial mixed land use area (Pitt 1987). Most of the variation in runoff volumes for different rains can be explained by rain volume variations alone. Rain intensity and antecedent periods are not very important when predicting runoff volumes. However, rain intensity information is very important for predicting runoff rates which are needed for drainage and flooding studies. It is also noted that the runoff duration is closely related to rain duration. A simple procedure for predicting runoff volume is possible using only total rain depth (and land development characteristics).

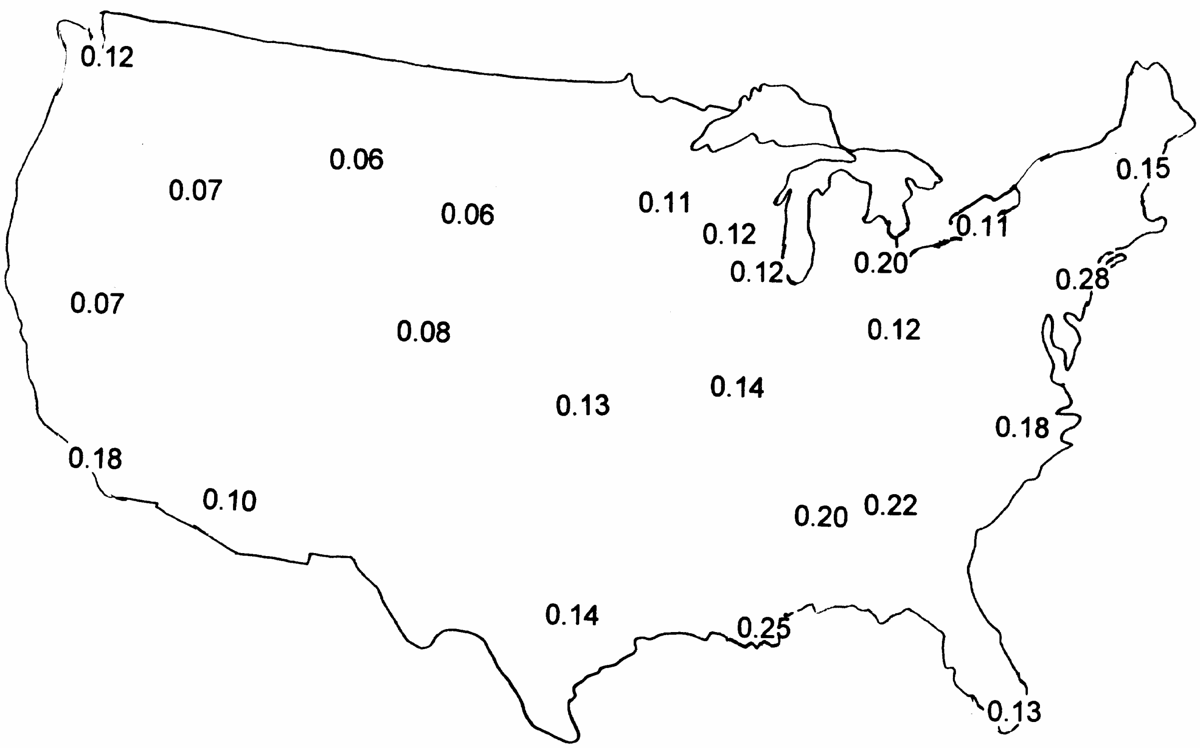


Figure 2-14. Median rain depth (in.).

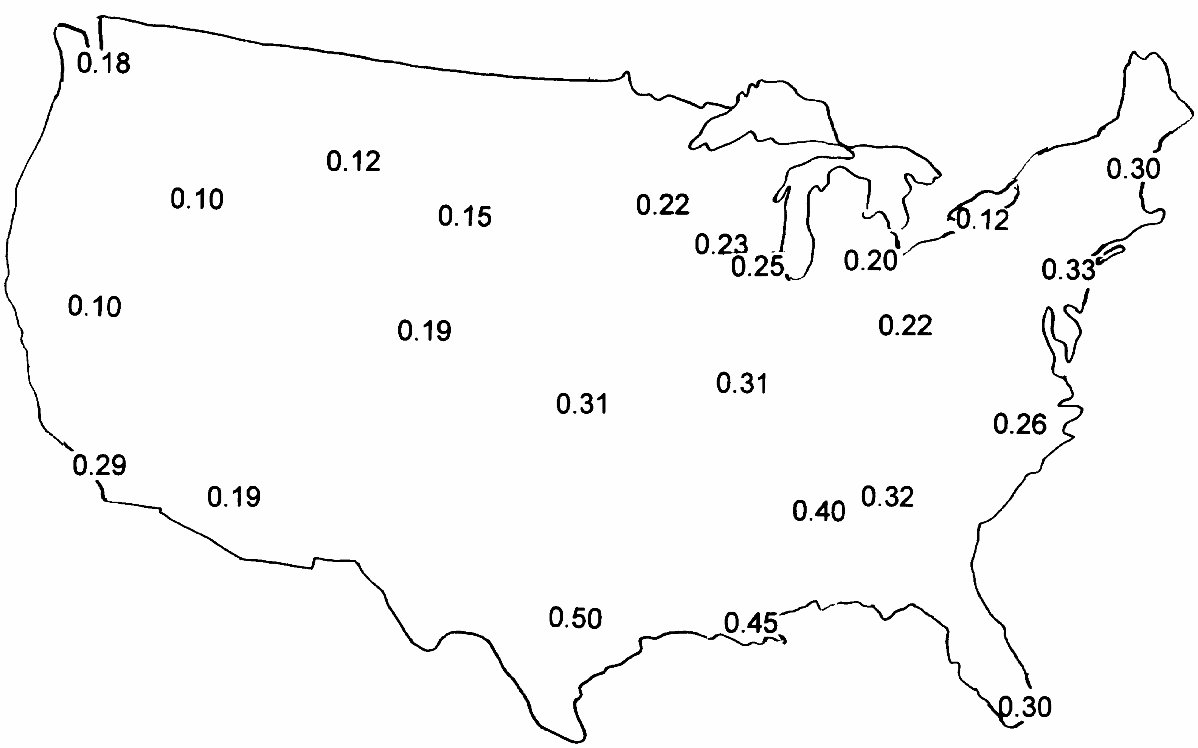


Figure 2-15. Lower breakpoint rain depth (in.).

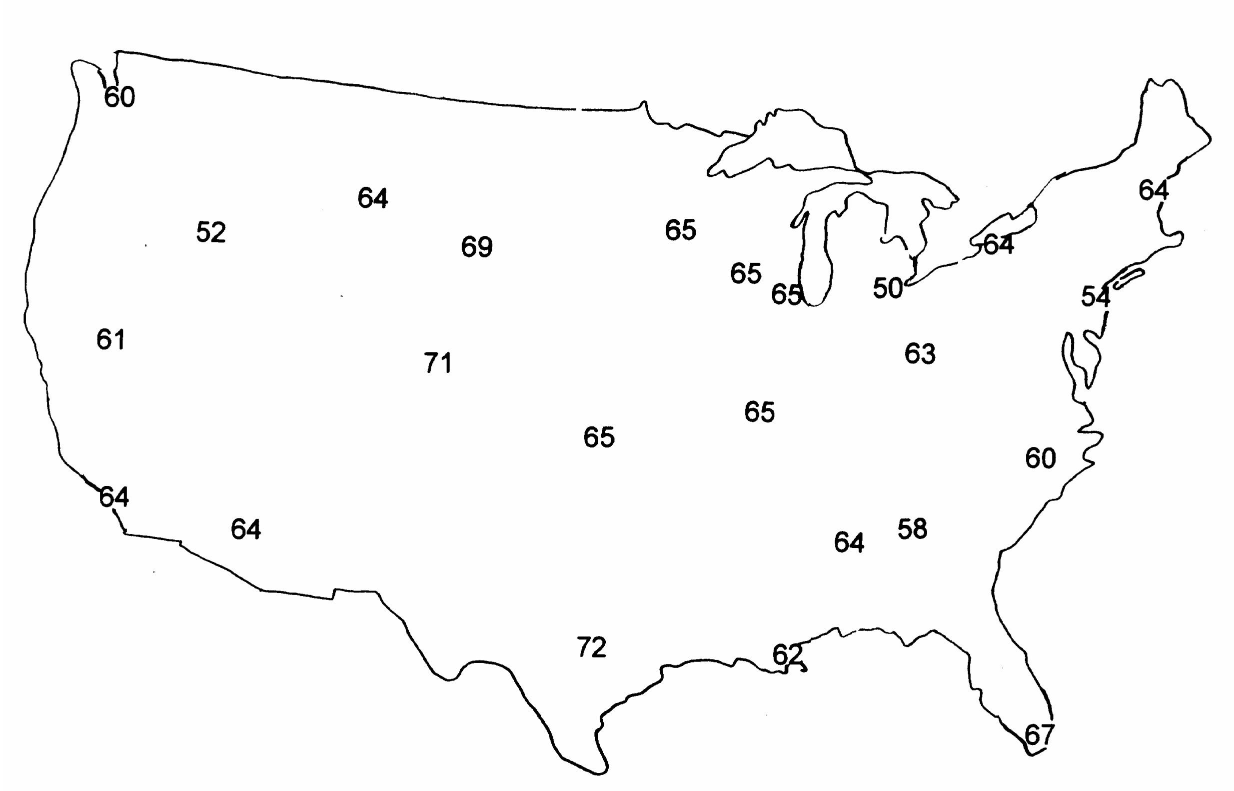


Figure 2-16. Percentage of rain events less than lower breakpoint.

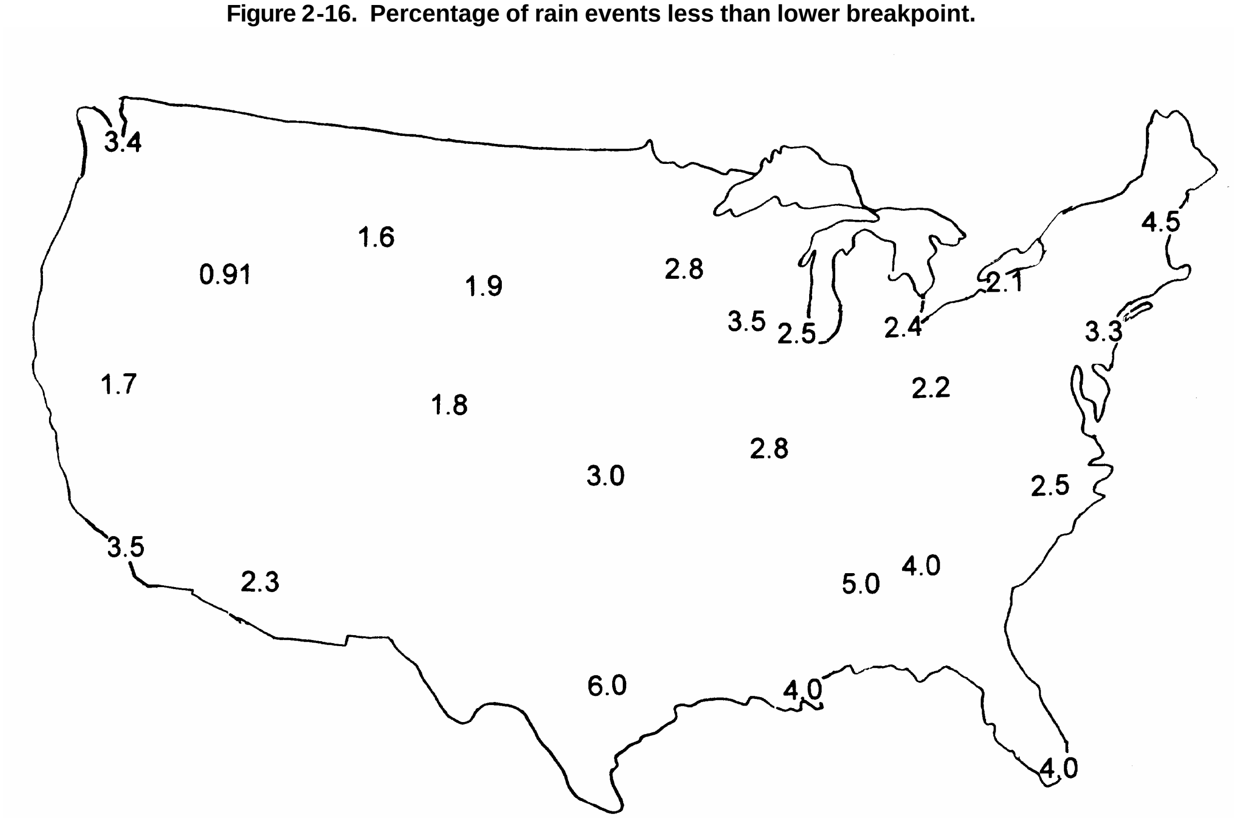


Figure 2-17. Upper breakpoint rain depth (in.).

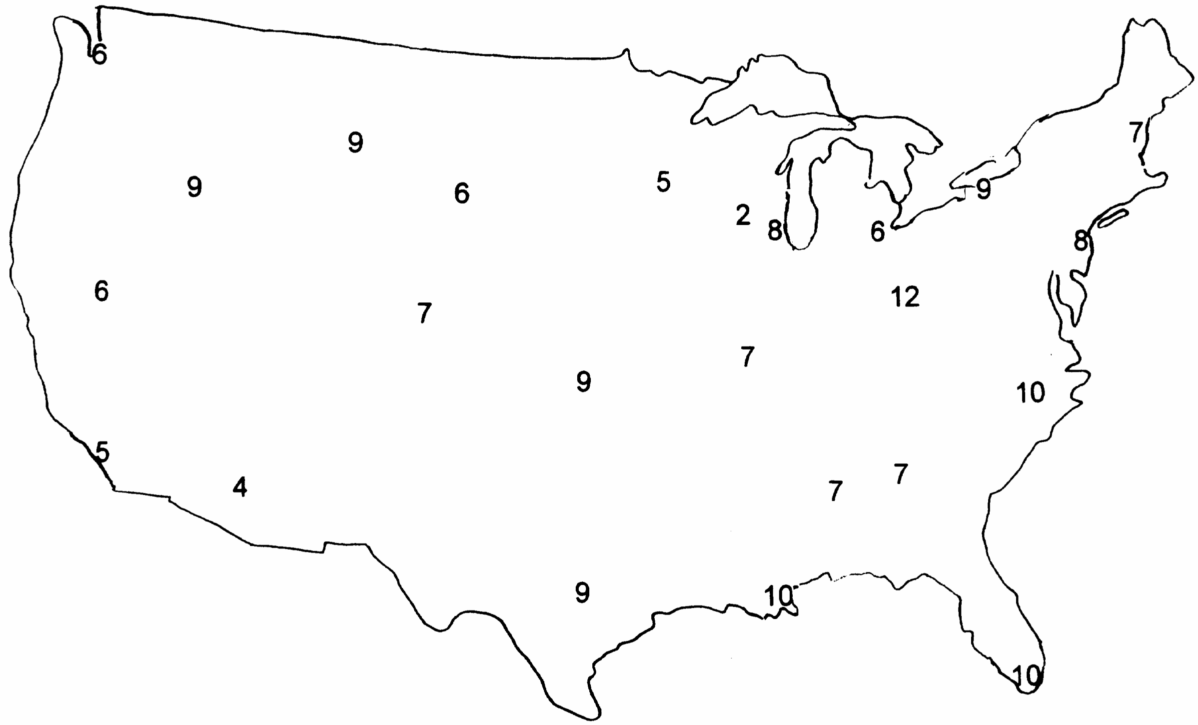


Figure 2-18. Percentage of runoff volume greater than upper breakpoint.

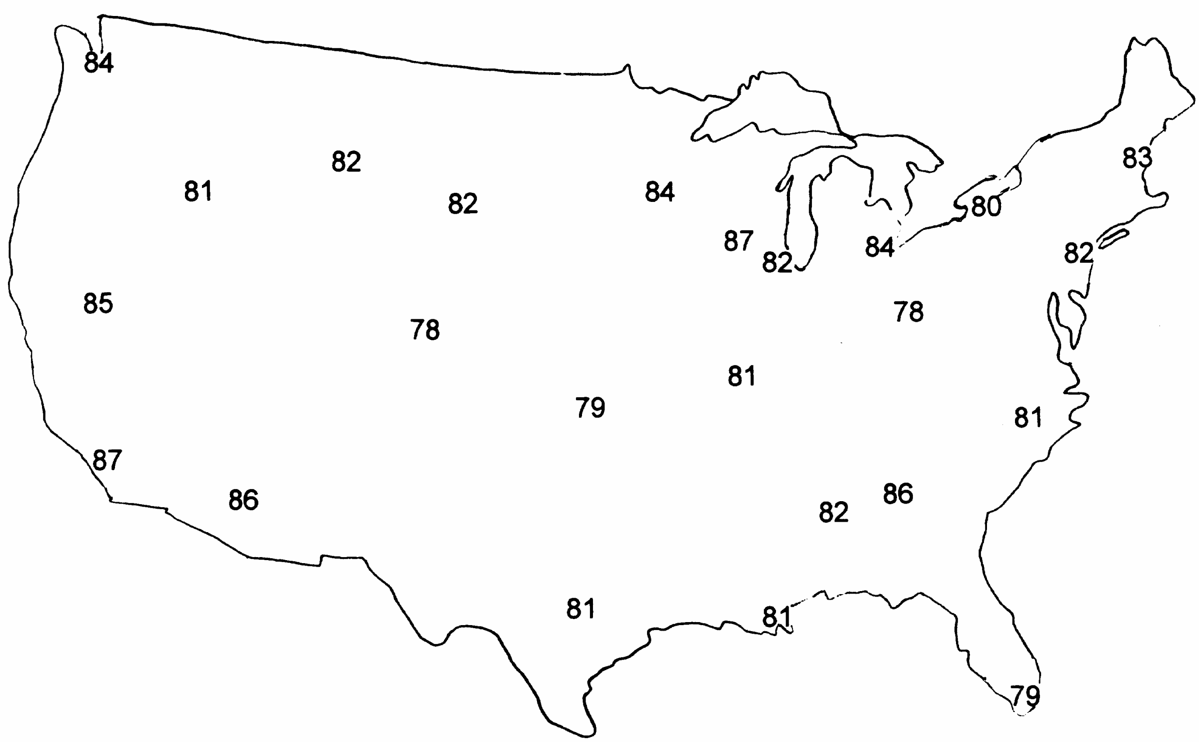
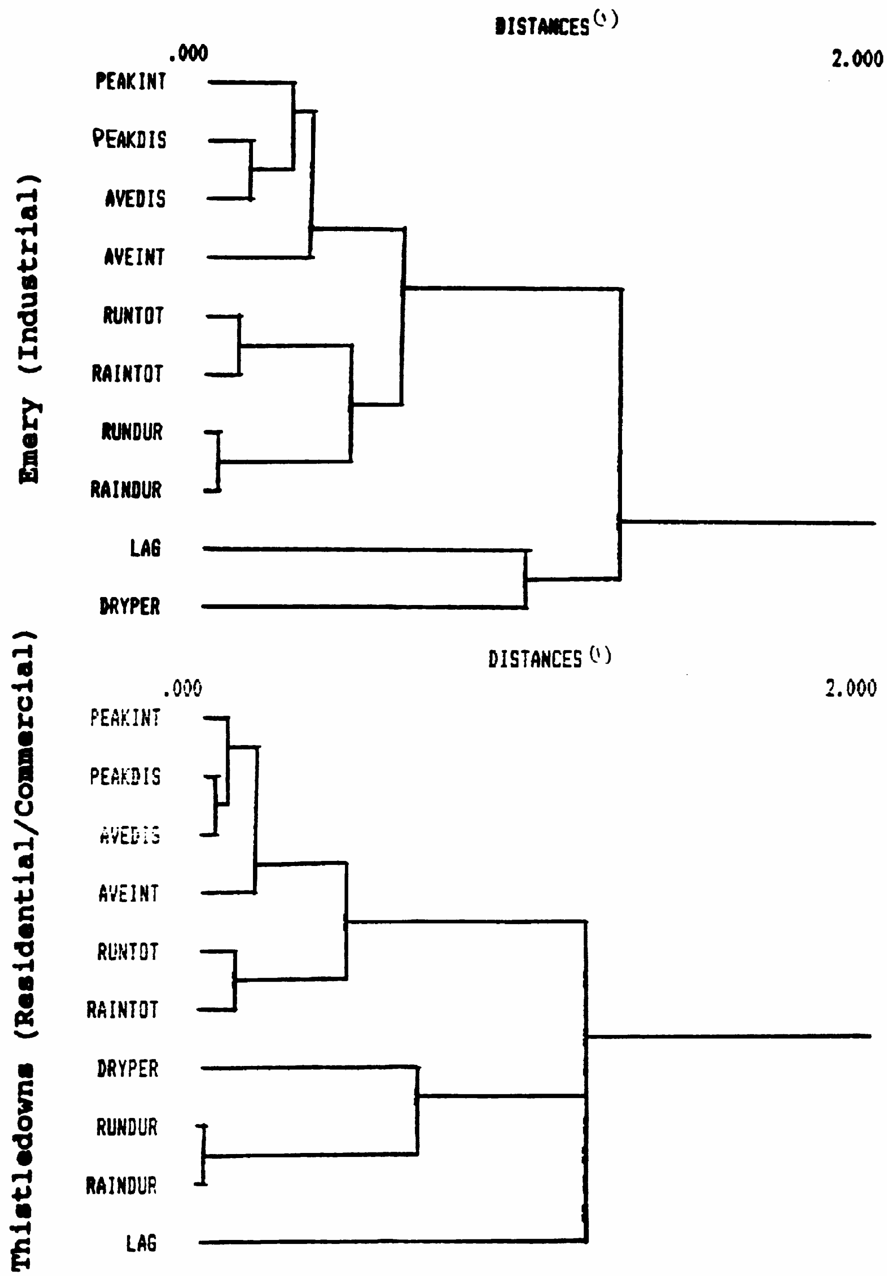


Figure 2-19. Percentage of runoff volume between breakpoints.



(1) Distance metric is 1-Pearson correlation coefficient (normalized) and the linkage method is nearest neighbor

Figure 2-20. Cluster analysis (dendogram) for basic urban hydrology structure (Pitt 1987).

Varying Contributing areas are Important in Urban Hydrology

Figure 2-21 shows the components of a hypothetical hydrograph for an urban area. For small rains, most of the runoff observed at the outfall originates from street surfaces and other directly connected impervious areas. However, as the rain depth increases, runoff from pervious areas become important. The critical problem is being able to predict when these component areas contribute significant runoff volumes (and pollutants). WinSLAMM (Pitt 1986 and 1992) was developed to enable predictions of runoff contributions (and source area controls), using a simplified urban hydrology approach appropriate for important small rains.

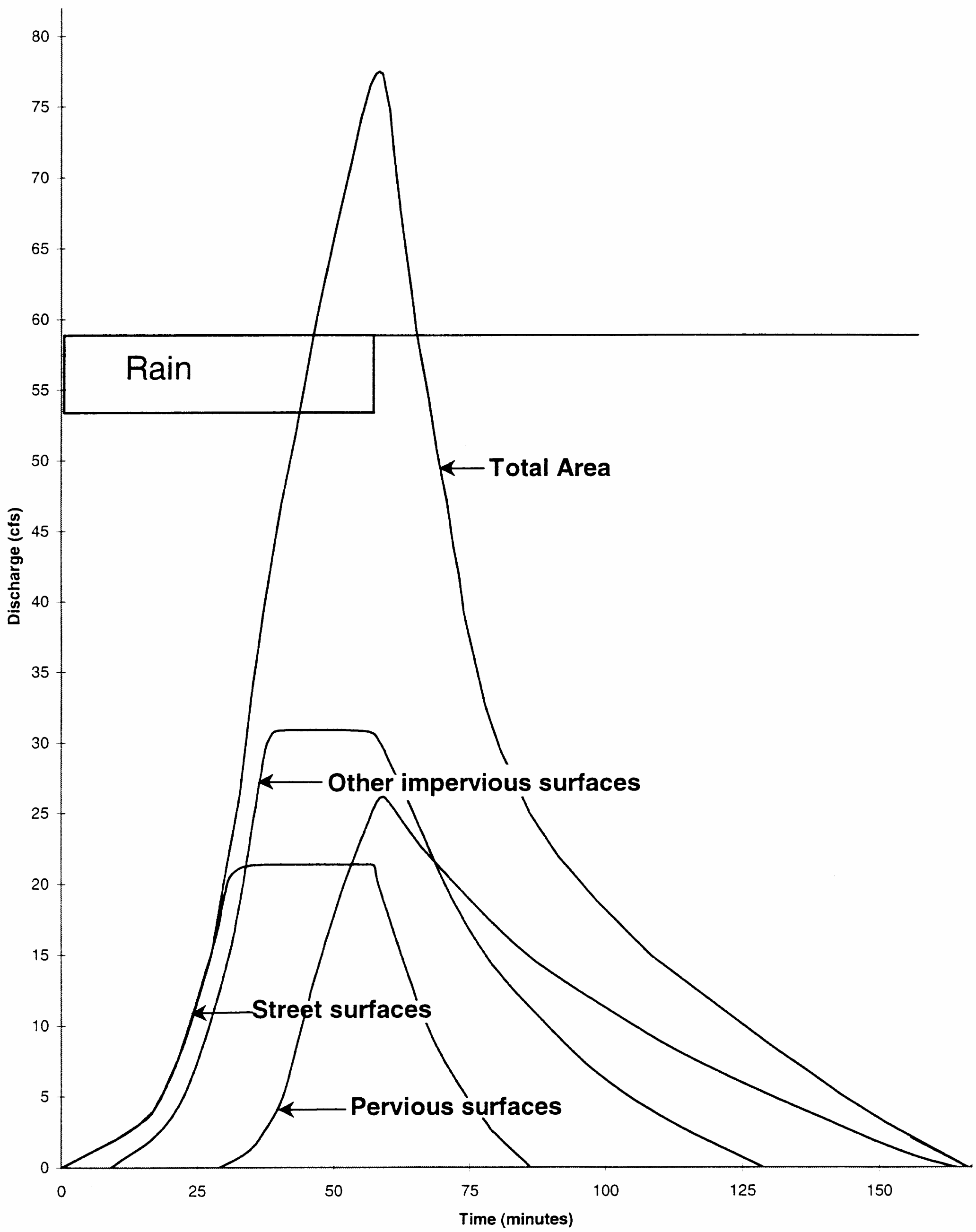


Figure 2-21. Variable contributing area unit hydrographs for urban site.

Observed Runoff Volumes Do Not Compare Well With Commonly Used Urban Runoff Prediction Methods
Some of the most commonly used stormwater design methods utilizes the NRCS curve number (CN) method, especially TR-20 and TR-55 (SCS 1986). The NRCS recommends against the use of the curve number procedure for rains less than one-half inch. Unfortunately, this warning is ignored in many urban runoff models that have been developed. As shown previously, small rains are very significant when analyzing urban runoff. In addition, the NRCS recommends that the curve number method should be used for individual components of the drainage area, if CN values differ by more than 5, instead of using a composite CN for the complete area. Unfortunately, many users of the CN method ignore these two basic warnings, and many urban stormwater models use composite CN values for all storms. The CN method is a suitable tool if properly used, unfortunately, it is frequently used for small storms and for water quality evaluations, well beyond its intended use addressing drainage design for conveyance objectives for large rains.

Figure 2-22a shows rainfall-runoff plots for eight monitored areas in Milwaukee. The curve is similar to the US. Natural Resources Conservation Service (NRCS) curve number (CN) rainfall-runoff plot contained in TR-55 (SCS 1986). This figure also shows the NRCS CN values calculated using actual P (precipitation) and Q (runoff quantity) data. CNs vary greatly with rain depth.

Figure 2-22b shows that CNs at the Milwaukee NURP monitored sites did not approach the published CN values for typical medium density residential areas until the rains were much greater than five inches. The Milwaukee high density land use areas can use published CN values for rains as small as two inches, while the Milwaukee commercial area CNs are correct when close to one inch.

Pitt, *et al*. 1999 shows numerous similar plots for other monitored locations from throughout the U.S., collected during the EPA's NURP projects in the early 1980s (EPA 1983), and from the EPA's rainfall-runoff-quality data base (Huber, *et al*. 1982). Figures 2-23 through 2-26 contain CN versus rain depth plots for many of these cities, including: 2 locations in Broward County, FL; 1 site in Dade County, FL; 2 sites in Salt Lake City, UT; and 2 sites in Seattle, WA (from the rainfall-runoff-quality data base), plus 4 sites in Champaign, IL; 5 sites in Irondequoit Bay, NY; 2 sites in Austin, TX; and 1 site in Rapid City, SD (from the NURP data). Figure 2-23 contains plots for areas with little urbanization, Figure 2-24 contains plots for medium density residential areas and mixed common urban areas, Figure 2-25 contains plots for high density and commercial areas, and Figure 2-26 contains plots for catchments having only major roadways. In all cases, the general pattern is the same: observed curve numbers are all very high for small rains, tapering off as the rains become large. All of the test watersheds are typical for these land uses and do not contain any unusual drainage designs or stormwater controls.

Table 2-2 is a summary of these observed curve numbers at several different rain depths, compared to typical curve numbers presented by the NRCS (SCS 1986) for these land uses. Several of the sites had adequate descriptions to enable curve numbers to be estimated, based on their directly connected impervious areas and soil texture. The following list shows these sites, with the NRCS recommended curve numbers, and the approximate rain depth where these curve numbers were observed:

- Broward Co., FL, residential land use (40% imperv., with sandy soils). NRCS CN = 61, observed at about 3.5 in. of rain.

- Champaign-Urbana, IL, single family residential land use (18% imperv., with silty, poorly drained soils). NRCS CN = 84, observed at about 1.2 in. of rain.

- Champaign-Urbana, IL, single family residential land use (19% imperv., with silty, poorly drained soils). NRCS CN = 84, observed at about 1.2 in. of rain.

- Dade Co., FL, high density residential land use (almost all impervious, "D" soils). NRCS CN = 92, observed at about 1.3 in. of rain.

Table 2-1. Rainfall and Runoff Distribution Characteristics for Different Locations from Throughout the U.S.

	Median rain depth, by count (in)	Corresponding percentage of runoff for the median rain depth	Rain depth associated with median runoff depth (in)	Lower breakpoint rain depth (in)	Percentage of rain events less than lower breakpoint	Percentage of runoff volume less than lower breakpoint	Upper breakpoint rain depth (in)	Percentage of rain events less than upper breakpoint	Percentage of runoff volume less than upper breakpoint	Percentage of runoff volume between breakpoints	Percentage of rain events between breakpoints
Columbia North Pacific											
Boise, ID	0.07	3 - 5	0.30 – 0.35	0.10	52	9 - 11	0.91	99	89 - 93	80 - 82	47
Seattle, WA	0.12	4 - 6	0.62 – 0.80	0.18	60	8 - 11	3.4	99	92 - 96	84 - 85	39
California											
Los Angeles, CA	0.18	3 - 5	1.2 – 1.5	0.29	64	7 - 10	3.5	99	92 - 98	85 - 88	35
Great Basin											
Reno, NV	0.07	3 - 5	0.35 – 0.41	0.10	61	8 - 10	1.7	99	93 - 95	85	38
Lower Colorado											
Phoenix, AZ	0.10	4 - 6	0.55 – 0.68	0.19	64	9 - 12	2.3	99	94 - 98	85 - 87	35
Missouri											
Billings, MT	0.06	2 - 4	0.55 – 0.60	0.12	64	8 - 10	1.6	99	89 - 93	81 - 83	35
Denver, CO	0.08	2 - 4	0.50 – 0.60	0.19	71	13 - 17	1.8	99	91 - 95	78	28
Rapid City, SD	0.06	2 - 4	0.50 – 0.55	0.15	69	10 - 13	1.9	99	92 - 96	82 - 83	30
Arkansas-White-Red											
Wichita, KS	0.13	2 - 5	1.1 – 1.4	0.31	65	10 - 13	3.0	99	88 - 93	78 - 80	34
Texas Gulf											
Austin, TX	0.14	2 – 3	1.4 – 1.8	0.50	72	8 - 12	6.0	99	88 - 94	80 - 82	27
Upper Mississippi											
Minneapolis, MN	0.11	3 - 5	0.73 – 1.0	0.22	65	9 - 13	2.8	99	94 - 96	83 - 85	34
Madison, WI	0.12	3 - 5	0.78 – 0.98	0.23	65	9 - 13	3.5	99	97 - 99	86 - 88	34
Milwaukee, WI	0.12	2 - 4	0.9 – 1.1	0.25	65	9 - 12	2.5	99	89 - 95	80 - 83	34
St. Louis, MO	0.14	4 - 6	1.0 – 1.2	0.31	65	10 - 13	2.8	99	90 - 95	80 - 82	34
Great Lakes											
Detroit, MI	0.20	7 - 11	0.72 – 0.81	0.20	50	7 - 11	2.4	99	92 - 95	85 - 84	49
Buffalo, NY	0.11	2 - 4	0.61 – 0.72	0.12	64	8 - 12	2.1	99	88 - 93	80 - 81	35
Ohio											
Columbus, OH	0.12	3 - 5	0.80 – 1.0	0.22	63	8 - 12	2.2	99	85 - 91	77 - 79	36
North Atlantic											
Portland, ME	0.15	2 - 4	1.1 – 1.5	0.30	64	8 - 12	4.5	99	90 - 96	82 - 84	35
Newark, NJ	0.28	6 - 12	1.2 – 1.5	0.33	54	8 - 12	3.3	99	89 - 94	81 - 82	45
Lower Mississippi											
New Orleans, LA	0.25	3 - 5	1.7 – 2.2	0.45	62	7 - 11	4.0	99	88 - 93	81 - 82	37
South Atlantic Gulf											
Atlanta, GA	0.22	3 – 5	1.2 – 1.7	0.32	58	5 – 9	4.0	99	91 – 95	86	41
Birmingham, AL	0.20	3 - 5	1.2 – 1.5	0.40	64	8 - 13	5.0	99	90 - 96	82 - 83	35
Raleigh, NC	0.18	4 - 6	1.0 – 1.2	0.26	60	7 - 11	2.5	99	87 - 93	80 - 82	39
Miami, FL	0.13	3 - 5	1.2 – 1.6	0.30	67	9 - 13	4.0	99	87 - 93	78 - 80	32

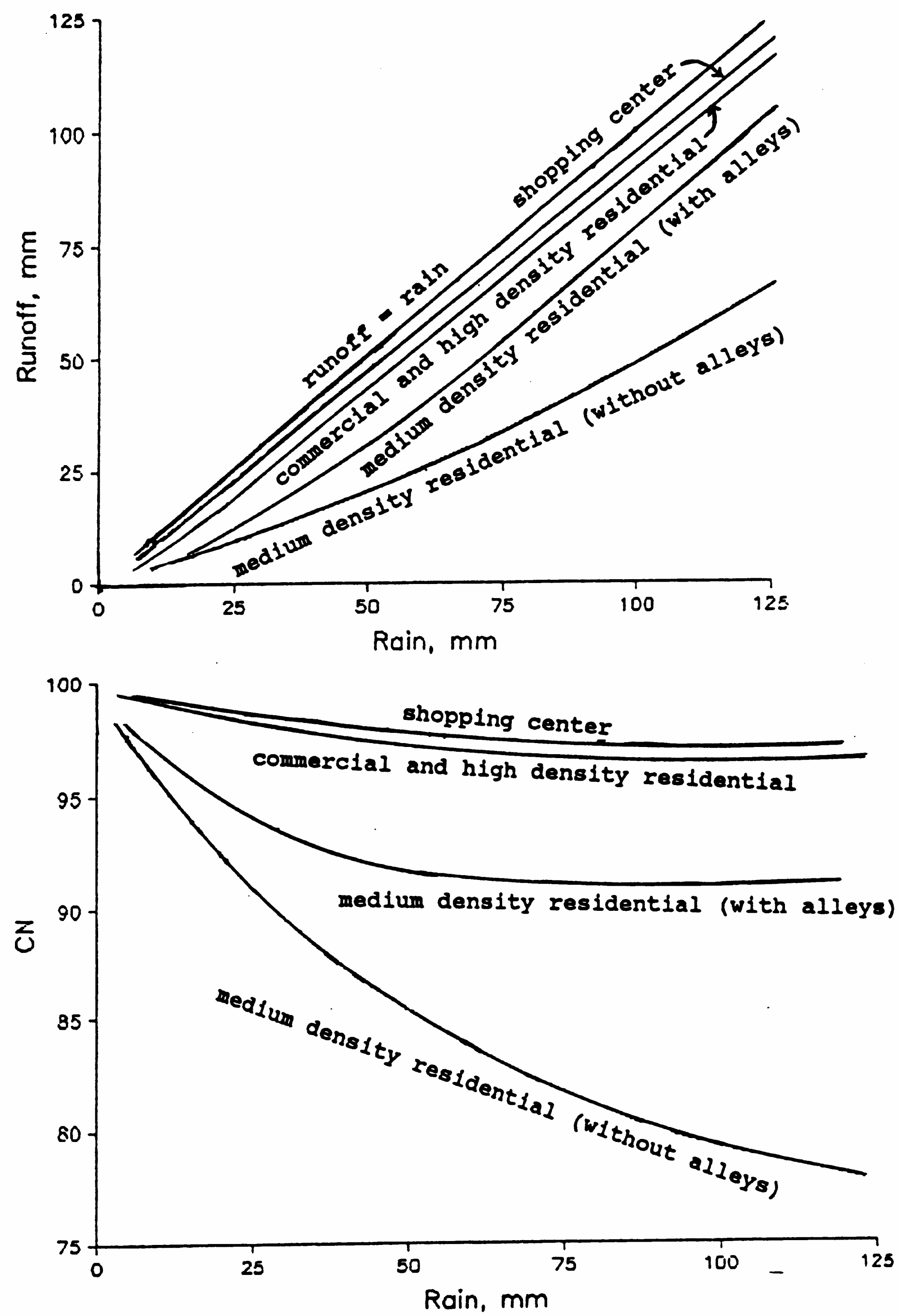


Figure 2-22. Observed rainfall-runoff and curve numbers for Milwaukee (Pitt 1987).

- Champaign-Urbana, IL, commercial land use (40% imperv., with silty and poorly drained soils). NRCS CN = 87, observed at about 1.1 in. of rain.

- Champaign-Urbana, IL, commercial land use (55% imperv., with silty and poorly drained soils). NRCS CN = 91, observed at about 0.8 in. of rain.

- Broward Co., FL, transportation catchment (54% imperv., with sandy soils). NRCS CN = 73, observed at about 1.7 in. of rain.

- Salt Lake City, UT, roadway land use (mostly paved, sandy loam). NRCS CN = 89, observed at about 0.3 in. of rain.

- Salt Lake City, UT, transportation catchment (imperv. Raods, clay loam). NRCS CN = 95, observed at about 0.15 in. of rain.

For the rains less than the matching point (rain depth where the NRCS recommended CN was observed), the actual CN is larger than the recommended CN and the predicted runoff using the NRCS methods would be less than actually occurred. Similarly, for rains larger than the matching point, the actual CN is smaller than the recommended CN and the predicted runoff using the NRCS CN method would be greater than actually occurred. The magnitude of the runoff differences varies greatly, depending on the CN values and the rain depth. As an example, if the recommended NRCS CN was 84, but the actual CN was really 98 for a 0.2 in. rain (similar to the Champaign, IL, medium density residential sites), the percentage error is infinite. For a 1 in. rain, the actual CN at this site was about 86 and the recommended NRCS value remains at 84. The difference now is much smaller, as the rain depth being examined is close to the matching point depth of 1.2 inches. If the rain depth of concern was much larger, say 3 inches, the errors would be in the other direction, as summarized below:

	0.2 in. rain (matching point of 1.2 in)	1 in. rain (matching point of 1.2 in)	3 in. rain (matching point of 1.2 in)
CN of 84 (recommended by NRCS)	0 in. of runoff predicted by NRCS	0.15 in. of runoff predicted by NRCS	1.52 in. of runoff predicted by NRCS
Actual CN and predicted runoff	0.10 in. of runoff observed (actual CN of 98)	0.20 in. of runoff observed (actual CN of 86)	0.91 in. of runoff observed (actual CN of 74)
	Actual is infinitely larger, predicted is infinitely less.	Actual is larger, predicted is less. Error of 25%.	Actual is less, predicted is larger. Error of –67%.

The overall annual runoff depth error associated with using the NRCS recommended CN method depends on the frequency of rains having the different errors. Because the matching point rainfall depths are close to the rain depth associated with the median runoff depth, as shown previously on 2-1, the annual errors may be within reason. However, the errors associated with individual events, and for the three classes of rain depths described earlier, are likely very large. This is a significant problem with stormwater quality management where accurate representations of the sources of the runoff are needed in order to evaluate control practices and development options. If the relative sources of the runoff flows are in great error, inappropriate and wasteful expenditures are likely.

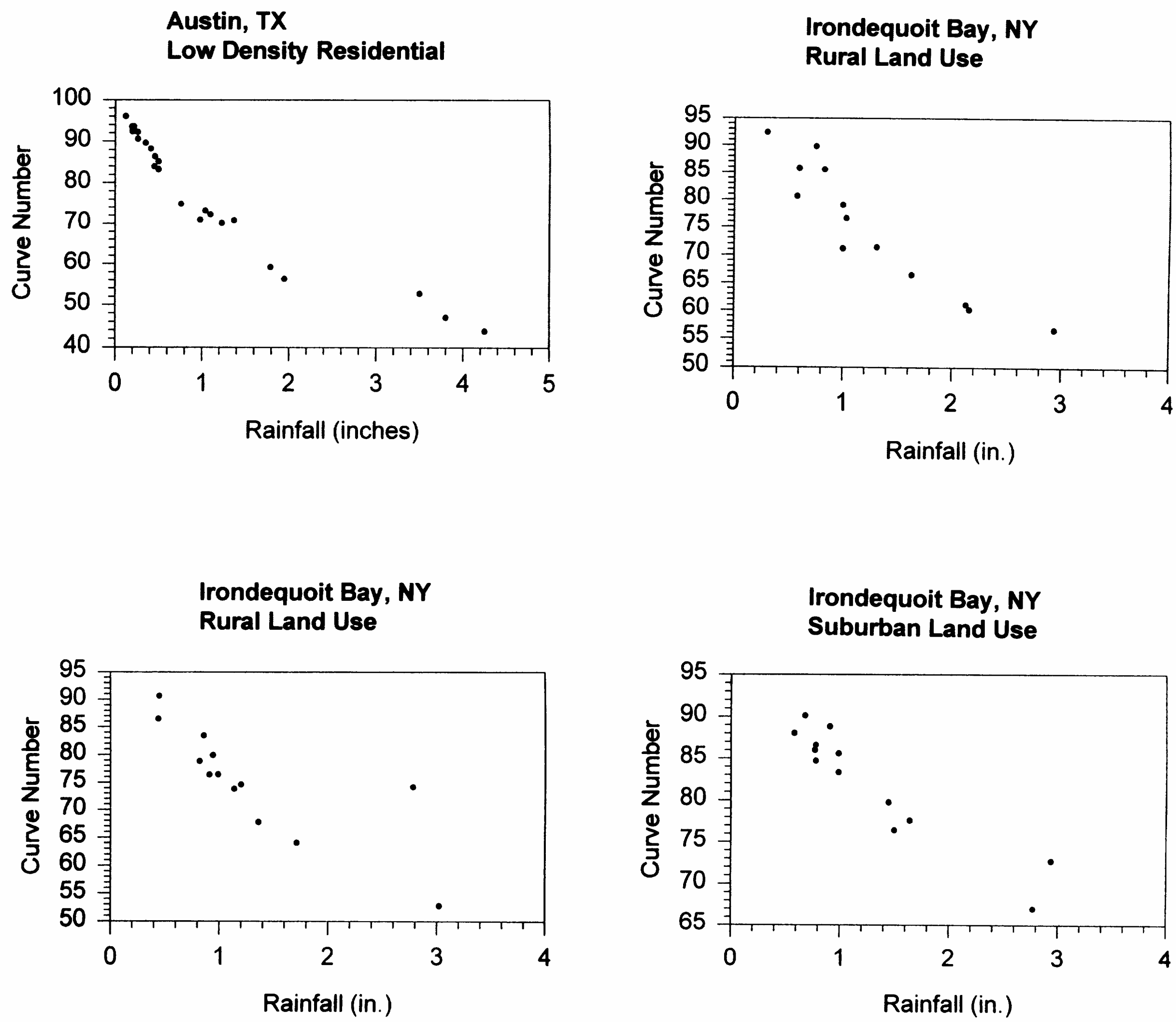


Figure 2-23. Low density development observed CN vs. rain depth plots.

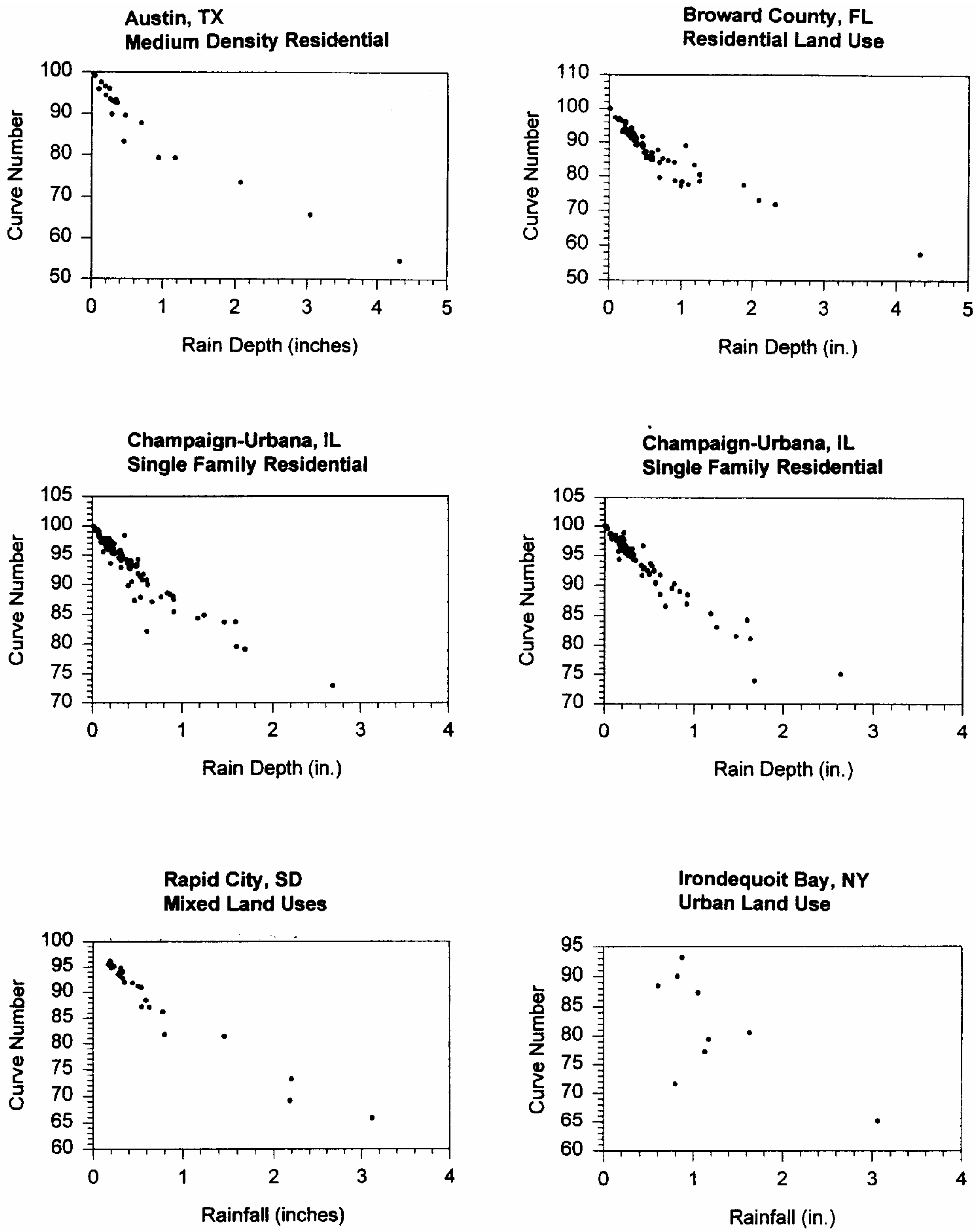


Figure 2-24. Medium density land use area observed CN vs. rain depth plots.

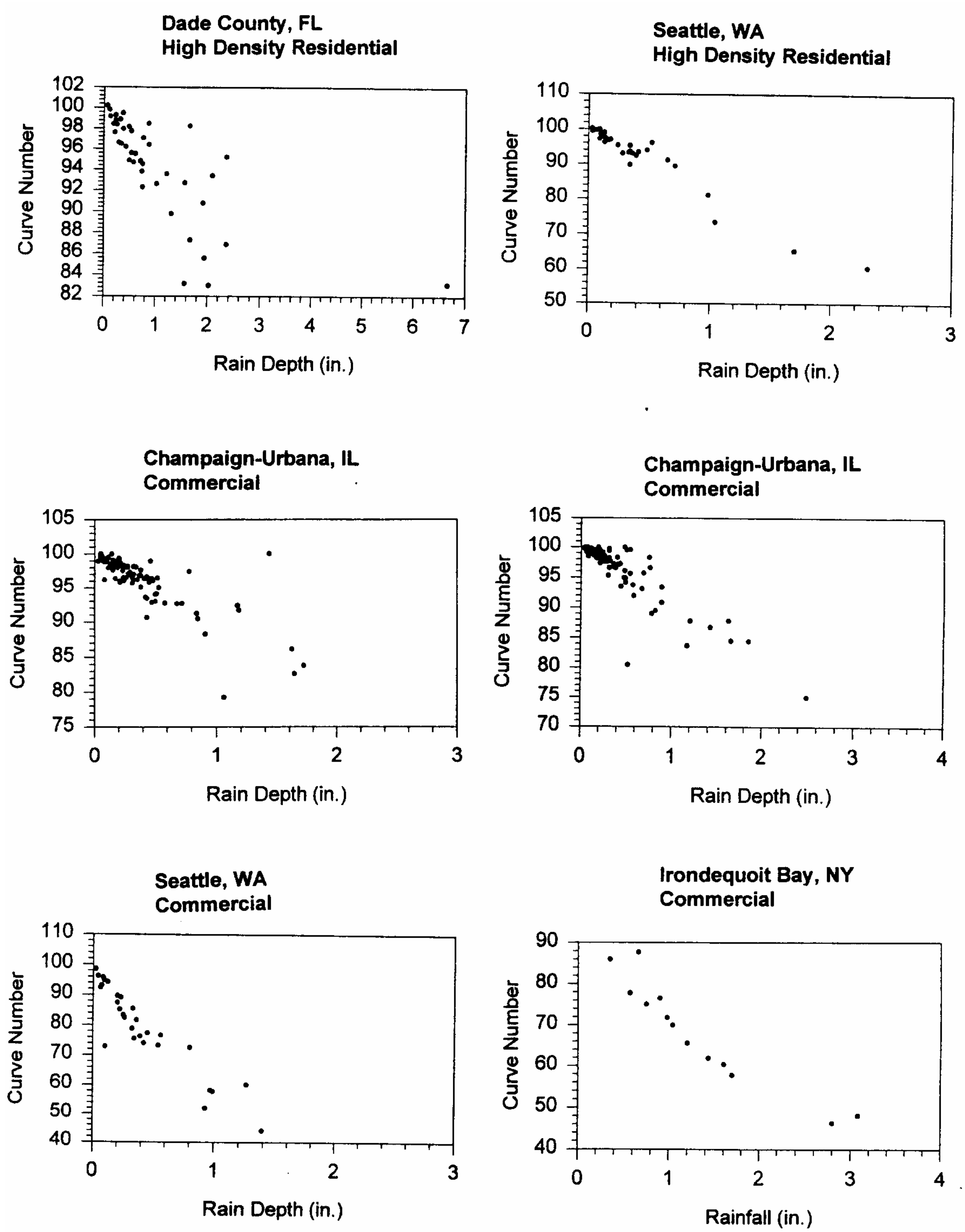


Figure 2-25. High density residential and commercial area observed CN vs. rain depth plots.

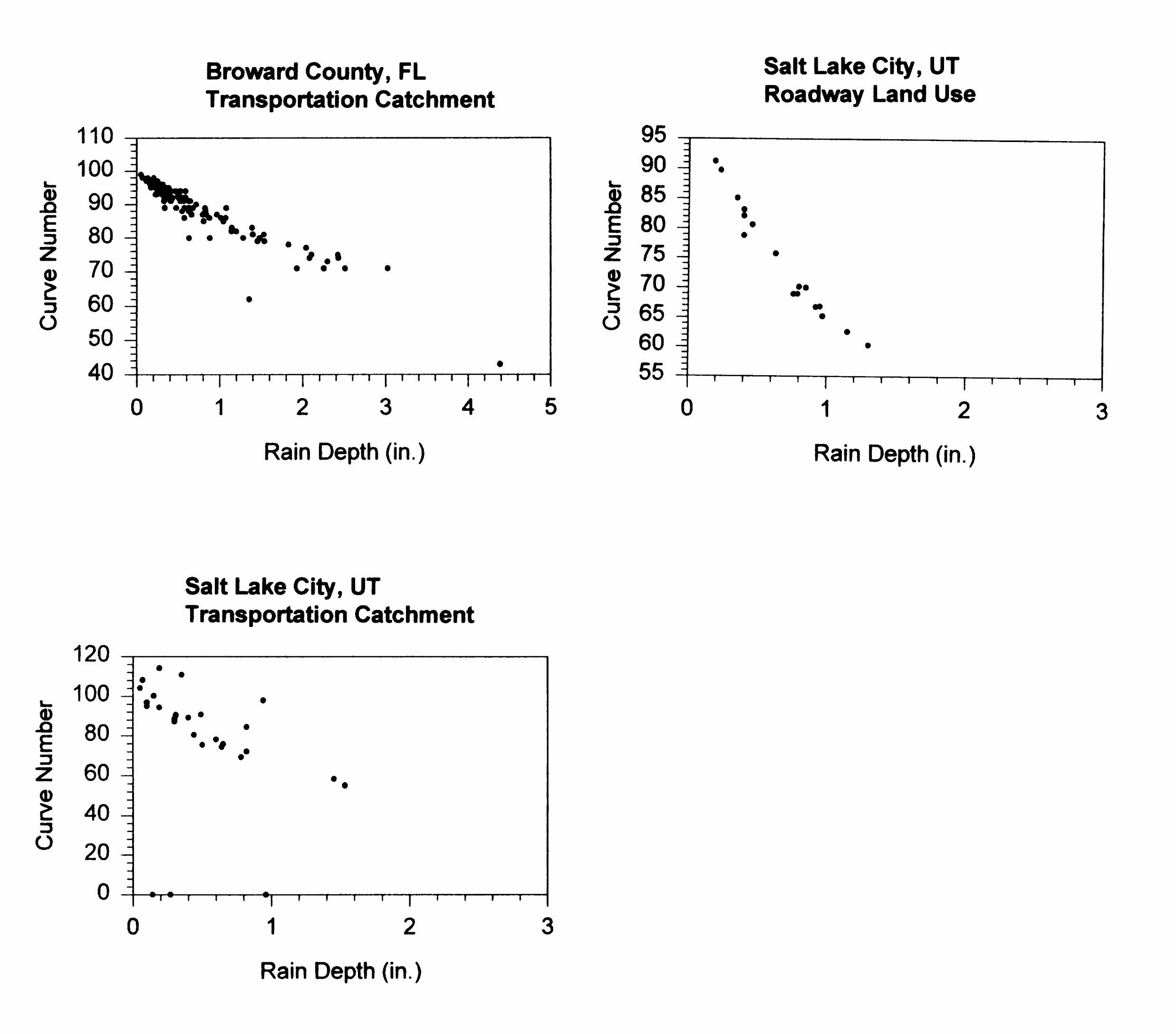


Figure 2-26. Transportation land use area observed CN vs. rain depth plots.

Table 2-2. Observed Curve Numbers Compared to Typically Used Values

Land Use and Location	Directly connected imperviousness	0.2 in. rain	0.5 in. rain	1 in. rain	3 in. rain	For max. rain observed	Estimated CN from NRCS tables for different soil conditions (if possible, most likely CN highlighted, based on available site description):			
Low Density/Suburban							A (sandy to sandy loam)	B (silt loam or loam)	C (sandy clay loam)	D (silty to clayey)
Austin, TX	21%	94	84	72	53	42 (5 in.)	51	68	79	84
Irondequoit Bay, NY	Rv = 0.1	95	88	76	55	52 (4 in.)	46	65	77	82
Irondequoit Bay, NY	Rv = 0.2	94	86	77	57	52 (4 in.)	51	68	79	84
Irondequoit Bay, NY	Rv = 0.2	94	89	84	69	67 (4 in.)	51	68	79	84
Medium Density Residential										
Austin, TX	39%	96	89	82	66	52 (5 in.)	61	75	83	87
Broward County, FL	40% (sandy soils)	96	89	81	65	54 (5 in.)	**61**	75	83	87
Champaign-Urbana, IL	18% (silty, poorly drained soils)	96	94	87	72	71 (4 in.)	51	68	79	**84**
Champaign-Urbana, IL	19 % (silty, poorly drained soils)	98	93	86	74	72 (4 in.)	51	68	79	**84**
Rapid City, SD	mixed	95	92	84	67	63 (4 in.)	?	?	?	?
High Density Residential										
Dade County, FL	"Almost all imperv." (D soils)	99	97	94	87	82 (7 in.)	77	85	90	**92**
Seattle, WA	?	94	89	80	56 (max.)		77	85	90	92
Commercial										
Champaign-Urbana	40% (silty, poorly drained soils)	97	95	89	81 (max.)		61	75	83	**87**
Champaign-Urbana	55% (silty, poorly drained soils)	99	95	89	74	73 (4 in.)	73	82	88	**91**
Seattle, WA	?	90	76	61	44 (max.)		?	?	?	?
Irondequoit Bay, NY	?	92	82	72	46	46 (4 in.)	?	?	?	?
Transportation										
Broward County, FL	54% (sandy soils)	96	93	86	62	53 (5 in.)	**73**	82	88	91
Salt Lake City, UT	Mostly paved (sandy loam)	91	81	67	na	na	**89**	92	94	95
Salt Lake City, UT	"imperv. roads" (clay loam)	95	84	73	na	na	89	92	94	**95**

Actual Volumetric Runoff Coefficients (Rv) Vary With Storm Size.
Figure 2-27 shows how the volumetric runoff coefficients (the ratio of runoff depth to rainfall depth) change with rain depth. After subtracting initial abstractions, continuous losses can be assumed to be mostly infiltration. After a sufficient amount of rain has occurred, all losses have been satisfied. Each unit increase in rain then results in a unit increase in runoff volume.

Small rain depths result in runoff that have small Rv values. As the rain depth increases, the Rv increases. Rv values are only "constant" over a small range in rain depths. During many urban runoff monitoring projects, only small ranges of rains are typically represented. Therefore, "averaged" Rv values are incorrectly used with the understanding that they are useful over a wider range than justified. The NURP data was collected in the early 1980s, while the rainfall-runoff-quality data base information was collected much earlier. There was significant variation in the accuracies of monitoring rainfall and runoff for the different locations. This is most evident at test sites having large amounts of directly connected pavement. Many of the measured runoff events had greater runoff volumes than the measured rainfall volumes (Rv values greater than 1.0 and calculated CN values greater than 100). This of course cannot occur in the absence of other flow sources and was likely associated with random measurement errors. The best measurements were probably made with errors approaching 25%, while some test sites used newly available equipment and errors may have been greater. These errors are much more obvious at high density and commercial sites than at the more commonly monitored medium density residential sites.

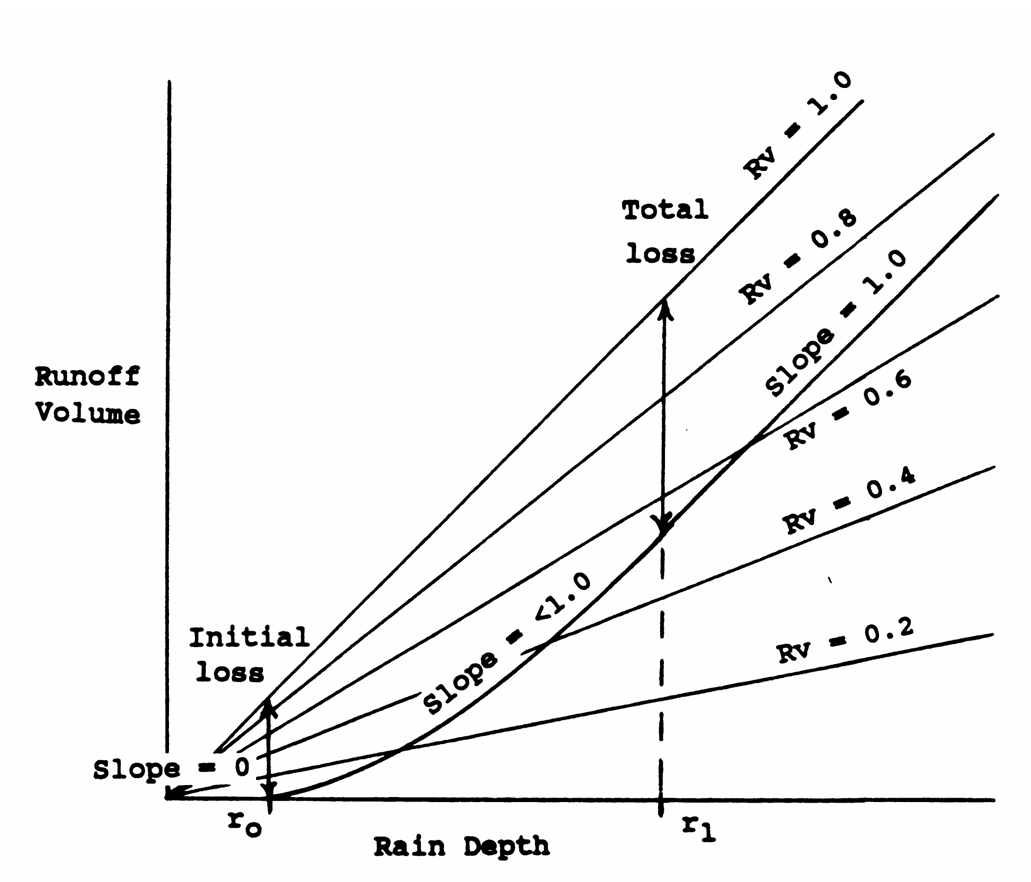


Figure 2-27. Rainfall-runoff plot showing losses and Rv values (Pitt 1987).

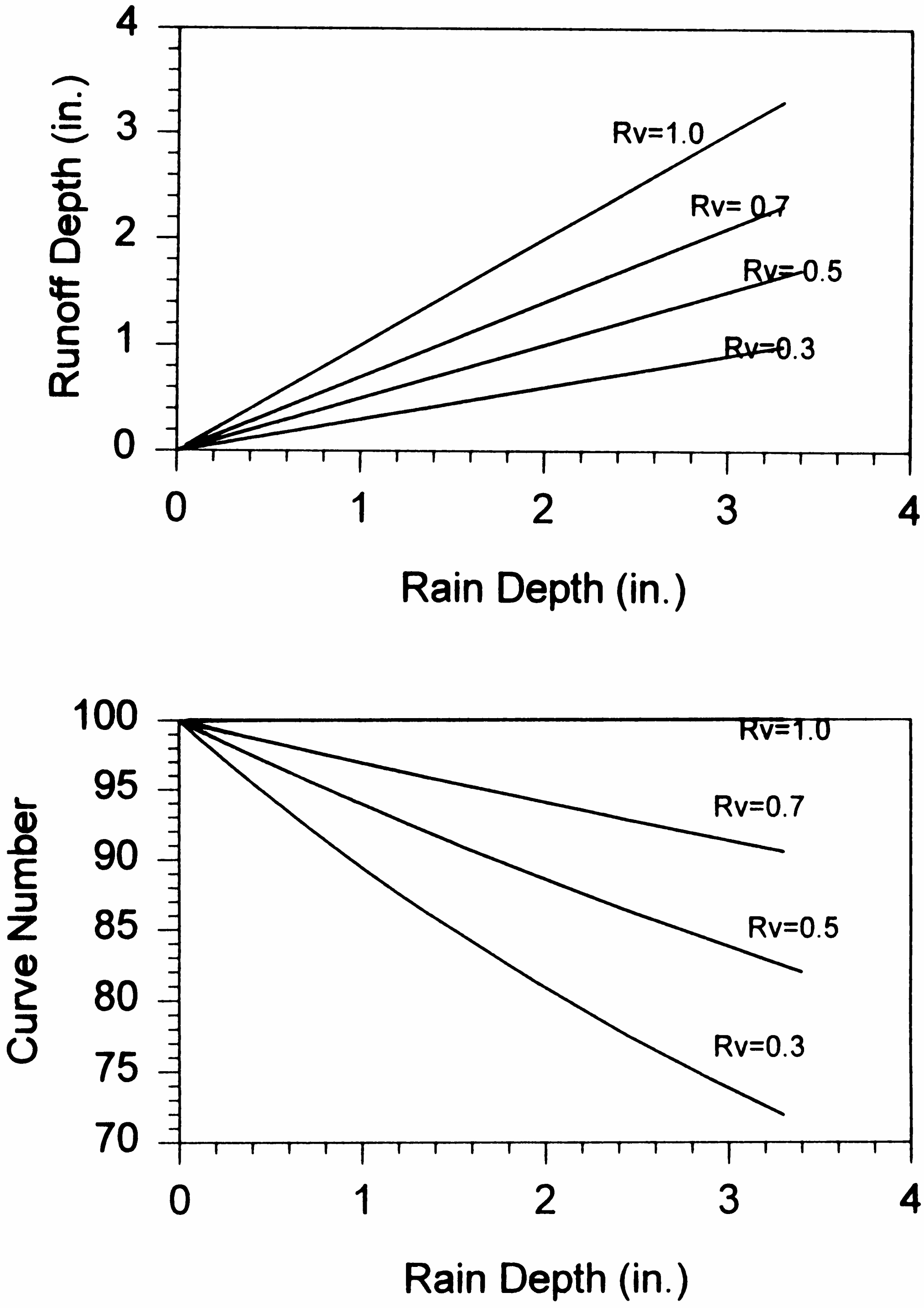


Figure 2-28. Idealized plots of Rv and CN values.

Figure 2-28 shows a plot of runoff depth versus rain depth and another plot of the NRCS CN versus rain depth for a set of artificial rain and runoff data. These plots were prepared to visually show the relationship between Rv and NRCS CN values. If the data has relatively constant Rv values for all rains, the CN plots will naturally decrease substantially with increasing rain depth (again, as indicated in almost all of the measured data). It is interesting to note that the calculated NRCS CN is always very close to 100 for very small rain and runoff values, irrespective of the Rv ratio. The Rv values likely increase with increasing rain depth, which is evident if the observations can be obtained with small measurement errors and if the range of rains observed is large. Flow and rainfall measurement errors are much more obvious on the Rv plots, especially for the small rains, than on the CN plots.

Small Storm Hydrology Model

Runoff Process for Paved Surfaces

When rain falls on an impervious surface, much of it will flow off the surface and contribute to the total urban runoff. With the exception of infiltration, these losses are mostly associated with the initial portions of the rain and are termed initial abstractions. Water may also infiltrate through pavement, or through cracks or seams in the pavement. For small rains, a much greater portion of the rain will be lost to these runoff loss processes than for large rains.

Paved surfaces are usually considered impervious, implying no infiltration. However, some researchers have concluded that paved surfaces do indeed experience infiltration losses. Falk and Niemczynowicz (1978) found that smooth paved surfaces had lower infiltration losses, compared to poorly maintained surfaces which had losses of about 7 percent of the total rain. Pratt and Henderson (1981) were asked after their presentation at the *Second International Conference on Urban Storm Drainage* if the variation of the runoff coefficient that they observed for pavement could be due to infiltration through the surface which is commonly considered to be zero. They agreed that this variation was likely due to the difference in the permeability of the “impervious” catchment surfaces. They found that gaps between concrete sections in the curbs and gutters were the principal means of runoff losses. Willeke (1966) found that cracks in gutters could allow significant amounts of water to infiltrate, especially if sandy soils underlaid concrete. Davies and Hollis (1981) found an average runoff loss from a paved road surface to be about 85 percent of the rain depth. This loss was considered about evenly divided between detention storage and infiltration through the pavement, especially through cracks in the gutter. Cedergren (1974) measured infiltration rates through typical “sealed” seams of about 20 mm per hour (with pavement seams located about every 8 meters).

Infiltration of Rain Water Through Pavement Can be a Substantial Portion of the Total Rain for Most Events
Initial abstractions are dependent of pavement texture and slope, while infiltration is dependent on pavement porosity and pavement cracks. Pavement is relatively porous. It is the pavement base course that is much more resistant to percolation. Infiltrated water is therefore forced to flow laterally towards the pavement edges. If the flow path is long, then the resulting infiltration is limited. Figure 2-29 is an example from a typical pavement runoff test (Pitt 1987). Initial abstractions may be about 1 mm for pavement, while the total infiltration may be between 5 and 10 mm. The maximum losses may occur after about 20 mm of rain.

Variable Runoff Losses as a Function of Time Indicate Very Different Infiltration Values for Different Rain Intensities
Figure 2-30a shows that high infiltration rates are associated with high rainfall intensities (Pitt 1987). The Horton equation predicts a single infiltration relationship as a function of time, irrespective of rain intensity. When variable runoff losses are plotted against total rain depth (Figure 2-30b) a single relationship is seen (rain intensity multiplied by time duration gives rain depth). Horton actually recommended infiltration as a function of rain depth, but current practice of using double-ring infiltrometers to calibrate the Horton equation does not allow infiltration measurements to be made as a function of rain depth, only as a function of time for the ponded test conditions.

Infiltration in Disturbed Urban Soils

Disturbed Urban Soils Do Not Behave as Indicated by Typically Used Models

More rain infiltrates through pavement surfaces and less rain infiltrates through soils than typically assumed. Double-ring infiltrometer test results from Oconomowoc, WI, urban soils (Table 2-3) indicated highly variable infiltration rates for soils that were generally sandy (NRCS A/B hydrologic group soils). The median initial rate was about 3 in/hr, but ranged from 0 to 25 in/hr. The final rates also had a median value of about 3 in/hr after at least two hours of testing, but ranged from 0 to 15 in/hr. Many infiltration rates actually increased with time during these tests. In about 1/3 of the cases, the observed infiltration rates remained very close to zero, even for these sandy soils. Areas that experienced substantial disturbances or traffic (such as school playing fields) had the lowest infiltration rates, typically even lower than concrete or asphalt! These values indicate the large variability in infiltration rates that may occur in areas having supposedly similar soils. Obviously, these variations can significantly affect site specific runoff predictions. The lowest infiltration rates were observed in areas having heavy foot traffic and in areas obviously impacted by silt, while the highest rates were in relatively undisturbed areas.

Table 2-3. Ranked Oconomowoc, WI, Double Ring Infiltration Test Results

	Observed urban soil Infiltration rates (in/hr):	
Initial Rate	**Final Rate (after 2 hours)**	**Total Observed Rate Range**
25	15	11 to 25
22	17	17 to 24
14.7	9.4	9.4 to 17
5.8	9.4	0.2 to 9.4
5.7	9.4	5.1 to 9.6
4.7	3.6	3.1 to 6.3
4.1	6.8	2.9 to 6.8
3.1	3.3	2.4 to 3.8
2.6	2.5	1.6 to 2.6
0.3	0.1	<0.1 to 0.3
0.3	1.7	0.3 to 3.2
0.2	<0.1	<0.1 to 0.2
<0.1	0.6	<0.1 to 0.6
<0.1	<0.1	all <0.1
<0.1	<0.1	all <0.1
<0.1	<0.1	all <0.1

In an attempt to explain much of the variation shown in the above early tests, recent tests of infiltration through disturbed urban soils were conducted in the Birmingham, AL, area by the author and UAB students. Eight categories of soils were tested, with about 15 to 20 individual tests conducted in each of eight categories (comprising a full factorial experiment). Numerous replicates were needed in each category because of the expected high variation in infiltration rates. The eight categories tested were as follows:

Category	**Soil Texture**	**Compaction**	**Moisture**
1	Sand	Compact	Saturated
2	Sand	Compact	Dry
3	Sand	Non-compact	Saturated
4	Sand	Non-compact	Dry
5	Clay	Compact	Saturated
6	Clay	Compact	Dry
7	Clay	Non-compact	Saturated
8	Clay	Non-compact	Dry

Figure 2-31 contains plots showing the interactions of moisture and compaction on infiltration for both soil texture conditions. Four general conditions were observed to be statistically unique:

- noncompact sandy soils
- compact sandy soils
- noncompact and dry clayey soils
- all other clayey soils

Compaction has the greatest effect on infiltration rates in sandy soils, with little detrimental effects associated with soil moisture. Clay soils, however, are affected by both compaction and moisture. Compaction is seen to have about the same effect as moisture on these soils, with saturated and compacted clayey soils having very little effective infiltration. In most cases, the mapped soils were similar to what was actually measured in the field. However, significant differences were found at many of the 146 test locations. Table 2-4 shows that the 2-hour averaged infiltration rates and their COVs in each of the four major categories were about 0.5 to 2. Although these COV values are generally high, they are much less than if compaction was ignored. These data are being fitted to conventional infiltration models, but the high variations within each of the four main categories makes it difficult to identify legitimate patterns, implying that average infiltration rates within each event may be most suitable for predictive purposes. The remaining uncertainty can be considered using Monte Carlo components in runoff models. More detailed analyses of these data will be presented in the Toronto stormwater modeling conference next year.

Table 2-4. Infiltration Rates for Different Soil Texture, Moisture, and Compaction Conditions

	Number of tests	Average infiltration rate (in/hr)	COV
noncompact sandy soils	29	17	0.43
compact sandy soils	39	2.7	1.8
noncompact and dry clayey soils	18	8.8	1.1
all other clayey soils	60	0.69	2.1

Very large errors in soil infiltration rates can easily be made if published soil maps and typical models are used for typically disturbed urban soils. Knowledge of compaction (which can be mapped using a cone pentrometer, or estimated based on expected activity on grassed areas) can be used to much more accurately predict stormwater runoff quantity.

Basic Characteristics of the Small Storm Hydrology Model

Figure 2-29 earlier showed the small storm hydrology model which describes the shape of the relationship between rainfall and runoff. Both small-scale and large-scale tests, described by Pitt (1987), obtained data to calibrate and verify this model for homogeneous impervious and pervious areas. The runoff response curve shown on Figure 2-29 departs from the x-axis at the rainfall depth when runoff begins (r_0). This depth lag corresponds to initial runoff losses. After some rain depth (r_1), runoff losses become insignificant. For impervious areas, this is when the detention storage volume becomes filled, evaporation becomes insignificant due to pavement cooling, infiltration through the pavement or through cracks slows practically to nothing, and dirt and debris become saturated. Between these two rain depths, infiltration losses occur.

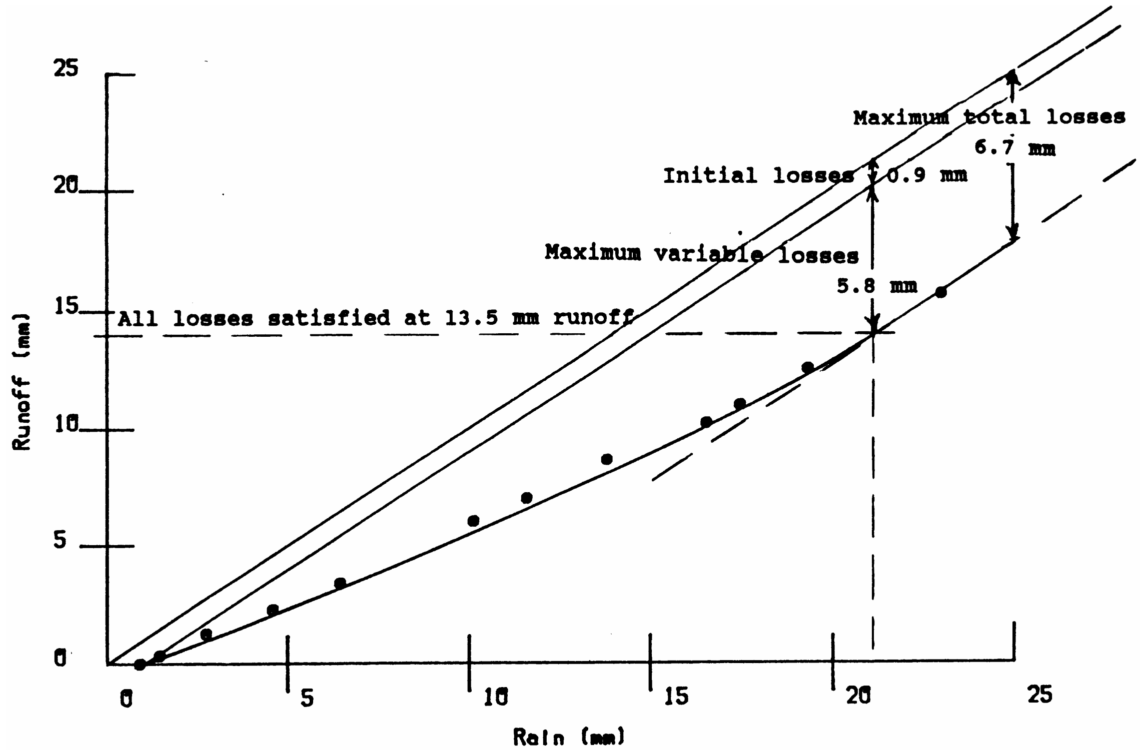


Figure 2-29. Example pavement test runoff-rainfall plot for high intensity rains, clean and rough streets (Pitt 1987).

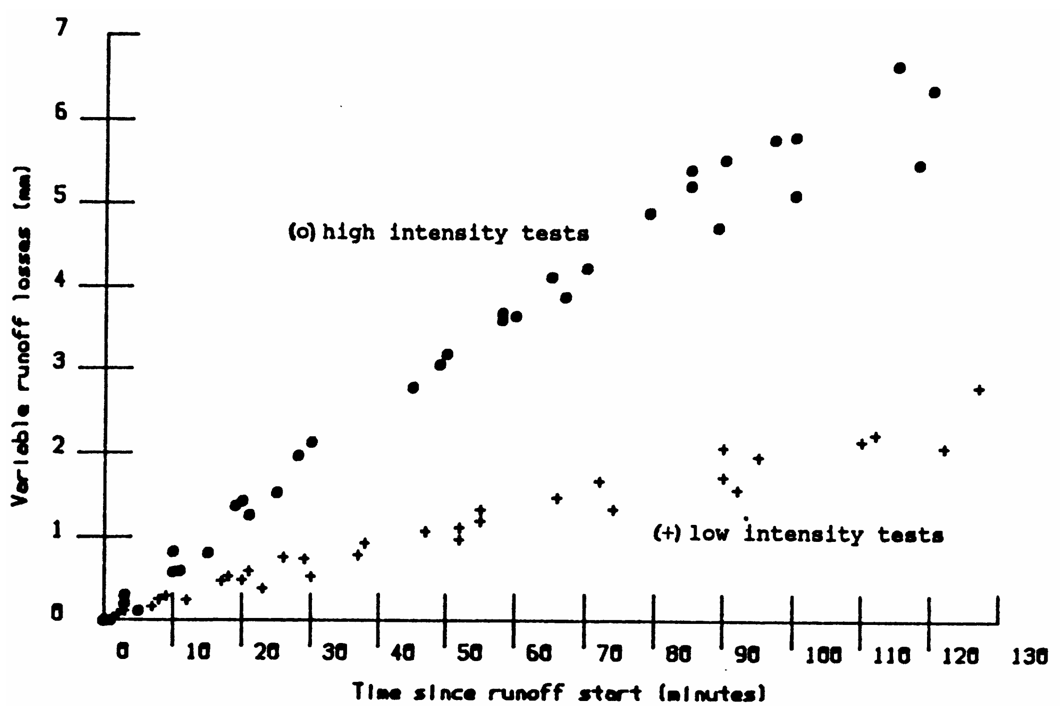


Figure 2-30a. Pavement infiltration rates for time since start of rain (Pitt 1987).

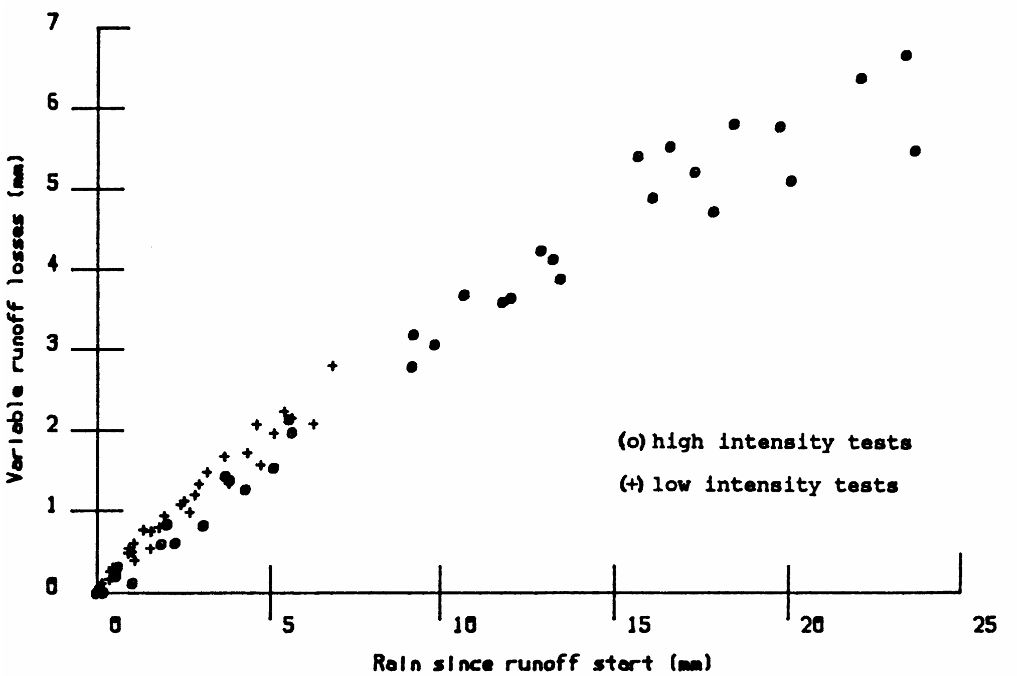


Figure 2-30b. Pavement infiltration rates for rain depth since start of rain (Pitt 1987).

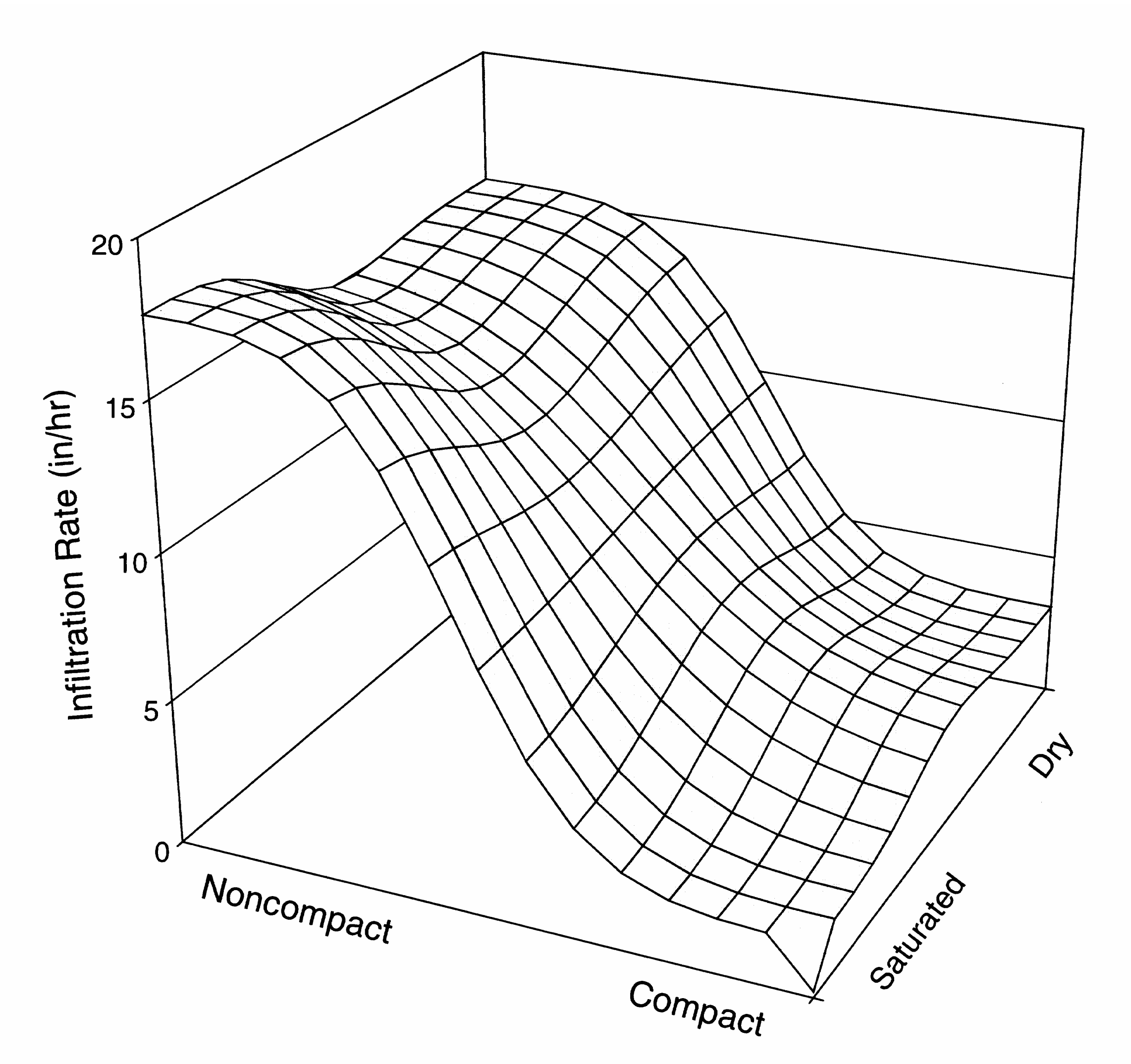


Figure 2-31. 3-D plots showing interactions affecting infiltration rates in sandy soils.

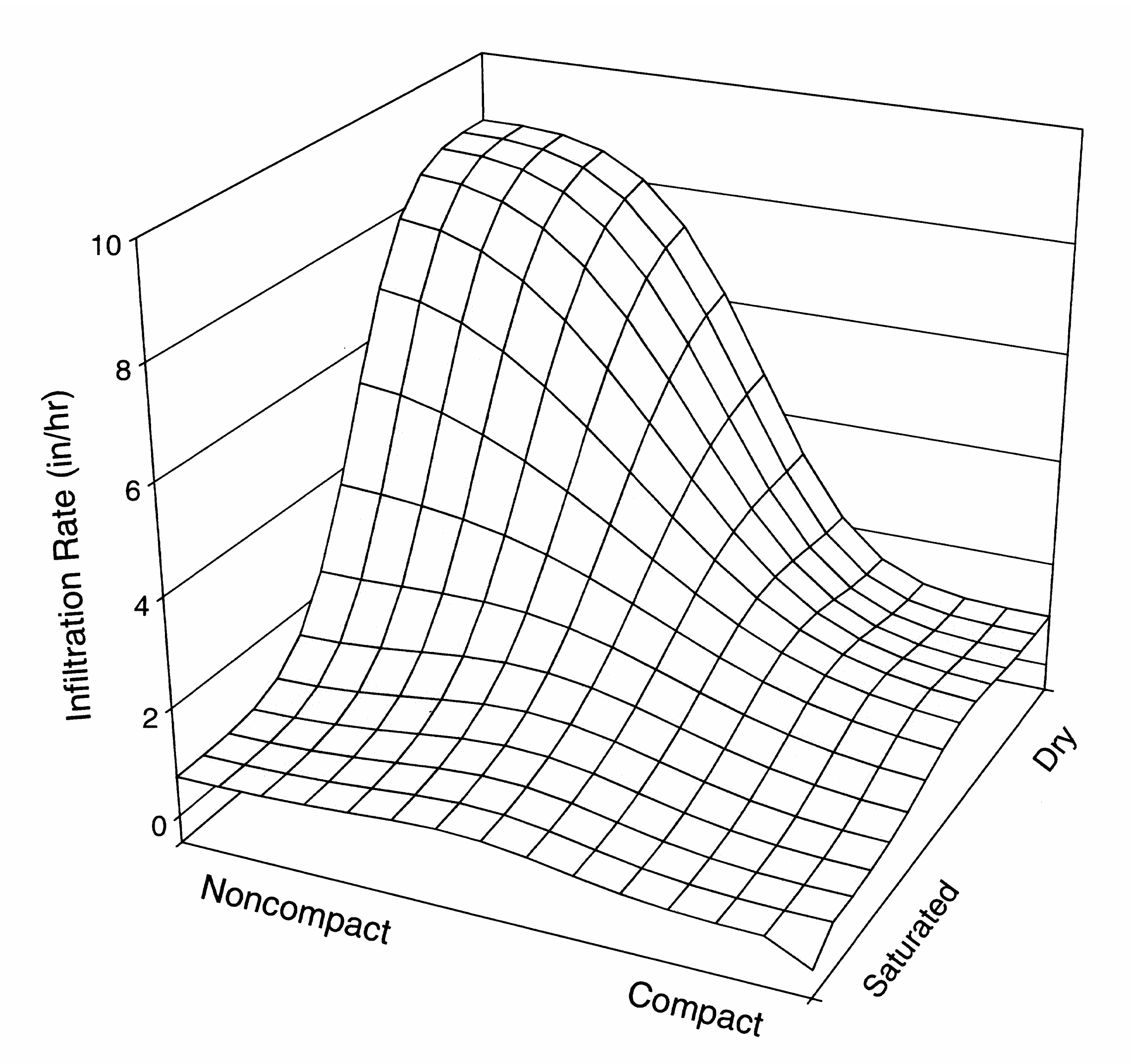


Figure 2-32. 3-D plots showing interactions affecting infiltration rates in clayey soils.

Both small-scale and large-scale tests, described by Pitt (1987), obtained data to calibrate and verify a model for homogeneous impervious and pervious areas. The runoff response curve departs from the x-axis at the rainfall depth when runoff begins. This depth lag corresponds to initial runoff losses (detention storage, evaporation losses due to pavement cooling, and dirt and debris absorbing moisture for pavements). After some rain depth, infiltration into the ground (or pavement or through cracks) slows practically to nothing, and each additional increment of rainfall results in a similar increment of runoff. Between these two rain depths, infiltration losses occur. Figure 2-33 shows the model describing these infiltration losses. This figure plots cumulative variable runoff losses (F, inches or mm), ignoring the initial losses, versus cumulative rain (P, inches or mm), after runoff begins. The slope of this line is the instantaneous variable runoff loss (infiltration) occurring at a specific rain depth after runoff starts. A simple nonlinear model can be used to describe this relationship which is similar to many other infiltration models. For a constant rain intensity (i), total rain depth since the start of runoff (P), equals intensity times the time since the start of runoff (t). The small storm hydrology nonlinear model for this variable runoff loss (F) is therefore:

$$F = bit + a(1 - e^{-git}) \quad \text{or} \quad F = bP + a(1 - e^{-gP})$$

Three basic model parameters were used to define the model behavior, in addition to initial runoff losses and rain depth: “a”, the intercept of the equilibrium loss line on the cumulative variable loss axis; “b”, the rate of the variable losses after equilibrium; and “g”, an exponential coefficient. If variable losses are zero at equilibrium, then “b” would be zero. Because this plot does not consider initial runoff losses, the variable loss line must pass through the origin. This model reduces to the SCS model when the “b” value is zero and “a” is S’, and when Ia is 0.16 (80% of 0.2) of “a”. This general model also reduces to the Horton equation when cumulative rain depth since the start of the event is used instead of just time since the start of rain.

Observed runoff data from both small- and large-scale tests were fitted to this equation to determine the values for a, b, and g for observed i and t (or P), and F values. In addition, outfall runoff observations from many different heterogeneous land uses were used to verify the calibrated model (Pitt 1987).

Comparison of the Small Storm Hydrology Model with the Horton Infiltration Equation

The Horton equation is used in many urban runoff models to predict infiltration losses (Skaggs, *et al*. 1969). The small storm hydrology model can be directly compared to the Horton infiltration equation. The total storm infiltration rate is:

$$F = \int F(t)dt$$

where F(t) is an instantaneous infiltration rate. The instantaneous infiltration rate is then:

$$F(t) = df/dt.$$

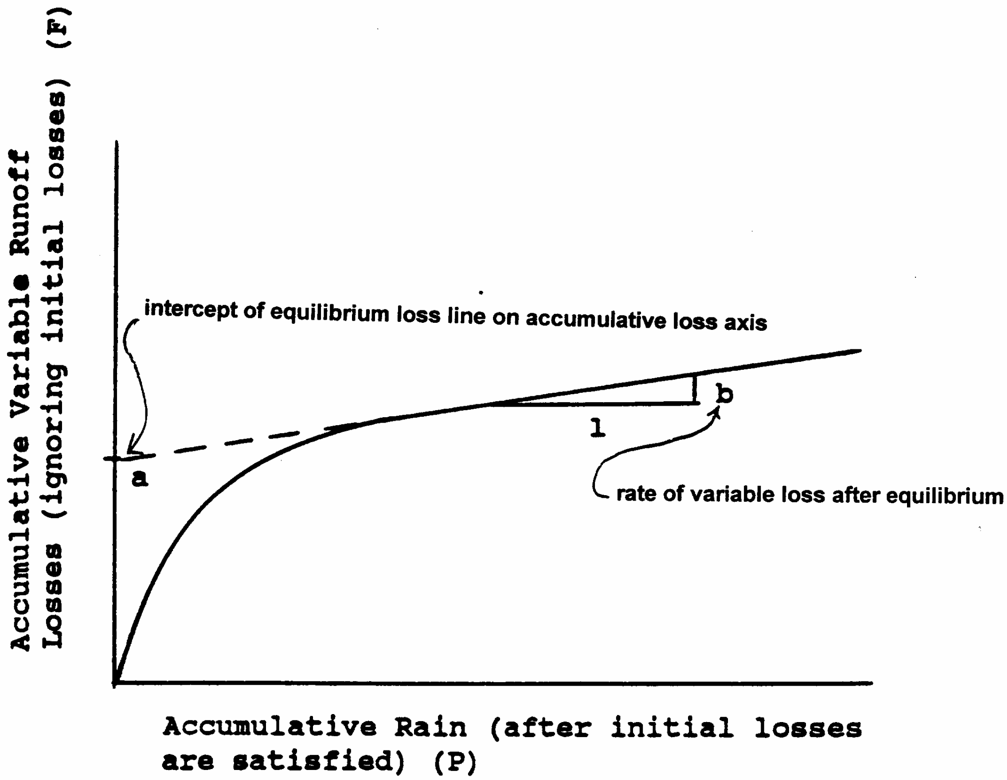
From the small storm hydrology model:

$$F(t) = bi + agi(e^{-git}).$$

Therefore, the Horton infiltration equation is:

$$F(t) = Fc + (Fo - Fc)(e^{-kt}),$$

where Fc is the final equilibrium infiltration rate, Fo is the initial infiltration rate, k is the decay coefficient, and t is the time since the rain began. Therefore the small storm hydrology model and the Horton equation are equivalent if the following relationships are simultaneously true:



$$F = bP + a(1 - e^{-gP})$$

where F = accumulative variable losses

g = exponential coefficient

P = accumulated rainfall

If b = 0, then a = total losses and no steady state losses occur (equivalent to SCS model)

Note: time since runoff started is not a factor (as implied by most users of Horton equation).

Figure 2-33. Small storm rainfall-runoff infiltration model (ignoring initial abstractions) (Pitt 1987).

$bi = Fc$, or $b = Fc/i$

$-git = -kt$, or $g = k/i$

$agi = Fo - Fc$, or $a = (Fo - Fc)/gi$, or $a = (Fo - Fc)/k$.

Rearranging gives:

$Fc = ib$ (if Fc is zero, then b is also zero),

$Fo = ib + aig = i(b + ag)$, and

$k = ig$.

Based on these relationships, it is seen that the time since runoff began (t) is not a factor in determining any of the Horton infiltration parameters; but rain intensity (i) is a factor.

During the small-scale pavement runoff tests (Pitt 1987), the measured accumulative infiltration rates for the high rain intensity tests were much greater than for the low rain intensity tests for the same time since the start of the rain. The infiltration rates (depth per time) were therefore much greater for the high intensity tests. In urban hydrology studies, infiltration losses in pervious areas are usually considered to be the most important loss mechanism (Hromadka 1982). The previous discussion shows that infiltration is also an important loss mechanism for pavements. Simple infiltration estimation methods have received much attention in runoff analyses (Singh and Buapeng 1977). Singh and Buapeng found that errors in infiltration estimation may be large and may therefore be responsible for major errors in runoff predictions. One of the possible sources of infiltration estimation errors is the general lack of consideration of the apparent relationship between infiltration rate and rain intensity.

The relationship between rain intensity and infiltration can be related to the concept of variable contributing areas in heterogeneous watersheds. Areas having low infiltration capacities produce runoff during rains having relatively low intensities, while greater intensity rains are required to produce runoff from areas having high infiltration capacities. Therefore, an overall area infiltration rate appears to be variable and dependent on rain intensity. These variations have not been reported in the literature for homogeneous areas (such as large paved areas). However, infiltration in pavement "systems" includes infiltration through the pavement itself, infiltration through pavement cracks and seams, and infiltration through the pavement base. These different processes would have different infiltration rates; infiltration analysis for the whole system would therefore be intensity dependent.

Comparison of the Small Storm Hydrology Model with the NRCS Curve Number Procedure

The Natural Resources Conservation Service curve number procedure (SCS 1986) is commonly used in the design of storm drainage systems. The following paragraphs illustrate how the small storm hydrology model can interface with models using curve numbers. The small storm hydrology model can be used to select curve numbers, allowing the better incorporation of the mutual drainage and flood control benefits of many water quality control measures into the design of storm drainage systems (Pitt 1987).

The NRCS CN procedure can also be compared with the small storm hydrology model and the Horton infiltration equation. The small storm hydrology model can be rewritten, knowing that $P = it$ so that $F = bP + a(1 - e^{-gP})$. However, the NRCS procedure assumes that the final equilibrium infiltration rate is zero ($Fc = 0$), therefore b is also zero, leaving: $F = a(1 - e^{-gP})$. When b is zero, the intercept of the runoff loss line is equal to the maximum runoff losses, ignoring initial runoff abstractions. Therefore, the NRCS S' value (maximum variable loss, without Ia, the initial abstractions) can be substituted for "a" in this equation:

$$F = S'(1 - e^{-gP}).$$

There is a distinct relationship between S and CN [CN = 1,000/(S + 10)], and therefore between S' (which is assumed to be equal to 0.8S by the NRCS) and CN in the NRCS procedure. Therefore, each curve number has a unique S' value. Because the NRCS CN procedure assumes zero final infiltration, the small storm hydrology model b value is zero and the "a" value is equal to S', as shown above. The small storm hydrology model g value was determined using a nonlinear computer program (the NONLIN module of SYSTAT - The System for Statistics, Version 3, 1986, from SYSTAT, Inc., Evanston, Ill.) for the specific F verses P relationships unique for each curve number (and S' value). The maximum runoff loss, S', which ignores initial abstractions, occurs after little rain for large curve numbers, but is not reached even after 90 mm of rain for curve numbers less than about 80.

Table 2-5 shows the fitted small storm hydrology model equation parameter g values for several curve number values, using SYSTAT's NONLIN module. This table also shows the NRCS S' values and the Horton initial infiltration rate (Fo) and decay coefficients (k) for these curve numbers. According to the small storm hydrology model, the Horton equation parameters are all related to rain intensity for impervious surfaces, and the small storm hydrology model g parameter is directly related to the curve number (Pitt 1987).

Table 2-5. Small Storm Hydrology Model and Horton Infiltration Equation Parameters for Different NRCS Curve Number Values (Pitt 1987)

Curve Number	Fitted g from hypothesized model	SCS S' Value (ignores Ia) (mm)[1]	Initial Horton Infiltration Rate (Fo) (mm/hr)[2]	Horton Equation Decay Coefficient (k)[3] (1/hr)
99	0.22	2.03	0.45i	0.22i
95	0.042	10.7	0.45i	0.042i
90	0.022	22.6	0.50i	0.022i
85	0.016	35.8	0.57i	0.016i
80	0.012	50.8	0.61i	0.012i
75	0.010	67.8	0.67i	0.010i
70	0.0081	87.4	0.71i	0.0081i
60	0.0057	136	0.78i	0.0057i
50	0.0041	203	0.83i	0.0041i
40	0.0029	305	0.88i	0.0029i

(1) S' = 0.8S assumed by SCS. S' also equals a.
(2) Fo = S'gi, where i equals rain intensity (mm/hr).

Note: The SCS curve number procedure assumes that the final infil tration rate (Fc) is zero.

(3) K = gi, or Fo/S'

Volumetric Runoff Coefficients can be Calculated for Different Surfaces and Rains using the Small Storm Hydrology Model

Table 2-6 is a summary of the volumetric runoff coefficients (Rv, the ratio of runoff to rainfall volume) for different urban surfaces and rain depths from detailed source area runoff tests and through calibrating the small storm hydrology model (Pitt 1987). Flat roofs and unpaved parking areas behave strangely similar because of similar detention storage volumes and no infiltration. Large impervious areas have the largest runoff yields because of very poor pavement under-drainage. The drainage path through the pavement base is relatively thin and very long, making it very difficult for infiltrated water to drain from the base. Street widths are much narrower than the widths of large impervious areas and the base water can drain much more effectively. Pitched roofs have no infiltration rates, but do experience limited initial losses associated with flash evaporation and sorption of moisture in leaves and other roof or gutter debris. After three inches (no longer a "small" rain) the runoff yields from all impervious surfaces are similar (within 10%), but the differences can be very large for the small rains of most concern in water quality evaluations.

Table 2-6. Summary of Volumetric Runoff Coefficients for Urban Runoff Flow Calculations (Pitt 1987).

Rain Depth		Runoff Coefficients for Directly Connected Areas:						
		Flat roofs* (or large unpaved parking areas)	Pitched roofs*	Large impervious areas*	Small impervious areas and streets	Sandy soils	Typical urban soils	Clayey soils
mm	inches							
1	0.04	0.00	0.25	0.93	0.26	0.00	0.00	0.00
3	0.12	0.30	0.75	0.96	0.49	0.00	0.00	0.00
5	0.20	0.54	0.85	0.97	0.55	0.00	0.05	0.10
10	0.39	0.72	0.93	0.97	0.60	0.01	0.08	0.15
15	0.59	0.79	0.95	0.97	0.64	0.02	0.10	0.19
20	0.79	0.83	0.96	0.97	0.67	0.02	0.11	0.20
30	1.2	0.86	0.98	0.98	0.73	0.03	0.13	0.22
50	2.0	0.90	0.99	0.99	0.84	0.07	0.16	0.26
80	3.2	0.94	0.99	0.99	0.90	0.15	0.24	0.33
125	4.9	0.96	0.99	0.99	0.93	0.25	0.35	0.45

*If these "impervious" areas drain for a significant length across sandy soils, the sandy soil runoff coefficients will usually be applied to these areas, however, if these areas drain across typical, or clayey soils, the runoff coefficients will be reduced, depending on the land use and rain depth, according to the following table:

	Reduction factors for different rain depths (mm):									
	1	3	5	10	15	20	30	50	80	125
Strip commercial and shopping centers:	0.00	0.00	0.47	0.90	0.99	0.99	0.99	0.99	0.99	0.99
Other medium to high density land uses, with alleys:	0.00	0.08	0.11	0.16	0.20	0.29	0.46	0.81	0.99	0.99
Other medium to high density land uses, without alleys:	0.00	0.00	0.11	0.16	0.20	0.21	0.22	0.27	0.34	0.46

If low density land uses, use typical or clayey soil runoff coefficients.

The impervious and roof area values are for directly connected surfaces. If runoff is allowed to drain across grass areas, then the runoff yield may significantly decrease. However, sufficient length of drainage across the pervious surface in good condition is needed. For a relatively small paved surface, short pervious drainage paths are all that are needed. If the paved area is large, or if the pervious area has clayey or compacted soils, then much longer drainage paths are needed before significant infiltration occurs.

Table 2-6 does not accurately incorporate the effects of disturbed urban soils presented earlier, but the runoff coefficients shown generally bracket the range of likely conditions expected. Some users have had good success using an intermediate soil Rv value, half way between the clayey and sandy soil conditions shown, and only using the extreme values for more unusual cases. The four urban soil categories identified earlier better represent the conditions encountered, and appropriate coefficients are currently being developed.

The runoff coefficients and indirect connection correction values were determined from calibrating the small storm hydrology model for large urban watersheds having variable complexities in Toronto and in Milwaukee (Pitt 1987). The first calibrations were conducted for simple areas. The first area was the large parking area of a commercial shopping area. The runoff coefficients for this area were used to determine the runoff relationships from large flat roofs from another shopping area that was made of mostly paved large parking and roof areas in order to determine runoff characteristics for flat roofs. The next step was to evaluate runoff data for two high density residential areas that had very little pervious areas and had all of the impervious areas directly connected. The street runoff was subtracted from the total area runoff observations to obtain information solely for pitched roofs. Finally, two medium density residential areas were studied in areas that had clayey soils and all of the impervious areas were directly connected. Roof, street and other impervious area runoff information was subtracted to obtain clayey soil runoff coefficients. Similarly, a medium density residential area was studied in an area having sandy soils to obtain sandy soil runoff coefficients. Finally, two medium density residential areas having unconnected impervious areas were studied to obtain correction coefficients.

Excellent Verification of Small Storm Hydrology Model for Many Conditions

The final runoff coefficients were verified using additional runoff data from these same areas (that were not used in the calibration efforts) and from areas located elsewhere. Figures 2-34 through 2-37 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, the “Burbank” site was a medium density residential area. These sites were monitored as part of the EPA’s NURP project in Milwaukee (Bannerman, *et al*. 1983). Figures 2-36 and 2-37 are for two residential sites monitored by the WI DNR in Superior, WI, and in Marquette, MI, during 1993 and 1994. These last two sites were compared to the small storm hydrology component of WinSLAMM with no local calibration, demonstrating the excellent fit of observed and predicted flows.

The model was subsequently calibrated for these two sites to enable better fits for the larger events. It was originally expected that this model would not work very well for very large storms, especially in areas having appreciable pervious areas, where rain intensity was expected to have a more significant effect on infiltration than for small rains. The largest rains observed for the two Milwaukee sites were greater than three inches, a very large rain that would not be expected to commonly occur. Even these rains had runoff quantities that were well predicted by this runoff model.

Example Application using the Small Storm Hydrology Model

The small storm hydrology model can be used to predict runoff volume yields for many different land uses and development conditions. It was specifically developed to determine runoff yields and corresponding water pollutant yields for small storms for stormwater quality investigations. As shown during the verification process, it is also useful for predicting runoff yields for moderate storms that are used for drainage design. If used in conjunction with a model that can account for water losses associated with stormwater controls (such as WinSLAMM, the Source Loading and Management Model, Pitt 1986 and 1992) it can also be used to show the mutual drainage benefits associated with these controls. As an example, the use of roadside swales, disconnections of impervious areas from the drainage system, or using infiltration devices, can all have dramatic benefits in reducing runoff volumes, even for relatively large rains.

The small storm hydrology model can be used to predict runoff yields associated with different land uses and development practices. It can also be used to predict sources of water within the drainage area. If the variable quality of runoff from each source area is known, then runoff pollutant yield estimates (and reductions) can also be made. WinSLAMM uses this approach. This information is very important when determining the best management strategy for water volume and runoff pollutant reduction. This example problem shows how the runoff yield predictions and sources of water for a simple area can be predicted for different rain depths. The benefits of source area disconnections are also shown.

Predicting Runoff Yields from Different Source Areas

• Calculate runoff quantity (inches) and distributions (%) by source area for the following conditions:

- Rain depths: 0.12; 0.79; 3.2 inches
- Medium density residential area (conventional curb and gutters, all impervious areas are directly connected to the drainage system and clayey soils are common), having the following surface area distribution:

pitched roofs	6%
driveways	5
sidewalks	3
streets	12
front yards	45
back yards	29

• Calculations:

		0.12 inch (3 mm) rain			0.79 inch (20 mm) rain		
area:	%	Rv	weighted Rv	contrib-ution	Rv	weighted Rv	contrib-ution
roofs	6	0.75	0.045	31 %	0.96	0.058	17 %
driveways	5	0.49	0.025	17	0.67	0.034	10
sidewalks	3	0.49	0.015	10	0.67	0.020	6
streets	12	0.49	0.059	41	0.67	0.080	24
frontyards	45	0.00	0.00	0	0.20	0.090	24
backyards	29	0.00	0.00	0	0.20	0.058	17
Total:	100	n/a	0.014	100	n/a	0.34	100

The Rv values are from Table 2-6 for the appropriate rain depths and source area. Weighted Rv values are determined by multiplying the Rv values by the percentage of the area represented. The weighted Rv values are summed to obtain a Rv value for the whole land use area. The percentage runoff yields are the ratios of the individual weighted Rv values to the summed whole area Rv.

- runoff for the 0.12 inch rain: (0.014)(0.12in)=0.017 in runoff
- runoff for the 0.79 inch rain: (0.34)(0.79in) = 0.27 in runoff
- similar calculations for the 3.2 inch rain results in a Rv of 0.48, therefore, the runoff for this rain: (0.48)(3.2 in) = 1.6 in runoff.

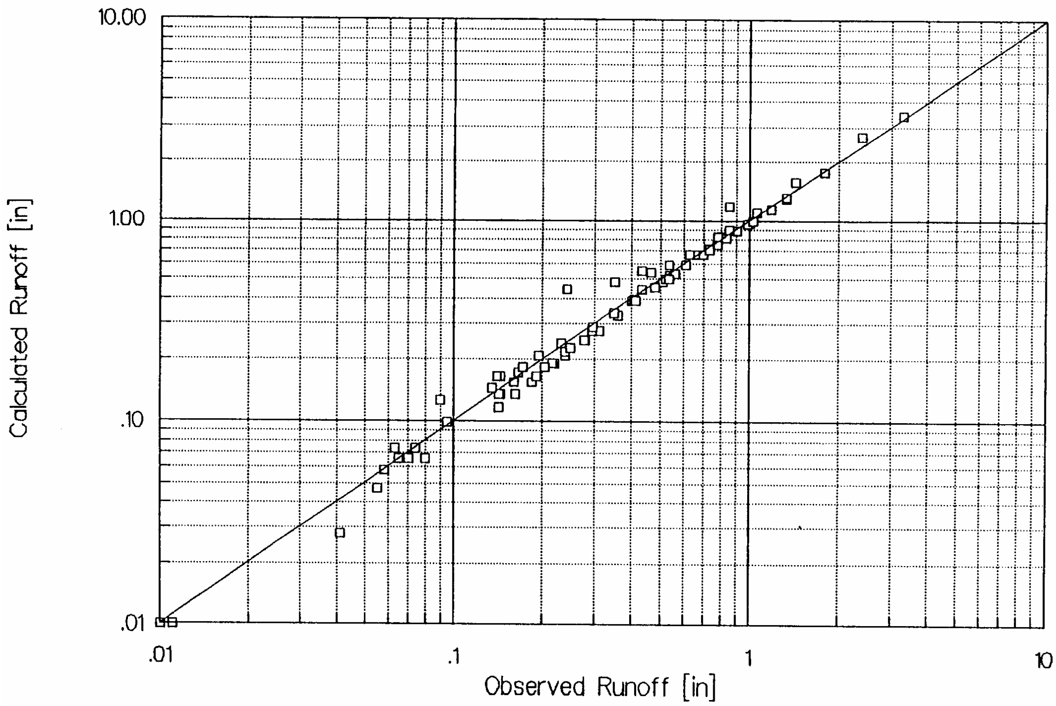


Figure 2-34. Verification of WinSLAMM hydrology component – Post Office commercial site, Milwaukee, WI.

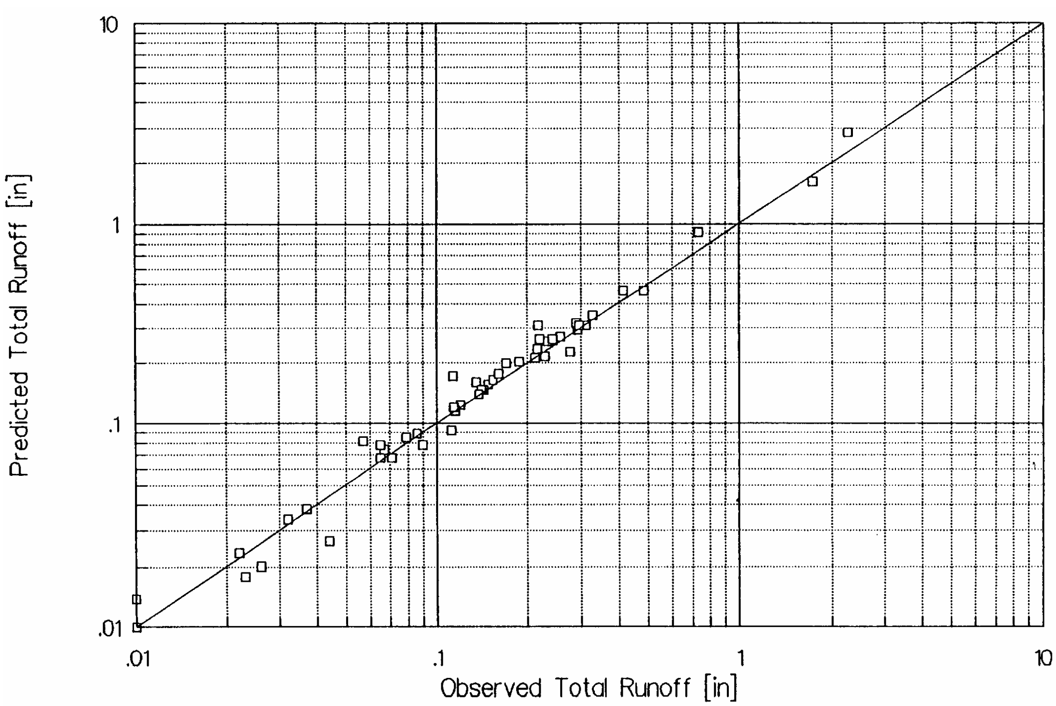


Figure 2-35. Verification of WinSLAMM hydrology component – Burbank residential site, Milwaukee, WI.

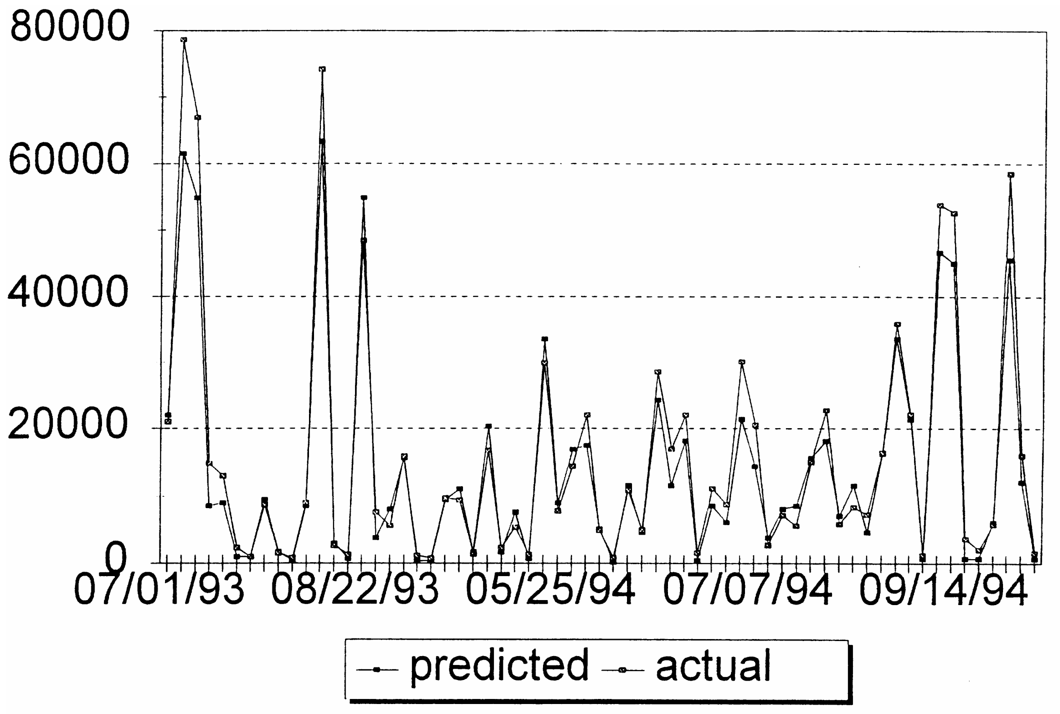


Figure 2-36. Verification of WinSLAMM hydrology component – Superior, WI, test site.

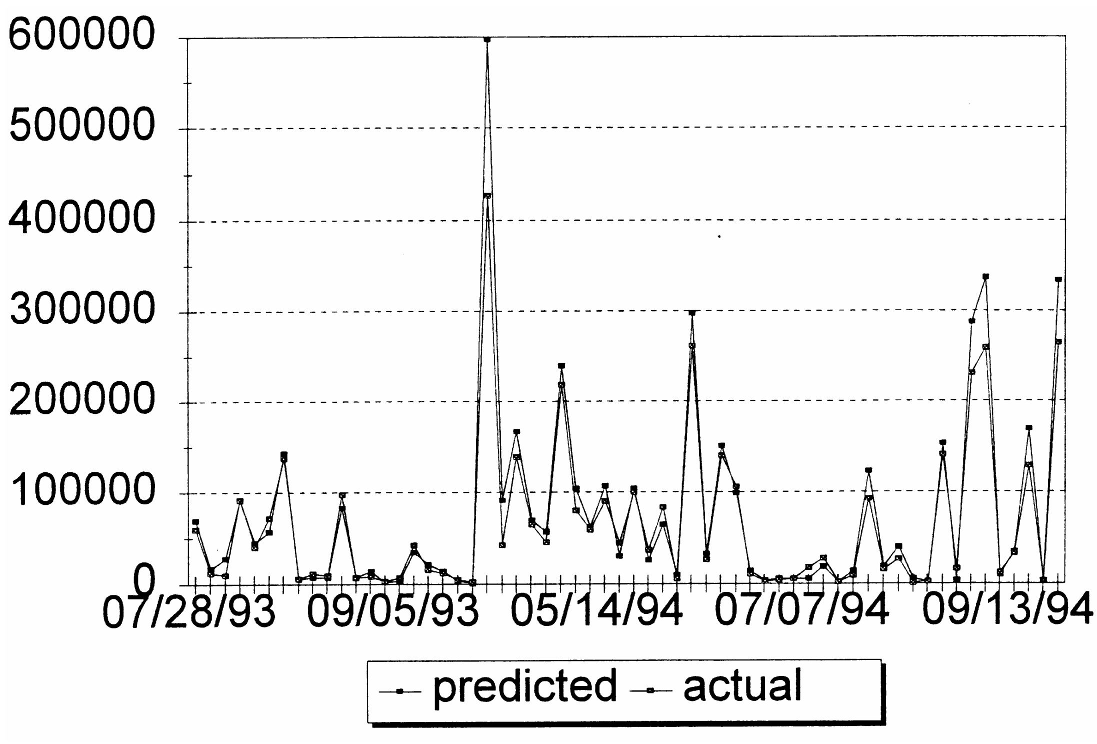


Figure 2-37. Verification of WinSLAMM hydrology component – Marquette, MI, test site.

As the rain depth changes, the percentage contributions from each area also changes. For the smallest rain, all of the runoff is contributed from the directly connected impervious areas. However, pervious areas contribute almost half (44%) of the runoff for the 0.79 inch rain.

Benefits of source area drainage disconnections can also be predicted for this example. The following calculations show the effects of disconnecting all of the roof, driveway and sidewalk areas for this land use:

Original weighted Rv values:

	0.12" rain	0.79" rain	3.2" rain
roofs+ driveways+ walks	0.084	0.11	0.13
streets	0.059	0.08	0.11
yards	0	0.15	0.24
total Rv:	0.14	0.34	0.48
total runoff:	0.017"	0.27"	1.6"

With disconnections:

	0.12" rain	0.79" rain	3.2" rain
roofs+ driveways+ walks	(0)(0.084)= 0	(0.21)(0.11)= 0.023	(0.34)(0.13)= 0.044
streets	0.059	0.08	0.11
yards	0	0.15	0.24
total Rv:	0.06	0.25	0.39
total runoff:	0.01"	0.20"	1.3"
approx. % reduction:	60	25	20

The runoff contributions from the disconnected areas are decreased by the factors shown on Table 2-6 for medium density areas (with no alleys) having clayey soils. These dis connections can have significant effects on the runoff quantities generated for small rains. The runoff reductions for the larger rain will also likely be important for drainage design. Similar percentage reductions in peak runoff rates are also expected for these conditions.

Conclusions

Runoff volume is the most important hydraulic parameter needed for most water quality studies, while peak flow rate and time of concentration are the most important parameters for most flooding and drainage studies. Commo n small rains account for much more of the annual runoff volume than rare flooding events. Pitt (1987) showed that estimates of runoff volume could be made with only rain depth information. Other rain characteristics (including antecedent conditions, durations, intensities, etc.) did not substantially improve runoff volume predictions, but are likely needed for peak flow rate predictions.

The literature indicates that both initial runoff abstractions (mostly detention/storage) and continuous runoff losses (infiltration) are important for impervious surfaces. Recent work with disturbed urban soils has also shown that care must be taken when using soil maps for developed conditions. The small storm hydrology model successfully predicts runoff from several types of paved, roofed, and disturbed soil urban surfaces. This model was shown to accurately predict runoff volumes for a wide range of rain conditions.

This model was used to examine long-term rain conditions at many locations throughout the U.S. to indicate the significance of small and moderate sized rains in stormwater management. These smaller rains, compared to the typical "design storm" rains used for drainage system design, contribute the vast majority of stormwater pollutants. Stormwater control practices must therefore effectively address these smaller storms to provide effective pollutant and flow reduction schemes.

References

Bannerman, R., K. Baun, M. Bohn, P.E. Hughes, and D.A. Graczyk. *Evaluation of Urban Nonpoint Source Pollution Management in Milwaukee County, Wisconsin*, Vol. I. PB 84-114164. US Environmental Protection Agency, Water Planning Division, November 1983.

Cedergren, H.R. *Drainage of Highway and Airfield Pavements*. John-Wiley and Sons, New York, 1974.

Davies, H. and T. Hollis. "Measurements of rainfall-runoff volume relationships and water balance for roofs and roads," *Second International Conference on Urban Storm Drainage*, Urbana, Illinois, June 1981.

EPA (U.S. Environmental Protection Agency). *Final Report for the Nationwide Urban Runoff Program*. Water Planning Division, Washington, D.C., December 1983.

Falk, J. and J. Niemczynowicz. "Characteristics of the above-ground runoff in sewered catchments." in *Urban Storm Drainage*. P.R. Helliwell, ed. John Wiley and Sons, New York, 1978.

Gregory. M. and W. James. "Management of time-series data for long-term, continuous modeling." *Advances in Modeling the Management of Stormwater Impacts*. pp. 115 – 151. Computational Hydraulics International, Guelph, Ontario. 1996.

Heaney, J.P., W.C. Huber, M.A. Medina, Jr, M.P. Murphy, S.J. Nix, and S.M. Hasan. *Nationwide Evaluation of Combined Sewer Overflows and Urban Stormwater Discharges, Volume II: Cost Assessment and Impacts*. EP2-600/2-77-064b. NTIS PB-266005. 363 pgs. U.S. Environmental Protection Agency. Cincinnati, Ohio. March 1977.

Hormadka, T.V. II. *Computer Methods in Urban Hydrology, Rational Methods and Unit Hydrograph Methods*. Lighthouse Publications, Anaheim, California, 1982.

Huber, W.C. *Urban Rainfall-Runoff-Quality Data Base: Addendum I: Statistical Analysis and Additional Data*. EP2-600/2-81-238, U. S. Environmental Protection Agency, Cincinnati, Ohio, 1981

Pitt, R. "The incorporation of urban runoff controls in the Wisconsin Priority Watershed Program." In: *Advanced Topics in Urban Runoff Research*, (Edited by B. Urbonas and L.A. Roesner). Engineering Foundation and ASCE, New York. pp. 290-313. 1986.

Pitt, R. *Small Storm Flow and Particulate Washoff Contributions to Outfall Discharges*. Ph.D. dissertation, Department of Civil and Environmental Engineering, the University of Wisconsin, Madison, 1987.

Pitt, R. and M. Bozeman. *Sources of Urban Runoff Pollution and Its Effects on an Urban Creek*. EP2-600/S2-82-090, U.S. Environmental Protection Agency, Cincinnati, Ohio, December 1982.

Pitt, R. and J. Voorhees. "Source loading and management model (SLAMM)." *Seminar Publication: National Conference on Urban Runoff Management: Enhancing Urban Watershed Management at the Local, County, and State Levels*. March 30 – April 2, 1993. Center for Environmental Research Information, U.S. Environmental Protection Agency. EPA/625/R-95/003. Cincinnati. Ohio. pp. 225-243. April 1995.

Pitt, R., M. Lilburn, S. Nix, S.R. Durrans, S. Burian, J. Voorhees, and J. Martinson *Guidance Manual for Integrated Wet Weather Flow (WWF) Collection and Treatment Systems for Newly Urbanized Areas (New WWF Systems)*. U.S. Environmental Protection Agency. 612 pgs. December 1999.

Pratt, C.J. and R.J. Henderson. "Overland flow and catchment characteristics," *Second International Conference on Urban Storm Drainage*, Urbana, Illinois, June 1981.

SCS (U.S. Soil Conservation Service). *Urban Hydrology for Small Watersheds*. U.S. Dept. of Agriculture Tech. Release No. 55 (revised), June 1986.

Singh, V.P. and S. Buapeng. "Effect of rainfall-excess determination on runoff computation." *Water Resources Bulletin*, Vol. 13, No. 3, June 1977.

Skaggs, R.W., L.E. Huggins, E.J. Monke and G.R. Foster. "Experimental evaluation of infiltration equations." *Transactions of the American Society of Agricultural Engineers*, pp 822-828. 1969.

Willeke, G.E. "Time in urban hydrology." *Journal of the Hydraulics Division*, Proceedings of the American Society of Civil Engineers, Vol. 92, No. HY1, January 1966.

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3. Sources of Stormwater Pollutants, Including Pollutant Buildup and Washoff

Introduction

This section presents pollutant accumulation and washoff processes that have been observed during extensive field projects. These processes are fundamental components of many stormwater models. This section also describes pollutant characteristics of particulates that are removed during rains, and sheetflow quality from most source areas.

This material was mostly extracted from the final draft of:

Pitt, R. *Stormwater Quality Management*, CRC Press. New York, expected publication in 2000.

The accumulation and washoff information presented here was obtained from many research projects (as listed in the references) and initially described in Pitt's dissertation:

Pitt, R. *Small Storm Urban Flow and Particulate Washoff Contributions to Outfall Discharges*, Ph.D. Dissertation, Civil and Environmental Engineering Department, University of Wisconsin, Madison, WI, November 1987.

Descriptions of street dirt measurements and washoff tests are summarized from many studies and this discussion is from:

Burton, G.A. and R. Pitt. *Manual for Evaluating Stormwater Runoff Effects, A Tool Box of Procedures and Methods to Assist Watershed Managers.* CRC/Lewis Publishers, New York. Expected publication in 2000.

The Source Concept

Urban runoff is comprised of many separate source area flow components that are combined within the drainage area and at the outfall before entering the receiving water. Considering the combined outfall conditions alone may be adequate when evaluating the long term, area-wide effects of many separate outfall discharges to a receiving water. However, if better predictions of outfall characteristics (or the effects of source area controls) are needed, then the separate source area components must be characterized. The discharge at the outfall is made up of a mixture of contributions from different source areas. The "mix" depends on the characteristics of the drainage area and the specific rain event. The overall effectiveness of source area controls in reducing stormwater discharges is, therefore, highly site and storm specific, as site and rain characteristics control how important each source is in contributing pollutants to the overall flow.

Various urban source areas all contribute different quantities of runoff and pollutants depending on their characteristics. Impervious source areas may contribute most of the runoff during small rain events. Examples of these source areas include paved parking lots, streets, driveways, roofs, and sidewalks. Pervious source areas become important contributors for larger rain events. These pervious source areas include gardens, lawns, bare ground, unpaved parking areas and driveways, and undeveloped areas. The relative importance of the individual sources is a function of their areas, their pollutant washoff potentials, and the rain characteristics.

The washoff of debris and soil during a rain is dependent on the energy of the rain and the properties of the material. Pollutants are also removed from source areas by winds, litter pickup, or other cleanup activities. The runoff and pollutants from the source areas flow directly into the drainage system, onto impervious areas that are directly connected to the drainage system, or onto pervious areas that will attenuate some of the flows and pollutants, before they discharge to the drainage system.

Sources of pollutants on paved areas include on-site particulate storage that cannot be removed by usual processes such as rain, wind, and street cleaning. Atmospheric deposition, deposition from activities on these paved surfaces (e.g., auto traffic, material storage) and the erosion of material from upland areas that directly discharge flows onto these areas, are the major sources of pollutants to the paved areas. Pervious areas contribute pollutants mainly through erosion processes where the rain energy dislodges soil from between vegetation. The runoff from these source areas enters the storm drainage system where sedimentation in catchbasins or in the sewerage may affect their ultimate discharge to the outfall. In-stream physical, biological, and chemical processes affect the pollutants after they are discharged to the ultimate receiving water.

Knowing when the different source areas become "active" (when runoff initiates from the area, carrying pollutants to the drainage system) is critical. If pervious source areas are not contributing runoff or pollutants, then the prediction of urban runoff quality is greatly simplified. The mechanisms of washoff and delivery yields of runoff and pollutants from paved areas are much better known than from pervious urban areas (Novotny and Chesters

1981). In many cases, pervious areas are not active except during rain events greater than at least five or ten mm. For smaller rain depths, almost all of the runoff and pollutants originate from impervious surfaces (Pitt 1987). However, in many urban areas, pervious areas may contribute the majority of the runoff, and some pollutants, when rain depths are greater than about 20 mm. The actual importance of the different source areas is highly dependent on the specific land use and rainfall patterns. Obviously, in areas having relatively low-density development, especially where moderate and large sized rains occur frequently (such as in the Southeast portion of the US), pervious areas typically dominate outfall discharges. In contrast, in areas having significant paved areas, especially where most rains are relatively small (such as in the arid west of the US), the impervious areas dominate outfall discharges. The effectiveness of different source controls is, therefore, quite different for different land uses and climatic patterns.

If the number of events exceeding a water quality objective are important, then the small rain events are of most concern. Stormwater runoff typically exceeds some water quality standards for practically every rain event (especially for bacteria and some heavy metals). In the US's upper midwest, the median rain depth is about six mm, while in the US's southeast, the median rain depth is about twice this depth. For these small rain depths and for most urban land uses, directly connected paved areas usually contribute most of the runoff and pollutants. However, if annual mass discharges are more important (e.g. for long-term effects), then the moderate rains are more important. Rains from about 10 to 50 mm produce most of the annual runoff volume in many areas of the US. Runoff from both impervious and pervious areas can be very important for these rains. The largest rains (greater than 100 mm) are relatively rare and do not contribute significant amounts of runoff pollutants during normal years, but are very important for drainage design. The specific source areas that are most important (and controllable) for these different conditions vary widely. This section describes sources of urban runoff flows and pollutants based on many studies reported in the literature.

Sources and Characteristics of Urban Runoff Pollutants

Years of study reveal that the vast majority of stormwater toxicants and much of the conventional pollutants are associated with automobile use and maintenance activities and that these pollutants are strongly associated with the particulates suspended in the stormwater (the non-filterable components or suspended solids). Reducing or modifying automobile use to reduce the use of these compounds, has been difficult, with the notable exception of the phasing out of leaded gasoline. Current activities, concentrated in the San Francisco, CA area, focus on encouraging brake pad manufacturers to reduce the use of copper.

The effectiveness of most stormwater control practices is, therefore, dependent on their ability to remove these particles from the water, or possibly from intermediate accumulating locations (such as streets or other surfaces) and not through source reduction. The removal of these particles from stormwater is dependent on various characteristics of these particles, especially their size and settling rates. Some source area controls (most notably street cleaning) affect the particles before they are washed-off and transported by the runoff, while others remove the particles from the flowing water. This discussion, therefore summarizes the accumulation and washoff of these particulates and the particle size distribution of the suspended solids in stormwater runoff to better understand the effectiveness of source area control practices.

Table 3-1 shows that most of the organic compounds found in stormwater are associated with various human-related activities, especially automobile and pesticide use, or are associated with plastics (Verschueren 1983). Heavy metals found in stormwater also mostly originate from automobile use activities, including gasoline combustion, brake lining, fluids (e.g., brake fluid, transmission oil, anti-freeze, grease), undercoatings, and tire wear (Durum 1974, Koeppe 1977, Rubin 1976, Shaheen 1975, Solomon and Natusch 1977, and Wilbur and Hunter 1980). Auto repair, pavement wear, and deicing compound use also contribute heavy metals to stormwater (Field, *et al.* 1973 and Shaheen 1975). Shaheen (1975) found that eroding area soils are the major source of the particulates in stormwater. He also investigated many different materials that contribute to the street dust and dirt loading (Table 3-2). The eroding area soil particles, and the particles associated with road surface wear, become contaminated with exhaust emissions and runoff containing the polluting compounds. Shaheen found that gasoline and oils have heavy concentrations of many pollutants, while break linings and asphalt pavement wear have high concentrations of many heavy metals. Even litter materials (such as cigarette butts) can contribute metals and other pollutants. Most of these compounds become tightly bound to these particles and are then transported through the urban area and drainage system, or removed from the stormwater, with the particulates. Stormwater concentrations of zinc, fluoranthene, 1,3-

dichlorobenzene, and pyrene are unique in that substantial fractions of these compounds remain in the water and are less associated with the particulates.

Table 3-1. Uses and Sources for Organic Compounds found in Stormwater (Verschueren 1983)

Compound	Example Use/Source
Phenol	gasoline, exhaust
N-Nitroso-di-n-propylamine	contaminant of herbicide Treflan
Hexachloroethane	plasticizer in cellulose esters, minor use in rubber and insecticide
Nitrobenzene	solvent, rubber, lubricants
2,4-Dimethylphenol	asphalt, fuel, plastics, pesticides
Hexachlorobutadiene	rubber and polymer solvent, transformer and hydraulic oil
4-Chloro-3-methylphenol	germicide; preservative for glues, gums, inks, textile, and leather
Pentachlorophenol	insecticide, algaecide, herbicide, and fungicide mfg., wood preservative
Fluoranthene	gasoline, motor and lubricating oil, wood preservative
Pyrene	gasoline, asphalt, wood preservative, motor oil
Di-n-octylphthalate	general use of plastics

Table 3-2. Concentrations of Materials Found on Urban Roadways (Shaheen 1975)

Material	Tot. Vol. Solids (mg/g)	BOD[a] (mg/g)	COD (mg/g)	Grease (mg/g)	Petroleum (mg/g)	n-Paraffins (mg/g)
Gasoline	999.5	154.0	682.1	1.3	1.3	1.3
Lubricating Grease	973.9	143.3		753.1	665.8	566.3
Motor Oil	996.9	143.8	220.8	989.2	937.7	850.0
Transmission Fluid	999.8	102.6	198.3	985.6	941.7	875.4
Antifreeze	987.8	37.6	1102.4	143.8	69.6	6.1
Undercoating	998.7	89.8	309.5	958.1	182.8	120.7
Asphalt Pavement	64.2	1.2	85.5	21.4	15.0	9.0
Concrete	70.7	1.4	63.6	2.7	1.3	1.0
Rubber	986.3	26.8	2097.4	191.6	97.8	56.0
Diesel Fuel	999.9	80.2	399.0	385.3	307.8	209.7
Brake Linings	285.3	16.9	416.5	30.5	8.3	7.6
Brake Fluid	999.8	25.8	2420.8	883.0	33.1	18.6
Cigarettes	862.2	85.4	776.8	30.0	21.2	2.7
Salt (b)	74.7	-	-	0.0	0.0	0.0
Cinders	0.0	-	59.3	1.3	1.2	1.2
Area Soil (c)	-	-	-	-	-	-

(a) BOD determinations were made on "pure" materials using a seed of unacclimated sewage organisms.

(b) Results are on a dry weight basis. Salt as received contained 3.7% water, assayed 93.2% sodium chloride, and contained less than 0.005% cyanide.

(c) Soils from the Washington, D.C. area contained a magnetic fraction of from 8.9 to 12.5%, less than 0.05 mg rubber per gram, less than 3×10^5 asbestos fibers per gram, 50 to 100 mg/g volatile solids and 15 to 80 mg/g COD.

Material	Metals Content (µg/g) Lead	Mercury	Chromium	Copper	Nickel	Zinc
Gasoline	663	0	15	4	10	10
Lubricating Grease	0	0	0	0	0	164
Motor Oil	9	0	0	3	17	1060
Transmission Fluid	8	0	0	0	21	244
Antifreeze	6	0	0	76	16	14
Undercoating	116	0	0	0	476	108
Asphalt Pavement	102	0	357	51	1170	164
Concrete	450	0	93	99	264	417
Rubber	1110	0	182	247	174	617
Diesel Fuel	12	0	15	8	8	12
Brake Linings	1050	0	2200	30600	7454	124
Brake Fluid	7	0	19	5	31	15
Cigarettes	492	0	71	716	193	560
Salt	2	0	2	2	9	1
Cinders	0	0	0	3	4	7
Area Soil	0	0	36	23	25	27
Detection Limit	2	0.05	2	1	1	0.01

All areas are affected by atmospheric deposition, while other sources of pollutants are specific to the activities conducted on the areas. As examples, the ground surfaces of unpaved equipment or material storage areas can become contaminated by spills and debris, while undeveloped land remaining relatively unspoiled by activities can still contribute runoff solids, organics, and nutrients, if eroded. Atmospheric deposition, deposition from activities on paved surfaces, and the erosion of material from upland unconnected areas are the major sources of pollutants in urban areas.

Many studies have examined different sources of urban runoff pollutants. These significant pollutants have been shown to have a potential for creating various receiving water impact problems. Most of these potential problem pollutants typically have significant concentration increases in the urban feeder creeks and sediments, as compared to areas not affected by urban runoff.

The important sources of these pollutants are related to various uses and processes. Automobile related potential sources usually affect road dust and dirt quality more than other particulate components of the runoff system. The road dust and dirt quality is affected by vehicle fluid drips and spills (e.g., gasoline, oils) and vehicle exhaust, along with various vehicle wear, local soil erosion, and pavement wear products. Urban landscaping practices potentially affecting urban runoff include vegetation litter, fertilizer and pesticides. Miscellaneous sources of urban runoff pollutants include firework debris, wildlife and domestic pet wastes and possibly industrial and sanitary wastewaters. Wet and dry atmospheric contributions both affect runoff quality. Pesticide use in an urban area can contribute significant quantities of various toxic materials to urban runoff. Many manufacturing and industrial activities, including the combustion of fuels, also affect urban runoff quality.

Natural weathering and erosion products of rocks contribute the majority of the hardness and iron in urban runoff pollutants. Road dust and associated automobile use activities (gasoline exhaust products) historically contributed most of the lead in urban runoff. However, the decrease of lead in gasoline has resulted in current stormwater lead concentrations being about one tenth of the levels found in stormwater in the early 1970s (Bannerman, *et al*. 1993). In certain situations, paint chipping can also be a major source of lead in urban areas. Road dust, contaminated by tire wear products and zinc plated metal erosion material, contributes most of the zinc to urban runoff. Urban landscaping activities can be a major source of cadmium (Phillips and Russo 1978). Electroplating and ore processing activities can also contribute chromium and cadmium.

Many pollutant sources are specific to a particular area and on-going activities. For example, iron oxides are associated with welding operations and strontium, used in the production of flares and fireworks, would probably be found on the streets in greater quantities around holidays, or at the scenes of traffic accidents. The relative contribution of each of these potential urban runoff sources, is, therefore, highly variable, depending upon specific site conditions and seasons. Specific information is presented in the following subsections concerning the qualities of various rocks and soils, urban and rural dustfall, and precipitation.

Chemical Quality of Rocks and Soils

The abundance of common elements in the lithosphere (the earth's crust) is shown in Table 3-3 (Lindsay l979). Almost half of the lithosphere is oxygen and about 25% is silica. Approximately eight percent is aluminum and five percent is iron. Elements comprising between two percent and four percent of the lithosphere include calcium, sodium, potassium and magnesium. Because of the great abundance of these materials in the lithosphere, urban runoff transports only a relatively small portion of these elements to receiving waters, compared to natural processes. Iron and aluminum can both cause detrimental effects in receiving waters if in their dissolved forms. A reduction of the pH substantially increases the abundance of dissolved metals.

Table 3-3. Common Elements in the Lithosphere (Lindsay 1979)

Abundance Rank	Element	Concentration in Lithosphere (mg/kg)
1	O	465,000
2	Si	276,000
3	Al	81,000
4	Fe	51,000
5	Ca	36,000
6	Na	28,000
7	K	26,000
8	Mg	21,000
9	P	1,200
10	C	950
11	Mn	900
12	F	625
13	S	600
14	Cl	500
15	Ba	430
16	Rb	280
17	Zr	220
18	Cr	200
19	Sr	150
20	V	150
21	Ni	100

Table 3-4, also from Lindsay (1979), shows the rankings for common elements in soils. These rankings are quite similar to the values shown previously for the lithosphere. Natural soils can contribute pollutants to urban runoff through local erosion. Again, iron and aluminum are very high on this list and receiving water concentrations of these metals are not expected to be significantly affected by urban activities alone.

The values shown on these tables are expected to vary substantially, depending upon the specific mineral types. Arsenic is mainly concentrated in iron and manganese oxides, shales, clays, sedimentary rocks and phosphorites. Mercury is concentrated mostly in sulfide ores, shales and clays. Lead is fairly uniformly distributed, but can be concentrated in clayey sediments and sulfide deposits. Cadmium can also be concentrated in shales, clays and phosphorites (Durum 1974).

Street Dust and Dirt Pollutant Characteristics

Most of the street surface dust and dirt materials (by weight) are local soil erosion products, while some materials are contributed by motor vehicle emissions and wear (Shaheen 1975). Minor contributions are made by erosion of street surfaces in good condition. The specific makeup of street surface contaminants is a function of many conditions and varies widely (Pitt 1979).

Table 3-4. Common Elements in Soils (Lindsay 1979)

Abundance Rank	Element	Typical Minimum (mg/kg)	Typical Maximum (mg/kg)	Typical Average (mg/kg)
1	O	- -	- -	490,000
2	Si	230,000	350,000	320,000
3	Al	10,000	300,000	71,000
4	Fe	7,000	550,000	38,000
5	C	- -	- -	20,000
6	Ca	7,000	500,000	13,700
7	K	400	30,000	8,300
8	Na	750	7,500	6,300
9	Mg	600	6,000	5,000
10	Ti	1,000	10,000	4,000
11	N	200	4,000	1,400
12	S	30	10,000	700
13	Mn	20	3,000	600
14	P	200	5,000	600
15	Ba	100	3,000	430
16	Zr	60	2,000	300
17	F	10	4,000	200
18	Sr	50	1,000	200
19	Cl	20	900	100
20	Cr	1	1,000	100
21	V	20	500	100

Automobile tire wear is a major source of zinc in urban runoff and is mostly deposited on street surfaces and nearby adjacent areas. About half of the airborne particulates lost due to tire wear settle out on the street and the majority of the remaining particulates settle within about six meters of the roadway. Exhaust particulates, fluid losses, drips, spills and mechanical wear products can all contribute lead to street dirt. Many heavy metals are important pollutants associated with automobile activity. Most of these automobile pollutants affect parking lots and street surfaces. However, some of the automobile related materials also affect areas adjacent to the streets. This occurs through the wind transport mechanism after being resuspended from the road surface by traffic-induced turbulence.

Automobile exhaust particulates contribute many important heavy metals to street surface particulates and to urban runoff and receiving waters. The most notable of these heavy metals has been lead. However, since the late 1980s, the concentrations of lead in stormwater has decreased substantially (by about ten times) compared to early 1970 observations. This decrease, of course, is associated with significantly decreased consumption of leaded gasoline.

Solomon and Natusch (1977) studied automobile exhaust particulates in conjunction with a comprehensive study of lead in the Champaign-Urbana, IL area. They found that the exhaust particulates existed in two distinct morphological forms. The smallest particulates were almost perfectly spherical, having diameters in the range of 0.1 to 0.5 µm. These small particles consisted almost entirely of PbBrCl (lead, bromine, chlorine) at the time of emission. Because the particles are small, they are expected to remain airborne for considerable distances and can be captured in the lungs when inhaled. The researchers concluded that the small particles are formed by condensation of PbBrCl vapor onto small nucleating centers, which are probably introduced into the engine with the filtered engine air.

Solomon and Natusch (1977) found that the second major form of automobile exhaust particulates were rather large, being roughly 10 to 20 µm in diameter. These particles typically had irregular shapes and somewhat smooth surfaces. The elemental compositions of these irregular particles were found to be quite variable, being predominantly iron, calcium, lead, chlorine and bromine. They found that individual particles did contain aluminum, zinc, sulfur, phosphorus and some carbon, chromium, potassium, sodium, nickel and thallium. Many of these elements (bromine, carbon, chlorine, chromium, potassium, sodium, nickel, phosphorus, lead, sulfur, and thallium) are most likely condensed, or adsorbed, onto the surfaces of these larger particles during passage through the exhaust system. They believed that these large particles originate in the engine or exhaust system because of their very high iron content. They found that 50 to 70 percent of the emitted lead was associated with these large particles, which would be deposited within a few meters of the emission point onto the roadway, because of their aerodynamic properties.

Solomon and Natusch (1977) also examined urban particulates near roadways and homes in urban areas. They found that lead concentrations in soils were higher near roads and houses. This indicated the capability of road dust and peeling house paint to contaminate nearby soils. The lead content of the soils ranged from130 to about 1,200 mg/kg. Koeppe (1977), during another element of the Champaign-Urbana lead study, found that lead was tightly bound to various soil components. However, the lead did not remain in one location, but it was transported both downward in the soil profile and to adjacent areas through both natural and man-assisted processes.

Atmospheric Sources of Urban Runoff Pollutants

Atmospheric processes affecting urban runoff pollutants include dry dustfall and precipitation quality. These have been monitored in many urban and rural areas. In many instances, however, the samples were combined as a bulk precipitation sample before processing. Automatic precipitation sampling equipment can distinguish between dry periods of fallout and precipitation. These devices cover and uncover appropriate collection jars exposed to the atmosphere. Much of this information has been collected as part of the Nationwide Urban Runoff Program (NURP) and the Atmospheric Deposition Program, both sponsored by the USEPA (EPA 1983a).

This information must be interpreted carefully, because of the ability of many polluted dust and dirt particles to be resuspended and then redeposited within the urban area. In many cases, the measured atmospheric deposition measurements include material that was previously residing and measured in other urban runoff pollutant source areas. Also, only small amounts of the atmospheric deposition material would directly contribute to runoff. Rain is subjected to infiltration and the dry fall particulates are likely mostly incorporated with surface soils and only small fractions are then eroded during rains. Therefore, mass balances and determinations of urban runoff deposition and accumulation from different source areas can be highly misleading, unless transfer of material between source areas and the effective yield of this material to the receiving water is considered. Depending on the land use, relatively little of the dustfall in urban areas likely contributes to stormwater discharges.

Dustfall and precipitation affect all of the major urban runoff source areas in an urban area. Dustfall, however, is typically not a major pollutant source but fugitive dust is mostly a mechanism for pollutant transport. Most of the dustfall monitored in an urban area is resuspended particulate matter from street surfaces or wind erosion products from vacant areas (Pitt 1979). Point source pollutant emissions can also significantly contribute to dustfall pollution, especially in industrial areas. Transported dust from regional agricultural activities can also significantly affect urban stormwater.

Wind transported materials are commonly called "dustfall." Dustfall includes sedimentation, coagulation with subsequent sedimentation and impaction. Dustfall is normally measured by collecting dry samples, excluding rainfall and snowfall. If rainout and washout are included, one has a measure of total atmospheric fallout. This total atmospheric fallout is sometimes called "bulk precipitation." Rainout removes contaminants from the atmosphere by condensation processes in clouds, while washout is the removal of contaminants by the falling rain. Therefore, precipitation can include natural contamination associated with condensation nuclei in addition to collecting atmospheric pollutants as the rain or snow falls. In some areas, the contaminant contribution by dry deposition is small, compared to the contribution by precipitation (Malmquist 1978). However, in heavily urbanized areas, dustfall can contribute more of an annual load than the wet precipitation, especially when dustfall includes resuspended materials.

Table 3-5 summarizes rain quality reported by several researchers. As expected, the non-urban area rain quality can be substantially better than urban rain quality. Many of the important heavy metals, however, have not been detected in rain in many areas of the country. The most important heavy metals found in rain have been lead and zinc, both being present in rain in concentrations from about 20 μg/L up to several hundred μg/L. It is expected that more recent lead rainfall concentrations would be substantially less, reflecting the decreased use of leaded gasoline since these measurements were taken. Iron is also present in relatively high concentrations in rain (about 30 to 40 μg/L).

Table 3-5. Summary of reported rain quality.

	Rural-Northwest (Quilayute, WA)[1]	Rural-Northeast (Lake George, NY)[1]	Urban-Northwest (Lodi, NJ)[2]	Urban-Midwest (Cincinnati, OH)[3]	Other Urban[3]	Continental Avg. (32 locations)[1]
Suspended solids, mg/L				13		
Volatile suspended solids, mg/L				3.8		
Inorganic nitrogen, mg/L as N				0.69		
Ammonia, mg/L as N					0.7	
Nitrates, mg/L as N					0.3	
Total phosphates, mg/L as P					<0.1	
Ortho phosphate, mg/L as P				0.24		
Scandium, µg/L	<0.002	nd				nd
Titanium, µg/L	nd	nd				nd
Vanadium, µg/L	nd	nd				nd
Chromium, µg/L	<2	nd	1			nd
Manganese, µg/L	2.6	3.4				12
Iron, µg/L	32	35				
Cobalt, µg/L	0.04	nd				nd
Nickel, µg/L	nd	nd	3			43
Copper, µg/L	3.1	8.2	6			21
Zinc, µg/L	20	30	44			107
Lead, µg/L			45			

1) Rubin 1976
2) Wilbur and Hunter 1980
3) Manning, *et al*. 1976

The concentrations of various urban runoff pollutants associated with dry dustfall are summarized in Table 3-6. Urban, rural and oceanic dry dustfall samples contained more than 5,000 mg iron/kg total solids. Zinc and lead were present in high concentrations. These constituents can have concentrations of up to several thousand mg of pollutant per kg of dry dustfall. Spring, *et al*. (1978) monitored dry dustfall near a major freeway in Los Angeles, CA. Based on a series of samples collected over several months, they found that lead concentrations on and near the freeway can be about 3,000 mg/kg, but as low as about 500 mg/kg 150 m (500 feet) away. In contrast, the chromium concentrations of the dustfall did not vary substantially between the two locations and approached oceanic dustfall chromium concentrations.

Much of the monitored atmospheric dustfall and precipitation would not reach the urban runoff receiving waters. The percentage of dry atmospheric deposition retained in a rural watershed was extensively monitored and modeled in Oakridge, TN (Barkdoll, *et al*. 1977). They found that about 98% of the lead in dry atmospheric deposits was retained in the watershed, along with about 95% of the cadmium, 85% of the copper, 60% of the chromium and magnesium and 75% of the zinc and mercury. Therefore, if the dry deposition rates were added directly to the yields from other urban runoff pollutant sources, the resultant urban runoff loads would be very much overestimated.

Tables 3-7 and 3-8 report bulk precipitation (dry dustfall plus rainfall) quality and deposition rates as reported by several researchers. For the Knoxville, KY, area (Betson 1978), chemical oxygen demand (COD) was found to be the largest component in the bulk precipitation monitored, followed by filterable residue and nonfilterable residue. Table 3-8 also presents the total watershed bulk precipitation, as the percentage of the total stream flow output, for the three Knoxville watersheds studies. This shows that almost all of the pollutants presented in the urban runoff streamflow outputs could easily be accounted for by bulk precipitation deposition alone. Betson concluded that bulk precipitation is an important component for some of the constituents in urban runoff, but the transport and resuspension of particulates from other areas in the watershed are overriding factors.

Table 3-6. Atmosphere dustfall quality.

Constituent, (mg constituent/kg total solids)	Urban[1]	Rural/ suburban[1]	Oceanic[1]	Near freeway (LA)[2]	500' from freeway (LA)[2]
pH				4.3	4.7
Phosphate-Phosphorous				1200	1600
Nitrate-Nitrogen, µg/L				5800	9000
Scandium, µg/L	5	3	4		
Titanium, µg/L	380	810	2700		
Vanadium, µg/L	480	140	18		
Chromium, µg/L	190	270	38	34	45
Manganese, µg/L	6700	1400	1800		
Iron, µg/L	24000	5400	21000		
Cobalt, µg/L	48	27	8		
Nickel, µg/L	950	1400			
Copper, µg/L	1900	2700	4500		
Zinc, µg/L	6700	1400	230		
Lead, µg/L				2800	550

1) Summarized by Rubin 1976
2) Spring 1978

Rubin (1976) stated that resuspended urban particulates are returned to the earth's surface and waters in four main ways: gravitational settling, impaction, precipitation and washout. Gravitational settling, as dry deposition, returns most of the particles. This not only involves the settling of relatively large fly ash and soil particles, but also the settling of smaller particles that collide and coagulate. Rubin stated that particles that are less than 0.1 µm in diameter move randomly in the air and collide often with other particles. These small particles can grow rapidly by this coagulation process. These small particles would soon be totally depleted in the air if they were not constantly replenished. Particles in the 0.1 to 1.0 µm range are also removed primarily by coagulation. These larger particles grow more slowly than the smaller particles because they move less rapidly in the air, are somewhat less numerous and, therefore, collide less often with other particles. Particles with diameters larger than 1 µm have appreciable settling velocities. Those particles about 10 µm in diameter can settle rapidly, although they can be kept airborne for extended periods of time and for long distances by atmospheric turbulence.

The second important particulate removal process from the atmosphere is impaction. Impaction of particles near the earth's surface can occur on vegetation, rocks and building surfaces. The third form of particulate removal from the atmosphere is precipitation, in the form of rain and snow. This is caused by the rainout process where the particulates are removed in the cloud-forming process. The fourth important removal process is washout of the particulates below the clouds during the precipitation event. Therefore, it is easy to see that re-entrained particles (especially from street surfaces, other paved surfaces, rooftops and from soil erosion) in urban areas can be readily redeposited through these various processes, either close to the points of origin or at some distance away.

Table 3-7. Bulk precipitation quality.

Constituent (all units mg/L except pH)	Urban (average of Knoxville St. Louis & Germany)[1]	Rural (Tennessee)[1]	Urban (Guteburg, Sweden)[2]
Calcium	3.4	0.4	
Magnesium	0.6	0.1	
Sodium	1.2	0.3	
Chlorine	2.5	0.2	
Sulfate	8.0	8.4	
pH	5.0	4.9	
Organic Nitrogen	2.5	1.2	
Ammonia Nitrogen	0.4	0.4	2
Nitrite plus Nitrate-N	0.5	0.4	1
Total phosphate	1.1	0.8	0.03
Potassium	1.8	0.6	
Total iron	0.8	0.7	
Manganese	0.03	0.05	
Lead	0.03	0.01	0.05
Mercury	0.01	0.0002	
Nonfilterable residue	16		
Chemical Oxygen Demand	65		10
Zinc			0.08
Copper			0.02

1) Betson 1978
2) Malmquist 1978

Pitt (1979) monitored airborne concentrations of particulates near typical urban roads. He found that on a number basis, the downwind roadside particulate concentrations were about 10% greater than upwind conditions. About 80% of the concentration increases, by number, were associated with particles in the 0.5 to 1.0 µm size range. However, about 90% of the particle concentration increases by weight were associated with particles greater than 10 µm. Pitt found that the rate of particulate resuspension from street surfaces increases when the streets are dirty (cleaned infrequently) and varied widely for different street and traffic conditions. The resuspension rates were calculated based upon observed long-term accumulation conditions on street surfaces for many different study area conditions, and varied from about 0.30 to 3.6 kg per curb-km (one to 12 lb per curb-mile) of street per day.

Murphy (1975) described a Chicago study where airborne particulate material within the city was microscopically examined, along with street surface particulates. The particulates from both of these areas were found to be similar (mostly limestone and quartz) indicating that the airborne particulates were most likely resuspended street surface particulates, or were from the same source.

Table 3-8. Urban bulk precipitation deposition rates (Betson 1978)[1].

Rank	Constituent	Average Bulk Deposition Rate (kg/ha/yr)	Average Bulk Prec. as a % of Total Streamflow Output
1	Chemical oxygen demand	530	490
2	Filterable residue	310	60
3	Nonfilterable residue	170	120
4	Alkalinity	150	120
5	Sulfate	96	470
6	Chloride	47	360
7	Calcium	38	170
8	Potassium	21	310
9	Organic nitrogen	17	490
10	Sodium	15	270
11	Silica	11	130
12	Magnesium	9	180
13	Total Phosphate	9	130
14	Nitrite and Nitrate-N	5.7	360
15	Soluble phosphate	5.3	170
16	Ammonia Nitrogen	3.2	1,100
17	Total Iron	1.9	47
18	Fluoride	1.8	300
19	Lead	1.1	650
20	Manganese	0.54	270
21	Arsenic	0.07	720
22	Mercury	0.008	250

1) Average for three Knoxville, KY, watersheds.

PEDCo (1977) found that the re-entrained portion of the traffic-related particulate emissions (by weight) is an order of magnitude greater than the direct emissions accounted for by vehicle exhaust and tire wear. They also found that particulate resuspensions from a street are directly proportional to the traffic volume and that the suspended particulate concentrations near the streets are associated with relatively large particle sizes. The medium particle size found, by weight, was about 15 µm, with about 22% of the particulates occurring at sizes greater than 30 µm. These relatively large particle sizes resulted in substantial particulate fallout near the road. They found that about 15% of the resuspended particulates fall out at 10 m, 25% at 20 m, and 35% at 30 m from the street (by weight).

In a similar study Cowherd, *et al.* (1977) reported a wind erosion threshold value of about 5.8 m/s (13 mph). At this wind speed, or greater, significant dust and dirt losses from the road surface could result, even in the absence of traffic-induced turbulence. Rolfe and Reinbold (1977) also found that most of the particulate lead from automobile emissions settled out within 100 m of roads. However, the automobile lead does widely disperse over a large area. They found, through multi-elemental analyses, that the settled outdoor dust collected at or near the curb was contaminated by automobile activity and originated from the streets.

Source Area Sheetflow and Particulate Quality

The following discussion summarizes the source area sheetflow and particulate quality data obtained from several studies conducted in California, Washington, Nevada, Wisconsin, Illinois, Ontario, Colorado, New Hampshire, and New York since 1979. Most of the data obtained were for street dirt chemical quality, but a relatively large amount of parking and roof runoff quality data have also been obtained. Only a few of these studies evaluated a broad range of source areas or land uses.

Source Area Particulate Quality

Particulate potency factors (usually expressed as mg pollutant/kg dry particulate residue) for many samples are summarized on Tables 3-9 and 3-10. These data can help recognize critical source areas, but care must be taken if they are used for predicting runoff quality because of likely differential effects due to washoff and erosion from the different source areas. These data show the variations in chemical quality between particles from different land uses and source areas. Typically, the potency factors increase as the use of an area becomes more intensive, but the variations are slight for different locations throughout the country. Increasing concentrations of heavy metals with decreasing particle sizes was also evident, for those studies that included particle size information. Only the quality of the smallest particle sizes are shown on these tables because they best represent the particles that are removed during rains.

Warm Weather Sheetflow Quality

Sheetflow data, collected during actual rain, are probably more representative of runoff conditions than the previously presented dry particulate quality data because they are not further modified by washoff mechanisms. These data, in conjunction with source area flow quantity information, can be used to predict outfall conditions and the magnitude of the relative sources of critical pollutants. Tables 3-11 through 3-14 summarize warm weather sheetflow observations, separated by source area type and land use, from many locations. The major source area categories are listed below:

1. Roofs
2. Paved parking areas
3. Paved storage areas
4. Unpaved parking and storage areas
5. Paved driveways
6. Unpaved driveways
7. Dirt walks
8. Paved sidewalks
9. Streets
10. Landscaped areas
11. Undeveloped areas
12. Freeway paved lanes and shoulders

Table 3-9. Summary of observed street dirt mean chemical quality (mg constituent/kg solids).

Constituent	Residential	Commercial	Industrial
P	620 (4)		670 (4)
	540 (6)	400 (6)	
	1100 (5)	1500 (5)	
	710 (1)	910 (1)	
	810 (3)		
TKN	1030 (4)		560 (4)
	3000 (6)	1100 (6)	
	290 (5)	340 (5)	
	2630 (3)	4300 (2)	
	3000 (2)		
COD	100,000 (4)		65,000 (4)
	150,000 (6)	110,000 (6)	
	180,000 (5)	250,000 (5)	
	280,000 (1)	340,000 (1)	
	180,000 (3)	210,000 (2)	
	170,000 (2)		
Cu	162 (4)		360 (4)
	110 (6)	130 (6)	
	420 (2)	220 (2)	
Pb	1010 (4)		900 (4)
	1800 (6)	3500 (6)	
	530 (5)	2600 (5)	
	1200 (1)	2400 (1)	
	1650 (3)	7500 (2)	
	3500 (2)		
Zn	460 (4)		500 (4)
	260 (5)	750 (5)	
	325 (3)	1200 (2)	
	680 (2)		
Cd	<3 (5)	5 (5)	
	4 (2)	5 (2)	
Cr	42 (4)		70 (4)
	31 (5)	65 (5)	
	170 (2)	180 (2)	

References; location; particle size described:
(1) Bannerman, *et al*. 1983 (Milwaukee, WI) <31μm
(2) Pitt 1979 (San Jose, CA) <45 μm
(3) Pitt 1985 (Bellevue, WA) <63 μm
(4) Pitt and McLean 1986 (Toronto, Ontario) <125 μm
(5) Pitt and Sutherland 1982 (Reno/Sparks, NV) <63 μm
(6) Terstriep, *et al*. 1982 (Champaign/Urbana, IL) >63 μm

Table 3-10. Summary of observed particulate quality for other source areas (means for <125μm particles) (mg constituent/kg solids).

	P	TKN	COD	Cu	Pb	Zn	Cr
Residential/Commercial Land Uses							
	1500	5700	240,000	130	980	1900	77
Roofs	600	790	78,000	145	630	420	47
Paved parking	400	850	50,000	45	160	170	20
Unpaved driveways	550	2750	250,000	170	900	800	70
Paved driveways	360	760	25,000	15	38	50	25
Dirt footpath	1100	3620	146,000	44	1200	430	32
Paved sidew alk	1300	1950	70,000	30	50	120	35
Garden soil	870	720	35,000	35	230	120	25
Road shoulder							
Industrial Land Uses							
Paved parking	770	1060	130,000	1110	650	930	98
Unpaved parking/storage	620	700	110,000	1120	2050	1120	62
Paved footpath	890	1900	120,000	280	460	1300	63
Bare ground	700	1700	70,000	91	135	270	38

Source: Pitt and McLean 1986 (Toronto, Ontario)

Table 3-11. Sheetflow quality summary for other source areas (mean concentration and source of data).

Pollutant and Land Use	Roofs	Paved Parking	Paved Storage	Unpaved Parking/Storage	Paved Driveways	Unpaved Driveways	Dirt Walks	Paved Sidewalks	Streets
Total Solids (mg/L)									
Residential:	58 (5) 64 (1) 18 (4)	1790 (5)	73 (5)		510 (5)		1240 (5)	49 (5)	325 (5) 235 (4)
Commercial:	95 (1) 190 (4)	340 (2) 240 (1) 102 (7)							325 (4)
Industrial:	113 (5)	490 (5)	270 (5)	1250 (5)	506 (5)	5620 (5)		580 (5)	1800 (5)
Suspended Solids (mg/L)									
Residential:	22 (1) 13 (5)	1660 (5)	41 (5)		440 (5)		810 (5)	20 (5)	242 (5)
Commercial:		270 (2) 65 (1) 41 (7)							242 (5)
Industrial:	4 (5)	306 (5)	202 (5)	730 (5)	373 (5)	4670 (5)		434 (5)	1300 (5)
Dissolved Solids (mg/L)									
Residential:	42 (10 5 (5)	130 (5)	32 (5)		70 (5)		430 (5)	29 (5)	83 (5) 83 (4)
Commercial:		70 (2) 175 (1) 61 (7)							83 (5)
Industrial:	109 (5)	184 (5)	68 (5)	520 (5)	133 (5)	950 (5)		146 (5)	500 (5)

Table 3-11. Sheetflow quality summary for other source areas (mean concentration and source of data) (Continued).

Pollutant and Land Use	Roofs	Paved Parking	Paved Storage	Unpaved Parking/Storage	Paved Driveways	Unpaved Driveways	Dirt Walks	Paved Sidewalks	Streets
BOD_5 (mg/L)									
Residential:	3 (4)	22 (4)							13 (4)
Commercial:	7 (4)	11 (1) 4 (8)							
COD (mg/L)									
Residential:	46 (5) 27 (1) 20 (4)	173 (5)	22 (5)		178 (5)			62 (5)	174 (5) 170 (4)
Commercial:	130 (4)	190 (2) 180 (4) 53 (1) 57 (8)							174 (5)
Industrial:	55 (5)	180 (5)	82 (5)	247 (5)	138 (5)	418 (5)		98 (5)	322 (5)
Total Phosphorus (mg/L)									
Residential:	0.03 (5) 0.05 (1) 0.1 (4)				0.36 (5)		0.20 (5)	0.80 (5)	0.62 (5) 0.31 (4)
Commercial:	0.03 (4) 0.07 (4)	0.16 (1) 0.15 (7) 0.73 (5) 0.9 (2) 0.5 (4)							0.62 (5)
Industrial:	<0.06 (5)	2.3 (5)	0.7 (5)	1.0 (5)	0.9 (5)	3.0 (5)		0.82 (5)	1.6 (5)

Table 3-11. Sheetflow quality summary for other source areas (mean concentration and source of data) (Continued).

Pollutant and Land Use	Roofs	Paved Parking	Paved Storage	Unpaved Parking/Storage	Paved Driveways	Unpaved Driveways	Dirt Walks	Paved Sidewalks	Streets
Total Phosphate (mg/L)									
Residential:	<0.04 (5) 0.08 (4)				<0.2 (5)		0.66 (5)	0.64 (5)	0.07 (5) 0.12 (4)
Commercial:	0.02 (4)	0.03 (5) 0.3 (2) 0.5 (4) 0.04 (7) 0.22 (8)	<0.02 (5)						0.07 (5)
Industrial:	<0.02 (5)	0.6 (5)	0.06 (5)	0.13 (5)	<0.02 (5)	0.10 (5)		0.03 (5)	0.15 (5)
TKN (mg/L)									
Residential:	1.1 (5) 0.71 (4)				3.1 (5)		1.3 (5)	1.1 (5)	2.4 (5) 2.4 (4)
Commercial:	4.4 (4)	3.8 (5) 4.1 (2) 1.5 (4) 1.0 (1) 0.8 (8)							2.4 (5)
Industrial:	1.7 (5)	2.9 (5)	3.5 (5)	2.7 (5)	5.7 (5)	7.5 (5)		4.7 (5)	5.7 (5)
Ammonia (mg/L)									
Residential:	0.1 (5) 0.9 (1) 0.5 (4)	0.1 (5)	0.3 (5)		<0.1 (5)		0.5 (5)	0.3 (5)	<0.1 (5) 0.42 (4)
Commercial:	1.1 (4)	1.4 (2) 0.35 (4) 0.38 (1)							<0.1 (5)
Industrial:	0.4 (5)	0.3 (5)	0.3 (5)	<0.1 (5)	<0.1 (5)	<0.1 (5)		<0.1 (5)	<0.1 (5)

Table 3-11. Sheetflow quality summary for other source areas (mean concentration and source of data) (Continued).

Pollutant and Land Use	Roofs	Paved Parking	Paved Storage	Unpaved Parking/Storage	Paved Driveways	Unpaved Driveways	Dirt Walks	Paved Sidewalks	Streets
<u>Phenols (mg/L)</u>									
Residential:	2.4 (5)	12.2 (5)	30.0 (5)		9.7 (5)		<0.4 (5)	8.6 (5)	6.2 (5)
Industrial:	1.2 (5)	9.4 (5)	2.6 (5)	8.7 (5)	7.0 (5)	7.4 (5)		8.7 (5)	24 (7)
<u>Aluminum (µg/L)</u>									
Residential:	0.4 (5)	3.2 (5)	0.38 (5)		5.3 (5)		<0.03 (5)	0.5 (5)	1.5 (5)
Industrial:	<0.2 (5)	3.5 (5)	3.1 (5)	9.2 (5)	3.4 (5)	41 (5)		1.2 (5)	14 (5)
<u>Cadmium (µg/L)</u>									
Residential:	<4 (5) 0.6 (1)	2 (5)	<5 (5)		5 (5)		<1 (5)	<4 (5)	<5 (5)
Commercial:		5.1 (7) 0.6 (8)							<5 (5)
Industrial:	<4 (5)	<4 (5)	<4 (5)	<4 (5)	<4 (5)	<4 (5)		<4 (5)	<4 (5)
<u>Chromium (µg/L)</u>									
Residential:	<60 (5) <5 (4)	20 (5) 71 (4)	<10 (5)		<60 (5)		<10 (5)	<60 (5)	<60 (5) 49 (4)
Commercial:	<5 (4)	19 (7) 12 (8)							<60 (5)
Industrial:	<60 (5)	<60 (5)	<60 (5)	<60 (5)	<60 (5)	70 (5)		<60 (5)	<60 (5)

Table 3-11. Sheetflow quality summary for other source areas (mean concentration and source of data) (Continued).

Pollutant and Land Use	Roofs	Paved Parking	Paved Storage	Unpaved Parking/Storage	Paved Driveways	Unpaved Driveways	Dirt Walks	Paved Sidewalks	Streets
Copper (µg/L)									
Residential:	10 (5) <5 (4)	100 (5)	20 (5)		210 (5)		20 (5)	20 (5)	40 (5) 30 (4)
Commercial:	110 (4)	40 (2) 46 (4) 110 (7)							40 (5)
Industrial:	<20 (5)	480 (5)	260 (5)	120 (5)	40 (5)	140 (5)		30 (5)	220 (5)
Lead (µg/L)									
Residential:	<40 (5) 30 (3) 48 (1) 17 (4)	250 (5)	760 (5)		1400 (5)		30 (5)	80 (5)	180 (5) 670 (4)
Commercial:	19 (4) 30 (1)	200 (2) 350 (3) 1090 (4) 146 (1) 255 (7) 54 (8)							180 (5)
Industrial:	<40 (5)	230 (5)	280 (5)	210 (5)	260 (5)	340 (5)		<40 (5)	560 (5)

Table 3-11. Sheetflow quality summary for other source areas (mean concentration and source of data) (Continued).

Pollutant and Land Use	Roofs	Paved Parking	Paved Storage	Unpaved Parking/Storage	Paved Driveways	Unpaved Driveways	Dirt Walks	Paved Sidewalks	Streets
Zinc (µg/L)									
Residential:	320 (5) 670 (1) 180 (4)	520 (5)	390 (5)		1000 (5)		40 (5)	60 (5)	180 (5) 140 (4)
Commercial:	310 (1) 80 (4)	300 (5) 230 (4) 133 (1) 490 (7)							180 (5)
Industrial:	70 (5)	640 (7)	310 (5)	410 (5)	310 (5)	690 (5)		60 (5)	910 (5)

References:
(1) Bannerman, *et al*. 1983 (Milwaukee, WI) (NURP)
(2) Denver Regional Council of Governments 1983 (NURP)
(3) Pitt 1983 (Ottawa)
(4) Pitt and Bozeman 1982 (San Jose)
(5) Pitt and McLean 1986 (Toronto)
(6) STORET Site #590866-2954309 (Shop-Save-Durham, NH) (NURP)
(7) STORET Site #596296-2954843 (Huntington-Long Island, NY) (NURP)

Table 3-12. Sheetflow quality summary for undeveloped landscaped and freeway pavement areas (mean observed concentrations and source of data).

Pollutants	Landscaped Areas	Undeveloped Areas	Freeway Paved Lane and Shoulder Areas
Total Solids, mg/L	388 (4)	588 (4)	340 (5)
Suspended Solids, mg/L	100 (4)	400 (1) 390 (4)	180 (5)
Dissolved Solids, mg/L	288 (4)	193 (4)	160 (5)
BOD_5, mg/L	3 (3)	- - - -	10 (5)
COD, mg/L	70 (3) 26 (4)	72 (1) 54 (4)	130 (5)
Total Phosphorus, mg/L	0.42 (3) 0.56 (4)	0.40 (1) 0.68 (4)	- - - -
Total Phosphate, mg/L	0.32 (3) 0.14 (4)	0.10 (1) 0.26 (4)	0.38 (5)
TKN, mg/L	1.32 (3) 3.6 (4)	2.9 (1) 1.8 (4)	2.5 (5)
Ammonia, mg/L	1.2 (3) 0.4 (4)	0.1 (1) <0.1 (4)	- - - -
Phenols, µg/L	0.8 (4)	- - - -	- - - -
Aluminum, µg/L	1.5 (4)	11 (4)	- - - -
Cadmium, µg/L	<3 (4)	<4 (4)	60 (5)
Chromium, µg/L	10 (3)	<60 (4)	70 (5)
Copper, µg/L	<20 (4)	40 (1) 31 (3) <20 (4)	120 (5)
Lead, µg/L	30 (2) 35 (3) <30 (4)	100 (1) 30 (2) <40 (4)	2000 (5)
Zinc, µg/L	10 (3)	100 (1) 100 (4)	460 (5)

References:
(1) Denver Regional Council of Governments 1983 (NURP)
(2) Pitt 1983 (Ottawa)
(3) Pitt and Bozeman 1982 (San Jose)
(4) Pitt and McLean 1986 (Toronto)
(5) Shelly and Gaboury 1986 (Milwaukee)

Table 3-13. Source area bacteria sheetflow quality summary (means).

Pollutant and Land Use	Roofs	Paved Parking	Paved Storage	Unpaved Parking/ Storage	Paved Driveways	Unpaved Driveways	Dirt Walks	Paved Sidewalks	Streets	Land-scaped	Un-developed	Freeway Paved Lane and Shoulders
Fecal Coliforms (#/100 ml)												
Residential:	85 (2) <2 (3) 1400 (4)	250,000 (4)	100 (4)		600 (4)			11,000 (4)	920 (3) 6,900 (4)	3300 (4)	5400 (2) 49 (3)	1500 (7)
Commercial	9 (3)	2900 (2) 350 (3) 210 (1) 480 (5) 23,000 (6)										
Industrial:	1600 (4)	8660 (6)	9200 (4)	18,000 (4)	66,000 (4)	300,000 (4)		55,000 (4)	100,000 (4)			
Fecal Strep (#/100 ml)												
Residential:	170 (2) 920 (3) 2200 (4)	190,000 (4)	<100 (4)		1900 (4)		1800 (4)		>2400 (3) 7300 (4)	43,000 (4)	16,500 (2) 920 (3)	2200 (7)
Commercial:	17 (2)	11,900 (2) >2400 (3) 770 (1) 1120 (5) 62,000 (6)										
Industrial:	690 (4)	7300 (4)	2070 (4)	8100 (4)	36,000 (4)	21,000 (4)		3600 (4)	45,000 (4)			
Pseudo, Aerug (#/100 ml)												
Residential:	30,000 (4) 50 (4)	1900 (4)	100 (4)		600 (4)		600 (4)		570 (4)	2100 (4)		
Industrial:		5800 (4)	5850 (4)	14,000 (4)	14,300 (4)	100 (4)		3600 (4)	6200 (4)			

References:

(1) Bannerman, *et al*. 1983 (Milwaukee, WI) (NURP)

(2) Pitt 1983 (Ottawa)

(3) Pitt and Bozeman 1982 (San Jose)

(4) Pitt and McLean 1986 (Toronto)

(5) STORET Site #590866-2954309 (Shop-Save-Durham, NH) (NURP)

(6) STORET Site #596296-2954843 (Huntington-Long Island, NY) (NURP)

(7) Kobriger, *et al.* 1981 and Gupta, *et al*. 1977

Table 3-14. Source area filterable pollutant concentration summary (means).

	Residential			Commercial			Industrial		
	Total	Filterable	Filterable (%)	Total	Filterable	Filterable (%)	Total	Filterable	Filt. (%)
Roof Runoff									
Solids (mg/L)	64 58	42 45	66 (1) 77 (3)				113	110	97 (3)
Phosphorus (mg/L)	0.054	0.013	24 (1)						
Lead (µg/L)	48	4	8 (1)						
Paved Parking									
Solids (mg/L)				240 102 1790	175 61 138	73 (1) 60 (4) 8 (3)	490	138	28 (3)
Phosphorus (mg/L)				0.16 0.9	0.03 0.3	19 (1) 33 (2)			
TKN (mg/L)				0.77	0.48	62 (5)			
Lead (µg/L)				146 54	5 8.8	3 (1) 16 (5)			
Arsenic (µg/L)				0.38	0.095	25 (5)			
Cadmium (µg/L)				0.62	0.11	18 (5)			
Chromium (µg/L)				11.8	2.8	24 (5)			
Paved Storage									
Solids (mg/L)				73	32	44 (3)	270	64	24 (3)

References:

(1) Bannerman, *et al*. 1983 (Milwaukee) (NURP)
(2) Denver Regional Council of Governments 1983 (NURP)
(3) Pitt and McLean 1986 (Toronto)
(4) STORET Site #590866-2954309 (Shop-Save-Durham, NH) (NURP)
(5) STORET Site #596296-2954843 (Huntington-Long Island, NY) (NURP)

Toronto warm weather sheetflow water quality data were plotted against the rain volume that had occurred before the samples were collected to identify any possible trends of concentrations with rain volume (Pitt and McLean 1986). The street runoff data obtained during the special washoff tests were also compared with the street sheetflow data obtained during the actual rain events (Pitt 1987). These data observations showed definite trends of solids concentrations verses rain volume for most of the source area categories, as shown later. Sheetflows from all pervious areas combined had the highest total solids concentrations from any source category, for all rain events. Other paved areas (besides streets) had total solids concentrations similar to runoff from smooth industrial streets. The concentrations of total solids in roof runoff were almost constant for all rain events, being slightly lower for small rains than for large rains. No other pollutant, besides SS, had observed trends of concentrations with rain depths for the samples collected in Toronto. Lead and zinc concentrations were highest in sheetflows from paved parking areas and streets, with some high zinc concentrations also found in roof drainage samples. High bacteria populations were found in sidewalk, road, and some bare ground sheetflow samples (collected from locations where dogs would most likely be "walked").

Some of the Toronto sheetflow contributions were not sufficient to explain the concentrations of some constituents observed in runoff at the outfall. High concentrations of dissolved chromium, dissolved copper, and dissolved zinc in a Toronto industrial outfall during both wet and dry weather could not be explained by wet weather sheetflow observations (Pitt and McLean 1986). As an example, very few detectable chromium observations were obtained in any of the more than 100 surface sheetflow samples analyzed. Similarly, most of the fecal coliform populations observed in sheetflows were significantly lower than those observed at the outfall, especially during snowmelt. It is expected that some industrial wastes, possibly originating from metal plating operations, were the cause of these high concentrations of dissolved metals at the outfall and that some sanitary sewage was entering the storm drainage system.

Table 3-14 summarizes the little filterable pollutant concentration data available for different source areas. Most of the available data are for residential roofs and commercial parking lots.

Sources of Stormwater Toxicants Case Study in Birmingham, AL

Pitt, *et al*. (1995) studied stormwater runoff samples from a variety of source areas under different rain conditions as summarized in Table 3-15. All of the samples were analyzed in filtered (0.45 µm filter) and non-filtered forms to enable partitioning of the toxicants into "particulate" (non-filterable) and "dissolved" (filterable) forms.

Table 3-15. Numbers of samples collected from each source area type.

Local Source Areas[1]	Residential	Commercial/ Institutional	Industrial	Mixed
Roofs	5	3	4	
Parking Areas	2	11	3	
Storage Areas	na	2	6	
Streets	1	1	4	
Loading Docks	na	na	3	
Vehicle Service Area	na	5	na	
Landscaped Areas	2	2	2	
Urban Creeks				19
Detention Ponds				12

1) All collected in Birmingham, AL.

The samples listed in Table 3-15 were all obtained from the Birmingham, AL, area. Samples were taken from shallow flows originating from homogeneous source areas by using several manual grab sampling procedures. For deep flows, samples were collected directly into the sample bottles. For shallow flows, a peristaltic hand operated vacuum pump created a small vacuum in the sample bottle, which then gently drew the sample directly into the container through a Teflon™ tube. About one liter of sample was needed, split into two containers: one 500 ml glass bottle with Teflon™ lined lid was used for the organic and toxicity analyses and another 500 ml polyethylene bottle was used for the metal and other analyses.

An important aspect of the research was to evaluate the effects of different land uses and source areas, plus the effects of rain characteristics, on sample toxicant concentrations. Therefore, careful records were obtained of the amount of rain and the rain intensity that occurred before the samples were obtained. Antecedent dry period data were also obtained to compare with the chemical data in a series of statistical tests.

All samples were handled, preserved, and analyzed according to accepted protocols (EPA 1982 and 1983b). The organic pollutants were analyzed using two gas chromatographs, one with a mass selective detector (GC/MSD) and another with an electron capture detector (GC/ECD). The pesticides were analyzed according to EPA method 505, while the base neutral compounds were analyzed according to EPA method 625 (but only using 100 ml samples). The pesticides were analyzed on a Perkin Elmer Sigma 300 GC/ECD using a J&W DB-1 capillary column (30m by 0.32 mm ID with a 1 µm film thickness). The base neutrals were analyzed on a Hewlett Packard 5890 GC with a 5970 MSD using a Supelco DB-5 capillary column (30m by 0.25 mm ID with a 0.2 µm film thickness). Table 3-16 lists the organic toxicants that were analyzed.

Table 3-16. Toxic pollutants analyzed in samples.

Pesticides Detention Limit = 0.3 µg/L	Phthalate Esters Detention Limit = 0.5 µg/L	Polycyclic Aromatic Hydrocarbons Detention Limit = 0.5 µg/L		Metals Detention Limit = 1 µg/L
BHC (Benzene hexachloride)	Bis(2-ethylhexyl) Phthalate	Acenaphthene	Fluoranthene	Aluminum
Heptachlor	Butyl benzyl phthalate	Acenapthylene	Fluorene	Cadmium
Aldrin	Di-n-butyl phthalate	Anthracene	Indeno (1,2,3-cd) pyrene	Chromium
Endosulfan	Diethyl phthalate	Benzo (a) anthracene	Naphthalene	Copper
Heptachlor epoxide	Dimethyl phthalate	Benzo (a) pyrene	Phenanthrene	Lead
DDE (Dichlorodiphenyl dichloroethylene)	Di-n-octyl phthalate	Benzo (b) fluoranthene	Pyrene	Nickel
DDD (Dichlorodiphenyl dichloroethane)		Benzo (ghi) perylene		Zinc
DDT (Dichlorodiphenyl trichloroethane)		Benzo (k) fluoranthene		
Endrin		Chrysene		
Chlordane		Dibenzo (a,h) anthracene		

Metallic toxicants, also listed in Table 3-16, were analyzed using a graphite furnace equipped atomic absorption spectrophotometer (GFAA). EPA methods 202.2 (Al), 213.2 (Cd), 218.2 (Cr), 220.2 (Cu), 239.2 (Pb), 249.2 (Ni), and 289.2 (Zn) were followed in these analyses. A Perkin Elmer 3030B atomic absorption spectrophotometer was used after nitric acid digestion of the samples. Previous research (Pitt and McLean 1986; EPA 1983a) indicated that low detection limits were necessary in order to measure the filtered sample concentrations of the metals, which would not be achieved by use of a standard flame atomic absorption spectrophotometer. Low detection limits would enable partitioning of the metals between the solid and liquid phases to be investigated, an important factor in assessing the fates of the metals in receiving waters and in treatment processes.

The Microtox™ 100% sample toxicity screening test, from Azur Environmental (previously Microbics, Inc.), was selected for this research after comparisons with other laboratory bioassay tests. During the first research, 20 source area stormwater samples and combined sewer samples (obtained during a cooperative study being conducted in New York City) were split and sent to four laboratories for analyses using 14 different bioassay tests. Conventional bioassay tests were conducted using freshwater organisms at the EPA's Duluth, MN, laboratory and using marine organisms at the EPA's Narragansett Bay, RI, laboratory. In addition, other bioassay tests, using bacteria, were also conducted at the Environmental Health Sciences Laboratory at Wright State University, Dayton, OH. The tests represented a range of organisms that included fish, invertebrates, plants, and microorganisms.

The conventional bioassay tests conducted simultaneously with the Microtox™ screening test for the 20 stormwater sheetflow and combined sewer overflow (CSO) samples were all short-term tests. However, some of the tests were indicative of chronic toxicity (e.g., life cycle tests and the marine organism sexual reproduction tests), whereas the others would be classically considered as indicative of acute toxicity (e.g., Microtox™ and the fathead minnow tests). The following list shows the major tests that were conducted by each participating laboratory:

1. University of Alabama at Birmingham, Environmental Engineering Laboratory
   Microtox™ bacterial luminescence tests (10-, 20-, and 35-minute exposures)
   using the marine *Photobacterium phosphoreum.*

2. Wright State University, Biological Sciences Department
   Macrofaunal toxicity tests:
   Daphnia magna (water flea) survival; *Lemma minor* (duckweed) growth;
   and *Selenastrum capricornutum* (green alga) growth.
   Microbial activity tests (bacterial respiration):
   Indigenous microbial electron transport activity;
   Indigenous microbial inhibition of β-galactosidase activity;
   Alkaline phosphatase for indigenous microbial activity;
   Inhibition of β-galactosidase for indigenous microbial activity; and
   Bacterial surrogate assay using *O*-nitrophenol-β-D-galactopyranside
   activity and *Escherichia coli.*

3. EPA Environmental Research Laboratory, Duluth, MN
   Ceriodaphnia dubia (water flea) 48-h survival; and
   Pimephales promelas (fathead minnow) 96-h survival.

4. EPA Environmental Research Laboratory, Narragansett Bay, RI
   Champia parvula (marine red alga) sexual reproduction (formation of cystocarps
   after 5 to 7 d exposure); and
   Arbacua punctulata (sea urchin) fertilization by sperm cells.

Table 3-17 summarizes the results of the toxicity tests. The *C. dubia. P. promelas,* and C. *Parvula* tests experienced problems with the control samples and, therefore, these results are therefore uncertain. The *A. pustulata* tests on the stormwater samples also had a potential problem with the control samples. The CSO test results (excluding the fathead minnow tests) indicated that from 50% to 100% of the samples were toxic, with most tests identifying the same few samples as the most toxic. The toxicity tests for the stormwater samples indicated that 0% to 40% of the samples were toxic. The Microtox™ screening procedure gave similar rankings for the samples as the other toxicity tests.

Table 3-17. Fraction of samples rated as toxic.

Sample series	Combined sewer overflows (%)	Stormwater (%)
Microtox™ marine bacteria	100	20
C. Dubia	60	0[1]
P. promelas	0[1]	0[1]
C. parvula	100	0[1]
A. punctulata	100	0[1]
D. magna	63	40
L. minor	50[1]	0

1) Results uncertain, see text

Laboratory toxicity tests can result in important information on the effects of stormwater in receiving waters, but actual in-stream taxonomic studies should also be conducted. A recently published proceedings of a conference on stormwater impacts on receiving streams (Herricks 1995) contains many examples of actual receiving water impacts and toxicity test protocols for stormwater.

All of the Birmingham samples represented separate stormwater. However, as part of the Microtox™ evaluation, several CSO samples from New York City were also tested to compare the different toxicity tests. These samples were collected from six CSO discharge locations having the following land uses:

1. 290 acres, 90% residential and 10% institutional.
2. 50 acres, 100% commercial.
3. 620 acres, 20% institutional, 6% commercial, 5% warehousing, 5% heavy industrial, and 64% residential.
4. 225 acres, 13% institutional, 4% commercial, 2% heavy industrial. and 81% residential.
5. 400 acres, 1% institutional and 99% residential.
6. 250 acres, 88% commercial. 6% warehousing, and 6% residential.

Therefore, there was a chance that some of the CSO samples may have had some industrial process waters. However, none of the Birmingham sheetflow samples could have contained any process waters because of how and where they were collected.

The Microtox™ screening procedure gave similar toxicity rankings for the 20 samples as the conventional bioassay tests. It is also a rapid procedure (requiring about one hour) and only requires small (<1 mL) sample volumes. The Microtox™ toxicity test uses marine bioluminescence bacteria and monitors the light output for different sample concentrations. About one million bacteria organisms are used per sample, resulting in highly repeatable results. The more toxic samples produce greater stress on the bacteria test organisms that results in a greater light attenuation compared to the control sample. Note that the Microtox™ procedure was not used during this research to determine the absolute toxicities of the samples or to predict the toxic effects of stormwater runoff on receiving waters. It was used to compare the relative toxicities of different samples that may indicate efficient source area treatment locations, and to examine changes in toxicity during different treatment procedures.

Results

Table 3-18 summarizes the source area sample data for the most frequently detected organic toxicants and for all of the metallic toxicants analyzed. The organic toxicants analyzed, but not reported, were generally detected in five, or less, of the non-filtered samples and in none of the filtered samples. Table 3-18 shows the mean, maximum, and minimum concentrations for the detected toxicants. Note that these values are based only on the observed concentrations. They do not consider the non-detectable conditions. Mean values based on total sample numbers for each source area category would therefore result in much lower concentrations. The frequency of detection is therefore an important consideration when evaluating organic toxicants. High detection frequencies for the organics may indicate greater potential problems than infrequent high concentrations.

Table 3-18. Stormwater toxicants detected in at least 10% of the source area sheetflow samples (µg/L, unless otherwise noted).

	Roof areas		Parking areas		Storage areas		Street runoff		Loading docks		Vehicle service areas		Landscaped areas		Urban creeks		Detention ponds	
	N.F.[1]	F.[2]	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.
Total samples	12	12	16	16	8	8	6	6	3	3	5	5	6	6	19	19	12	12
Base neutrals (detection limit = 0.5 µg/L)																		
1,3-Dichlorobenzene detection frequency = 20% N.F. and 13% F.																		
No. detected[3]	3	2	3	2	1	1	1	1	0	0	3	2	3	2	2	0	1	1
Mean[4]	52	20	34	13	16	14	5.4	3.3			48	26	29	5.6	93		27	21
Max.	88	23	103	26							72	47	54	7.5	120			
Min.[5]	14	17	3.0	2.0							6.0	4.9	4.5	3.8	65			
Fluoranthene detection frequency = 20% N.F. and 12% F.																		
No. detected	3	2	3	2	1	0	1	1	0	0	3	2	3	2	1	0	2	1
Mean	23	9.3	37	2.7	4.5	0	0.6	0.5			39	3.6	13	1.0	130		10	6.6
Max.	45	14	110	5.4							53	6.8	38	1.3			14	
Min.	7.6	4.8	3.0	2.0							0.4	0.4	0.7	0.7			6.6	
Pyrene detection frequency = 17% N,F, and 7% F.																		
No. detected	1	0	3	2	1	0	1	1	0	0	3	2	2	0	1	0	2	1
Mean	28		40	9.8	8		1.0	0.7			44	4.1	5.3		100		31	5.8
Max.			120	20							51	7.4	8.2				57	
Min.			3.0	2.0							0.7	0.7	2.3				6.0	
Benzo(b)fluoranthene detection frequency = 15% N.F. and 0% F.																		
No. detected	4	0	3	0	0	0	1	0	0	0	2	0	1	0	2	0	0	0
Mean	76		53				14				98		30		36			
Max.	260		160								110				64			
Min.	6.4		3.0								90				8.0			
Benzo(k)fluoranthene detection frequency = 11% N.F. and 0% F.																		
No. detected	0	0	3	0	0	0	1	0	0	0	2	0	1	0	2	0	0	0
Mean			20				15				59		61		55			
Max.			1								103				78			
Min.			3.0								15				31			
Benzo(a)pyrene detection frequency = 15% N.F. and 0% F.																		
No. detected	4	0	3	0	0	0	1	0	0	0	2	0	1	0	2	0	0	0
Mean	99		40				19				90		54		73			
Max.	300		120								120				130			
Min.	34		3.0								60				19			

Table 3-18. Stormwater toxicants detected in at least 10% of the source area sheetflow samples (µg/L, unless otherwise noted).Continued.

	Roof areas		Parking areas		Storage areas		Street runoff		Loading docks		Vehicle service areas		Landscaped areas		Urban creeks		Detention ponds	
	N.F.[1]	F.[2]	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.
Total samples	12	12	16	16	8	8	6	6	3	3	5	5	6	6	19	19	12	12
Bis(2-chloroethyl) ether detection frequency = 12% N.F. and 2% F.																		
No. detected	3	1	2	0	0	0	1	0	0	0	1	1	1	0	1	0	1	0
Mean	42	17	20				15				45	23	56		200		15	
Max.	87	2	39															
Min.	20		2.0								6.0	4.9	4.5	3.8	65			
Bis(chloroisopropyl) ether detection frequency = 13% N.F. and 0% F.																		
No. detected	3	0	3	0	0	0	0	0	0	0	2	0	1	0	2	0	0	0
Mean	99		130								120		85		59			
Max.	150		400								160				78			
Min.	68		3.0								74				40			
Naphthalene detection frequency = 11% N.F. and 6% F.																		
No. detected	2	0	1	1	0	0	0	0	0	0	2	1	1	0	1	1	2	2
Mean	17		72	6.6							70	82	49		300	6.7	43	12
Max.	21										100						68	17
Min.	13										37						18	6.6
Benzo(a)anthracene detection frequency = 10% N.F. and 0% F.																		
No. detected	1	0	3	0	0	0	0	0	0	0	2	0	1	0	1	0	0	0
Mean	16		24								35		54		61			
Max.			73								39							
Min.			3.0								31							
Butylbenzyl phthalate detection frequency = 10% N.F. and 4% F.																		
No. detected	1	0	2	1	0	0	0	0	0	0	2	2	1	0	1	0	1	0
Mean	100		12	3.3							26	9.8	130		59		13	
Max.			21								48	16						
Min.			3.3								3.8	3						
Pesticides (detection limit = 0.3 µg/L)																		
Chlordane detection frequency = 11% N.F. and 0% F.																		
No. detected	2	0	2	0	3	0	1	0	0	0	1	0	0	0	0	0	0	0
Mean	1.6		1.0		1.7		0.8			0.8								
Max.	2.2		1.2		2.9													
Min.	0.9		0.8		1.0													

Table 3-18. Stormwater toxicants detected in at least 10% of the source area sheetflow samples (µg/L, unless otherwise noted).Continued.

	Roof areas		Parking areas		Storage areas		Street runoff		Loading docks		Vehicle service areas		Landscaped areas		Urban creeks		Detention ponds	
	N.F.[1]	F.[2]	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.
Total samples	12	12	16	16	8	8	6	6	3	3	5	5	6	6	19	19	12	12
Metals (detection limit = 1µg/L)																		
Lead detection frequency = 100% N.F. and 54% F.																		
No. detected	12	1	16	8	8	7	6	4	3	1	5	2	6	1	19	15	12	8
Mean	41	1.1	46	2.1	105	2.6	43	2.0	55	2.3	63	2.4	24	1.7	20	1.4	19	1.0
Max.	170		130	5.2	330	5.7	150	3.9	80		110	3.4	70		100	1.6	55	1.0
Min.	1.3		1.0	1.2	3.6	1.6	1.5	1.1	25		27	1.4	1.4		1.4	<1	1	<1
Zinc detection frequency = 99% N.F. and 98% F.																		
No. detected	12	12	16	16	8	7	6	6	2	2	5	5	6	6	19	19	12	12
Mean	250	220	110	86	1730	22	58	31	55	33	105	73	230	140	10	10	13	14
Max.	1580	1550	650	560	13100	100	130	76	79	62	230	230	1160	670	32	23	25	25
Min.	11	9	12	6	12	3.0	4.0	4.0	31	4.0	30	11	18	18	<1	<1	<1	<1
Copper detection frequency = 98% N.F. and 78% F.																		
No. detected	11	7	15	13	8	6	6	5	3	2	5	4	6	6	19	17	12	8
Mean	110	2.9	116	11	290	250	280	3.8	22	8.7	135	8.4	81	4.2	50	1.4	43	20
Max.	900	8.7	770	61	1830	1520	1250	11	30	15	580	24	300	8.8	440	1.7	210	35
Min.	1.5	1.1	10	1.1	10	1.0	10	1.0	15	2.6	1.5	1.1	1.9	0.9	<1	<1	0.2	<1
Aluminum detection frequency = 97% N.F. and 92% F.																		
No. detected	12	12	15	15	7	6	6	6	3	1	5	4	5	5	19	19	12	12
Mean	6850	230	3210	430	2320	180	3080	880	780	18	700	170	2310	1210	620	190	700	210
Max.	71300	1550	6480	2890	6990	740	10040	4380	930		1370	410	4610	1860	3250	500	1570	360
Min.	25	6.4	130	5.0	180	10	70	18	590		93	0.3	180	120	<5	<5	<5	<5
Cadmium detection frequency = 95% N.F. and 69% F.																		
No. detected	11	7	15	9	8	7	6	5	3	3	5	3	4	2	19	15	12	9
Mean	3.4	0.4	6.3	0.6	5.9	2.1	37	0.3	1.4	0.4	9.2	0.3	0.5	0.6	8.3	0.2	2	0.5
Max.	30	0.7	70	1.8	17	10	220	0.6	2.4	0.6	30	0.5	1	1	30	0.3	11	0.7
Min.	0.2	0.1	0.1	0.1	0.9	0.3	0.4	0.1	0.7	0.3	1.7	0.2	0.1	0.1	<0.1	<0.1	0.1	0.4
Chromium detection frequency = 91% N.F. and 55% F.																		
No. detected	7	2	15	8	8	5	5	4	3	0	5	1	6	5	19	15	11	8
Mean	85	1.8	56	2.3	75	11	9.9	1.8	17		74	2.5	79	2.0	62	1.6	37	2.0
Max.	510	2.3	310	5.0	340	32	30	2.7	40		320		250	4.1	710	4.3	230	3.0
Min.	5.0	1.4	2.4	1.1	3.7	1.1	2.8	1.3	2.4		2.4		2.2	1.4	<0.1	<0.1	<0.1	<0.1

Table 3-18. Stormwater toxicants detected in at least 10% of the source area sheetflow samples (μg/L, unless otherwise noted).Continued.

	Roof areas		Parking areas		Storage areas		Street runoff		Loading docks		Vehicle service areas		Landscaped areas		Urban creeks		Detention ponds	
	N.F.[1]	F.[2]	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.
Total samples	12	12	16	16	8	8	6	6	3	3	5	5	6	6	19	19	12	12
Nickel detection frequency = 90% N.F. and 37% F.																		
No. detected	10	0	14	4	8	1	5	0	3	1	5	1	4	1	18	16	11	8
Mean	16		45	5.1	55	87	17		6.7	1.3	42	31	53	2.1	29	2.3	24	3.0
Max.	70		130	13	170		70		8.1		70		130		74	3.6	70	6.0
Min.	2.6		4.2	1.6	1.9		1.2		4.2		7.9		21		<1	<1	1.5	<1
Other constituents (always detected, analyzed only for non-filtered samples)																		
pH																		
Mean	6.9		7.3		8.5		7.6		7.8		7.2		6.7		7.7		8.0	
Max.	8.4		8.7		12		8.4		8.3		8.1		7.2		8.6		9.0	
Min.	4.4		5.6		6.5		6.9		7.1		5.3		6.2		6.9		7.0	
Suspended solids																		
Mean	14		110		100		49		40		24		33		26		17	
Max.	92		750		450		110		47		38		81		140		60	
Min.	0.5		9.0		5.0		7.0		34		17		8.0		5.0		3.0	

1) N.F.: concentration associated with a non-filtered sample.
2) F.: concentration after the sample was filtered through a 0.45 μm membrane filter.
3) Number detected refers to the number of samples in which the toxicant was detected.
4) Mean values based only on the number of samples with a definite concentration of toxicant reported (not on the total number of samples analyzed).
5) The minimum values shown are the lowest concentration detected, they are not necessarily the detection limit.

Table 3-18 also summarizes the measured pH and SS concentrations. Most pH values were in the range of 7.0 to 8.5 with a low of 4.4 and a high of 11.6 for roof and concrete plant storage area runoff samples, respectively. This range of pH can have dramatic effects on the speciation of the metals analyzed. The SS concentrations were generally less than 100 mg/L, with impervious area runoff (e.g., roofs and parking areas) having much lower SS concentrations and turbidities compared to samples obtained from pervious areas (e.g., landscaped areas).

Out of more than 35 targeted organic compounds analyzed, 13 were detected in more than 10% of all samples, as shown in Table 3-18. The greatest detection frequencies were for 1,3-dichlorobenzene and fluoranthene, which were each detected in 23% of the samples. The organics most frequently found in these source area samples (i.e., polycyclic aromatic hydrocarbons (PAH), especially fluoranthene and pyrene) were similar to the organics most frequently detected at outfalls in prior studies (EPA 1983a).

Roof runoff, parking area and vehicle service area samples had the greatest detection frequencies for the organic toxicants. Vehicle service areas and urban creeks had several of the observed maximum organic compound concentrations. Most of the organics were associated with the non-filtered sample portions, indicating an association with the particulate sample fractions. The compound 1,3-dichlorobenzene was an exception, having a significant dissolved fraction.

In contrast to the organics, the heavy metals analyzed were detected in almost all samples, including the filtered sample portions. The non-filtered samples generally had much higher concentrations, with the exception of zinc, which was mostly associated with the dissolved sample portion (i.e., not associated with the SS). Roof runoff generally had the highest concentrations of zinc, probably from galvanized roof drainage components, as previously reported by Bannerman, *et al*. (1983). Parking and storage areas had the highest nickel concentrations, while vehicle service areas and street runoff had the highest concentrations of cadmium and lead. Urban creek samples had the highest copper concentrations, which were probably due to illicit industrial connections or other non-stormwater discharges.

Table 3-19 shows the relative toxicities of the collected stormwaters. A wide range of toxicities was found. About 9% of the non-filtered samples were considered highly toxic using the Microtox™ toxicity screening procedure. About 32% of the samples were moderately toxic and about 59% were considered non-toxic. The greatest percentage of samples considered the most toxic were from industrial storage and parking areas. Landscaped areas also had a high incidence of highly toxic samples (presumably due to landscaping chemicals) and roof runoff had some highly toxic samples (presumably due to high zinc concentrations). Treatability study activities indicated that filtering the samples through a range of fine sieves and finally a 0.45µm filter consistently reduced sample toxicities. The chemical analyses also generally found much higher toxicant concentrations in the non-filtered sample portions, compared to the filtered sample portions.

Replicate samples were collected from several source areas at three land uses during four different storm events to statistically examine toxicity and pollutant concentration differences due to storm and site conditions. These data indicated that variations in Microtox™ toxicities and organic toxicant concentrations may be partially explained by rain characteristics. As an example, high concentrations of many of the PAHs were associated with long antecedent dry periods and large rains (Barron 1990).

Pollution Prevention Associated with Selection of Building Materials

The selection of alternative building materials exposed to weather can have a significant effect on runoff quality. The above information showed obvious problems associated with roof runoff caused by the exposure of galvanized metal flashing to rain water. Treated wood has also been of concern as a likely source of heavy metal and organic toxicants.

Table 3-19. Relative toxicity of samples using Microtox ä (non-filtered).

Local Source Areas	Highly Toxic (%)	Moderately Toxic (%)	Not Toxic (%)	Number of Samples
Roofs	8	58	33	12
Parking Areas	19	31	50	16
Storage Areas	25	50	25	8
Streets	0	67	33	6
Loading Docks	0	67	33	3
Vehicle Service Areas	0	40	60	5
Landscaped Areas	17	17	66	6
Urban Creeks	0	11	89	19
Detention Ponds	8	8	84	12
All Areas	9	32	59	87

Microbics suggested toxicity definitions for 35 minute exposures:
Highly toxic - light decrease >60%
Moderately toxic - light decrease <60% & >20%
Not toxic - light decrease <20%

The detection of pentachlophenols in stormwater indicates important leaching from treated wood. Frequent detections of polycyclic aromatic hydrocarbons (PAHs) during the U.S. Environmental Protection Agency's Nationwide Urban Runoff Program (EPA 1983a) may possibly indicate leaching from creosote treated wood, in addition to fossil fuel combustion sources. High concentrations of copper, and some chromium and arsenic observations also indicate the potential of leaching from "CCA" (copper, chromium, and arsenic) treated wood. The significance of these leachate products in the receiving waters is currently unknown, but altematives to these preservatives should be considered. Many cities use aluminum and concrete utility poles instead of treated wood poles. This is especially important considering that utility poles are usually located very close to the drainage system ensuring an efficient delivery of leachate products. Many homes currently use wood stains containing pentachlorophenol and other wood preservatives. Similarly, the construction of retaining walls, wood decks and playground equipment with treated wood is common. Some preservatives (especially creosote) cause direct skin irritation, besides contributing to potential problems in receiving waters. Many of these wood products are at least located some distance from the storm drainage system, allowing some improvement to surface water quality by infiltration through pervious surfaces.

There is growing interest in the development and use of environmentally sensitive construction materials. Studies conducted at the University of Alabama at Birmingham (Pitt, *et al*., 1995) investigated toxic contributions to urban wet weather flow from sources such as roofs, parking areas, storage areas, streets, loading docks, vehicle service areas, and landscaped areas. Roof runoff, vehicle service area and parking lot samples were found to have the greatest organic toxicant detection frequencies and the highest levels of detected metals. However, relative pollutant contributions from various roofing, wooden and paving materials themselves are also a concern which has not been adequately addressed. Due to the common use of these surfaces in our urban environments, reduction of emissions at the source is desirable, and material substitution would seem a good place to start.

Roofing and Paving Materials

Other studies have verified the UAB research, confirming the important role played by roofs and paved surfaces to pollutant contributions to wet weather flow. Boller (1997) identified heavy metals such as cadmium, copper, lead and zinc as the critical metals in domestic wastewaters and, based on his flow studies, concluded that runoff from roofs and streets contribute 50-80% of these metals to the total mass flow in Swiss combined sewer systems. Roof runoff samples, from tile, polyester, and flat gravel roofs were analyzed and metal concentrations were found to vary tremendously with roof type. First flush analyses showed polyester roofs contributing highest concentrations of copper (6,817 μg/L), zinc (2,076 μg/L), cadmium (3.1 μg/L) and lead (510 μg/L). Concentrations in runoff from tile roofs were copper (1,905 μg/L), zinc (360 μg/L), cadmium (2.1 μg/L) and lead (172 μg/L). Runoff from flat gravel roofs also contributed copper (140 μg/L), zinc (36 μg/L), cadmium (0.2 μg/L) and lead (22 μg/L). Runoff from roofs was found to contain not only heavy metals, but polyaromatic hydrocarbons (PAHs) and organic halogens as well. Mottier and Boller (1996), working in Zurich, measured metals concentrations in road runoff and found average values of 300 μg/L for lead, 4 μg/l for cadmium, 150 μg/L for copper and 500 μg/L for zinc. Information on pavement material type was not included. Averaged roof runoff concentrations (from tile and polyester roofs) were also measured at 16 μg/L for lead, 0.17 μg/L for cadmium, 225 μg/L for copper and 42 μg/l for zinc. Boller concluded that copper installations on buildings seem to represent the largest source for the discharges of this metal into the environment. He estimated annual zinc and copper corrosion from roof metal installations at 4-14 grams/sq. meter and 7.5-15 grams/sq. meter respectively. Stark, *et al* (1995) arrived at a similar conclusion, estimating that stormwater from roofs may be responsible for more the 60% of the copper in Austria's combined sewers.

Researchers in Marquette, Michigan, collecting wet weather flow concurrently at 33 sites during 12 storms detected discernable differences in runoff quality between a variety of impervious source areas (Steuer, *et al*. 1997). Commercial and residential rooftops were found to produce the lowest concentrations of suspended solids, but the highest concentrations of dissolved metals such as lead, zinc, cadmium, and copper. Parking lots produced the highest concentrations for all PAH compounds and high concentrations of zinc, total cadmium and total copper. Low traffic streets were also identified as a major producer of total cadmium.

Forster (1996) sampled and analyzed roof runoff for heavy metals (Cd, Cu, Zn, Pb) between April 1993 and May 1994. Measurement were made with an experimental roof system situated on the Campus of the University of Bayreuth and at various locations in the urban area of Bayreuth, Northern Bavaria. The experimental roof systems allowed the influence of different roof materials (concrete tiles, zinc sheet, pantiles, fibrous cement) on runoff quality to be compared. Large differences in runoff pollutant concentrations from various roofs were interpreted to indicate that the pollutants were not only being transported to the surface via the atmosphere, but also originating from the material itself. Extremely high values of zinc and copper were measured when the roof system or parts of it were made of metal panels, flashing, and gutters. For example, runoff concentrations from zinc sheet roofing started almost three orders of magnitude higher and remained more than twenty times above the values measured for the roofs affected only by atmospheric deposition. Forster noted the most critical effect of runoff pollution containing heavy metals is their high ecotoxicity in receiving waters. Mean runoff concentration values at his study sites exceeded by about two orders of magnitude local toxicity thresholds. Peak values exceeded thresholds by a factor of 1000 or more. Forster concluded by advocating abandoning the use of exposed metal surfaces on roofs and walls of buildings.

Good (1993) reported the results of one time sampling of runoff from a rusty galvanized metal roof, a weathered metal roof, a built-up roof of plywood covered with roofing paper and tar, a flat tar-covered roof which had been painted with a fibrous reflective aluminum paint, and a relatively new anodized aluminum material at a sawmill facility on the coast of Washington . The research was carried out following the discovery that stormwater samples from the site were acutely toxic and contained high concentrations of zinc. Differences in contributions of copper, lead, and zinc were noticed between each roof type. Built-up roofing contributed the highest concentrations of dissolved copper (128 μg/L) and total copper (166 μg/L), approximately 10 times higher than levels detected in runoff from the other roofs sampled. Runoff from the rusty galvanized metal roof contained the highest concentrations of dissolved lead (35 μg/L) and total lead (302 μg/L), dissolved zinc (11,900 μg/L) and total zinc (12,200 μg/L). High concentrations of zinc were noted in runoff from each type of roof sampled at the site. Dissolved metals concentrations and toxicity remained high in roof runoff samples collected three hours after the beginning of the storm event, indicating metals leaching continued throughout storm events. All roof runoff samples were found to be highly toxic to rainbow trout with the aluminum painted roof least toxic. Roof runoff sample concentrations exceeded the water quality criteria for copper, lead, and zinc in all samples, though the greatest exceedences were for zinc. Acid rain and the high ionic content of the coastal atmosphere were thought to have contributed to the rapid corrosion of the galvanized metal roofs and leaching of zinc. Interestingly, plastic rain gutters were also reported as a source of lead.

Thomas and Greene (1993) working in and near Armidale, Australia found differences in metal contaminate levels between urban and rural roofs associated with variations in atmospheric deposition and differences related to antecedent dry periods. He also found runoff water quality influenced by different roof types. Zinc concentrations were significantly higher in galvanized iron roof catchments, while pH, conductivity and turbidity levels were higher in concrete tile roof catchments.

Pitt, *et al*. (1995) found high concentrations of organic constituents in runoff from several types of paved source areas. Paved areas receive pollutant contributions from vehicle exhaust emissions, tire and brake wear, vehicle corrosion and leaks, carry-in and atmospheric deposition, which are then washed off to varying degrees in subsequent rains. However, differences noted between sampling sites indicate potential differences in contribution of organics from paving materials themselves. Polycyclic aromatic hydrocarbons (PAHs) in particular are of concern, because they are known to have potential for adverse effects to a large number of invertebrates, fishes, birds, and mammals (Kennish 1992). Chlorination of PAHs in water treatment plants have also been found to produce carcinogenic by-products (Kopfler, *et al*. 1977).

Exposed Wooden Material/Treated Wood

Typical treated woods include chromated-copper-arsenate (CCA), ammoniacal copper zinc arsenate (ACZA), pentachlorophenol (PCP), and creosote. The volume of treated wood produced in the United States in 1987 was as follows: CCA/ACZA – 11.9 million cubic meters, PCP – 1.4 million cubic meters, Creosote – 2.8 million cubic meters.

Both arsenic and chromium are heavy metals which have acute environmental health risks associated with them. Copper does not generally constitute a human health risk, however, low concentrations of copper, in certain ionic forms, are highly toxic to marine fauna and flora. The known toxicity of arsenic and chromium to humans has resulted in concern about the possible introduction into the environment of large amounts of these metals in treated wood products (Brooks 1993).

Pentachlorophenol is a highly chlorinated, synthetic preservative containing pentachlorophenol, 2,3,4,6-tetrachlorophenol, higher chlorophenols, dioxins and furans. Arsenault (1975) and Stranks (1976) reported the presence of pentachlorophenol around the base of, and in drainage ditches near treated utility poles. Stranks reported drainage ditch waters with 1.8 times the 96-h LC50 of chlorophenol for salmonids near PCP treated utility poles. In 1991, the EPA determined that the use of pentachlorophenol poses the risk of oncogenicity because of the presence of hexachlorodibenzo-p-dioxin and hexacholorobenzene, both of which have the potential to produce teratogenic/fetotoxic effects) (CALEPA 1996).

Creosote is a rather complex chemical that is comprised of more than 160 different distillates that occur in coal-tar, including aromatic hydrocarbons (such as naphthalene, anthracene, benzene, toluene, xylene, acenaphthene, phenanthrene, and fluorene), tar acids (such as phenols, cresols, xylenols, and naphthols), and tar bases (including pyridines, guinolines, and acridines) many of which are toxicants and carcinogens. The EPA determined that creosote has the potential for oncogenicity and mutagenicity (CALEPA 1996).

Preliminary Leaching Tests to Investigate Building Material Contributions to Stormwater Contamination

Pitt, *et al*. (1999) examined the leaching effects associated with different building materials that may affect runoff quality, as part of his studies on the construction of pilot-scale treatment units. This information is summarized in the following paragraphs as an indication of the potential benefits of using alternative building materials. An important consideration when constructing any treatability apparatus is potential contamination of the test solutions by materials used in the construction of the device. Therefore, before the pilot-scale Multi-Chambered Treatment Train (MCTT) was constructed, a series of tests were conducted to examine the leachability of different potential construction materials. Samples of the various materials were left to soak in de-ionized water for set periods of time, and then the water was analyzed for a broad list of constituents of interest.

Samples of each material were immersed for a period of 72 h in approximately 500 mL of laboratory grade 18 megohm water. A sample blank was also prepared. Analyses conducted on each of these samples, and the sample blank included toxicity screening, major ion, and toxicant analyses. Table 3-20 presents the contaminants that were found in the leaching water at the end of the test in high concentrations that may affect the test results. The most serious problems occur with plywood, including both treated and untreated wood. Attempting to seal the wood with Formica and caulking was partially successful, but toxicants were still leached. Covering of the Formica clad plywood with polyethylene plastic sheeting was finally used to eliminate any potential problem in the pilot-scale treatment constructed. Fiberglass screening material, especially before cleaning, also causes a potential problem with plasticizers and other organics. PVC and aluminum may be acceptable materials, if phthalate esters and aluminum contamination can be tolerated.

Table 3-20. Potential Sample Contamination from Materials that may be used in Treatability Test Apparatus

Material:	Contaminant observed:
untreated plywood	toxicity, chloride, sulfate, sodium, potassium, calcium, 2,4-dimethylphenol, benzylbutyl phthalate, bis(2-ethylhexyl) phthalate, phenol, N-nitro-so-di-n-propylamine, 4-chloro-3-methylphenol, 2,4-dinitrotoluene, 4-nitrophenol, alpha BHC, gamma BHC, 4,4'-DDE, endosulfan II, methoxychlor, and endrin ketone
treated plywood (CCA)	toxicity, chloride, sulfate, sodium, potassium, hexachloroethane, 2,4-dimethylphenol, bis(2-chloroethoxyl) methane, 2,4-dichlorophenol, benzylbutyl phthalate, bis(2-ethylhexyl) phthalate, phenol, 4-chloro-3-methylphenol, acenaphthene, 2,4-dinitrotoluene, 4-nitrophenol, alpha BHC, gamma BHC, beta BHC, 4,4'-DDE, 4,4'-DDD, endosulfan II, endosulfan sulfate, methoxychlor, endrin ketone, and copper (likely), chromium (likely), arsenic (likely)
treated plywood (CCA) and Formica	toxicity, chloride, sulfate, sodium, potassium, **bis(2-chloroethyl) ether***, diethylphthalate, phenanthrene, anthracene, benzylbutyl phthalate, bis(2-ethylhexyl) phthalate, **phenol***, N-nitro-so-di-n-propylamine, **4-chloro-3-methylphenol***, 4-nitrophenol, pentachlorophenol, alpha BHC, 4,4'-DDE, endosulfan II, methoxychlor, endrin ketone, and copper (likely), chromium (likely), arsenic (likely)
treated plywood (CCA), Formica and silica caulk	lowered pH, toxicity, **bis(2-chloroethyl) ether***, hexachlorocyclopentadiene, diethylphthalate, bis(2-ethylhexyl) phthalate, **phenol***, N-nitro-so-di-n-propylamine, **4-chloro-3-methylphenol***, alpha BHC, heptachlor epoxide, 4,4'-DDE, endosulfan II, and copper (likely), chromium (likely), arsenic (likely)
Formica and silica caulk	lowered pH, toxicity, 4-chloro-3-methylphenol, aldrin, and endosulfan 1
silica caulk	lowered pH, toxicity, and heptachlor epoxide
PVC pipe	N-nitrosodiphenylamine, and 2,4-dinitrotoluene
PVC pipe with cemented joint	**bis(2-ethylhexyl) phthalate***, acenaphthene, and endosulfan sulfate
plexiglass and plexiglass cement	naphthalene, benzylbutyl phthalate, and bis(2-ethylhexyl) phthalate, and endosulfan II
aluminum	toxicity, and aluminum (likely)
plastic aeration balls	2,6-dinitrotoluene
filter fabric material	acenaphthylene, diethylphthalate, benzylbutyl phthalate, bis(2-ethylhexyl) phthalate, and pentachlorophenol
sorbent pillows	diethylphthalate, and bis(2-ethylhexyl) phthalate
black plastic fittings	pentachlorophenol
reinforced PVC tubing	diethylphthalate, and benzylbutyl phthalate
fiberglass window screening	toxicity, dimethylphthalate, **diethylphthalate***, bis(2-ethylhexyl) phthalate, di-n-octyl phthalate, phenol, 4-nitrophenol, pentachlorophenol, and 4,4'-DDD
Delrin™	benzylbutyl phthalate
Teflon™	nothing
glass	zinc (likely)

* the observed concentrations in the leaching solution were very large compared to the other materials.

Metals exposed to rain water are of obvious concern, as indicated by the roof runoff data. Treated wood is of obvious concern and should be avoided in locations near directly connected paved areas. It is also likely that runoff from fresh asphalt pavement can produce toxic effects, while aged asphalt surfaces do not cause problems. In many cases, much reduced amounts of toxicants reach the drainage system if the sheetflow water from these materials is allowed to drain across landscaped areas, where most of the heavy metals and organic toxicants seemed to be tightly sorbed to soil particulates. Of course, these soil particulates can erode and contribute contaminated sediments to the stormwater, while others can adversely affect groundwater (Pitt, *et al*. 1996). Selection of alternative materials is preferred. Most plastics, or plastic-coated metals should be acceptable, along with many traditional building materials (glass, brick and concrete), but much additional work needs to be done in this area.

Street Dirt Accumulation

The washoff of street dirt and the effectiveness of street cleaning as a stormwater control practice are highly dependent on the available street dirt loading. Street dirt loadings are the result of deposition and removal rates, plus "permanent storage." The permanent storage component is a function of street texture and condition and is the quantity of street dust and dirt that cannot be removed naturally by rains or winds, or by street cleaning equipment. It is literally trapped in the texture, or cracks, of the street. The street dirt loading at any time is this initial permanent loading plus the accumulation amount corresponding to the exposure period, minus the re-suspended material removal by wind and traffic-induced turbulence. Removal of street dirt can occur naturally by winds and rain, or by human activity (e.g., by the turbulence of traffic or by street cleaning equipment). Very little removal occurs by any process when the street dirt loadings are small, but wind removal may be very large with larger loadings, especially for smooth streets (Pitt 1979).

It takes many and frequent samples to ascertain the accumulation characteristics of street dirt. The studies briefly described in this discussion typically involved collecting many hundreds of composite street dirt samples during the course of the one to three year projects from each study area. With each composite sample made up of about 10 to 35 subsamples, a great number of subsamples were used to obtain the data. Without high resolution (and effective) sampling, it is not possible to identify the variations in loadings and effects of rains and street cleaning. Figures 3-1 and 3-2 are examples of the measured street dirt loading as a function of time for both smooth and rough streets (Pitt (1979). These plots clearly show accumulation rates (and increases in particle size of the street dirt) as time between street cleaning lengthens.

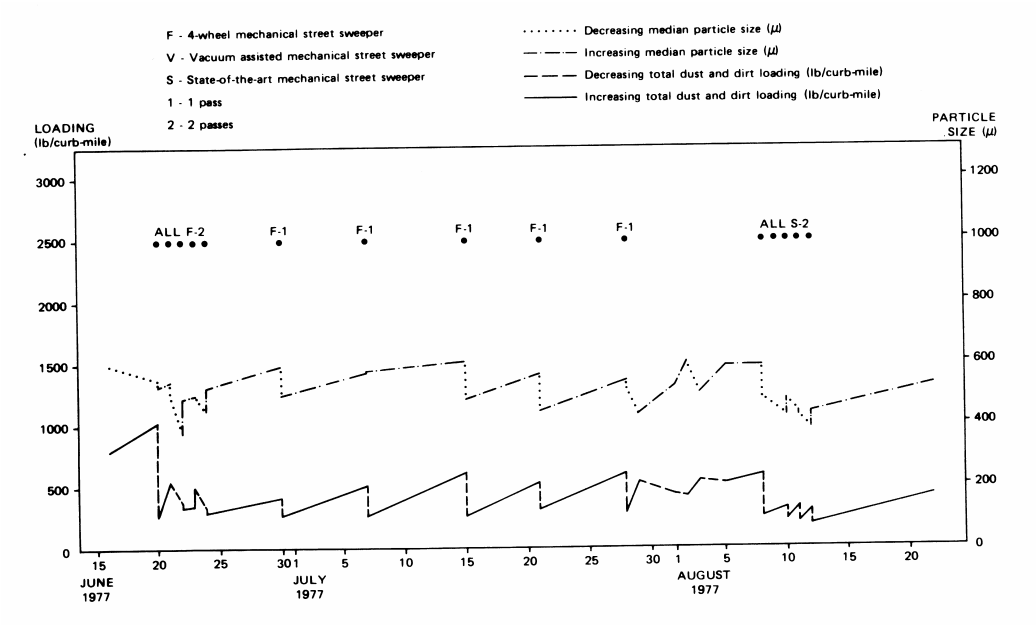


Figure 3-1. Street dirt accumulation and particle size changes on good asphalt streets in San Jose, CA (Pitt 1979).

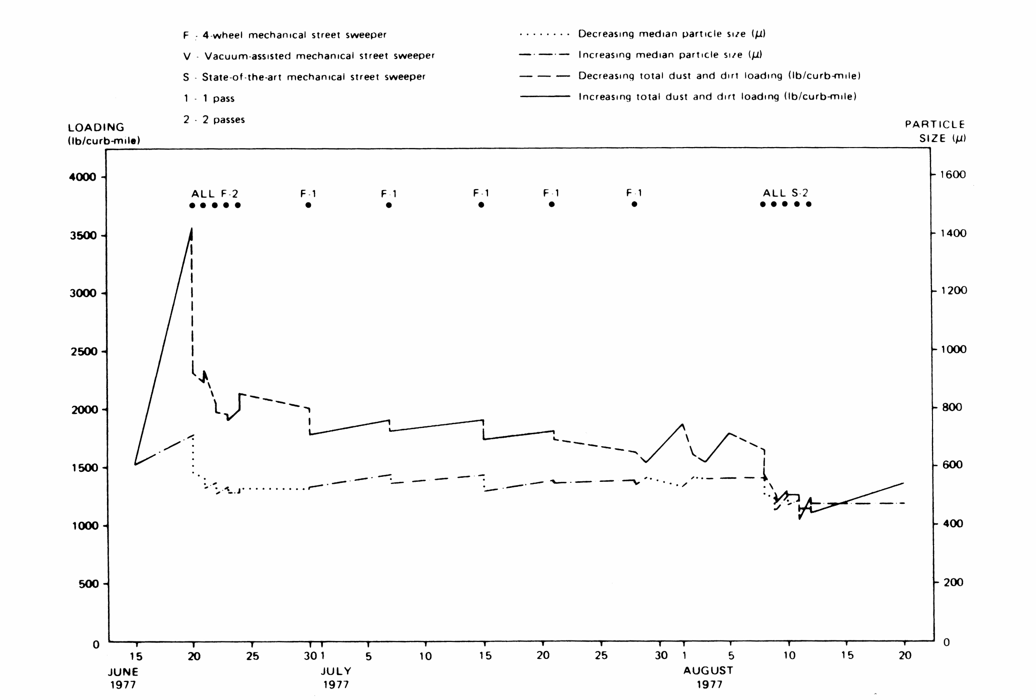


Figure 3-2. Street dirt accumulation and particle size changes on rough asphalt streets in San Jose, CA (Pitt 1979).

Figure 3-3 shows very different street dirt loadings for two San Jose, CA residential study areas (Pitt 1979). The accumulation and deposition rates (and therefore the amounts lost to air) are quite similar, but the initial loading values (the permanent storage values) are very different. The loading differences were almost solely caused by the different street textures.

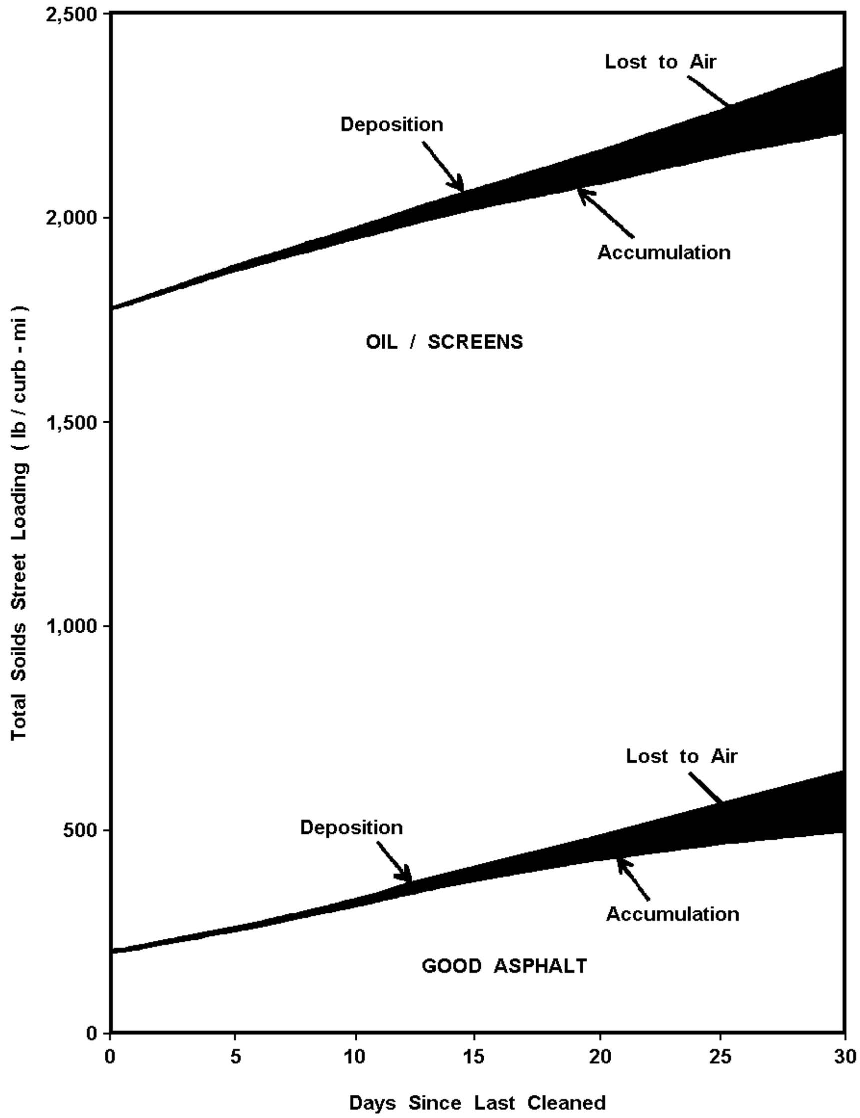


Figure 3-3. Deposition and accumulation of street dirt (Pitt 1979).

In early studies (APWA 1969; Sartor and Boyd 1972; and Shaheen 1975) it was assumed that the initial loading values were zero. However, the sampling procedures employed were very effective in removing all loose material from the streets, including the loadings that could not be removed by rains or street cleaning. Calculated accumulation rates for rough streets were therefore very large, as they were forced through the origin. The early, uncorrected, Sartor and Boyd accumulation rates that ignored the initial loading values were almost ten times the corrected values that had reasonable "initial loads."

A street dirt loading equation that can be used to represent street dirt loading (Pitt 1979) is:

$$Y = ax - bx^2 + c$$

where Y = street loading at time x,
a, b, and c are second order polynomial curve coefficients
ax represents the deposition loading
bx^2 represents the amount lost to the air
and c represents the initial storage loading

This curve should only be used over the range of observed accumulation periods. For long accumulation periods, this quadratic equation may predict decreasing loadings.

At very long accumulation periods relative to the rain frequency, the wind losses may approximate the deposition rate, resulting in very little loading increases. For Bellevue, Washington, with interevent rain periods averaging about 3 days, steady loadings were observed only after about 1 week (Pitt 1985). In Castro Valley, California, the rain interevent periods were much longer (ranging from about 20 to 100 days) and steady loadings were never observed (Pitt and Shawley 1982).

The accumulation period for each observed loading is needed before these accumulation curve coefficients can be calculated. It is the time since the streets were last cleaned, or the time since the last “significant” rain. A significant rain is usually considered to be about 10 mm, or larger, that occurs over a few hours. These rains normally remove at least 90% of the “available” street dirt washoff load, as will be described in the following discussion.

Street dirt loading data is difficult to fit to any curve because of many potential measurement and interpretation errors. The measurements are usually obtained with 25 percent allowable errors due to the large cost increases needed to collect enough sub-samples to significantly reduce these errors. As an example, it requires about five times as many street dirt subsamples for a 10 percent allowable error as compared to a 25 percent allowable error (Pitt 1979). Many areas also have frequent (every few days) rains. In most cases, frequent rains keep the street dirt loadings very close to the initial storage value, with little observed increase in dirt accumulation over time. If the loading value is not very well correlated with accumulation time, linear regression curve fitting may not be appropriate.

Other problems arise when attempting to use least squares regression techniques with data that contain different distributions of residuals (errors) over the range of predictor variables, or if the errors are not independent. This is especially true with street dirt accumulation data, as there are usually few street dirt loading observations associated with long accumulation periods. The shorter accumulation period observations usually have much smaller errors (due to smaller allowable data ranges) than the observations having longer accumulation periods (which are not as constrained). The short period loadings are relatively low, and the range of observed loadings at these low accumulation periods range from zero to values two or three times higher than the predicted loadings. The observed loadings at the longer accumulation periods are also constrained at zero for minimum values, but the range of possible values is much larger than for the lower loadings. The errors for these longer period observations can be greater because of the greater opportunity for other factors that are not included in the regression relationship to be prominent. These other factors include variable winds and moisture conditions. If the data is extensive, then it may be separated into seasonal groupings to reduce the variations of these other factors. Logarithmic transformations of the loading values can sometimes produce normally distributed residuals over the range of data that are necessary for least-squares regression analyses.

Early measurements of across-the-street dirt distributions made by Sartor and Boyd (1972) indicated that about 90 percent of the street dirt was within about 30 cm of the curb face (typically within the gutter area). These measurements, however, were made in areas of no parking (near fire hydrants because of the need for water for the sampling procedures that were used), and the traffic turbulence was capable of blowing most of the street dirt against the curb barrier (or over the curb onto adjacent sidewalks or landscaped areas) (Shaheen 1975). In later tests, Pitt (1979) and Pitt and Sutherland (1982) examined street dirt distributions across-the-street in many additional situations. They found distributions similar to Sartor and Boyd's observations only on smooth streets, with moderate to heavy traffic, and with no on-street parking. In many cases, most of the street dirt was actually in the driving lanes, trapped by the texture of rough streets. If extensive on-street parking was common, much of the street dirt was found several feet out into the street, where much of the resuspended (in air) street dirt blew against the parked cars and settled to the pavement. Figure 3-4 shows across-the-street distributions of street dirt, both before and after street cleaning for a relatively busy roadway (having no parking) in Bellevue, WA (Pitt 1985). Only about 20% of the street dirt was near the curb before street cleaning, while 90% was within about 8 ft. After cleaning, the load was even more evenly distributed, as the street cleaner preferentially removed street dirt near the curb and blew some dirt out into the street.

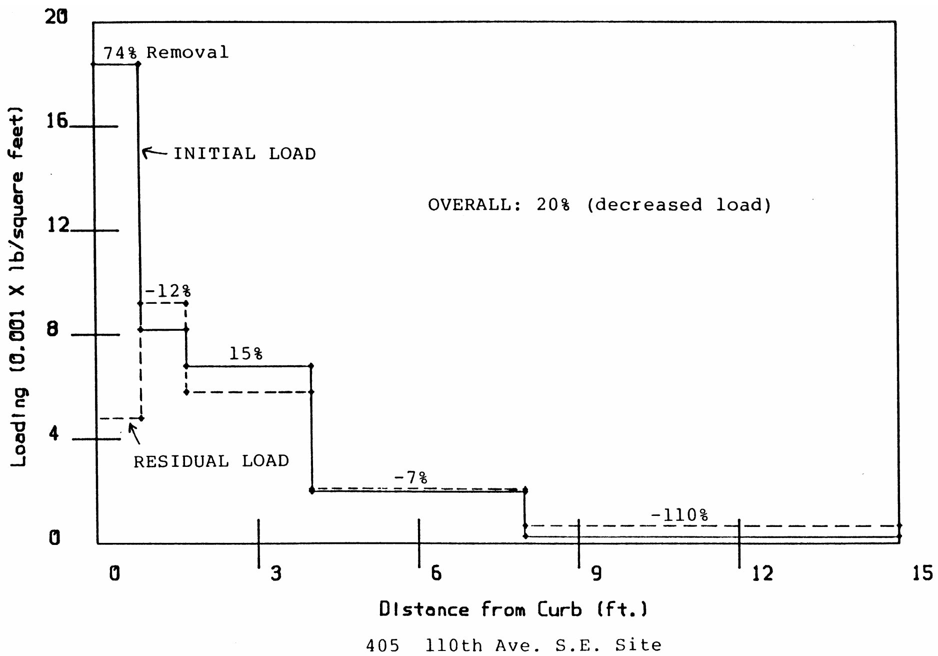


Figure 3-4. Re-distribution of street dirt across the street during street cleaning (Pitt 1985).

Methodology for Street Dirt Accumulation Measurements

Pitt and McLean (1984) conducted street dirt accumulation studies as part of the Humber River study portion of TAWMS (Toronto Area Watershed Management Study). Detailed results were also presented by Pitt (1987). An industrial street with heavy traffic (Norseman) and a residential street with light traffic (Glen Roy) in Toronto were monitored about twice a week for three months. At the beginning of this period, intensive street cleaning (one pass per day for each of three consecutive days) was conducted to obtain reasonably clean streets. Street dirt loadings were then monitored every few days to measure the accumulation rates of street dirt. Street dirt sampling procedures developed by Pitt (1979) were used. Basically, industrial vacuums were used to clean many separate subsample strips across the roads which were then combined for analysis.

Street Surface Particulate Sampling Procedures

The street dirt sampling procedures described here were developed by Pitt (1979) and were extensively used during many of the EPA's Nationwide Urban Runoff Program (NURP) projects (EPA 1983) and other street cleaning performance studies and washoff studies (Pitt 1987). These procedures were developed to be much for flexible and more accurate indicators of street dirt loading conditions than previous sampling methods used during earlier studies (such as Sartor and Boyd 1972, for example).

Powerful dry vacuum sampling, as used in this sampling procedure, is capable of removing practically all of the particulates (>99%) from the street surface, compared to wet sampling. It can also remove most of the other major pollutants from the street surface (>80% for COD, phosphates and metals, for example). Wet sampling (used by Sartor and Boyd 1972), better removes some of these other constituents, but is restricted to single area sampling, requires long periods of time, requires water (and usually fire hydrants further restricting sample collection locations to areas having no parked cars), and basically is poorly representative of the variable conditions present. Dry sampling can be used in many locations throughout an area, is fast, and can also be used to isolate specific sampling areas (such as driving lanes, areas with intensive parking, and even airport runways and freeways, if special safety precautions are used). It is especially useful when coupled with appropriate experimental design tools to enable suitable numbers of subsamples to be collected representing subareas, and finally, the collected dry samples can be readily separated into different particle sizes for discrete analyses.

Equipment Description. A small half-ton trailer was used to carry the generator, two stainless steel industrial vacuum units, vacuum hose and wand, miscellaneous tools, and a fire extinguisher. This equipment can also be fitted in a pick-up truck, but much time is then lost with frequent loading and unloading equipment, especially considering the frequent sampling that is typically used for a study of this nature (sampling at least once a week, and sometimes twice a day before and after street cleaning or rains). A truck with a suitable hitch and signal light connections was used to pull the trailer. The truck also had warning lights, including a roof-top flasher unit. The truck operated with its headlights and warning lights on during the entire period of sample collection. The sampler and hose tender both wore orange, high-visibility vests. The trailer was equipped with a caution sign on its tailgate. In addition, both the truck and the street cleaner used to clean the test area were equipped with radios (CB radios were adequate), so that the sampling team could contact the street cleaner operator when necessary to verify location and schedule for specific test areas.

Experiments were conducted to determine the most appropriate vacuum and filter bag combination. Two-horsepower (hp) industrial vacuum cleaners with one secondary filter and a primary dacron filter bag were selected. The vacuum units were heavy duty and made of stainless steel to reduce contamination of the samples. Two separate 2-hp vacuums were used together by joining their intakes with a wye connector. This combination extended the useful length of the 1.5 in. vacuum hose to 35 ft. and increased the suction so that it was adequate to remove all particles of interest from the street surface. Unfortunately, two vacuums had to be cleaned to recover the samples after the sample collection. A wand and a “gobbler” attachment were also needed. The aluminum gobbler attached to the end of the wand and is triangular in shape and about 6 in. across. Since it was scrapped across the street during sample collection, it wore out periodically and needed replacement. The generator used to power the vacuum units was of sufficient power to handle the electrical current load drawn by the vacuum units, about 5000 watts for two 2-hp vacuums. Honda water-cooled generators are extremely quite and reliable for this purpose. Finally a secure, protected garage was used to store the trailer and equipment near the study areas when not in use.

Sampling Procedure. Because the street surfaces were more likely to be dry during daylight hours (necessary for good sample collection), collection did not begin before sunrise nor continue after sunset. During extremely dry periods, some sampling was conducted during dark hours, but that required additional personnel for traffic control. Two people were required for sampling at all times, one acting as the sampler, the other acting as the vacuum hose tender and traffic controller. This lessened individual responsibility and enabled both persons to be more aware of traffic conditions.

Before each day of sampling, the equipment was checked to make sure that the generator’s oil and gasoline levels were adequate, and that vacuum hose, wand, and gobbler were in good condition. Dragging the vacuum hose across asphalt streets required periodic hose repairs (usually made using gray duct tape). A check was also made to ensure that the vacuum units were clean, the electrical cords were securely attached to the generator, and the trailer lights and warning lights were operable. The generator required about 3 to 5 minutes to warm up before the vacuum units were turned on one at a time (about 5 to 10 seconds apart to prevent excessive current loading on the generator). The amperage and voltage meters of the generator were also periodically checked. The generator and vacuums were left on during the complete subsamping period to lessen strain associated with multiple shutoffs and startups. Obviously, the sampling end of the vacuum hose was carefully secured between subsamples to prevent contamination.

Each subsample included all of the street surface material that would be removed during a severe rain (including loose materials and caked-on mud in the gutter and street areas). The location of the subsample strip was carefully selected to ensure that it had no unusual loading conditions (e.g., a subsample was not collected through the middle of a pile of leaves; rather, it was collected where the leaves were lying on the street in their normal distribution pattern). When possible, wet areas were avoided. If a sample was wet and the particles caked around the intake nozzle, the caked mud from the gobbler was carefully scraped into the vacuum hose while the vacuum units were running.

Subsamples were collected in a narrow strip about 6 in. wide (the width of the gobbler) from one side of the street to the other (curb to curb). In heavily traveled streets where traffic was a problem, some subsamples consisted of two separate one-half street strips (curb to crown). Traffic was not stopped for subsample collection; the operators waited for a suitable traffic break. On wide or busy roadways, a subsample was often collected from two strips several feet apart, halfway into the street. On busy roadways with no parking and good street surfaces, most particulates were found within a few feet of the curb, and a good subsample could be collected by vacuuming two adjacent strips from the curb as far into the traffic lanes as possible. Only a sufficient (and safe) break in traffic allowed a subsample to be collected halfway across the street.

Subsamples taken in areas of heavy parking were collected between vehicles along the curb, as necessary. The sampling line across the street did not have to be a continuous line if a parked car blocked the most obvious and easiest subsample strip. A subsample could be collected in shorter (but very close) strips, provided the combined length of the strip was representative of different distances from the curb. Again, in all instances, each subsample was representative of the overall curb-to-curb loading condition.

When sampling, the leading edge of the gobbler was slightly elevated above the street surface (0.125 in.) to permit an adequate air flow and to collect pebbles and large particles. The gobbler was lifted further to accept larger material as necessary. If necessary, leaves in the subsample strip were manually removed and placed in the sample storage container to prevent the hose from clogging. If a noticeable decrease in sampling efficiency was observed, the vacuum hoses were cleaned immediately by disconnecting the hose lengths, cleaning out the connectors (placing the debris into the sample storage container), and reversing the air flows in the hoses (blowing them out by connecting the hose to the vacuum exhaust and directing the dislodged debris into the vacuum inlet). If any mud was caked on the street surface in the subsample strip, the sampler loosened it by scraping a shoe along the subsample path (being certain that street construction material was not removed from the subsample path unless it was very loose). Scraping caked-on mud was done after an initial vacuum pass. After scraping was completed, the strip was revacuumed. A rough street surface was sampled most easily by pulling (not pushing) the wand and gobbler toward the curb. Smooth and busy streets were usually sampled with a pushing action, away from the curb.

An important aspect of the sample collection was the speed at which the gobbler was moved across the street. A very rapid movement significantly decreased the amount of material collected; too slow a movement required more time than was necessary. The correct movement rate depended on the roughness of the street and the amount of material on it. When sampling a street that had a heavy loading of particulates, or a rough surface, the wand was pulled at a velocity of less than 1 ft per second. In areas of lower loading and smoother streets, the wand was pushed at a velocity of 2 to 3 ft per second. The best indication of the correct collection speed was by examining how well the street was visually being cleaned in the sampling strip and by listening to the collected material rattle up the wand and through the vacuum hose. The objective was to remove everything that was lying on the street that could be removed by a significant rainstorm. It was quite common to leave a visually cleaner strip on the street where the subsample was collected, even on streets that appeared to be clean before sampling.

In all cases, the hose tender continuously watched traffic and alerted the sampler of potentially hazardous conditions. In addition, he played out the hose to the sampler as needed and kept the hose as straight as possible to prevent kinking. If a kink developed, sampling stopped until the hose tender straightened the hose. While working near the curb out of the traffic lane (typically an area of high loadings), the sampler visually monitored the performance of the vacuum sampler and periodically checked for vehicles. In the street, the sampler constantly watched traffic and monitored the collection process by listening to particles moving up the wand. A large break in traffic was required to collect dust and dirt from street cracks in the traffic lanes, because the sampler had to watch the gobbler to make sure that all of the loose material in the cracks was removed.

When moving from one subsample location to another, the hose, wand, and gobbler were securely placed in the trailer. All subsamples were composited in the vacuums for each study area. The hose was placed away from the generator's hot muffler to prevent hose damage. The generator and vacuum units were left on and in the trailer during the entire subsample collection period. This helped dry damp samples and reduced the strain on the vacuum and generator motors.

The length of time it took to collect all of the subsamples in an area varied with the number of subsamples and the test area road texture and traffic conditions. The number of subsamples required in each area was determined using experimental design sample effort equations, with seasonal special sampling efforts to measure the variability of street dirt loadings in each area. The variabilities were measured using a single, small 1.5 HP industrial vacuum, with a short hose. The vacuum was emptied, the sample collected, and weighed (in the lab) after each individual sample so the variability in loadings could be directly measured. During the first phase of the San Jose study (Pitt 1979), the test areas required the following sampling effort in order to stay within a 25% allowable error goal:

Test Area	No. of Subsamples	Sampling Duration
Downtown - poor asphalt street surface	14	0.5 hr.
Downtown - good asphalt street surface	35	1 hr.
Keyes Street - oil and screens street surface	10	0.5-1 hr.
Keyes Street - good asphalt street surface	36	1 hr.
Tropicana - good asphalt street surface	16	0.5-1 hr.

The dirtiest streets required the least sampling effort because the coefficients of variation for loadings represented by the individual subsample strips was much smaller than for the cleaner streets. In the oil and screens test area, the sampling procedure was slightly different because of the relatively large amount of pea gravel (screens) that was removed from the street surface. The gobbler attachment was drawn across the street more slowly (at a rate of about 3 seconds per ft.). Each subsample was collected by a half pass (from the crown to the curb of the street) and therefore contained one-half of the normal sample. Two curb-to-curb passes were made for each Tropicana subsample because of the relatively low particulate loadings in this area, as several hundred grams of sample material were needed for the laboratory tests. In addition, an after street cleaning subsample was not collected from exactly the same location as the before street cleaning subsample (they were taken from the same general area, but at least a few feet apart).

A field-data record sheet kept for each sample contained:

- Subsample numbers
- Dates and time of the collection period
- Any unusual conditions or sampling techniques.

Subsample numbers were crossed off as each subsample was collected. After cleaning, subsample numbers were marked if the street cleaner operated next to the curb at that location. This differentiation enabled the effect of parked cars on street cleaning performance to be analyzed. In addition, photographs (and movies) were periodically made to document the methods and street loading conditions.

Sample Transfer. After all subsamples for a test area were collected, the hose and wye connections were cleaned by disconnecting the hose lengths, reversing them, and holding them in front of the vacuum intake. Leaves and rocks that may have become caught were carefully removed and placed in the vacuum can, the generator was then turned off. The vacuums were either emptied at the last station or at a more convenient location (especially in a sheltered location out of the wind and sun).

To empty the vacuums, the top motor units were removed and placed out of the way of traffic. The vacuum units were then disconnected from the trailer and lifted out. The secondary, coarse vacuum filters were removed from the vacuum can and were carefully brushed with a small stiff brush into a large funnel placed in the storage can. The primary dacron filter bags were kept in the vacuum can and shaken carefully to knock off most of the filtered material. The dust inside the can was allowed to settle for a few minutes, then the primary filter was removed and brushed carefully into the sample can with the brush. Any dirt from the top part of the bag where it was bent over the top of the vacuum was also carefully removed and placed into the sample can. Respirators and eye protection is necessary to minimize exposure to the fine dust.

After the filters were removed and cleaned, one person picked up the vacuum can and poured it into the large funnel on top of the sample can, while the other person carefully brushed the inside of the vacuum can with a soft 3- to 4-in. paint brush to remove the collected sample. In order to prevent excessive dust losses, the emptying and brushing was done in areas protected from the wind. To prevent inhaling the sample dust, both the sampler and the hose tender wore mouth and nose dust filters while removing the samples from the vacuums.

To reassemble the vacuum cans, the primary dacron filter bag was inserted into the top of the vacuum can with the filters's elastic edge bent over the top of the can. The secondary, coarse filter was placed into the can and assembled on the trailer. The motor heads were then carefully replaced on the vacuum cans, making sure that the filters were on correctly and the excessive electrical cord was wrapped around the handles of the vacuum units. The vacuum hoses and wand were attached so that the unit was ready for the next sample collection.

The sample storage cans were labeled with the date, the test area's name, and an indication of whether the sample was taken before or after the street cleaning test or if it was an accumulation (or other type) of sample. Finally, the lids of the sample cans were taped shut and transported to the laboratory for logging-in, storage, and analysis.

Summary of Observed Accumulation Rates

Table 3-21 summarizes many accumulation rate measurements obtained from throughout North America. In the earliest studies (APWA 1969; Sartor and Boyd 1972; and Shaheen 1975), the initial street dirt loading values after a major rain or street cleaning were assumed to be zero. Calculated accumulation rates for rough streets were therefore very large. Later tests measured the initial loading values close to the end of major rains and street cleaning and found that they could be relatively high, depending on the street texture. When these starting loadings were considered for the earlier measurements, the re-calculated accumulation rates were much lower. The early, uncorrected, Sartor and Boyd accumulation rates that ignored the initial loading values were almost ten times the corrected values shown on this table. Unfortunately, most urban stormwater models used these very high early accumulation rates as default values.

Table 3-21. Street dirt loadings and deposition rates.

	Initial Loading Value (grams/curb-meter)	Daily Deposition Rate (grams/curb-meter-day)	Maximum Observed Loading (grams/curb -meter)	Days to Observed Maximum Loading	Reference
Smooth and Intermediate Textured Streets					
Reno/Sparks, NV – good condition	80	1	85	5	Pitt and Sutherland 1982
Reno/Sparks, NV – good with smooth gutters (windy)	250	7	400	30	Pitt and Sutherland 1982
San Jose, CA – good condition	35	4	>140	>50	Pitt 1979
U.S. nationwide – residential streets, good condition	110	6	140	5	Sartor and Boyd 1972 (corrected)
U.S. nationwide – commercial street, good condition	85	4	140	5	Sartor and Boyd 1972 (corrected)
Reno/Sparks, NV – moderate to poor condition	200	2	200	5	Pitt and Sutherland 1982
Reno/Sparks, NV – new residential area (construction)	710	17	910	15	Pitt and Sutherland 1982
Reno/Sparks, NV – poor condition, with lipped gutters	370	15	630	35	Pitt and Sutherland 1982
San Jose, CA – fair to poor condition	80	4	230	70	Pitt 1979
Castro Valley, CA – moderate condition	85	10	290	70	Pitt and Shawley 1982
Ottawa, Ontario – moderate condition	40	20	Na	Na	Pitt 1983
Toronto, Ontario – moderate condition, residential	40	32	100	>10	Pit and McLean 1986
Toronto, Ontario – moderate condition, industrial	60	40	351	>10	Pit and McLean 1986
Believue, WA – dry period, moderate condition	140	6	>230	20	Pitt 1985
Believue, WA – heavy traffic	60	1	110	30	Pitt 1985
Believue, WA – other residential sites	70	3	140	30	Pitt 1985
Average:	150	9	>270	>25	
Range:	35 – 710	1 – 40	85 – 910	5 – 70	
Rough and Very Rough Textured Streets					
San Jose, CA – oil and screens overlay	510	6	>710	>50	Pitt 1979
Ottawa, Ontario – very rough	310	20	Na	Na	Pitt 1983
Reno/Sparks, NV	630	10	860	35	Pitt and Sutherland 1982
Reno/Sparks, NV – windy	540	34	>1,400	>40	Pitt and Sutherland 1982
San Jose, CA – poor condition	220	6	430	30	Pitt 1979
Ottaw a, Ontario – rough	200	20	Na	Na	Pitt 1983
U.S. nationwide – industrial streets (poor condition)	190	10	370	10	Sartor and Boyd 1972 (corrected)
Average:	370	15	>750	>30	
Range:	190 - 630	6 - 34	370 - >1,400	10 - >50	

The most important factors affecting the initial loading and maximum loading values shown on Table 3-21 were found to be street texture and street condition. When data from many locations are studied, it is apparent that smooth streets have substantially less loadings at any accumulation period compared to rough streets for the same land use. Very long accumulation periods relative to the rain frequency result in high street dirt loadings. During these conditions, the wind losses of street dirt (as fugitive dust) may approximate the deposition rate, resulting in relatively constant street dirt loadings. At Bellevue, WA, typical interevent rain periods average about three days. Relatively constant street dirt loadings were observed in Bellevue because the frequent rains kept the loadings low and very close to the initial storage value, with little observed increase in dirt accumulation over time (Pitt 1985). In Castro Valley, CA, the rain interevent periods were much longer (ranging from about 20 to 100 days) and steady loadings were only observed after about 30 days when the loadings became very high and fugitive dust losses caused by the winds and traffic turbulence moderated the loadings (Pitt and Shawley 1982).

Pitt and McLean (1986) studied street dirt accumulation rates and the effects of street cleaning in Toronto. An industrial street with heavy traffic and a residential street with light traffic were monitored about twice a week for three months. At the beginning of this period, intensive street cleaning (one pass per day for each of three consecutive days) was conducted to obtain reasonably clean streets. Street dirt loadings were then monitored every few days to measure the accumulation rates of street dirt. The street dirt particulate loadings were quite high before the initial intensive street cleaning period and were reduced to their lowest observed levels immediately after the last street cleaning. After street cleaning, the loadings on the industrial street increased much faster than for the residential street. Right after intensive cleaning, the street dirt particle sizes were also similar for the two land uses. However, the loadings of larger particles on the industrial street increased at a much faster rate than on the residential street, indicating more erosion or tracking materials being deposited onto the industrial street. The residential street dirt measurements did not indicate that any material was lost to the atmosphere as fugitive dust, probably because of the low street dirt accumulation rate and the short periods of time between rains. The street dirt loadings never had the opportunity to reach the high loading values needed before they could be blown from the streets by winds or by traffic-induced turbulence. The industrial street, in contrast, had a much greater street dirt accumulation rate and reached the critical loading values needed for fugitive losses in the relatively short periods between the rains.

Washoff of Street Dirt

Background

The degradation of the road surface and traffic related discharges are responsible for most of the particulate discharges in urban runoff. The smallest particulates from urban areas are usually discharged during the early parts of storms, but small particulates from impervious surfaces may also be discharged during later parts of storms. Shaheen (1975) found that road surface particulates and polluted area soils (affected by traffic related pollutants) contribute most of the urban runoff particulate pollutants. Many urban runoff models assume that “all” of the pollutants and runoff flows in urban areas originate from directly connected impervious areas, ignoring contributions from pervious areas. The correct interpretation of particulate washoff from impervious surfaces is therefore critical to understanding urban runoff quality. This discussion summarizes some of the procedures that are commonly used to estimate particulate washoff from impervious surfaces, presents the results of washoff tests, and describes a revised street dirt washoff model.

Washoff of particulates from impervious surfaces is dependent on the available supply of particulates and the capacity of the runoff to transport the loosened material. The accumulation of the material is dependent on many site specific land use and geographic features, plus the intended or unintended losses of materials.

Brief descriptions follow of two methods (the Yalin equation and the Sartor and Boyd equation) currently used in most urban runoff studies for estimating particulate washoff from impervious surfaces. They can be used to obtain satisfactory estimates of particulate washoff, if their limitations are recognized and if rough estimates are all that are required. Unfortunately, they are often used in situations beyond their limits (such as for small rains, unusual street dirt loadings, or rough pavement textures). Certain washoff equation parameters have also been misunderstood (such as confusing total street dirt load with “available” street dirt load). The use of these washoff equations in large and well documented urban runoff computer models also implies more confidence in their accuracy than may be warranted.

A field study is briefly summarized that found significant washoff differences for various particle sizes. These observed washoff quantities are compared to the values obtained with these two washoff models, but the observed washoff quantities are shown to be much less than predicted with the washoff equations. These data observations and the existing washoff models' inabilities to accurately predict washoff lead to the series of washoff tests conducted by Pitt (1987) and the development of washoff models sensitive to important environmental conditions.

Yalin Equation

Novotny and Chesters (1981) presented the Yalin equation as the best candidate from the many models presented in the literature to describe sediment washoff and transport in urban areas. The Yalin equation relates the sediment carrying capacity to runoff flow rate (Yalin 1963). Yalin assumed that sediment motion begins when the lift force of flow exceeds a critical lift force. Once a particle is lifted from the bed, the drag force of the flow moves it downstream until the weight of the particle forces it back to the bed. The Yalin equation is used to predict particle transport, for specific particle sizes, on a weight per unit flow width basis. It is used for fully turbulent channel flow conditions, typical of shallow overland flow in urban areas. The receding limb (tail) of a hydrograph may have laminar flow conditions, and the suspended sediment carried in the previously turbulent flows would settle out. The predicted constant Yalin sediment load would therefore only occur during periods of rain; and the sediment load would decrease, due to sedimentation, after the rain stops. The equation is presented in the following form:

$$p = 0.635\ s\ [1 - (1 / a*s) \ln (1 + a*s)]$$

where p = particle transport, grams/meter-second

a and s are calculated, based on particle density, particle diameter, and shear velocity.

To use the equation, the particle shear velocity (v_*, m/sec) must be calculated:

$$v_* = (gHS)^{0.5}$$

where g = acceleration of gravity = 9.81 m/sec^2

H = flow depth, meters

S = energy gradient slope, m/m

The particle Reynolds number (X) must also be known:

$$X = v_*\ D / u$$

where D = particle diameter, meters

u = kinematic viscosity of fluid = 10^{-6} m^2/sec for water

The critical particle bedload tractive force (Y_{cr}), the tractive force at which the particle begins to move, can be obtained from a Shield's diagram (Figure 3-5). Shen (1981) warned that Shield's diagram cannot be used alone to predict "self-cleaning" velocities, it gives only a lower limit below which deposition will occur. It defines the boundary between bed movement and stationary bed conditions. The diagram does not consider the particulate supply rate in relationship to the particulate transport rate. Reduced particulate transport occurs if the sediment supply rate is less than the transport rate.

The actual tractive force is also calculated:

$Y = v_*^2 / (p_s - 1)g*D$

where p_s = specific density of particle, g/cm3

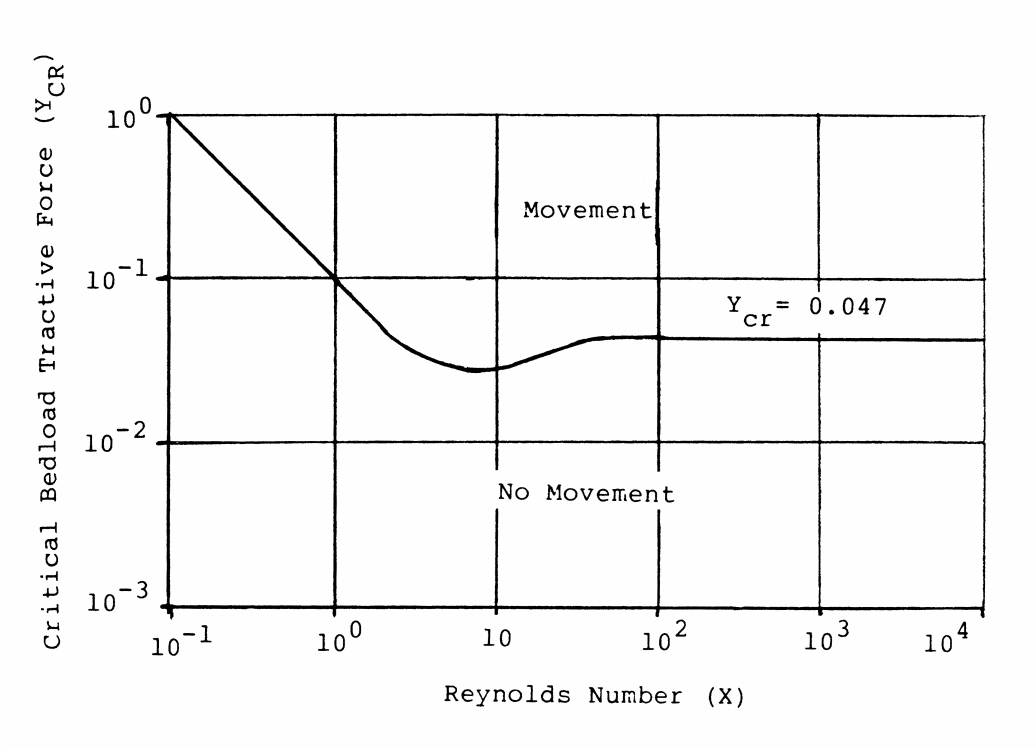


Figure 3-5. Shield's diagram for particle tractive force (from Novotny and Chesters 1981).

The Yalin coefficients can be calculated knowing Y, Y_{cr}, and p_s:

$s = Y / Y_{cr}$

and $a = 2.45\, p_s$-$0.4\, (Y_{cr})^{0.5}$

The Yalin equation by itself is therefore not sensitive to particulate supply; it only predicts the carrying capacity of flowing waters. Models must be used that account for total particulate discharge and "stop" transport when the particulate supply is exhausted.

Besides the particulate supply rate, the Yalin equation is also very sensitive to local flow parameters (specifically gutter flow depth); a hydraulic model that can accurately predict sheetflow across impervious surfaces and gutter flow is needed. Sutherland and McCuen (1978) statistically analyzed a modified form of the Yalin equation, in conjunction with a hydraulic model (the Basic Inlet Hydrograph Model - BIHM), for different gutter flow conditions. Except for the largest particle sizes, the effect of rain intensity on particle washoff was negligible. A set of equations, shown on Table 3-22, were developed relating the percentage washoff (TS_i) of each of six particle sizes to gutter slope, impervious area, initial solids loading, and the gutter length before the storm drain inlet. These washoff percentages assume a one-hour uniform rain of 13 mm. These washoff percentages can then be modified for other total rains, by the K_j factors given in Table 3-23:

$TS_j = K_j\, TS_i$

where TS_j = percent total solids removal (for a specific size range)

TS_i = percent total solids removal for the standard 13 mm rain (for a specific size range)

K_j = factor relating the standard rain to the actual rain

Table 3-22. Washoff Equations for Different Particle Sizes (Sutherland and McCuen 1978)

Range	R	S_e(%)	Equation
1	0.92	2.29	$T_1 = 91.4+0.76\ G^{1.92}+0.1\ I-0.01\ S-0.0032\ L$
2	0.89	1.49	$T_2 = 95.6+0.65\ G^{1.55}+0.061\ I-0.0058\ S-0.0028\ L$
3	0.94	3.74	$T_3 = 83.6+G^{2.14}+0.2\ I-0.0019\ S-0.0063\ L$
4	0.95	6.60	$T_4 = 64.2+1.35\ G^{2.45}+0.39\ I-0.036\ S-0.0073\ L$
5	0.96	9.59	$T_5 = 33.6\ 1.58\ G^{2.7}+1^{0.9}-0.062\ S$
6	0.99	3.40	$T_6 = (G-1.44)(-3.7+0.5\ I^{0.95}-0.02\ S+0.026\ L)$

R = correlation coefficient

S_e = standard error of estimate.

T_i = removal percentage for particle size range i

G = slope of gutter in percent.

I = impervious area in percent.

S = initial total solids loading in lbs/curb mile.

L = length of gutter in feet.

Note: if T_i exceeds 100 it is assumed to equal 100 in the model.

Source: Sutherland and McCuen, 1978

Table 3-23. Kj Values used in Yalin Sediment Transport Model (Sutherland and McCuen 1978)

TS_i	Total Volume j: 1/8	1/4	1/2	3/4	1	1-1/4	1-1/2	1-3/4	2	2-1/2	3
100	0.84	0.92	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
97	0.835	0.938	1.0	1.021	1.031	1.031	1.031	1.031	1.031	1.031	1.031
94	0.808	0.915	1.0	1.032	1.053	1.064	1.064	1.064	1.064	1.0064	1.064
93	0.731	0.882	1.0	1.048	1.075	1.075	1.075	1.075	1.075	1.075	1.075
90	0.778	0.889	1.0	1.055	1.089	1.1	1.111	1.111	1.111	1.111	1.111
88	0.670	0.852	1.0	1.063	1.091	1.108	1.119	1.131	1.136	1.136	1.136
84	0.417	0.798	1.0	1.083	1.119	1.143	1.161	1.178	1.190	1.190	1.190
76	0.303	0.658	1.0	1.125	1.184	1.224	1.25	1.263	1.270	1.289	1.316
72	0.239	0.542	1.0	1.125	1.208	1.264	1.305	1.333	1.347	1.369	1.389
64	0.156	0.375	1.0	1.219	1.344	1.406	1.469	1.515	1.563	1.563	1.563
61	0.082	0.295	1.0	1.230	1.352	1.426	1.492	1.533	1.582	1.606	1.639
45	0.044	0.178	1.0	1.489	1.689	1.811	1.911	1.978	2.044	2.149	2.222
44	0.057	0.159	1.0	1.477	1.704	1.841	1.954	2.045	2.114	2.182	2.232
15	0.0	0.133	1.0	2.6	3.933	4.733	5.233	5.6	5.9	6.233	6.333
2	0.0	0.0	1.0	4.0	11.0	20.0	26.5	30.5	33.75	38.0	41.0

TS_j = the percentage removal of total solids in a particle size range due to a total rainfall volume measured in inches.

TS_i = the percentage removal of total solids in a particle size range due to a total rainfall volume of 1/2 inches.

The Yalin equation is based on classical sediment transport equations, and requires some assumptions concerning the micro-scale aspects of gutter flows and street dirt distributions. The Yalin equation, as typically used in urban runoff models, assumes that all particles lie within the gutter, and no significant washoff occurs by sheetflows traveling across the street towards the gutter. The early measurements of across-the-street dirt distributions made by

Sartor and Boyd (1972) indicated that about 90 percent of the street dirt was within about 30 cm of the curb face (typically within the gutter area). These measurements, however, were made in areas of no parking (near fire hydrants because of the need for water for the sampling procedures that were used), and the traffic turbulence was capable of blowing most of the street dirt against the curb barrier (or over the curb onto adjacent sidewalks or landscaped areas). In later tests, Pitt (1979) examined street dirt distributions across-the-street in many situations. He found distributions similar to Sartor and Boyd's observations only on smooth streets, with moderate to heavy traffic, and with no on-street parking. In many cases, most of the street dirt was actually in the driving lanes, trapped by the texture of rough streets. If on-street parking was common, much of the street dirt was found on the outside edge of the parking lanes, where the resuspended (in air) street dirt blew against the parked cars and settled to the pavement. Some later modeling efforts (most notably later versions of the MUNP and PTM models, Sutherland personal communication) adjusted the total street loading to estimate the loading present only in the gutter. Washoff of in-street particulates was still not considered.

Another process that may result in washoff less than predicted by Yalin is bed armoring (Sutherland, *et al*. 1982?). As the smaller particulates are removed, the surface is covered by predominantly larger particulates which are not effectively washed off by the rain. Eventually, these larger particulates hinder the washoff of the trapped, under-lying, smaller particulates. Debris on the street, especially leaves, can also effectively armor the particulates, reducing the washoff of particulates to very low levels (Singer and Blackard 1978).

Sartor and Boyd Washoff Equation

Observations of particulate washoff during controlled tests may result in empirical washoff models that are not as limited as incomplete theoretical models. Washoff experiments using actual streets and natural street dirt and debris are affected by street dirt distributions and armoring. Their disadvantage is the assumption of transferability. If the washoff experiments are conducted for many situations then it may be possible to use the resultant model for other situations.

The earliest controlled street dirt washoff experiments were conducted by Sartor and Boyd (1972) during the summer of 1970 in Bakersfield, California. Their data are used in many urban runoff models (including SWMM, Huber and Heaney 1981; STORM, COE 1975; and HSPF, Donigian and Crawford 1976) to estimate the percentage of the available particulates on the streets that would wash off during rains of different magnitudes. They used a rain simulator having many nozzles and a drop height of 1-1/2 to 2 meters in street test areas of about 5 by 10 meters. Tests were conducted on concrete, new asphalt, and old asphalt, using simulated rain intensities of about 5 and 20 mm/hr. They collected and analyzed runoff samples every 15 minutes for about two hours for each test. Figure 3-6 shows two plots of their data, showing the asymptotic shape of the accumulative washoff curves for several particle sizes. Sartor and Boyd fitted their data to an exponential curve, assuming that the rate of particle removal of a given size is proportional to the street dirt loading and the constant rain intensity:

$$dN/dt = k\, r\, N$$

where dN/dt = the change in street dirt loading per unit time

k = proportionality constant

r = rain intensity (in/hr)

N = street dirt loading (lb/curb-mile)

This equation, upon integration, becomes:

$$N = N_o\, e^{-krt}$$

where N = residual street dirt load (after the rain)

N_o = initial street dirt load

t = rain duration

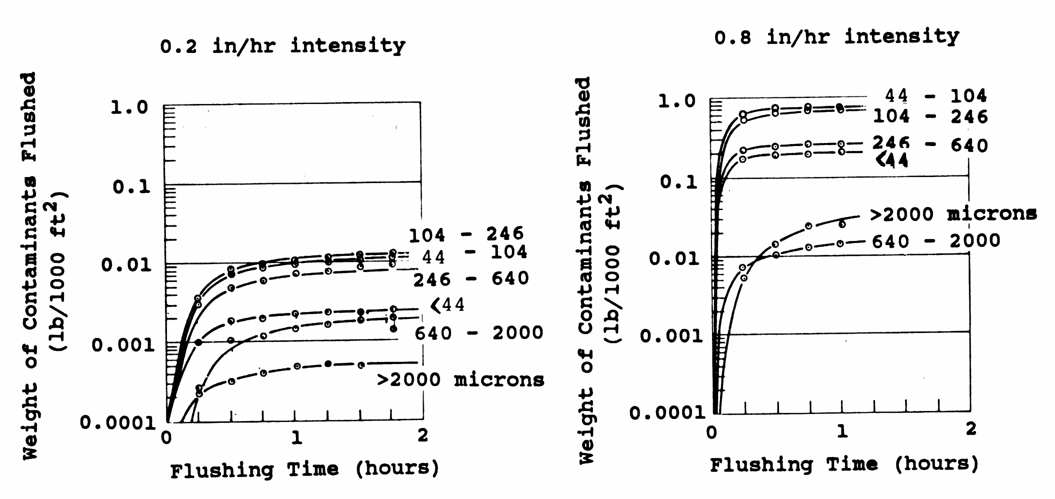


Figure 3-6. Street dirt washoff during high intensity rain tests (Sartor and Boyd 1973).

Street dirt washoff is therefore equal to No minus N. The variable combination rt, or rain intensity times rain duration, is equal to total rain volume (R). This equation further reduces to:

$$N = N_o e^{-kR}$$

Therefore, this equation is only sensitive to total rain, and not rain intensity.

These figures also did not show the total street dirt loading that was present during the tests and modelers have assumed that the asymptotic maximum shown was the total “before-rain” loading. However, the total street dirt loadings were several times greater than the maximum washoff amount observed.

Because of decreasing particulate supplies, the exponential washoff curve predicts decreasing concentrations of particulates with time since the start of a constant rain (Alley 1980 and 1981).

The proportionality constant, k, was found by Sartor and Boyd to be slightly dependent on street texture and condition, but was independent of rain intensity and particle size. The value of this constant is usually taken as 0.18/mm, assuming that 90 percent of the particulates will be washed from a paved surface in 1 hour during a 13 mm/hour rain. However, Alley (1981) fitted this model to watershed outfall runoff data and found that the constant varied for different storms and pollutants, for a single study area. Novotny (undated) examined “before” and “after” rain event street particulate loading data using the Milwaukee NURP data and found almost a three-fold difference between the constant value for fine (<45 microns) and medium sized particles (100 to 250 microns); 0.026/mm for the fine particles and 0.01/mm for the medium sized particles, both much less than the “accepted” value. Jewell, *et al*. (1980) also found large variations in outfall “fitted” constant values for different rains compared to the typical default value. Either the assumption of the high removal of particulates during the 13 mm/hr storm was incorrect or/and the equation cannot be fitted to outfall data (which assumes that all the particulates are originating from homogeneous paved surfaces during all storm conditions).

This washoff equation has been used in many urban runoff models (including SWMM, STORM, and HSPF), but the N_o factor has been frequently misinterpreted. It has been assumed to be the total initial street loading, when in fact it is only the portion of the total street load available for washoff (the maximum asymptotic washoff load observed during the washoff tests). STORM and SWMM use an availability factor (A) for particulate residue as a calibration procedure in order to reduce the washoff quantity for different rain intensities (Novotny and Chesters 1981):

$$A = 0.057 + 0.04 (r^{1.1})$$

where r is the rain intensity (mm/hr), and A must be less than 1.0. This regression equation is used to adjust the relative importance of the particulate residue contributions from pervious and impervious source areas. This availability factor is equal to 1.0 for all rain intensities greater than about 18 mm/hr. For rains of 1 mm/hr, this availability factor reduces to about 0.10. HSPF does not use an availability factor in an attempt to be "more universally applicable" (Donigian and Crawford 1976). Instead, calibration of observed with predicted outfall yields are used to "adjust" the accumulation and washoff rates directly in HSPF. The availability factor in SWMM does not really have a significant effect on the variation of the predicted runoff load. However, it does affect the relationship between the runoff volume and the particulate washoff (and therefore concentration).

Jewell, *et al*. (1980) stressed the need to have local calibration data before using the exponential washoff equation, as the default values can be very misleading. The exponential washoff equation for impervious areas is justified, but washoff coefficients for each pollutant would improve its accuracy.

Street Dirt Washoff Observations and Comparisons with the Yalin, and Sartor and Boyd Washoff Equations
Particle dislodgement and transport characteristics at impervious areas can be directly measured using relatively easy washoff tests. These tests are used to supplement dry street dirt sampling at impervious source areas. Street dirt sampling, or other pavement dirt sampling, is misleading because little of the sampled dirt actually washes off during rains.

The Bellevue, Washington, urban runoff project (Pitt 1985) included about 50 pairs of street dirt loading observations close to the beginnings and ends of rains. These before and after loading values were compared to determine significant differences in loadings that may have been caused by the rains. The observations were affected by rains falling directly on the streets, along with flows and particulates originating from non-street areas. The net loading differences were therefore affected by street dirt washoff (by direct rains on the street surfaces and by gutter flows augmented by "upstream" area runoff) and by erosion products that originated from non-street areas that may have settled out in the gutters. When all the data were considered together, the net loading difference was about 10 to 13 grams/curb-m removed. This amounted to a street dirt load reduction of about 15 percent, which was much less than predicted using the previously described washoff models.

Very large reductions in street dirt loadings for the small particles were observed during rains in Bellevue, but the largest particles actually increased in loadings (due to settled erosion materials), as shown in Figure 3-7. The particles were not source limited, but armor shielding may have been important. Most of the weight of solid material in the runoff was in the fine particle sizes (<63 µm). Very few washoff particles greater than 1000 µm were found, in fact, loadings increased for the largest sizes. Urban runoff outfall particle size analyses in Bellevue (Pitt 1985) resulted in a median particle size of about 50 µm. Similar results were obtained in the Milwaukee NURP study (Bannerman, *et al*. 1983).

Particulate residue washoff predictions for Bellevue conditions were made using the Sutherland and McCuen modification of the Yalin equation, and the Sartor and Boyd equation. Three particle size groups (<63, 250-500, and 2000-6350 µm), and three rains, having depths of 5, 10, and 20 mm and 3-hour durations, were considered. The gutter lengths for the Bellevue test areas averaged about 80 m, with gutter slopes of about 4.5 percent. Typical total initial street dirt loadings for the three particle sizes were: 9 g/curb-meter for <63 µm, 18 g/curb-meter for 250-500 µm, and 9 g/curb-meter for 2000-6350 µm. The actual Bellevue net loading removals during the storms was about 45 percent for the smallest particle size group, 17 percent for the middle particle size group, and -6 percent (6 percent loading increase) for the largest particle size group. The predicted removals were 90 to 100 percent using the Sutherland and McCuen method, 61 to 98 percent using the Sartor and Boyd equation, and 8 to 37 percent using the availability factor with the Sartor and Boyd equation. The ranges given reflect the different rain volumes and intensities only. There were no large predicted differences in removal percentages as a function of particle size. The availability factor with the Sartor and Boyd equation resulted in the closest predicted values, but the great differences in washoff as a function of particle size was not predicted.

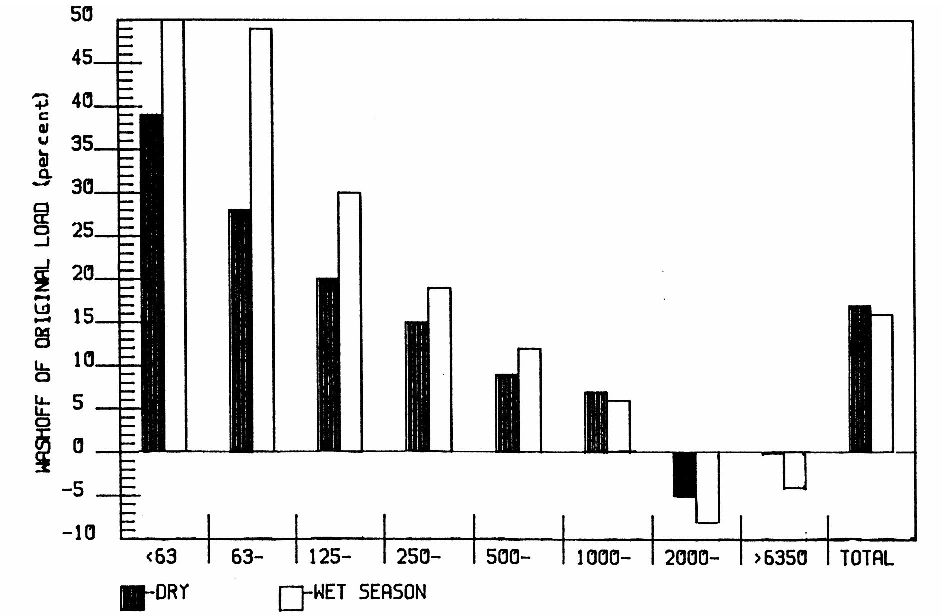


Figure 3-7. Observed washoff of street dirt during tests in Bellevue, WA (Pitt 1985).

The rain energy needed to remove larger particles is much greater than for small particles. Therefore, rains are much more effective in removing fine particles than large particles. In contrast, mechanical street cleaning equipment preferentially remove the larger particles compared to the small particles. Vacuum street cleaning equipment should be able to remove the finer partic les better than the larger particles, but most vacuum street cleaners cannot remove the fine particles effectively under typically moist conditions and in the presence of larger particles that cover most of the finer street dirt. Therefore, particles of different sizes "behave" quite differently on streets. Typical street dirt total solids loadings show a "saw-tooth" pattern with time between street cleaning or rain washoff events. The patterns for the separate particle sizes are considerably different than the pattern for total residue. Typical mechanical street cleaners remove much (about 70 percent) of the coarse particles in the path of the street cleaner, but they remove very little of the finer particles (Sartor and Boyd 1972; Pitt 1979). Rains, however, remove very little of the large particles, but can remove large amounts (about 50 percent) of the fine particles (Bannerman, *et al*. 1983; Pitt 1985; Pitt 1987). The intermediate particle sizes show reduced removals by both street cleaners and rain.

The Bellevue street dirt washoff observations included effects of additional runoff volume and particulates originating from non-street areas. The additional flows should have produced more gutter particulate washoff, but upland erosion materials may also have settled in the gutters (as noted for the large particles). However, across-the-street dirt loading measurements indicated that much of the street dirt was in the street lanes, not in the gutters, before and after rains. This dirt distribution reduces the importance of these extra flows and particulates from upland areas. The increased loadings of the largest particles after rains were obviously caused by upland erosion, but the magnitude of the settled amounts was quite small compared to the total street dirt loadings.

Small-Scale Washoff Tests

Street dirt has a wide range of particle sizes and the chemical quality varied greatly for the different particle sizes. It is therefore important to mostly focus on the fraction that will be removed during rains. There is much confusion if the easily measured street dirt loadings are assumed to be totally available for washoff. Washoff tests can therefore be used to estimate the fraction of the total loading measured on the street that can be removed during rains.

In order to clarify street dirt washoff, Pitt (1987) conducted numerous controlled washoff tests on city streets in Toronto. These tests were arranged as an overlapping series of 2^3 factorial tests, and were analyzed using standard factorial test procedures described by Box, *et al*. (1978). The experimental factors examined included: rain intensity, street texture, and street dirt loading. The differences between available and total street dirt loads were also related to the experimental factors. The samp les were analyzed for total solids (total residue), dissolved solids (filterable residue: <0.45 µm), and SS (particulate residue: >0.45 µm). Runoff samples were also filtered through 0.45 µm filters and the filters were microscopically analyzed (using low power polarized light microscopes to differentiate between inorganic and organic debris) to determine particulate size distributions from about 1 to 500 µm. The runoff flow quantities were also carefully monitored to determine the magnitude of initial and total rain water losses on impervious surfaces.

Table 3-24 presents the site data along with the basic rain and runoff observations obtained during these tests. All tests were conducted for about two hours, with total rain volumes ranging from about 5 to 25 mm. The test code explanations follow:

Test code	Rain intensity	Street dirt loading	Street texture
HCR	High	Clean	Rough
HDR	High	Dirty	Rough
LCR	Light	Clean	Rough
LDR	Light	Dirty	Rough
HDS	High	Clean	Smooth
HCS	High	Dirty	Smooth
LDS	Light	Clean	Smooth
LCS	Light	Dirty	Smooth

Table 3-24 shows the specific experimental levels that each variable was held to during each test. Unfortunately, the streets during the LDS test were not as dirty as anticipated and was actually a replicate with the LCS tests. The experimental analyses were modified to indicate these unanticipated duplicate observations.

Table 3-24. Experimental Levels for each Test Factor

	Rain intensity	Street dirt loading	Street texture
Expected to enhance percentage washoff:	High (11.0 to 12.2 mm/hr)	Dirty (10.5 to 12.6 g/m^2)	Smooth (0.3 to 0.4 mm detention storage)
Expected to retard percentage washoff:	Low (2.9 to 3.2 mm/hr)	Clean (1.7 to 2.6 g/m^2)	Rough (1.1 mm detention storage)

A simple artificial rain simulator was constructed using 12 lengths of "soaker" hose, suspended on a wooden framework about one meter above the road surface. "Rain" was applied by connecting the hoses to a manifold, having individual valves to adjust constant rain intensities for the different areas. The manifold was in turn connected to a fire hydrant. The flow rate needed for each test was calculated based on the desired rain intensity and the area covered. The flow rates were carefully monitored by using a series of ball flow gauges before the manifold. The distributions of the test rains over the study areas were also monitored by placing about 20 small graduated cylinders over the area during the rains. In order to keep the drop sizes representative of sizes found during natural rains, the surface tension of the water drops hanging on the plastic soaker hoses was reduced by applying a light coating of Teflon spray to the hoses.

It was difficult to obtain even distributions of rain during the light rain tests in Toronto using the manifold, so a single hose was used that was manually moved back and forth over the test area during the smaller rain tests (three people took 30-minute shifts). To keep evaporation reasonable for the rain conditions, the test sites were also shaded during sunny days. Blank water samples were also obtained from the manifold for background residue analyses. The filterable residue of the “rain” water (about 185 mg/L) could cause substantial errors when calculating total solids washoff.

The areas studied were about 3 by 7 meters each. The street side edges of the test areas were edged with plywood, about 30 cm in height and imbedded in thick caulking, to direct the runoff towards the curbs with minimal leakage. All runoff was pumped continuously from downstream sumps (made of caulking and plastic sand bags) to graduated 1000 L Nalgene containers. The washoff samples were obtained from the pumped water going to the containers every 5 to 10 minutes at the beginning of the tests, and every 30 minutes near the end of the test. Final complete rinses of the test areas were also conducted (and sampled) at the tests’ conclusions to determine total loadings of the monitored constituents.

The samples were analyzed for total residue, filtrate residue, and particulate residue. Runoff samples were also filtered through 0.4 micron filters and microscopically analyzed (using low power polarized light microscopes to differentiate between inorganic and organic debris) to determine particulate residue size distributions from about 1 to 500 microns. The runoff flow quantities were also carefully monitored to determine the magnitude of initial and total rain water losses on impervious surfaces.

These tests are different from the important early Sartor and Boyd (1972) washoff experiments in the following ways:

- They were organized in overlapping factorial experimental designs to identify the most important main factors and interactions.
- Particle sizes were measured down to about one micron (in addition to particulate residue and filterable residue measurements).
- The precipitation intensities were lower in order to better represent actual rain conditions of the upper midwest.
- Observations were made with more resolution at the beginning of the tests.
- Washoff flow rates were frequently measured.
- Emphasis was placed on total street loading, not just total available loading.
- Bacteria population measurements were also periodically obtained.

Figures 3-8 through 3-10 are plots of total solids, suspended solids, and filterable solids concentrations during these tests. The total solids concentrations varied from about 25 to 3000 mg/L, with an obvious decrease in concentrations with increasing rain depths during these constant rain intensity tests. No concentrations greater than 500 mg/L occurred after about two mm of rain. All concentrations after about 10 mm of rain were less than 100 mg/L. Total solids concentrations were independent of the test conditions. A wide range in runoff concentrations was also observed for SS, with concentrations ranging from about 1 to 3000 mg/L. Again, a decreasing trend of concentrations was seen with increasing rain depths, but the data scatter was larger because of the experimental factors. The dissolved solids (<0.45 µm) concentrations ranged from about 20 to 900 mg/L, comprising a surprisingly large percentage of the total solids loadings. For small rain depths, dissolved solids comprised up to 90 percent of the total solids. After 10 mm of rain depth, the filterable residue concentrations were all less than about 50 mg/L.

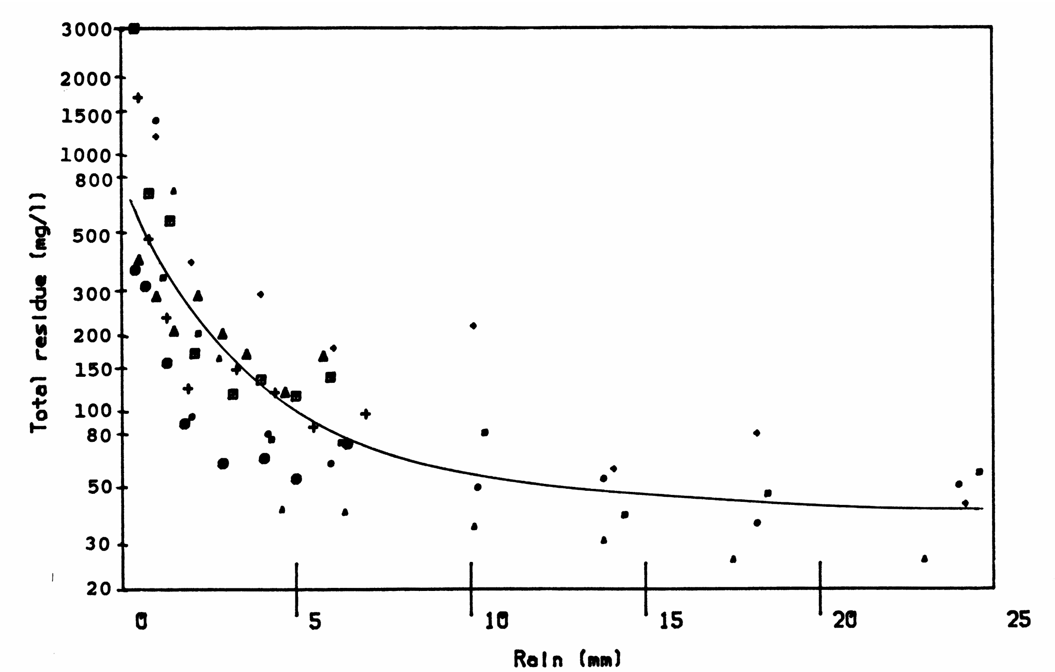


Figure 3-8. Total solids concentration decreases with rain depth increases during constant rain intensity washoff tests in Toronto (Pitt 1987).

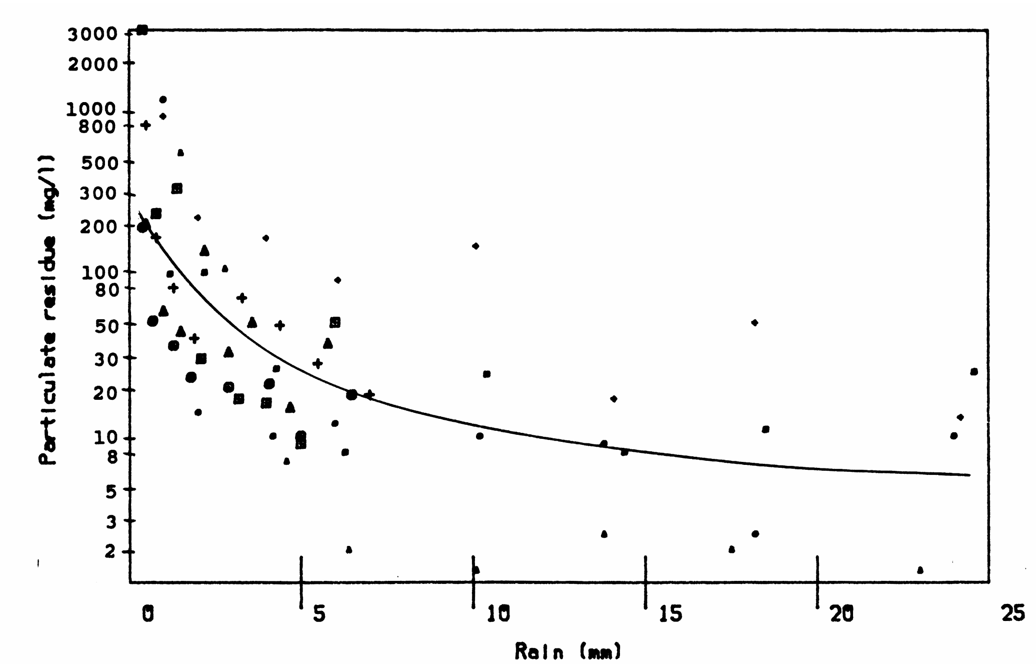


Figure 3-9. Suspended solids concentration decreases with rain depth increases during constant rain intensity washoff tests in Toronto (Pitt 1987).

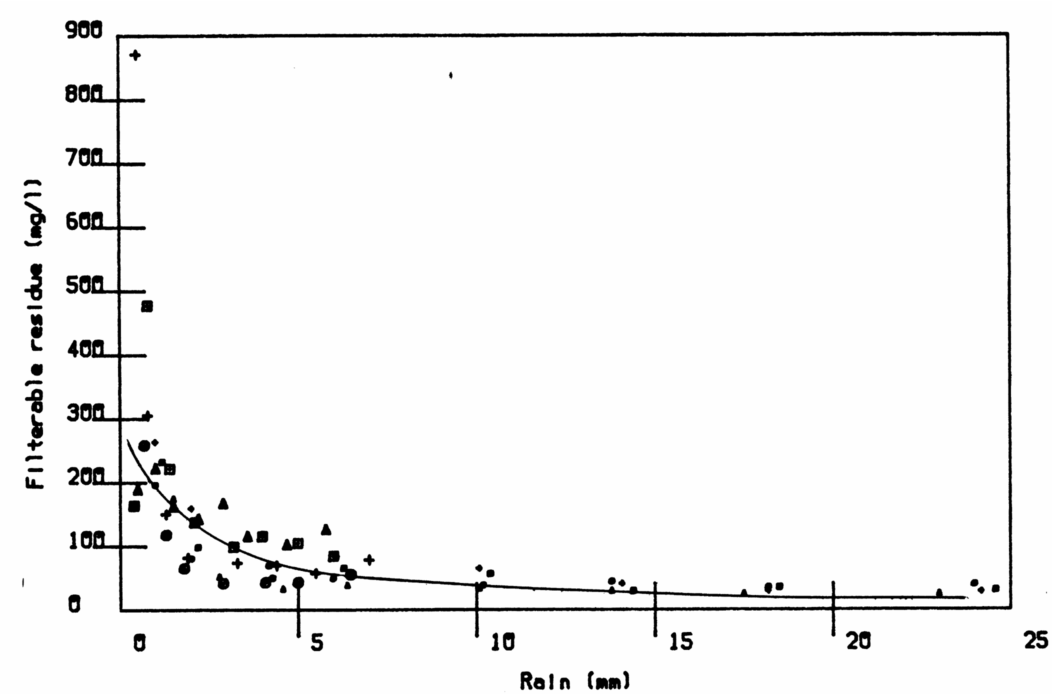


Figure 3-10. Dissolved solids concentration decreases during street dirt washoff tests in Toronto (Pitt 1987).

Manual particle size analyses were also conducted on the suspended solids washoff samples, using a microscope with a calibrated recticle. Figures 3-11 through 3-13 are examples of particle size distributions for three tests. These plots show the percentage of the particles that were less than various sizes, by measured particle volume (assumed to be similar to weight). The plots also indicate median particle sizes of about 10 to 50 µm, depending on when the sample was obtained during the washoff tests. All of the distributions showed surprisingly similar trends of particle sizes with elapsed rain depth. The median size for the sample obtained at about one mm of rain was much greater than for the samples taken after more rain. The median particle sizes of material remaining on the streets after the washoff tests were also much larger than for most of the runoff samples, but were quite close to the initial samples' median particle sizes. The washoff water at the very beginning of the test rains, therefore, contained many more larger particles than during later portions of the rains. Also, a substantial amount of larger particles remained on the streets after the test rains. Most street runoff waters during test rains in the 5 to 15 mm depth category had median suspended solids particle sizes of about 10 to 50 µm. However, dissolved solids (less than 0.45 µm) made up most of the total solids washoff for elapsed rain depths greater than about five mm.

These particle size distributions indicate that the smaller particles were much more important than indicated during previous tests. As an example, the Sartor and Boyd (1972) washoff tests (rain intensities of 50 mm/h for two hour durations) found median particle sizes of about 150 µm which were typically three to five times larger than were found during these lower-intensity tests. They also did not find any significant particle size distribution differences for different rain depths (or rain duration), in contrast to the Toronto tests, which were conducted at more likely rain intensities (3 to 12 mm/hr for two hours).

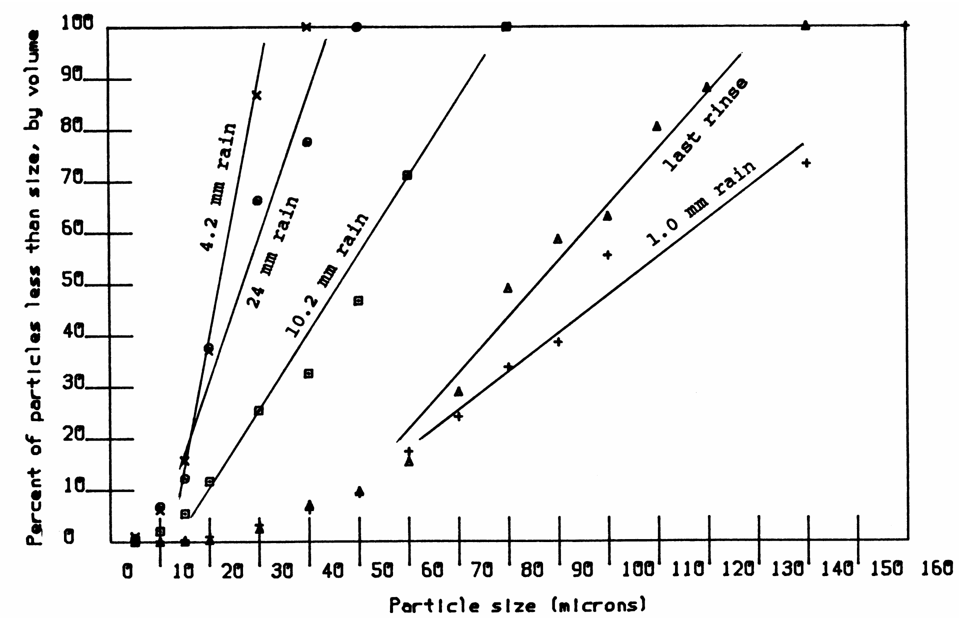


Figure 3-11. Particle size distributions during high rain intensity, clean and smooth street (HCS) tests (Pitt 1987).

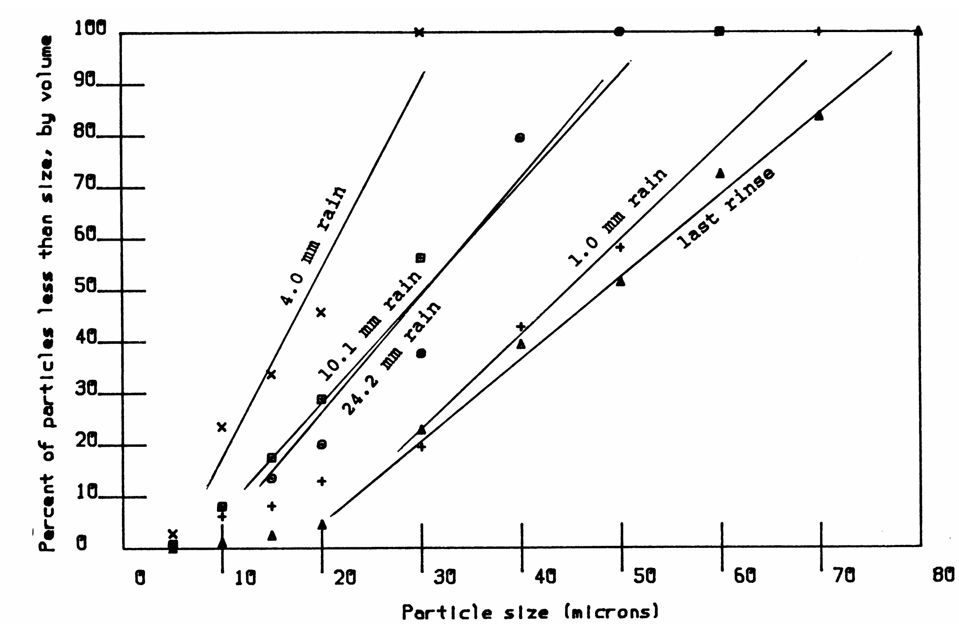


Figure 3-12. Particle size distributions during high rain intensity, dirty and smooth street (HDS) tests (Pitt 1987).

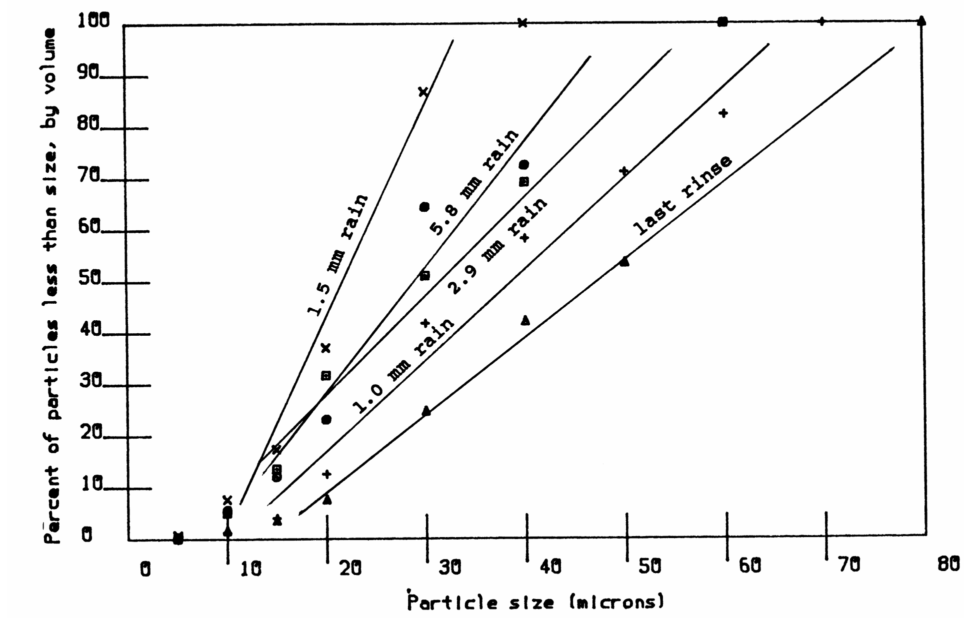


Figure 3-13. Particle size distributions during light rain intensity, clean and rough street (LCR) tests (Pitt 1987).

Washoff Equations for Individual Tests

The particulate washoff values obtained during these Toronto tests were expressed in units of grams per square meter and grams per curb-meter, concentrations (mg/L), and the percent of the total initial loading washed off during the test. Plots of accumulative washoff are shown on Figures 3-14 through 3-21. These plots show the asymptotic washoff values observed in the tests, along with the measured total street dirt loadings. The maximum asymptotic values are the "available" street dirt loadings (N_o). The measured total loadings are seen to be several times larger than these "available" loading values. As an example, the asymptotic available total solids value for the HDS (high intensity rain, dirty street, smooth street) test (Figure 3-20) was about 3 g/m^2 while the total load on the street for this test was about 14 g/m^2, or about five times the available load. The differences between available and total loadings for the other tests were even greater, with the total loads typically about ten times greater than the available loads. The total loading and available loading values for dissolved solids were quite close, indicating almost complete washoff of the very small particles. However, the differences between the two loading values for SS were much greater. Shielding, therefore, may not have been very important during these tests, as almost all of the smallest particles were removed, even in the presence of heavy loadings of large particles.

The actual data are shown on these figures, along with the fitted Sartor and Boyd exponential washoff equations. In many cases, the fitted washoff equations greatly over-predicted suspended solids washoff during the very small rains (usually less than one to three mm in depth), possibly due to shielding. In all cases, the fitted washoff equations described suspended solids washoff very well for rains greater than about 10 mm in depth.

Tables 3-25 through 3-27 present the equation parameters for each of the eight washoff tests for total solids, suspended solids, and filterable solids. Pitt (1987) concluded that particulate washoff (defined by the suspended solids washoff) should be divided into two main categories, one for high intensity rains with dirty streets, possibly divided into categories by street texture, and the other for all other conditions. Factorial tests also found that the availability factor (the ratio of the available loading, N_o, to the total loading) varied depending on the rain intensity and the street roughness, as indicated below:

- Low rain intensity and rough streets: 0.045
- High rain intensity and rough streets, or low rain intensity and smooth streets: 0.075
- High rain intensity and smooth streets: 0.20

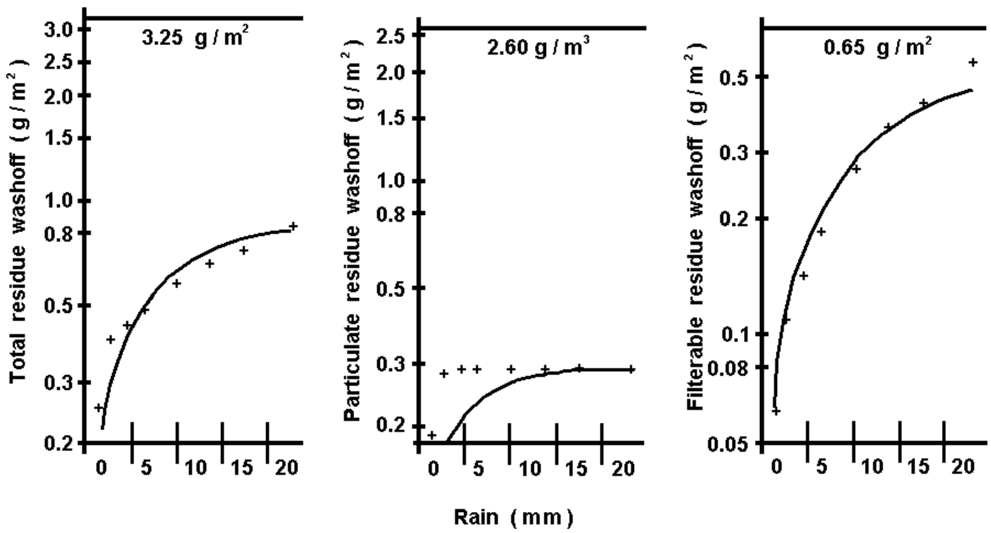


Figure 3-14. Washoff plots for HCR test (high rain intensity, clean, and rough street) (Pitt 1987).

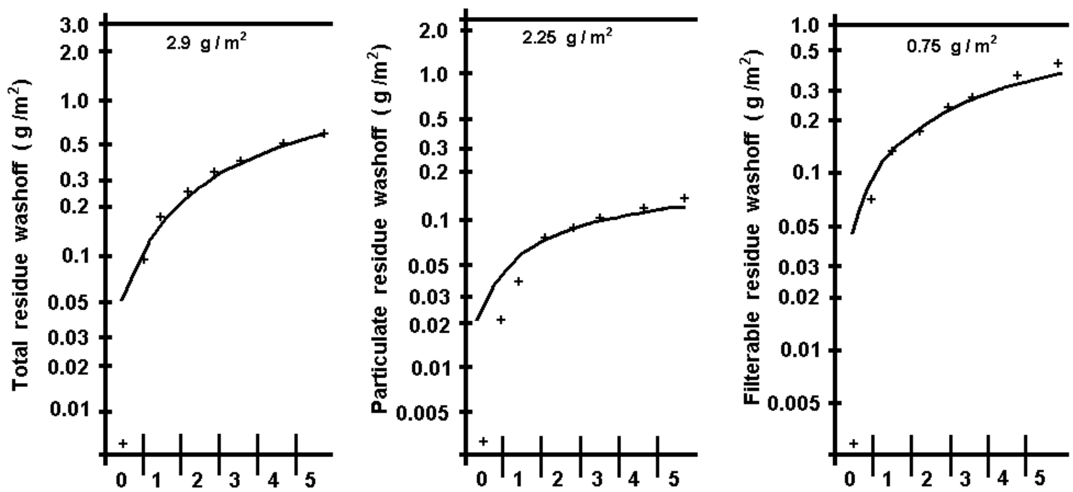


Figure 3-15. Washoff plots for LCR test (light rain intensity, clean, and rough street) (Pitt 1987).

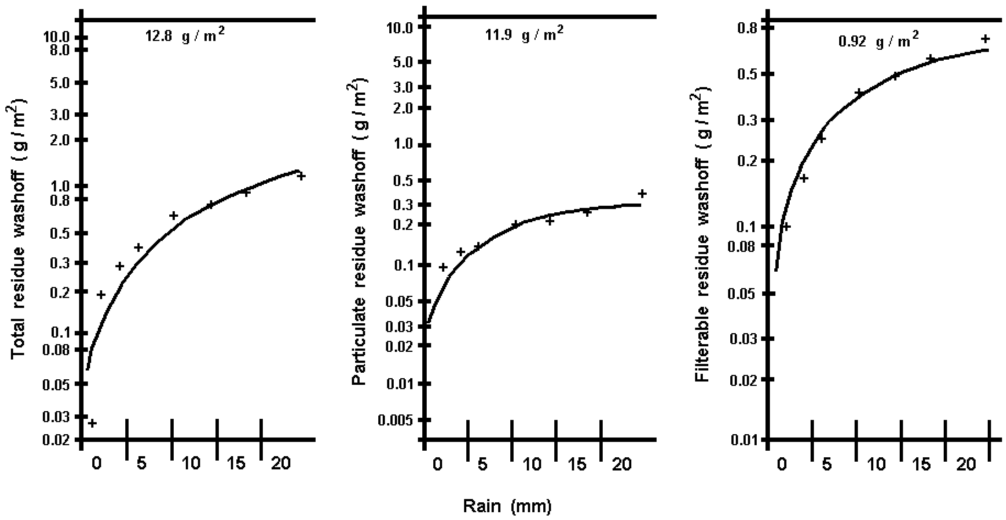


Figure 3-16. Washoff plots for HDR test (high rain intensity, dirty, and rough street) (Pitt 1987).

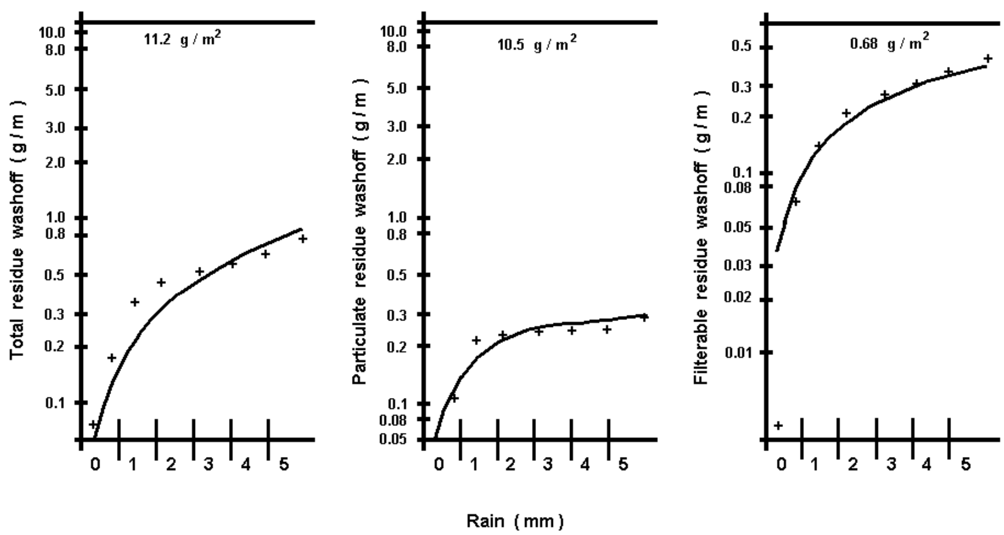


Figure 3-17. Washoff plots for LDR test (light rain intensity, dirty, and rough street) (Pitt 1987).

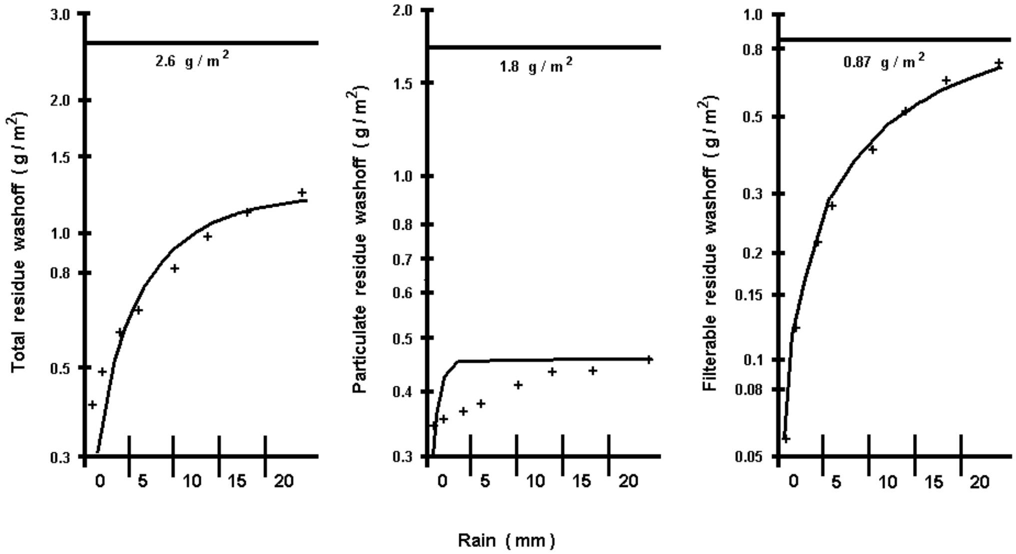


Figure 3-18. Washoff plots for HCS test (high rain intensity, clean, and smooth street) (Pitt 1987).

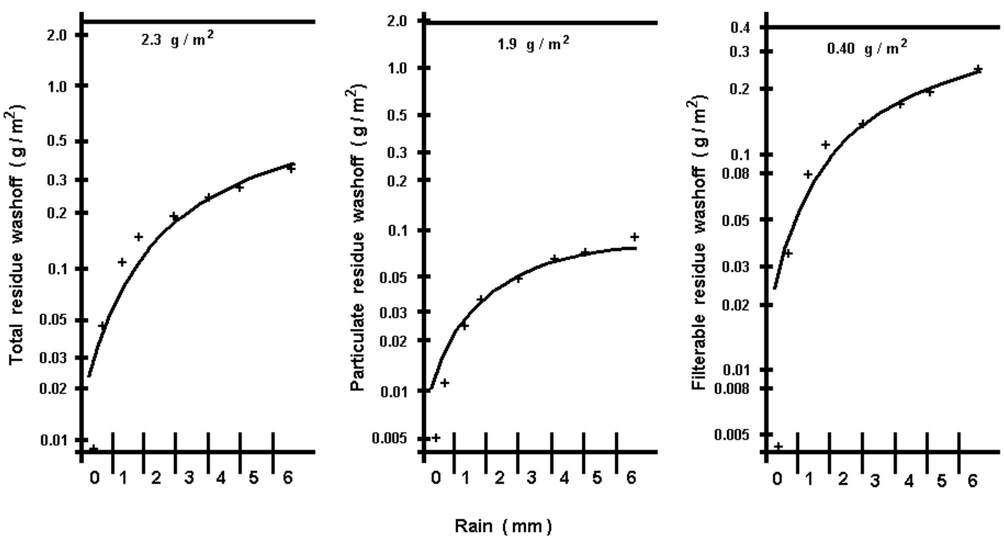


Figure 3-19. Washoff plots for LCS test (light rain intensity, clean, and smooth street) (Pitt 1987).

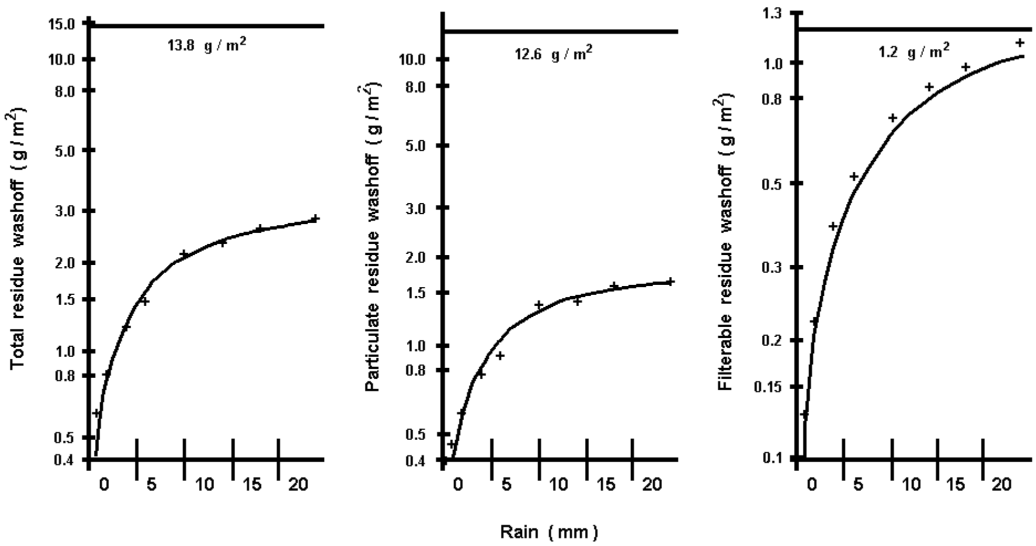


Figure 3-20. Washoff plots for HDS test (high rain intensity, dirty, and smooth street) (Pitt 1987).

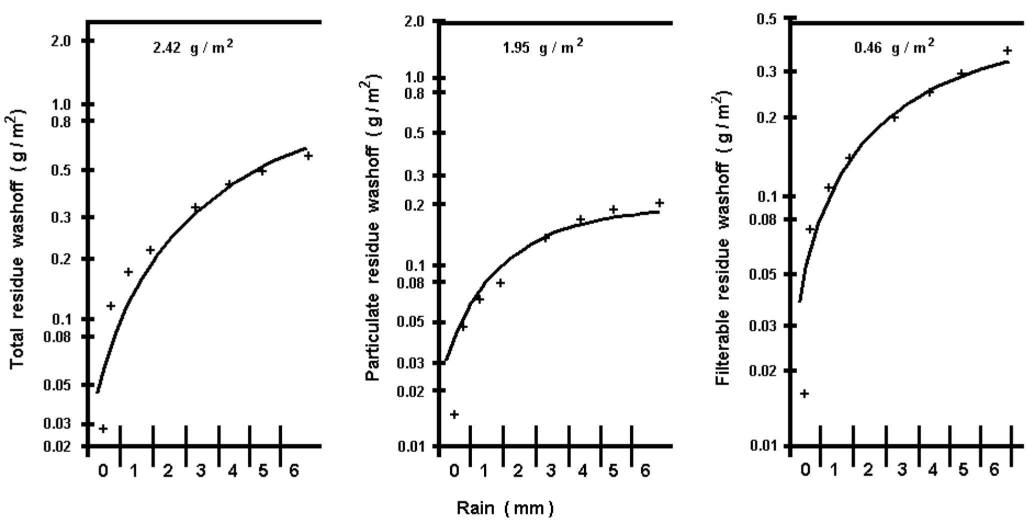


Figure 3-21. Washoff plots for LCS replicate test (light rain intensity, clean, and smooth street) (Pitt 1987).

Table 3-25. Total solids washoff coefficients (Pitt 1987)[1]

Test condition code	Rain intensity category	Street dirt loading category	Street texture category	N_o (g/m^2) measured total initial total solids load	Calculated k (1/hr)	Standard error for k (1/hr)	N_o (g/m^2) available initial total solids load	Calculated k (1/hr)	Standard error for k (1/hr)
HCR	high	clean	rough	3.25	0.016	0.002	0.84	0.145	0.018
LCR	low	clean	rough	2.99	0.038	0.001	0.58	0.304	0.032
HDR	high	dirty	rough	12.82	0.004	<0.001	1.14	0.078	0.006
LDR	low	dirty	rough	11.22	0.013	0.001	0.74	0.383	0.024
HCS	high	clean	smooth	2.62	0.033	0.005	1.21	0.146	0.021
LCS	low	clean	smooth	2.32	0.026	0.001	0.35	0.301	0.024
HDS	high	dirty	smooth	13.82	0.012	0.001	2.74	0.138	0.008
LCS	low	clean	smooth	2.42	0.042	0.002	0.57	0.300	0.024

1) Note:

$$N = N_o e^{-kR}$$

Obviously, washoff was more efficient for the higher rain energy and smoother pavement tests. The worst case was for a low rain intensity and rough street, where only about 4.5% of the street dirt would be washed from the pavement. In contrast, the high rain intensities on the smooth streets were more than four times more efficient in removing the street dirt.

If a selected model requires available loading values instead of the total loading values, then a procedure must be used to adjust the total loading values (such as attempted by the availability term in STORM and SWMM). In all cases, the k term must be appropriate for the model form. However, the use of an available loading value for N_o requires the use of a substantially larger k term compared to using the total loading value.

Table 3-26. Suspended solids washoff coefficients (Pitt 1987)

Test condition code	Rain intensity category	Street dirt loading category	Street texture category	N_o (g/m^2) available suspended solids load	Calculated k (1/hr)	Standard error for k (1/hr)	Ratio of available load to total initial load
HCR	high	clean	rough	0.295	0.832	0.064	0.11
LCR	low	clean	rough	0.138	0.344	0.038	0.061
HDR	high	dirty	rough	0.375	0.077	0.008	0.032
LDR	low	dirty	rough	0.291	0.619	0.052	0.028
HCS	high	clean	smooth	0.462	1.007	0.321	0.26
LCS	low	clean	smooth	0.091	0.302	0.024	0.047
HDS	high	dirty	smooth	1.66	0.167	0.015	0.13
LCS	low	clean	smooth	0.209	0.335	0.031	0.11

Table 3-27. Filterable solids washoff coefficients (Pitt 1987)

Test condition code	Rain intensity category	Street dirt loading category	Street texture category	N_o (g/m^2) measured total initial filterable solids load	Calculated k (1/hr)	Standard error for k (1/hr)
HCR	high	clean	rough	0.651	0.061	0.004
LCR	low	clean	rough	0.745	0.139	0.006
HDR	high	dirty	rough	0.915	0.058	0.002
LDR	low	dirty	rough	0.680	0.163	0.006
HCS	high	clean	smooth	0.871	0.070	0.003
LCS	low	clean	smooth	0.395	0.154	0.007
HDS	high	dirty	smooth	1.223	0.085	0.002
LCS	low	clean	smooth	0.463	0.183	0.008

The total residue models were fitted using both total and available residue values to show the differences in the proportionality terms (k) for each loading type. In three cases (HCR, HCS, and HDS), the available residue form of the equations provided much better model residual analyses and were therefore preferred over the candidate equations using total loadings. The k values varied greatly (by about 5 to 30 times), depending on the use of total or available loadings.

Some of the attempts at fitting outfall data to the washoff model used total street dirt loading values, while the Sartor and Boyd values were based on available loadings. Obviously, this difference in loading definition easily could have been responsible for causing such different k values to be identified. The available loading forms of the equations for these washoff tests produced the largest k values (0.078 to 0.38), and are similar to the reported Sartor and Boyd value of 0.18 that is used as a "default" in many urban runoff models. The total loading model k terms are much smaller (0.004 to 0.042) and are close to those reported by Novotny (undated) (0.019 to 0.026) using Milwaukee NURP street dirt washoff observations and actual measured total street dirt loadings.

Selecting the appropriate k term for the correct form of N_o is critical. As an example, the rain volume needed to produce 90 percent washoff can be calculated using the standard washoff equation as follows:

$N = N_o\, e^{-kR}$

for 90 percent washoff, $N = 0.1\ N_o$, and

$0.1\ N_o = N_o\, e^{-kR}$, or

$0.1 = e^{-kR}$, and

$(1/k)\ \log_e (0.1) = R$, therefore

$R = 2.303/k$ for 90 percent washoff.

For a k value of 0.3 (the LCS model for available total residue loadings), the rain needed for 90 percent washoff would be 8 mm. This rain would produce a washoff total of about 0.32 g/m^2 using the appropriate available N_o loading of 0.35 g/m^2. If the k value of 0.026 was used instead (appropriate for the total loading form of the LCS model), a rain of almost 90 mm would be needed for 90 percent washoff (more than ten times the rain depth predicted using the larger k value). In this case however, a total N_o value of 2.32 g/m^2 should be used, producing a washoff quantity of about 2.1 g/m^2 (more than 6.5 times the total residue washoff produced above). In all cases, the fitted models should obviously be used with caution beyond the test conditions. The 8 mm rain prediction is well within the test conditions, while the 90 mm rain prediction is almost four times the maximum rain used in these washoff tests. Other relationships between k values and rain quantities (mm) to produce specific percent washoffs are as follows:

Percent washoff	Rain needed (mm)
99.9	6.908/k
99	4.605/k
95	2.996/k
90	2.303/k
75	1.386/k
50	0.693/k
25	0.288/k
10	0.105/k

From these relationships, it is obvious that washoff occurs faster for larger k values (the washoff curves presented in Figures 3-14 through 3-21 would be steeper for larger k values if the figures were plotted without log scales).

The selected particulate residual washoff models were all based on the available loading model form because of superior model residual behavior. Therefore, an additional relationship is needed to predict available loading from total observed loading. The available particulate residue loadings ranged from about 3 to 25 percent (with an average of about 10 percent) of the total particulate residual loadings.

The filterable residue washoff models, however, were all based on total measured filterable residue loadings. These different preferred model forms for particulate and filterable residue were most likely caused by the differences in washoff efficiencies for different sized particles. Particulate residues were not nearly as efficiently removed during the washoff tests and were better related to much reduced "available" particulate residue loading values. Filterable residues in contrast, were much more efficiently removed and related well to total loadings (not much filterable residue was left on the streets after the washoff tests, making the available loadings very similar to the total loadings for filterable residue). Table 3-28 contains the availability relationship for suspended solids.

Table 3-28. Fraction of total street dirt suspended solids available for washoff (Pitt 1987).

Ratio of "available" particulate residue loadings to total particulate residue loadings.

$I = 0.08 \pm 0.04$
$T = -0.08 \pm 0.05$

$$\hat{Y} = 0.097 + 0.04(I) - 0.04(T)$$

I+T+ (high and rough) : $\hat{Y} = 0.10$
I+T- (high and smooth): $\hat{Y} = 0.18$
I-T+ (low and rough) : $\hat{Y} = 0.02$
I-T- (low and smooth) : $\hat{Y} = 0.10$

Maximum Washoff Capacity

Another important consideration in calculating washoff of street dirt during rains is the carrying capacity of the flowing water. If the water velocity is high, it is much more capable of carrying particulates than for lower water velocities. This is the basic concept of the Yalin equation (using the Shield's diagram) and numerous other sediment transport equations: there is a physical limit to the ability of water to transport sediment. In contrast, the conventional washoff plots and equations presented earlier result in a “percentage” washoff of the total load, irrespective of the resultant concentration. However, when observing the plot of suspended solids concentration vs. rain depth for many washoff test plots (Figure 3-9), the pattern is quite distinct and appears to be generally independent on initial street loading (there is substantial scatter in this plot which likely reflects some site conditions). The washoff mostly is controlled by the carrying capacity of the water, and not source limitations, as there is substantial material on the street after the end of most rains. Therefore, this carrying capacity must be considered when predicting washoff quantities. If the calculated washoff is greater than the carrying capacity (such as would occur for relatively heavy street dirt loads and low to moderate rain intensities), then the carrying capacity is limiting. For high rain intensities, the carrying capacity is likely sufficient to transport most all of the washoff material.

In order to determine this carrying capacity for street runoff, data from washoff tests conducted by Pitt (1987) and Sartor and Boyd (1972), shown previously as Figures 3-6 and 3-14 through 3-21, were further examined. The maximum washoff amounts (g/m^2) for six different tests conducted on smooth streets were plotted against the rain intensity (mm/hr) used for the tests. This plot is shown in Figure 3-22, illustrating the exponential equation fitted to these data:

$$W = 0.0636\ e^{0.237P}$$

Where W = the maximum washoff, $grams/meter^2$
and P = average rain intensity, mm/hr

These are the maximum washoff values possible, representing the carrying capacity of the runoff. If the predicted washoff, using the previous “standard” washoff equations, is smaller than the values shown in this figure, then those values can be used directly. However, if the predicted washoff is greater than the values shown in this figure, then the values in the figure should be used.

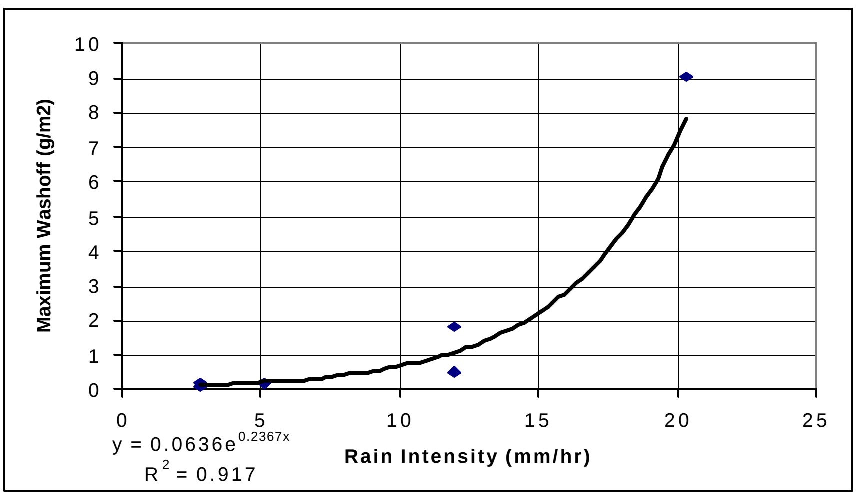


Figure 3-22. Maximum washoff capacity for smooth streets (based on Pitt 1987 and Sartor and Boyd 1972 measurements).

The resulting sheetflow concentrations associated with these maximum washoff values depends on the rain durations at these average rain intensities. As an example, for typical 6 hour durations, the resulting concentrations are very similar to the fitted line on the suspended solids concentration vs. rain depth plot shown on Figure 3-9 (about 100 mg/L for 1 to 2 mm rains, decreasing to about 10 mg/L for rains of about 25 mm in depth). For very large rains, having sustained high rain intensities, the available street dirt loading would most likely be limiting.

Comparison of Particulate Residue Washoff Using Previous Washoff Models and Revised Washoff Model

This discussion briefly compares the washoff observations obtained during these washoff tests with predicted washoff values obtained using the Sartor and Boyd (1972) washoff model (with and without the "availability" factor). Table 3-29 shows the predicted washoff values along with the observed values for the conditions that occurred during the washoff tests. In all cases, serious over-predictions in street dirt washoff resulted by using these common washoff models. Even with the availability factor, the predicted Sartor and Boyd washoff quantities were almost two to more than five times greater than observed. Without the availability factor, the modeled washoff quantities were at least five times greater than the observed values. The residuals (all reflecting over-predictions) of these modeled estimates ranged from 0.2 to 7 g/m^2 when using the availability factor, compared to residuals mostly less than 0.05 g/m^2 when the model developed from these washoff tests was used. Lower residuals obtained by using the revised model could be expected because these data were not independent from the data used in developing the revised washoff model.

Table 3-29. Comparisons of Observed Washoff with Sartor and Boyd Equation Predictions (Pitt 1987).

	Calculated Sartor and Boyd Washoff (g/m^2)	Calculated Sartor and Boyd Washoff With Avail. Factor (g/m^2)	Observed Washoff (g/m^2)
Clean Streets			
Light rains	1.47	0.28	0.08 to 0.18
Heavy rains	2.17	1.41	0.28 to 0.45
Dirty Streets			
Light rains	7.73	1.47	0.28
Heavy rains	11.42	7.42	0.30 to 1.5

As stated previously, over-predicted street dirt washoff quantities would result in under-predictions of particulate residue from other sources during model calibration. These over-predictions, especially combined with commonly over-predicted runoff flow volumes, dramatically affect the relative importance of different urban runoff pollutant source areas and estimated effectiveness of source area controls.

Summary of Street Particulate Washoff Tests

The above discussion summarized street particulate washoff observations obtained during special washoff tests, along with the associated street dirt accumulation measurements. The objectives of these tests were to identify the significant rain and street factors affecting particulate washoff and to develop appropriate washoff models. These tests and calculations were also used to clarify apparent confusion caused by misuse of washoff equations in urban runoff models.

The controlled washoff experiments identified important relationships between "available" and "total" particulate loadings and the significant effects of the test variables on the washoff model parameters. Past modeling efforts have typically ignored or misused this relationship to inaccurately predict the importance of street particulate washoff. The available loadings were almost completely washed off streets during rains of about 25 mm (as previously assumed). However, the fraction of the total loading that was available was at most only 20 percent of the total loading, and averaged only 10 percent, with resultant actual washoffs of only about 9 percent of the total loadings. Based on extrapolating the washoff models, only very large rains (possibly approaching 100 mm in depth) could ever be expected to wash off most of the total particulate street dirt load. These very large rains are well beyond the range of any washoff tests. However, observed street dirt washoff during actual rains near this size have not produced substantially greater washoff quantities than observed during the tests conducted during this research. The correctly used exponential washoff models only appear to be applicable for rains in the range of about 3 to 30 mm, which are the most important rains for water quality studies.

The fractions of the particulate residue loadings that were available for washoff was affected by both rain intensity and texture. In many model applications, total initial loading values (as usually measured during field studies) are used in conjunction with model parameters for available loadings, resulting in predicted washoff values that are many times over-predicted. This has the effect of incorrectly assuming greater pollutant contributions originating from streets and less from other areas during rains. This in turn results in inaccurate estimates of the effectiveness of different source area urban runoff controls.

Street dirt accumulation values have also been observed before and after rains. A tested industrial street experienced a much greater accumulation rate than the residential street, probably because of increased tracking of debris from unpaved driveways and parking areas and greater deposition of particulates from the heavy car and truck traffic. As shown in a summary of much accumulation data from throughout the US, smooth streets had much lower initial loadings immediately after street cleaning, but street texture did not affect particulate accumulations as much as land use.

These accumulation and washoff relationships were included in the Source Loading and Management Model (WinSLAMM) to describe street dirt washoff processes.

Observed Particle Size Distributions in Stormwater

A final note needs to be included in this section pertaining to the sizes of stormwater runoff particulates. The particle size distributions of stormwater greatly affect the ability of most controls to reduce pollutant discharges, and accumulation and washoff of particulates from source areas determines the particle sizes entering the storm drainage systems. Sedimentation and filtration controls are much more effective for large particles than for small particles, for example. Conventional street cleaning preferentially removes large particles from streets, but rains preferentially remove the smallest particle sizes. Inaccurate particle size assumptions of stormwater particulates than therefore dramatically affect performance predictions.

During several research projects, Pitt determined particle size analyses of 121 stormwater samples from three states that were not affected by stormwater controls (southern New Jersey as part of inlet tests; Birmingham, AL as part of MCTT pilot-scale tests; and in Milwaukee and Minocqua, WI, as part of the MCTT full-scale tests). These samples represented stormwater entering the stormwater controls being tested. Particle sizes were measured using a Coulter Multi-Sizer IIe and verified with microscopic, sieve, and settling column tests.

Figures 3-23 through 3-25 are grouped box and whisker plots showing the particle sizes (in µm) corresponding to the 10th, 50th (median) and 90th percentiles of the cumulative distributions. If 90% control of SS is desired, for example, then the particles larger than the 90th percentile would have to be removed by a sedimentation device. The median particle sizes ranged from 0.6 to 38 µm and averaged 14 µm. The 90th percentile sizes ranged from 0.5 to 11 µm and averaged 3 µm. These particle sizes are all substantially smaller than have been typically assumed for stormwater. In all cases, the New Jersey samples had the smallest particle sizes, followed by Wisconsin, and then Birmingham, AL, which had the largest particles. The New Jersey samples were obtained from gutter flows in a residential semi-xeroscaped neighborhood, the Wisconsin samples were obtained from a public works yard in Milwaukee, and the Birmingham samples were collected from a long-term parking area.

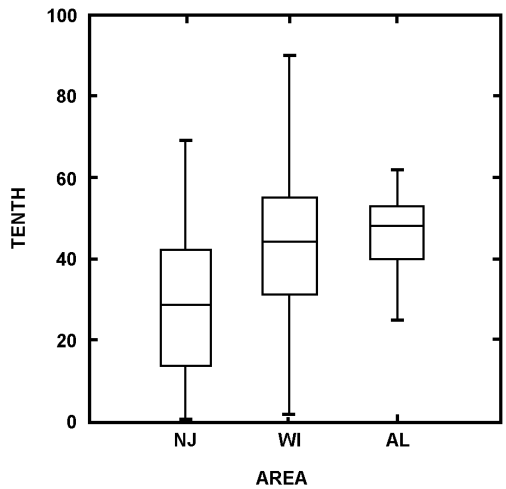


Figure 3-23. Tenth percentile particle sizes for stormwater inlet flows.

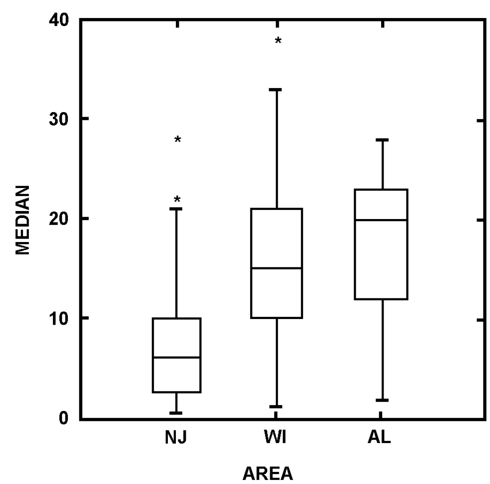


Figure 3-24. Fiftieth percentile particle sizes for stormwater inlet flows.

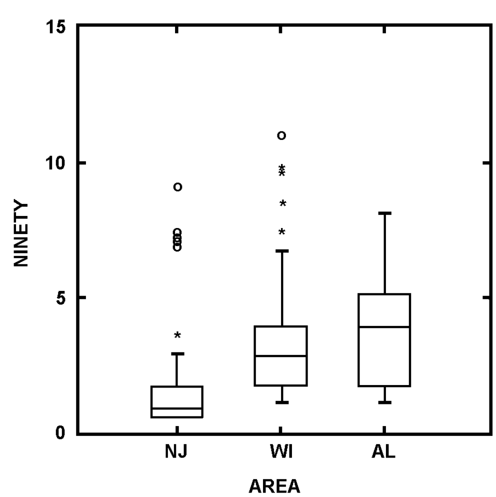


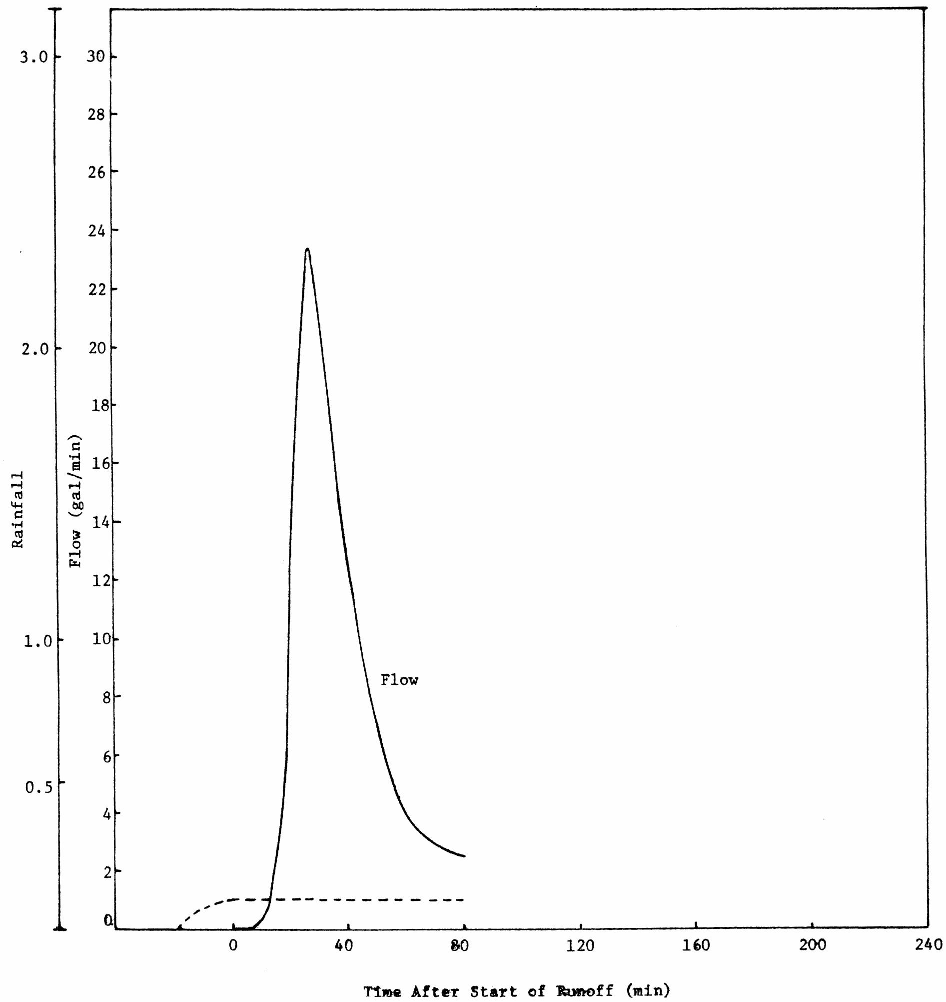
Figure 3-25. Ninetieth percentile particle sizes for stormwater inlet flows.

"First-Flush" of Stormwater Pollutants from Pavement

"First flush" refers to the relatively high pollutant concentrations at the beginning of a wet weather event, with decreasing concentrations as the event progresses. Sutherland (personal communication) suggests examining it by preparing a double mass curve, with accumulative runoff volumes (x axis) vs. accumulative pollutant mass (y axis). If first flush occurs, the resulting curve will bow upward initially and generally stay above the diagonal straight line from 1 to 100% (unfortunately, I don't have a good illustration). There is frequent mention of the phenomena of "first flush" as an opportunity for stormwater control, specifically as the reason why treatment of the first ½ inch of runoff is adequate. Concentrations at outfalls of most urban drainages do not routinely experience pronounced first flushes. However, they are well documented for combined systems, where CSO concentrations are very large at the beginning of events when accumulated sanitary solids in the sewerage can be easily scoured by a slight rise in the flow rate.

The controlled pavement washoff tests described in this section show large solids concentrations at the beginning of the tests, with significant decreases as the test progresses. These tests were conducted with constant "rain" intensities (and therefore constant kinetic energy). The initial abstractions and infiltration of water through the pavement also results in less runoff at the beginning of the test. However, there is an abundance of material on pavement surfaces that is not removed easily by low to moderate rain intensities. If the rain intensity increases later in the event, then pollutant concentrations would likely increase according as the available energy to dislodge and transport particulates increase. In addition, these tests were conducted with the simplest drainage conditions. In a real watershed, many source areas are contributing pollutants, but the travel times from the sources to the outfall are highly varied. This would moderate the high concentrations observed during the simple tests, as the first flushed material would arrive at different times at the outfall. In addition, as flows decrease during times of decreasing rain intensity, the transport ability (carrying capacity) of the water decreases, with deposition in the drainage system (onto pavement, in gutters, in grass channels, in the sewerage, etc.). These flow contribution irregularities, coupled with varying rain intensities during storms, generally masks significant first flush conditions at outfalls.

An example of first flush from a relatively simple watershed is shown in Figure 3-26 through 3-28 (Shaheen 1975). The test watershed was a portion of the Washington, D.C. beltway (I495), almost totally paved and guttered. This relatively small, but common rain (about 0.1 inch) produced peak flows of about 24 gal/min. The event had a relatively constant rain intensity and classical hydrograph shape with a rapid rise and drop. This event also had a pronounced first flush, with high concentrations of total solids, suspended solids, and lead at the beginning of the event, decreasing to about half. Constituents more associated with filterable fractions (soluble zinc and soluble lead) had little change over the period of the event. In contrast, another event at the same location is shown in Figures 3-29 and 3-30. The initial rainfall was about the same as for the other event, but significantly increased after about 2 hours. The hydrograph shows an initial rise and drop corresponding to the first part of the event, but the majority of the runoff occurred later in the event. The concentrations also showed an initial period of relatively high values, and then dropped, but later significantly increased when the rain intensity increased. The period of high concentrations (and high pollutant yields) occurred about two hours after rain started, conflicting with the first flush "theory." The concept of treating the first ½ inch of runoff from each event is usually successful, as almost all rains produce less than this amount, and about 80% of annual flows in many parts of North America, not because capturing the first flush allows treatment of a significantly more polluted and smaller portion of the runoff.



(Outfall on Western End of I 495 Overpass at Northwest Branch)

Figure 3-26. Rain and flow for storm event of Sept. 18, 1973, Washington, D.C. beltway freeway site (Shaheen 1975).

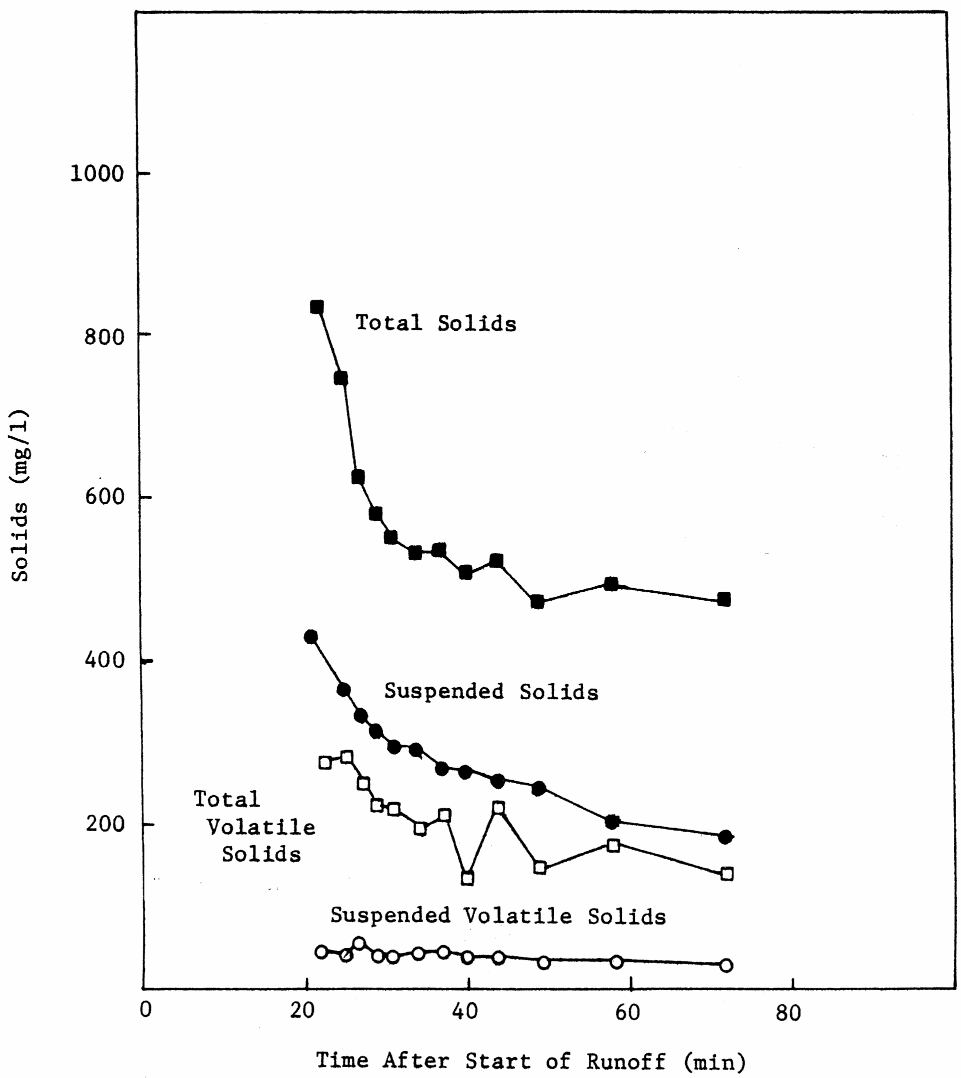


Figure 3-27. Solids concentrations for storm event of Sept. 18, 1973, Washington, D.C. beltway freeway site (Shaheen 1975).

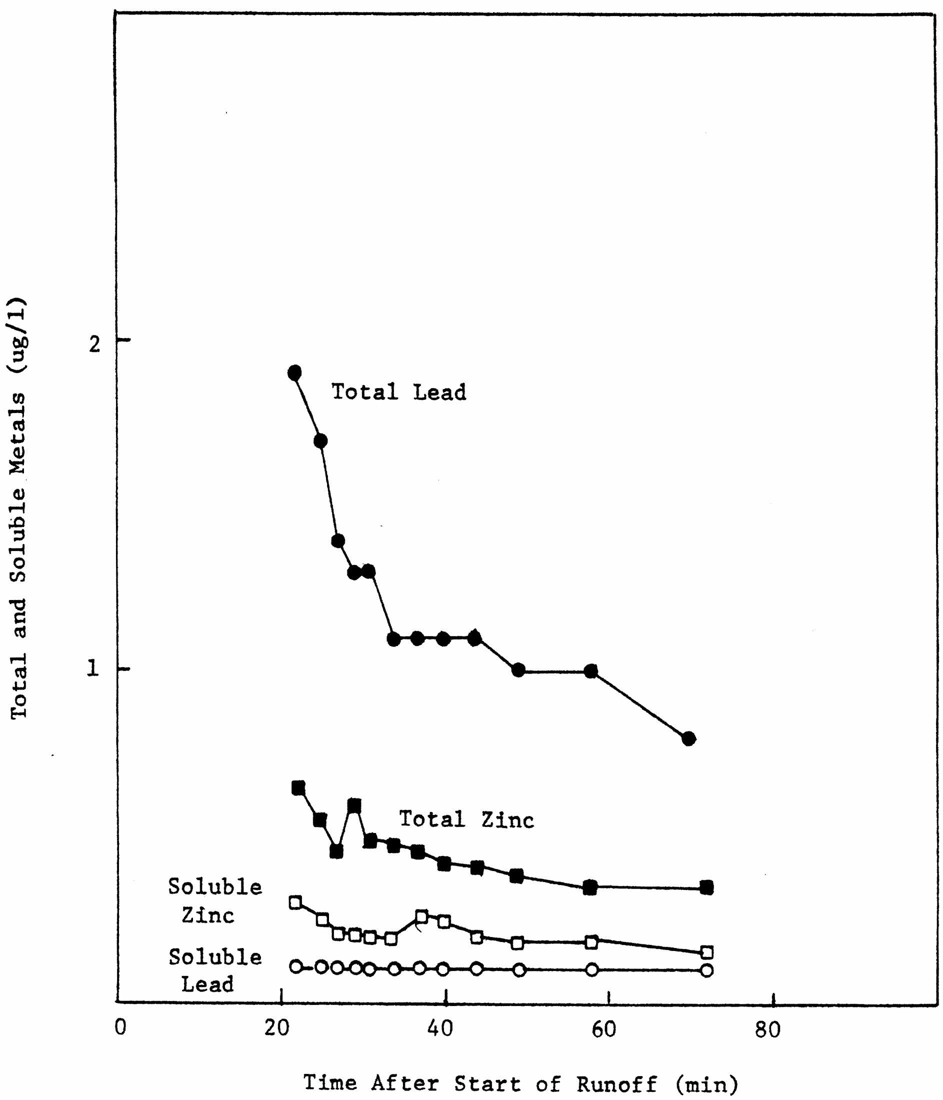


Figure 3-28. Heavy metal concentrations for storm event of Sept. 18, 1973, Washington, D.C. beltway freeway site (Shaheen 1975).

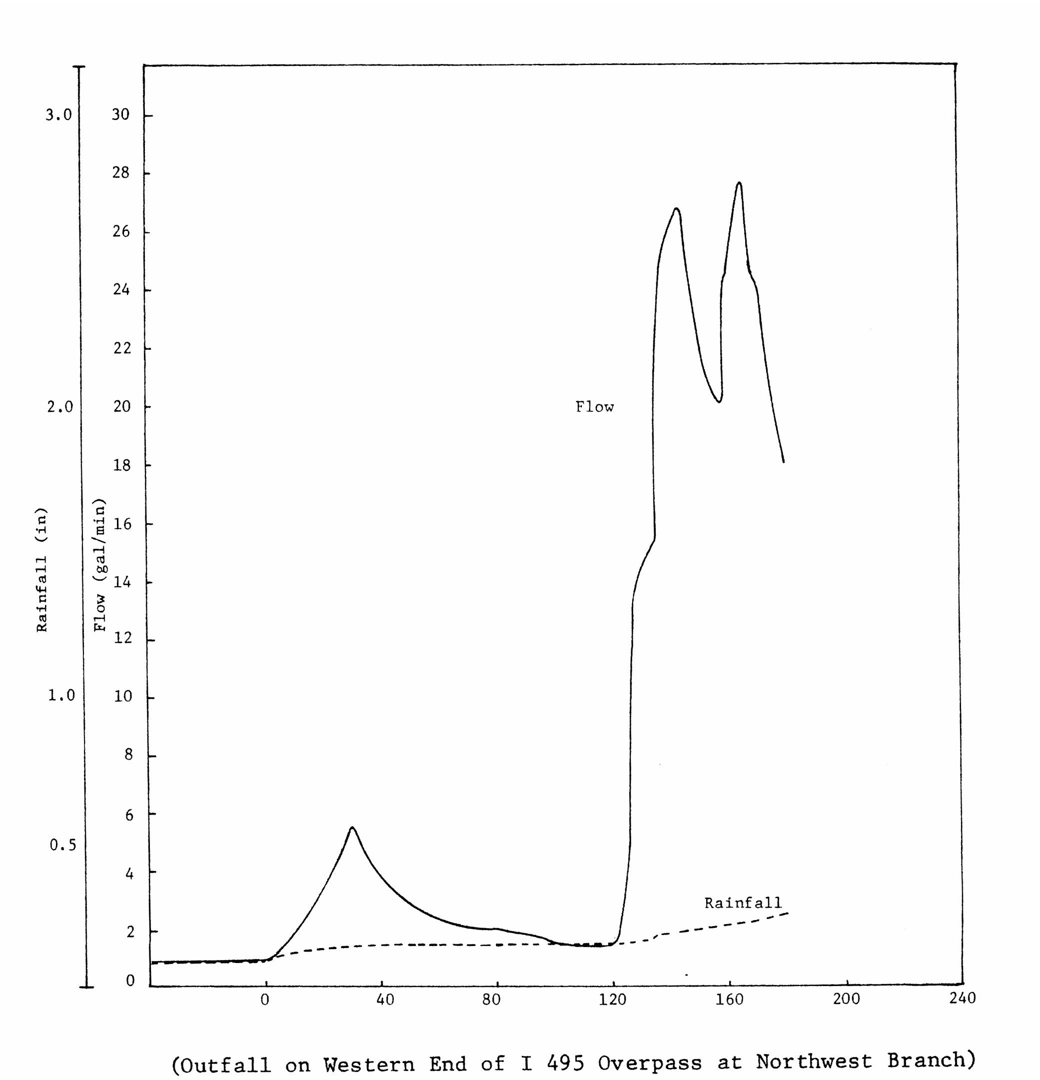


Figure 3-29. Rain and flow for storm event of Aug. 21, 1973, Washington, D.C. beltway freeway site (Shaheen 1975).

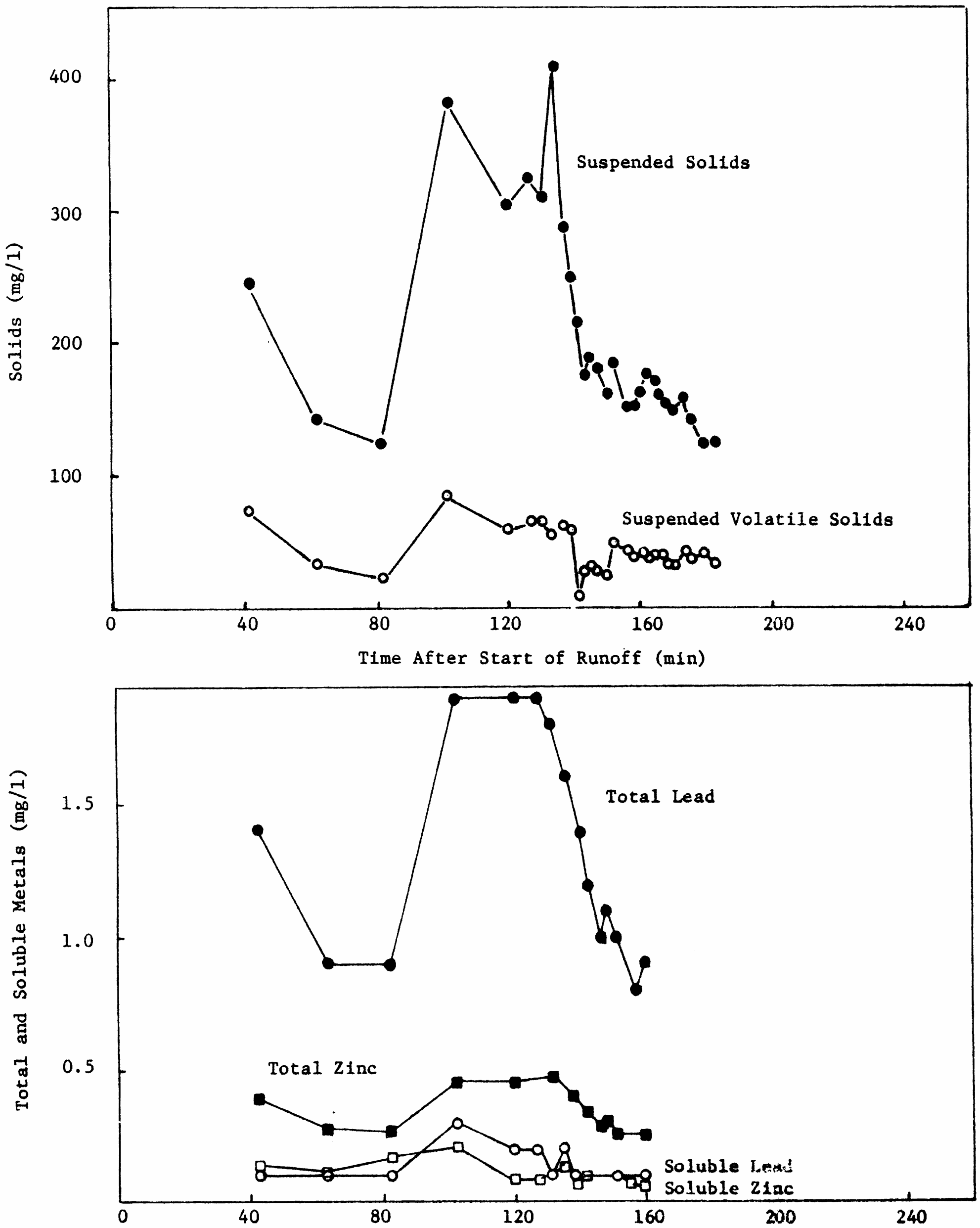


Figure 3-30. Pollutant concentrations for storm event of Aug. 21, 1973, Washington, D.C. beltway freeway site (Shaheen 1975).

Comparisons of First-Flush vs. Composite Samples at Stormwater Outfalls

Maestre, *et al*. (2004) compared outfall sample concentrations from NPDES permits, using data obtained as part of a EPA 104b(3) project that compiled monitoring information from many permit holders. As part of their NPDES stormwater permit, some communities collected grab samples during the first 30 minutes of the event to evaluate a "first flush" in contrast to the flow-weighted composite data. More than 400 paired samples representing the first flush and composite samples from eight communities (mostly located in the southeast U.S.) from the National

Stormwater Quality Database (NSQD) (http://civil.eng.ua.edu/~rpitt/Research/ms4/mainms4.shtml) were reviewed. Box and probability plots were prepared for 22 major constituents. Nonparametric statistical analyses were then used to measure the differences between the sample sets. This discussion presents the results of this preliminary analysis, including the effects of storm size and land use on the presence and importance of first flushes. Only concentration data were available for these analyses, so traditional accumulative mass curves could not be developed.

It is expected that peak concentrations generally occur during periods of peak flow (and highest rain energy). On relatively small paved areas, however, it is likely that there will always be a short period of relatively high concentrations associated with washing off of the most available material (Pitt 1987). This peak period of high concentrations may be overwhelmed by periods of high rain intensity that may occur later in the event. In addition, in more complex drainage areas, the routing of these short periods of peak concentrations may blend with larger flows and may not be noticeable. A first flush in a separate storm drainage system is therefore most likely to be seen if a rain occurs at relatively constant intensity over a paved area having a simple drainage system.

A total of 417 storm events with paired first flush and composite samples were available from the NSQD. The majority of the events were located in North Carolina (76.2%), but some events were also from Alabama (3.1%), Kentucky (13.9%) and Kansas (6.7%). All of the data were from end-of pipe samples in separate storm drainage systems.

The initial analyses were used to select the constituents and land uses that meet the requirements of the statistical comparison tests. Probability plots, box plots, concentration vs. precipitation, and standard descriptive statistics, were performed for 22 constituents for each land use, and for all land uses combined. Nonparametric statistical analyses were performed after the initial analyses. Mann Whitney and Fligner Policello tests were most commonly used. Minitab and Systat statistical programs, along with Word and Excel macros, were used during the analysis.

The Mann-Whitney and Fligner-Policello non-parametric tests were selected to determine if there were statistically significant differences between the first flush and composite data sets for each land use and constituent. These tests are very useful because they require only data symmetry, not normality, to evaluate the hypothesis. The null hypothesis during the analysis was that the median concentrations of the first flush and composite data sets were the same. The alternative hypothesis was that the medians were different, with a confidence of at least 95%.

Results

A complete description of these analyses is presented in Maestre, *et al*. (2004). Table 3-30 shows the results of the analysis. The ">" sign indicates that the median of the first flush data set is higher than for the composite data set. The "=" sign indicates that the there is not enough information to reject the null hypothesis. Events without enough data are represented with an "X". Also shown on this table are the ratios of the medians of the first flush and the composite data sets for each constituent and land use. The first flush samples were larger than for the composite samples if the ratio is great than one. Generally, a statistically significant first flush is associated with a median concentration ratio of about 1.4, or greater (the exceptions are where the number of samples in a specific category is small). The largest significant ratios are about 2.5, indicating that the first flush concentrations may be about 2.5 times greater than the composite concentrations. More of the larger ratios are found in the commercial and institutional land use categories, areas where larger paved areas are likely to be found. The smallest ratios are associated with the residential, industrial, and open space land uses, locations where there may be larger areas of unpaved surfaces.

Results indicate that for 55% of the evaluated cases, the median of the first flush data set was significantly larger than for the composite sample set. In the remaining 45% of the cases, both medians were expected to be the same, or the concentrations were possibly greater later in the events. About 70% of the constituents in the commercial land use category had first-flushes, while about 60% of the constituents in the residential, institutional and the mixed (mostly commercial and residential) land use categories had first flushes, and about 45% of the constituents in the industrial land use category had first-flushes. In contrast, no constituents were found to have first-flushes in the open space category.

COD, BOD_5, TDS, TKN, and Zn all had first flushes in all areas (except for the open space category). In contrast, turbidity, pH, fecal coliforms, fecal strep., total N, dissolved and ortho-P never showed a statistically significant first flush in any category. The conflict with TKN and total N implies that there may be some other factors involved in the identification of first flushes besides land use. If additional paired data becomes available during later project periods, it may be possible to extend these analyses to consider rain effects, drainage area, and geographical location.

Table 3-29. Presence of Significant First Flushes (ratio of first flush to composite median concentrations)

Parameter	Commercial	Industrial	Institutional	Open Space	Residential	All Combined
Turbidity	= (1.32)	X	X	X	= (1.24)	= (1.26)
pH	= (1.03)	= (1.00)	X	X	= (1.01)	= (1.01)
COD	> (2.29)	> (1.43)	> (2.73)	= (0.67)	> (1.63)	> (1.71)
TSS	> (1.85)	= (0.97)	> (2.12)	= (0.95)	> (1.84)	> (1.60)
BOD_5	> (1.77)	> (1.58)	> (1.67)	= (1.07)	> (1.67)	> (1.67)
TDS	> (1.82)	> (1.32)	> (2.66)	= (1.07)	> (1.52)	> (1.55)
O&G	> (1.54)	X	X	X	= (2.05)	> (1.60)
Fecal Coliform	= (0.87)	X	X	X	= (0.98)	= (1.21)
Fecal Strep.	= (1.05)	X	X	X	= (1.30)	= (1.11)
Ammonia	> (2.11)	= (1.08)	> (1.66)	X	> (1.36)	> (1.54)
NO_2 NO_3	> (1.73)	> (1.31)	> (1.70)	= (0.96)	> (1.66)	> (1.50)
Total N	= (1.35)	= (1.79)	X	= (1.53)	= (0.88)	= (1.22)
TKN	> (1.71)	> (1.35)	X	= (1.28)	> (1.65)	> (1.60)
Total P	> (1.44)	= (1.42)	= (1.24)	= (1.05)	> (1.46)	> (1.45)
P Dissolved	= (1.23)	= (1.04)	= (1.05)	= (0.69)	> (1.24)	= (1.07)
Phosphate Ortho	X	= (1.55)	X	X	= (0.95)	= (1.30)
Cd	> (2.15)	= (1.00)	X	= (1.30)	> (2.00)	> (1.62)
Cr	> (1.67)	= (1.36)	X	= (1.70)	= (1.24)	> (1.47)
Cu	> (1.62)	> (1.24)	= (0.94)	= (0.78)	> (1.33)	> (1.33)
Pb	> (1.65)	> (1.41)	> (2.28)	= (0.90)	> (1.48)	> (1.50)
Ni	> (2.40)	= (1.00)	X	X	= (1.20)	> (1.50)
Zn	> (1.92)	> (1.540	> (2.48)	= (1.25)	> (1.58)	> (1.59)

Summary

Pollutants can originate from many source areas in urban watersheds. During small storms, directly connected paved areas (such as streets) contribute the majority of pollutants and flows. However, as the rain events increase in size, other areas become important. Receiving water impacts are associated with a variety of storm types, and WinSLAMM can be used to identify the significant pollutant sources for each category of storm, and can also evaluate the benefits of alternative stormwater controls under a wide variety of conditions.

References

Alley, W. M. Determination of the decay coefficient in the exponential washoff equation. *International Symposium on Urban Runoff*. University of Kentucky. Lexington, KY. July. 1980

Alley, W. M. . Estimation of impervious-area washoff parameters. *Water Resources Research*. Vol. 17, No. 4, pp 1161-1166. 1981

American Public Works Association. *Water Pollution Aspects of Urban Runoff*. Water Pollution Control Research Series WP-20-15. Federal Water Pollution Control Administration. January. 1969

Arsenault, R.D. *Pentachlorophenol and Contained Chlorinated Diabenzodioxins in the Environment.* Proceedings of the American Wood Preservers Association, 1975,

Bannerman, R., K. M. Baun, P. E. Bohn, and D. A. Graczyk. *Evaluation of Urban Nonpoint Source Pollution Management in Milwaukee County, Wisconsin*. PB 84-114164. U.S. Environmental Protection Agency. Chicago, IL. 1983

Bannerman, R., D. W. Owens, R. B. Dodds, and N. J. Hornewer. Sources of pollutants in Wisconsin stormwater. *Water Science and Technology*. Vol. 28, No. 3-5, pp. 241-259. 1993

Barkdoll, M. P., D. E. Overton, and R. P. Beton. Some effects of dustfall on urban stormwater quality. *Water Pollution Control Federation*. 49(9):1976-84. 1977

Barron, P. *Characterization of Polynuclear Aromatic Hydrocarbons in Urban Runoff*. Master's Thesis. The University of Alabama at Birmingham Department of Civil Engineering. Birmingham, AL. 1990

Betson, R. P. Precipitation and streamflow quality relationships in an urban area. *Water Resources Research*. 14(6):1165-1169. 1978

Boller, M. Tracking Heavy Metals Reveals Sustainability Deficits of Urban Drainage Systems, *Water Science & Technology*. 35(9): 77-87, 1997

Box, G. E. P., W. G. Hunter, and J. S. Hunter. *Statistics for Experimenters*. John Wiley and Sons. New York, NY. 1978

Brooks, Kenneth M. *Literature Review and Assessment of the Environmental Risks Associated with the Use of CCA and ACZA Treated Wood Products in Aquatic Environments*, prepared for Western Wood Preservers Institute, Vancouver, WA.

CALEPA, California Environmental Protection Agency, Draft Concept Paper, Task C.1. 1996.

COE (U.S. Corps of Engineers). Hydrologic Engineering Center. *Urban Storm Water Runoff: STORM. Generalized Computer Program.* 723-58-L2520. Davis, CA. May. 1975

Cowherd, C. J., C. M. Maxwell, and D. W. Nelson. *Quantification of Dust Entrainment from Paved Roadways*. EPA-450 3-77-027. U.S. Environmental Protection Agency. Research Triangle Park, NC. July. 1977

Denver Regional Council of Governments. *Urban Runoff Quality in the Denver (Colorado) Region*. Prepared for the U.S. EPA. Washington, DC. PB85-101640. September. 1983

Donigian, A. S., Jr. and N.H. Crawford. *Modeling Nonpoint Pollution from the Land Surface.* EPA-600/3-76-083. U.S. Environmental Protection Agency. Athens, GA. July. 1976

Durum, W. H. Occurrence of some trace metals in surface waters and groundwaters. In *Proceeding of the Sixteenth Water Quality Conference.* Am. Water Works Assoc., Univ. of Illinois Bull. 71(108). Urbana, IL. 1974

EPA. *Methods for Organic Chemical Analyses of Municipal and Industrial Wastewater.* Environmental Monitoring and Data Support Laboratory. EPA-600/4-82-057. U.S. Environmental Protection Agency. Cincinnati, OH. 1982

EPA. *Results of the Nationwide Urban Runoff Program.* Water Planning Division. PB 84-185552. Washington, D.C. December. 1983a

EPA. *Methods for Chemical Analysis of Water and Wastes*. EPA-600/4-79-020. U.S. Environmental Protection Agency. Cincinnati, OH. 1983b

Field, R., E.J. Struzeski, Jr., H.E. Masters and A.N. Tafuri. *Water Pollution and Associated Effects from Street Salting.* EPA-R2-73-257. U.S. Environmental Protection Agency. Cincinnati, OH. May. 1973

Forster, Jurgen, *Heavy Metal and Ion Pollution Patterns in Roof Runoff*, Proceeding of the Seventh International Conference on Urban Storm Drainage, Hannover, Germany, 1996:

Good, James C. *Roof Runoff as a Diffuse source of metals and Aquatic Toxicity in Stormwater*, Water Science Technology. Vol28, No.3-5, pp317-321, 1993.

Gupta, M., D. Mason, M. Clark, T. Meinholz, C. Hansen, and A Geinopolos. *Screening Flotation Treatment of Combined Sewer Overflows Volume I - Bench Scale and Pilot Plant Investigations*. EPA-600/2-77-069a. U.S. Environmental Protection Agency. Cincinnati, OH. August. 1977

Herricks, E. E. *Stormwater Runoff and Receiving Systems: Impact, Monitoring, and Assessment.* CRC/Lewis Publishers. Boca Raton, FL. 1995

Huber, W.C. and J.P. Heaney. *The USEPA Storm Water Management Model, SWMM: A ten-year Perspective*. Second international Conference on Urban Storm Drainage. Urbana, IL. June. 1981

Jewell, T.K., D.D. Adrian and D.W. Hosmer. Analysis of stormwater pollutant washoff estimation techniques. *International Symposium on Urban Storm Runoff*. University of Kentucky. Lexington, KY. July. 1980

Kennish, M.J. *Ecology of Estuarines:Anthropogenic Effects*. CRC, Boca Raton , FL. USA.1992

Kobriger, N.P., T.L. Meinholiz, M.K. Gupta, and R.W. Agnew. *Constituents of Highway Runoff. Vol. 3. Predictive Procedure for Determining Pollution Characteristics in Highway Runoff.* FHWA/RD-81/044. Federal Highway Administration. Washington, D.C. February. 1981

Koeppe, D. E. comp. Vol. IV: Soil-water-air-plant studies. In: *Environmental Contamination by Lead and Other Heavy Metals.* G. L. Rolfe and K. A. Peinbold, eds. Institute for Environmental Studies. Univ. of Illinois. Urbana-Champaign, IL. July. 1977

Kopfler, F. C., R.G. Melton, J.L. Mullaney, and R. G. Tardiff. *Human Exposure to Water Pollutants*. In: Fate of Pollutants in the Air and Water Environments Part 2, I.H. Suffet, ed. John Wiley & Sons, 1977. pp 419-434.

Lindsay, W. L. *Chemical Equilibria in Soils*. John Wiley and Sons. New York, NY. 1979

Maestre, A., Pitt, R. E., and R. Morquecho. “Nonparametric statistical tests comparing first flush with composite samples from the NPDES Phase 1 municipal stormwater monitoring data.” *Stormwater and Urban Water Systems Modeling*. In: *Models and Applications to Urban Water Systems*, Vol. 12 (edited by W. James). CHI. Guelph, Ontario, forthcoming 2004.

Malmquist, Per-Arne. Atmospheric Fallout and Street Cleaning - Effects on Urban Stream Water and Snow. *Prog. Wat Tech*., 10(5/6): 495-505. Pergamon Press. Great Britain. September. 1978

Manning, M.J., R.H. Sullivan, and T.M. Kipp. *Nationwide Evaluation of Combined Sewer Overflows and Urban Stormwater Discharges. Vol. III: Characterization of Discharges.* U.S. Environmental Protection Agency. Cincinnati, OH. October. 1976

Mottier and Boller. *Quantitative and Qualitative Aspekte des Dachwassers*, Proceedings Engelberg Courses, VSA, Strassbugstrasse 10, CH-8026 Zurich.1996

Murphy, W. *Roadway Particulate Losses*. American Public Works Assoc. Unpublished. 1975

Novotny, V. and G. Chesters. *Handbook of Nonpoint Pollution Sources and Management.* Van Norstrand Reinhold Company. New York, NY. 1981

PEDCo-Environmental, Inc. *Control of Re-entrained Dust from Paved Streets.* EPA-907/9-77-007. U.S. Environmental Protection Agency. Kansas City, MO. 1977

Phillips, G. R., and R. C. Russo. *Metal Bioaccumulation in Fishes and Aquatic Invertebrates: A Literature Review*. EPA-600-3-78-103, U.S. Environmental Protection Agency. Duluth, MN. December. 1978

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

Pitt, R. and R. Sutherland. *Washoe County Urban Stormwater Management Program. Volume 2, Street Particulate Data Collection and Analyses.* Washoe Council of Governments. Reno, NV. August. 1982

Pitt, R. *Urban Bacteria Sources and Control in the Lower Rideau River Watershed*. Ottawa, Ontario. Ontario Ministry of the Environment. ISBN 0-7743-8487-5. 165 pgs. 1983

Pitt, R. *Characterizing and Controlling Urban Runoff through Street and Sewerage Cleaning.* U.S. Environmental Protection Agency. Storm and Combined Sewer Program. Risk Reduction Engineering Laboratory. EPA/600/S2-85/038. PB 85-186500. Cincinnati, OH. June. 1985

Pitt, R. *Small Storm Urban Flow and Particulate Washoff Contributions to Outfall Discharges*. Ph.D. dissertation submitted to the Department of Civil and Environmental Engineering. University of Wisconsin - Madison. 1987

Pitt R. and M. Bozeman. *Sources of Urban Runoff Pollution and Its Effects on an Urban Creek*. EPA 600/S2-82-090. U.S. Environmental Protection Agency. Cincinnati, OH. 1982

Pitt, R. and J. McLean. *Toronto Area Watershed Management Strategy Study. Humber River Pilot Watershed Project*. Ontario Ministry of the Environment. Toronto, Ontario. 1986

Pitt, R. and G. Shawley. *A Demonstration of Non-Point Source Pollution Management on Castro Valley Creek.* Alameda County Flood Control and Water Conservation District (Hayward, CA) for the Nationwide Urban Runoff Program. U.S. Environmental Protection Agency. Water Planning Division. Washington, D.C. June. 1982

Pitt, R. and R. Sutherland. *Washoe County Urban Stormwater Management Program*, Washoe Council of Governments, Reno, NV, August 1982.

Pitt, R., M. Lalor, R. Field, D.D. Adrian, and D. Barbe. *Investigation of Inappropriate Pollutant Entries into Storm Drainage Systems, A User's Guide.* EPA/600/R-92/238. U.S. Environmental Protection Agency. Cincinnati, OH. 1993

Pitt, R., Clark, S., Parmer, K., and Field, R. *Groundwater Contamination from Stormwater Infiltration*. Ann Arbor Press. Chelsea, Michigan. 218 pages.1996

Pitt, R., R. Field, M. Lalor, and M. Brown. *Urban stormwater toxic pollutants: assessment, sources and treatability*., Water Environment Research. Vol. 67, No. 3, pp. 260-275. May/June 1995. Discussion and closure in Vol. 68, No. 4, pp. 953-955. July/August 1996.

Rolfe, G.L. and K.A. Reinhold. *Vol. I.- Introduction and Summary. Environmental Contamination by Lead and Other Heavy Metals.* Institute for Environmental Studies. University of Illinois. Champaign-Urbana, IL. July. 1977

Rubin, A. J., ed. *Aqueous-Environmental Chemistry of Metals.* Ann Arbor Science Publishers. Ann Arbor, MI. 1976

Sartor J. and G. Boyd. *Water Pollution Aspects of Street Surface Contaminants*. EPA-R2-72-081, U.S. Environmental Protection Agency. November. 1972

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

Shelley, P.E. and D.R. Gaboury. Estimation of pollution from highway runoff - initial results. *Conference on Urban Runoff Quality - Impact and Quality Enhancement Technology*. Henniker, NH. Edited by B. Urbonas and L.A. Roesner. Proceedings published by the American Society of Civil Engineering. New York, NY. June. 1986

Shen, H.W. Some basic concepts on sediment transport in urban storm drainage systems. *Second International Conference on Urban Storm Drainage*. Urbana, IL. June. 1981

Singer, M.J. and J. Blackard. Effect of mulching on sediment in runoff from simulated rainfall. *Soil Sci. Soc. Am.* J., 42:481-486. 1978

Solomon, R.L., and D.F.S. Natusch. *Vol:lll: Distribution and characterization of urban dists. In: Environmental Contamination by Lead and Other Heavy Metals*. G. L. Rolfe and K. G. Reinbold, eds. Institute for Environmental Studies. Univ. of Illinois. Urbana-Champaign, IL. July. 1977

Spring, R. J., R. B. Howell, and E. Shirley. *Dustfall Analysis for the Pavement Storm Runoff Study (I-405 Los Angeles)*. Office of Transportation Laboratory. California Dept. of Transportation. Sacramento, CA. April. 1978

Stark, W., R. Kernbeis, H. Raeissi, H.P. Brunner. *Wo liegen die Grenzen der Schadstoffentfrachtung des Klarschlannes?* 1. Teil:Schwermetalle, Report TU Viewnna, Institute for Water Quality and Refuse Management, Vienna. 1995

Steuer, Jeffrey, William Selbig, Nacy Hornewer, and Jeffrey Prey, *Sources of Contamination in an Urban Basin in Marquette, Michigan and an Analysis of Concentrations, Loads, and Data Quality,* U.S. Geological Survey Water-Resources Investigations Report 97-4242. Middleton, Wisconsin, 1997

Stranks, D.W. *Wood Preservatives: Their Depletion as Fungicides and Fate in the Environment.* Canadian Forest Service Technical Report 10, 1976.

Sutherland, R., and R.H. McCuen. Simulation of urban nonpoint source pollution. *Water Resources Bulletin*. Vol. 14, No. 2, pp 409-428. April. 1978

Sutherland, R., W. Alley, and F. Ellis. *Draft Users' Guide for Particulate Transport Model (PTM)*. CH2M–HILL. Portland, OR for the U.S. Geological Survey. (undated)

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

Thomas, P.R. and G.R. Greene, *Rainwater Quality from Different Roof Catchments*, Water Science Tech. Vol. 28, No. 3-5, pp.291-299, 1993

Verschueren, K. *Handbook of Environmental Data on Organic Chemicals*, 2nd edition. Van N Reinhold Co. New York, NY. 1983

Wilber, W. G., and J.V. Hunter. *The Influence of Urbanization on the Transport of Heavy Metals in New Jersey Streams.* Water Resources Research Institute. Rutgers University. New Brunswick, NJ. 1980

Yalin, M.S. An expression for bed load transportation. *Journal of the Hydraulics Division*, Proceedings of the American Society of Civil Engineers. Vol 89, pp 221-250. 1963

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4. Stormwater Quality Controls in WinSLAMM

Introduction

Many alternative urban runoff control practices are available at the sources where the sediment is generated (eroded) and at inputs to sewerage systems. These include infiltration devices (such as subsurface infiltration trenches, surface percolation areas, and porous pavements), grass drainage swales, grass filters, detention basins, street cleaning, and catchbasin cleaning. Other practices include those specialized for construction sites, such as site mulching and the use of filter fencing. Another important practice is the elimination of inappropriate discharges to sewerage through cross-connections. Outfall controls most commonly include wet detention ponds.

The first concern when investigating alternative treatment methods is determining the needed level of stormwater control. This determination has a great affect on the cost of the stormwater management program and needs to be carefully made. Problems that need to be reduced range from sewerage maintenance issues to protecting many receiving water uses. As an example, Laplace, *et al*. (1992) recommends that all particles greater than about 1 to 2 mm in diameter be removed from stormwater in order to prevent deposition in sewerage. The specific value is dependent on the energy gradient of the flowing water in the drainage system and the hydraulic radius of the sewerage. This treatment objective can be easily achieved using a number of cost-effective source area and inlet treatment practices. In contrast, much greater levels of stormwater control are likely needed to prevent excessive receiving water degradation. Specific treatment goals usually specify about 80% reductions in suspended solids concentrations. In most stormwaters, this would require the removal of most particulates greater than about 10 μm in diameter, about 1% of the 1 mm size to prevent sewerage deposition problems. Obviously, the selection of a treatment goal must be done with great care. The Engineering Foundation/ASCE, Mt. Crested Butte conference held in 1993 included many presentations describing receiving water impacts associated with stormwater discharges (Herricks 1995). Similarly, Pitt (1996) summarized numerous issues concerning potential groundwater impacts associated with sub-surface stormwater disposal. These references illustrate the magnitudes and variations of typical problems that can be caused by untreated stormwater. Specific control programs will therefore need to be unique for a specific area due to these variations.

There are many stormwater control practices, but all are not suitable in every situation. It is important to understand which controls are suitable for the site conditions and can also achieve the required goals. This will assist in the realistic evaluation for each practice of: the technical feasibility, implementation costs, and long-term maintenance requirements and costs. It is also important to appreciate that the reliability and performance of many of these controls have not been well established, with most still in the development stage. This is not to say that emerging controls cannot be effective, however, they do not have a large amount of historical data on which to base designs or to be confident that performance criteria will be met under the local conditions. The most promising and best understood stormwater control practices are wet detention ponds. Less reliable in terms of predicting performance, but showing promise, are stormwater filters, wetlands, and percolation basins (Roesner, *et al.* 1989). Grass swales also have shown great promise during the EPA's Nationwide Urban Runoff Program (NURP) (EPA 1983) and other research projects.

A study of 11 types of stormwater quality and quantity control practices currently being used in Prince George's County, Maryland (Metropolitan Washington Council of Governments 1992) was conducted to examine their performance and longevity. This report concluded that several types of the stormwater control practices had either failed or were not performing as well as intended. Generally, wet ponds, artificial marshes, sand filters, and infiltration trenches achieved moderate to high levels of removal for both particulate and soluble pollutants. Only wet ponds and artificial marshes demonstrated an ability to function for a relatively long time without frequent maintenance. Control practices which were found to perform poorly were infiltration basins, porous pavements, grass filters, swales, smaller "pocket" wetlands, extended detention dry ponds, and oil/grit separators. Infiltration stormwater controls had high failure rates which could often be attributed to poor initial site selection and/or lack of proper maintenance. The poor performance of some of the controls was likely a function of poor design, improper installation, inadequate maintenance, and/or unsuitable placement of the control. Greater attention to these details would probably reduce the failure rate of these practices. The wet ponds and artificial marshes were much more robust and functioned adequately under a wider range of marginal conditions. Other important design considerations include: safety for maintenance access and operations, hazards to the general public (e.g., drowning) or nuisance (e.g., mosquito breeding), acceptance by the public (e.g., enhance area aesthetics and property values).

The majority of the stormwater treatment processes are most effective for the removal of particulates only, especially the settleable solids fraction. Removal of dissolved, or colloidal, pollutants is minimal and therefore pollution prevention or control at the sources offers a more effective way to control the dissolved pollutants. Fortunately, most toxic stormwater pollutants (heavy metals and organic compounds) are mostly association with stormwater particulates (Pitt, *et. al.* 1994). Therefore, the removal of the solids will also remove much of the pollutants of interest. Notable exceptions of potential concern include: nitrates, chlorides, zinc, pathogens, 1,3-dichlorobenzene, fluoranthene, and pyrene.

A successful stormwater management program requires several components (after Field, *et al*. 1994):

- *Regulations, Local Ordinances, and Public Education.* This should be the primary component because it is likely to be the most cost effective. Mainly non-structural practices (such as simple site layout options, selection of drainage system components, etc.) and requirements for controls at new developments are particularly effective. Even though not quantified, public education to encourage careful selection of landscaping chemicals, proper disposal of household toxic substances, etc., are all important stormwater control activities.

- *Pollution Prevention.* Pollution prevention is an important component of any stormwater management program. Both non-structural and structural practices can be used to prevent pollutants from coming into contact with stormwater. These practices include:

    – selection of alternative building materials (decreasing the use of galvanized metals, for example);

    – flow diversion practices to keep uncontaminated stormwater from contacting contaminated surfaces, or to keep contaminated stormwater from contacting uncontaminated stormwater. This is accomplished by a variety of exposure minimization structural means, such as covering storage areas, using berms and curbs, etc.;

    – management practices can include plans to recover released or spilled pollutants; and preventative practices including a variety of monitoring techniques intended to prevent releases;

– public works practices (such as catchbasin and sewerage cleaning, leaf removal, etc.) are also important pollution prevention controls;

– investigation and control of inappropriate discharges into storm drainage systems;

– controlling construction site sediment erosion by vegetative and structural means; and

– infiltration practices through site development options (direct roof and paved area runoff to lawns, use swale drainages, etc.) which infiltrate source area runoff into the groundwater, thereby reducing surface runoff during storms, recharging local groundwaters, and maintaining low flow conditions in streams.

• *Critical Source Area and Outfall Treatment.* These are mainly structural practices to provide upstream pollutant removal at the source, controlled stormwater releases to the conveyance system, outfall controls, and infiltration or reuse of the stormwater. Upstream pollutant removal at critical source areas provides treatment of stormwater at highly polluting locations (such as vehicle service facilities, storage areas, junk yards, etc.) before it enters the stormwater conveyance system. Downstream, en4-of-pipe, controls may also be needed in industrial areas or at outfalls from large drainages. Large-scale infiltration, through the use of percolation ponds for example, may also be used at outfall locations, especially after pre-treatment using wet detention ponds.

Several reviews of stormwater management practices from throughout the world have recently been published. Stahre (1993) described practices in Scandinavia, Driscoll and Strecker (1993) described U.S. and Canadian practices, and Pratt (1993) described UK stormwater management activities.

The following discussion summarizes the possible levels of performance that may be achieved by various stormwater control practices. Stormwater control practices may be grouped into several general categories, including: regulations and public education, public works practices, sedimentation, infiltration, filtration and combination practices, and construction site erosion controls.

Treatment of Flows at Sources of Urban Runoff Pollution and at Outfalls

Most stormwater needs to be treated to prevent harm either to the surface waters or the groundwaters. One approach is to treat the runoff from critical source areas before it mixes with the runoff from less polluted areas. The general features of critical source areas appear to be large paved areas, heavy vehicular traffic, and outdoor use or storage of problem pollutants. The control of runoff from relatively small critical areas may be the most cost-effective approach for treatment/reduction of stormwater toxicants. However, in order for a treatment device to be useable, it must be inexpensive, both to purchase and maintain, and effective. Outfall stormwater controls, being located at the outfalls of storm drainage systems, treat all the flows that originate from the watershed. The level of treatment provided, of course, is greatly dependent on many decisions concerning the design of the treatment devices. Source area controls are, of course, physically smaller than outfall controls but may be difficult to locate on a crowded site, and there could be a great number of them located in a watershed. In all cases, questions must be answered about the appropriate level of control needed, where the control should be provided, and what controls should be used. These questions can best be answered by using a comprehensive stormwater quality management model. During this research effort, we are examining the use of the Source Loading and Management Model (WinSLAMM), in conjunction with the Storm Water Management Model (SWMM), to address these issues. WinSLAMM is unique in that it can evaluate a large number of source and outfall stormwater quality controls for a large number of rains. Table 4-1 shows the stormwater control measures that are currently available in WinSLAMM. The results of recent research funded by the EPA are currently being used to expand WinSLAMM. This matrix of controls illustrates how some source area controls can be used at both source areas and at outfalls. Infiltration, filtration, and sedimentation controls can be used at both source areas and at outfalls, even though the sizes and specific designs of the specific practices must be varied to fit the site and to handle the specific flows. Therefore, the following literature review of stormwater quality management options includes practices that are usually considered as source area controls (such as street cleaning) and those that are usually considered as outfall controls (such as wet detention ponds). This review is organized into the following general categories, and topics, of control practices:

- public works practices (street cleaning, drainage inlets, oil and grease separators, and inappropriate discharges),
- sedimentation and wetlands (wet detention ponds, chemical addition, dry detention ponds, and wetlands),
- infiltration (infiltration trenches, rain gardens, grass swales, grass filter strips, porous pavement, and groundwater protection), and
- filtration and combination practices (sand, activated carbon, peat moss, composted leaves, and filter fabrics).

Table 4-1. Source Area, Drainage System, and Outfall Control Options Currently Available in WinSLAMM[1]

	Infiltration trenches	Biofiltrat-ion/rain gardens	Cisterns/ rain barrels	Wet detentio n pond	Grass drainag e swale	Street cleaning	Catch-basins	Porous pavemen t
Roof	X	X	X	X				
Paved parking/storage	X	X	X	X				X
Unpaved parking/storage	X	X		X				
Playgrounds	X	X	X	X				X
Driveways		X	X					X
Sidewalks/walks		X	X					X
Streets/alleys		X				X		
Undeveloped areas	X	X		X				
Small landscaped areas	X	X						
Other pervious areas	X	X		X				
Other impervious areas	X	X	X	X				X
Freeway lanes/shoulders	X	X		X				
Large turf areas	X	X		X				
Large landscaped areas	X	X		X				
Drainage system		X			X		X	
Outfall	X	X		X				

[1] Development characteristics affecting runoff, such as roof and pavement draining to grass instead of being directly connected to the drainage system, are included in the individual source area descriptions.

Public Works Practices

Numerous public works practices affect stormwater quality and quantity. The most significant being the design, construction, and maintenance of the stormwater drainage system. Obviously, managing stormwater quantity to provide drainage and to prevent flooding must remain the primary objective of stormwater drainage systems. Over the years, addressing this objective, while ignoring other receiving water beneficial uses, has resulted in many problems. It is now possible, as demonstrated by numerous examples from around the world, to provide stormwater drainage that addresses these numerous, and seeming conflicting objectives.

Other public works practices affecting stormwater quality may include: landscaping maintenance on public rights-of-ways, roadway and utility construction erosion controls, erosion controls at sanitary landfills, runoff control at public works garages, street cleaning, and storm drainage inlet cleaning. This section specifically addresses street and catchbasin cleaning, two commonly recommended stormwater control practices because of their apparent ease of use in existing built-up areas. Many of the on-site "ultra-urban" controls described later)filtration and combination practices) are suitable for public works facilities, such as maintenance yards.

Street Cleaning

Street cleaning was extensively studied as an urban runoff water quality control practice because of the large quantities of pollutants found on streets during early research in the U.S. (Sartor and Boyd 1972). Because streets were assumed to contribute most of the urban runoff flows and pollutants, street cleaning was assumed to be a potentially effective practice. Unfortunately, not all research has shown street cleaning to be effective because of the different sized particles that street cleaners remove compared to the particles that are mostly removed by rains. Furthermore, in many areas, rains are relatively frequent and keep the streets cleaner than typical cleaner threshold values. However, in the arid west of the U.S., rains are very infrequent, allowing streets to become quite dirty during the late summer and fall. Extensive street cleaning during this time has been shown to result in important suspended solids and heavy metal reductions in runoff (Pitt 1979, Pitt and Shawley 1982). Street cleaning should not be confused with flushing operations that really do not remove particles from the street, but simply transfer them to the sewer systems and possibly to the receiving waters. Street flushing in areas served by combined sewers, however, should be considered an alternative in areas having suitable water supplies.

Street cleaning plays an important role in most public works departments as an aesthetic and safety control measure. Street cleaning is also important to reduce massive dirt and debris buildups present in the spring in the northern regions. Leaf cleanup by street cleaning is also necessary in most areas in the fall.

Particles of different sizes "behave" quite differently on streets. Typical street dirt total solids loadings show a "saw-tooth" pattern with time between street cleaning or rain washoff events. The patterns for the separate particle sizes are considerably different than the pattern for total residue. Typical mechanical street cleaners remove much (about 70 percent) of the coarse particles in the path of the street cleaner, but they remove very little of the finer particles (Sartor and Boyd 1972; Pitt 1979). Rains, however, remove very little of the large particles, but can remove large amounts (about 50 percent) of the fine particles (Bannerman, *et al*. 1983; Pitt 1985; Pitt 1987). The intermediate particle sizes show reduced removals by both street cleaners and rain.

Factors significantly affecting street cleaning performance include particle loadings, street texture, moisture, parked car conditions, and equipment operating conditions (Pitt, *et al*. 1976; Pitt 1979). If the 500-1000 μm particle loadings are less than about 75 kg/curb-km for smooth asphalt streets, conventional street cleaning does little good. As the loadings increase, so do the removals: with loadings of about 10 kg/curb-km, less than 25 percent removals can be expected, while removals of up to about 50 percent can be expected if the initial loadings are as high as 40 kg/curb-km for this particle size. The removal performance decreases substantially for smaller particles, including those that are most readily washed off the street during rains and contribute to stormwater pollution.

Increased performance was obtained with a modified regenerative-air street cleaner, especially at low loadings during tests in Bellevue, WA (Pitt 1985). The improved performance was much greater for fine particle sizes, where the mechanical street cleaner did not remove any significant quantities of material. The larger particles were removed with about the same effectiveness for both street cleaner types. Other tests of vacuum street cleaners (Pitt 1979) and regenerative-air street cleaners (Pitt and Shawley 1982) showed very few differences in performance when compared to more standard mechanical street cleaners. These earlier tests were conducted in areas having much higher street loadings, especially for the larger particle sizes, than in Bellevue. It is expected that the high loadings of the large particles armored the small particles, so they could not be removed. For high loadings, it may be best to use a tandem operation, where the streets are first cleaned with a mechanical street cleaner to remove the large particles, followed by a regenerative-air street cleaner to remove the finer particles.

Much information concerning street cleaning productivity has been collected previously in many areas. The early tests (Clark and Cobbin 1963; and Sartor and Boyd 1972) were conducted in controlled strips using heavy loadings of simulates instead of natural street dirt at typical loadings. Later tests, from the mid 1970s to mid 1980s, were conducted in large study areas (20 to 200 ha) by measuring actual street dirt loadings on many street segments immediately before and after typical street cleaning. These large-scale tests are of most interest, as they monitored both street surface phenomena and runoff characteristics. The following list briefly describes these large-scale street cleaning performance tests:

- San Jose, California, tests during 1976 and 1977 (Pitt 1979) considered different street textures and conditions; multiple passes, vacuum-assisted, and two types of mechanical street cleaners; a wide range of cleaning frequencies; and effects of parking densities and parking controls.

- Castro Valley, California, tests during 1979 and 1980 (Pitt and Shawley 1982) considered street slopes, mechanical and regenerative-air street cleaners, and several cleaning frequencies.

- Reno/Sparks, Nevada, tests during 1981 (Pitt and Sutherland 1982) considered different lan4-uses, street textures, equipment speeds, multiple passes, full-width cleaning, and vacuum and mechanical street cleaners in an arid and dusty area.

- Bellevue, Washington, tests from 1980 through 1982 (Pitt 1985) considered mechanical, regenerative-air, and modified regenerative-air street cleaners, different lan4-uses, different cleaning frequencies, and different street textures in a humid and clean area.

- Champaign-Urbana, Illinois, tests from 1980 and 1981 (Terstriep, *et al*. 1982) examined spring clean-up, different cleaning frequencies and lan4-uses, and used a three-wheel mechanical street cleaner.

- Milwaukee, Wisconsin, tests from 1979 to 1983 (Bannerman, *et al*. 1983) examined various street cleaning frequencies at five study sites, including residential and commercial lan4-uses and large parking lots.

- Winston-Salem, North Carolina, tests during their NURP project examined different lan4-uses and cleaning frequencies.

Sutherland (1996, and with Jelen 1996) has conducted recent tests using a new style street cleaner that shows promise in removing large fractions of most of the street dirt particulates, even the small particles that are most heavily contaminated. The Enviro Whirl I, from Enviro Whirl Technologies, Inc. is capable of much improved removal of fine particles from the streets compared to any other street cleaner ever tested. This machine was also able to remove large fractions of the fine particles even in the presence of heavy loadings of large particles. This is a built-in tandem machine, incorporating rotating sweeper brooms within a powerful vacuum head. Model analyses for Portland, OR, indicate that monthly cleaning in a residential area may reduce the suspended solids discharges by about 50%, compared to only about 15% when using the older mechanical street cleaners that were tested during the early 1980s.

The pollutant removal benefits of street cleaning is directly dependent on the contributions of pollutants from the streets. In the Pacific Northwest region of the U.S., the large number of mild rains results in much of the runoff pollutants originating from the streets. In the Southeast, in contrast, where the rains are much larger, with greater rain intensities, the streets contribute a much smaller fraction of the annual pollutant loads for the same residential land uses. However, in heavily paved areas, such as large parking lots or paved storage areas, street cleaning of these surfaces, especially with an effective machine like the Enviro Whirl, should result in significant runoff improvements.

These many tests have examined a comprehensive selection of alternative street cleaning programs. Not all alternatives have been examined under all conditions, but sufficient information has been collectively obtained to examine many alternative street cleaning control options. Few instances of significant and important reductions in runoff pollutant discharges have been reported during these large-scale tests.

The primary and historical role of street cleaning is for litter control. Litter is also an important water pollutant in receiving waters. Litter affects the aesthetic attributes and recreation uses of waters, plus it may have direct negative biological and water quality effects. Litter has not received much attention as a water pollutant, possibly because it is not routinely monitored during stormwater research efforts. The City of New York recently conducted a special study to investigate the role of enhanced street cleaning (using intensive manual street sweeping) to reduce floatable litter entering the City's waterways (Newman, *et al*. 1996). During the summer of 1993, the City hired temporary workers to manually sweep near-curb street areas and sidewalks in a pilot watershed area having 240 km of curb face. Two levels of manual sweeping supplemented the twice per week mechanical street cleaning the area normally receives. Continuous litter monitoring was also conducted to quantify the differences in floatable litter loadings found on the streets and sidewalks. An additional four manual sweepings each week to the two mechanical cleanings reduced the litter loadings by about 64% (on a weight basis) and by about 51% (on a surface area basis). Litter loading analyses were also conducted in areas where almost continuous manual sweeping (8 to 12 daily sweeps, 7 days per week) was conducted by special business organizations. In these special areas, the litter loadings were between 73 and 82% cleaner than comparable areas only receiving the twice weekly mechanical cleaning. They concluded that manual sweeping could be an important tool in reducing floatable pollution, especially in heavily congested areas such as Manhattan. New York City is also investigating catch basin modifications and outfall netting for the control of floatable litter.

Conventional street cleaning does not have a very positive effect on stormwater quality because conventional street cleaners preferentially remove the large particles, and the smaller particles from the street that are most effectively removed during rains. Valiron (1992) confirmed the many earlier U.S. studies by showing that street cleaners only remove about 15% of the finest particles (less than 40 µm), while close to 80% of the largest particles (>2,000 µm) are removed.

Ellis (1986) concluded that street cleaning is most efficient if conventional street sweeping (using broom operated equipment) is conducted in a tandem operation with vacuuming, and if it is done three times per week. He did find that conventional tandem sweeping-vacuum machines are very sensitive to the clogging of their filters and to street moisture levels which causes particles to adhere to the street surface, preventing their efficient removal. The Enviro Whirl, mentioned above, is a new tandem machine that overcomes many of these problems. General street cleaning efficiency depends on the speed of the machines, the number of passes, the street loading and street texture, and interference from parked vehicles (Pitt 1979).

Flushing operations, using low pressure water, is more efficient than broom sweeping for the removal of fine particles. In combined sewer systems, the flushed pollutants are treated at the downstream municipal wastewater plant. However, deposition of the particulates in separate sewer systems is a potential problem, as the pollutants typically remain in the sewerage until the next storm event.

In most cases, streets are not cleaned often enough to maintain low street dirt loadings. A frequency of about 6 to 7 cleanings per week is needed to remove about 50 to 55% of the particles (Bertran4-Krajewski 1991, Valiron 1992, Vignoles and Herremans 1992). This very high cleaning frequency is typically only conducted in commercial districts of large cities.

Butler, *et al*. (1993) examined the benefits and costs of street and gully pot use for the prevention of sediments from entering combined sewerage. They compared these costs with those associated with removal of the sediment from the sewerage and removal at the sewage treatment facility. In one example, they found that the minimum total cost would be achieved with a street cleaning interval of about once every six to eight weeks, but the total costs of sediment removal would not be significantly increased if there was no street cleaning. The street cleaning costs would increase directly and linearly with increased cleaning effort, while the costs of particulate removal by the other methods would be reduced with increased street cleaning. However, the total costs would increase with increased street cleaning because the cost savings from the other treatment options were more than off-set by the increased street cleaning costs. For this combined sewerage system example, they concluded that it was more cost-effective to remove the sediment at the treatment facility. They do point out that the main requirements for street cleaning in the UK are determined by the Environmental Protection Act and stress litter removal. Sediment removal by street cleaning was never a stated objective.

Summary of Street Cleaning as a Stormwater Control Practice
Normal street cleaning operations for aesthetics and traffic safety purposes are not very satisfactory from a stormwater quality perspective. These objectives are different and the removal efficiency for fine and highly polluted particles is very low. Unless the street cleaning operations can remove the fine particles, they will always be limited in their pollutant removal effectiveness. Some efficient machines are now available to clean porous pavements and infiltration structures, and new tandem machines that incorporate both brooms and vacuums have recently been shown to be very efficient, even for the smaller particles. Conventional street cleaning operations preferentially remove the largest particles, while rain preferentially remove the smallest particles. In addition, street cleaners are very inefficient when the street dirt loadings are low, when the street texture is course, and when parked cars interfere. However, it should also be noted that streets are not the major source of stormwater pollutants for all rains in all areas. Streets are the major source of pollutants for the smallest rains, but other areas contribute significant pollutants for moderate and large rains. Therefore, the ability of street cleaning to improve runoff quality is dependent on many issues, including the local rain patterns and other sources of runoff pollutants. More research is needed to investigate newer pavement cleaning technologies in areas such as industrial storage areas and commercial parking areas which are critical pollutant sources.

Street Cleaning Effectiveness Calculations used in WinSLAMM
WinSLAMM keeps track of this street dirt accumulation, rain washoff, and street cleaner removal pattern for each street in the study area, as indicated in the attached calculation flowsheet. The accumulation and washoff equations were described in the previous section. Factors significantly affecting street cleaning performance include particle loadings, street texture, moisture, parked car conditions, and equipment operating conditions (Pitt, *et al*. 1976; Pitt 1979). Figure 4-1 is an example of a performance plot from a series of street cleaner tests conducted in Bellevue, Washington (Pitt 1984). It shows the dramatic effect loadings have on street cleaner performance. If the total solids loadings on the street before cleaning are less than about 300 lbs/curb-mile for smooth asphalt streets, conventional mechanical street cleaning does little good, as reflected on the data for the Mobil mechanical broom sweeper. As the loadings increase, so do the removals. With loadings approaching 700 lbs/curb-mile, removals of up to about 40 percent can be expected. The number of data observations for these higher loadings were rare for these Bellevue tests, and most of the observations were for very low loadings (75 to 400 lbs/curb-mile of total solids).

Figure 4-1 also shows the improved performance obtained with a regenerative-air street cleaner, especially at low loadings, as shown for the Tymco cleaner. The improved performance was much greater at the low initial street dirt loadings, where the mechanical street cleaner did not remove any significant quantities of material. Forty percent removals occurred at about 150 lbs/curb-mile, in the lower range of observed conditions, and increased to about 60% removals at about 700 lbs/curb-mile.

Other tests of vacuum street cleaners (Pitt 1979) and regenerative-air street cleaners (Pitt and Shawley 1981) showed very few differences in performance when compared to standard mechanical street cleaners. These earlier tests were conducted in areas having much higher street loadings, especially for the larger particle sizes, than in Bellevue. It is expected that the high loadings of the large particles armored the small particles, so they could not be effectively removed. For high loadings, it may be best to first clean with a mechanical street cleaner to remove the large particles, followed by a regenerative-air street cleaner to remove the finer particles. Recent improvements in street cleaners have incorporated both technologies in the same unit, with much improved cleaning capabilities, as noted above.

WinSLAMM uses a series of linear first order equations describing the slope of the performance line, and the intersection of this performance line with the diagonal indicating no removal (the threshold value). No street cleaning benefit occurs if the initial street loading is less than this threshold value.

Much information concerning street cleaning productivity has been collected previously in many areas. The early tests (Clark and Cobbin 1963; and Sartor and Boyd 1972) were conducted in controlled strips using simulants instead of street dirt. The later tests were conducted in large study areas (50 to 500 acres) by measuring actual street dirt loadings on many street segments immediately before and after typical street cleaning. These large-scale tests are of most interest and were used to develop the street cleaning performance curves used in WinSLAMM.

For both Street Loading Iterations

For the street areas of each Land Use, determine the LUCurbRatio, the ratio of each street length divided by the sum of the street lengths for the Land Use

For each street area, initialize subroutine for first rainfall event only -

- Determine Julian Street Cleaning Dates
- Determine Maximum Load -
    - If c = 0 then MaxLoad = a + b * 30
    - If c < 0 then MaxLoad = a - b^2/c
- Adjust initial load for Winter Season Exclusion, if selected by user
- Determine Maximum Accumulation Time

For each Street Area, for each Rainfall Event

Accumulation Duration (AccumDur) = Current Time – Time of Previous Event (either Street Dirt Removal or Washoff)

Calculation Accumulation:

BeforeEventLoad = B*AccumDur + C*AccumDur^2 + Prior Load

Determine Type of Event –
Street Dirt Removal (Type 1) or
Washoff (Type 2)

Washoff (Event Type 2)

Calculate Washoff:

Determine Availability Factor (f(street texture))
N_0 = BeforeEventLoad * Availablilty Factor
Determine k

Determine Residual Street Load after Storm (N*)

N* = N_0 * exp(-k * rain depth)

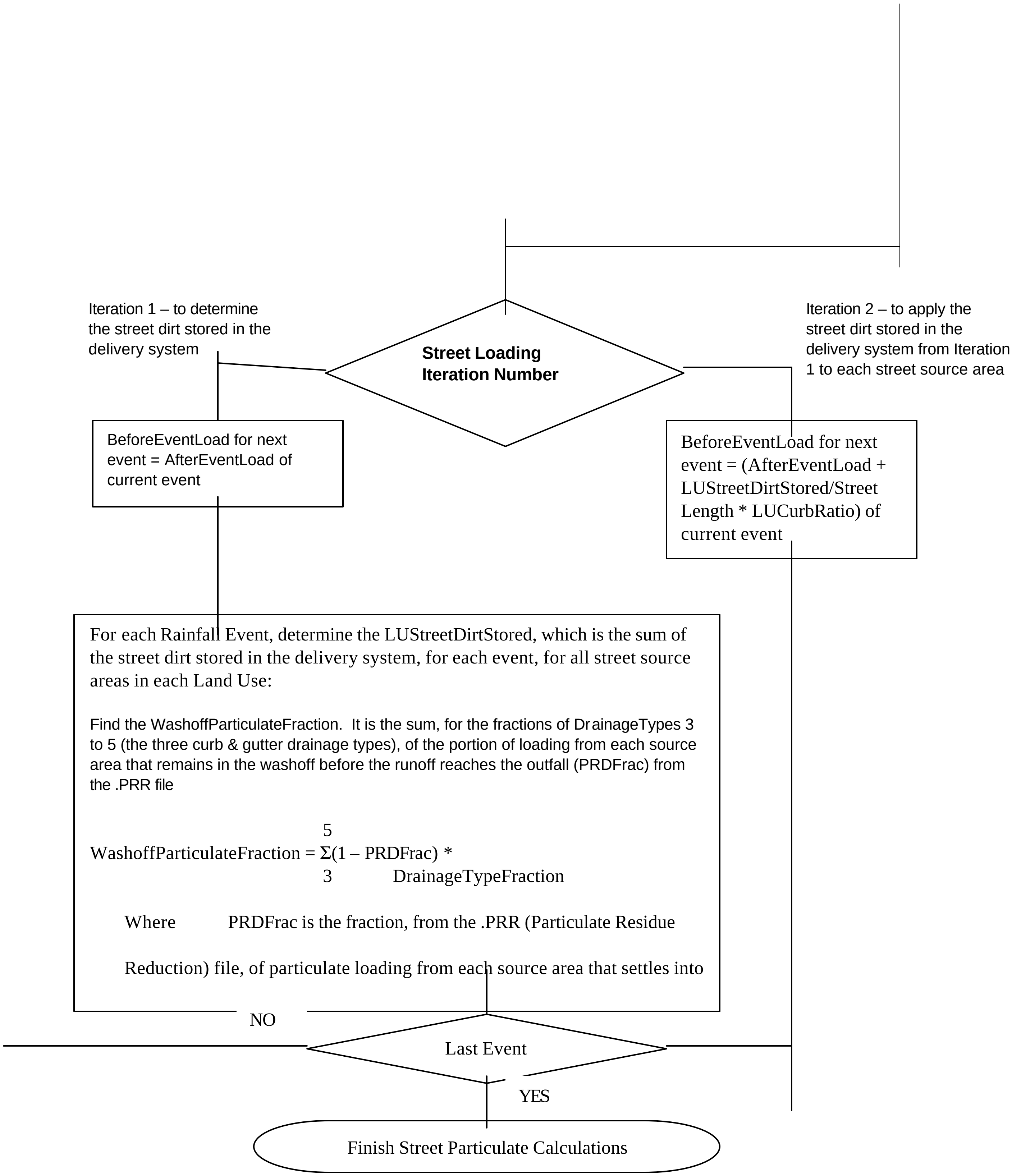
Load Unavailable After Rain = BeforeEventLoad – N_0
AfterEventLoad = Load Unavailable After Rain + N*
Initial Washoff = BeforeEventLoad – AfterEventLoad
[lbs/curb-mi]

Street Dirt Removal by Street Cleaning (Event Type 1)

If BeforeEventLoad < B / (1 – M) Then
AfterEventLoad = BeforeEventLoad
Else
AfterEventLoad = M * BeforeEventLoad + B

Determine Street Delivery:

Calculate Street Delivery Reduction Factor, StreetDeliveryFraction, from .STD parameter file:


Iteration 1 – to determine the street dirt stored in the delivery system
Street Loading Iteration Number
Iteration 2 – to apply the street dirt stored in the delivery system from Iteration 1 to each street source area
BeforeEventLoad for next event = AfterEventLoad of current event
BeforeEventLoad for next event = (AfterEventLoad + LUStreetDirtStored/Street Length * LUCurbRatio) of current event
For each Rainfall Event, determine the LUStreetDirtStored, which is the sum of the street dirt stored in the delivery system, for each event, for all street source areas in each Land Use:
Find the WashoffParticulateFraction. It is the sum, for the fractions of DrainageTypes 3 to 5 (the three curb & gutter drainage types), of the portion of loading from each source area that remains in the washoff before the runoff reaches the outfall (PRDFrac) from the .PRR file
WashoffParticulateFraction = Σ(1 – PRDFrac) * DrainageTypeFraction (Σ from 3 to 5)
Where PRDFrac is the fraction, from the .PRR (Particulate Residue
Reduction) file, of particulate loading from each source area that settles into
NO
Last Event
YES
Finish Street Particulate Calculations

Storm Drainage System Inlet Structures

Storm drainage system inlet structures can be separated into three general categories. The first category is a simple inlet that is comprised of a grating at the curb and a box, with the discharge located at the bottom of the box which connects directly to the main storm drainage or combined sewerage. This inlet simply directs the runoff to the drainage system and contains no attributes that would improve water quality. However, large debris (several cm in size) may accumulate (if present in the stormwater, which is unlikely) in them. The second type of inlet is similar to the simple inlet, but it contains a sump that typically extends up to 0.5 to 1 m below the bottom of the outlet. This is termed a catchbasin in the U.S., or a gully pot in the U.K. (usually smaller than a catchbasin), and has been shown to trap appreciable portions of the course sediment (somewhat less than a mm in size and larger). The third category is also similar to the simple inlet, but contains some type of screening to trap debris. These include small cast iron perforated buckets placed under the street grating as used in Germany, large perforated stainless steel plates placed under the inlet grating as used in Austin, Texas, and a number of proprietary devices incorporating filter fabric or other types of screening placed to intercept the stormwater flow. This last category may trap large debris and litter, depending on the overflow provisions, but have not been shown to produce important water quality improvements.

Catchbasins and Gully Pots

Catchbasin performance has been investigated for some time in the U.S. Sartor and Boyd (1972) conducted controlled field tests of a catchbasin in San Francisco, using simulated sediment in fire hydrant flow. They sampled water flowing into and out of a catchbasin for sediment and basic pollutant analyses, for varying conditions and times since flow began. Lager, *et al*. (1977) was the first EPA funded research effort that included a theoretical laboratory investigation to evaluate sedimentation in catchbasins and to develop effective designs. They also conducted extensive laboratory tests using simulated runoff.

The mobility of catchbasin sediments was investigated by Pitt (1979) during a research project sponsored by the U.S. EPA's Storm and Combined Sewer Section. Long-duration tests were conducted using an “idealized” catchbasin (based on Lager, *et al*.’s 1977 design), retro-fitted in San Jose, CA. The research focused on re-suspension of sediment from a full catchbasin over an extended time period. This project used particulate fluorescent tracers mixed with catchbasin sediment. It was concluded that the amount of catchbasin and sewerage sediment was very large in comparison with storm runoff yields, but was not very mobile. Cleaning catchbasins would enable catchbasins to continue to trap sediment instead of reaching a steady-state loading and allowing flows to remain untreated.

The removal of overlying water above sediment in catchbasins readily occurs and has been noted by Sartor and Boyd (1972) as their largest water quality problem. However, Pitt (1985) statistically compared catchbasin supernatant with outfall water quality and could not detect any significant differences. EDP (1980) examined “first flushes” from catchbasins and found the quality of the water leaving the catchbasins to be much less than the high concentrations of pollutants in the gutter flows during early parts of rains. However, Butler, *et al*. (1995) have recently investigated gully pot supernatant water and have found that it may contribute to the more greatly polluted first flush of stormwater reported for some locations. Specific problems have been associated with the anaerobic conditions that rapidly form in the supernatant water during dry weather, causing the release of oxygen demanding material, ammonium, and possible sulfides. These anaerobic conditions also affect the bio-availability of the heavy metals in the flushed water.

Aronson, *et al*. (1983) reported a field evaluation of three catchbasins in West Roxbury, MA, for four events. An inlet strainer was also tested for three events at each site. They monitored suspended solids and conventional pollutants.

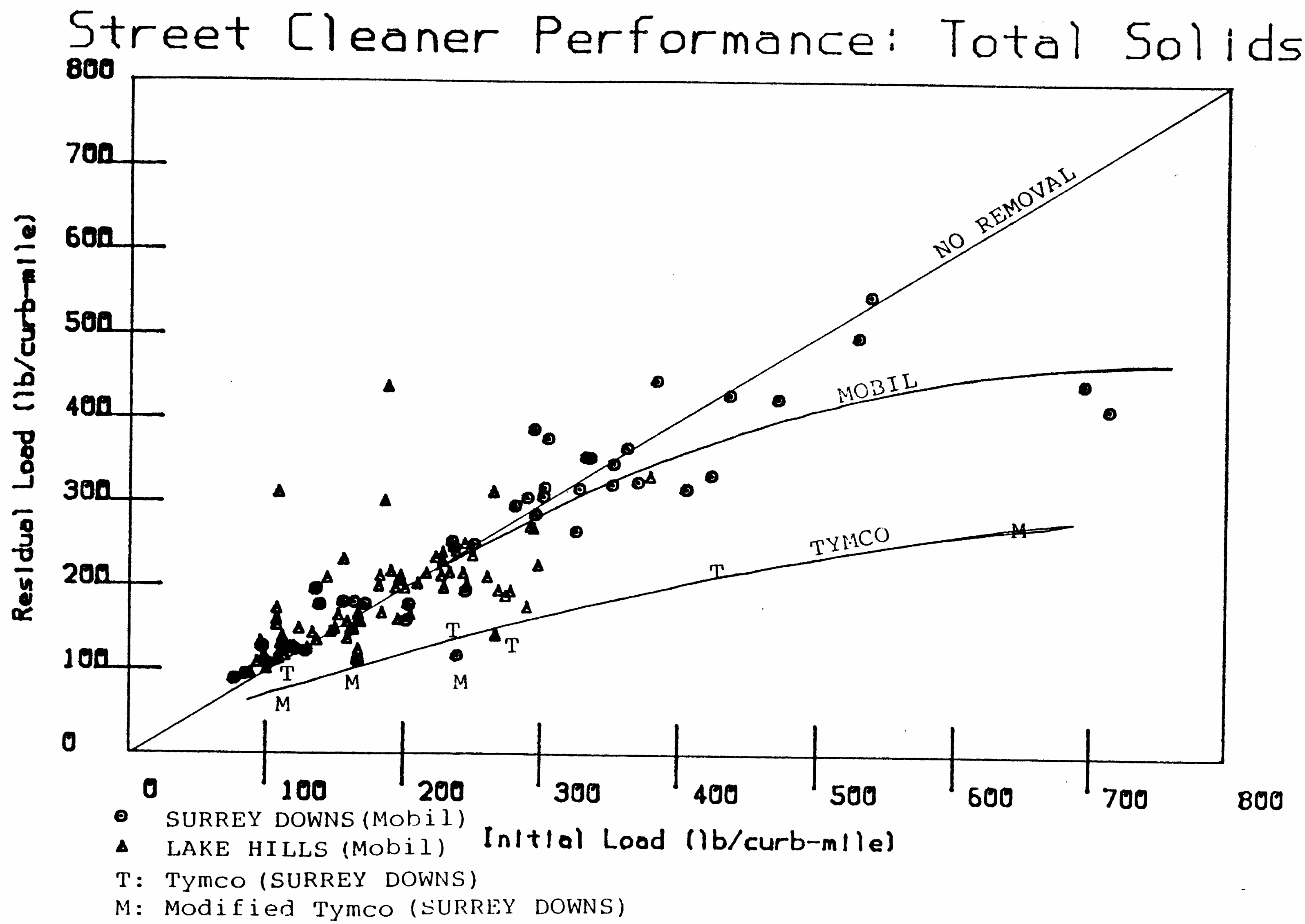


Figure 4-1. Measured performance of street cleaners in Bellevue, WA, for different total solids loadings on the street before cleaning (Pitt 1984).

Catchbasins, simple inlets, man-holes, and sewerage sediment accumulations were monitored at more than 200 locations in Bellevue, Washington at two mixed residential and commercial study areas (Pitt 1985). These locations were studied over three years to monitor accumulation of sediment and sediment quality. The sediment in the catchbasins and the sewerage was found to be the largest particles that were washed from the streets. A few unusual locations were dominated by erosion sediment from steep hillsides adjacent to the storm sewer inlets. The sewerage and catchbasin sediments had a much smaller median particle size than the street dirt and were therefore more potentially polluting than the particulates that can be removed by street cleaning, but the particulates were much larger than those generally found in stormwater. Basically, catchbasins remove the largest particulates that are washed from the watershed during rains, preventing them from being deposited in downstream sewerage and in the receiving water. If the catchbasins are full, they also cannot remove any additional particulates from the runoff. Catchbasin sump particulates can be conveniently removed to restore the trapping of these particulates, and some of the runoff pollutants. Cleaning catchbasins twice a year was found to allow the catchbasins to capture particulates for most rains. This cleaning schedule was found to reduce the annual discharges of total solids and lead by between 10 and 25 percent, and COD, total Kjeldahl nitrogen, total phosphorus, and zinc by between 5 and 10 percent (Pitt and Shawley 1982).

The median particle size of the sump particles is shown to be between about 300 and 3000 µm, with less than 10% of the particles smaller than 100 µm, the typical upper limit of particles found in stormwater (Butler, *et al*. 1995). Catchbasin sumps trap the largest particles that are flowing in the water, and allow the finer particles to flow through the inlet structure. Relatively few pollutants are associated with these coarser solids found in the sumps, compared to the finer particles.

Butler, *et al*. (1995) and Butler and Karunaratne (1995) present equations for sediment accumulation in gully pots, based on detailed laboratory tests. The sediment trapping performance was found to be dependent on the flow rate passing through the gully pot, and to the particle sizes of the sediment. The depth of sediment in the gully pot had a lesser effect on the capture performance. In all cases, decreased flows substantially increased the trapping efficiency and larger particles had substantially greater trapping efficiency than smaller particles, as expected.

Butler, *et al*. (1993) examined the buil4-up rate of sediment in roadside gully pots. They found that for most gullies, the buil4-up rate is fairly constant, at about 18 mm per month, while the average rates ranged from 14 to 24 mm per month. The average drainage area for each of the gully pots examined was 228 m^2. They also evaluated the costs of sediment removal by gully pots, comparing them to street cleaning costs, sewerage cleaning costs, and costs to remove the sediment at the treatment facility. They concluded that it was more cost-effective to remove the sediment at the treatment facility. However, they also concluded that the transport of all sediments to the treatment facility is not practicable for most systems, and the role of gully pots in limiting sediment entry to the sewerage system was deemed vital.

Storm Drain Inlets with Filters

Little information is available in the literature concerning the performance of filter fabrics in removing stormwater pollutants. They have been used for years in controlling construction site runoff, but in filter fence arrangements, where they act as small impoundments and not as true filters. Research at the University of Alabama at Birmingham (Clark, *et al*. 1995) is analyzing many filter fabrics, including fabrics being used in the inlet devices. The biggest disadvantage of using filter fabrics in catchbasins is their likelihood of quickly clogging. During controlled laboratory tests, they were found to provide important reductions (about 50%) in suspended solids and COD. However, the filter fabrics can only withstand very thin accumulations of sediment before they clog. The maximum sediment thickness on the fabrics before absolute clogging was between 1 and 2 mm, and the sediment loading was about 3.8 kg sediment per m^2 of fabric. The median particle size was 43 µm, 90% of the particles were smaller than 96 µm, and the largest particle observed was 130 µm in the runoff sample used in these clogging tests.

If the stormwater had a typical suspended solids concentration of 100 mg/L, then about 40 meters of stormwater could be loaded on the filter fabric before absolute failure due to clogging. If the suspended solids concentration was a high 500 mg/L, then only about 7.5 meters of stormwater could be loaded. These are small loading rates and would require extremely large filter surfaces or very frequent fabric exchanges. As an example, if a 1 ha paved area drained to an inlet having a 1 m^2 filter fabric, and the runoff had a suspended solids concentration of 100 mg/L, a rainfall of only about 5 mm would cause absolute clogging. This would basically require exchanging the filter after almost every rain, plus having the filter clog even before the end of many common rains. If the water was pre-treated (such as in the multi-chambered treatment train (MCTT) which uses the Gunderboom fabric, as described later under combination devices), then much more rain can be tolerated before clogging. In the Minocqua, WI, MCTT, for example, a Gunderboom filter fabric 24 m^2 in area is used for a paved drainage area about 1 ha in size (Pitt 1996). Because of the pre-treatment provided in the MCTT before the filter fabric (suspended solids are about 5 mg/L, and less than about 10 µm in size) and the large area of fabric, this filter should tolerate at least 2.5 meters of rain over the drainage area before clogging and needing replacement (at least 3 to 4 years of operation).

Three storm drain inlets were evaluated in Stafford Township, New Jersey as part of an EPA sponsored research project (Clark, *et al*. 1995; Pitt, *et al*. 1997). A conventional catchbasin, with a sump, and two representative designs that used filter material were tested. The inlet devices were located in a residential area. The filter fabrics were also evaluated in the laboratory using stormwater runoff from a large parking area on the campus of UAB. The monitoring program began in January 1994 and included 12 inlet and effluent samples from each device over several different storms, ending in late summer of 1994. Complete organic and metallic toxicant analyses, in addition to conventional pollutants, were included in the analytical program. An optimally designed catchbasin with a sump was constructed by installing a sump in the bottom of an existing storm drain inlet by digging out the bottom and placing a section of 36 inch concrete pipe on end. The outlet pipe was reduced to 8 inches and the sump depth was 36 inches. Inlet water was sampled before entering the catchbasin, while outlet water was sampled after passing through the unit. Twelve storms were evaluated for each of the three inlet units by making composite influent and effluent samples using a dipper grab sampler over the storm duration. The samples were analyzed for a broad range of conventional pollutants, metals, and organic toxicants, both in total and filtered forms. The catchbasin with the sump was the only device that showed important and significant removals for several pollutants:

total solids (0 to 50%, average 22%).
suspended solids (0 to 55%, average 32%).
turbidity (0 to 65%, average 38%).
color (0 to 50%, average 24%).

Design Suggestions to Enhance Pollution Control with Storm Drain Inlet Structures

The goal is a storm drainage inlet device that:

- prevents entry of unwanted material and is safe for small children and pets,
- does not cause flooding when it clogs with debris,
- does not force stormwater through the captured material,
- does not have adverse hydraulic head loss properties,
- maximizes pollutant reductions, and
- requires inexpensive and infrequent maintenance.

The following suggestions and design guidelines should meet these criteria (Pitt, *et al*. 1997). These options are all suitable for retro-fitting into existing simple storm drainage inlets. However, the materials used should be concrete, plastic, aluminum or stainless steel; especially do not use galvanized metal or treated woods. Catchbasins in newly developing areas could be more optimally designed than the suggestions below, especially by enlarging the sumps and by providing large and separate offset litter traps.

1) The basic catchbasin (having an appropriately sized sump) and an inverted outlet should be used in most areas. This is the most robust configuration. In almost all full-scale field investigations, this design has been shown to withstand extreme flows with little scouring losses, no significant differences between supernatant water quality and runoff quality, and minimal insect problems. It will trap the be4-load from the stormwater (especially important in areas

using sand for traction control) and will trap a low to moderate amount of suspended solids (about 30 to 45% of the annual loadings). The largest fraction of the sediment in the flowing stormwater will be trapped, in preference to the finer material that has greater amounts of associated pollutants. Their hydraulic capacities are designed using conventional procedures (grating and outlet dimensions), while the sump is designed based on the desired cleaning frequency. Figure 4-2 is this basic recommended configuration (from Lager, *et al*. 1977).

The size of the catchbasin sump is controlled by three factors: the runoff flow rate, the suspended solids concentration in the runoff, and the desired frequency at which the catchbasin will be cleaned without sacrificing efficiency. Table 4-2 shows the calculated volume of sediment captured in a catchbasin sump for a one acre paved drainage area and for runoff having 50 to 500 mg/L suspended solids concentrations. The 1976 Birmingham, AL, rain year was used to obtain typical rain depths and flow rates for each rain. The Rv (volumetric runoff coefficient) was obtained from the small storm hydrology tests conducted by Pitt (1987).

An estimate of the required catchbasin sump volume and cleanout frequency can be calculated using this table and site conditions. For example, assume the following conditions:

- paved drainage area: 1.3 ha (3.3 acres),
- 250 mg/L suspended solids concentration, and
- 640 mm (25 in) of rain per year.

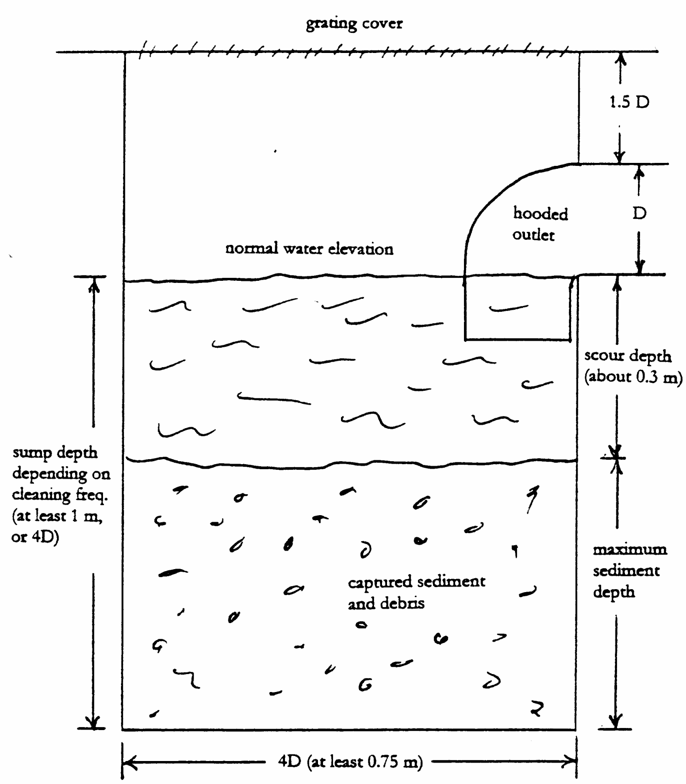


Figure 4-2 conventional catchbasin with inverted sump (after Lager, *et al.* 1977).

Table 4-2. Approximate Suspended Solids Accumulations in Catchbasin Sump for Different Accumulative Rain Depths and Suspended Solids Concentrations, for Birmingham, AL, Rain Pattern (m^3/ha and ft^3/acre of pavement)

Total Rainfall (mm)	Total Rainfall (inches)	50 mg/L SS conc.		100 mg/L SS conc.		250 mg/L SS conc.		500 mg/L SS conc.	
130	5	0.0092	0.13	0.019	0.27	0.047	0.67	0.092	1.3
250	10	0.019	0.27	0.038	0.54	0.092	1.3	0.19	2.7
380	15	0.028	0.40	0.057	0.81	0.14	2.0	0.28	4.0
640	25	0.047	0.67	0.092	1.3	0.24	3.4	0.47	6.7
1,300	50	0.092	1.3	0.19	2.7	0.47	6.7	0.92	13
2,500	100	0.19	2.7	0.38	5.4	0.92	13	1.9	27
5,100	200	0.38	5.4	0.78	11	1.9	27	3.8	54

The sediment accumulation rate in the catchbasin sump would be about 0.24 m^3/ha (3.4 ft^3/acre) of pavement per year. For a 1.3 ha (3.3 acre) paved drainage area, the annual accumulation would therefore be about 0.3 m^3 (10 ft^3). The catchbasin sump diameter should be at least four times the diameter of the outlet pipe. Therefore, if the outlet from the catchbasin is a 250 mm (10 in) diameter pipe, the sump should be at least 1 m (40 in) in diameter (having a surface area of 0.8 m^3, or 9 ft^2). The annual accumulation of sediment in the sump for this situation would therefore be about 0.4 m (1.3 ft). If the sump was to be cleaned about every two years, the total accumulation between cleanings would therefore be about 0.8 m (2.6 ft). An extra 0.3 m (1 ft) of sump depth should be provided as a safety factor because of potential scour during unusual rains. Therefore, a total sump depth of about 1.1 m (3.6 ft) should be used. In no case should the total sump depth be less than about 1 m (3 ft) and the sump diameter less than about 0.75 m (2.5 ft). This would provide an effective sump volume of about 0.8 m^3 (9 ft^3) assuming a safety factor of about 1.6.

2) A relatively safe ad4-on to the basic recommended configuration is an adversely sloped inclined screen covering the outlet side of the catchbasin, as shown in Figure 4-3. The inclined screen would be a relatively coarse screening (such as the SoilSave™, which is a 6 mm thick plastic foam and has 1 mm apertures) that should trap practically all trash of concern. The bottom edge of the inclined screen would be solidly attached to the inside wall of the catchbasin below the inverted outlet. The screen would tilt outwards so it covers the inverted outlet. The sides of the screen need to be sealed against the sides of the catchbasin. The top edge of the screen would extend slightly above the normal water surface. A solid top plate would extend out from the catchbasin wall on the outlet side covering the top opening of the inclined screen. This plate would overhang the top of the screen, but provide a slot opening above the screen for a large overflow in case the screen was clogged. The slot opening should be several inches high and extend the width of the catchbasin. This design will also capture grit and the largest suspended solids, plus much of the trash. This design would allow the trapped material to fall into the sump instead of being forced against the screen by out-flowing water.

Summary of Sewerage Inlet Devices as Stormwater Control Practices

The best catchbasin configuration for a specific location would be dependent on site conditions and would probably incorporate a combination of features from several different inlet designs. The primary design should incorporate a catchbasin with a sump, as described by Lager, *et al*. (1977), and an inverted (hooded) outlet. If large enough, catchbasins with sumps have been shown to provide a moderate level of suspended solids reductions in stormwater under a wide range of conditions in many studies in the U.S. and Europe. The use of filter fabrics in catchbasins is not likely to be beneficial because of their rapid clogging from retained sediment and trash. The use of coarser screens in catchbasin inlets is also not likely to result in water quality improvements, based on conventional water pollutant analyses. However, well designed and maintained screens can result in substantial trash and litter reductions. It is important that the screen not trap organic material in the flow path of the stormwater. Tests during recent research found that stormwater flowing through decomposing leaves degraded the stormwater quality (Pitt, *et al*. 1997). Prior research (Pitt 1979 and 1985) has shown that if most of the trapped material is contained in the catchbasin sump, it is out of the direct flow path and unlikely to be scoured during high flows, or to degrade

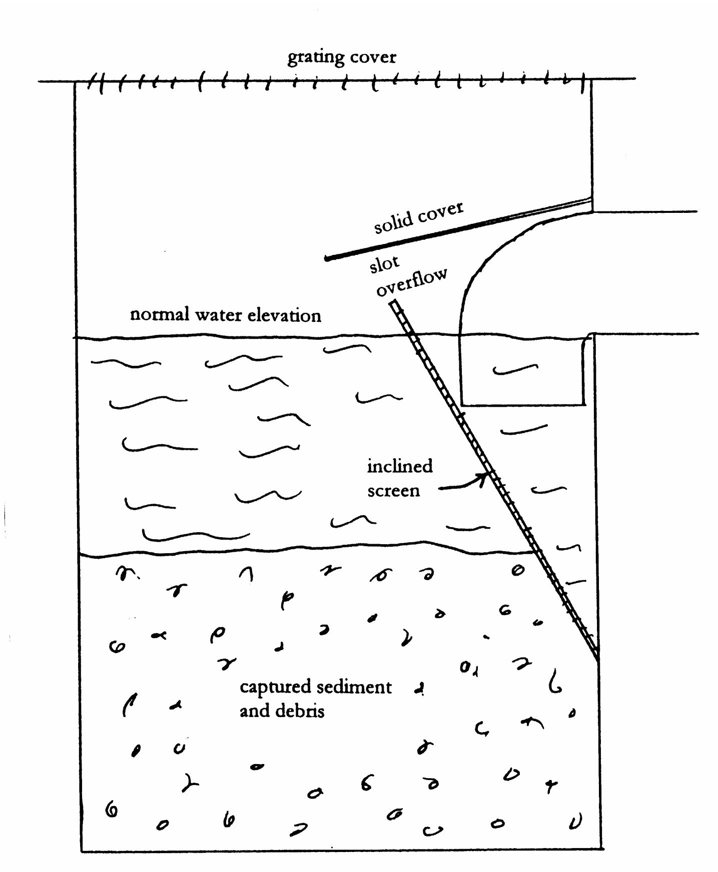


Figure 4-3. Catchbasin with sump and inclined screen (Pitt, et al. 1997).

overlying supernatant water. Storm drainage inlet devices also should not be considered as leaf control options, or used in areas having very heavy trash loadings, unless they can be cleaned after practically every storm.

Catchbasin Cleaning Performance Calculations used in WinSLAMM

WinSLAMM calculates catchbasin cleaning water quality benefits by keeping track of the accumulation of sediment in the catchbasins from rains and the amount of material removed during catchbasin cleaning operations. Research (Lager, *et al*. 1977a, Pitt 1979, and Pitt 1984) has found that the amount of material accumulated in catchbasins is related to the inflow rate. The following nonlinear equation describes this accumulation of sediment in catchbasins (with a calculated R^2 value of 0.97):

Percent removal from inflow = 44.04 (0.51^{x}) (1.061^{x^2}), for values of x less than 5 ft^3/sec, and

Percent removal from inflow = 6.5 percent for values of x greater than 5 ft^3/sec.

where x is the inlet flow rate (in ft^3/sec). These equations have been found to be applicable for catchbasin sumps ranging from 2 to 100 ft^3 in volume.

After the catchbasins are 60 percent full, the sediment accumulation is zero. Therefore, cleaning operations need to be scheduled to maintain the catchbasin accumulation of sediment below 60 percent of capacity. When the catchbasin is fuller than this amount, no sediment removal occurs. The following list summarizes some sediment removal values for different flow rates:

Flow rate (ft^3/sec)	Percent removal
0.01	44 %
0.25	37
0.50	32
1.25	21
3.2	9.5
4.7	6.9
>5.0	6.5

Several studies (Sartor and Boyd 1972, Lager, *et al*. 1977a, Pitt 1979, and Pitt 1984) have found very small sediment loading changes due to flushing during rains. Pitt (1984) even monitored about 200 catchbasins during a period of time that included a rain of greater than 4 inches, with no appreciable change in sediment loadings in the catchbasins. It was possible that flushed material was immediately replaced during the same rain, but the net change was zero.

The removal of overlying water above sediment in catchbasins readily occurs and has been noted by Sartor and Boyd (1972) as their largest water quality problem. However, Pitt (1984) statistically compared catchbasin supernatant with outfall water quality and could not detect any significant differences. EDP (1980) examined "first flushes" from catchbasins and found the quality of the water leaving the catchbasins to be much less than the high concentrations of pollutants in the gutter flows during early parts of rains. It is possible that bacteria and soluble heavy metal concentrations could be increased by the residence times between rains due to "favorable" chemical and temperature conditions in catchbasins.

Because street cleaning and catchbasins tend to remove the same particle size group, WinSLAMM ignores catchbasin sediment accumulation for streets that also have street cleaning. The catchbasins do affect the sediment originating from other source areas though.

Sedimentation

Detention ponds are probably the most common management practice for the control of stormwater sediment. If properly designed, constructed, and maintained, they can be very effective in controlling a wide range of pollutants and peak runoff flow rates. In an early 1980 survey of cities in the U.S. and Canada, the American Public Works Association found more than 2,000 wet ponds, more than 6,000 dry ponds, more than 3,000 parking lot multi-use detention areas, and more than 500 rooftop storage facilities (Smith 1982). About half of the wet detention ponds were publicly owned. In some areas of the U.S., detention ponds have been required for some time and are therefore much more numerous than elsewhere. In Montgomery County, Maryland, as an example, detention ponds were first required in 1971, with more than 100 facilities planned during that first year, and about 50 actually constructed. By 1978, more than 500 detention facilities had been constructed in Montgomery County alone (Williams 1982). In DuPage County, Illinois, near Chicago, more than 900 stormwater detention facilities (some natural) receive urban runoff (McComas and Sefton 1985).

There is probably more information concerning the design and performance of detention ponds in the literature than for any other stormwater control device. Wet detention ponds are also a very robust method for reducing stormwater pollutants. They typically show significant pollutant reductions as long as a few design-related attributes are met (most important being size). Many details are available to enhance performance, and safety, that should be followed. Many processes are responsible for the pollutant removals observed in wet detention ponds. Physical sedimentation is the most significant removal mechanism. However, biological and chemical processes can also contribute important pollutant reductions. The extensive use of aquatic plants, in a controlled manner, can provide additional pollutant removals. Magmedov, *et al*. (1996), for example, report on the use of wetlands for treatment of stormwater runoff in the UK and in the Ukraine, including design guidelines. Wet detention ponds also are suitable for enhancement with chemical and advanced physical processes. Lamella separators, air floatation, filtration, and UV disinfection are examples of treatment enhancements being investigated in France (Bernard, *et al*. 1996; Delporte 1996).

Wet Detention Pond Performance Reported in the Literature

The use of detention ponds for both water quality and quantity benefits is relatively new. Wet pond stormwater quality benefits have been commonly reported in the literature since the 1970s, while the water quality benefits of dry detention ponds have only recently been adequately described (Hall 1990).

The Nationwide Urban Runoff Program included full-scale monitoring of nine wet detention ponds (EPA 1983). The Lansing project included two up-sized pipes, plus a larger detention pond. The NURP project located in Glen Ellyn (west of Chicago) monitored a small lake, the largest pond monitored during the NURP program. Ann Arbor, Michigan, monitoring included three detention ponds, Long Island, New York, studied one pond, while the Washington D.C. project included one pond. About 150 storms were completely monitored at these ponds, and the performances ranged from negative removals for the smallest up-sized pipe installation, to more than 90 percent removal of suspended solids at the largest wet ponds. The best wet detention ponds also reported BOD_5 and COD removals of about 70 percent, nutrient removals of about 60 to 70 percent, and heavy metal removals of about 60 to 95 percent.

The Lansing NURP project monitored a wet detention pond (Luzkow, *et al*. 1981). The monitored pond was located on a golf course (receiving urban runoff from an adjacent residential and commercial area). Suspended solids removals were about 70 percent for moderate rains (10 to 25 mm rains) while phosphorus removals were usually greater than 50 percent. Total Kjeldahl nitrogen removals ranged from about 30 to 50 percent.

Two wet detention ponds near Toronto, Ontario, were monitored from 1977 through 1979 (Brydges and Robinson 1980). Lake Aquitaine is 1.9 ha in size and receives runoff from a 43 ha urban watershed. Observed pollutant reductions were about 70 to 90 percent for suspended solids, 25 to 60 percent for nitrogen, and about 80 percent for phosphorus. The much smaller Lake Wabukayne (0.8 ha) received runoff from a much larger urban area (186 ha). The smaller Lake Wabukayne experienced much smaller pollutant reductions: about 30 percent for suspended solids, less than 25 percent for nitrogen, and 10 to 30 percent for phosphorus.

Oliver, *et al*. (1981), monitored a small lake detention facility in Rolla, Missouri. Suspended solids yield reductions averaged about 88 percent, with 54 and 60 percent yield reductions for COD and total phosphorus. Organic nitrogen yields were reduced by about 22 percent.

Gietz (1983) studied a 1.3 ha wet detention pond serving a 60 ha urban watershed near Ottawa, Ontario. Batch operation of the pond resulted in substantial pollutant control improvements for particulate residue, bacteria, phosphorus, and nitrate nitrogen. Continuous operation gave slightly better performance for BOD_5 and organic nitrogen. Suspended solids reductions were about 80 to 95 percent, BOD_5 reductions were about 35 to 45 percent, bacteria was reduced by about 50 to 95 percent, phosphorus by about 70 to 85 percent, and organic nitrogen by about 45 to 50 percent.

Yousef (1986) reported long-term nutrient removal information for a detention pond in Florida having very long residence times and substantial algal and rooted aquatic plant growths. He found 80 to 90 percent removals of soluble nutrients due to plant uptake. Particulate nutrient removals, however, were quite poor (about ten percent).

Hvitve4-Jacobsen, *et al*. (1987) along with Martin and Miller (1987) described pollutant removal benefits of wet detention ponds. Niemczynowicz (1990) described stormwater detention pond practices in Sweden. Van Buren, *et al*. (1996) also recently reported on the performance of a on-stream pond located in Kingston, Ontario. They describe their monitoring activities and measures taken to enhance performance.

Hvitve4-Jacobsen, *et al*. (1994) examined the most effective treatment systems for treating urban and highway runoff in Denmark. They concluded that wet detention ponds were the most efficient and suitable solution for the removal of most pollutants of concern from both highway and urban runoff. Denmark does not have any effluent standards and the acceptable pollutant discharges are therefore determined based on specific receiving water requirements. They concluded that CSO problems were causing acute receiving water effects (hydraulic problems, oxygen depletion, high bacterial pollution, etc.), requiring treatment designs based on design storm concepts. However, both urban and highway runoff were mostly causing accumulative (chronic) effects (associated with suspended solids, toxicants, and nutrient discharges) and treatment designs therefore need to be based on long-term pollutant mass discharge reductions. It was evident that relatively low concentrations of pollutants must be reduced, and that large volumes of water must be treated in a short time period. For these reasons, and for the specific pollutants of concern, they concluded that wet detention ponds were the most effective option, even though the first wet detention pond was only constructed in Denmark in 1989. Their recommended design was based on: detention pond volume (about 250 m^3 per effective hectare of drainage area), water depth, pond shape, use of plants (covering at least 30% of the water surface), and the use of a grit removal forebay. This pond design was evaluated using the computer program MOUSE/SAMBA for long-term simulations using Aalborg, Denmark, rains. The resulting mass removals using this design were excellent for suspended solids (80 to 90%) phosphorus (60 to 70%) and heavy metals (40 to 90%).

Mayer, *et al*. (1996) examined sediment and water quality conditions in four wet detention ponds in Toronto. They found that poor water circulation in the summer months between rains decreased the pond water quality, especially for dissolved oxygen and nutrients. Anaerobic conditions near the pond water-sediment interface in two of the ponds caused elevated ammonia concentrations. They felt that decomposition of nitrogenous organic matter (from terrestrial and aquatic plant debris) was the likely source of the ammonia. They also found prolific algal growths in the same two ponds in the summer, with chlorophyll *a* concentrations of about 30 μg/L. The chlorophyll *a* concentrations in the other two ponds were much lower, between about 3 and 10 μg/L.

Maxted and Shaver (1996) examined the biological and habitat characteristics downstream from several headwater wet detention ponds in Delaware to measure beneficial effects. They found that the ponds did not improve the habitat conditions or several benthic indices, compared to similar sites without ponds, when the watershed impervious cover exceeded about 20%. They stress that more research is needed examining other stream indicators, especially in less developed watersheds and in other parts of the country. They concluded that riparian zone protection, which is commonly overlooked in extensively developed watersheds, needs much more attention. The use of stormwater management practices apparently only is able to overcome part of the detrimental effects of development.

Stanley (1996) examined the pollution removal performance at a dry detention pond in Greenville, NC, during eight storms. The pond was 0.7 ha in size and the watershed was 81 ha of mostly medium density single family residential homes, with some multifamily units, and a short commercial strip. The observed reductions were low to moderate for suspended solids (42 to 83%), phosphate (-5 to 36%), nitrate nitrogen (-52 to 21%), ammonia nitrogen (-66 to 43%), copper (11 to 54%), lead (2 to 79%), and zinc (6 to 38%). Stanley also summarized the median concentration reductions at dry detention ponds studied by others, shown in Table 4-3. In all cases, the removals of the stormwater pollutants is substantially less than would occur at well designed and operated wet detention ponds. The resuspension of previously deposited sediment during subsequent rains was typically noted as the likely cause of these low removals. The conditions at the Greenville pond were observed three years after its construction. The most notable changes was that the pond bottom and interior banks of the perimeter dike were covered with weeds and many sapling trees (mostly willows), indicating that the interior areas have been too wet to permit mowing. The perforated riser was also partially clogged and some pooling was occurring near the pond outlet. It seemed that the dry pond was evolving into a wetlands. The monitoring activity was conducted a few months after the pond was constructed and was not affected by these changes. Stanley felt that the wetlands environment, with the woody vegetation, if allowed to spread, could actually increase the pollutant trapping performance of the facility. With continued no maintenance, the dry pond will eventually turn into a wet pond, with a significant permanent pool. The pollutant retention capability would increase, at the expense of decreased hydraulic benefits and less flood protection than originally planned. Maintenance problems in dry ponds had also been commonly noted in earlier Maryland surveys.

The benefits of off-line stormwater detention ponds were examined by Nix and Durrans (1996). Off-line ponds (side-stream ponds) are designed so that only the peak portion of a stream flow is diverted to the pond (by an in-stream diversion structure). They are designed to reduce the peak flows from developed areas, with no direct water quality benefits, and are typically dry ponds. Off-line ponds are smaller (by as much as 20 to 50%) than on-line ponds (where the complete storm flow passes through the pond) for the same peak flow reductions. However, the outflow hydrographs from the two types of ponds are substantially different. The off-line ponds produce peak outflows earlier and the peak flows no not occur for as long a period of time. If located in the upper portion of a watershed, off-line ponds may worsen flooding problems further downstream, whereas downstream on-line ponds tend to worsen basin outlet area flooding. Off-line dry ponds can be used in conjunction with on-line wet ponds to advantage to provide both water quality and flood prevention benefits. Off-line ponds have an advantage in that they do not interfere with the passage of fish and other wildlife and they do not have to dramatically affect the physical character of the by-passed stream itself. On-line dry ponds would substantially degrade the steam habitat by removing cover and radically changing the channel dimensions. The peak flow rate reductions can also have significant bank erosion benefits in the vicinity of the pond, although these benefits would be decreased further downstream.

Problems with Wet Detention Ponds

Wet detention ponds may experience various operating and nuisance problems. The following discussion attempts to describe these negative aspects of wet ponds, as reported in the literature, and to describe how they have been overcome through specific designs.

Safety of Wet Detention Ponds

The most important wet detention pond design guidelines are to maintain public safety. The following discussion briefly summarizes common suggestions to maintain and improve safety at wet detention facilities. Marcy and Flack (1981) state that drownings in general most often occur because of slips and falls into water, unexpected depths, cold water temperatures, and fast currents. Four methods to minimize these problems include: eliminate or minimize the hazard, keep people away, make the onset of the hazard gradual, and provide escape routes. Many of the design suggestions and specifications contained in this section are intended to accomplish these methods.

Jones and Jones (1982) consider safety and landscaping together because landscaping can be an effective safety element. They feel that appropriate slope grading and landscaping can provide a more desirable approach than wide-spread fencing around a wet detention pond. Fences are expensive to install and maintain and usually produce unsightly pond edges. They collect trash and litter, challenge some individuals who like to defy barriers, and impede emergency access if needed. Marcy and Flack (1981) state that limited fencing may be appropriate in special areas. When the pond side slopes cannot be made gradual (such as when against a railroad right-of-way or close to a roadway), steep sides having submerged retaining walls may be needed. A chain link fence located directly on the top of the retaining wall very close to the water's edge would be needed (to prevent human occupancy of the narrow ledge on the water side of the fence). Another area where fencing may be needed is at the inlet and outlet structures. However, fencing usually gives a false sense of security, as most can be easily crossed (Eccher 1991).

Pond side slopes need to be gradual near the water edge, with a submerged shallow ledge close to shore. Aquatic plants on the ledge would decrease the chance of continued movement to deeper water and thick vegetation on shore near the water edge would discourage access to the water edge and decrease the possibility of falling into the water accidentally. Pathways should not be located close to the water's edge, or turn abruptly near the water.

Marcy and Flack (1981) also encourage the placement of escape routes in the water whenever possible. These could be floats on cables, ladders, han4-holds, safety nets, or ramps. However, they should not be placed to encourage entrance into the water.

Table 4-3. Summary of Dry Detention Pond Pollutant Removal (Stanley 1996)

	Detention pond name and location						
	Lakeridge northern Virgina[a]	London northern Virgina[b]	Stedwick Montgomery Co., Md.[c]	Maple Run Austin, Tex.[d]	Oakhampton Baltimore, Md.[e]	Lawrence Kans.[f]	Greenville, N.C.[g]
Watershed, acres	88	11	34	28	17	12	200
Imperviousness, %						49	
Hours to drain after filling	1–2	<10	6–12	–9		6–16	75
Storms monitored	28	27	25	17		19	8
Removal efficiencies, %							
TSS	14	29	70	30	87	3	71
TP	20	40	13	18	26	19	14
PO_4-P	–6				–12	0	26
TN	10	25	24	35			26
NO_3-N	9			52	–10	20	–2
NH_4-N				55	54	69	9
TOC				30		–3	10
POC							45
DOC							–6
Cu				31			26
Pb		39	62	29		66	55
Zn	–10	24	57	–38		65	26

Each study differs with respect to pond design, number of storms monitored, pollutant removal calculation techniques, and monitoring techniques. Therefore, exact comparisons cannot be made.

[a] MWCOG (1983); [b] OWML (1987); [c] Schueler and Helfrich (1988); [d] City of Austin, 1991 personal communication, cited in Schueler *et al.* (1992); [e] Baltimore Department of Public Works (1989); [f] Pope and Hess (1988); [g] this study.

The use of inlet and outlet trash racks and antivortex baffles is also needed to prevent access to locations having dangerous water velocities. Racks need to be placed where water velocities are less than three feet per second through the racks to allow people to escape and the openings should be less than 6 inches across (Marcy and Flack 1981). Besides maintaining safe conditions, racks also help keep trash from interfering with the operation of outlet structures.

Eccher (1991) lists the following pond attributes to ensure maximum safety, while having good ecological control:

1) There should be no major abrupt changes in water depth in areas of uncontrolled access,
2) slopes should be controlled to insure good footing,
3) all slope areas should be designed and constructed to prevent or restrict weed and insect growth (generally requiring some form of hardened surface on the slopes), and
4) shoreline erosion needs to be controlled.

Nuisance Conditions in Wet Detention Ponds and Degraded Water Quality
Most new detention ponds require from three to six years before an ecological balance is obtained (Ontario 1984). Excessive algal growths, fish kills, and associated nuisance odors may occur during this period, creating management problems for municipal officials and developers. Water quality is also generally poor in wet detention ponds, but unauthorized swimming can be common if alternative swimming facilities are not conveniently available. The poorest water and sediment quality in wet detention ponds usually occurs near the inlets and in depressions (Free and Mulamoottil 1983 and Wigington, *et al*. 1983). Some urban lakes have also been subjected to duck plagued disease which is a deadly virus that thrives in lakes having excessive algae growths (Ontario 1984). Schueler and Galli (1992) reported that water discharged from wet detention ponds may be warmed by as much as 10 to 15°F in the summer months, unless shaded or subsurface discharges are used.

The haphazard installation of detention ponds can increase downstream flooding and erosion problems if a regional analysis and careful plan is not developed and followed (Duru 1981 and 1983, Jones and Jones 1982, and Hawley, *et al*. 1981). This can occur by increasing the duration of erosive flow velocities and by adding the delayed high discharge flows from a pond to the natural high flows from upstream areas. These problems can be substantially reduced with careful design and maintenance, as described in the following paragraphs.

Attitudes of Nearby Residents and Property Values
Wet detention ponds may create potential nuisance conditions if they are not properly designed or maintained. However, many people living near wet detention ponds do so because of the close presence of the wetlands, and their property values are typically greater than lots further from the ponds (Marsalek 1982). Marsalak (1982) also reported that small (well maintained) wet detention ponds are less subject to controversy that larger ponds (that are more commonly neglected). Debo and Ruby (1982) summarized a survey conducted in Atlanta of residents living near and downstream of 15 small detention ponds and found that almost half of the people surveyed who lived in the immediate areas of the ponds did not even know that they existed. Wiegand, *et al*. (1986) also stated that wet detention ponds, when properly maintained, are more preferred by residents than any other urban runoff control practice.

Emmerling-DiNovo (1995) reported on a survey of homeowners in the Champaign-Urbana area living in seven subdivisions having either dry or wet detention ponds. She reported that past studies have recognized that developers are well aware that proximity to water increases the appeal of a development. Detention ponds can create a sense of identity, distinguishing one development from another, and can be prominent design elements. Increased value is important because the added cost of the detention facility, including loss of developable land, must be recovered by increasing the housing costs. Others have also found that the higher costs of developments having stormwater detention facilities can also be offset by being able to sell the housing faster. In a prior survey in Columbia, MD, 73% of the respondents would be willing to pay more for property located in an area having a wet detention pond if designed to enhance fish and wildlife use. Although the residents were concerned about nuisances and hazards, they felt that these concerns were out-weighed by the benefits. In her survey, Emmerling-DiNovo (1995) received 143 completed surveys. Overall attractiveness of the neighborhood was the most important factor in purchasing their home. Resale value was the second most important factor, while proximity to water was slightly important. More than 74% of the respondents believed that wet detention ponds contributed positively to the image of the neighborhood and they were a positive factor in choosing that subdivision. In contrast, the respondents living in the subdivisions with the dry ponds felt that the dry ponds were not a positive factor in locating in their subdivision. Respondents living adjacent to the wet ponds felt that the presence of the pond was very positive in the selection of their specific lot. The lots adjacent to the wet ponds were reported to be worth about 22% more than lots that were not adjacent to the wet ponds. Lots adjacent to the dry ponds were actually worth less (by about 10%) than other lots. Dry detention ponds actually decreased the assessed values of adjacent lots in two of the three dry basin subdivisions studied. The respondents favored living adjacent to wet ponds even more than next to golf courses. Living adjacent to dry ponds were the least preferred location.

Another example of increased land value occurred in Fairfax, VA (*Land and Water* 1996). A 1.6 acre wet detention pond was constructed using a modular concrete block retaining wall system. Total construction time was about six weeks and resulted in an attractive pond that added substantial value to the new housing development.

The Hennepin (MN) park district (John Barten, personal communication) reports that the park district is frequently asked by developers to be allowed to “improve” the parks by putting their wet detention ponds on park land that is adjacent to new developments. Needless to say, the park district cannot afford to convert their dry land to lakes which would dramatically decrease the utilization of the park by the park users. The park district is also frequently asked by residents of subdivisions to improve the water quality in the wet detention ponds located in their subdivisions, especially to allow fishing and swimming. The residents do not understand that their “lake” is actually a water treatment system and is not a natural lake or park and is not intended for water contact recreation or fishing. However, because many of these subdivisions are marketed by stressing the benefits of “lakeside” living, some of the residents expect the city to improve the wet detention ponds for recreational use. The park department, under a lot of citizen and political pressure, has actually had to construct new wet detention ponds upstream of some of these wet detention ponds.

Maintenance Requirements of Wet Detention Ponds

In order for detention ponds to perform as anticipated, they must be regularly maintained. Poor operation and maintenance not only reduces the pollutant and flow rate reduction effectiveness of detention ponds, but can cause detention facilities to become eyesores, nuisances, and health hazards (Poertner 1974). If a pond does not “need” maintenance (such as sediment removal), then it is not providing significant water quality benefits. Ponds can be designed to minimize maintenance, however, a maintenance free detention facility (that is working properly) does not exist (SEMCOG 1981).

Institutional arrangements must be made to insure continued detention pond maintenance after construction. SEMCOG (1981) recommends that appropriate maintenance programs specifically identify the organization or person who will perform the maintenance and how the maintenance operations will be financed. They also found that major detention pond maintenance (dredging) is usually needed within about ten years after pond construction. More frequent (routine) maintenance may include: structural repairs (bank stabilization), removal of debris and litter from the water and surrounding land, grass cutting, fence repairing, algal control, mosquito control, and possible fish stocking. Wet detention ponds require a lot of attention.

Routine Maintenance Requirements

The following summary of routine maintenance requirements is based on a discussion by Schueler (1987).

Mowing. The most costly routine maintenance required of a detention facility is mowing the surrounding area. In residential areas, frequent mowing (up to 12 times a year) may be necessary to maintain a lawn surrounding the pond. Some native plants (such as in the small prairie surrounding the Monroe Street detention pond in Madison at the University of Wisconsin Arboretum) require much less maintenance. In all cases, the emergency spillway, side slopes, and pond embankments need to be mowed at least twice a year to control undesirable plants that may interfere with pond operation. Attractive landscaping and adequate landscaping maintenance are always needed. Careful plant selection (water and salt tolerant, disease and winter hardy, and slow growing) should be made in conjunction with a landscape architect or the Soil Conservation Service.

Debris and litter removal. During the routine mowing operations and after each major storm, debris and litter should also be removed from the site, especially from the inlet and outlet grates and the water surface.

Inspections. Wet detention ponds need to be inspected at least once a year, and after each major storm. The inspection should include checking the pond embankments for subsidence, erosion, and tree growth. The conditions of the emergency spillway and inlets and outlets also need to be determined during the inspection. The adequacy of any channel erosion protection measures near the pond should also be investigated. Sediment accumulation in the pond (especially near, and in, the inlets and outlets) also needs to be examined.

Sediment Removal from Wet Detention Ponds

Large sediment accumulations in detention ponds can have significantly adverse affects on pond performance. Bedner and Fluke (1980) reported on the long term effects of detention ponds that received little maintenance. Lack of dredging actually caused the silte4-in ponds to become a major sediment source to downstream areas. Poorly maintained ponds only delayed the eventual delivery of the sediment downstream, they did not prevent it.

Based on the NURP detention pond monitoring results (EPA 1983), a pond having a surface area of about 0.6 percent of the contributing area should remove about 90 percent of the settleable solids (particulate residue) from the runoff. The Milwaukee NURP project (Bannerman, *et al*. 1983) estimated an annual sediment delivery of about 500 pounds per acre for medium density residential land uses and about 2500 pounds per acre for commercial areas. Other land uses contribute sediment generally between these values. Assuming a density of about 120 pounds per cubic feet, about 3.6 and 18 cubic feet of sediment would be deposited in a well designed detention pond for each medium density residential or commercial acre per year. With a pond 0.6 percent of the contributing area in size, this would only result in the deposition of between 0.2 and 0.9 inches per year. McComas and Sefton (1985) report two measured sediment accumulation rates in Chicago area wet detention ponds (about two and three percent of the drainage pond in size) of 0.24 and 1.3 inches per year. Kamedulski and McCuen (1979) report a much greater sedimentation rate of about three inches per year in another pond. When uncontrolled construction site erosion is allowed to enter a detention pond, the pond can literally fill up over night.

Most of the sedimentation would occur near the inlet and the resulting sediment accumulation would be very uneven throughout the pond. Sediment removal in a wet pond may therefore be needed about every five to ten years, depending on the variation in sediment deposition over the pond and the sacrificial storage volume designed.

It is necessary to plan for required maintenance during the design and construction of detention ponds. Ease of access of heavy equipment and the possible paving of a sediment trap near the inlet would ease maintenance problems. Deposited sediment can be heavily polluted and may require special disposal practices. Sediment concentrations of up to 100,000 mg organic carbon, several thousand mg lead, several hundred mg zinc, and more than ten mg arsenic per kg dry sediment are not uncommon for lakes receiving urban runoff (Pitt and Bozeman 1979). Dredged sediment is usually placed directly onto trucks, or is placed on the pond banks for dewatering before hauling to the disposal location. One common practice is to keep an area adjacent to the detention pond available for on-site sediment disposal. Small mounds can be created of the dried sediment and covered with top soil and planted.

Poertner (1974) reviewed various sediment removal procedures. An underwater scoop can be pulled across the pond bottom and returned to the opposite side with guiding cables. If drains and underwater roads were built during the initial pond construction, the pond can be drained and front-en4-loaders, draglines, and trucks can directly enter the pond area. Small hydraulic dredges can also be towed on trailers to ponds. The dredge pumps sediment to the shore through a floating line where the sediment is then dewatered and loaded into trucks or piled. A sediment trap can also be constructed near the inlet of the pond. The entrances into the pond are widened and submerged dams are used to retain the heavier materials in a restricted area near the inlets. This smaller area can then be cleaned much easier and with less expense than the complete pond. Hey and Schaefer (1983) report the successful use of a submerged dam across the pond inlet in Lake Ellyn.

The estimated cost of removing sediment from a detention pond varies widely, depending on the amount to be removed and the disposal requirements. Costs as low as one dollar per cubic yard have been reported, but this low cost does not include any possible special disposal practices. Sediment removal costs are estimated to generally range from about $5 to $25 per cubic yard of sediment removed.

Problems with Contaminated Sediments in Wet Detention Ponds. Frequently, concern arises about the safety of disposing sediments from wet detention ponds. There have recently been several studies that have addressed this issue, as summarized in the following paragraphs. Dewberry and Davis (1990) analyzed sediments from 21 ponds in northern Virginia. They found trace metals in many of the sediments, but the available forms of the metals were significantly less than applicable toxic thresholds. They concluded that the dredged materials could be safely disposed either on-site or at sanitary landfills without danger of health problems. However, they recommend that sediment samples from specific ponds be analyzed before dredging.

Yousef and Lin (1990) conducted extensive pond water quality and sediment quality analyses in six wet detention ponds in Florida as part of a Florida Dept. of Transportation study to develop pond maintenance procedures. The ponds had all been constructed from 4 to 13 years prior to analyses and received runoff from various urban watersheds that all contained different amounts of highway runoff. The dissolved oxygen levels in the ponds all dropped significantly with depth, in many cases being lower than 1 mg/L at the water-sediment interface. The pH of the pond water was also generally acidic in all of the ponds, being from 5.5 to 7.2 throughout the water columns. The temperature differences between the water surface and the bottom of the ponds was generally less than 1^{o}C. The sediment accumulation rates were found to be between 0.25 and 0.72 cm per year and correlated with pond age, size of drainage basin and size of pond. The bottom material was found to be poorly graded sand. Appreciable amounts of heavy metals (Cu: 7 to 73 μg/g, Ni: 12 to 82 μg/g, Pb: 84 to 1025 μg/g, and Zn: 13 to 538 μg/g), and nutrients (N: 1.1 to 5.2 mg/g, and P: 0.1 to 1.2 mg/g) were found in the surface layers of the sediments. However, the concentrations of the pollutants decreased rapidly with depth, generally being less than 10% of the surface sediment concentrations below 20 cm beneath the water-sediment interface. The bottom sediments were also analyzed to determine the TCLP extractable portions of the metals. These were found to be significantly less than the whole sediment metal concentrations (Cu: 0.13, Ni: 0.31, Pb: 0.27, and Zn: 0.33). They determined that the TCLP extractable fraction was lowest for sediments having higher clay and organic material. They concluded that the sediments could be removed during normal maintenance operations and disposed of on non-agricultural land.

Jones (1995) and Jones, *et al*. (1996) discuss the implications that the Resource Conservation and Recovery Act (RCRA) may have on sediments that need to be removed from stormwater management facilities, as summarized in the following discussion. The "mixture" (40 CFR Section 261.3(a)(2)(iv)) and "derived from" (40 CFR Sections 261.3(c)(2)(1) and 261.3(d)(2)) rules can cause sediments having very low concentrations of pollutants to be classified as "hazardous." These regulations are likely to be changed in the near future, with clearer definitions for non-hazardous operations and facilities. Sediments are evaluated as being hazardous when the wet detention pond is being dredged, not while they remain in-place. Many of the materials that are listed as hazardous under RCRA may enter stormwater, especially at vehicle service facilities, industrial facilities, and even golf courses and parks. These include solvents, degreasers, hydraulic fluids, herbicides, fungicides, and pesticides. For the sediments to be considered hazardous under the current RCRA mixture rule, the source of the specific material containing the listed hazardous material must contain more than 10% of the hazardous material. This is irrespective of how much of the material actually enters the stormwater. Therefore, site inventories become important tools in determining if a sediment would be classified as hazardous. If a listed material is used on the site, but it would not come in contact with rain (either through normal use or spills), the sediment would not likely be classified as hazardous. It is difficult to conduct detailed site surveys for a large drainage area having many separate owners, but it is feasible for small wet ponds serving single facilities. Jones (1995) and Jones, *et al*. (1996) also discuss other options to minimize the chance that wet pond sediment would be classified as hazardous under RCRA:

- Reduce the likelihood that listed substances would come in contact with precipitation or runoff.
- Inventory and track hazardous materials and encourage the use of replacement compounds.
- Install stormwater pre-treatment facilities to localize the problem.
- Reduce the accumulation rate, and increase the storage area for sediment in the pond.

Vegetation Removal from Wet Detention Ponds

In shallow detention ponds, excessive rooted aquatic plant (macrophyte) growths may occur over the entire pond surface. In deeper ponds, rooted aquatic plant growths are usually restricted close to the shoreline (Ontario 1984).

Floating algae may create problems anywhere in a lake, irrespective of pond depth. As noted earlier, a narrow band of natural rooted aquatic plants along the narrow “safety” shelf is desirable as a barrier and to add habitat for pond wildlife.

Excessive algal growths create nuisance problems with strong odors, but more serious problems may also occur. Schimmenti (1980) reports that decaying vegetation, if not removed, promotes the breeding of mosquitoes. Certain types of algae (*Anabaena, Aphanizomenon*, and *Anacystis*) naturally produce toxins that can kill animals (including fish) which drink the water and can cause skin irritation and nausea in humans (Ontario 1984). Algae is usually mechanically controlled in detention ponds by using algae harvestors or by dewatering the pond. Certain fish also consume large amounts of algae, but the most common type of algae control is by using aquatic herbicides. Many rooted aquatic plant growth problems can be significantly reduced by using a deep pond which restricts light penetration.

Small weed harvestors can be delivered to a detention pond by trailer. The use of chemicals for algae control is popular, but must be carefully done to prevent contamination of the receiving water. Dead algae and rooted plants must also be removed to prevent odor and dissolved oxygen problems. Mechanical barriers can also be placed on the pond bottom to reduce rooted aquatic plant growth. AquaScreen is a fairly fine, dark mesh that is laid on the pond bottom that restricts sunlight from reaching the rooted aquatic plants. In tests conducted on Lake Washington, Perkins (1980) concluded that a two or three month use of the material resulted in about an 80 percent reduction of rooted aquatic plants where the material had been placed. Again, increased pond depth, possibly at less cost, can do the same thing.

Guidelines to Enhance Pond Performance

The Natural Resources Conservation Service (NRCS, renamed from SCS, undated) has prepared a design manual that addresses specific requirements for such things as anti-seep collars around outlet pipes, embankment widths, type of fill required, foundations, emergency spillways, etc., for a variety of wet detention pond sizes and locations. That manual must be followed for detailed engineering requirements.

The rest of this discussion presents some of the many design suggestions that have been made by researchers having many years of design and monitoring experience with detention ponds. Akeley (1980) listed several modifications that can be made to existing ponds to improve their performance. Gravel, or cement, should be added along unstable banks and near the inlet and control structures. A baffle should be placed at the inlet to reduce turbulence, and barriers can be used to separate the pond into compartments to reduce short-circuiting. On-going maintenance is also needed to remove deposited sediment. Hawley, *et al*. (1983) also recommended similar design considerations. Hey and Schaefer (1983) found that a submerged dam near the pond inlets significantly reduced the area requiring maintenance dredging.

Insect Control, Fish Stocking and Planting Desirable Aquatic Plants

Mosquito problems at wet detention ponds are increased when large water level fluctuations occur, especially when vast amounts of aquatic plants are wetted and available for egg laying. If ponds drain to normal water levels within several hours after a rain has ended, if aquatic vegetation is kept to a minimum (such as only along a narrow ledge close to shore), and if the pond shape allows adequate water movement and wind disturbance, then mosquito problems should be minimal.

Schimmenti (1980) made several recommendations to reduce the possibility of mosquito problems in detention ponds. Wet ponds should have adequate water quality to support surface feeding fish, such as sunfish, and various minnows, that feed on mosquitoes. Carp or crayfish also make adequate biological controls for midges, reducing the need for chemical controls (Ontario 1984).

Some developers have tried to stock trout, yellow perch, and northern pike in detention ponds, but no reproduction and poor wintering soon eliminates these less tolerant fish. Detention ponds receiving urban runoff are likely to contaminate fish, making them unsuitable for consumption. Brydges and Robinson (1980) have conducted extensive heavy metal and pesticide analyses in fish in two wet detention ponds near Toronto, Ontario and have found little problem accumulations of these substances. However, other studies have reported problem toxic pollutant concentrations in fish from waters receiving urban runoff, so allowing fish consumption in wet detention facilities should only be allowed after careful study. Therefore, game fish should not generally be used in ponds, and consumptive fishing should be discouraged. Fathead minnows, stocked for mosquito control, have survived in detention ponds in Ontario.

Rooted aquatic plants should be planted along much of the shallow perimeter shelf to deter small children, for aesthetics and to provide wildlife habitat. The use of native aquatic plants is to be encouraged to lessen maintenance costs and to prevent nuisance plants from becoming established in a waterway (such as purple loosestrife). Plants that could be established in wet detention ponds include arrowhead and cattails. Cattails sometimes interfere with the operation of a surface outlet because of large floating pieces clogging the weir. Subsurface weirs and trash racks (both recommended) would decrease this problem. Other rooted aquatic plants may also be used in wet detention ponds, but their selection and planting should be done in consultation with a landscape architect and a wildlife biologist. Fuhr (1996) warns against planting trees and brush on an impoundment because seepage problems may result by root action.

An interesting use of aquatic plants to enhance wet detention pond performance was described in the February 1991 *Lake Line*. Nutri-Pods, developed by the Limnion Corporation of Concord, CA, are two m diameter mesh balls, initially filled about 25% full with coontail (*Ceratophyllum demersum*). One to five Nutri-Pods are used per acre of pond surface, for ponds at least one acre in size. These reduce nutrient concentrations in the water and successfully compete with other aquatic plants, including planktonic algae. They were tested on a 27 acre lake near Sacramento, CA, which underwent periodic major increases in nutrients (phosphates as high as 50 mg/L) from fertilizing surrounding land. It took about two to four weeks for the Nutri-Pods to stabilize the lake after each major increase. Adding *Elodea* to the Nutri-Pods helped to keep nutrient concentrations very low (phosphorus at about 0.01 mg/L and nitrates less than 0.1 mg/L). The Nutri-Pods are inspected every few weeks and when they approach 100% capacity with the internal aquatic plants, they are removed from the water, and plants are removed, except for about 25% which are used as a starter. The Nutri-Pods therefore use aquatic plants to improve wet detention pond water quality, while enabling controlled harvesting with very little specialized equipment.

Pond Side Slopes

Reported recommended side slopes of detention ponds have ranged from 4:1 (four horizontal units to one vertical unit) to 10:1. Steeper slopes will cause problems with grass cutting and may erode. Steep slopes are not as aesthetically pleasing and are more dangerous than gentle slopes (Chambers and Tottle 1980). Sclueler (1986) also recommends a minimum slope of 20:1 for land near the pond to provide for adequate drainage.

The slope near the waterline, and for about one foot below, should be relatively steep (4:1) to reduce mosquito problems (by reducing the amount of frequently wetted land surface), and to provide relatively fast pond drawdown after common storms. However, a flat underwater shelf several feet wide and about one foot below the normal pond surface is needed as a safety measure to make it easier for anyone who happens to fall into the pond to regain their footing and climb out. This shelf should also be planted with native rooted aquatic plants (marcrophytes) to increase the aesthetics and habitat benefits of a pond and to create a barrier making unwanted access to deep water difficult.

Another method of treating pond edges is placing gravel along the pond edge to decrease erosion and to make mowing easier (Chambers and Tottle 1980). This method requires placing a layer of gravel about one foot deep and 15 feet wide along the pond edge, from about ten feet above the normal waterline edge and extending about five into the water.

Enhancing Pond Performance During Severe Winter Conditions

Oberts (1990 and 1994) monitored four urban wet detention ponds during both warm and cold weather in Minnesota. The ponds performed as expected during warm weather, providing typical removals of suspended solids (80%), lead (68%), and TP (52%). However, he found that the ponds did a much worse job of removing suspended solids (39%), organic matter (12% for COD), nutrients (4 % for TKN to 17% for TP) and lead (20%) in the winter. He found that thick ice, which can form as much as 1 m in thickness, effectively eliminated much of the detention volume for incoming snowmelt water. In addition, the first melting water was forced under the ice, causing scour of the previously sediments. Later snowmelt water flowed across the surface of the ice, with very little sedimentation opportunities. Any sediment that was accumulated on top of the underlying ice was later discharged when the ice melted. Similar research in Minnesota wetlands also showed similar dismal performance during winter conditions, for much the same reasons.

Oberts (1990 and 1994) proposed several improvements in stormwater management during winter conditions. His initial recommendation is to utilize infiltration and grass filtering in waterways before any detention facilities. He found that substantial infiltration can occur, even in clayey soils, underlying the snow. The ground under snowpacks is rarely frozen and infiltration can be significant until the soil becomes saturated. If the snowmelt is originating from areas having automobile activity (streets and parking areas) or sidewalks, care must be taken because the snowmelt likely would have high concentrations of salts which would adversely affect the local groundwater (Pitt 1996). The design of the detention pond should be modified for winter operations (Oberts 1994). A low flow channel leading to and through the pond will discourage the formation of ice. The pond can also be aerated to prevent ice formation, however, if it gets extremely cold, ice formation could then be very thick and rapid. The most important suggestion by Oberts is to use a special riser for the outlet of the pond that can be used to draw down the water elevation during the winter. Ice would then form near the bottom of the pond and seal off the sediments. As the snowmelt occurs, the bottom outlets on the riser should be closed, forming a deeper pond for better sedimentation.

Droste and Johnston (1993) examined snowmelt quality from snow disposal areas in Ottawa and conducted treatability tests to examine the benefits of different settlement times in 1 L test columns. They found that 2 to 6 hour settling times in these columns produced suspended solids and metal removals approaching 90%. These tests were conducted in controlled laboratory conditions and were not subjected to the actual site problems identified by Oberts. These tests do indicate that sedimentation treatment of snowmelt is likely beneficial, especially if the unique problems of scour and ice formation can be overcome.

Mayer, *et al*. (1996) examined the performance of four wet detention ponds in Toronto during different seasons and during non-storm conditions. The thick ice cover on the ponds during the winter severely affected the pond water quality. In addition, snowmelt and runoff from rainfall occurring on an existing snowpack, were poorly treated by the ponds. Few of the biochemical processes that normally enhance pollutant removal in wet detention ponds during warm weather are available during the winter, plus the ice pack decreases the efficiency of the physical processes, as noted by Oberts. Water beneath the winter ice was typically devoid of oxygen, causing the release of ammonia from sediments and increasing the water column concentrations to about 0.5 mg/L. High grit concentrations in snowmelt, associated with winter sanding of streets, were effectively removed in the detention ponds. However, the high chloride concentrations, from salting of the streets, were not affected by the ponds, as expected.

Particle Settling Characteristics in Stormwater

Knowing the settling velocity characteristics associated with stormwater particulates is necessary when designing wet detention ponds. Particle size is directly related to settling velocity (using Stokes law, for example, and using appropriate shape factors, specific gravity and viscosity values) and is usually used in the design of detention facilities. Particle size can also be much more rapidly measured in the laboratory than settling velocities. Settling tests for stormwater particulates need to be conducted for about three days in order to quantify the smallest particles that are of interest in the design of wet detention ponds. If designing rapid treatment systems (such as grit chambers or vortex separators) for CSO treatment, then much more rapid settling tests can be conducted. Probably the earliest description of conventional particle settling tests for stormwater samples was made by Whipple and Hunter (1981).

The particle size distributions of stormwater at different locations in an urban area greatly affect the ability of different source area and inlet controls in reducing the discharge of stormwater pollutants. A series of recent U.S. Environmental Protection Agency (USEPA) funded research projects has examined the sources and treatability of urban stormwater pollutants (Pitt, *et al*. 1995). This research has included particle size analyses of 121 stormwater inlet samples from three states (southern New Jersey; Birmingham, Alabama; and at several cities in Wisconsin) in the U.S. that were not affected by stormwater controls. Particle sizes were measured using a Coulter Counter Multi-Sizer IIe and verified with microscopic, sieve, and settling column tests. Figures 4-4 and 4-5 are grouped box and whisker plots showing the particle sizes (in μm) corresponding to the 10^{th}, 50^{th} (median) and 90^{th} percentiles of the cumulative distributions. If 90 percent control of suspended solids (by mass) was desired, then the particles larger than the 90th percentile would have to be removed, for example. In all cases, the New Jersey samples had the smallest particle sizes (even though they were collected using manual “dipper” samplers and not automatic samplers that may miss the largest particles), followed by Wisconsin, and then Birmingham, Alabama, which had the largest particles (which were collected using automatic samplers). The New Jersey samples were obtained from gutter flows in a residential neighborhood that was xeroscaped, the Wisconsin samples were obtained from several source areas, including parking areas and gutter flows mostly from residential, but from some commercial areas, and the Birmingham samples were collected from a long-term parking area on the UAB campus. In contrast, Figure 4-6 is a plot of stormwater particle sizes from the outfall at the Monroe St. site in Madison, WI (collected using both an automated sampler and be4-load samplers). These data were also not affected by stormwater controls, but do show the significant shift in particle sizes in stormwater at the outfall compared to source area sheetflow. The median particle size at the outfall was only about 8 µm, and the 90th percentile value was less than 1 µm. At the source areas, the median particle size was about twice as large, at about 15 µm, while the 90th percentile size was about 3 µm. The bed load sampler also enabled larger particles moving in the stormwater to be effectively sampled. The bed load sampler material represented about 10% (by weight) of the annual sediment load (mostly in sizes larger than about 300 µm), while the automatic sampler captured about 90% of the annual load (mostly in sizes from <1 µm to about 300 µm).

The median particle sizes ranged from 0.6 to 38µm and averaged 14µm. The 90th percentile sizes ranged from 0.5 to 11µm and averaged 3µm. These particles were all substantially smaller than have been typically assumed for stormwater. The suspended solids concentrations ranged from 4 to 1080 mg/L (averaging 130 mg/L), while the turbidity ranged from 1 to 290 NTU (averaging 41 NTU). Notably lacking was a better relationship between suspended solids and turbidity, or between suspended solids and any of the particle sizes. Additional data obtained by Pitt and Barron (1989) for the USEPA described particle sizes from many different source flows in the Birmingham, Alabama, area. These data did not indicate any significant differences in particle size distributions for different source areas or land uses, except that the roof runoff had substantially smaller particle sizes.

Pisano and Brombach (1996) recently summarized numerous solids settling curves for stormwater and CSO samples. They are concerned that many of the samples analyzed for particle size are not representative of the true particle size distribution in the sample. As an example, it is well known that automatic samplers do not sample the largest particles that are found in the bedload portion of the flows. Particles having settling velocities in the 1 to 15 cm/sec range are found in grit chambers and catchbasins, but are not seen in stormwater samples obtained by automatic samplers, for example. It is recommended that bedload samplers be used to supplement automatic water samplers in order to obtain more accurate particle size distributions (Burton and Pitt 1997). Selected US and Canadian settling velocity data are shown in Table 4-4. The CSO particulates have much greater settling velocities than the other samples, while the stormwater has the smallest settling velocities.

More than 13,000 CSO control tanks have been built in Germany using the ATV 128 rule (Pisano and Bromback 1996). This rule states that clarifier tanks (about 1/3 of these CSO tanks) are to retain all particles having settling velocities greater than 10 m/hr (0.7 cm/sec), with a goal of capturing 80% of the settleable solids. Their recent

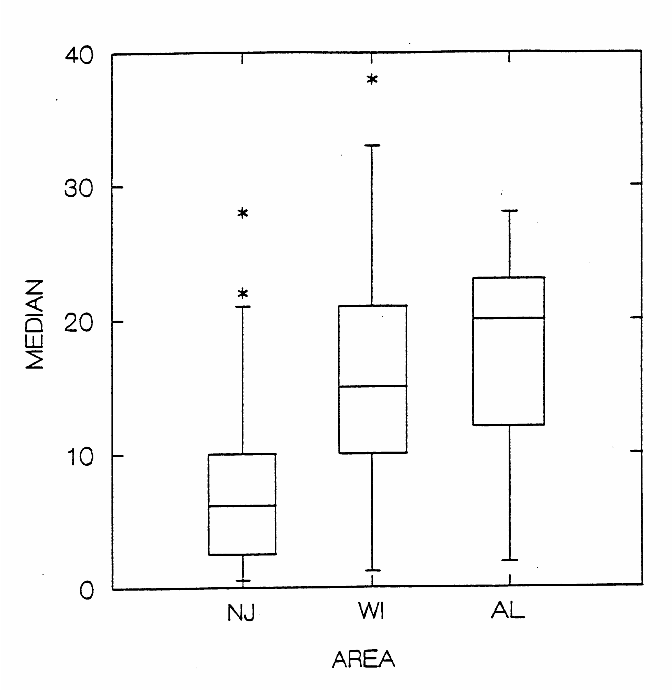


Figure 4-4. Median particle sizes for stormwater sheetflow samples (Pitt, *et al.* 1995).

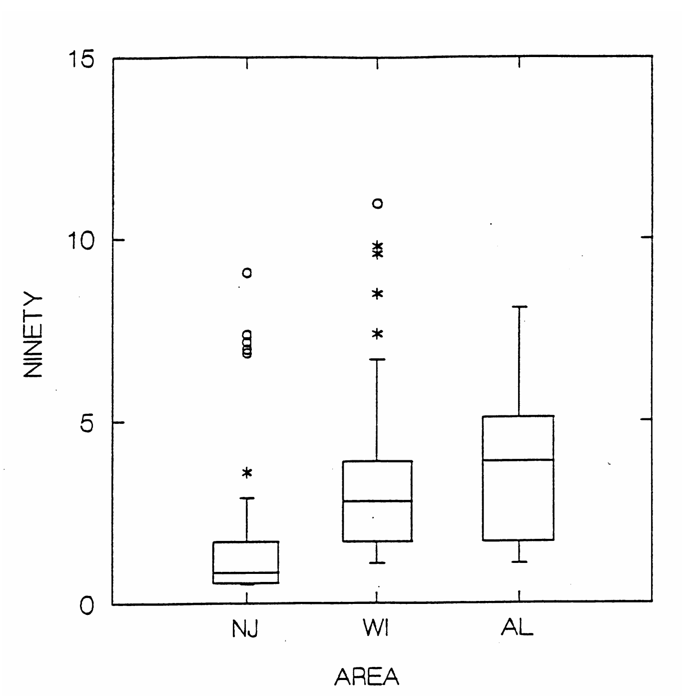


Figure 4-5. Ninetieth percentile particle sizes for stormwater sheetflow samples (Pitt, *et al.* 1995).

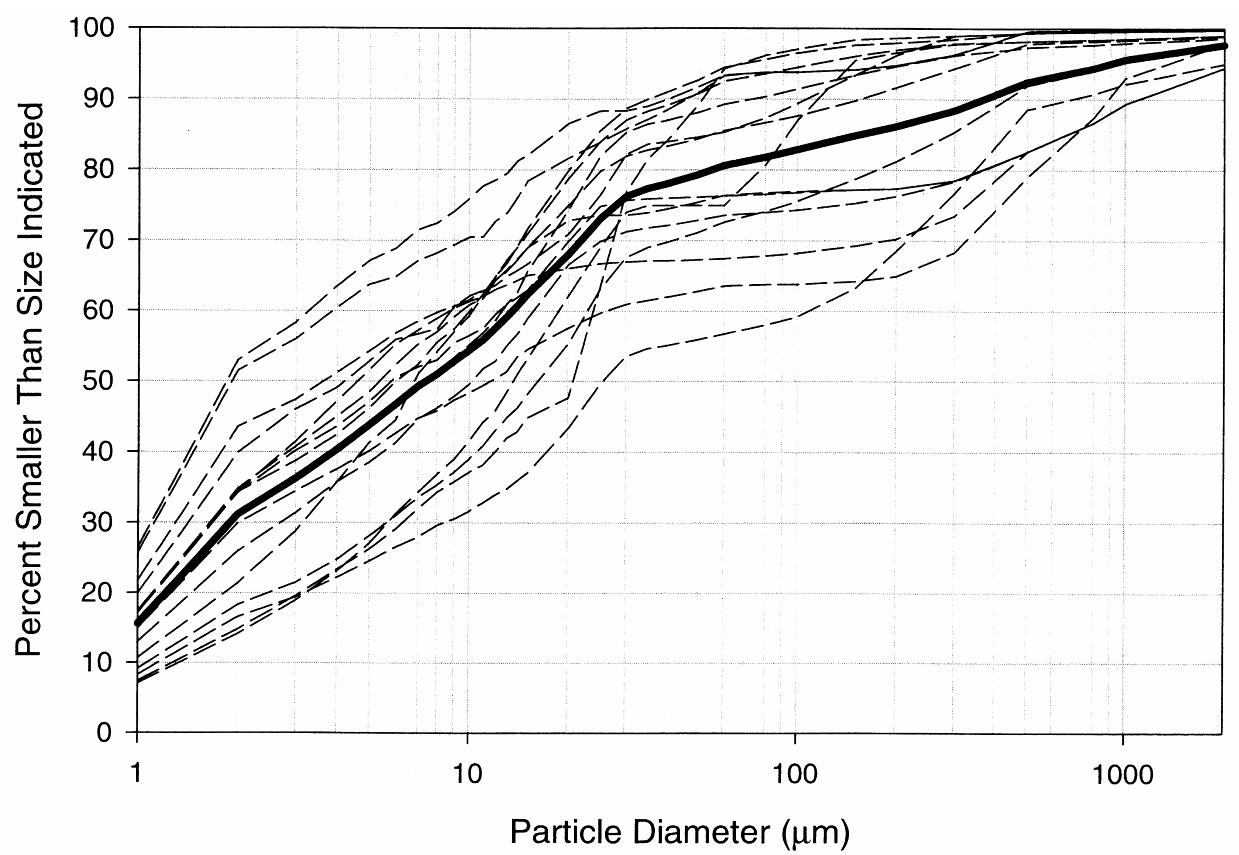


Figure 4-6. Stormwater outfall particle size distribution, Monroe St., Madison, WI (WI DNR unpublished data).

measurements of overflows from some of these tanks indicate that the 80% capture was average for these tanks and that the ATV 128 rule appears to be reasonable.

The relationship between solids retention and pollution retention is important for wet detention ponds. Becker, *et al*. (1995) used settling column tests to measure the settling characteristics of different pollutants in sanitary sewage. They found that the majority of the particulate fractions of COD, copper, TKN, and total phosphorus was associated with particles having settling velocities of 0.04 to 0.9 cm/sec.

Vignoles and Herremans (1995) also examined the heavy metal associations with different particles sizes in stormwater samples from Toulouse, France. They found that the vast majority of the heavy metal loadings in stormwater were associated with particles less than 10 µm in size, as shown on Table 4-5. They concluded that stormwater control practices must be able to capture the very small particles.

Wet Detention Pond Design Procedures

The basic design approaches for wet detention ponds consider either slug flow or completely mixed flow. Martin (1989) reviews these flow regimes and conducted five tracer studies in a wet detention pond/wetland in Orlando, FL, to determine the actual flow patterns under several storm conditions. Completely mixed flow conditions assumes that the influent is completely and instantaneously mixed with the contents of the pond. The concentrations are therefore uniform throughout the pond. Under plug flow conditions, the flow proceeds through the pond in an orderly manner, following streamlines and with equal velocity. The concentrations vary in the direction of flow and

Table 4-4. Settling Velocities for Wastewater, Stormwater, and CSO

Samples	Geometric Means of Settling Velocities Observed (cm/sec)	Range of Medians of Settling Velocities Observed (cm/sec)
dry weather wastewater (sanitary sewage)	0.045	0.030 to 0.066
stormwater	0.011	0.0015 to 0.15
CSO	0.22	0.01 to 5.5

Source: Pisano and Bromback (1996)

Table 4-5. Percentages of Suspended Solids and Distribution of Heavy Metal Loadings Associated with Various Stormwater Particulate Sizes (Toulouse, France) (Percentage associated with size class, concentration in mg/kg)

	>100 μm	50 to 100 μm	40 to 50 μm	32 to 40 μm	20 to 32 μm	10 to 20 μm	<10 μm
Suspended solids	15%	11%	6%	9%	10%	14%	35%
Cadmium	18 (13)	11 (11)	6 (11)	5 (6)	5 (5)	9 (6)	46 (14)
Cobalt	9 (18)	5 (16)	4 (25)	6 (20)	6 (18)	10 (22)	60 (53)
Chromium	5 (21)	4 (25)	2 (26)	6 (50)	3 (23)	9 (39)	71 (134)
Copper	7 (42)	8 (62)	3 (57)	4 (46)	4 (42)	11 (81)	63 (171)
Manganese	8 (86)	4 (59)	3 (70)	3 (53)	4 (54)	7 (85)	71 (320)
Nickel	8 (31)	5 (27)	4 (31)	5 (31)	5 (27)	10 (39)	63 (99)
Lead	4 (104)	4 (129)	2 (181)	4 (163)	5 (158)	8 (247)	73 (822)
Zinc	5 (272)	6 (419)	3 (469)	5 (398)	5 (331)	16 (801)	60 (1,232)

Source: Vignoles and Herremans (1995)

are uniform in cross section. The steady state resident time for both flow conditions is the same for both flow patterns, namely the pond volume divided by the discharge rate. Historically, wet detention ponds have been designed using the plug flow concept, probably because it had been used in conventional clarifier designs for water and wastewater treatment. In reality, detention ponds exhibit a combination flow pattern that Martin terms moderately mixed flow. He found that the type of mixing that actually occurs is dependent on the ratio of the storm volume to the pond storage volume. If the ratio is less than one, plug flow likely predominates. If the ratio is greater than one, the flow type is not as obvious. With faster flows in the pond, short-circuiting effectively reduces the available pond storage volume (and therefore the resident time), with less effective treatment.

The stormwater management system that Martin (1989) monitored was comprised of a 0.2 acre wet detention pond followed by a 0.7 acre wetland. The drainage area was 41.6 acres, with 33% roadway, 28% forest, 27% high density residential, and 13% low density residential land uses. The system was therefore about 2% of the drainage area, with the wet detention pond portion about 0.5% of the drainage area. The pond's maximum available live storage volume was 18,500 ft^3. The system produces moderate to high pollutant reductions of solids, lead, and zinc (between 50 and 80%) and smaller reductions for nitrogen and phosphorus (between 30 and 40%). At low discharges and with large storage volumes, the pond was found to be moderately well mixed with residence times not much less than the maximum expected if operating under ideal mixing conditions, with little short-circuiting apparent. At higher discharges and with less storage volume, significant short-circuiting occurred.

Driscoll (1989; and EPA 1986) presented a basic methodology for the design and analysis of wet detention ponds. A pond operates under dynamic conditions when the storage of the pond is increasing with runoff entering the pond and with the stage rising, and when the storage is decreasing when the pond stage is lowering. Quiescent settling occurs during the dry period between storms when storage is constant and when the previous flows are trapped in the pond, before they will be partially or completely displaced by the next storm. The relative importance of the two settling periods depends on the size of the pond, the volume of each runoff event, and the inter-event time between the rains.

Driscoll (1989) produced a summary curve, shown as Figure 4-7, that relates wet pond performance to the ratio of the surface area of the pond to the drainage area, based on the numerous NURP wet detention pond observations. The NURP ponds were in predominately residential areas and were drained with conventional curb and gutters. This figure indicates that wet ponds from about 0.3 to 0.8 percent of the drainage area should produce about 90% reductions in suspended solids. Southeastern ponds need to be larger than ponds in the Rocky Mountain region because of the much greater amounts of rain and the increased size of the individual events in the southeast. Also, wet ponds intending to remove 90% of the suspended solids need to be about twice as large as ponds with only a 75% suspended solids removal objective.

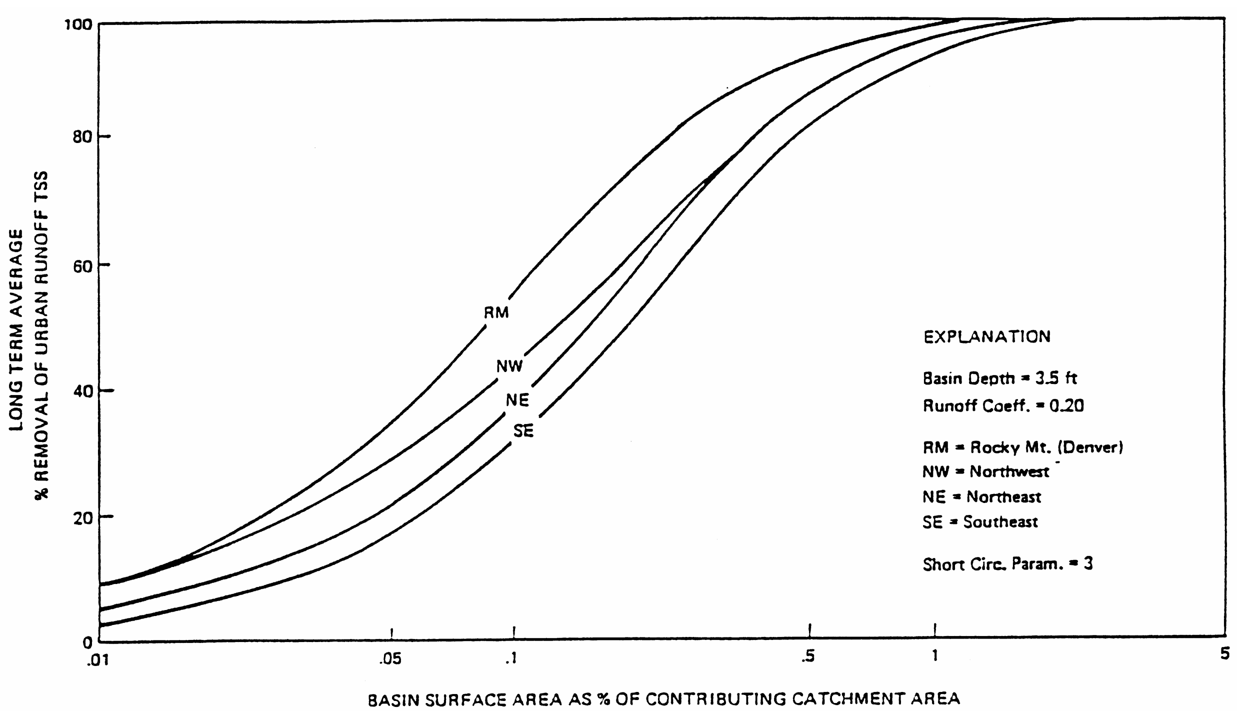


Figure 4-7. Regional variations in wet detention pond performance, US EPA NURP data (Driscoll 1989).

Under dynamic conditions, particle trapping can be predicted using the basic Fair and Geyer (1954) equation that considers short-circuiting effects:

$$R = 1 - [1 + (1/n) \times (v_s /(Q/A))]^{-n}$$

where R = fraction of initial solids removed
v_s = settling velocity of particles of concern
Q = wet pond discharge
A = wet pond surface area

n = short-circuiting factor

The short-circuiting factor is typically given a value of 1 for very poor conditions, 3 for good conditions, and 5 for very good conditions. When n is extremely large, the equation reduces to the theoretical removal rate for the particle size of concern. Short-circuiting allows some large particles to be discharged that theoretically would be completely trapped in the pond. However, the following typical example shows that this has a very small detrimental effect on the suspended solids (and pollutant) removal rate of a pond.

The effect of short circuiting has little effect on suspended solids removal, especially in a well designed wet detention pond (one that is large, compared to the drainage area). For example, consider a pond that is designed to theoretically trap all particles greater than 5 µm (or having a theoretical suspended solids capture rate of about 90%, assuming that particles greater than 5 µm make up 90% of the mass of the suspended solids). The following capture of different particles would occur, for a very poor short-circuiting condition (n = 1):

Particle size:	Percent of mass of all particles smaller than size:	Removal of particle size with very poor short-circuiting conditions:
5 µm	10%	50%
20 µm	35%	94%
100 µm	95%	98%

The total effect would likely be less than 10% degraded performance for suspended solids: instead of 90% suspended solids reduction, it may be about 80% for this condition. The largest degraded performance is for particles close to the "design" size of the pond (where $Q/A = v_s$).

Very little degraded performance was observed at a pond monitored during NURP (EPA 1983) in Lansing, MI. A golf course pond located across the street from a commercial strip was converted into a stormwater pond, but the inlets and outlets were adjacent to each other in order to reduce construction costs. It was assumed that severe short circuiting would occur because of the close proximity of the inlet and outlet, but the pond produced suspended solids removals close to what was theoretically predicted, and similar to other ponds having much similar pond area to watershed area ratios. Actually, the close inlet and outlet may have resulted in less short-circuiting because the momentum of the inflowing waters may have forced the water to travel in a general circular pattern around the pond, instead of directly flowing across the pond (and "missing" some edge area) if the outlet was located at the opposite side of the pond. In another example, the USGS and the Wisconsin Department of Natural Resources have been monitoring the Monroe St. wet detention pond in Madison for a number of years. Particle size distributions of influent (including bedload) and effluent have been monitored for about 50 storms. The actual particle size distributions and suspended solids removals have been compared to calculated pond performance, using the DETPOND computer program (Pitt and Voorhees 1989; Pitt 1993a and 1993b), for different short-circuiting factors. The pond is producing suspended solids removals as designed, but the particle size distributions of the effluent indicate some moderate short circuiting (some large particles are escaping from the pond). The short circuiting has not significantly reduced the effectiveness of the pond. Therefore, care should be taken in locating and shaping ponds to minimize short circuiting problems, but not at the expense of other more important factors (especially size, or constructing the pond at all). Poor pond shapes probably cause greater problems by producing stagnant areas where severe aesthetic and nuisance problems originate.

A discussion of wet detention pond design procedures must include three very important publications that all stormwater managers should have. Tom Schueler's *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban Best Management Practices* (1987) includes many alternative wet pond designs for various locations and conditions. *Watershed Protection Techniques* is a periodical published by Schueler at the Center for Watershed Protection (Silver Spring, Maryland) and includes many summaries of current stormwater management research, including new developing design procedures and performance data for detention ponds. In addition, Peter

Stahre's and Ben Urbonas's book on *Stormwater Detention for Drainage, Water Quality and CSO Management* (1990) includes in-depth discussions on many detention pond design and operational issues.

Wet Detention Pond Design Guidelines for Suspended Solids Reductions

A wet detention pond performance specification for water quality control needs to result in a consistent level of protection for a variety of conditions, and to allow a developer a large range of options to best fit the needs of the site. It must also be easily evaluated by the reviewing agency and be capable of being integrated into the complete stormwater management program for the watershed. It should have minimal effects on the hydraulic routing of stormwater flows, unless a watershe4-wide hydraulic analyses is available that specifies the specific hydraulic effects needed at the specific location. The following specifications should meet these objectives under most conditions. However, the specific pond sizes should be confirmed through continuous long-term simulations using many years of actual rainfall records for the area of interest. These guidelines should therefore be considered as a starting point and modified for specific local conditions. As an example, it may be desirable to provide less treatment than suggested by the following guidelines (Vignoles and Herremans 1996). The following guidelines were developed by Pitt (1993a and 1993b), based on literature information and on his personal experience.

1) The wet pond should have a minimum water surface area corresponding to land use, and desired pollutant control. The following values were extrapolated from extensive wet detention pond monitoring, mainly the EPA's NURP (EPA 1983) studies:

Percent of drainage area required as pond surface for control of suspended solids:

Land Use	5 µm (90 percent)	20 µm (65 percent)
Freeways	2.8 percent	1.0 percent
Industrial areas	2.0	0.8
Commercial areas	1.7	0.6
Institutional areas	1.7	0.6
Residential areas	0.8	0.3
Open space areas	0.6	0.2 .

These values are based on expected runoff volumes for typical development conditions and would therefore vary considerably for different development practices, especially if using infiltration practices. These surface area criteria have been shown to result in consistent pond performance, when used with the following criteria and good design practice.

2) The freeboard storage (the storage volume above the normal wet pond surface and below the invert of the emergency spillway) should be adequate to provide for 13 mm of runoff from the watershed, for a medium density residential area. For a typical medium density residential area, a rain of about 32 mm would produce this runoff depth. For a shopping center, a much smaller rain of about 15 mm would produce 13 mm of runoff. Pond performance is very closely related to flow rates and runoff volumes. Therefore, in order to provide a constant level of protection, freeboard storage needs to be provided for the runoff volume that would result from a constant rain depth (such as for 32 mm of rain). A pond for a highly impervious watershed would therefore be much larger than for a similar sized watershed characterized with less impervious areas. Areas having relatively clayey soils (such as SCS hydrologic type D soils) would also require larger ponds than similar areas having sandy soils. However, this rain depth specification will also be sensitive to the use of on-site infiltration controls that would be needed for most developments.

3) Require a specific surface area for each stage elevation, depending on the outlet structure selected and the desired level of pollutant control. This specification regulates the detention time periods and the draining period to produce consistent removals for all rains. The ratio of outlet flow rate to pond surface area for each stage value

needs to be at the most 0.04 mm/sec for 5 µm (about 90 percent) control, 0.15 mm/sec for 10 µm (about 80 percent) control, and 0.61 mm/sec for 20 µm (about 65 percent) control. In practice, the desired pond surface area to stage relationship (simply the shape of the hole) is compared to the minimum surface areas needed at each stage for various candidate outlet structures. As an example, the following list summarizes the minimum surface areas needed to control all particles greater than 10-micrometer particles. Also shown are the freeboard storage values below each elevation:

	45^{o} V-notch		90^{o} V-notch	
stage (feet)	storage (acre-ft)	surface (acres)	storage (acre-ft)	surface (acres)
0.5	<0.01	0.01	0.01	0.02
1.0	0.01	0.05	0.04	0.12
1.5	0.06	0.14	0.15	0.32
2.0	0.16	0.27	0.41	0.68
3.0	0.43	0.76	1.7	1.8
4.0	1.6	1.6	4.6	3.8
5.0	3.8	2.7	9.7	6.8
6.0	7.3	4.3	18	11

The large stage values are only needed for ponds having hydraulic benefits and the water quality objectives may not apply. Many alternative outlet devices could be selected, depending on the pond geometry, and still obtain relatively consistent pond performance.

4) The ponds must be constructed according to specific design guidelines to insure the expected performance and adequate safety. The guidelines need to specify such things as pond depth, side slopes, vegetation, and shape.

Summary of Detention Ponds as a Stormwater Control

Detention ponds are probably the most commonly used stormwater quality devices and have substantial literature documenting their performance and problems. Wet detention ponds have been shown to be very effective, if their surface area is large enough in comparison to the drainage area and expected runoff volume. Small wet ponds and dry ponds have been shown to be much less effective. Detention ponds can be easily integrated into a comprehensive stormwater management program, but only if land is available and if installed at the time of development. They are very difficult and expensive to retro-fit into existing areas. Care must also be taken to minimize safety and environmental hazards associated with ponds in urban areas. In addition to safety concerns, contaminated sediment management and poor water quality are major issues.

WinSLAMM Calculation Procedures for Wet Detention Ponds

WinSLAMM calculates particulate deposition in wet detention ponds using the upflow velocity method (Linsley and Franzini 1964). Hydrograph routing through the pond is first calculated using the storage-indication procedure summarized by McCuen (1982) and as used by the RESVOR reservoir routing subroutine of the Natural Resources Conservation Service in Tech. Releases 20 and 55 (SCS 1986).

Detention pond hydraulic performance is dependent on the basin inflow hydrograph, the stage-area curve of the pond, and the outfall structure. The inflow hydrograph is based on the rain being considered and the source areas. Small storm hydrology principles are used by WinSLAMM to calculate runoff volume. Related research on urban hydrograph shapes (Pitt 1987) was used to statistically describe the peak and duration of the inflowing runoff hydrograph. The model user must describe the stage-surface area relationship for each pond and select the outlet structures. WinSLAMM allows a variety of outlet structures to be used in many combinations (including rectangular weirs, various V-notch weirs, orfices, drop structures, etc.). Weir ratings are built into WinSLAMM from standard weir formulas. In addition, the user can describe any stage-outfall velocity desired, reflecting laboratory tests, or open channels.

WinSLAMM expands on the storage-indication procedure by calculating incremental upflow velocities for each calculation interval. WinSLAMM automatically determines the most efficient calculation interval. The upflow velocity is defined as the pond outfall rate divided by the pond surface area. Any particle that has a settling velocity greater than this upflow velocity will be retained in the pond. The user describes a particle size distribution for the inflowing water, which WinSLAMM uses to calculate the particle settling rates from Stoke and Newton settling equations. WinSLAMM calculates the critical particle sizes retained in each calculation interval and sums the retained particles for the complete event. Hydraulic performance of an outfall pond is also summarized by giving the peak flow rate reduction factor (PRF) and the pond flushing ratio (ratio of incoming runoff volume to normal pond volume for each event. The stan4-alone detention pond program (WinDETPOND) results in much more performance information, if desired, along with allowing the user to specify any runoff inflow hydrograph.

Infiltration

Benefits and Problems Associated with Stormwater Infiltration

In most urban areas, stormwater is directed to subsurface drainage systems. In areas having combined sewer systems, such as in most of Europe, in the large cities of Asia, and in many older cities of the U.S., this additional water causes overflows of raw or poorly treated domestic sewage during periods of moderate to heavy rainfalls. Even in areas having separate sewerage systems, the use of conventional subsurface sewerage radically alters the receiving waters. The frequent and high flows in receiving waters causes detrimental biological conditions, causes increased erosion of channels, causes flood damage, and dramatically reduces the amount of rainfall that recharges the local groundwaters. This recharge reduction causes severe low flow problems in many areas during prolonged dry periods, further worsening the biological habitat, decreasing recreation benefits, and reducing the assimilative capacity for downstream wastewater discharges.

Infiltration techniques have been used for many years to control stormwater quality and flooding. They offer many advantages when integrated into conventional drainage systems (Azzout, *et al*. 1994, Novatech 1992, Novatech 1995):

- lower the costs of the sewerage systems;
- limited required maintenance;
- good integration in urban environment;
- preservation of the hydrological balance in the environment.

The following infiltration techniques are most often used :

- reservoir structure and porous pavements;
- drainage trenches;
- infiltration wells;
- dry basins.

Upland infiltration devices are located at urban source areas and can significantly reduce both stormwater runoff volume and contaminant contributions from the treated areas to the receiving waters. All infiltration devices redirect runoff waters from the surface to the sub-surface environments. Therefore, they must be carefully designed using sufficient site specific information to protect the groundwater resources and to achieve the desired water quality management goals.

With development, natural groundwater recharge is reduced, with increased surface water flows during wet weather and significantly reduced surface water flows (that rely on groundwater discharge) during dry weather. The use of infiltration can help maintain the natural groundwater recharge in an urbanizing area and maintain adequate receiving water base flows during critical dry weather periods.

The Lake Tahoe (California/Nevada) Regional Planning Agency has developed a preliminary set of design guidelines for infiltration devices (Lake Tahoe 1978). They recommend the use of infiltration trenches to collect and infiltrate runoff from impervious surfaces, such as driveways, roofs, and parking lots. A secondary objective of infiltration devices in the Lake Tahoe area is to reduce soil erosion caused by high runoff flow rates. The Ontario Ministry of the Environment (1984) also included infiltration devices in its general stormwater management plan.

Beale (1992) described numerous methods to reduce problems in storm drainage. The traditional approach had been for the rapid removal of stormwater from a development to the nearest watercourse or sewer system. This approach cannot continue due to the high economic and social cost associated with upgrading existing sewerage and/or increased flooding in urban areas. Three main options are: 1) reduce flows entering the drainage system, 2) increase the capacity of the drainage system (the traditional approach), or 3) attenuate flows within the drainage system. The methods available include, indicating the role that infiltration has, especially in conjunction with storage:

to reduce incoming flows:

- Diversion
- Infiltration (plane infiltration, basin infiltration, soakaways, infiltration trenches, or infiltration boreholes)
- Control flows entering drainage (rooftop detention, control in down pipes, control in gully outlets, control by gully spacing

to attenuate flows in drainage:

- Attenuation in drainage (surface flooding, oversize sewer, on-line tank, off-line tank, storage ponds, or tank design)
- Attenuation in watercourse (on-line storage ponds, or off-line storage ponds)

Numerous recent papers describe the successful use of stormwater infiltration throughout the world. Musiake, *et al*. (1990) described the use of shallow infiltration facilities is Tokyo, and Stenmark (1990) described the use of infiltration facilities in cold climates. Other stormwater infiltration experience has been described by Wada and Miura (1990), Harada and Ichikawa (1993),Yamada (1993), and Duchene, *et al*. (1993). The Technical University of Denmark has recently conducted numerous research projects concerning the benefits of infiltration as a source area control to reduce combined sewer overflows (Geldof, *et al*. 1994; Mikkelsen, *et al*. 1994; Rosted Petersen, *et al*. 1994; and Jacobsen and Mikkelsen 1996). Rosted Petersen, *et al*. (1994), for example, found that the optimal solution for reducing CSO volumes by 40% required infiltrating 65% of the paved areas using infiltration trenches having total storage volumes of 3.6 mm. This corresponds to a return period of 0.04 years (about 2 weeks), in contrast to the commonly applied design return periods of 2 to 10 years.

Geldof, *et al*. (1993) describe many stormwater problems that can be reduced by using infiltration. The Experimental Sewer System (ESS) in Tokyo includes many infiltration components (infiltration inlets, infiltration trenches, infiltration curbs, and permeable pavements) and has significantly reduced the amount and frequency of urban flooding (Fujita 1993). The ESS has reduced the stormwater peak flows by 60% and runoff volume by 50%, compared to conventional storm sewerage systems. Furthermore, the cost of the ESS is about 1/3 of the cost of conventional detention facilities, and only about 1/10 of the cost of underground detention facilities. The infiltration trenches used as part of the ESS have been easily installed in parks and alongside roads, with little interference to the intensive use of the land. Figure 4-8 is a schematic showing the major components of the ESS.

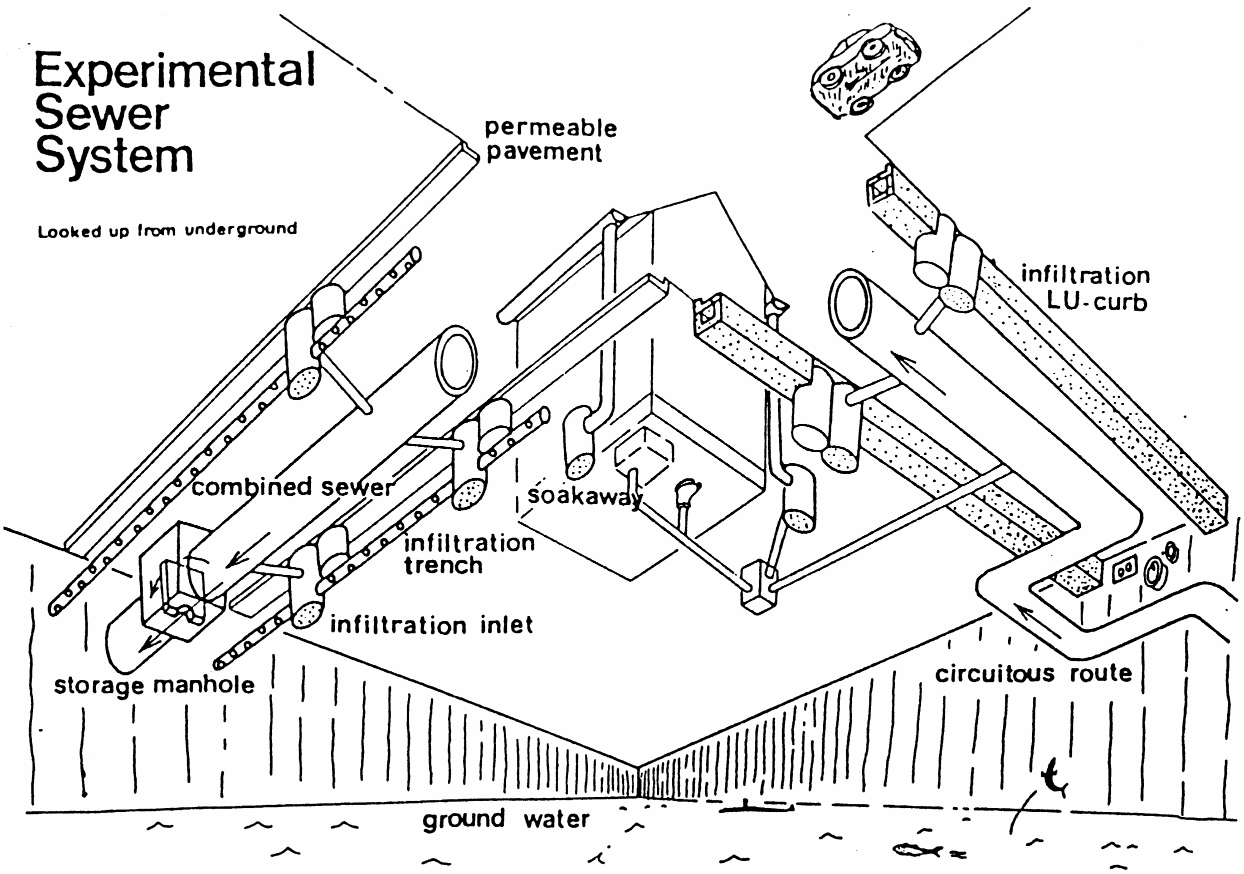


Figure 4-8. Major components of the Experimental Sewer System (ESS) in Tokyo, Japan (Fujita 1990).

The main purpose of stormwater infiltration in Tokyo has shifted away from improving the conveyance of stormwater (flood prevention, soil erosion prevention, and reduction of pollution discharges) to restoring groundwater (maintenance of river base flows, prevention of heat island effects, and prevention of ground subsidence) (Fujita 1993).

The ESS is likely the largest stormwater infiltration enterprise in the world today. It is made possible by the large infiltration capacity of Tokyo area soils and the knowledge of the limitations of alternatives (Fujita 1993). Detention basins had been used in newly developing housing complexes to reduce the stormwater flow rates to sewerage, but they were much more expensive than the use of infiltration. Infiltration also has the great benefit of re-directing stormwater away from the sewerage for groundwater recharge, instead of just delaying the discharge of the runoff into the sewerage. Japanese sewerage authorities made a landmark change in policy, with a new emphasis on "reducing stormwater runoff" volume, instead of the traditional goal of "draining stormwater quickly through sewer pipes" (Fujita 1993).

The ESS includes the following components in Tokyo (from 1981 to 1992):

length of sewers	337 km
area served by ESS	1,329 ha
population served by ESS	166,000
number of infiltration inlets	30,994
length of infiltration trenches	201 km
length of infiltration curbs	70 km
permeable pavement area	450,000 m^2
cost of construction	$US 493 million

The ESS concept has been now employed in many other Japanese cities, in addition to other areas in Tokyo. The total area of permeable pavement in Tokyo is about 3,740,000 m^2 as of 1990 (about 2.5% of the total road area in the city). Parking lots in public areas are commonly covered with permeable pavement, in addition to private parking lots. Efforts are also being made to encourage stormwater infiltration in public areas (such as at schools, athletic stadiums, tennis courts, etc.). The total estimated infiltration effort in Tokyo (in addition to the ESS) is summarized below (1981 to 1989):

permeable pavement area	3.74 km^2
length of infiltration trenches	571 km
number of infiltration inlets	86,000
length of infiltration curbs	145 km

Fujita (1994) further describes the Tokyo ESS. All footpaths are now made using porous pavements in Tokyo and some of the paver blocks are being made using ash from incinerated sewage sludge. Residents like the porous pavement walkways because no puddles form and they are not slippery. About 15,000 of these soakaways have been built in the City of Koganei (about 15 km west of central Tokyo) in the 10 years preceding 1993. As a result, many of the natural springs, which had previously dried up with conventional storm drainage use, have been revived. The extensive use of soakaways also decreases the amount of stormwater entering sewerage, enabling reductions in pipe sizes, but that has not been implemented as yet.

The infiltrating inlet is made using two adjacent small tanks. The first tank contains the inlet to the street and has a perforated plastic bucket to capture large debris, plus a grit chamber ("mudpit"). The overflow goes into the second small tank that has a perforated bottom for infiltrating stormwater. The bottom of the tank is open, but filled with gravel atop which is placed two semi-circular plates made of porous concrete to act as a filter to minimize clogging. If the runoff entering the infiltration inlet exceeds the infiltration capacity of the inlet, the excess water flows to infiltration trenches connected to the tank, up from the bottom. The ends of the infiltration trenches are covered with stainless steel screening to further minimize the entry of clogging particles into the trenches. If the runoff flow exceeds the total infiltration capacity of the whole inlet system, then the overflow enters the sewerage pipe. They have found that cleaning the perforated basket and the mudpit twice a year is sufficient to prevent clogging. They have not needed to clean any infiltration trench, as none have clogged in the ten years of operation.

Infiltration curbs are placed along both sides of streets to allow additional stormwater infiltration. The L-shaped curb is made using porous pavement if possible, although the porous concrete curb cannot withstand the weight of large vehicles. In areas where heavy vehicles are likely, normal concrete curb pieces are used. Any stormwater infiltrated through the curb is carried in the U-shaped trough which is porous or perforated.

Infiltration also improves the receiving water quality in areas served by either combined or separate sewers (Geldof, *et al*. 1993). Decreased amounts, frequencies, and durations of overflows from combined systems have dramatically lowered the discharges of many pollutants. The number of overflows in combined sewers in Tokyo have decreased from about 36 per year to about 7 in areas served by the ESS. The resulting BOD discharges have also been reduced by about 45%. Phosphorus and heavy metals in separate sewer discharges can be substantially reduced with the widespread use of infiltration (Hvitve4-Jacobsen, *et al*. 1992).

Wada and Miura (1993) constructed a field test site to measure the effects of the different infiltration devices being used in Tokyo. The test site included four permeable pavement lengths, two lengths of infiltration trench, an infiltration roadside gutter, and seven infiltration street inlets. Detailed runoff and subsurface flow measurements were made during artificial rains for a variety of conditions. They produced a model that accurately simulated observed runoff values. An interesting conclusion was that groundwater had significant influence on the infiltration rates of the devices if it was within 1.5 m from the bottom of the infiltration devices.

Herath and Musiake (1994) developed and tested a stormwater model in Tokyo that successfully simulated complex arrangements of infiltration systems on a watershed scale. A lumped model was produced that accurately reproduced both flow volumes and hydrographs in areas having infiltration facilities.

The most difficult problems related to the Tokyo infiltration facilities have been clogging and groundwater contamination (Fujita 1993). A high-pressure water jet has been successfully used to restore clogged permeable pavements, along with other measures to protect the devices. Groundwater monitoring has been conducted for ten years in the ESS area, with no indication of groundwater contamination. However, efforts to improve service life and to protect groundwater quality are continuing.

Groundwater recharge is also an important benefit of infiltration (Geldof, *et al*. 1993). The Netherlands experiences sinking groundwater tables, with the deterioration of nature reserves and the drying out of moorlands during periods of drought. Infiltration of stormwater has been shown to be a viable alternative in recharging the groundwaters, compared to restrictions in domestic water pumping and prohibiting irrigation in urban areas.

Other benefits of infiltration, according to Geldof, *et al*. (1993) include preventing salt water intrusion in coastal areas, preventing consolidation of soils near buildings, and reducing damage from frost penetration.

This radical alteration of the local hydrologic cycle has prompted the use of infiltration of stormwater to mitigate these affects. As an example, Krijci, *et al*. (1993) described the mandatory use of stormwater infiltration in Switzerland to decrease the burden on combined and separate sewerage systems. The 1992 Swiss Water Pollution Control Law requires that unpolluted wastewater must be infiltrated. If local conditions prevent infiltration, then special authorization is required and detention is used. A simple system is used to determine the suitability of stormwater for infiltration, depending on the area drained and the use of the groundwater. As an example, runoff from roofs, bike lanes, and walking paths must be infiltrated in all areas, even if the groundwater has high importance as a drinking water source. Surface infiltration is required (and subsurface infiltration is prohibited) for this runoff in most drinking water protection zones. The infiltration of roadway and parking area runoff is more restricted, where only surface infiltration is allowed for all areas. Any infiltration of highway and freeway runoff is only allowed in exceptional situations. In all cases, “clean” water (runoff from yard drainage, spring water, groundwater, and cooling water) is forbidden in combined sewers.

Conradin (1995) describes how Zurich is complying with the Swiss Water Pollution Control Law. The city has 50 to 100 year old sewerage, about 80% being combined sewerage and 20% being separate sewerage. Clean flows (fountain water, spring water, yard drainage, cooling system water, and possibly roof runoff) are required to be diverted from the sewerage. All other stormwater will be directed to the combined sewerage and newly renovated treatment plants. The city is converting its system to a partially separate system that collects the clean water and directly diverts it to the Limmat River. Zurich is building open brooks along streets and walkways to collect these waters. The open brooks provide natural water channels and aesthetically revitalizes the urban area. About 12 km of brooks have been built as of 1995, and as much as 30 km total are planned. The current brooks divert about 150 L/sec from the sewerage. The brooks are designed to carry about two to five times the dry weather flows, with excess diverted to the sewerage and the treatment plants.

Payne and Davies (1993) describe the *Manual on Infiltration Methods for Stormwater Source Control* recently developed by the National Rivers Authority in the UK. This manual takes a careful approach to protect groundwater quality. Infiltration policies of about 20% of the local governments surveyed in the UK prohibit, or strongly discourage, the use of stormwater infiltration, while about 45% encourage its use, with reservations. Soakaways are the most common method of stormwater infiltration in the UK. The perceived benefits of soakaways are reduced burden on the sewer system, followed by lowered cost and ease of construction. Perceived disadvantages include the dependence on local soil conditions for their success, the lack of precise design methodologies, and uncertain maintenance responsibilities. The protection of groundwater is a high priority in the *Manual*, even though “environmental friendliness” was not a highly ranked issue when surveying the local governments. Roof runoff is acceptable for infiltration for all groundwater protection zones, while infiltration of runoff from paved areas is restricted generally directly related to the amount of automobile activity. Infiltration of runoff from industrial areas and from vehicle service areas is most restricted and requires pretreatment, at least, even in the least protected groundwater zone. They found that biofiltration controls offer a viable option for pretreatment of runoff before infiltration, but their success greatly relies on long-term maintenance.

Pratt and Powell (1993) describe a new approach for infiltration trench designs for the UK, developed by the Building Research Establishment. This is a reasonable storage/treatment approach, and relies on site investigations of soil properties. Soil infiltration rate measurements are made in relatively large test excavations of 0.3 to 1 m in width and 1 to 3 m in length, and of similar depth as the final infiltration device. Infiltration through the trench bottom is assumed to be insignificant due to clogging (as also assumed by many other trench designers), with all infiltration occurring through the upper half of the trench sides. This provides a conservative infiltration area that attempts to estimate long-term infiltration trench performance. Rains with 10-year return frequencies are used in this design in order to provide significant relief to storm sewerage for critical flooding events. BRESOAK software was developed to enable the investigation of alternative trench geometries. In most cases, the most effective trench design is determined to be long, narrow, and relatively deep, similar in geometry as many of the trenches in the successful Tokyo ESS. In some areas, these trench shapes are not allowed. Wisconsin, for example, requires all trenches to be wider than they are deep to maximize the amount of infiltration occurring through surface soils to increase soil aquifer treatment (SAT) of the infiltrating stormwater in order to minimize groundwater contamination.

Candaras, *et al*. (1995) describe an exfiltration and filtration demonstration project in Etobicoke, Ontario, near Toronto. The exfiltration system was developed to eliminate the discharge of stormwater for frequent rains, while improving the function of traditional drainage systems. The City of Etobicoke adopted a new stormwater management concept that promotes three levels of control:

1) Major drainage system (overland flow) designed to transport runoff from large and infrequent rains (such as the 100 year storm),
2) Minor drainage system (typical stormwater conveyance system) designed to transport the runoff from smaller and more frequent rains (such as the 2 and 5 year storms), and
3) Micro drainage system designed to eliminate runoff form the very frequent rains (such as rains of about 10 to 15 mm in depth).

The city developed two basic devices, currently being tested to accomplish these goals. The exfiltration system is a pair of small diameter, perforated PVC pipe that is installed below conventional storm drainage pipe. All three pipes run from manhole to manhole, but the perforated pipes are plugged at the downstream end to eliminate short-circuiting. The pipe trench is wrapped in a geotextile and back filled with 15 mm clear stone. If the storm exceeds the capacity of the stone, the excess water flows through the conventional pipe. The filtration system uses a perforated PVC pipe located above the conventional pipe, with both ends plugged. The catchbasin inlet has a lower outlet that directs runoff to the perforated pipe. The clear stone trench lining acts as a filter for the percolating water, which is picked up by another series of two perforated pipes located under the conventional pipe and connected to the lower manhole. If the filter capacity is exceeded, water flows out of the upper outlet from the catchbasin directly into the conventional pipe. Preliminary monitoring has shown that the test devices have performed better than expected.

A recurrent theme in the literature is concern for lack of appropriate design guidelines for infiltration practices (Petersen, *et al*. 1993). Very little design guidance for specific stormwater infiltration practices existed for Europe before 1991. Somewhat more guidance had been available in the U.S. However, much of the U.S. guidance had been transferred from other areas of the country having greatly different rainfall, topographic, soil, and frost conditions, with little modification. In addition, long-term performance information on infiltration practices is also limited. This makes predictions of useful life very difficult. The high failure rate of many types of infiltration practices, mostly associated with lack of any maintenance, is also of great concern, along with concerns of groundwater contamination. However, the extensive and successful use of stormwater infiltration in Tokyo, and elsewhere, plus the absence of groundwater contamination problems from stormwater infiltration for most areas, indicates that stormwater infiltration is feasible in many situations. Newer guidelines (such as described by Pratt and Powell 1993) also offer a uniform and reasonably conservative approach for the design of infiltration devices. The goal is to identify those conditions where stormwater infiltration is most likely to be successful, stress the use of robust infiltration practices (such as grass swales), be conservative in useful life estimates, provide appropriate pretreatment, and ensure adequate maintenance. It is important to use alternative stormwater controls (such as detention and biofiltration) in areas and situations that are marginal for infiltration.

General Infiltration Practices

Infiltration Device Performance Reported in the Literature

The Long Island and metropolitan Washington D.C. NURP projects (EPA 1983) examined the performance of several types of infiltration devices. The Long Island project studied a series of interconnected percolating catchbasins which were found to reduce stormwater discharges by more than 99 percent. The Washington D.C. study found that porous pavement reduced the pavement pollutant runoff loadings by 85 to 95 percent, while an infiltration trench reduced urban runoff flows by about 50 percent. The EPA concluded that, with a reasonable degree of site specific design considerations to compensate for soil characteristics, infiltration devices can be very effective in controlling urban runoff. Local conditions that can make recharge inappropriate include steep slopes, slowly percolating soils, shallow groundwater, and close-by important uses of the groundwater.

Modernizing the combined sewerage system in Tündern a suburb of Hameln, Germany, is necessitated by extensive growth during the 25 years since the current system was constructed (Adams 1993). Conventional methods would require replacement of about 40% of the sewer, plus construction of detention basins. However, the depth to groundwater (at least 2.5 m below the ground surface), plus the sandy soil, encouraged the investigation of de-centralized infiltration as an alternative. Design calculations indicate that the flooding frequency would decrease by about half, and that the COD discharges would be decreased by about 45% by using stormwater infiltration. The infiltration option would help restore the natural hydrologic cycle and reduce current problems at a much reduced cost.

An extensive report was prepared by Kuo, *et al*. (1989) on infiltration trenches. This report included an examination of the theoretical behavior of infiltrating water, and it presented the results of laboratory model studies.

Summary of Infiltration Devices as Stormwater Controls

Infiltration devices are unique in that they reduce stormwater volumes, in addition to peak flow rates and pollutant discharges. They discharge the stormwater to the groundwater and care must be taken to prevent groundwater contamination. Significant reductions in most pollutants occur in the vadose zone above the saturated layer. However, some stormwaters should not be considered for infiltration, including snowmelt water (especially in areas of de-icing salt use), industrial runoff (due to likelihood of high concentrations of filterable toxicants), and construction site runoff (due to clogging by sediment). The majority of stormwater flows can likely be safely infiltrated with significant reductions in surface water discharges and important equalizations of the hydrological cycle in urban areas. Pratt (1996) describes the current widespread installations of “soakaways” in the UK (tens of thousands per year), despite the extensive storm drainage systems available. Most are used for infiltrating runoff from small paved areas and roofs. Unfortunately, little systematic research has been conducted on their benefits and problems. Schmitt (1966) also describes current German regulations favoring the use of infiltration controls for stormwater located at source areas to reduce combined sewer problems.

WinSLAMM Calculation Procedures for Infiltration Devices

Infiltration devices are assumed to affect water volume, but not pollutant concentrations. As the water volume is reduced, the pollutant yield is obviously decreased. WinSLAMM calculates the runoff volume reductions for each source area (served by an infiltration device) for each individual rain in the study period. Runoff volume reduction is assumed to be equal to:

$$\text{volume reduction} = (Pr/Rr)\ (As/At)$$

where Pr is the percolation volume rate,
Rr is the runoff rate to the device,
As is the area served by the device, and
At is the total study area.

The ratio Pr/Rr used in this equation can never be greater than 1.0. The percolation volume rate is the capacity of the infiltration device to infiltrate runoff, expressed as:

Pr = (1 + 0.67/width to depth ratio) (percolation rate)(percolation area)

The side walls of an infiltration trench have 0.33 of the infiltration capacity as the trench bottom, reflected in the 0.67 factor in the equation (assuming two side walls). The runoff rate is the flow rate of water entering the infiltration device:

Rr = runoff volume / runoff duration

The runoff volume for the source area is calculated using the procedures described in Section 3, or basically the event volumetric runoff coefficient times the area served times the rain depth. The runoff duration is the base of the inflow hydrograph and is calculated using the regression equation derived by Pitt (1987):

Runoff duration = 0.90 + 0.98 (rain duration), expressed in hours

An example of use of this procedure follows:

Percolation rate = 3 in/hr
Total rain = 1.7 in
Rain duration = 6 hours
Volumetric runoff coefficient = 0.35
Area served by infiltration trench = 1.3 acres
Total area in study = 5.6 acres
Trench bottom area (percolation area) = 5500 ft^2
Trench width/depth ratio = 2

Therefore:

runoff volume = 0.35 (1.7 in)(1.3 acres) = 0.774 ac-in
runoff duration = 0.90 + 0.98(6 hours) = 6.78 hours

and Rr = 0.774/6.78 = 0.114 ac-in/hr = 0.115 ft^3/sec.

Pr = [1 + 0.67/2] (3 in/hr) (5500 ft^2) (ft/12 in) (hr/3600 sec) = 0.510 ft^3/sec.

Therefore Pr/Rr = 0.51/0.114 = 4.434 which is greater than 1.0, so 1.0 must be used in the equation. (The infiltration trench is oversized for this event: all of the runoff from the service area is infiltrated.) The study area volume reduction performance is therefore: 1.3 acres/5.6 acres = 0.23. (23 percent of the runoff and pollutant yield are infiltrated).

Grass Swales and Grass Filter Strips

Grass swale drainages can be used in place of concrete curb and gutter drainages in most land uses, except strip commercial, manufacturing industrial, and high density residential areas. Grass swales reduce urban runoff problems by a combination of mechanisms. Infiltration of the runoff and associated pollutants is probably the most important process. Filtering of particulate pollutants in grass waterways may also occur, but the flows are usually too large (and deep) to permit effective filtering by the grass. Groundwater contamination concerns are frequently raised whenever stormwater infiltration is proposed. Pitt (1996) reported that groundwater contamination is not a major concern for most stormwaters, if using surface spreading (such as occurs in grass swales). Lind and Karro (1995) also recently reported on the accumulation of stormwater pollutants in the surface soils of swales, minimizing groundwater contamination problems.

Performance of Grass Swales and Filters as Reported in the Literature

Several large-scale urban runoff monitoring programs have included test sites that were drained by grass swales. Bannerman, *et al*. (1979), as part of the International Joint Commission (IJC) monitoring program to characterize urban runoff inputs to the Great Lakes, monitored a residential area served by swales and a similar residential area served by concrete curb and gutters in the Menomonee River watershed in the Milwaukee area. This monitoring program included extensive flow and pollutant concentration measurements during a variety of rains. They found that the swale drained area, even though it had soils characterized as poorly drained, had significantly less flows and pollutant yields (up to 95 percent less) as compared to the curb and gutter area.

The ability of grass swales to reduce source area sheetflow pollutant concentrations was also monitored by the Durham, New Hampshire NURP project (EPA 1983). A special grass swale was constructed to treat runoff from a commercial parking lot. Flow measurements were not available to measure pollutant yield reductions, but pollutant concentration reductions were found. Soluble and particulate heavy metal (copper, lead, zinc, and cadmium) concentrations were reduced by about 50 percent. COD, nitrate nitrogen, and ammonia nitrogen concentrations were reduced by about 25 percent, while no significant concentration reductions were found for organic nitrogen, phosphorus, and bacteria.

Wang, *et al*. (1980) monitored the effectiveness of grass swales at several freeway sites in Washington. They found that 55 to 75 m of grass swale removed most of the heavy metals in the runoff. Lead was more consistently and effectively removed than the other metals, possibly because of its greater association with particulates in the runoff. Lead concentration reductions, with 55 m grass swales, were typically 80 percent, or more, while copper was reduced by about 60 percent, and zinc was reduced by about 70 percent. They concluded that it may be necessary to remove the contaminated sediments and replant the grass periodically to prevent the dislodgment of the deposited polluted sediment. Part of the swales monitored by Wang, *et al*. (1980) were bare earth lined. Pollutant concentrations were not found to be effectively reduced in these sections, and the earth lining was not contaminated. Again, infiltration effects on flow volumes and pollutant yields were not monitored, and the concentration observations were only affected by grass filtration.

A project to specifically study the effects of grass swale drainages was also conducted in Brevard County, Florida by Kercher, *et al*.(1983). Two adjacent low density residential areas, about 5.6 ha in area and having about 50 homes, were selected for study. One area had conventional concrete curbs and gutters, while the other had grass swales for roadside drainage. The two areas had very similar characteristics (soils, percentage imperviousness, slopes, vegetation, etc.). Thirteen rains were monitored in the areas for flow and several selected pollutants. The curb and gutter area produced runoff flows during all 13 events, while the grass swale area only produced runoff during three events. Estimated annual pollutant yields from the curb and gutter area were much greater than for the grass swale area. BOD_5 annual discharges from the guttered area were estimated to be about 130 times the discharges from the swale area. Yield increases from the guttered area as compared to the swale area for some other pollutants were reported as follows: 160 times for total nitrogen, 450 times for total phosphorus, and 90 times for suspended solids. The grass swale system also cost about one-half the cost of the curb and gutter system.

In another large scale urban runoff monitoring project, Pitt and McLean (1986) monitored a residential area in Toronto served about evenly by both swales and concrete curbs and gutters. The pollutant concentrations in both types of drainage systems were similar, but the area had annual flows (and therefore pollutant yields) about 25 percent less than if the area was served solely by curbs and gutters. For small but frequent rains (less than about 13 mm), very little runoff was observed in the grass swales. If the area had all grass swales, the flow and pollutant yields would have been even less.

Schueler (1996) summarized grass swale performance literature and related pollutant reductions to drainage swales or water quality swales. The water quality swales had appreciable concentration and mass reductions, mainly by enhancing infiltration through the swale bottom, widening the bottom width of the swale, providing a subsurface infiltration trench under the swale, or even by planting wetland plants in a swale that was in an area that has a high groundwater table. The drainage channels provided little concentration reductions, but some had significant mass reductions due to infiltration. In all cases, more care can be taken in designing swales to enhance their water quality performance, while still providing necessary drainage benefits. Claytor and Schueler (1996) have published a manual for designing water quality swales (along with other stormwater filtering systems).

Yu, *et al*. (1993) constructed and monitored a grass filter in Charlottesville, VA. A 4 ha paved commercial area drained to the 3,800 m^2 grass filter. Stormwater was directed to the grass filter via an infiltration trench and a level spreader. The level spreader system cost about $15,000 (1986). The filter had moderate removals for suspended solids (54 to 84%), total phosphorus (25 to 40%), and zinc (47 to 55%), but only poor removals for nitrate nitrogen (-27 to 20%) and lead (-16 to 55%).

Summary of Grass Swales for Stormwater Control

Grass swales (and grass filters in general) may be an effective stormwater control practice to reduce pollutants before the stormwater is discharges. Grass swales are inexpensive compared to conventional curb and gutter systems, but their use is restricted to areas that have relatively low density developments. In addition, current design and construction practices for grass swales are very poor, leading to many problems with maintenance. Much greater care needs to be used in the utilization of grass swales.

Grass Swale Performance Calculations in WinSLAMM

WinSLAMM calculates the performance of grass swales in a similar manner as other infiltration devices, by assuming (Pr/Rr) (As/At) as indicative of swale infiltration. WinSLAMM calculates runoff volume entering the swale as the addition of all upland source area flows. The water percolation rate in the swale is calculated by:

Pr = (dynamic percolation rate) (percolation area)

where the percolation area is simply the swale length times the swale width. The percolation rate in the swale is for dynamic flow conditions and is generally about ½ of the typically measured static infiltration rate (Wanielista, *et al.* 1983).

This procedure is generally independent of swale routing: it assumes that the water is in the swale long enough to be infiltrated. “Long” swales serving “small” service areas encourage infiltration. Grass filters include infiltration as a function of flow distance for different slopes and infiltration rates and can therefore be used to estimate needed flow length in swales (Pitt 1985 and 1987). Obviously, swale design (like all other controls) must be carefully done to encourage performance. As an example, these procedures would not be appropriate for steep swale gradients. The ratio of area served by swales to total area therefore needs to be reduced if steep swales are present, or if the swales are “short.”

The swale length is calculated from the swale density times the area served by swales. Typical swale density values for different land uses are as follows (Pitt and McLean 1986):

Land Use	Swale Density (ft/acre)
Low density residential	160
Medium density residential	350
High density residential	375
Strip commercial	630
Shopping centers	280
Industrial	125

Of course, not all of these land uses, especially high density residential or strip commercial areas, are suitable for grass swales. Again, the selection and design of any control practice must be carefully done.

An example of the calculations for swale performance follows:

Total contributing area flows = 1140 ft^3

Rain duration = 5.5 hours
Dynamic percolation rate in swale = 3.5 in/hr (1/2 of measured static infiltration rate)
Swale density = 350 ft/acre
Wetted swale width = 5 ft
Area served by swales = 1.5 acres
Study area = 3.3 acres

Therefore the runoff duration = 0.90 + 0.98 (5.5 hours) = 6.29 hours, and:

Rr = 1140 ft^3/6.29 hrs = 181 ft^3/hr = 0.05 ft^3/sec

Pr = (3.5 in/hr)(350 ft/acre)(1.5 acre)(5 ft)(hr/3600 sec)(ft/12 in) = 0.21 ft^3/sec

Therefore Pr/Rr = 0.213/0.05 = 4.26, which is greater than 1.0 and the swale is larger than necessary for this rain (total infiltration). The study area runoff reduction is therefore 1.5 acres/3.3 acres = 0.46 (46 percent reduction in flows and pollutant yields due to the swales).

Porous Pavements

Porous pavement is a "hard" surface that can support a certain amount of activity, while still allowing water to pass through. Porous pavement is generally used in areas of low traffic, such as service roads, storage areas, and parking lots. Several different types of porous pavement exist. Open mixes of asphalt appear to be similar to regular asphalt, but only use a specific size range of rocks in the hot mix. The porosity of the finished asphalt is much higher than regular asphalt, if properly designed and constructed. Concrete grids have open holes up to several cm wide, possibly containing sand or gravel. It is possible to plant grass in the holes, if traffic is very light and if light and moisture conditions are adequate. Recent tests have found few problems with porous pavement in areas having severe winters. They can be designed to eliminate all of the runoff from paved areas.

Performance of Porous Pavements as Reported in the Literature

Porous pavements can be effectively used in areas having soils with adequate percolation characteristics. The percolation requirements for porous pavements are not as critical as they are for other infiltration devices, unless runoff from other areas is directed towards the paved area. The percolation of the soils underlying the porous pavement installation only need to exceed the rain intensity directly. In most cases, several cm of storage is available in the asphalt base to absorb short periods of very high rain intensities. Diniz (1980) states that the entire area contributing to the porous pavement can be removed from the surface hydrologic regime.

Gburek and Urban (1983) studied a porous pavement parking lot in Pennsylvania. They found that percolation below the pavement occurred soon after the start of rain. For small rains (less than 6 mm), no percolation under the pavement was observed, with all of the rain being contained in the pavement base. Percolation during large rains was equal to about 70 to 90 percent of the rainfall, resulting in similar runoff flow and pollutant reductions of 70 to 90 percent. The differences between the rain amounts and the observed percolation quantities were caused by flash evaporation (not estimated) and storage in the asphalt base material.

Goforth, *et al*. (1983 and 1984) evaluated a porous pavement parking lot in Austin, Texas over several years under heavy traffic conditions. Infiltration rates through the pavement averaged about 45 m per hour, while the 50 mm pavement base had an infiltration rate of about 1,800 mm per hour.

Day (1980) conducted a series of laboratory tests using several different types of concrete grid pavements. The geometry of the grid was more important than the percentage of open space in determining the ability of the grid to absorb and detain rainwater. The volumetric runoff coefficients from the grids ranged from 0.06 to 0.26 (resulting in runoff volume and pollutant reductions from about 75 to 95 percent) depending on the rain intensity, ground slope, and subsoil type.

Numerous recent papers have described successful applications of porous pavements throughout the world. Niemczynowicz and Hogland (1987) describe tests of porous pavements in Sweden. Hogland (1990) gave an overview of porous pavement use in the U.S. and in Sweden. Pratt (1990) described design and maintenance issues, Nawang and Saad (1993) and Sztruhar and Wheater (1993) presented results of experimental field tests of porous pavements, and Fujita (1993) described the extensive use of porous pavements as part of the Experimental Sewer System in Tokyo.

Recent work at the University of Guelph in Ontario (Thompson and James 1995) has found that porous pavement systems can also be effective filters to remove particulate pollutants from the runoff, even with an underdrain that captures the runoff after pavement percolation. Runoff from typical pavement also had greater masses of pollutants than runoff from the porous pavements. Porous pavement research at the University of Essen in Germany (personal communication, Wolfgang Geiger 1995) also found significant water quality benefits from using porous pavement systems. However, Diniz (1993) measured the water quality of underdrain water from different porous pavement systems, gravel trenches located on the edge of an asphalt area, and conventional asphalt and concrete pavement during controlled sprinkler tests. Lead concentrations were about the same for all surfaces (12 to 25 μg/L, flow-weighted averages), while zinc (20 to 90 μg/L for porous pavements, vs. 7 to 12 μg/L for conventional pavements) and TKN (1.4 to 2.2 mg/L for porous pavements, vs. 0.5 to 1.3 mg/L for conventional pavements) were all higher for the porous pavement drain waters, compared to the conventional pavement runoff. Some, but not all, of the suspended solids and COD porous pavement drainage water concentrations were greater than for the conventional pavement runoff. The few data presented make conclusions uncertain, but it is likely that porous pavement may contribute some pollutants to the water, while removing others. In all cases, the amount of runoff diverted from the surface flows can be very large.

Recent French experiments in Nantes, Bordeaux and Paris have shown that porous pavements (with substantial subsurface reservoir capacity) were very efficient in reducing the pollutant loads discharged into the receiving water (Baladès, *et al*. 1995a and 1995b). These French studies have shown that the pollutant removal efficiencies of suspended solids can be between 50 and 70%, between 54 and 89% for COD, and between 78 and 93% for lead. These reductions were associated with the high amount of infiltration of water, and associated pollutants, through the pavements, away from the surface drainage. These experiments confirm results from previous studies in other countries (Hogland, *et al*. 1987, Pratt, *et al*. 1989, Pratt, *et al*. 1995).

Analyses of samples taken at the outlet of porous pavement structures by Baladès, *et al*. (1995a and 1995b) have shown that the discharged water met the French national standards for raw waters to be used for drinking water supplies, and that there were no problems that would restrict this water from being infiltrated directly into the ground.

The use of porous pavements in cold climates was investigated by Stenmark (1995) in northern Sweden. A 3.3 ha drainage area was modified because of existing problems associated with frost heaves and ice blocking the conventional drainage system. A porous pavement was installed over a thick subbase having a drainage pipe to remove excessive water. The width of the streets were also reduced to accommodate wider roadside grass swales, and the street surface was re-shaped to eliminate backwater problems. During preliminary observations, much less snowmelt water (about 30 to 40% of the accumulated water content of the snow, instead of close to 100%) originated from the area than from conventionally paved areas. Infiltration measurements in frozen soils indicated infiltration rates of about 0.004 mm/min (0.01 in/hr) to 5 mm/min (12 in/hr) for silts and sands. Increased water content in the frozen soil decreased the infiltration rates. Frost heaving was also reduced because the road materials were more homogeneous (no manholes, gutters, or shallow pipes were used), with less differences in heat properties. Frost heaving was more pronounced in a special test area having a thinner subbase. They concluded that the subbase should be at least 0.6 m thick.

The primary objective of using porous pavements is to mimic natural flow and infiltration conditions as closely as possible. It is therefore very important to pay attention to the following aspects to reduce groundwater contamination potential (Pitt 1996):

- depth to groundwater;
- groundwater uses;

- risks due to industrial activities in the catchment;
- use and traffic levels on the porous pavement;
- use of de-icing salts on the street.

Maintenance of Porous Pavements

Clogging of porous pavements is only a superficial phenomenon (typically extending to a depth of about 1 to 2 cm). Progressive clogging with time is caused by an increase of accumulated solids in the first few centimetres of the pavement and not to the moving of the clogging front within the pavement structure. The decrease in permeability in porous pavement may cause a drop by about 50% over three years. The mean diameter of the particles which are responsible for this clogging is about 300 µm. For sites where there is only a thin porous pavement layer above an impervious structure layer, it has been observed that the mean diameter of the clogging particles is finer, with about 30% of the particles responsible for the clogging being finer than 100 µm. Typical street dirt mean particle sizes are in the range of 200 µm, indicating that the particles responsible for the clogging are very common. Particles in these sizes are also suitable for effective removal by most conventional street cleaning operations. The masses of particles extracted from porous pavements depend on the use of the street, on the traffic intensity, on the cleaning equipment used and on the cleaning frequency. However, the amount of extracted particles is always very high: 0.2 to 1.5 kg/m^2. The highest value has been measured several times in residential streets which have not been cleaned during the last 2 or 3 years (Artières1987).

The masses of particles extracted from impervious streets range between 0.5 and 2 kg/m^2, depending on the site, on the cleaning frequency, and on the cleaning machine. As shown by several authors (Sartor, *et al*. 1974, Novotny, *et al*. 1985, Artières 1987), 50 to 80% of the mass of particles accumulated on streets are located near the curb for light parking conditions. The curb-side loading decreases as the parking density increases (Pitt 1979). It is very important to be able to efficiently clean the part of the street where the street dirt is located. Cleaning in the driving lanes may also be needed in areas where parking conditions are intense. The street surface texture, the street dirt loading, the parking conditions, and the street cleaning equipment operating conditions all have a significant effect on the cleaning efficiency. Severe porous pavement clogging will require very powerful cleaning techniques, whereas regular cleaning with usual techniques should be satisfactory to keep the porous pavement surface in a relatively good state.

Summary of Porous Pavement Control Benefits

For porous pavements subjected to traffic below 100 vehicles/day, and especially for parking lots, monthly cleaning by vacuuming is sufficient to keep an almost constant infiltration capacity. If clogging is already evident, a stronger cleaning technique using high pressure water jetting and vacuuming is necessary. Techniques which recycle the cleaning water are obviously preferred in order to avoid flushing of the pollutants to the receiving water. In all sites where measurements have been carried out, the extraction was very efficient and the porous pavement infiltration capacity was usually well restored. Bertran4-Krajewski, *et al*. (1994), in a comparative study of available street cleaning techniques, showed that they have the following ability to improve infiltration through partially clogged porous pavements (cm/s enhanced infiltration capacity after cleaning):

- simple wetting and sweeping (<0.01 cm/s);
- sweeping and vacuuming (0.13 cm/s);
- vacuuming (0.28 cm/s); and
- high pressure jetting and vacuuming (0.80 cm/s).

WinSLAMM Calculation Procedures for Porous Pavements

WinSLAMM uses a calculation procedure similar to the general infiltration device procedure for porous pavement performance. However, porous pavements are only assumed to treat the paved area, with no additional flows from upland areas discharging to the pavement. The volume reduction is therefore:

(Pr/Ir) (Ap/At)

where Pr is the percolation rate of the porous pavement, the pavement base, or the soil, whichever is less,
Ir is the rain intensity: total rain/rain duration,
Ap is the paved area, and
At is the total study area.

Again, the ratio Pr/Ir must be less than, or equal to, 1.0. An example follows:

Percolation rate = 3 in/hr
Total rain = 1.7 in
Rain duration = 6 hrs
Porous pavement area = 0.7 acres
Total study area = 5.3 acres

Therefore Ir = 1.7 in/6 hrs = 0.283 in/hr

The ratio of Pr/Ir therefore is 3/0.283 = 10.6 which indicates an over-design for this rain, requiring the use of 1.0 in the performance equation. The volume reduction is therefore 0.7 acres/5.3 acres = 0.13 (13 percent reduction in flow and pollutant yield).

Filtration of Stormwater

Treatment of Stormwater Using Filtration Media

Small source area stormwater runoff treatment devices using various forms of filtration have been developed and are currently being marketed. The control of small critical area contributions to urban runoff may be the most cost-effective approach for treatment/reduction of stormwater toxicants. The general features of the critical source areas appear to be large paved areas, heavy vehicular traffic (especially frequent and large numbers of vehicle starts, such as at convenience stores) and outdoor use or storage of problem pollutants. The following paragraphs describe the different filtering media that have been evaluated for stormwater control:

Sand

The use of sand filtration is common throughout the U.S. Water supply treatment plants have successfully used sand filtration for many years. Wastewater treatment plants often use sand filtration to polish their effluent before release, especially as the regulatory requirements become more stringent. Sand filtration of stormwater began in earnest in Austin, Texas. The Austin sand filters are used both for single sites and for drainage areas less than 20 ha. The filters are designed to hold and treat the first 13 mm of runoff and the pollutant removal ability of the sand filters has been found to be very good.

According to the City of Austin design guidelines, the minimum depth of sand should be 0.5 m. If the City's design guidelines are followed, the assumed pollutant removal efficiencies, which are based upon the preliminary results of the City of Austin’s stormwater monitoring program, are as follows:

Pollutant	Removal Efficiency (%)
Fecal Coliform Bacteria	76
Total Suspended Solids (TSS)	70
Total Nitrogen	21
Total Kjeldahl Nitrogen	46
Nitrate - Nitrogen	0
Total Phosphorus	33
BOD	70
Total Organic Carbon	48
Iron	45
Lead	45
Zinc	45

Ref: City of Austin 1988.

In Washington, D.C., sand filters are used both to improve water quality and to delay the entrance of large slug inputs of runoff into the combined sewer system. Water quality filters are designed to retain and treat 8 to 13 mm of runoff with the final design based upon the amount of imperviousness in the watershed.

The State of Delaware considers the sand filter to be an acceptable method for achieving the eighty percent reduction requirement of suspended solids. Sand filters in Delaware are intended for sites which have impervious areas that will drain directly to the filter. The purpose of the sand filter in many areas is to help prevent or postpone clogging of an infiltration device. According to the State of Delaware guidelines, sand filtration is “intended for use on small sites where overall site imperviousness is maximized. Examples of these sites would be fast food restaurants, gas stations or industrial sites where space for retrofitting with other infiltration devices, such as detention ponds, is not available” (Shaver undated).

According to Delaware’s recommendations, the sand filter will adequately remove particulates (TSS removal efficiency 75 - 85 %) but will not remove soluble compounds. Studies of a sand filter in Maryland show that it is now just becoming clogged after six years of use in a heavily used parking lot. Inspection of the sand below the surface of the filter has shown that oil, grease and finer sediments have migrated into the filter, but only to a depth of approximately 50 to 75 mm (Shaver undated).

It has been generally expected that sand would retain any particles that it trapped. However, preliminary tests (Clark, *et al*. 1995) showed that fresh sand (without aging and associated biological growths) by itself did not retain stormwater toxicants (which are mostly associated with very fine particles). This lack of ability to retain stormwater toxicants prompted the investigation of other filtration media during this research. Combinations of filtration media, especially those using organic materials (activated carbon, peat moss, composted leaves and ion exchange resins) along with sand, are currently being investigated for their ability to more permanently retain stormwater pollutants.

Activated Carbon

Activated carbon filtration/separation has long been used in the chemical process industry and in hazardous waste cleanup as an effective method for removing trace organics from liquids. Activated carbon is made first by charring materials such as almond, coconut and walnut hulls, other woods, or coal. The char particles are activated by exposing them to an oxidizing gas at high temperatures. The activation process makes the particles porous which creates a large internal surface area available for pollutant adsorption (Metcalf and Eddy 1991).

The ability of the activated carbon to adsorb organics is based upon the molecular structure, solubility and the substitute groups on the organic molecule. Examples of compounds adsorbed by activated carbon include *n*-butyl phthalate, chlorobenzene, carbon tetrachloride, phenol, chloroform and nitrobenzene. Compounds that activated carbon does not adsorb include butylamine, cyclohexylamine, ethylenediamine and hexamethylenediamine. In the adsorption process, molecules attach themselves to the solid surface through attractive forces between them and the adsorbent carbon (Bennett, *et al*. 1982). Activated carbon filtration is limited by the number of adsorption sites in the media.

Activated carbon has a very small net surface charge and is ineffective at removing free hydrated metal ions, unless they are complexed with easily-adsorbed organics prior to contact with the activated carbon filter. However, once they are complexed with these usually insoluble organics, the complexed metals are readily adsorbed onto the carbon which results in high removal rates (Rubin and Mercer 1981).

Composted Leaves

Composts made from yard waste, primarily leaves, have been found to have a very high capacity for adsorbing heavy metals, oils, greases, nutrients and organic toxins due to the humic content of the compost. These humic compounds are stable, insoluble and have a high molecular weight. The humics act like polyelectrolytes and adsorb the toxicants.

The composted leaf filter was developed by W&H Pacific (now Stormwater Management) for Washington County (Washington), the Unified Sewer Agency and the Metropolitan Service District of Washington County (W&H Pacific 1992). The exact content of the composts and aging process for the composts used by W&H Pacific are not public knowledge with the result that the filter installation/maintenance company supplies the compost to the stormwater treatment device owner. The initial filter design consists of a bottom impermeable membrane with a drainage layer above. Above the drainage layer is a geotextile fabric above which is the compost material. A new design, the CSF II includes a concrete vault, having a flow spreader and a main tank area. The tank includes modular units containing the compost, and the stormwater flows horizontally through the compost. These modular units can be easily removed for maintenance. The actual pollutant removal occurs in the compost material. The removal processes that occur in the compost are filtration, adsorption, ion exchange and biodegradation of organics. Testing of a prototype of the initial design has shown the following pollutant removal rates:

Pollutant	Removal Rate (%)
Turbidity	84
Suspended Solids	95
Total Volatile Suspended Solids	89
COD	67
Settleable Solids	96
Total Phosphorus	40
Total Kjeldahl Nitrogen	56
Cooper	67
Zinc	88
Aluminum	87
Iron	89
Petroleum Hydrocarbons	87

Ref: W&H Pacific 1992.

Peat Moss

Peat is partially decomposed organic material, excluding coal, that is formed from dead plant remains in water in the absence of air. The physical structure and chemical composition of peat is determined by the types of plants (mosses, sedges and other wetland plants) from which it is formed. Peat is physically and chemically complex and is highly organic. Peat's main components are humic and fulvic acids and cellulose.

Peat’s permeability varies greatly and is determined by its degree of decomposition and the plants from which it came. Generally, the more decomposed the peat is, the lower its hydraulic conductivity. Peats are generally light-weight when dry and are highly adsorptive of water. Because of the lignins, cellulosic compounds and humic and fulvic acids in peat, peat is highly colloidal and has a high cation-exchange capacity. Peat also is polar and has a high specific adsorption for dissolved solids such as transition metals and polar organic compounds. Peat has an excellent natural capacity for ion exchange with copper, zinc, lead and mercury, especially at pH levels between 3.0 and 8.5. This adsorption, complexing and exchange of various metal cations occur principally through the carboxyl, phenolic and hydroxyl groups in the humic and fulvic acids. This capacity to bind and retain cations, though, is finite and reversible and is determined mostly by the pH of the solution.

Peat is an excellent substrate for microbial growth and assimilation of nutrients and organic waste materials because of its high C:N:P ratio, which often approaches 100:10:1. Nitrifying and denitrifying bacteria are typically present in large numbers in natural peat. Peat's ability to retain phosphorus in the long-term is related to its calcium, aluminum, iron and ash content with the higher the content of each of the above constituents, the higher the retention capability.

Peat moss (sphagnum moss) is a fibric peat. It has easily identifiable undecomposed fibrous organic materials and its bulk density is generally less than 0.1 g/cc. Because of its highly porous structure, peat moss can have a high hydraulic conductivity, up to 140 cm/hr. It is typically brown and/or yellow in color and has a high water holding capacity.

For filtration devices, peat generally has been combined with sand to create a peat-sand filter (PSF). The PSF is a “man-made” filtration system, unlike the sand or peat filtration systems that were first used as wastewater treatment systems in areas where these soils naturally occur. The PSF removes most of the phosphorus, BOD and pathogens and with a good grass cover, additional nutrient removal occurs.

The Peat-Sand Filter System designed by the Metropolitan Washington Council of Governments (Washington, D.C.) has a good grass cover on top underlain by 300 to 500 mm of peat. The peat layer is supported by a 100 mm mixture of sand and peat which is supported by a 500 to 600 mm layer of fine to medium grain sand. Under the sand is gravel and the drainage pipe. The mixture layer is required because it provides the necessary continuous contact between the peat and the sand layers, ensuring a uniform water flow. Because this is a biological filtration system, it works best during the growing season when the grass cover can provide the additional nutrient removal that will not occur in the peat-sand regimes of the system (Galli 1990).

The PSF is usually an aerobic system. However, modifications to the original design by the Metropolitan Washington Council have been made to account for atypical site conditions or removal requirements. The estimated pollutant removal efficiency for the PSF system for stormwater runoff is given below:

Pollutant	Removal Efficiency (%)
Suspended Solids	90
Total Phosphorus	70
Total Nitrogen	50
BOD	90
Trace Metals	80
Bacteria	90

Ref. Galli 1990.

Recent Filtration Tests

The Department of Civil and Environmental Engineering at the University of Alabama at Birmingham is engaged in a multi-year cooperative agreement with the Storm and Combined Sewer Program of the U.S. EPA. Additional funding was provided by the U.S. Army Corps of Engineers Construction Engineering Research Laboratory in Champaign, IL. As part of this cooperative agreement, potential filtration and sorption media for stormwater runoff treatment from critical source areas were examined (Clark 1996).

Stormwater filters currently in operation typically use sand, leaf compost, or peat. This research tested the capabilities of these media, plus others with expected pollutant removal capability (activated carbon, Zeolite, a cotton milling waste, and a waste agrofiber), in both controlled laboratory and field tests. Influent and effluent samples from each test column were analyzed for toxicity (using Microtox™ screening test), turbidity, conductivity, pH, major anions and cations, semi-volatile organics, pesticides, particle size distribution, and heavy metals. This research also tested the influence that atypical influent pH and ionic strengths have on a medium's pollutant removal capability, since a potential exists that stormwater filters will be retrofit or designed for places that either receive snowmelt runoff with its high salt concentrations or runoff from an area, such as an industry or commercial establishment, where the pH is unusual. The pollutant removal abilities of two geotextiles were also investigated and their removal capacities compared with that of the traditional media.

The main objective of this research was to monitor a variety of media used to treat stormwater runoff to determine their overall pollutant removal capabilities. Generally, a variety of mechanisms, including straining, sorption, and ion-exchange, are responsible for removing pollutants during "filtration". No attempt was made to determine which mechanisms were responsible for removing a particular pollutant. In these tests, it soon became apparent that the media were limited by clogging caused by suspended solids in the stormwater runoff. Clogging occurred long before reductions in the pollutant removal capabilities could be determined when using typical pavement runoff. It is suggested that in order to lengthen the run time and better use the pollutant retention capacity of the media, the influent suspended solids concentration should be no more than about 10 mg/L.

Table 4-6 provides a ranking of the media based only on suspended solids removal during 12 filter tests using stormwater collected from a large parking area on the UAB campus. Another series of 12 tests were also conducted using stormwater collected from the same location, but pretreated by settling for 1 to 3 days in a 1 m deep tank.

Table 4-7 shows the levels of removal of stormwater pollutants that had significantly different influent and effluent concentrations after passing through the media (for normal stormwater that was not pretreated). Pollutant removal efficiency increased for all the media after they had aged because they typically develop a biofilm that aids in pollutant removal, and they have fewer small particles available in the medium to be washed out. Because many of the pollutants in stormwater runoff are associated with the particulate matter, more significant reductions in pollutant concentrations were noted when the runoff was not pretreated prior to filtering and when the media itself removed significant quantities of suspended solids.

Table 4-6. Removal Efficiency for Suspended Solids

Ranked Media	Percent TSS Reduction (Pretreated) (Avg. Influent TSS = 10 mg/L)	Percent TSS Reduction (Avg. Influent TSS = 30 to 60 mg/L)
Sand	>50%	>90%
Carbon-Sand		>90%
Zeolite-Sand	20 - 50%	>90%
Filter Fabrics		10%
Peat-Sand	<10 %	80-90%
Enretech-Sand		>90%
Compost-Sand		80%

Table 4-7. Pollutant Removal for Stormwater Treatment Media (not pretreated, TSS = 30 to 50 mg/L)

Media	Additional Comments
Carbon-Sand	Reduced toxicity (>95%), color (60%), alkalinity (30 to 50%), nitrate (95%), potassium (45%), suspended and volatile solids (50 to 80%), COD (50%), while increasing sulfate concentration in effluent.
Peat-Sand	Reduced toxicity (60%), fluoride (<10%), hardness and alkalinity (60%), while increasing turbidity, color, COD, and small particle concentrations in effluent. Lowered pH 1 unit.
Zeolite-Sand	Reduced toxicity (50 to 80%), potassium (35%), solids (15 to 50%), with minimal deterioration of effluent.
Sand	Reduced solids (10 to 70%), with minimal degradation of effluent.
Enretech-Sand	Reduced toxicity (< 10%), with minimal degradation of effluent.
Compost-Sand	Reduced toxicity (70 to >95%), large particle sizes (<30%), while increasing color and potassium

	concentration in effluent.
Filter Fabrics	Reduced solids (<30%), with minimal degradation of effluent.

Pretreatment of the stormwater was conducted to reduce the solids loadings on the media in order to increase the run times before clogging. This was done to better take advantage of the chemical retention capabilities of the filters. The settling reduced the stormwater suspended solids concentrations to about 10 mg/L, with about 90% of the particles being less than 10 µm in size (similar to the suspended solids conditions that is obtained using a well designed and operated wet detention pond). The pretreatment also reduced the other stormwater pollutant concentrations (for example, color and turbidity were reduced by about 50%, and COD by about 90%). This pretreatment had a significant effect on the media's pollutant removal performance, as shown in Table 4-8. The suspended solids concentrations were generally not further reduced by the media, and its removal by itself would no longer be a suitable criterion for selecting a treatment medium, if the stormwater was pretreated.

Table 4-8. Pollutant Removal for Stormwater Treatment Media (pretreated stormwater, TSS = 10 mg/L)

Media	Additional Comments
Carbon-Sand	Reduced toxicity (80%), color (25%), alkalinity (>95%), zinc (50 to 75%), COD (85 to 95%), 2,4-dinitrophenol (40%), bis(2-ethylhexyl) phthalate (90%), with minimal effluent degradation.
Peat-Sand	Reduced toxicity (60%), alkalinity and hardness (50 to 100%), chloride (<20%), large solids (<50%), zinc (60 to 70%), 2,4-dinitrophenol (35%), di-n-butyl phthalate (65%), bis(2-ethylhexyl) phthalate (20%), dieldrin (70%), while adding color, turbidity, and reducing pH (1-2 units).
Zeolite-Sand	Reduced toxicity (>90%), chloride (<10%), potassium (40%), calcium (15%), zinc (60 to 75%), bis(2-ethylhexyl) phthalate (80%), pentachlorophenol (90%), with minimal effluent degradation.
Enretech-Sand	Reduced volatile solids (20%), zinc (65 to 75%), 2,4-dinitrophenol (30%), pentachlorophenol (85%), with minimal effluent degradation.
Forest-Sand	Reduced zinc (75 to 80%), pentachlorophenol (90%), with minimal effluent degradation.
Sand	Reduced volatile solids (<10%), zinc (75 to 80%), bis(2-ethylhexyl) phthalate (100%), with minimal effluent degradation.
Compost-Sand	Reduced zinc (75 to 80%), while adding color to effluent.
Filter Fabrics	Reduced COD (20 to 50%), with minimal effluent degradation. Gunderboom reduced 2,4-dinitrophenol (75 to 80%) and di-n-butyl phthalate (75 to 80%).

As shown during these results, the characteristics of the influent water greatly influence the performance of the treatment medium. Generally, most stormwater filters are designed based upon the influent suspended solids concentration and desired suspended solids removal. For most applications, this likely will remain the primary design factor. However, the selection of the media may likely be different when the influent suspended solids concentration is low, or when the pH is not near neutral and/or the ionic strength is high. Stormwater filter designers also need to consider that most of these media are also ion exchange materials: when ions are removed from solution by the treatment material, other ions are released into the effluent. In most instances, these ions are not a problem in receiving waters, but the designer should know what is added to the water. For the activated carbon examined during these tests, the exchangeable ion was found to be mostly sulfate; while for the compost, the exchangeable ion was found to be mostly potassium. The Zeolite tested appeared to exchange sodium and some divalent cations (measured as increasing hardness) for the ions it removed.

The stormwater control objectives may dictate a combination of filter media. The peat-sand and compost-sand mixtures provided excellent removal for most pollutants, but they added some potentially undesirable constituents to the water. A three-media filter (peat, sand, and activated carbon) has been tested to deal with the addition of some of the undesirables. This design currently is in operation as the polishing chamber of a Multi-Chamber Treatment Train (MCTT) in Milwaukee, WI (Pitt 1996). Based upon the results from a year of monitoring, the addition of activated carbon to the peat-sand media has enhanced the removal ability of the material without adding the undesirable elements like color and turbidity to the effluent. For many stormwater treatment applications, this multi-media approach may be the best solution for treating runoff before it reaches any sensitive receiving waters.

Roberts (1996) described the use of underground detention storage using pipes, in combination with an underground stormwater filtration system as an emerging technology. The city of Alexandria has recently published a regional stormwater management manual that includes several designs for sand filters. In addition, the Center for Watershed Protection (1996) has also recently published a design manual for stormwater filtration. Tenney, *et al*. (1995), at the University of Texas, also recently published a detailed report on highway runoff filtration systems.

Design of Stormwater Filters

The information obtained during this EPA sponsored research can be used to develop design guidelines for stormwater filtration, especially in conjunction with reported information in the literature. The design of a stormwater filter needs to be divided into two phases. The first phase is the selection of the media to achieve the desired pollutant removal goals. The second phase is the sizing of the filter to achieve the desired run time before replacement of the media. The main objective of this research was to monitor a variety of filtration media to determine their pollutant removal capabilities, as noted previously. However, it soon became apparent that the filters were more limited by clogging caused by suspended solids in the stormwater, long before reductions in their pollutant removal capabilities could be identified. Therefore, measurements in filter run times, including flow rates and clogging parameters, were added to the research activities. However, the small-scale filter set-ups used for the pollutant removal measurements (using 1 L test columns) probably under-predicted the actual run times that could be achieved under full-scale applications. Even with the increased filter depth utilization and better drying between storms that may be achieved with full-scale applications, pretreatment of the stormwater so the suspended solids content is about 10 mg/L, or less, is probably necessary in order to take greater advantage of the pollutant retention capabilities of most of the media. This level of pretreatment, however, may make further stormwater control unnecessary, except for unusual conditions. Of course, it may be more cost-effective to consider shortened filter run times, without pretreatment, and not utilize all of the pollutant retention capabilities of the media.

Selection of Filtration Media for Pollutant Removal Capabilities. The selection of the filter media needs to be based on the desired pollutant removal performance and the associated conditions. If based on suspended solids alone for untreated stormwater (a likely common and useful criteria), then the filtration media would be ranked according to the following:

1) >90% control of suspended solids: compost/sand, act. carbon/sand, Zeolite/sand, Enretech/sand
2) 80 - 90% control of suspended solids: sand, peat/sand
3) very little control of suspended solids: filter fabrics

If based on a wider range of pollutants for untreated stormwater, then the ranking would be as follows:

1) sand, act. carbon/sand, Enretech/sand (no pollutant degradation, but sand by itself may not offer "permanent" pollutant retention until aged and has biological growths and/or deposition of silts and oils - that is the reason supplements were added to the sand during this research)
2) Zeolite/sand (no degradation)
3) compost/sand (color degradation)
4) peat moss/sand (turbidity and pH degradation)
5) filter fabrics alone (very little pollutant removal benefit)

Pre-settling of the stormwater was conducted to reduce the solids loadings on the filters to increase the run times before clogging in order to take better advantage of the pollutant retention capabilities of the filters. Settling reduced the stormwater suspended solids to about 10 mg/L, with about 90% of the particles (by volume) less than 10 μm in size. The untreated stormwater had a suspended solids concentration of about 30 to 50 mg/L, but many of the particles were larger, with about 90% of the particles being less than 50 μm. The pre-settling also reduced the other stormwater pollutants (color and turbidity by about 50%, and COD by about 90%, for example). This pre-settling was similar to what would occur with a well designed and operated wet detention pond. This pre-settling had a significant effect on the filter performance, as noted, and the rankings would be as follows, considering a wide range of stormwater pollutants (suspended solids removal by itself would not be a suitable criteria, as it is not likely to be reduced any further by the filters after the pre-settling):

1) peat moss/sand (with degradation in color, turbidity, and pH)
2) activated carbon/sand (no degradation, but fewer benefits)
3) Enretech/sand, forest/sand, sand (few changes, either good or bad)
4) compost/sand (many negative changes)

Obviously, knowing the stormwater control objectives and options will significantly affect the selection of the treatment media. This is most evident with the compost material. If suspended solids removal is the sole criterion, with minimal stormwater pre-treatment, then it is the recommended choice (if one can live with a slight color increase in the stormwater, which is probably not too serious). However, if a filter is to be used after significant pre-treatment in order to have a longer filter life, a compost filter would be the last choice (not considering economics).

The following list summarizes the likely significant reductions in concentrations observed for the filters:

- Sand: Medium to high levels of control for most pollutants, if the stormwater is not pre-treated. These levels of control are associated with retention of suspended solids and the associated particulate fractions of the pollutants. Can relatively easily flush previously captured pollutants. With pretreatment, has little additional benefit. Likely minimum effluent concentrations: 10 mg/L for suspended solids, 50 HACH color units, 10 NTU for turbidity.

- Peat moss/sand: Medium to high levels of control for most pollutants, for both untreated and pre-settled stormwater. Largest range and number of pollutants benefited under pre-settled conditions. Caused increases in color and turbidity, and reductions in pH (by about one pH unit). Likely minimum effluent concentrations: 5 mg/L for suspended solids, 85 HACH color units, 10 - 25 NTU for turbidity.

- Activated carbon/sand: Very good control for most pollutants, especially if the stormwater is not pre-treated. Also large number of benefited pollutants under pre-settled conditions. Caused no adverse changes for any pollutant. Likely minimum effluent concentrations: 5 mg/L for suspended solids, 25 HACH color units, 5 NTU for turbidity.

- Zeolite/sand: Medium to high levels of control for many pollutants for untreated stormwater, but no likely benefits for pre-settled stormwater. Caused increased color and turbidity on pre-settled stormwater. Likely minimum effluent concentrations: 10 mg/L for suspended solids, 75 HACH color units, 15 NTU for turbidity.

- Compost/sand: Medium to very high levels of control for many pollutants for untreated stormwater, but worsened water quality for many pollutants if pre-settled. Increased color under all conditions and had increased phosphate and potassium in effluent. Likely minimum effluent concentrations: 10 mg/L for suspended solids, 100 HACH color units, 10 NTU for turbidity.

- Enretech/sand: Medium to high levels of control for many pollutants for untreated stormwater, but had little effect on pre-settled stormwater. Likely minimum effluent concentrations: 10 mg/L for suspended solids, 80 HACH color units, 10 NTU for turbidity.

- Filter fabrics: No significant and/or important reductions for any pollutants using either untreated or pre-settled stormwater.

Design of Filters for Specified Filtration Durations. The filtration durations measured during these tests can be used to develop preliminary filter designs. It is recommended that allowable suspended solids loadings be used as the primary controlling factor in filtration design. Clogging is assumed to occur when the filtration rate becomes less than about 1 m/day. Obviously, the filter would still function at smaller filtration flow rates, especially for the smallest rains in arid areas, but an excessive amount of filter by-passing would likely occur for moderate rains in humid areas. Tables 4-9 and 4-10 summarize the observed filtration capacities of the different media tested. The wide ranges in filter run times as a function of water are mostly dependent on the suspended solids content of the water, especially when the water is pre-treated. Therefore, the suspended solids loading capacities are recommended for design purposes.

Table 4-9. Filtration Capacity as a Function of Suspended Solids Loadings

Filtration Media	Capacity to 20 m/day	Capacity to 10 m/day	Capacity to <1 m/day
Sand	150-450 gSS/m^2	400->2000 gSS/m^2	1200-4000 gSS/m^2
Peat/sand	100-300	150-1000	200-1700
Peat	?	?	200
Leaves	?	?	2100
Activated carbon/sand	150-900	200-1100	500->2000
Zeolite/sand	200-700	800-1500	1200->2000
Compost/sand	100-700	200-750	350-800
Enretech/sand	75-300	125-350	400-1500

Table 4-10. Filtration Capacity as a Function of Pre-Treated Water (generally <10 mg SS /L) Loading

Filtration Media	Capacity to 20 m/day	Capacity to 10 m/day	Capacity to <1 m/day
Sand	6-20 m	8->25 m	13->40 m
Peat/sand	3-17	4-22	7-30
Activated carbon/sand	5-25	6->25	15->40
Zeolite/sand	7-25	8->25	14->40
Compost/sand	3-20	4-30	6->30
Enretech/sand	3-11	4-25	15->30

The most restrictive materials (the Enretech and Forest Products media) are very fibrous and still show compaction, even when mixed with sand. The most granular media (activated carbon and the Zeolite) are relatively uniform in shape and size, but have sand interspersed to fill the voids to slow the water to increase the contact time for better pollutant removal. The sand has the highest filtration rates because it has the most uniform shape and size.

The test observations indicated that only about 2.5 cm of the filter columns (about 10%) were actually used for solids retention during these tests. A full-scale filter could utilize about 5 times these depths for solids retention, if care was taken to allow selective piping to deeper depths, while not providing short-circuiting through the complete filter column. This could be most easily accomplished by placing a turf grass layer on top of the media (as in the peat-sand filter designs of the Metropolitan Washington (D.C.) Council of Governments). It is recommended that the roots of the grass used in the cover layer do not extend below about one-half of the filtration depth (the root depth should therefore be up to about 12 cm). Mechanical removal of the clogged layer to recover filter flow rates was not found to be very satisfactory during this research, but has been used successfully during full-scale operations. Great care must be taken when removing this layer, as loosening the media, besides increasing the flow capacity of the filter, will also enable trapped pollutants (associated with the suspended solids) to be easily flushed from the media.

The flow rates through filters that have thoroughly dried between filter runs significantly increases. Our small-scale tests restricted complete drying during normal inter-event periods which may occur more commonly with full-scale filters. Wetting and drying of filters (especially peat) has been known to produce solution channels through the media that significantly increases the flow. If these solution channels extend too far through the filter, they would cause short-circuiting and would therefore reduce pollutant retention. Adequate filter depths will minimize this problem. Table 4-11 shows the observed increases in filter flow rates for saturated (and partially clogged filters) and the associated flow capacity recovery for filters that have been thoroughly dried and then re-wetted. The filter fabrics did not indicate any flow rate improvements with wetting and drying, while the peat moss/sand filter had the greatest improvement in flow capacity (by about ten times), as expected. The other media showed much more modest improvements (but still about two to three times).

Table 4-11. Filter Flow Rates (m/day) for Saturated (and Partially Clogged) Filters and Recovered Filtration Capacity after Through Drying

Filter Condition	sand	peat moss/ sand	act. carbon/ sand	Zeolite/ sand	compost/ sand	Enretech/ sand	forest/ sand	Emcon™ fabric	Gunder-boom™ fabric
Saturated/ partially clogged	13	4.0	17	17	13	8.4	8.4	850	200
Recovered flow capacity after drying	40	42	33	39	32	24	17	850	200
Increase in flow (multiple)	3.1X	11X	1.9X	2.3X	2.5X	2.9X	2.0X	1.0X	1.0X

The above filter capacity ranges are associated with varying test conditions and may be further grouped into the following approximate categories, as shown on Table 4-12, which are multiplied by 5 to account for an anticipated greater filter flow capacity associated with full-scale applications.

Table 4-12. Expected Full-Scale Media Flow Capacities

Capacity to <1 m/day	Capacity to 10 m/day	Filtration Media Category
5,000 gSS/m^2	1,250 gSS/m^2	Enretech/sand; Forest/sand
5,000	2,500	Compost/sand; Peat/sand
10,000	5,000	Zeolite/sand; Act. Carbon/sand
15,000	7,500	Sand

Filter designs can be made based on the predicted annual discharge of suspended solids to the filtration device and the desired filter replacement interval. As an example, Table 4-13 shows the volumetric runoff coefficients (Rv) that can be used to approximate the fraction of the annual rainfall that would occur as runoff for various land uses and surface conditions, based on small-storm hydrology concepts (Pitt 1987). In addition, Table 4-14 summarizes likely suspended solids concentrations associated with different urban areas and waters.

Table 4-13. Volumetric Runoff Coefficients (Rv) for Different Urban Areas

Area	Volumetric Runoff Coefficient (Rv)
Low density residential land use	0.15
Medium density residential land use	0.3
High density residential land use	0.5
Commercial land use	0.8
Industrial land use	0.6
Paved areas	0.85
Sandy soils	0.1

Clayey soils	0.3

Table 4-14. Typical Suspended Solids Concentrations in Runoff from Various Urban Surfaces

Source Area	Suspended Solids Concentration (mg/L)
Roof runoff	10
Paved parking, storage, driveway, streets, and walk areas	50
Unpaved parking and storage areas	250
Landscaped areas	<500
Construction site runoff	10,000
Detention pond effluent water	20
Mixed stormwater	150
Effluent after high level of pre-treatment of stormwater	5

Using the information in the above two tables and the local annual rain depth, it is possible to estimate the annual suspended solids loading from an area. The following three examples illustrate these simple calculations.

1) A 1.0 ha paved parking area, in an area receiving 1.0 m of rain per year:

(50 mg SS/L) (0.85) (1 m/yr) (1 ha) (10,000 m^2/ha) (1,000 L/m^3) (g/1,000 mg) = 425,000 g SS/yr

Therefore, if a peat/sand filter is to be used having an expected suspended solids capacity of 5,000 g/m^2 before clogging, then 85 m^2 of this filter will be needed for each year of desired operation for this 1.0 ha site. This is about 0.9% of the paved area per year of operation. If this water is pre-treated so the effluent has about 5 mg/L suspended solids, then only about 0.2% of the contributing paved area would be needed for the filter. A sand filter would only be about 1/3 of this size.

2) A 100 ha medium density residential area having 1.0 m of rain per year:

(150 mg SS/L) (0.3) (1 m/yr) (100ha) (10,000 m^2/ha) (1,000 L/m^3) (g/1,000 mg) = 45,000,000 g SS/yr

The unit area loading of suspended solids for this residential area (450 kg SS/ha-yr) is about the same as in the previous example (425 kg SS/ha-yr), requiring about the same area dedicated for the filter. The reduced amount of runoff is balanced by the increased suspended solids concentration.

3) A 1.0 ha rooftop in an area having 1.0 m of rain per year:

(10 mg SS/L) (0.85) (1 m/yr) (1 ha) (10,000 m^2/ha) (1,000 L/m^3) (g/1,000 mg) = 85,000 g SS/yr

The unit area loading of suspended solids from this area (85 kg SS/ha-yr) is much less than for the other areas and would only require a filter about 0.2% of the roofed drainage area per year of operation.

It is recommended that the filter media be about 50 cm in depth and that a surface grass cover be used, with roots not extending beyond half of the filter depth. This should enable a filtration life of about five times the basic life observed during these tests. In addition, it is highly recommended that significant pre-treatment of the water be used to reduce the suspended solids concentrations to about 10 mg/L before filtration for pollutant removal. This pre-treatment can be accomplished using grass filters, wet detention ponds, or other specialized treatment (such as the sedimentation chamber in the multi-chambered treatment train, MCTT). The selection of the specific filtration media should be based on the desired pollutant reductions, but should in all cases include amendments to plain sand if immediate and permanent pollutant reductions are desired.

Summary of Filtration as a Stormwater Control

In all cases, comprehensive chemical analyses are showing limited changes in the pollutant reductions with time. The media is apparently clogging before the media is experiencing chemical break-though. It is not yet clear if depth filtering media will be a cost-effective stormwater control, considering the pre-treatment needed to prevent clogging. The pretreatment alone may provide adequate control alone, with the additional filtration cost. Large-scale filtration installations (especially sand) have been shown to perform well for extended periods of time with minimal problems. The use of supplemental materials (such as organic compounds) should increase their performance for soluble compounds.

WinSLAMM Calculation Procedures for Media Filters

WinSLAMM is currently being modified to incorporate media filters using on-going research. The specific procedures have not yet been finalized, although they will be similar to the design procedures described above (clogging as a critical issue, with pollutant removal relatively constant until clogging).

Combination Devices (Example use of the Multi-Chambered Treatment Train, MCTT)

Earlier bench-scale treatability studies, sponsored by the U. S. Environmental Protection Agency (EPA), found that the most beneficial treatment for the removal of stormwater toxicants (as measured using the Microtox™ test) included quiescent settling for at least 24 hours in a 1 meter settling column (generally 40% to 90% reductions), screening through at least 40 µm screens (20% to 70% reductions), and aeration and/or photo-degradation for at least 24 hours (up to 80% reductions) (Pitt, *et al*. 1995). The MCTT contains aeration, sedimentation, sorption, and sand/peat filtration and was developed by Pitt at the University of Alabama at Birmingham (Robertson, *et al*. 1995).

The MCTT is most suitable for use at relatively small and isolated paved critical source areas, from about 0.1 to 1 ha (0.25 to 2.5 acre) in area, where surface land is not available for stormwater controls. Typical locations include gas stations, junk yards, bus barns, public works yards, car washes, fast food restaurants, convenience stores, etc., and other areas where the stormwater has a high probability of containing high concentrations of oils and filterable toxic pollutants that are difficult to treat by other means. A typical MCTT requires between 0.5 and 1.5 percent of the paved drainage area, which is about 1/3 of the area required for a well-designed wet detention pond, and is generally installed below ground. A pilot-scale MCTT was constructed in Birmingham, AL, at a large parking area at the University of Alabama at Birmingham campus, and tested over a six month monitoring period. Two additional full-scale MCTT units have also been constructed and are being monitored as part of Wisconsin’s 319 grant from the U.S. EPA. Complete organic and metallic toxicant analyses, in addition to conventional pollutants, are included in the evaluation of these units.

Figure 4-9 shows a general cross-sectional view of a MCTT. It includes a special catchbasin followed by a two chambered tank that is intended to reduce a broad range of toxicants (volatile, particulate, and dissolved). The MCTT includes a special catchbasin (based on Lager, *et al*.’s 1977 design) followed by two tank chambers that is intended to reduce a broad range of suspended solids and stormwater toxicants (volatile, particulate, and dissolved). The runoff enters the catchbasin chamber by passing over a flash aerator (small column packing balls with counter-current air flow) to remove any highly volatile components present in the runoff (unlikely). This catchbasin also serves as a grit chamber to remove the largest (fastest settling) particles. The second chamber serves as an enhanced settling chamber to remove smaller particles and has inclined tube settlers to enhance sedimentation. The settling time in this main settling chamber usually ranges from 20 to 70 hours. This chamber also contains fine bubble diffusers and sorbent pads to further enhance the removal of floatable hydrocarbons and additional volatile compounds. The water is then pumped to the final chamber at a slow rate to maximize pollutant reductions. The

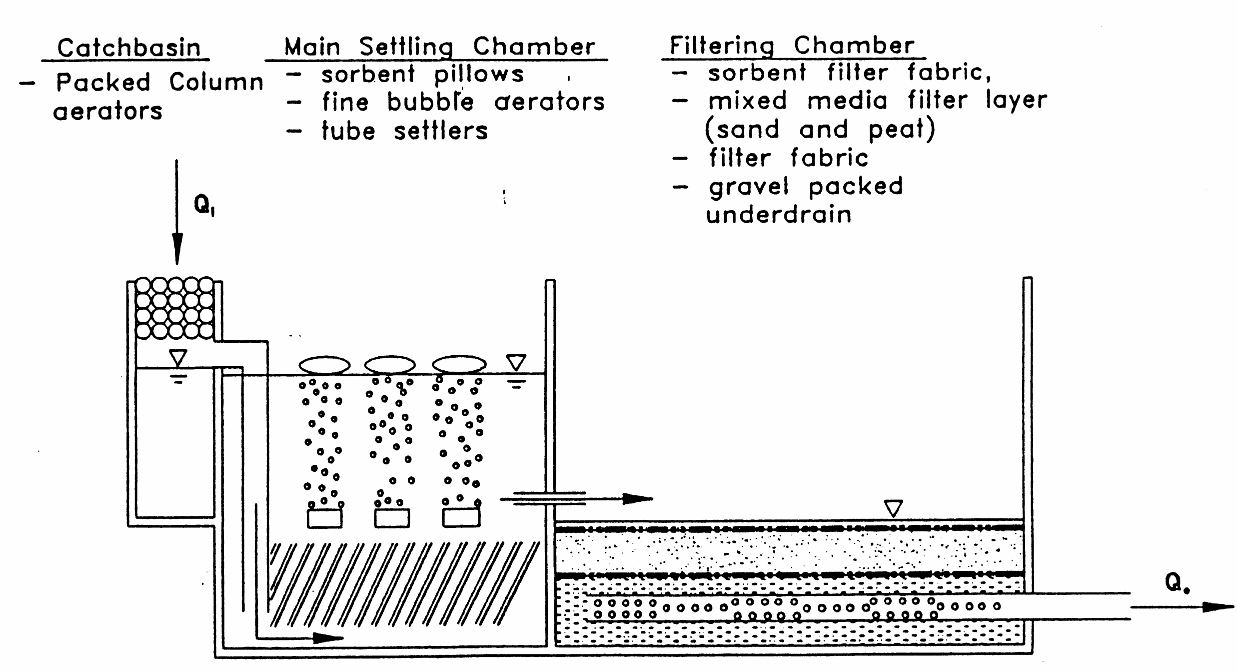


Figure 4-9. General schematic of MCTT (Pitt 1995).

final chamber contains a mixed media (sand and peat) slow filter, with a filter fabric layer. The MCTT is typically sized to totally contain all of the runoff from a 6 to 20 mm (0.25 to 0.8 in) rain, depending on treatment objectives, inter-event time, typical rain size, and rain intensity for an area.

Table 4-15 shows the median toxicity reductions for various holding times for a 2.1m deep main settling chamber, based on laboratory bench-scale treatability tests. Table 4-16 shows how this device would operate for Birmingham, Alabama, rains. Short holding times result in much of the annual rainfall being treated (the unit is empty before most of the rains begin, because it rains about every 3 to 5 days), but each rain is not treated very well, because of the short settling periods. Therefore, the annual treatment level approaches a constant level with long holding periods. In this example, a relatively large main settling chamber is needed in order to contain large fractions of most of the rains. Long-term continuous analyses have been conducted to identify the most cost-effective MCTT sizes (and holding times) for different treatment objectives for many U.S. locations (Pitt 1996).

Table 4-15. Median Toxicity Reductions for Different Treatment Holding Times

Holding Period for 2.1 m depth (h)	Median Toxicity Reduction (%) per Individual Rain
6	46
12	60
24	75
36	84
48	92
72	100

Table 4-16. Effects of Storage Volume and Holding Periods on Annual Runoff Treated and on Total Annual Toxicity Reduction (Birmingham, AL rains)

Holding Period (h)	Storage volume corresponding to: 12.7 mm rain with 10.2 mm runoff (0.50 in. rain with 0.40 in. runoff) % Annual Runoff Treated	% Annual Toxicity Reduction	Storage volume corresponding to: 38.1 mm rain with 33.5 mm runoff (1.50 in. rain with 1.32 in. runoff) % Annual Runoff Treated	% Annual Toxicity Reduction
6	84	39	100	46
12	62	37	100	60
24	52	39	98	73
36	48	41	91	77
48	46	42	88	81
72	44	44	84	84

During monitoring of 13 storms at the Birmingham pilot-scale MCTT facility (designed for 90% toxicity reductions), the following overall median removal rates were observed: 96% for total toxicity (as measured using the Microtox™ screening test), 98% for filtered toxicity, 83% for suspended solids, 60% for COD, 40% for turbidity, 100% for lead, 91% for zinc, 100% for n-Nitro-di-n-proplamine, 100% for pyrene, and 99% for bis (2-ethyl hexyl) phthalate. The color was increased by about 50% due to staining from the peat and the pH decreased by about one-half pH unit, also from the peat media. Ammonia nitrogen was increased by several times, and nitrate nitrogen had low removals (about 14%). The MCTT performed better than intended because of the additional treatment provided by the final ion exchange/filtration chamber. It had very effective removal rates for both filtered and particulate stormwater toxicants and suspended solids. Increased filterable toxicant removals were obtained in the peat/sand mixed media filter/ion exchange chamber, at the expense of increased color, lowered pH, and depressed COD and nitrate removal rates.

Preliminary results from the full-scale Wisconsin tests collaborate the high levels of treatment observed during the Birmingham pilot-scale tests. Table 4-17 shows the treatment levels that have been observed to date, based on seven tests in Minocqua (during one year of operation) and three tests in Milwaukee (during the first several months of operation). This initial data indicates very high removals (generally >90%) for suspended solids, COD, turbidity, phosphorus, lead, zinc, and many organic toxicants. None of the organic toxicants were ever observed in effluent water from either full-scale MCTT, even considering the excellent detection limits available in the Wisconsin laboratories. The MCTT effluent concentrations were also very low for all of the other constituents monitored: <10 mg/L for suspended solids, <0.1 mg/L for phosphorus, <5 μg/L for cadmium and lead, and <20 μg/L for copper and zinc. The pH changes in the Milwaukee MCTT were much less than observed during the Birmingham pilot-scale tests, possibly because of the added activated carbon in the final chamber in Milwaukee. Color was also much better controlled in the full-scale Milwaukee MCTT.

The Milwaukee installation is at a public works garage and serves about 0.1 ha (0.25 acre) of pavement. This MCTT was designed to withstand very heavy vehicles driving over the unit and was a custom-built concrete tank. The estimated cost was $54,000 (including a $16,000 engineering cost), but the actual cost was $72,000. The high cost was likely due to uncertainties associated with construction of an unknown device by the contractors and because it was a retrofitted installation. It therefore had to fit within very tight site layout constraints. As an example, installation problems occurred due to sanitary sewerage not being accurately located as mapped.

Table 4-17. Preliminary Performance Information for Full-Scale MCTT Tests (median removals and median effluent quality)

	Milwaukee MCTT (3 initial tests)	**Minocqua MCTT (7 initial tests)**
suspended solids	>95 (<5 mg/L)	85 (10 mg/L)
COD	90 (10 mg/L)	na
turbidity	90 (5 NTU)	na
pH	-7 (8 pH)	na
ammonia	50 (<0.03 mg/L)	na
nitrates	0 (0.3 mg/L)	na
phosphorus	90 (0.03 mg/L)	80 (0.1 mg/L)
cadmium	90 (0.1 µg/L)	na
copper	90 (3 µg/L)	65 (15 µg/L)
lead	95 (2 µg/L)	nd (<3 µg/L)
zinc	>85 (<20 µg/L)	90 (15 µg/L)
benzo(a)anthracene	>45 (<0.05 µg/L)	>65 (<0.2 µg/L)
benzo(b)fluoranthene	>95 (<0.1 µg/L)	>75 (<0.1 µg/L)
dibenzo(a,h)anthracene	>80 (<0.02 µg/L)	>90 (<0.1 µg/L)
fluoranthene	>95 (<0.1 µg/L)	>90 (<0.1 µg/L)
indeno(l,2,3-cd)pyrene	>90 (<0.1 µg/L)	>95 (<0.1 µg/L)
phenanthrene	>70 (<0.05 µg/L)	>65 (<0.2 µg/L)
pyrene	>80 (<0.05 µg/L)	>75 (<0.2 µg/L)

na: not analyzed
nd: not detected

The Minocqua site was a 1 ha (2.5 acre) newly paved parking area serving a state park and commercial area. This MCTT was constructed using standard 10' x 15' concrete culvert sections. It was located underneath a grassed area, with the runoff piped to the MCTT. It was also a retro-fitted installation, designed to fit within an existing storm drainage system. The installed cost of this MCTT was about $95,000. It is anticipated that MCTT costs could be substantially reduced if designed to better integrate with a new drainage system and not installed as a retro-fitted stormwater control practice. Plastic tank manufactures have also expressed an interest in preparing pre-fabricated MCTT units that could be sized in a few standard sizes for small critical source areas. It is expected that these pre-fabricated units would be much less expensive and easier to install than the custom-built units tested to date.

The development and testing of the MCTT showed that the treatment unit provided substantial reductions in stormwater toxicants (both in particulate and filtered phases), and suspended solids. Increases in color and a slight decrease in pH also occurred during the filtration step at the pilot-scale unit. The main settling chamber resulted in substantial reductions in total and dissolved toxicity, lead, zinc, certain organic toxicants, suspended solids, COD, turbidity, and color. The filter/ion exchange unit is also responsible for additional filterable toxicant reductions. However, the catchbasin/grit chamber did not indicate any significant improvements in water quality, although it is an important element in reducing maintenance problems by trapping bulk material.

WinSLAMM Calculation Procedures for Combination Devices (specifically the MCTT)

WinSLAMM is currently being modified to incorporate combination devices. The MCTT will be modeled using the catchbasin procedures, plus the detention pond procedures for the main settling chamber, and finally the media filter procedures for the last chamber (if used).

References and Bibliography

Adams, R. "Stormwater infiltration as a part of an environmentally compatible drainage concept." Proceedings of the 6^{th} *International Conference on Urban Storm Drainage*. Edited by J. Marsalek and H.C. Torno. Niagara Falls, Ontario. September 12 - 17, 1993. IAWQ, London. Published by Seapoint Publishers, Victoria, B.C. pp. 975 - 980. 1993.

Aires, N, and J.P. Tabuchi. "Hydrocarbons separators and stormwater treatment." (in French) *TSM, Special Issue «Stormwater»*, no 11, pp 862-864. 1995.

Akeley, R.P. "Retention basins for control of urban stormwater quality." In Proceedings: *National Conference on Urban Erosion and Sediment Control: Institutions and Technology*, EPA-905/9-80-002, Chicago, January 1980.

Alhajjar, B.J., Harkin, J.M., and Chesters, G. "Detergent formula and characteristics of wastewater in septic tanks." *J. Water Poll. Control Fed*., 61(5). 1989.

Allard, L.A., E. Graham, W. Platz, R. Carr, and J. Wheeler. "The StormTreat™ system used as a storm water best management practice." Proceedings of: *Watershed'96, A National Conference on Watershed Management*. June 8 -12, 1996. Baltimore, MA. Tetra Tech, Inc. ISBN: 1-57278-028-2. pp. 463 - 465. 1996.

Aronson, G., D. Watson, and W. Pisano. *Evaluation of Catchbasin Performance for Urban Stormwater Pollution Control*. U.S. EPA. Grant No. R-804578. EPA-600/2-83-043. 78 pages. Cincinnati, June 1983.

Artières, O. *Deposits in Sewer Systems : Origins, Characteristics, Pollution, Transport*. (in French) PhD thesis of the Louis Pasteur University of Strasbourg, 214 p. September 1987.

Austin, Texas (City of). *Design Guidelines for Water Quality Control Basins* . Environmental DCM. City of Austin Transportation and Public Services Department. 1988.

Austin, G., A. Iatrou, and A. Rheams. "Art and fun help save Lake Pontchartrain." Proceedings: *Urban Wet Weather Pollution: Controlling Sewer Overflows and Stormwater Runoff*. June 16 - 19, 1996. Quebec City, Quebec. Water Environment Federation, Alexandria, VA. pp. 9-33 - 9-36. 1996.

Ayyoubi, A.H. *Physical Treatment of Urban Storm Water Runoff Toxicants*. MSCE Thesis. Department of Civil Engineering. University of Alabama at Birmingham. Birmingham, Alabama. 118 pages. 1993.

Azzout, Y., S. Barraud, F.N. Crès, and E. Alfakih. "Alternative techniques for urban storm drainage." (in French) *Tech et Doc, ed. Lavoisier*, Paris, 372 p. 1994.

Baladès, J.D., P. Bourgogne, and H. Madiec. "Assessment of pollutant removal through a compensating technique structure." (in French) *International Conference NOVATECH 92*, Lyon, pp. 66-75. 1992.

Baladès, J.D., P. Bourgogne, and Gourioux. "A reservoir structure pavement for the urban storm drainage of a supermarket area of 120.000 m2 in Bordeaux." (in French) *International Conference NOVATECH 95*, Lyon, pp. 329-336. 1995a.

Baladès, J.D., M. Legret, and H. Madiec. "Porous pavements as tools to control the pollutant loads on urban streets." (in French) *International Conference NOVATECH 95*, Lyon, pp. 345-352. 1995b.

Bannerman, R., J.G. Konrad, and D. Becker. *The IJC Menomonee River Watershed Study*. EPA-905/4-79-029. US Environmental Protection Agency. Chicago Illinois. 1979.

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

Barron. P.F. *Characterization of Polynuclear Aromatic Hydrocarbons in Urban Runoff*. MSCE Thesis . Department of Civil Engineering. The University of Alabama at Birmingham, Birmingham. Alabama. 90 pages. 1990.

Barten, J.M. "Lawn fertilizer as a source of phosphorus runoff." North American Lake Management Society (NALMS) Conference presentation. Minneapolis/St. Paul. October 1996.

Beale, D.C. "Recent developments in the control of urban runoff." *Water and Environmental Management*. Vol. 6, no. 2, pp. 141 - 150. April 1992.

Beech, R.M. and A.F. Dake. *Designing an Effective Communication Program: A Blueprint for Success*. University of Michigan, School of Natural Resources and Environment. For the U.S. Environmental Protection Agency, Region 5. 1992.

Becker, F.A., P.D. Hedges, and R.P.M. Smisson. "The relationship between pollutants and specific sewage settling velocity fractions." *NOVATECH 95, 2nd International Conference on Innovative Technologies in Urban Storm Drainage*. May 30 - June 1, 1995. Lyon, France. pp. 607-610. Organized by Eurydice 92 and Graie. 1995.

Bedner, R.E. and D.J. Fluke. *Demonstration of Debris Basin Effectiveness in Sediment Control*. Environmental Protection Agency, Industrial Environmental Research Laboratory - Cincinnati, EPA-600/7-80-154. Cincinnati, Ohio, 1980.

Bennett, Gary F., Frank S. Feates and Ira Wilder. *Hazardous Materials Spills Handbook*. McGraw-Hill Book Company, New York, 1982. pp. 9-9 - 9-57.

Bernard, C., P. Herviou, T. Poujol, and C. Zobrist. "Procedures for treatment of stormwater and quality objectives: two practical representative examples." Proceedings: *Urban Wet Weather Pollution: Controlling Sewer Overflows and Stormwater Runoff*. Quebec City, Quebec. June 16 - 19, 1996. Water Environment Federation, Alexandria, VA. Pp. 15-59 - 15-68. 1996.

Bertran4-Krajewski, J.-L. "Modeling of flows and of solid transport in sewer systems: literature review." (in French) *Lyonnaise des Eaux/ENGEES report*, Strasbourg, 207 p April 1991.

Bertran4-Krajewski, J.-L., B. Breuil, L. Herremans, and D. Renard. "How to reduce stormwater discharges and their impact on receiving water?" (in French) *La Houille Blanche*, no1/2, pp 155-169. 1994.

Brydges, T. and G. Robinson. "Two examples of urban stormwater impoundment for aesthetics and for protection of receiving waters." In: *Restoration of Lakes and Inland Waters: International Symposium on Inland Waters and Lake Restoration*. Portland, Main, September 1980. Proceedings published by the U.S. Environmental Protection Agency, Washington, D.C. 1986.

Butler, D., P. Clark, and J. Payne. "Management of sediment in drainage catchments." Proceedings of the *6th International Conference on Urban Storm Drainage*. Edited by J. Marsalek and H.C. Torno. Niagara Falls, Ontario. September 12 - 17, 1993. IAWQ, London. Published by Seapoint Publishers, Victoria, B.C. pp. 736 - 741. 1993.

Butler, D. and S.H.P.G. Karunaratne. "The suspended solids trap efficiency of the roadside gully pot." *Wat. Res*. Vol. 29, No. 2. pp. 719-729. 1995.

Butler, D., Y. Xiao, S.H.P.G. Karunaratne, and S. Thedchanamoorthy. "The gully pot as a physical and biological reactor." *Water Science & Technology*. Vol. 31, No. 7, pp. 219-228. 1995.

Cairncross and R.G. Feacham. *Environmental Health Engineering in the Tropics*. John Wiley & Son. NY. 1993.

Candaras, A.M., L.M.J. Carvalho, and M-K. Koo. "City of Etobicoke exfiltration and filtration systems pilot/demonstration project." *Modern Methods for Modeling the Management of Stormwater Impacts*. Edited by W. James. Computational Hydraulics International, Guelph, Ontario. pp. 399 - 419. 1995.

Chambers, G.M. and C.H. Tottle. *Evaluation of Stormwater Impoundments in Winnipeg*. Report SCAT-1, Environment Canada, Ottawa, April 1980.

Clark, D.E.,Jr., and W.C. Cobbin. *Removal Effectiveness of Simulated Dry Fallout from Paved Areas by Motorized and Vacuumized Street Sweepers*. USNRDL-TR-746, U.S. Naval Radiological Defense Laboratory, Alexandria, Virginia, 1963.

Clark, S., R. Pitt, and R. Field. "Stormwater treatment: inlet devices and filtration." Presented at the *Stormwater NPDES Related Monitoring Needs* ASCE conference, Mt. Crested Butte, CO. Proceedings edited by H. Torno. Published by ASCE, New York. pp. 641-650. 1995.

Clark, S. *Evaluation of Filtration Media for Stormwater Runoff Treatment*. MSCE thesis. Department of Civil and Environmental Engineering, University of Alabama at Birmingham. 442 pgs. 1996

Claytor, R. and T. Schueler. *Design of Stormwater Filtering Systems*. Center for Watershed Protection. Silver Spring, MD. 200 pgs. September 1996.

Conradin, F. "Zurich modifies collection system by building open brooks." *Water Environment & Technology*. pp. 26 - 27. November 1995.

Day, G.E. "Investigation of concrete grid pavements." In Proceedings - *National Conference on Urban Erosion and Sediment Control: Institutions and Technology*, EPA-905/9-80-002, U.S. Environmental Protection Agency, Chicago, Ill., January 1980.

Debo, T.N. and Ruby. "Detention ordinances -- Solving or causing problems?," Proceedings: *Conference on Stormwater Detention Facilities, Planning, Design, Operation, and Maintenance.* Henniker, New Hampshire, Edited by W. DeGroot, published by the American Society of Civil Engineers, New York, August 1982.

Delporte, C. "Treating rainfall - enhancing discharges from urban areas using lamellar decantation." Proceedings: *Urban Wet Weather Pollution: Controlling Sewer Overflows and Stormwater Runoff*. Quebec City, Quebec. June 16 - 19, 1996. Water Environment Federation, Alexandria, VA. Pp. 15-1 - 15-9. 1996.

Dewberry and Davis, Inc. *Investigation of Potential Sediment Toxicity from BMP Ponds*. Prepared for the Northern Virginia Planning District Commission, the Occoquan Policy Board, and the Virginia State Water Control Board. May 1990.

Diniz, E.V. *Porous Pavement; Phase I, Design and Operational Criteria*. EPA-600/2-80-135. U.S. Environmental Protection Agency, Cincinnati, Ohio, August 1980.

Diniz, E.V. "Hydrologic and water quality comparisons of runoff from porous and conventional pavements." In: *Integrated Stormwater Management*. Edited by R. Field, M.L. O'Shea, and K.K. Chin. Lewis Publishers. Boca Raton. pp. 149 - 162. 1993.

Driscoll, E. D. “Detention and retention controls for urban stormwater.” Engineering Foundation Conference: *Urban Runoff Quality - Impact and Quality Enhancement Technology*. Henniker, New Hampshire, edited by B. Urbonas and L. A. Roesner. Pp. 145 - 163. Published by the American Society of Civil Engineers, New York, June 1986.

Driscoll, E. D. “Long term performance of water quality ponds.” Engineering Foundation Conference: *Design of Urban Runoff Quality Controls*. Potosi, Missouri. July 10 - 15, 1988. Edited by L. A. Roesner, B. Urbonas and M.B. Sommen. Published by the American Society of Civil Engineers, New York, June 1989.

Driscoll, E.D. and E.W. Strecker “Assessment of BMP’s being used in the U.S. and Canada.” Proceedings of the *6th International Conference on Urban Storm Drainage*. Edited by J. Marsalek and H.C. Torno. Niagara Falls, Ontario. September 12 - 17, 1993. IAWQ, London. Published by Seapoint Publishers, Victoria, B.C. pp. 945 - 950. 1993.

Droste, R.L. and J.C. Johnston. “Urban snow dump quality and pollutant reduction in snowmelt by sedimentation.” *Canadian Journal of Civil Engineering*. Vol. 20, pp. 9-21. February 1993.

Duchene, M., E. McBean, and N. Thomson. “Infiltration characteristics associated with the use of trenches in stormwater management.” Proceedings of the *6th International Conference on Urban Storm Drainage*. Edited by J. Marsalek and H.C. Torno. Niagara Falls, Ontario. September 12 - 17, 1993. IAWQ, London. Published by Seapoint Publishers, Victoria, B.C. pp. 1115 - 1120. 1993.

Duru, J. O. “On-site detention: A stormwater management or mismanagement technique.” *Second International Conference on Urban Storm Drainage*, Urbana, Illinois, June 1981.

Eccher. C.J. “Thoughtful design is prime factor in water safety.” *Lake Line*. pp. 4-8. May 1991.

EDP (Environmental Design and Planning, Inc.). *Evaluation of Catchbasin Monitoring*. Contract No. R804578010, U.S. Environmental Protection Agency, Cincinnati, Ohio, March 1980.

Ellis, J.B. “Pollutional aspects of urban runoff.” *Urban Runoff Pollution*, NATO ASI series, vol. G10, Springer Verlag, Berlin, pp. 1-38. 1986.

Ellis, J.B. “Wetland BMP design for urban runoff pollution control in Europe and Australia.” Proceedings of the *6th International Conference on Urban Storm Drainage*. Edited by J. Marsalek and H.C. Torno. Niagara Falls, Ontario. September 12 - 17, 1993. IAWQ, London. Published by Seapoint Publishers, Victoria, B.C. pp. 957 - 962. 1993.

Emmerling-DiNovo, C. “Stormwater detention basins and residential locational decisions.” *Water Resources Bulletin*. Vol. 31, no. 3, pp. 515-521. June 1995.

EPA (U.S. Environmental Protection Agency). *Final Report for the Nationwide Urban Runoff Program*. Water Planning Division, Washington, D.C., December 1983.

EPA (U.S. Environmental Protection Agency). *Methodology for Analysis of Detention Basins for Control of Urban Runoff Quality*. Office of Water, NonPoint Source Division. Washington, D.C., September 1986.

EPA. *Urban Runoff Management Information/Education Products*. Developed for US EPA Region 5, Water Division, Wetlands and Watershed Section Watershed Management Unit and USEPA Office of Wastewater Enforcement and Compliance Permits Division, NPDES Program Branch, Stormwater Section, Version 1. 1993.

EPA. *Nonpoint Source News Notes*. Issue #46. Also available through http://www.epa.gov. August/September 1996.

Fair, G.M. and J.C. Geyer. *Water Supply and Waste Water Disposal*. John Wiley and Sons. New York. 1954.

Federal Register. 55 (No. 222; November 16), 48062. 1990.

Field, R. and R. Pitt. “Combined sewer overflow control through in-receiving water storage: an efficiency evaluation.” *Water Environment Federation Specialty Conference on A Global Perspective for Reducing CSOs: Balancing Technologies, Costs, and Water Quality*. Louisville, KT. July 1994a.

Field, R. and R. Pitt. “Optimization of CSO storage and treatment systems.” *Water Environment Federation Specialty Conference on A Global Perspective for Reducing CSOs: Balancing Technologies, Costs, and Water Quality*. Louisville, KT. July 1994b.

Field, R., R. Pitt, D. Jaeger, and M. Brown. “Combined sewer overflow control through in-receiving water storage: an efficiency evaluation.” *Water Resources Bulletin*, the Journal of the American Water Resources Association. Vol. 30, No. 5. pp. 921-928. October 1994.

Field, R. M.P. Brown, W.V. Vilkelis. *Stormwater Pollution Abatement Technologies*. U.S. Environmental Protection Agency, Office of Research and Development. Cincinnati. OH. EPA/600/R-94/129. 1994.

Field, R., R. Pitt, M. Lalor, M. Brown, W. Vilkelis, and E. Thackston. “Investigation of dry-weather pollutant entries into storm-drainage systems.” *J. Envir. Eng*. Vol. 120, No. 5, pp. 1044-1066. Sept./Oct. 1994.

Field, R., R. Pitt, M. Brown, and T. O’Conner. “Combined sewer overflow control using storage in seawater.” *Water Research*. Elsevier Science. Vol. 29, No. 6, pp. 1505-1514. 1995.

Forndran, A., R. Field, K. Dunkers, and D. Moran. “Balancing flow for CSO abatement.” *Water Environment & Technology*. pp. 54-58. May 1991.

Fourage, M. “Assessment of the efficiency of a prefabricated separator for stormwater treatment. Thoughts to and tests of materials to trap hydrocarbons.” (in French) *Unpublished DESS student report, Universities of Nancy and Metz*, September 1992.

Free, B. M. and G. G. Mulamoottil. “The limnology of Lake Wabukayne, A storm-water impoundment.”, *Water Resources Bulletin*, Vol. 19, no. 5, pg. 821, October 1983.

Fuhr, M. “Will your pond hold water?” *Land and Water*, Vol. 40, no. 6, pg. 38. Nov./Dec. 1996.

Fujita, S. “Infiltration in congested urban areas of Tokyo.” Proceedings of the *6th International Conference on Urban Storm Drainage*. Edited by J. Marsalek and H.C. Torno. Niagara Falls, Ontario. September 12 - 17, 1993. IAWQ, London. Published by Seapoint Publishers, Victoria, B.C. pp. 993 - 998. 1993.

Fujita, S. “Infiltration structures in Tokyo.” *Water Science and Technology*. Vol. 30, no. 1, pp. 33 - 41. 1994.

Galli, John. *Peat-Sand Filters: A Proposed Stormwater Management Practice for Urbanized Areas.* Prepared for the Coordinated Anacostia Retrofit Program and Office Of Policy and Planning, D.C. Department of Public Works. December 1990.

Gburek, W.J. and J.B. Urban. “Storm water detention and groundwater recharge using porous asphalt - initial results.” *1983 International Symposium on Urban Hydrology, Hydraulics and Sediment Control*, University of Kentucky, Lexington, Kentucky, July 1983.

Geldof, G., P. Jacobsen, and S. Fujita. “Urban stormwater infiltration perspectives.” Proceedings of the *6th International Conference on Urban Storm Drainage*. Edited by J. Marsalek and H.C. Torno. Niagara Falls, Ontario. September 12 - 17, 1993. IAWQ, London. Published by Seapoint Publishers, Victoria, B.C. pp. 963 - 968. 1993.

Geldof, G., P. Jacobsen, and S. Fujita. “Urban stormwater infiltration perspectives.” *Water Science and Technology*. Vol. 29, no. 1 - 2, pp. 245-254. 1994.

Gietz, R.J. *Urban Runoff Treatment in the Kennedy-Burnett Settling Pond*. For the Rideau River Stormwater Management Study, Pollution Control Division, Works Department, Regional Municipality of Ottawa-Carleton, Ottawa, Ontario, March 1983.

Goforth, G.F., E.V. Diniz, and J.B. Rauhut. *Stormwater Hydrological Characteristics of Porous and Conventional Paving Systems*. EPA-600/2-83-106, U.S. Environmental Protection Agency, Cincinnati, Ohio, February 1984 (also dated October 1983).

Green, M.B. and J.R. Martin. “Constructed reed beds clean up storm overflows on small wastewater treatment works.” *Water Environment Research*. Vol. 68, no. 6, pp. 1054 - 1060. Sept./Oct. 1996.

Grottker, M. “Pollutant removal by gully pots in different catchment areas.” *The Science of the Total Environment*. Vol. 93. pp. 515-522. 1990.

Hall, M.J. “The design of flood storage ponds: catering for both quality and quantity of runoff.” *Developments in Storm Drainage - A Symposium on Infiltration and Storage of Stormwater in New Developments*. Sheffield City. Jan. 1990. Pp. 21 - 33. 1990.

Harada, S. and A. Ichikawa. “A study on the performance of the drainage infiltration strata.” Proceedings of the *6th International Conference on Urban Storm Drainage*. Edited by J. Marsalek and H.C. Torno. Niagara Falls, Ontario. September 12 - 17, 1993. IAWQ, London. Published by Seapoint Publishers, Victoria, B.C. pp. 1104 - 1109. 1993.

Harper, H.H. and J.L. Herr. “Alum treatment of stormwater - The first ten years: What have we learned and where do we go from here?” North American Lake Management Society (NALMS) Conference presentation. Minneapolis/St. Paul. October 1996.

Hawley, M. E., T. R. Bondelid, and R. H. McCuen. “A planning method for evaluating downstream effects of detention basins.” *Water Resources Bulletin*, Vol. 17. no. 5, pg. 806, October 1981.

Heinzmann, B. “Coagulation and flocculation of stormwater from a separated storm sewer - A new possibility for enhanced treatment.” *2nd International Conference on: Upgrading of Wastewater Treatment Plants*. Berlin. September 21 - 24, 1993. Sponsored by IAWQ and EWPCA. Pp. 304 - 313. 1993.

Herr, J.L. and H.H. Harper. “The evaluation and design of an alum stormwater treatment system to improve water quality in Lake Maggiore, St. Petersburg, Florida” North American Lake Management Society (NALMS) Conference presentation. Minneapolis/St. Paul. October 1996.

Herath, S. and K. Musiake. “Simulation of basin scale runoff reduction by infiltration systems.” *Water Science and Technology*. Vol. 29, no. 1 - 2, pp. 267 - 275. 1994.

Hey, D.L. and G.C. Schaefer. *An Evaluation of the Water Quality Effects of Detention Storage and Source Control*. U.S. Environmental Protection Agency and the Northeastern Illinois Planning Commission, Chicago, August 1983.

Hvitve4-Jacobsen, T., K. Keiding, and Y.A. Yousef. "Urban runoff pollution removal in wet detention ponds." Proceedings of the 4th *International Conference on Urban Storm Drainage*. Lausanne, Switzerland. August 1987. Water Resources Publications. pp. 137 - 142. 1987.

Hvitve4-Jacobsen, T., N.B. Johansen, and Y.A. Yousef. "Treatment systems for urban and highway runoff in Denmark." In: the 4th International Symposium on Highway Pollution, Madrid, Spain. May 18-22, 1992. *The Science of the Total Environment*, 1992.

Hvitve4-Jacobsen, T., N.B. Johansen, and Y.A. Yousef. "Treatment systems for urban and highway runoff in Denmark." *The Science of the Total Environment*. No. 146/147, pp. 499-506. 1994.

Herricks, E.E., editor. *Stormwater Runoff and Receiving Systems: Impact, Monitoring, and Assessment*. Engineering Foundation and ASCE. CRC/Lewis. Boca Raton, FL. 1995.

Hogland, W., J. Niemczynowicz , and T. Wahlman. "The unit superstructure during the construction period." *The Science of the Total Environment*, 1987, vol. 59, pp. 411-424. 1987.

Hogland, W. "Pervious asphalt construction - an overview of the situation in Sweden and the U.S.A." *Developments in Storm Drainage - A Symposium on Infiltration and Storage of Stormwater in New Developments*. Sheffield City. Jan. 1990. Pp. 122 - 135. 1990.

Jackson, H.B. "Global needs and developments in urban sanitation." *Proc. Int. Conf. On Low Cost Sewerage*. Univ.Leeds, UK, July 1995.

Jacobsen, P. and P.S. Mikkelsen. "Reduction of urban runoff pollutant loads using detention ponds and stormwater infiltration techniques." *Proceedings of the 7th Conference of Urban Storm Drainage*. Hanover, Germany. Sept. 9-13, 1996.

Jones, J. E. and D. E. Jones. "Interfacing considerations in urban detention ponding." Proceedings of the Conference: *Stormwater Detention Facilities, Planning, Design, Operation, and Maintenance*. Henniker, New Hampshire, Edited by W. DeGroot, published by the American Society of Civil Engineers, New York, August 1982.

Jones, J. "Beware the sediment scare." *Civil Engineering*. pp. 56-57. July 1995.

Jones, J., S. Anderson, J. Fognani. F.R. McGregor, and T. Axley. "Stormwater best management practices: When is sediment considered hazardous?" *Water Environment & Technology*. Vol. 8, no. 10, pp. 51-57. October 1996.

Kamedulski, G. E. and R. H. McCuen. "The effect of maintenance on storm water detention basin efficiency." *Water Resources Bulletin*, Vol. 15, no. 4, pg. 1146, August 1979.

Karunaratne, S.H.P.G. *The Influence of Gully Pot Performance on the Entry of Sediment into Sewers*. Ph.D. dissertation. South Bank University. London. 1992.

Kercher, W.C., J.C. Landon and R. Massarelli. "Grassy swales prove cost-effective for water pollution control". *Public Works*, April 1983.

Kloiber, S.M. and P.L. Brewonik. "Effectiveness of continuous alum treatment for phosphorus removal from stormwater." North American Lake Management Society (NALMS) Conference presentation. Minneapolis/St. Paul. October 1996.

Krejci, V., P. Haldimann, and M. Grottker. "Administrative aspects of stormwater infiltration in Switzerland." Proceedings of the *6th International Conference on Urban Storm Drainage*. Edited by J. Marsalek and H.C. Torno. Niagara Falls, Ontario. September 12 - 17, 1993. IAWQ, London. Published by Seapoint Publishers, Victoria, B.C. pp. 999 - 1004. 1993.

Kuo, C.Y., J.L. Zhu, and L.A. Dollard. *A Study of Infiltration Trenches*. VPI-VWRRC-BULL 163. 3.5C. Virginia Water Resources Research Center, Virginia Polytechnic Institute and State University. Blacksburg, VA. 87 pgs. 1989.

Lager, J.A., W.G. Smith, and G. Tchobanoglous. *Catchbasin Technology Overview and Assessment*. U.S. EPA. Contract No. 68-03-0274. EPA-600/2-77-051. 129 pages Cincinnati, May 1977.

Lager, J.A., W.G. Smith, W.G. Lynard, R.M. Finn, and E.J. Finnemore. *Urban Stormwater Management and Technology: Update and Users' Guide*. U.S. Environ. Protection Agency, EPA-600/8-77-014, 313 p. Cincinnati, Ohio, September 1977.

Lake Line "The Nutri-Pod: A new way." pp. 2-19. February 1991.

Lake Tahoe Regional Planning Agency. *Lake Tahoe Basin Water Quality Management Plan, Volume II, Handbook of Best Management Practices*. Lake Tahoe, California, January 1978.

Lalor, M. M. *Assessment of Non-Stormwater Discharges to Storm Drainage Systems in Residential and Commercial Lan4-Use Areas*, Ph.D. thesis, Vanderbilt University, Nashville, Tennessee. 1993.

Land and Water "Storm pond turned into selling feature" Vol. 40, no. 6, pg. 35. Nov./Dec. 1996.

Laplace, D., A. Bachoc, Y. Sanchez, and D. Dartus. "Truck sewer clogging development - description and solutions." *Water Science and Technology*. Vol. 25, No. 8, pp. 91-100. 1992.

Legrand, J., H. Maillot, F. Nougarède, and S. Defontaine. "A device for stormwater treatment in the urban development zone of Annœullin." (in French) *TSM*, no 11, pp 639-643. 1994.

Legret, M., D. Demare, V. Colandini, J-D. Balades, and H. Madiec. "Behaviour of metallic pollutants in a pervious road construction." Proceedings of the *6th International Conference on Urban Storm Drainage*. Edited by J. Marsalek and H.C. Torno. Niagara Falls, Ontario. September 12 - 17, 1993. IAWQ, London. Published by Seapoint Publishers, Victoria, B.C. pp. 1201 - 1206. 1993.

Lind, B.B. and E. Karro. "Stormwater infiltration and accumulation of heavy metals in roadside green areas in Goteborg, Sweden." *Ecological Engineering*. Vol. 5, no. 4, pp. 533-529. Dec. 1995.

Luzkow, S.M., D.A. Scherger, and J.A. Davis. "Effectiveness of two in-line urban stormwater best management practices (BMP's)." *1981 International Symposium on Urban Hydrology, Hydraulics, and Sediment Control*, University of Kentucky, Lexington, Kentucky, July 1981.

Magmedov, V.G., M.A. Zakharchenko, L.I. Yakovleva, and M.E. Ince. "Use of constructed wetlands for the treatment of runoff and drainage waters: the UK and Ukraine experience." *Water Science and Technology*. Vol. 33, no. 4 - 5, pp. 315-323. 1996.

Marcy, S. J. and J. E. Flack. "Safety considerations in urban storm drainage design." *Second International Conference on Urban Storm Drainage.* Urbana, Illinois, June 1981.

Marsalek, J., D. Weatherbe, and G. Zukovs. "Institutional aspects of stormwater detention." Proceedings of the Conference: *Stormwater Detention Facilities, Planning, Design, Operation, and Maintenance*. Henniker, New Hampshire, Edited by W. DeGroot, published by the American Society of Civil Engineers, New York, August 1982.

Martin, E. and R.A. Miller. "Efficiency of an urban stormwater detention system." Proceedings of the 4th *International Conference on Urban Storm Drainage*. Lausanne, Switzerland. August 1987. Water Resources Publications. pp. 143 - 148. 1987.

Martin, E.H. "Mixing and residence times of stormwater runoff in a detention system." Engineering Foundation Conference: *Design of Urban Runoff Quality Controls*. Potosi, Missouri. July 10 - 15, 1988. Edited by L. A. Roesner, B. Urbonas and M.B. Sommen. pp. 164 - 179. Published by the American Society of Civil Engineers, New York, June 1989.

Maxted, J. and E. Shaver. "The use of retention basins to mitigate stormwater impacts on aquatic life." Engineering Foundation Conference: *Effects of Watershed Development & Management on Aquatic Ecosystems*. Snowbird, Utah. August 4-9, 1996. To be published by the Engineering Foundation, New York, 1997.

Mayer, T., J. Marsalek, and E. Delos Reyes. "Nutrients and metal contaminants status of urban stormwater ponds." *Journal of Lake and Reservoir Management*. Vol. 12, no. 3, pp. 348-363. 1996.

McComas, S.R. and D.F. Sefton. "Comparison of stormwater runoff impacts on sedimentation and sediment trace metals for two urban impoundments." In: *Lake and Reservoir Management: Practical Applications*, proceedings of the Fourth Annual Conference and International Symposium, October, 1984, North American Lake Management Society, McAfee, New Jersey, 1985.

Metcalf & Eddy, Inc. *Wastewater Engineering: Treatment, Disposal, and Reuse*. McGraw-Hill Publishing Company, New York, New York. 1991.

Metcalf & Eddy Inc. *Handbook: Urban Runoff Pollution Prevention and Control Planning*. U.S. Environmental Protection Agency, Office of Research and Development. Cincinnati. OH. EPA/625/R-93/004. 1993.

Metropolitan Washington Council of Governments. *Analysis of Urban BMP Performance and Longevity*. Prince George's County, Department of Environmental Resources. 1992.

Mikkelsen, P.S., G. Weyer, C. Berry, Y. Walden, V. Colandini, S. Paulsen, D. Grotehusmann, and R. Rohlfing. "Pollution from urban stormwater infiltration." *Water Science and Technology*. Vol. 29, no. 1 - 2, pp. 293-302. 1994.

Montoya, B.l. *Urban Runoff Discharges From Sacramento, California*. CVRWQCB Report Number 87-1SPSS, prepared for the California Regional Water Quality Control Board, Central Valley Region. 1987.

Mugass, R.J. "Home lawn care practices to help protect surface water quality." North American Lake Management Society (NALMS) Conference presentation. Minneapolis/St. Paul. October 1996.

Musiake, K., J. Okamura, and J. Matsushita. "The urban hydrological system with shallow infiltration facilities - a case study of an area in Tokyo Metropolis." Proceedings of the 5th *International Conference on Urban Storm Drainage*. Osaka, Japan. July 1990. pp. 113 - 118. 1990.

Nawang, W.M. and S. Saad "Stormwater infiltration investigation using porous pavement" Proceedings of the *6th International Conference on Urban Storm Drainage*. Edited by J. Marsalek and H.C. Torno. Niagara Falls, Ontario. September 12 - 17, 1993. IAWQ, London. Published by Seapoint Publishers, Victoria, B.C. pp. 1092 - 1097. 1993.

Newman, T.L., W.M. Leo, J.A. Muekker, and R. Gaffoglio. “Effectiveness of street cleaning for floatables control.” Proceedings: *Urban Wet Weather Pollution: Controlling Sewer Overflows and Stormwater Pollution*. June 16 - 19, 1996. Quebec City, Quebec. Water Environment Federation. Alexandria, VA. 1996.

Niemczynowicz, J. and W. Hogland. “Tests of porous pavement in Lund, Sweden.” Proceedings of the 4*th* *International Conference on Urban Storm Drainage*. Lausanne, Switzerland. August 1987. Water Resources Publications. pp. 79 - 80. 1987.

Niemczynowicz, J. “Swedish stormwater detention practices.” Proceedings of the 5*th* *International Conference on Urban Storm Drainage*. Osaka, Japan. July 1990. pp. 197 - 202. 1990.

Niemczynowicz, J. “New aspects of urban drainage and pollution reduction towards sustainability.” *Wat.Sci.Tech*. Vol.30, No.5, pp269-277. 1994.

Nix, S.J. and S.R. Durrans. “Off-line stormwater detention systems.” *Water Resources Bulletin*. Vol. 32, no. 6, pp. 1329 - 1340. December 1996.

NOVATECH. “International conference on new technologies for urban storm drainage.” (in French and English) *GRAIE/Eurydice 92 editors*, Lyon, 568 p. 1992.

NOVATECH. “2nd International conference on new technologies for urban storm drainage.” (in French and English) *GRAIE/Eurydice 92*, Lyon, 670 p. 1995.

Novotny, V., H.M. Sung, R. Bannerman, and K. Baum. “Estimating non-point pollution from small urban watersheds.” *Journal of Water Pollution Control Federation*, vol. 57, no 4, pp 339-348. 1985.

Oberts, G. “Design considerations for management of urban runoff in wintry conditions.” Proceedings: *International Conference on Urban Hydrology under Wintry Conditions*. March 19 - 21, 1990. Narvik, Norway. 1990.

Oberts, G. Performance of stormwater ponds and wetlands in winter.” Technical note 16. *Watershed Protection Techniques*. Vol. 1, no. 2, pp. 64-68. Summer 1994.

Oliver, L.J. and S.G. Grigoropoulis. “Control of storm-generated pollution using a small urban lake.” *Journal Water Pollution Control Federation*, Vol 53, No. 5, May 1981.

Ontario (Province of). *Urban Drainage Design Guidelines (Draft)*. Urban Drainage Policy Implementation Committee, Technical Sub-Committee No. 3. March 1984.

Payne, J. and A. Davies. “Manual on infiltration methods for stormwater source control.” Proceedings of the *6th International Conference on Urban Storm Drainage*. Edited by J. Marsalek and H.C. Torno. Niagara Falls, Ontario. September 12 - 17, 1993. IAWQ, London. Published by Seapoint Publishers, Victoria, B.C. pp. 981 - 986. 1993.

Perkins, M. A. “Managing aquatic plants with fiberglass screens.” In: *Restoration of Lakes and Inland Waters*. Proceedings of the International Symposium on Inland Waters and Lake Restoration, Portland, Maine, September 1980, published by the U.S. Environmental Protection Agency, Washington. D.C., December 1980.

Petersen, C.R., T. Faarbaek, G.H. Jensen, G. Weyer, S. Fujita, K. Ishikawa, G. Geldof, C. Stenmark, and C.J. Pratt. “Urban stormwater infiltration design practice and technology: state of the art assessment.” Proceedings of the *6th International Conference on Urban Storm Drainage*. Edited by J. Marsalek and H.C. Torno. Niagara Falls, Ontario. September 12 - 17, 1993. IAWQ, London. Published by Seapoint Publishers, Victoria, B.C. pp. 969 - 974. 1993.

Pisano, W.C. and H. Brombach. “Solids settling curves: Wastewater solids data can aid design of urban runoff controls.” *Water Environment & Technology*. Vol. 8, no. 4, pp. 27-33. April 1996.

Pitt, R., J. Ugelow, and J.D. Sartor. *Systems Analysis of Street Cleaning Techniques*. Prepared for the American Public Works Association and the National Science Foundation, RANN Program, Washington, D.C., March 1976.

Pitt, R. *Demonstration of Nonpoint Pollution Abatement Through Improved Street Cleaning Practices*. U.S. EPA. Grant No. S-804432. EPA-600/2-79-161. 270 pages. Cincinnati, August 1979.

Pitt, R. and M. Bozeman. *Lake Merritt Management Plan*. City of Oakland Department of Public Works, Oakland, California, May 1979.

Pitt, R. and G. Shawley. *A Demonstration of Non-Point Source Pollution Management on Castro Valley Creek*. Alameda County Flood Control and Water Conservation District (Hayward, CA) for the Nationwide Urban Runoff Program, U.S. Environmental Protection Agency, Water Planning Division, Washington, D.C., June 1982.

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

Pitt, R. *Characterizing and Controlling Urban Runoff through Street and Sewerage Cleaning*. U.S. EPA. Contract No. R-805929012. EPA/2-85/038. PB 85-186500/AS. 467 pages. Cincinnati, June 1985.

Pitt, R. and J. McLean. *Toronto Area Watershed Management Strategy Study - Humber River Pilot Watershed Project*. Ontario Ministry of the Environment, Toronto, Ontario, June 1986.

Pitt, R. *Small Storm Urban Flow and Particulate Washoff Contributions to Outfall Discharges*. Ph.D. dissertation. Dept. of Civil and Environmental Engineering, the University of Wisconsin, Madison, Wisconsin. Listed in Dissertation Abstracts International, University Microfilms International, Vol. 49, No. 1, 1988. November 1987.

Pitt, R. and J. Voorhees. *DETPOND 4: A Water Quality Detention Pond Design Program; Model Documentation and Users Manual*. Wisconsin Department of Natural Resources, May 1989.

Pitt, R. and K. Dunkers. “Combined treatment of stormwater and lakewater in Lake Rönningesjön, Sweden.” *12th Annual International Symposium, North American Lake Management Society*, Cincinnati, Ohio, November 1992.

Pitt, R. “Detention pond design for water quality improvement.” *National ASCE Hydraulic Conference*. San Francisco, California. July 1993a.

Pitt, R. “The stormwater quality detention pond model (DETPOND).” *26th Annual Water Resources Conference*. University of Minnesota. October 1993b.

Pitt, R. and K. Dunkers. “Lake water quality improvements from treatment of stormwater using the Flow Balancing Method.” *66th Annual Water Environment Federation Conference*. Anaheim, California. October 1993.

Pitt, R. E., Field, R. I., Lalor, M. M., Adrian, D. D., Barbe', D.. *Investigation of Inappropriate Pollutant Entries into Storm Drainage Systems: A User's Guide.* Rep. No. EPA/600/R-92/238, NTIS Rep. No. PB93-131472/AS, US EPA, Storm and Combined Sewer Pollution Control Program (Edison, New Jersey), Risk Reduction Engineering Lab., Cincinnati, Ohio. 1993

Pitt, R. “Water quality trends from stormwater controls.” In: *Stormwater NPDES Related Monitoring Needs* (Edited by H.C. Torno). Engineering Foundation and ASCE. pp. 413-434. 1995a.

Pitt, R. “Preliminary investigation of EquaFlow™ system for Town Lake, Austin, TX.” Unpublished report prepared for Loomis and Associates and the City of Austin, TX, October 1995b.

Pitt, R. *Groundwater Contamination from Stormwater.* ISBN 1-57504-015-8. Ann Arbor Press, Inc. Chelsea, Michigan. 219 pages. 1996.

Pitt, R., R. Field, M. Lalor, and M. Brown. “Urban stormwater toxic pollutants: assessment, sources and treatability.” *Water Environment Research*. Vol. 67, No. 3, pp. 260-275. May/June 1995. Discussion and closure in Vol. 68, No. 4, pp. 953-955. July/August 1996.

Pitt, R. E. and Lalor, M. M. *Final Draft Report: Demonstration Project for the Investigation of Inappropriate Pollutant Entries into Storm Drainage Systems*. Contract No.68-C9-0033, U.S. Environmental Protection Agency, Risk Reduction Engineering Lab., Cincinnati, Ohio. To be published in 1997.

Pitt, R. “The control of toxicants at critical source areas.” In: *Effects of Watershed Development and Management on Aquatic Ecosystems*. Engineering Foundation Conference: *Effects of Watershed Development & Management on Aquatic Ecosystems*. Snowbird, Utah. August 4-9, 1996. To be published in 1997.

Pitt, R., R. Field, and K. Gordon. *An Evaluation of Storm Drainage Inlet Devices for Stormwater Quality Treatment*. Cooperative agreement CR 819573. U.S. Environmental Protection Agency, Risk Reduction Engineering Lab., Cincinnati, Ohio. To be published in 1997.

Poertner, H.G. *Practices in Detention of Urban Stormwater Runoff*. American Public Works Association, OWRR Contract No. 14-31-0001-3722, Chicago, 1974.

Poertner, H.G. *Stormwater Management in the United States*. Office of Water Research and Technology. Dept. of the Interior. Project No. C-5239. September 1980.

Pratt, C.J., G.E.P. Elliott, and G.A. Fulcher. “Suspended solids discharge from highway gully pots in a residential catchment.” *The Science of the Total Environment*. Vol. 59. pp. 355-364. 1987.

Pratt, C.J., J.D.G. Mantle, and P.A. Schoffield. “Urban stormwater reduction and quality improvement through the use of permeable pavements.” *Urban Discharges and Receiving Water Quality Impacts*. Pergamon Press, Oxford, 1989, pp. 123-132. 1989.

Pratt, C.J. “Permeable pavements; design and maintenance” *Developments in Storm Drainage - A Symposium on Infiltration and Storage of Stormwater in New Developments*. Sheffield City. Jan. 1990. Pp. 136 - 151. 1990.

Pratt, C.J. “An assessment of effectiveness of a BMP strategy in urban drainage in the U.K.” Proceedings of the *6th International Conference on Urban Storm Drainage*. Edited by J. Marsalek and H.C. Torno. Niagara Falls, Ontario. September 12 - 17, 1993. IAWQ, London. Published by Seapoint Publishers, Victoria, B.C. pp. 951 - 956. 1993.

Pratt, C.J. and J.J.M. Powell. “A new UK approach for the design of sub-surface infiltration systems.” Proceedings of the *6th International Conference on Urban Storm Drainage*. Edited by J. Marsalek and H.C. Torno. Niagara Falls, Ontario. September 12 - 17, 1993. IAWQ, London. Published by Seapoint Publishers, Victoria, B.C. pp. 987 - 992. 1993.

Pratt, C.J., J.D.G. Mantle, and P.A. Schoffield. "UK research into the performance of permeable pavement, reservoir structures in controlling stormwater discharge quantity and quality." *International Conference NOVATECH 95*, Lyon, pp. 337-344. 1995.

Pratt, C.J. "Research and development in methods of soakaway design." *Journal of the Chartered Institution of Water and Environmental Management*. Vol. 10, no. 1, pp. 47-51. Feb. 1996.

Ranchet, J., F. Penaud, R. Le Grand, A. Constant, P. Obry, and B. Soudieu. (1993). "Comparison of an impervious pavement and a porous pavement from hydraulic and stormwater pollutant removal points of view." (in French) *Bulletin de Liaison des Laboratoires des Ponts et Chaussées*, no 188 November/December 1993.

Roberts, B. "Storm-water treatment goes underground." *Civil Engineering*. pp. 56-57. July 1996.

Robertson, B., R. Pitt, A. Ayyoubi, and R. Field. "A multi-chambered stormwater treatment train." In: *Stormwater NPDES Related Monitoring Needs* (Edited by H.C. Torno). Engineering Foundation and ASCE. pp. 631-640. 1995.

Roesner, L.A., B.R. Urbonas and M.B. Sonnen, editors. *Design of Urban Runoff Quality Controls*. Proceedings of an Engineering Foundation Conference on Current Practice and Design Criteria for Urban Quality Control, American Society of Civil Engineers, NY. 1989.

Rosted Petersen, C.O., P. Jacobsen, P.S. Mikkelsen. "Design of stormwater infiltration for reduction of combined sewer overflow (CSO)." *Water Science and Technology*, Vol. 30, no. 1, pp. 53-61. 1994.

Rubin, Alan J. and D.L. Mercer. "Adsorption of free and complexed metals from solution by activated carbon." In: *Adsorption of Inorganics at Soli4-Liquid Interfaces*. Edited by Marc A. Anderson and Alan J. Rubin. Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, 1981. pp. 295-326.

Rupperd, Y. "A lamellar separator for urban street runoff treatment." (in French) *Bulletin de Liaison des Laboratoires des Ponts et Chaussées*, no 183, pp 85-90.1993.

Salvato, J.A. *Environmental Engineering and Sanitation*. 4th Ed. John Wiley & Sons. NY. 1992.

Sartor, J. and G. Boyd. *Water Pollution Aspects of Street Surface Contaminants*. U.S. EPA. Contract No. 14-12-921. EPA-R2-72-081. 236 pages. Washington, D.C., November 1972.

Sartor, J.D., G.B. Boyd, and F.J. Agardy. "Water pollution aspects of street surface contaminants." *Journal of Water Pollution Control Federation*, vol. 46, no 3, pp 458-467. 1974.

Schmitt, T.G. "Integrated storm water management in urban areas." *European Water Pollution Control*. Vol. 6, no. 3, pp. 14 - 20. May 1996.

Schimmenti, F.G. "Stormwater detention basins must control more than runoff." *American City and County*. December 1980.

Schumacher, J.W. and R.F. Grimes. "A model public education process for stormwater management." *Public Works*. Vol. 123. pp. 55 - 58. September 1992.

Schueler. T. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban Best Management Practices*. Metropolitan Washington Council of Governments. 280 pgs. 1987.

Schueler, T.R. and J. Galli. "The environmental impact of stormwater ponds." Engineering Foundation Conference: *Urban Runoff and Receiving Systems: An Interdisciplinary Analysis of Impact, Monitoring, and Management*. Mt. Crested Butte, Colorado. August 4-9, 1991. Published by the American Society of Civil Engineers, New York, June 1992.

Schueler, T. (editor). "Hydrocarbon hotspots in the urban landscape: can they be controlled?" *Watershed Protection Techniques*. Vol. 1, No. 1, pp. 3 - 5. Feb. 1994.

Schueler, T. (editor). "Vegetated rock filter treats stormwater pollutants in Florida" *Watershed Protection Techniques*. Vol. 2, No. 2, pp. 372 - 374. Spring 1996.

Schueler, T. (editor). "Ditches or biological filters? Classifying the pollutant removal performance of open channels" *Watershed Protection Techniques*. Vol. 2, No. 2, pp. 379 - 383. Spring 1996.

SEMCOG (Southeast Michigan Council of Governments). *Detention Basin Maintenance, Program Needs and Financing Options*. Technical Bulletin No. 3, Detroit, Michigan, May 1981.

Shaver, Earl. *Use of Sand Filters as an Urban Stormwater Management Practice*. State of Delaware Department of Natural Resources and Environmental Control.

Smith, W.G. "Water quality enhancement through stormwater detention." *Proceedings of the Conference on Stormwater Detention Facilities, Planning, Design, Operation, and Maintenance*, Henniker, New Hampshire, Edited by W. DeGroot, published by the American Society of Civil Engineers, New York, August 1982.

Stahre, P. "Assessment of BMP's being used in Scandinavia." Proceedings of the *6th International Conference on Urban Storm Drainage*. Edited by J. Marsalek and H.C. Torno. Niagara Falls, Ontario. September 12 - 17, 1993. IAWQ, London. Published by Seapoint Publishers, Victoria, B.C. pp. 939 - 944. 1993.

Stahre, P. and B. Urbonas. *Stormwater Detention for Drainage, Water Quality and CSO Management*. Prenticd Hall. Englewood Cliffs. 340 pgs. 1990.

Stanley, D.W. "Pollutant removal by a stormwater dry detention pond." *Water Environment Research*. Vol. 68, no. 6, pp. 1076 - 1083. Sept./Oct. 1996.

Stenmark, C. "Local infiltration of urban storm water in cold climate." Proceedings of the 5th *International Conference on Urban Storm Drainage*. Osaka, Japan. July 1990. pp. 809 - 814. 1990.

Stenmark, C. "An alternative road construction for stormwater management in cold climates." *Water Science & Technology*. Vol. 32, no. 1, pp. 79 - 84. 1995.

Sutherland, R.C. and S.L. Jelen. "Sophisticated stormwater quality modeling is worth the effort." In: *Advances in Modeling the Management of Stormwater Impacts*. Edited by W. James. Computational Hydraulics International. Guelph, Ontario. 1996.

Sutherland, R.C. "Studies show sweeping has beneficial impact on stormwater quality." *APWA Reporter*. pp. 8 - 23. 1996.

Swaffield, J.A. and L.S. Gallowin. *The Engineered Design of Building Drainage Systems*. Ashgate publishing, Aldershot. 1992.

Sztruhar, D. and H.S. Wheater. "Experimental and numerical study of stormwater infiltration through pervious parking lots." Proceedings of the *6th International Conference on Urban Storm Drainage*. Edited by J. Marsalek and H.C. Torno. Niagara Falls, Ontario. September 12 - 17, 1993. IAWQ, London. Published by Seapoint Publishers, Victoria, B.C. pp. 1098 - 1103. 1993.

Tenney, S., M.E. Barrett, J.F. Malina, R.J. Charbeneau, and G.H. Ward. *An Evaluation of Highway Runoff Filtration Systems*. Center for Research in Water Resources. Technical Report CRWR 265. The University of Texas at Austin. 133 pgs. September 1995.

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

Thompson, M.K. and W. James. "Provision of parking lot pavements for surface water pollution control studies." *Modern Methods for Modeling the Management of Stormwater Impacts*. Edited by W. James. Computational Hydraulics International, Guelph, Ontario. pp. 381 - 398. 1995.

Tyson, J.M. "Quo Vadis - sustainability?" *Water Science and Technology* Vol.32, No. 5-6, pp1-5. 1995.

Urbonas, B. and P. Stahre. *Stormwater: Best Management Practices and Detention*. Prentice Hall, Englewood Cliffs, NJ. 1993.

Valiron, F. "Usual techniques for stormwater pollutant removal in urban areas." (in French) *Provisory report for the Seine-Normandie Water Agency*, February 1992, 61 p. 1992.

Van Buren, M.A., W.E. Watt, and J. Marsalek. "Enhancing the removal of pollutants by an on-stream pond." *Water Science and Technology*. Vol. 33, no. 4 - 5, pp. 325-332. 1996.

Vignoles M., and L. Herremans. "Street cleaning: an alternative to stormwater treatment?" (in French). *NOVATECH International Conference*, Lyon, 1992, pp 272-283. 1992.

Vignoles M., and L. Herremans. "Metal pollution of sediments contained in runoff water in the Toulouse city." (in French). *NOVATECH 95, 2nd International Conference on Innovative Technologies in Urban Storm Drainage*. May 30 - June 1, 1995. Lyon, France. pp. 611-614. Organized by Eurydice 92 and Graie. 1995.

Vignoles, M. and L. Herremans. "Motorway pollution: total suspended solids in runoff water and settling tank design approach." *69th Annual Water Environment Federation Technical Exposition and Conference (WEFTEC)*. Dallas, TX. Water Environment Federation, Alexandria, VA. Vol. 4, parts I and II. Pp. 167-176. 1996.

Virginia Soil and Water Conservation Commission. *Virginia Erosion and Sediment Control Handbook*. 1980.

W&H Pacific (now Stormwater Management). *Compost Storm Water Filter (CSF): Answers to Typical Questions*. Stormwater Management, Portland, Oregon. 1992.

W&H Pacific (now Stormwater Management). *Compost Storm Water Treatment System: Executive Summary*. Stormwater Management, Portland, Oregon. 1992.

W&H Pacific (now Stormwater Management). *Methods and Results Summary: Compost Storm Water Filter System*. Stormwater Management, Portland, Oregon. 1992.

Wada, Y. and H. Miura "Effect and evaluation of storm runoff control by permeable combined infiltration facilities for controlling storm runoff." Proceedings of the 5th *International Conference on Urban Storm Drainage*. Osaka, Japan. July 1990. pp. 789 - 794. 1990.

Wada, Y. and H. Miura "Prediction and estimation of stormwater runoff control by the combined stormwater infiltration facilities with simulation model." In: *Integrated Stormwater Management*. Edited by R. Field, M.L. O'Shea, and K.K. Chin. Lewis Publishers. Boca Raton. pp. 337 - 353. 1993.

Wang, T.S., D.E. Spyridakis, B.W. Mar, and R.R. Horner. *Transport Deposition and Control of Heavy Metals in Highway Runoff*. WA-R4-39.10, U.S. Dept. of Transportation and Washington State Department of Transportation, Seattle, January 1980.

Water Environment & Technology. "Illinois turns to communities for grassroots watershed work." pg. 19. March 1996.

Whipple, W., Jr. And J.V. Hunter. "Settleability of urban runoff pollution." *Water Pollution Control Federation Journal*. Vol. 53, no. 12. pp. 1726-1731. Dec. 1981.

Wiegand, C., T. Schueler, W. Chittenden, and D. Jellick. "Comparative costs and cost effectiveness of urban best management practices." Engineering Foundation Conference: *Urban Runoff Quality - Impact and Quality Enhancement Technology*. Henniker, New Hampshire, edited by B. Urbonas and L. A. Roesner, published by the American Society of Civil Engineers, New York, June 1986.

Wigington, P. J., C. W. Randall, and T. J. Grizzard. "Accumulation of selected trace metals in soils of urban runoff detention basins." *Water Resources Bulletin*, Vol. 19, no. 5, pg. 709, October 1983.

Willett, Gerald. Urban Erosion, in *National Conference on Urban Erosion and Sediment Control; Institutions and Technology*. EPA 905/9-80-002. U.S. Environmental Protection Agency, 1980.

Williams, L.H. "Effectiveness of stormwater detention." *Proceedings of the Conference on Stormwater Detention Facilities, Planning, Design, Operation, and Maintenance*, Henniker, New Hampshire, Edited by W. DeGroot, published by the American Society of Civil Engineers, New York, August 1982.

Wind, S. "Three years after - failure or success." *Land and Water*, Vol. 40, no. 6, pg. 37. Nov./Dec. 1996.

Yamada, K. "Infiltration pitch for individual houses to mitigate storm water impact." Proceedings of the 6^{th} *International Conference on Urban Storm Drainage*. Edited by J. Marsalek and H.C. Torno. Niagara Falls, Ontario. September 12 - 17, 1993. IAWQ, London. Published by Seapoint Publishers, Victoria, B.C. pp. 1110 - 1114. 1993.

Yousef, Y.A., M.P. Wanielista, and H.H. Harper. "Design and effectiveness of urban retention basins." *Engineering Foundation Conference: Urban Runoff Quality - Impact and Quality Enhancement Technology*, Henniker, New Hampshire, edited by B. Urbonas and L. A. Roesner, published by the American Society of Civil Engineers, New York, June 1986.

Yousef, Y.A. and L.Y. Lin. "Toxicity of bottom sediments in detention ponds." *Environmental Engineering: Proceedings of the 1990 Specialty Conference*. pp. 809 - 816. American Society of Civil Engineering, New York. 1990.

Yu, S.L., S-L. Liao, G.M. Fitch, and S. Long. "Constructed wetlands for stormwater management." *69^{th} Annual Water Environment Federation Technical Exposition and Conference (WEFTEC)*. Dallas, TX. Water Environment Federation, Alexandria, VA. Vol. 7, parts I, II, and III. pp. 167-178. 1996.

Yu, S.L., M.A. Kasnick, and M.R. Byearne. "A level spreader/vegetative buffer strip system for urban stormwater management." In: *Integrated Stormwater Management*. Edited by R. Field, M.L. O'Shea, and K.K. Chin. Lewis Publishers. Boca Raton. pp. 93 - 103. 1993.

5. Using SLAMM

Introduction

This section is a detailed discussion of the calculation procedures developed for the original DOS based version of SLAMM and now found in the Windows version, WinSLAMM. Over the past few years, the program was completely re-written in Visual Basic, version 5, to be completely Windows-based. The current version is numbered 8. Version 6 added Monte Carlo components to the model, developed with funding from Region 5 of EPA. Version 7 was a hybrid version, using many of the older DOS calculation modules, but with the initial windows user interface modules. It also included numerous additional changes. This version 8 is the first complete Windows-based version (including the basic data input, calculation, and output modules found in the DOS version) and closely resembles version 7 in content and capabilities, with a few additional changes. We are planning a new version 9 soon to incorporate many new features from our recent stormwater research conducted over the past several years. The main changes made to the program since the original user guide and algorithm documentation was prepared include the following:

- Practically all of the variable names given in this section and the use of goto statements have been changed to reflect current programming practice. The HELP files in the model provide accurate guidance for the model in its present form. Most of the “parameter” file maintenance programs are still DOS-based, but have been modified. SLAMM can now easily evaluate large rain files - analyses containing more than 4 decades of data and many thousands of individual rain events have been successfully conducted.

• Monte Carlo stochastic components have been added to the pollutant calculations to provide better representations of the random nature of stormwater pollutants.

• The batch processor program, originally developed for the DOS program, was modified for use with the Windows-based program. It now works with users interfacing WinSLAMM with GIS programs.

• Selected processes have been corrected or changed to reflect bug fixes or process modifications. These changes include adding additional controls and flexibility for the analyses of detention ponds, more accurate descriptions of catchbasins in an area, and modifying the pollutant listing.

• An interface program for the use of WinSLAMM as a replacement for the RUNOFF block in SWMM was developed as the main activity of the EPA-sponsored activity reported in this report.

WinSLAMM (the **Win**dows version of the **S**ource **L**oading **A**nd **M**anagement **M**odel) is an urban rainfall runoff water quality model. It calculates runoff volumes and urban pollutant loadings from individual rain events. It also allows the user to reduce pollutant loadings from a source area such as a roof or street area by using control measures such as detention ponds or infiltration devices.

The model is in many ways a very large pollutant mass and flow accounting program. Runoff volumes are calculated by multiplying the rain depth by varying runoff coefficients. The resulting source area runoff volumes are then multiplied by particulate residue concentrations to get particulate residue loadings for each source area for the rain. The runoff coefficient is a function of rain depth, land use (*eg*, a residential land use), and source area. The particulate residue concentrations are a function of runoff depth, land use and source area. Other particulate pollutants are then related to the particulate residue values, while filterable pollutants are related to the runoff volumes.

Much of the program is devoted to identifying the appropriate runoff and particulate residue concentration values for a given rain depth, land use, and source area. The process is complicated by the large number of source areas within each land use and by the large number of variable combinations needed for a specific source area.

Hardware Requirements and Recommendations

WinSLAMM runs on personal computers under Windows 95, Windows 98, or Windows NT. The following computer features are required:

• Memory Requirements:
The model uses many dynamic, or variable-size, arrays. If a computer runs out of memory, either reduce the number of WinSLAMM source areas and rainfall events, or close other programs that are running on your computer. A typical Pentium computer can analyze a typical situation in a few seconds to a few minutes, even for a complete set of many rain years. The addition of detention ponds or a long list of pollutants in an analysis will significantly increase the computer computational time.

• Disk Storage:
The model creates and erases many temporary files while running. It requires only a few mb of storage on the hard drive, depending on the size of the rain files, etc.

• Printer:
The output may be sent to a printer or saved as a file. However, output can be many columns wide, and so users may need a printer operating in landscaped mode with a small sized font to print the output. The output can also be quite extensive, so we recommend that all output be saved to a file where it can be formatted as needed.

Description of the Files Associated WinSLAMM

WinSLAMM.EXE

This Windows version SLAMM combines the DOS Input, Calculation, and Output modules of the DOS version of SLAMM. The program generates a site description file needed to run WinSLAMM, which has the extension .DAT (referred to as data.DAT). Besides the basic site development data requested, alternative runoff controls are also described using this program. The program must be installed using the appropriated installation files. Place the first disk in the installation drive (or the CD if you have the CD version of the installation program) and run setup from the run command or use the "install new software" option in the control panel, then follow the on-screen directions.

The files needed to run SLAMM include:

- A mandatory rain.RAN file to describe the rain series.

- A mandatory runoff.RSV file containing the runoff coefficients for each surface type to generate surface runoff volume quantities.

- A mandatory particulate.PSC file describing the particulate residue (suspended solids) concentrations for each source area (except for roads) and land use, for several rain categories.

- A mandatory delivery.PRR file to account for deposition of particulate pollutants in the storm drainage system, before the outfall, or before outfall controls. The DELIVERY.PRR file is calibrated for swales, curb and gutters, undeveloped roadsides, or combinations of drainage conditions.

- An optional pollutant.PPD file to describe the particulate pollutant strengths related to particulate residue and to describe the filterable pollutant concentrations for each source area for each land use. This file is not needed if only runoff volume and particulate residue calculations are desired. This file also contains the coefficient of variation (COV) values for each pollutant for Monte Carlo simulation in WinSLAMM.

- An optional size.CPZ files for wet detention pond analyses to describe the runoff particulate size distributions. If no wet detention ponds are included in a WinSLAMM model, these files are not needed.

MPARAXX.EXE

MPARAXX is the utility program that produces, edits, and displays the above files needed by WinSLAMM. This is a DOS-based program and can be executed from the DOS prompt in the DOS shell within Windows. The example parameter files included on the disk can be printed to a file using MPARAXX.EXE and then read using any ASCII text editor.

MSCALCXX.EXE

MSCALCXX was the prior DOS version of the main SLAMM calculation program. It may be executed from the DOS prompt in the DOS shell within Windows. This program only asks for the data.DAT file name, previously prepared using SINPXX.EXE. It automatically links with the output program. SLAMM directs all of its output to a disk file. This file can be viewed and printed using most text editors or word processors. The output format generally requires a printer in landscape mode using a small font. The Windows version executes the calculation module by using the drop-down "Run" menu.

Creating or Editing a SLAMM Data File

Introduction

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

This section discusses how to create or edit a WinSLAMM data file that stores this information. The HELP files with version 8 of WinSLAMM offer additional direction for the current version of WinSLAMM.

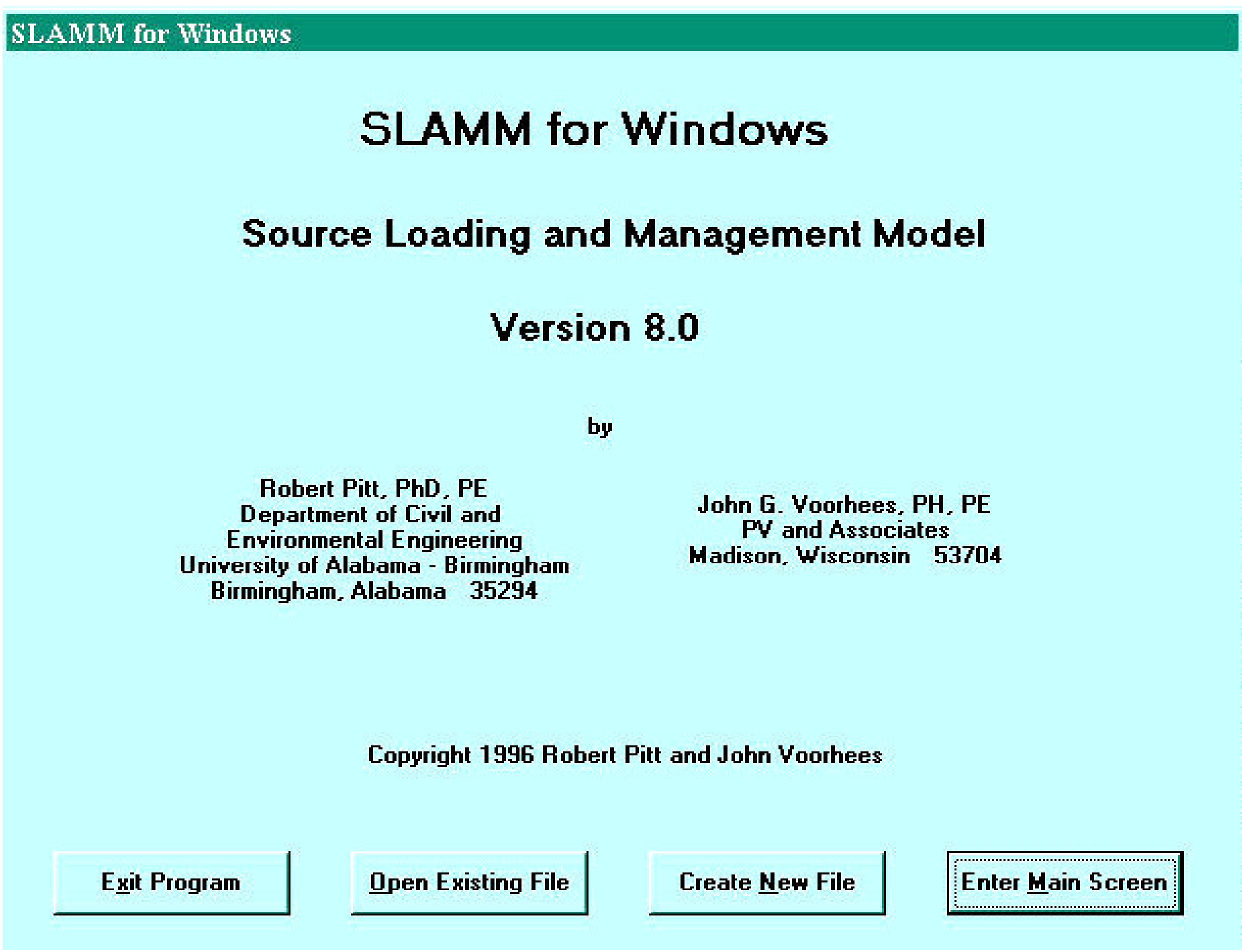
Table 5-1, lists the series of steps necessary to create a SLAMM data file.

Table 5-1. Steps For Creating A New SLAMM Data File

1. Start the Program
2. Enter Site, Drainage, and File Information
3. Enter Data
    - A. Land use area and source controls information
    - B. Catchbasin and drainage control information
    - C. Outfall control information
4. Enter Pollutant Analysis Selection Information
5. Save the Data File

Starting the Program

To run the program, double-click the WinSLAMM program icon or double-click WinSLAMM.EXE in Win95/98/NT Explorer. Select "Open Existing File" to open a file that has previously been created, select "Create New File" to create a new .DAT file using the new file data entry sequence editor, or select "Enter Main Screen" to enter the data editor. Press "Exit" to exit the program. The opening screen for WinSLAMM is shown below.

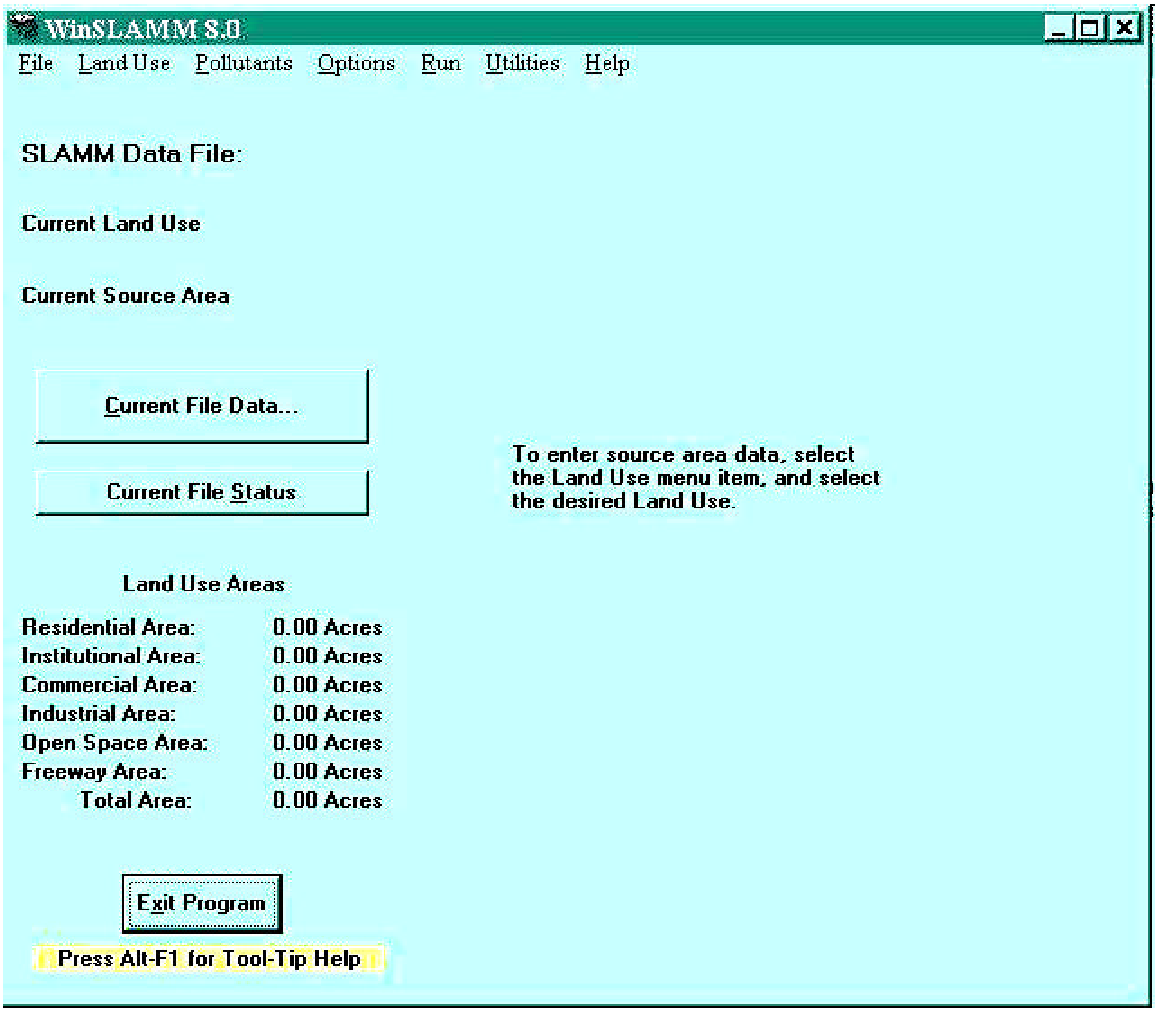


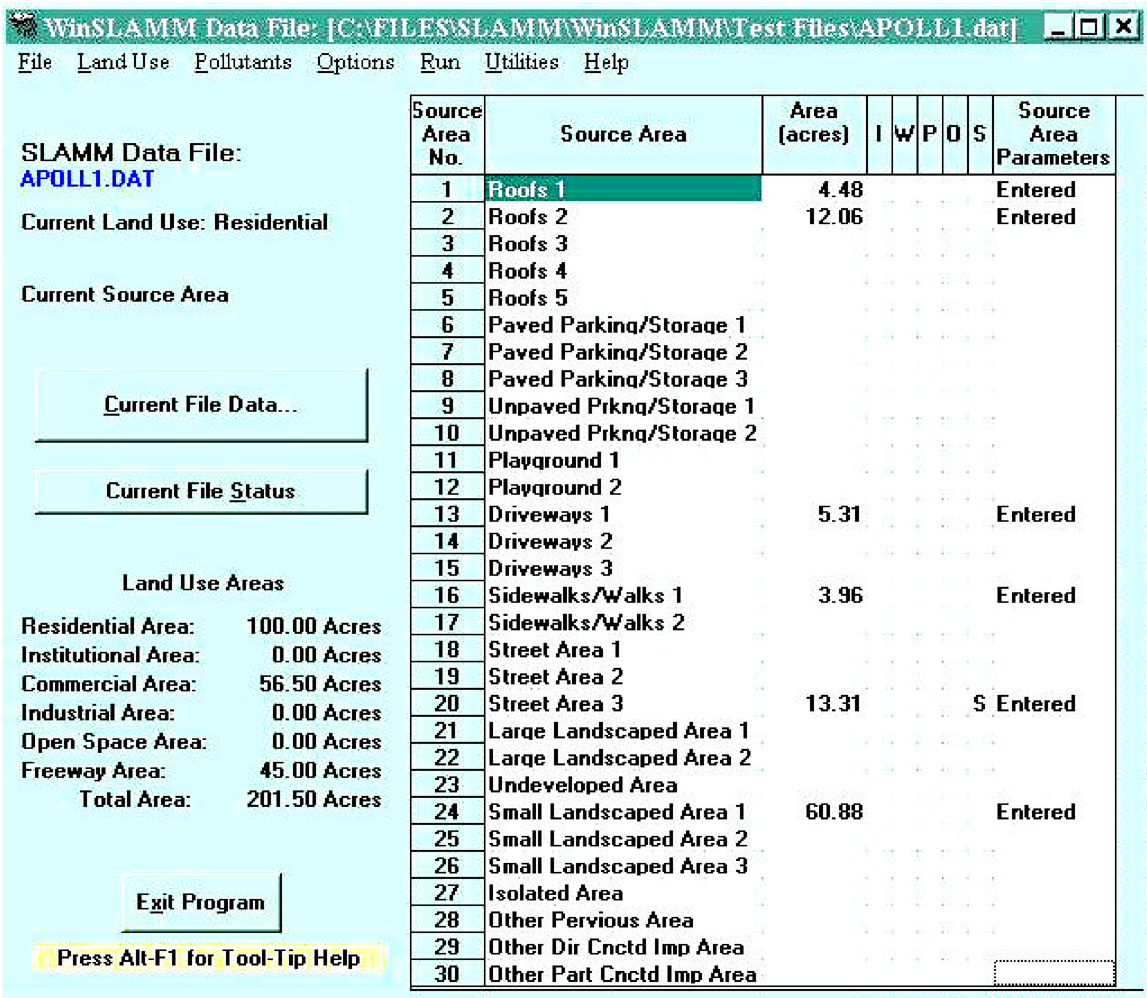
Main Data Entry Form

The main data entry form, which is illustrated below, allows you to enter the data needed to create a SLAMM data file. The main data entry form includes the following items:

- Menu items on the Main Menu bar
- A series of labels that identify the data file name, the current land use and source area, and the areas that have been entered for each land use
- A Current File Data button, described in more detail below
- A Current File Status button that determines if the minimum data needs of a WinSLAMM model run are met
- An Exit Program button
- A grid that lists the source areas for each land use and indicates whether source area parameters and control devices have been entered for each source area. Selecting a land use from the Land Use menu item accesses the grid for that land use.

The main menu is shown below, including a view of the land use screen:


WinSLAMM 8.0
File Land Use Pollutants Options Run Utilities Help
SLAMM Data File:
Current Land Use
Current Source Area
Current File Data...
Current File Status
To enter source area data, select the Land Use menu item, and select the desired Land Use.
Land Use Areas
Residential Area: 0.00 Acres
Institutional Area: 0.00 Acres
Commercial Area: 0.00 Acres
Industrial Area: 0.00 Acres
Open Space Area: 0.00 Acres
Freeway Area: 0.00 Acres
Total Area: 0.00 Acres
Exit Program
Press Alt-F1 for Tool-Tip Help



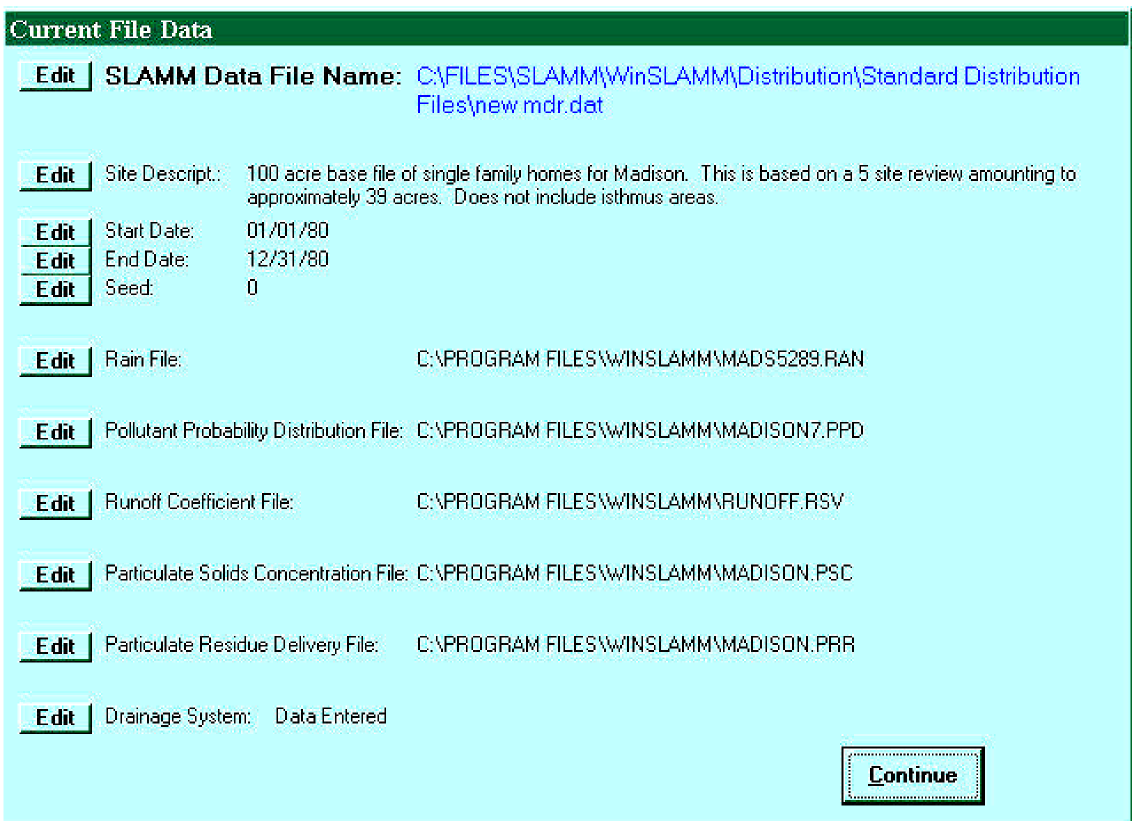
Current File Data Button

The Current File Data button allows the user to enter data critical to the operation of the model. This includes parameter file names and locations, Monte Carlo seed information, model run start and finish dates, and drainage information. A list of the items in the form is described below, followed by an illustration of the form.

1. SLAMM Data File Name. File names should subscribe to all the Windows file naming conventions. Do not use any extensions; the program will add them.
2. Site description for the file. The description may be up to 230 characters long.
3. Starting date of the study period. This date must be after 1952 and should correspond to the dates of the rain events in the rain file used in this SLAMM file. The format of the dates must be “MM/DD/YY” or “MM.DD.YY.”
4. Ending date of the study period. This date must be after the starting date, and have the same format as the starting date.
5. Seed. The seed is used for Monte Carlo simulations of pollutant strength. The seed must be an integer greater than zero. Enter zero (0) for a randomly generated seed based upon the clock time a model run begins. A negative seed value will force the model to use zeros for any COV values in the pollutant probability distribution file. This has the effect of turning off the Monte Carlo pollutant loading simulation, so the model instead calculates pollutant loadings based upon the average pollutant value.
6. Rain file name. Enter the name of the rain file used in the model run. Do not include the extension.

7. Pollutant probability distribution file name. Enter the name of the pollutant probability distribution file you want to use for the model run. Do not include the extension.
8. Runoff coefficient file name. Enter the name of the runoff coefficient file used in the model run. Do not include the extension.
9. Particulate solids concentration file name. Enter the name of the particulate solids concentration file used in the model run. Do not include the extension.
10. Particulate residue delivery file name. Enter the name of the particulate residue delivery file used in the model run. Do not include the extension.
11. Drainage system data. Enter the fraction of the total area controlled by each drainage system type. The sum of the fractions of each of the drainage types must equal 1. The five drainage types are listed below:

    1. Grass Swales. Enter additional information to characterize grass swales after entering the drainage type area fractions. This information is described in the outfall control section.
    2. Undeveloped roadside. This category is used to represent haphazard drainage along a road.
    3. Curb and Gutters, “valleys,” or sealed swales in poor condition (or very flat). This category may also be used if runoff is channeled along the edge of streets without curb and gutter.
    4. Curb and Gutters, “valleys,” or sealed swales in fair condition.
    5. Curb and Gutters, `“valleys,” or sealed swales in good condition (or very steep).



The printing options are included under the drop-down tab “file-output options”. Table 5-2 lists the main options available. There are also several one-line per event options that summarize long SLAMM runs well, especially when exporting the data into spreadsheet programs for further analyses, or when using the SLAMM-SWMM interface program.

Table 5-2. Printing Options

1. Print source areas by land use & outfall for each rain - complete printout.
2. Print source area totals and outfall summaries.
3. Print outfall data only for each rain.
4. Default option - Print outfall summaries only.

Data Entry

This section reviews the steps necessary to enter WinSLAMM land use and drainage system information into a file. The first sub-section reviews the land use area information, the second sub-section reviews the catchbasin and drainage control information, and the final sub-section reviews the outfall control information.

Land Use and Source Area Information

Characterize the six land uses by defining source areas. Enter source areas for each land use by selecting, from the main menu, "File/{Land Use}". A data entry spreadsheet, shown below, for the land use will appear on the "Main Data Entry" form. This spreadsheet lists all the available source areas for the land use, the area of the source area, the available controls, and the source area parameters. To enter an area, double-click on the area column box in the row of the desired land use. You will be prompted to enter the area of the source area as well as the required source area parameter information. To enter a control for the source area, double-click on the desired control box in the row of the selected source area. Land use areas 1 to 5 each have 30 source areas, while land use 6 (Freeways) has 10 source areas, as shown below.

Source Area No.	Source Area	Area (acres)	I	W	P	O	S	Source Area Parameters
1	Roofs 1	[illegible]						Entered
2	Roofs 2	12.23						Entered
3	Roofs 3							
4	Roofs 4							
5	Roofs 5							
6	Paved Parking/Storage 1							
7	Paved Parking/Storage 2							
8	Paved Parking/Storage 3							
9	Unpaved Prkng/Storage 1							
10	Unpaved Prkng/Storage 2							
11	Playground 1							
12	Playground 2							
13	Driveways 1	5.14						Entered
14	Driveways 2	1.01						Entered
15	Driveways 3							
16	Sidewalks/Walks 1	3.73						Entered
17	Sidewalks/Walks 2							
18	Street Area 1	3.92					S	Entered
19	Street Area 2	1.[illegible]					S	Entered
20	Street Area 3	7.49					S	Entered
21	Large Landscaped Area 1							
22	Large Landscaped Area 2							
23	Undeveloped Area							
24	Small Landscaped Area 1	63.09						Entered
25	Small Landscaped Area 2							
26	Small Landscaped Area 3							
27	Isolated Area							
28	Other Pervious Area							
29	Other Dir Cnctd Imp Area							
30	Other Part Cnctd Imp Area							

Table 5-3 is a list of the mian source areas WinSLAMM uses. In most cases, more than source area in each category is available for each land use. If a control option has been activated, the code letter for that control option will appear in the column. For example, in the data grid above, street sweeping has been activated, as indicated by the three S's in the S column. The control options available for each source area are illustrated in Figure 5-1. The information needed for each control option and the procedure to enter this information in a WinSLAMM data file is listed at the end of this section.

Table 5-3. SLAMM Source Areas

Roofs	Sidewalks/Walks	Other Impervious Areas
Paved Parking/Storage	Streets/Alleys	Freeway Lanes/Shoulders
Unpaved Parking/Storage	Undeveloped Areas	Large Turf Areas
Playgrounds	Small Landscaped Areas	Large Landscaped Areas
Driveways	Other Pervious Areas	

Each source area listed in Table 5-3 has specific data requirements that depend upon the characteristics of the source area and upon the source area's land use. These requirements are listed in Table 5-4 and 5-5, which are coding forms that list the land use and control practice information requirements. These sheets should be filled out before the data file is created.

Streets and alleys in land uses 1 through 5 require somewhat different characteristic information than freeway (Land Use 6), paved lane, and shoulder areas. To enter a user defined street dirt accumulation equation for a street area in land uses 1 through 5, the equation must be in the form of a quadratic equation, $Ax^2 + Bx + C$, where A is greater than 0, B is greater than 0, and C is less than or equal to 0.

Isolated areas, or disconnected areas, are areas within a land use that do not contribute runoff to the land use outfall. Isolated areas could be constructed, e.g. swimming pools, or natural land features such as kettle ponds. Source controls are not applicable to isolated areas.

The source areas in the Freeway land use include Paved Land and Shoulder Areas, Large Turf Areas, an Undeveloped Area, an Other Pervious Area, an Other Directly Connected Impervious Area, and an Other Partially Connected Impervious Area. A paved lane and shoulder area requires somewhat different source area data requirements than street and alley source.

Catchbasin and Drainage Control Information

Enter catchbasin and drainage control information by selecting, from the main menu, “Land Use/Catchbasin” or “Drainage Control”. The available options for catchbasins or drainage control are listed in Figure 5-1. The data requirements for each of these options is shown on Table 5-4 and are listed in a later section.

Outfall Control Information

Enter outfall control information by selecting , from the main menu, “Land Use/Outfall”. The available options for outfall controls are listed in Figure 5-1. The data requirements for each of these options is shown on Table 5-5 and are listed in the following section.

Source Area Control Device Information

This section describes the information necessary to apply a pollutant control device to a source area or outfall. Figure 5-1 lists the control devices applicable to a specific source area, the entire drainage area, or to the outfall. The control device options for each source area are also listed on the source area screen in the program under the column heading “Control Options Available.” To select a control option for a source area, follow the steps listed below upon entering a source area menu:

1. Enter the source area number.

2. Enter the area, in acres, of the source area.

3. Enter the source area characteristics. The model will request all parameters necessary for each source area, as described in Tables 5-4 and 5-5.

4. Enter the source area option letter to use a control device to reduce the runoff volume or pollutant loading coming from a source area. The letter for each control option is listed on Figure 5-1 and at the bottom of each source area menu in the program.

Figure 5-1. Source area, drainage system, and outfall control options available in SLAMM. [1]

	Infiltration device	Wet detention pond	Grass drainage swale	Street cleaning	Catchbasin cleaning	Porous pavement	Other
Roof	X	X					X
Paved parking/storage	X	X				X	X
Unpaved parking/storage	X	X					X
Playgrounds	X	X				X	X
Driveways						X	X
Sidewalks/walks						X	X
Streets/alleys				X			X
Undeveloped areas	X	X					X
Small landscaped areas	X						X
Other pervious areas	X	X					X
Other impervious areas	X	X				X	X
Freeway lanes/shoulders	X	X					X
Large turf areas	X	X					X
Large landscaped areas	X	X					X
Drainage system			X		X		X
Outfall	X	X					X

(1) Development characteristics affecting runoff, such as roof and pavement draining to grass instead of being directly connected to the drainage system, are included in the individual source area descriptions.

A description of the data necessary for each control device option is listed below.

Infiltration Devices

- Water percolation rate (in/hr).
- Area served by device (acres).
- Surface area of the device (square feet).
- Width to Depth ratio of the device. If the device is a spreading area, press ENTER.

Street Cleaning

The street cleaning control option can be applied to streets and alleys in land uses 1 through 5. No more than ten street cleaning schedule changes are allowed for each street or alley source area. Below is a description of the information requirements necessary to implement street cleaning.

- Street cleaning starting date (date format: MM/DD/YY).
- Street cleaning ending date (date format: MM/DD/YY).
- Street cleaning schedule. The cleaning frequency options range from none to daily.
- Street cleaning productivity. Select the default productivity by entering the parking density and the parking control status. The parking density options are:
    1. None
    2. Light
    3. Medium
    4. Extensive (short term)
    5. Extensive (long term)

- The parking control status indicates whether parking options such as limited parking hours or alternate side-of-the-street parking have been regulated by the municipality. If they have, answer "YES" to indicate that parking controls are imposed.

• Street sweeper productivity can also be described by entering the equation coefficients for the linear street cleaning equation, Y = mx + b, where is Y is the residual street dirt loading after street cleaning and x is the before street cleaning load (in lbs/curb-mile). Enter values for:

m (slope, less than 1)
b (intercept, greater than or equal to 1)

<u>Porous Pavement</u>

• Infiltration rate of pavement, base, or soil, whichever is the least (in/hr).
• Porous pavement area (acres).

<u>Wet Detention Ponds</u>

The wet detention pond algorithm in SLAMM is developed from the program DETPOND, a detention pond water quality analysis program developed by Pitt and Voorhees (1992). It uses the modified Puls hydraulic routing method and the surface overflow rate method for particulate sedimentation. The pond must have at least 3 feet of standing water below the lowest invert for these removal equations to be valid. Evaluate the pollutant removal capabilities of a wet detention pond either in specific source areas or at the outfall. The wet detention pond data requirements for SLAMM include:

• The particle size distribution in the pond influent.
• The initial stage elevation of the pond.
• The pond stage - area relationship.
• The pond outlet characteristics.

The input module creates a separate detention pond data file if one or more detention ponds are selected as a control device. The detention pond data file name is the same as the name of the SLAMM data file in the Site and File Information menu, but with the file extension ".PND." If the detention pond data file name is changed, the SLAMM data file name must also be changed to match it.

The model requires a particle size distribution file to evaluate the pollutant removal abilities of detention ponds. To create a particle size distribution file, use the SLAMM Parameter module discussed later. The model also requires the initial stage elevation of the pond and the pond stage - area relationship. The units for these values are in feet and, for the pond area, acres. The area of the pond at the datum (lowest) elevation must be zero. Enter at least five reasonably spaced stage increments. The increments can either be enter variably spaced, or at constant intervals.

SLAMM has the ability to characterize each detention pond with as many as ten different outlets. The pond outlet options are described below.

Rectangular Weir Characteristics:

1. Weir length (ft).
2. Height from bottom of weir opening (invert) to top of weir.
3. Height from datum (low elevation of pond) to bottom of weir opening (invert) (ft).

V-Notch Weir Characteristics

A) Weir angle:

1. 22.5 degrees.
2. 30 degrees.
3. 45 degrees.
4. 60 degrees.
5. 90 degrees.
6. 120 degrees.

B) Height from bottom of weir opening (invert) to top of weir.

C) Height from datum to bottom of weir opening (invert) (ft).

Orifice Characteristics:

1. Orifice diameter (ft).
2. Invert elevation above datum (ft).

Seepage Basin Characteristics:

1. Infiltration rate (inches/hr).
2. Width of device (ft).
3. Length of device (ft).
4. Invert elevation of seepage basin inlet above datum (ft).

Natural Seepage Infiltration Rates:
These stage elevations must correspond to the stage elevations entered for the pond stage - area elevations. The seepage rates are expressed in inches per hour. Enter 0 inches per hour for entry 0, stage 0.

Monthly Evaporation Rate
Enter the average pond surface evaporation rate, in inches per day, for each month of the year.

Other Outlet Characteristics:
This option allows you to describe a stage - discharge relationship that is independent of any other outlet discharge characteristics. The stage elevations must correspond to the pond stage - area elevations. Enter outflow values from zero stage level (datum), and enter 0 discharge at the 0 stage. I

Catchbasin Cleaning

- Total sump volume (cubic feet) in the drainage area.
- Area served by catchbasins control (acres).
- Percentage of the sump volume which is full at the beginning of the study period (0 to 100).
- Number of times the catchbasin is cleaned during the study period (cleaning up to 5 times is allowed).
- Date for each time the catchbasin is cleaned. The dates must be consecutive, within the study time period, and in the format "MM/DD/YY."

Other Flow or Pollutant Reduction Control

- Pollutant concentration reduction (fraction).
- Water volume (flow) reduction (fraction).
- Area served by other control (acres).

Grass Swales

- Swale infiltration rate (in/hr). This is typically about one-half of the infiltration rate as measured using a double-ring infiltrometer.
- Swale density (ft/acre).
- Wetted swale width (ft).
- Enter the area served by swales (acres).

Table 5-4a. Blank Coding Forms for SLAMM Source Areas

SLAMM Site Characterization Data Sheet

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

Source Area	Area (ac)						
Roofs 1	________	Flat/Pitched	Dir Con/Discon	Soil: Sandy/Clayey	Density: Low/Med or High	Alleys: Yes/No	IWO
Roofs 2	________	Flat/Pitched	Dir Con/Discon	Soil: Sandy/Clayey	Density: Low/Med or High	Alleys: Yes/No	IWO
Roofs 3	________	Flat/Pitched	Dir Con/Discon	Soil: Sandy/Clayey	Density: Low/Med or High	Alleys: Yes/No	IWO
Roofs 4	________	Flat/Pitched	Dir Con/Discon	Soil: Sandy/Clayey	Density: Low/Med or High	Alleys: Yes/No	IWO
Roofs 5	________	Flat/Pitched	Dir Con/Discon	Soil: Sandy/Clayey	Density: Low/Med or High	Alleys: Yes/No	IWO
Paved Parking 1	________		Dir Con/Discon	Soil: Sandy/Clayey	Density: Low/Med or High	Alleys: Yes/No	IWPO
Paved Parking 2	________		Dir Con/Discon	Soil: Sandy/Clayey	Density: Low/Med or High	Alleys: Yes/No	IWPO
Paved Parking 3	________		Dir Con/Discon	Soil: Sandy/Clayey	Density: Low/Med or High	Alleys: Yes/No	IWPO
Unpaved Parking 1	________		Dir Con/Discon	Soil: Sandy/Clayey	Density: Low/Med or High	Alleys: Yes/No	IWO
Unpaved Parking 2	________		Dir Con/Discon	Soil: Sandy/Clayey	Density: Low/Med or High	Alleys: Yes/No	IWO
Playground 1	________		Dir Con/Discon	Soil: Sandy/Clayey	Density: Low/Med or High	Alleys: Yes/No	IWPO
Playground 2	________		Dir Con/Discon	Soil: Sandy/Clayey	Density: Low/Med or High	Alleys: Yes/No	IWPO
Driveways 1	________		Dir Con/Discon	Soil: Sandy/Clayey	Density: Low/Med or High	Alleys: Yes/No	PO
Driveways 2	________		Dir Con/Discon	Soil: Sandy/Clayey	Density: Low/Med or High	Alleys: Yes/No	PO
Driveways 3	________		Dir Con/Discon	Soil: Sandy/Clayey	Density: Low/Med or High	Alleys: Yes/No	PO
Sidewalks 1	________		Dir Con/Discon	Soil: Sandy/Clayey	Density: Low/Med or High	Alleys: Yes/No	PO
Sidewalks 2	________		Dir Con/Discon	Soil: Sandy/Clayey	Density: Low/Med or High	Alleys: Yes/No	PO
Strts/Alleys 1	________	____ curb-miles	Texture: Smth/Int/Rough/ V Rough		Accum: Default/A:___ B:___ C:___	Init Load: Default/ ___ lbs	S
Strts/Alleys 2	________	____ curb-miles	Texture: Smth/Int/Rough/ V Rough		Accum: Default/A:___ B:___ C:___	Init Load: Default/ ___ lbs	S
Strts/Alleys 3	________	____ curb-miles	Texture: Smth/Int/Rough/ V Rough		Accum: Default/A:___ B:___ C:___	Init Load: Default/ ___ lbs	S
Lrg Landscapes 1	________			Soil: Sandy/Clayey			IWO
Lrg Landscapes 2	________			Soil: Sandy/Clayey			IWO
Undvlpd Area				Soil: Sandy/Clayey			IWO
Sml Landscapes 1	________			Soil: Sandy/Clayey			IO
Sml Landscapes 2	________			Soil: Sandy/Clayey			IO
Sml Landscapes 3	________			Soil: Sandy/Clayey			IO
Isolated Area							
Other Pervious Area	________			Soil: Sandy/Clayey			IWO
Other Directly Connected Area	________						IWPO
Other Disconnected Area	________			Soil: Sandy/Clayey	Density: Low/Med or High	Alleys: Yes/No	IWPO

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Table 5-4b. Blank Coding Forms for SLAMM Source Areas

SLAMM Site Characterization Data Sheet

Land Use: Freeways

Source Area	Area (ac)					
Paved Lanes/Shoulders 1	______	Texture: Smth/Int/Rough/ V Rough	ADT: ______ veh/day	Highway Length: ____ miles	Init Load: Default/ ___ lbs	IWO
Paved Lanes/Shoulders 2	______	Texture: Smth/Int/Rough/ V Rough	ADT: ______ veh/day	Highway Length: ____ miles	Init Load: Default/ ___ lbs	IWO
Paved Lanes/Shoulders 3	______	Texture: Smth/Int/Rough/ V Rough	ADT: ______ veh/day	Highway Length: ____ miles	Init Load: Default/ ___ lbs	IWO
Paved Lanes/Shoulders 4	______	Texture: Smth/Int/Rough/ V Rough	ADT: ______ veh/day	Highway Length: ____ miles	Init Load: Default/ ___ lbs	IWO
Paved Lanes/Shoulders 5	______	Texture: Smth/Int/Rough/ V Rough	ADT: ______ veh/day	Highway Length: ____ miles	Init Load: Default/ ___ lbs	IWO
Large Turf Areas	______	Soil: Sandy/Clayey				IWO
Undeveloped Areas	______	Soil: Sandy/Clayey				IWO
Other Pervious Area	______	Soil: Sandy/Clayey				IWO
Other Directly Connected Area	______					IWPO
Other Disconnected Area	______	Soil: Sandy/Clayey		Density: Low/Med or High	Alleys: Yes/No	IWPO

Model Run Starting Date : ____ /____ /____

Model Run Ending Date: ____ /____ /____

Parameter File Names:
Rain File: ______________ .RAN
Runoff Coefficient File: ______________ .RSV
Particulate Solids Concentration File: ______________ .PSC
Pollutant Relative Concentration File: ______________ .PPD
Particulate Residue Delivery File: ______________ .PRR

Seed: 0 / ______

[SLMFORM1.]

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Table 5-5a. Blank Coding Forms for SLAMM Control Practices

SLAMM Control Device Data Sheet

Control Device for Land Use :________________; Source Area: ______________

File name: ______________ .DAT

Infiltration Area or Trench: I

1. Water percolation rate (in/hr): ___________
2. Area served by device (acres): ___________
3. Surface area of the device (ft^2): ___________
4. Width to Depth Ratio of the Device: ___________

Street Cleaning S

1. Number of Street Cleaning Schedule Changes:
2. Start Cleaning Date / Cleaning Schedule No.

Start Cleaning Date	Cleaning Schedule No.
1 ___/___/___	________________
2 ___/___/___	________________
3 ___/___/___	________________
4 ___/___/___	________________
5 ___/___/___	________________
6 ___/___/___	________________
7 ___/___/___	________________
8 ___/___/___	________________
9 ___/___/___	________________
10 ___/___/___	________________

Cleaning Schedule Code

1. None
2. 7 Passes/wk
3. All weekdays
4. 4 Passes/wk
5. 3 Passes/wk
6. 2 Passes/wk
7. 1 Pass/wk
8. Every two weeks
9. Every 4 weeks
10. Every 8 weeks
11. Every 12 weeks

3. Final Street Cleaning Date: ___/___/___
4. Overall Street Cleaning Productivity:

   Default Cleaning Productivity:

   1. Parking Density
      1. None
      2. Light
      3. Medium
      4. Extensive (short term)
      5. Extensive (long term)
   2. Parking Controls: Yes / No

   User Defined Cleaning Productivity:

   m Slope (less than 1): _________

   b Intercept (greater than or equal to 1): _________

Porous Pavement P

1. Infiltration rate of pavement, base, or soil, whichever is the least (in/hr): _______
2. Porous Pavement Area (acres): ___________

Other Flow or Pollutant Reduction Control O

1. Pollutant concentration reduction (fraction): ________________
2. Water volume (flow) reduction (fraction): ________________
3. Area served by other control (acres): ________________

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Table 5-5b. Blank Coding Forms for SLAMM Control Practices

SLAMM Control Device Data Sheet

Catchbasin Cleaning C

1. Total sump volume (ft^3): ____________
2. Area served by other control (acres): ____________
3. Percentage of sump volume which is full at beginning of study period (0 to 100) ____________
4. Number of times catchbasin cleaned during study period (0 - 5 times): ____________
5. Date each time catchbasin is cleaned:
   1 ___/___/___
   2 ___/___/___
   3 ___/___/___
   4 ___/___/___
   5 ___/___/___

Grass Swales G

1. Swale infiltration rate (in/hr): ____________
2. Swale density (ft/acre): ____________
3. Wetted swales width (ft): ____________
4. Area served by swales (acres): ____________

Other Flow or Pollutant Reduction Control at the Outfall O

1. Particulate Residue Reduction due to rainfall delivery (fraction)

Rain (mm)	Particulate Reduction	Rain (mm)	Particulate Reduction
1	____________	25	____________
2	____________	30	____________
3	____________	40	____________
5	____________	50	____________
10	____________	60	____________
15	____________	70	____________
20	____________	80	____________

2. Water volume (flow) reduction (fraction): ____________
3. Area served by other control (acres): ____________

Drainage System Type	Fraction of Total Area
1. Grass Swales:	____________
2. Undeveloped roadside:	____________
3. Curbs and gutters in poor condition (or flat):	____________
4. Curbs and gutters in fair condition:	____________
5. Curbs and gutters in good condition (or steep):	____________

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Table 5-5c. Blank Coding Forms for SLAMM Control Practices

SLAMM Control Device Data Sheet

Wet Detention Ponds **D**

Diagram Outlet Structure in Space Below

1. Initial Stage Elevation (feet) above datum: ___________
2. Number of stage elevation increments required: ___________
3. Total number of outlets (maximum: 10): _________
4. Stage, pond area, seepage, and other outlet information:

Entry Number	Stage (ft)	Pond Area (acres)	Natural Seepage (cfs)	Other Outflow (cfs)
0	0.0	0.0	0.0	0.0
1	________	________	________	________
2	________	________	________	________
3	________	________	________	________
4	________	________	________	________
5	________	________	________	________
6	________	________	________	________
7	________	________	________	________
8	________	________	________	________
9	________	________	________	________
10	________	________	________	________
11	________	________	________	________
12	________	________	________	________
13	________	________	________	________
14	________	________	________	________
15	________	________	________	________
16	________	________	________	________
17	________	________	________	________
18	________	________	________	________
19	________	________	________	________
20	________	________	________	________
21	________	________	________	________
22	________	________	________	________
23	________	________	________	________
24	________	________	________	________
25	________	________	________	________
26	________	________	________	________
27	________	________	________	________
28	________	________	________	________
29	________	________	________	________
30	________	________	________	________

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Table 5-5d. Blank Coding Forms for SLAMM Control Practices

SLAMM Control Device Data Sheet

Wet Detention Ponds (continued)

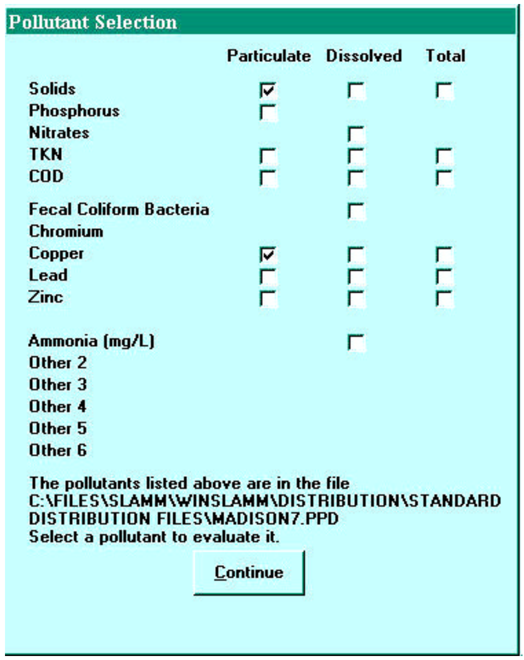
5. Outlet Characteristics
    1. Rectangular Weir
        1. Weir length (ft)
        2. Height from bottom of weir opening (invert) to top of weir: ________
        3. Height from datum to bottom of weir opening (invert) (ft): ________
    2. V-Notch Weir
        A) Weir angle
            1. 22.5 degrees
            2. 30 degrees
            3. 45 degrees
            4. 60 degrees
            5. 90 degrees
            6. 120 degrees
        B) Height from bottom of weir opening (invert) to top of weir: ________
        C) Height from datum to bottom of weir opening (invert) (ft): ________
    3. Orifice
        1. Orifice diameter (ft): ________
        2. Invert elevation above datum (ft): ________
    4. Seepage Basin characteristics
        1. Infiltration rate (in/hr): ________
        2. Width of device (ft): ________
        3. Length of device (ft): ________
        4. Invert elevation of seepage basin inlet above datum (ft): ________
    5. Monthly Evaporation Rate

Month Number	Month	Evaporation (in/day)
1	January	________
2	February	________
3	March	________
4	April	________
5	May	________
6	June	________
7	July	________
8	August	________
9	September	________
10	October	________
11	November	________
12	December	________

[SLMCONTR.]

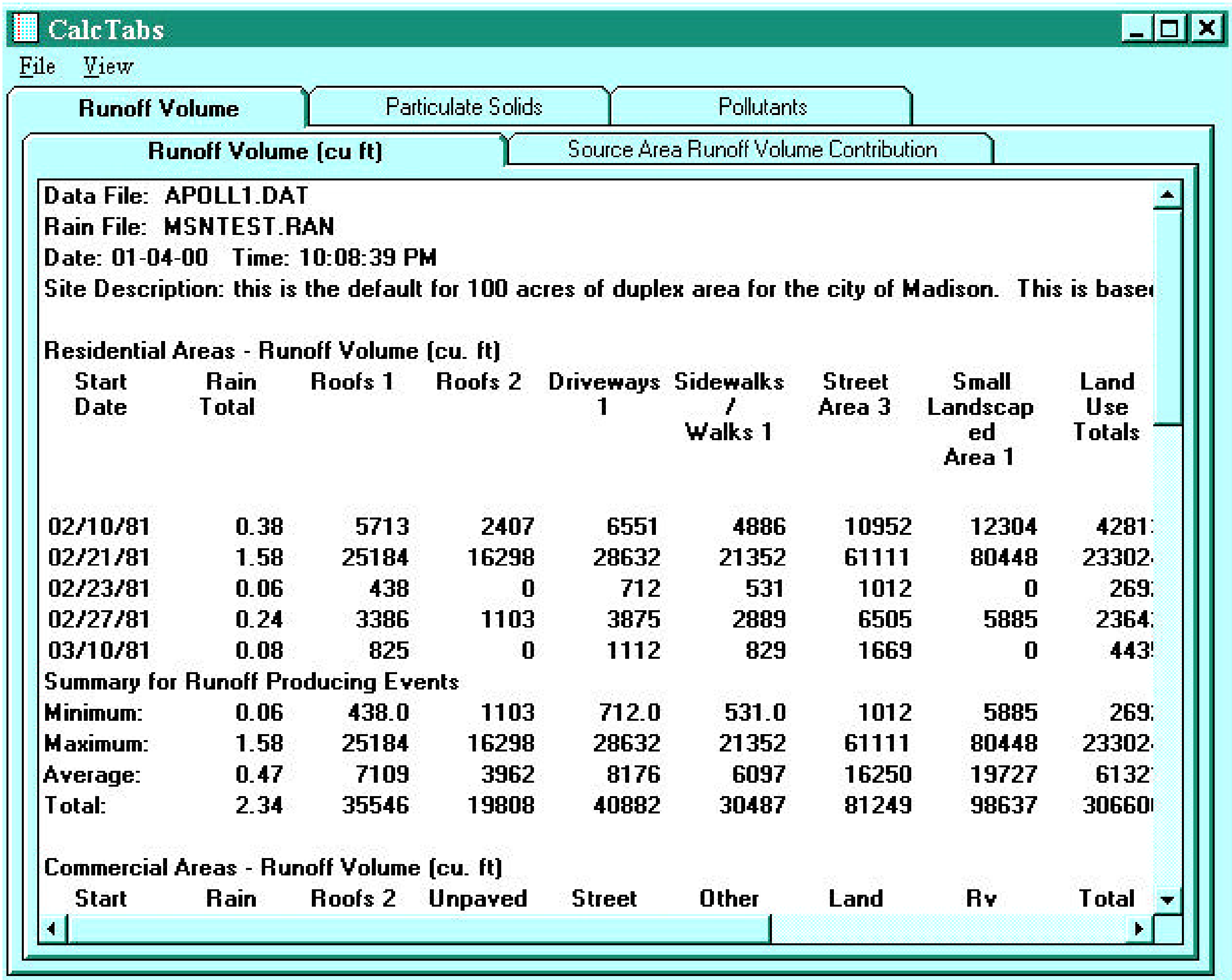
Pollutant Analysis Selection Information
Select "Pollutants" in the "Main Menu" to analyze pollutants in a WinSLAMM model run. It is necessary to enter the name of the pollutant probability distribution file before selecting the pollutants, as the model must examine this file to show which pollutants are available. To enter the name of the pollutant probability distribution file, select the "Current File Data" button.

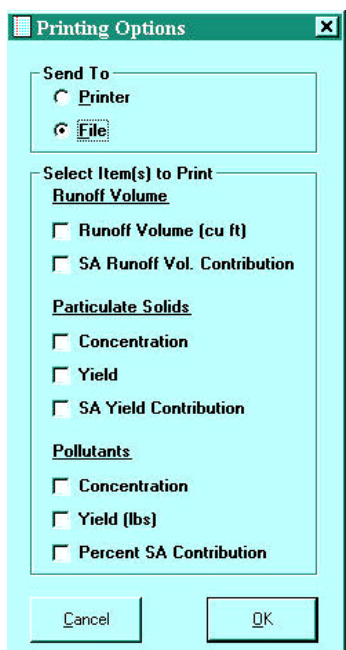
The pollutant selection box lists all of the available pollutants in the pollutant probability distribution file. To select a pollutant for analysis, click on its check box. To remove a checked box, simple click on it again. An example of the "Pollutant Selection" box is shown below, indicating that suspended solids (particulate solids) and particulate forms of copper are to be evaluated. Suspended solids are always evaluated and cannot be removed from the analysis.



Saving the Data File
To save a data file, from the main menu, select "File/Save". You will be prompted for a file name if you haven't already entered one. You may change the name of the file by selecting "File/Save As/Current Version". An example data.DAT file is also included on the distribution disk. This "new mdr.dat" file is a medium density residential land use file.

Creating WinSLAMM Output
To Run a WinSLAMM data.dat model, select the "Windows Calculation Module" menu item to create model output based upon the input data currently loaded in the WinSLAMM interface. You will be asked whether you want to save the input file. If you select "yes", the standard Windows "Save" dialog box will appear; enter the desired path and file name and press "OK". The program will then run and create the output in the format selected in the "File / Output Format Options" submenu. A typical calculation tabulation of the output is listed below. The "Print Option" in the file drop down menu item allows the user to select which of the outputs to print. The user must also elect to print the output to either a file, in Comma Separated Value (or .CSV) format, or directly to a printer. The printing options listing is also shown below.


CalcTabs
File View
Runoff Volume
Particulate Solids
Pollutants
Runoff Volume (cu ft)
Source Area Runoff Volume Contribution
Data File: APOLL1.DAT
Rain File: MSNTEST.RAN
Date: 01-04-00 Time: 10:08:39 PM
Site Description: this is the default for 100 acres of duplex area for the city of Madison. This is base
Residential Areas - Runoff Volume (cu. ft)
Start Date | Rain Total | Roofs 1 | Roofs 2 | Driveways 1 | Sidewalks / Walks 1 | Street Area 3 | Small Landscaped Area 1 | Land Use Totals
02/10/81 0.38 5713 2407 6551 4886 10952 12304 4281
02/21/81 1.58 25184 16298 28632 21352 61111 80448 23302
02/23/81 0.06 438 0 712 531 1012 0 269
02/27/81 0.24 3386 1103 3875 2889 6505 5885 2364
03/10/81 0.08 825 0 1112 829 1669 0 443
Summary for Runoff Producing Events
Minimum: 0.06 438.0 1103 712.0 531.0 1012 5885 269
Maximum: 1.58 25184 16298 28632 21352 61111 80448 23302
Average: 0.47 7109 3962 8176 6097 16250 19727 6132
Total: 2.34 35546 19808 40882 30487 81249 98637 30660
Commercial Areas - Runoff Volume (cu. ft)
Start Rain Roofs 2 Unpaved Street Other Land Rv Total


Printing Options
Send To
Printer
File
Select Item(s) to Print
Runoff Volume
Runoff Volume (cu ft)
SA Runoff Vol. Contribution
Particulate Solids
Concentration
Yield
SA Yield Contribution
Pollutants
Concentration
Yield (lbs)
Percent SA Contribution
Cancel
OK

Parameter Module Description

Introduction

The parameter module contains five subprograms that create the parameter files needed to run WinSLAMM. A brief discussion of the subprograms is listed below, and is followed by a detailed description of each subprogram.

1. Rain Data: Creates files listing rainfall depths, durations, and interevent time periods from actual or stochastically generated rainfall data.

2. Runoff Coefficient Data: Creates files containing the data needed to calculate runoff from specific urban source areas.

3. Particle Size Data: Creates files describing the particle size distribution of sediment in urban runoff entering detention ponds.

4. Particulate Solids Concentration Data: Creates files containing the particulate solids concentration data needed by WinSLAMM to predict particulate solids loadings in urban source areas and land uses.

5. Particulate Residue Reduction Data: Creates files that determine the particulate residue loading remaining in curb and gutter delivery systems after a storm event.

6. Pollutant Probability Distribution Data: Creates files describing pollutant (*e.g.* lead, zinc, etc.) concentrations from WinSLAMM source areas and land uses.

Rain Input Subprogram

Both WinSLAMM and WinDETPOND need rain depths, rain durations, and interevent time periods to calculate runoff volume and pollutant loadings. The rain input parameter subprogram records this rain information in a format the models can use. This information can be recorded from rainfall records or generated stochastically from rainfall statistics. Both forms of this data are discussed below.

There are eleven options in the rain input Module menu. They are listed in Table 5-6.

Table 5-6. Rain Input Module Menu

1. Create a Rain File
2. Review or edit a rain file
3. Print a rain file
4. Save a rain file with duration calculations
5. View rain file input instruction
6. Create a generated rain file
7. Calculate the Depth-Duration Rank Correlation
8. Create a Rainfile from Standard Format Data
9. Create a Rainfile from Standard Format Data with Duration and Rainfall Erosive Capacity Data
10. Create a Rainfile from Data Base Formatted Data
11. Leave Rain input Program

Select options 1, 2, or 3 to create, edit, and print a rain file containing rainfall data from recorded rainfall records. The only rain information needed by WinSLAMM is the starting and ending times of each rain and the total rain depth (in inches) of each rain. A rain file therefore consists of rainfall starting and ending dates and times, and rainfall depths. Hourly rainfall data is available from National Oceanic and Atmospheric Administration records. However, the rainfall data must be in the format described below. It will be necessary to examine the hourly rain data and determine the beginning and ending times of each rain event. It is conventional to select 6 hours of no rain as the separating time between adjacent rains for most urban areas.

Rainfall date and time.

The dates must be in the form MM/DD/YY or MM.DD.YY. A date entered as 1/4/88 is unacceptable; it must be entered as 01/04/88. Time must be in the form HH:MM or HH.MM. A time entered as 6:30 is unacceptable; it must be entered as 06:30. Time is entered in 24 hour increments, so afternoon or evening times must be entered as, for example, 18:15, not 06:15. The data entry process in this subprogram is designed to speed data input, and is described below. The process applies to both creating a new rain file and editing an existing file. When editing a file, if an entry is correct, press ENTER; and the existing value will remain unchanged. An analysis cannot currently contain rains from 1999 to 2000. If all the rains selected for analysis are before 2000, or all are after 2000, then there is no problem.

Entering Date and Time Information (Shortcut method):

- Before entering rainfall data, enter the number of distinct rainfall events.
- Before entering rainfall data, enter the last two digits of the year of the first rainfall. For example, type “89” for 1989.
- Enter the beginning date of the rainfall by entering two digits for the month and two digits for the day. Do not separate the two sets of digits with another character or a space.
- Enter the beginning time of the rainfall by entering two digits for the hour. If the rainfall started on the hour, press ENTER. If not, also enter two digits for the minutes. Do not separate the two sets of digits with another character or a space.
- Enter the ending date of the rainfall, if the date is different from the starting date, by entering two digits for the month and two digits for the day. If the ending date is the same as the starting date, press ENTER. Do not separate the two sets of digits with another character or a space. If the ending year is different that the starting year, enter the month, the day, and the new year in the following format: MMDDYY.
- Enter the ending time of the rainfall by entering two digits for the hour. If the rainfall started on the hour, press ENTER. If not, also enter two digits for the minutes.

Entering Rainfall Depth information:

The rain depth must be entered in units of hundredths of inches. For example, if the rainfall depth was 0.09 inches, enter “9.” If the rainfall depth was 1.25 inches, enter “125.” Rain files created with this module will have the extension “.RAN.”

Select option 4 to export rain depths, durations, and times between rains to a file in a comma separated value data format. This option has been provided so that these values can be exported to a spreadsheet to calculate mean rain depths, mean durations, and mean interevent periods that may be used to generate rain events statistically. The format of this export file is listed later. It has the extension “.RES.”

Option 5 is a help screen. It lists the data input and editing shortcuts available for entering the rain data. The help screen is listed in Table 5-7.

Table 5-7. Rainfall Input and Edit Help Screen

1. In the create rain file option, to avoid entering the year each time you enter a date, type before entering any data the last two digits of the year (*e.g.*, 89 for 1989) as a beginning rain data. Press ENTER and then enter all dates with just the month and the date.
2. Do not use “/” (slash) marks when entering dates. Use “0506” or “050689” for 05/06/89.
3. If the times have no minutes, do not add “:00” when entering a time. Enter the twohour digits only.
4. If the ending date is the same as the beginning date, press ENTER.
5. In the create rain file option, enter integers for rain depths. The program will change them to hundredths of an inch.
6. When editing a rain file, if a part of a data line is correct, press ENTER. The current value will be retained.

Select option 6 to create a stochastically generated rain file. This set of subroutines creates rain depths, rain durations, and interevent periods by assuming that the distribution of these parameters closely matches an exponential probability distribution. This assumption is reasonably valid for the small and medium sized rain events (Voorhees 1989) that cause most of the urban nonpoint source pollution problems (Pitt 1987). The rainfall duration can be modeled using either the exponential probability distribution or the gamma probability distribution. The output from this option can be entered into SLAMM or DETPOND as a rain file. To create a stochastically generated rain file, enter the information listed in Table 5-8.

Table 5-8. Information Needed to Create a Stochastically Generated Rain File

1. Generator data file name.
2. Mean rain depth (inches).
3. Minimum recorded rain depth (inches). This is zero unless there is a lower limit (arbitrary or established by data limitations) in the rainfall data.
4. Mean rain duration (hours). Also enter the duration variance to model the duration using the gamma distribution.
5. Mean time between rains (hours).
6. Minimum time between rains (hours; must be an integer). For example, if an interevent period is defined as being greater than three hours, enter 3.
7. Number of events to be generated.
8. Seed. This value initializes the random number generator. Select "0" to use a random seed taken from the computer's internal clock.
9. Enter the rank correlation coefficient for the rainfall depths and rainfall durations in the data. The rank correlation is found by ranking the depths and durations of the data and calculating the correlation of the ranks. Option 7 in this module will calculate this.
10. Rain file start date. The date must be in the form "MM/DD/YY."
11. Number of years of rainfall data. This value is altered by changing the mean time between rains, mean rain duration, or the number of events to be generated.

Option 7 is a two variable Spearman Rank Correlation program. It will calculate both the correlation coefficient (r) and the Spearman rank correlation coefficient for two variables. The data must be in one of three formats that are described later. The output from this option includes the file rain depth, duration, and interevent period averages and maximum values. The output is sent to a file with the extension "COR."

Option 8 is a subroutine that converts hourly rain data into a WinSLAMM rainfall file. The standard format with hourly data is in a comma separated value ASCII file. Each row in the file represents one day of rainfall data. The first value in each row is the date, in the form MM/DD/YY. The next twenty-four values in each row, each separated by a comma, represent hourly rainfall data. Zero rainfall values are acceptable. The user must also enter the minimum number of hours between rains (typically 6 hours) and the minimum rainfall depth to define a rainfall event (typically 0.01 inch). We use the hourly NOAA data as supplied by EarthInfo of Golden, CO, on their CD-ROMs. They supply hourly data all U.S. rain gages on 4 CD-ROMs which can be purchased individually. The CD-ROMs are updated yearly and include all previous data (usually as far back as 1948). The EarthInfo software is used to select the state and the city (specific rain gage). The hourly summary option and the export option is selected. Lotus WK1 file formats are selected for exporting. The file is then opened in Excel and cleaned up. The initial data columns are removed, leaving the date column as the first column. Then the "flag" columns are deleted, along with the "25^{th}" hourly column (the daily rain total) and top header rows. The file is then saved in ASCII format (ASCII MSDOS option in Excel 2000). This file is then indicated in the SLAMM parameter file module to create the SLAMM rain file using this option 8. A representative selection of US rain gage files are included on the distribution disk (and described in a following table).

Option 9 evaluates the erosion potential of different rains through an energy equation that evaluates the erosive power of each rainfall event. This option was included in the parameter module to evaluate the usefulness of the energy algorithm and to evaluate the relative erosion capability of each rain using external procedures (such as Excel); WinSLAMM currently does not use the information.

Option 10 is another subroutine that converts hourly rain data into a WinSLAMM rainfall file. The database file format is also a comma separated value file with three columns. The first column is the date in the form MM/DD/YY. The second column is the time, in hours, in the form 0100 for 1:00 AM, 1300 for 1:00 PM, and so on. The subroutine ignores any 2500 values that are often used to summarize the daily rainfall totals. The third column is the rainfall for the hour. The user must also enter the minimum number of hours between rains and the minimum rainfall depth to define a rainfall event.

The following examples show how various types of rain files are created.

Example 6: Create a Rainfile for Use in DETPOND

Create a rain file with the following four rainfall events:

01/14/87	11:00	01/15/87	03:00	0.21
01/16/87	14:00	01/16/87	16:00	0.05
01/17/87	18:00	01/19/87	02:00	3.79
01/21/87	21:00	01/22/87	07:00	0.46

Step Number	Command or Model Parameter	Enter Value:
1	Run the parameter module	DPPARA55
2	Select option 1: Rain data files	1
3	Select option 1: Create a rain file	1
4	Enter the number of rain events	4
5	Enter the last two digits of the year of the rain events	87
6	Enter the beginning date for the first event in the format MMDD	0114
7	Enter the beginning time for the first event in the format HHMM	1100
8	Enter the ending date for the first event in the format MMDD. If the ending date is the same as the beginning date, press enter	0115
9	Enter the ending time for the first event in the format HHMM	0300
10	Enter the rainfall depth multiplied by 100	21
11	Enter the second rainfall event	0116 1400 <ENTER> 1600 5
12	Enter the third rainfall event	0117 1800 0119 0200 379
13	Enter the fourth rainfall event	0121 2100 0122 0700 46
14	Enter the new rain file name	EX06
15	Exit the program	9 3

Example 7: Edit the Rain File Created in Example 6

Edit the rain file created in example 6 by:

1. Changing the beginning time of the second rainfall from 14:00 to 13:00
2. Insert this new rain event between events 3 and 4:
   01/20/87 03:00 01/20/87 12:00 0.34
3. Changing the rainfall depth of the fourth rainfall from 0.46 to 0.57

Step Number	Command or Model Parameter	Enter Value:
1	Run the parameter module	DPPARA55
2	Select option 1: Rain data files	1
3	Select option 2: Review or edit a rain file	2
4	Enter the name of the rain file you want to edit	EX06
5	Select the option to change a rain event	2
6	Enter the rain number you want to edit	2
7	Change the beginning time of the second rainfall from 14:00 to 13:00 using the format HHMM. Press enter to bypass those values you do not want to change	<ENTER 1300 <ENTER> <ENTER>
8	Before inserting a new rain event, enter the event year	4 87
9	Add a new rain event	1
10	Enter the rain number you want to insert the new rain after	3
11	Enter the beginning date for the new event in the format MMDD	0120
12	Enter the beginning time for the new event in the format HHMM	0300
13	Enter the ending date for the new event in the format MMDD. If the ending date is the same as the beginning date, press enter	<ENTER>
14	Enter the ending time for the new event in the format HHMM	1200
15	Enter the rainfall depth, multiplied by 100, for the new event	34
16	Select the option to change a rain event	2
17	Enter the rain number you want to edit	5
18	Change the rainfall depth of the fifth rainfall from 0.46 to 0.57. Press enter to bypass those values you do not want to change	<ENTER> <ENTER> <ENTER> <ENTER> 57
19	Enter the new rain file name	EX07
20	Exit the program	9 3

Example 8a: Create a Comma-Seperated-Value File from Measured Rain Data
(from CD ROM Database Hourly Rain Data)

The DetPond program can use actual hourly rain data in a comma-seperated format as follows:

```
01/01/90,0.00,0.01,0.00,0.01,0.02,0.01,0.05,1.10,0.07,0.03,0.01,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
01/03/90,0.00,0.00,0.00,0.01,0.01,0.01,0.00,0.10,0.01,0.01,0.01,0.00,0.00,0.00,0.00,0.00,0.01,0.00,0.00,0.01,0.00,0.00,0.01,0.00
01/04/90,0.03,0.01,0.00,0.00,0.00,0.01,0.05,0.00,0.07,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
01/07/90,0.00,0.00,0.00,0.00,0.00,0.01,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.01,0.00,0.00,0.00,0.00,0.01,0.00,0.00,0.00,0.00
01/10/90,0.01,0.01,0.03,0.02,0.15,0.09,0.10,0.03,0.01,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
```

This format shows the date and then 24 hourly rain depths. Many years of rain data from National Weather Service stations are available in CD ROM databases, which exports data files in a similar format. These output data files can be "cleaned up" into the correct format using a spreadsheet program, such as **Lotus** or **Excel**.

1) Extract hourly rain data from CD ROM database

Step Number	Task to Perform
1	Enter CD ROM database
2	Select state of interest
3	Select weather station(s) of interest
4	Select hourly rain data files
5	Filter hourly data files to years of interest
6	Output hourly data files by exporting to Lotus file with .wk1 extension
7	Name output file (name file EXHOUR.WK1 for this example)
8	Exit CD ROM database

2) Put output data file in correct Comma-Seperated-Value format

Example line with correct format:

```
01/01/90,0.00,0.01,0.00,0.01,0.02,0.01,0.05,1.10,0.07,0.03,0.01,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
```

Step Number	Task to Perform
1	Enter spreadsheet program such as Lotus or Excel
2	Open CD ROM output file (EXHOUR.WK1 for this example)
3	Delete unnecessary rows and columns
4	Save as Comma-Seperated-Value file (name file EXHOUR.CSV)

Rainall File Format

Step 1: Example of CD ROM File Imported Into Spreadsheet

PO_CODE	ID	IVISIO	UNITS	DATE	0100	FLG1	0200	FLG2	0300	FLG3	0400	FLG4	0500	FLG5	0600	FLG6	0700	FLG7	0800	FLG8	0900	FLG9	1000	FLG10	1100	FLG11	1200
========	======	=======	=======	=========	======	======	======	======	======	======	======	======	======	======	======	======	======	======	======	======	======	======	======	======	======	======	======
AL	831	2	in.	12/15/1975	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
AL	831	2	in.	12/16/1975	0.01		0.02		0.04		0.07		0.10		0.06		0.04		0.07		0.03		0.01		0.00		0.00
AL	831	2	in.	12/24/1975	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
AL	831	2	in.	12/25/1975	0.00		0.00		0.00		0.00		0.01		0.01		0.04		0.06		0.12		0.05		0.08		0.12
AL	831	2	in.	12/29/1975	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
AL	831	2	in.	12/30/1975	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.01		0.00		0.01		0.10
AL	831	2	in.	12/31/1975	0.02		0.03		0.01		0.01		0.00		0.04		0.12		0.03		0.01		0.00		0.02		0.01
AL	831	2	in.	01/01/1976	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
AL	831	2	in.	01/02/1976	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
AL	831	2	in.	01/03/1976	0.02		0.10		0.03		0.02		0.06		0.21		0.01		0.00		0.00		0.00		0.00		0.00
AL	831	2	in.	01/07/1976	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.20		0.17		0.15		0.04		0.01
AL	831	2	in.	01/11/1976	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.01		0.06		0.07
AL	831	2	in.	01/13/1976	0.02		0.01		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.01		0.00		0.00
AL	831	2	in.	01/20/1976	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.01		0.00		0.01		0.02		0.01
AL	831	2	in.	01/24/1976	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.01		0.02		0.00
AL	831	2	in.	01/25/1976	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.01
AL	831	2	in.	01/26/1976	0.26		0.39		0.04		0.02		0.01		0.00		0.01		0.00		0.00		0.00		0.00		0.00
AL	831	2	in.	02/01/1976	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
AL	831	2	in.	02/05/1976	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
AL	831	2	in.	02/06/1976	0.09		0.05		0.06		0.01		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
AL	831	2	in.	02/11/1976	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.01		0.00		0.00
AL	831	2	in.	02/18/1976	0.00		0.00		0.00		0.24		0.05		0.17		0.11		0.01		0.00		0.00		0.09		0.00
AL	831	2	in.	02/21/1976	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
AL	831	2	in.	03/01/1976	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
AL	831	2	in.	03/05/1976	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
AL	831	2	in.	03/06/1976	0.00		0.00		0.01		0.09		0.10		0.08		0.07		0.10		0.07		0.00		0.00		0.01
AL	831	2	in.	03/08/1976	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
AL	831	2	in.	03/09/1976	0.00		0.00		0.00		0.01		0.07		0.10		0.00		0.00		0.00		0.00		0.01		0.00
AL	831	2	in.	03/12/1976	0.00		0.00		0.00		0.00		0.00		0.02		0.01		0.08		0.17		0.02		0.00		0.00
AL	831	2	in.	03/15/1976	0.00		0.00		0.00		0.05		0.08		0.25		0.29		0.29		0.22		0.16		0.11		0.12
AL	831	2	in.	03/16/1976	0.27		0.33		0.21		0.18		0.13		0.01		0.00		0.00		0.00		0.00		0.00		0.00
AL	831	2	in.	03/20/1976	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.01		0.03
AL	831	2	in.	03/21/1976	0.12		0.26		0.12		0.01		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
AL	831	2	in.	03/24/1976	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
AL	831	2	in.	03/26/1976	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.05
AL	831	2	in.	03/27/1976	0.14		0.53		0.20		0.16		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
AL	831	2	in.	03/29/1976	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
AL	831	2	in.	03/30/1976	0.00		0.13		0.01		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00

Rainfall File Format

Step 2: Example of CD ROM File Imported Into Spreadsheet After Removing Unneeded Columns and Rows

12/15/1975	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.01	0.00	0.00	0.19	0.07	0.05	0.02
12/16/1975	0.01	0.02	0.04	0.07	0.10	0.06	0.04	0.07	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12/24/1975	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01
12/25/1975	0.00	0.00	0.00	0.00	0.01	0.01	0.04	0.06	0.12	0.05	0.08	0.12	0.09	0.08	0.22	0.15	0.06	0.08	0.00	0.00	0.00	0.00	0.01	0.00
12/29/1975	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.01	0.00
12/30/1975	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.10	0.18	0.01	0.05	0.00	0.01	0.00	0.04	0.10	0.05	0.12	0.30	0.07
12/31/1975	0.02	0.03	0.01	0.01	0.00	0.04	0.12	0.03	0.01	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
01/01/1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
01/02/1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
01/03/1976	0.02	0.10	0.03	0.02	0.06	0.21	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
01/07/1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.17	0.15	0.04	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
01/11/1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.07	0.08	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
01/13/1976	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.34	0.00	0.00	0.00	0.00
01/20/1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
01/24/1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
01/25/1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.00	0.02	0.13	0.08	0.58	0.25	0.23	0.28
01/26/1976	0.26	0.39	0.04	0.02	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
02/01/1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
02/05/1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.03	0.03	0.07	0.09
02/06/1976	0.09	0.05	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
02/11/1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
02/18/1976	0.00	0.00	0.00	0.24	0.05	0.17	0.11	0.01	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
02/21/1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.45	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
03/01/1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
03/05/1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.12	0.02	0.00	0.05	0.06	0.00	0.00	0.01
03/06/1976	0.00	0.00	0.01	0.09	0.10	0.08	0.07	0.10	0.07	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
03/08/1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.16	0.33	0.33	0.02	0.00
03/09/1976	0.00	0.00	0.00	0.01	0.07	0.10	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
03/12/1976	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.08	0.17	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.45	0.08	0.25	0.00	0.00	0.00
03/15/1976	0.00	0.00	0.00	0.05	0.08	0.25	0.29	0.29	0.22	0.16	0.11	0.12	0.23	0.22	0.12	0.02	0.02	0.31	0.02	0.00	0.00	0.00	0.00	0.00
03/16/1976	0.27	0.33	0.21	0.18	0.13	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
03/20/1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.39	0.24
03/21/1976	0.12	0.26	0.12	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
03/24/1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.01
03/26/1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.22	0.12	0.00	0.02	0.02	0.05	0.02	0.00	0.01	0.00	0.00	0.02
03/27/1976	0.14	0.53	0.20	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
03/29/1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.81	0.06	0.42	0.70	0.05	0.01	0.00	0.00
03/30/1976	0.00	0.13	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.20	0.18	0.12	0.00	0.07	0.07	0.01	0.00	0.14	0.14	0.16

Rainfile File Format

Step 4: Example of CD ROM File Saved as a SLAMM Rainfile

```
102
"12/15/75","16:00","12/16/75","10:00",".83"
"12/25/75","04:00","12/25/75","18:00","1.17"
"12/29/75","20:00","12/29/75","23:00",".05"
"12/30/75","08:00","12/31/75","12:00","1.35"
"01/02/76","22:00","01/03/76","07:00",".46"
"01/07/76","07:00","01/07/76","12:00",".57"
"01/11/76","09:00","01/11/76","14:00",".25"
"01/13/76","18:00","01/13/76","20:00",".38"
"01/20/76","07:00","01/20/76","12:00",".05"
"01/25/76","17:00","01/26/76","07:00","2.3"
"02/05/76","19:00","02/06/76","04:00",".51"
"02/18/76","03:00","02/18/76","11:00",".67"
"02/21/76","13:00","02/21/76","16:00",".61"
"03/05/76","14:00","03/06/76","13:00",".85"
"03/08/76","18:00","03/08/76","23:00",".92"
"03/09/76","03:00","03/09/76","06:00",".18"
"03/12/76","05:00","03/12/76","10:00",".3"
"03/12/76","17:00","03/12/76","21:00","1.18"
"03/15/76","03:00","03/15/76","19:00","2.51"
"03/16/76","00:00","03/16/76","06:00","1.13"
"03/20/76","10:00","03/20/76","12:00",".04"
"03/20/76","22:00","03/21/76","04:00","1.14"
"03/26/76","11:00","03/27/76","04:00","1.56"
"03/29/76","15:00","03/29/76","22:00","2.06"
"03/30/76","01:00","03/30/76","03:00",".14"
"03/30/76","12:00","03/31/76","04:00","2.08"
```

Notes:

1. This rainfile was created assuming that the time between rain events was three hours and the minimum rainfall depth was 0.04 inches.
2. This rainfile is a section of the EXHOUR.RAN example file created from the EXHOUR.WK1 CD ROM file. The program created 102 events from this file; only the events from 12/15/75 to 03/31/76 are shown here.

Description of Selected Rainfiles Included With The Program

The following are descriptions of some of the rain files included with the distribution of SLAMM. As an example, the BHAM76.RAN file contains all of the rains from 1976, as recorded at the Birmingham, AL, airport. The BHAM76.RAN file was selected to represent a typical Birmingham rain year. Similarly, the RAIN81.RAN file contains all of the 1981 rains observed at the Milwaukee Nationwide Urban Runoff Project (NURP) sampling locations. These files were used for the verification of the runoff volume and pollutant discharges using the observed NURP data. There are some relatively large rain files included that represent 30 to 50 years of rainfall observations. These files were produced from NOAA records (as recorded on EarthInfo CD-ROMs). Some of these files have rains as early as 1948, although the earliest rains that SLAMM can evaluate start on Jan 1, 1953. When selecting the rain file within SLAMM, the start and end dates of the evaluation period are automatically set to include all of the rains in the rain file. However, if earlier rains before 1953 are included in the rain file, a warning message is shown and the starting rain date for the evaluation is automatically moved to the earliest rain in 1953.

SLAMM is a fair weather program, as it currently does not include snowmelt (or baseflows). For areas with very cold winters (having extended periods of snowpacks each winter), the model should only be run for the rain season. For other areas, long-term continuous simulations are possible using the complete rain files covering several decades. The following is a listing of the rain files included with the download program, including brief descriptions of the rain series included in each file (you notice there are no 2000 year dates, that is another story).

File name	City	State/Province	Years	Approx. Rain Depth (in.)	Very Cold Winters?	Very Hot Summers?
Alby4895	Albany	New York	1948-1995	36	yes	no
Atl8792	Atlanta	Georgia	1987-1992	49	No	yes
Aust5292	Austin	Texas	1952-1992	32	No	yes
Bham4895	Birmingham	Alabama	1948-1995	55	No	yes
Bham76	Birmingham	Alabama	1976	55	No	yes
Bhamflod	Birmingham (series of extreme IDF rains)	Alabama	special	na	na	na
Bhamsrce	Birmingham (series for source evaluations)	Alabama	special	na	na	na
Boz8893	Bozeman	Montana	1988-1993	12	Yes	no
Buf8792	Buffalo	New York	1987-1992	36	Yes	no
CV80	Castro Valley (NURP data)	California	1980	15	no	no
Dal8893	Dallas	Texas	1988-1993	29	No	yes
Denv4895	Denver	Colorado	1948-1995	15	Yes	no
Dlt1975	Duluth	Minnesota	1975 (a typical year)	30	Yes	no
Gb1969	Green Bay	Wisconsin	1969 (a typical year)	28	Yes	No
Gb1982	Green Bay	Wisconsin	1982 (a typical year)	28	Yes	no
Lax4895	Los Angeles	California	1948-1995	13	No	no
LH80	Lake Hills (Bellevue) (NURP Data)	Washington	1980	35	No	No
LH81	Lake Hills (Bellevue) (NURP Data)	Washington	1981	35	No	No
LH82	Lake Hills (Bellevue) (NURP Data)	Washington	1982	35	No	No
LR7276	Little Rock	Arkansas	1972-1976	49	No	yes
Mads4895	Madison	Wisconsin	1948-1995	31	Yes	no
Miam5292	Miami	Florida	1952-1992	60	No	yes
Milwflod	Milwaukee (series of extreme IDF rains)	Wisconsin	special	na	na	na
Milw81	Milwaukee (NURP data)	Wisconsin	1981	31	Yes	no
Milw83	Milwaukee (NURP data)	Wisconsin	1983	31	Yes	no
Milw88	Milwaukee (monitoring period data)	Wisconsin	1988	31	Yes	no
Milw5288	Milwaukee	Wisconsin	1952-1988	31	Yes	no
Minn5289	Minneapolis	Minnesota	1952-1989	25	Yes	no
Mke1969	Milwaukee	Wisconsin	1969 (a typical year)	31	Yes	No
Monroe94	Madison (Monroe St)	Wisconsin	1994	31	Yes	no
Mps1959	Minneapolis	Minnesota	1959 (a typical year)	25	yes	no
Msn1968	Madison	Wisconsin	1968	31	yes	no
Msn1981	Madison	Wisconsin	1981	31	yes	no
Msntest	Madison (a small test file)	Wisconsin	1981 (only 5 events)	31	yes	no
Newk5292	Newark	New Jersey	1952-1992	42	No	no
Newo5495	New Orleans	Louisiana	1954-1995	54	No	yes
Newtor83	Toronto (TAWMS data)	Ontario	1983	32	Yes	No

File name	City	State/Province	Years	Approx. Rain Depth (in.)	Very Cold Winters?	Very Hot Summers?
Phen8391	Phoenix	Arizona	1983-1991	7	No	yes
NYNY4895	New York	New York	1948-1995	44	no	no
Por8892	Portland	Maine	1988-1992	44	No	no
RC8893	Rapid City	South Dakota	1988-1993	16	Yes	no
RCMD4895	Richmond	Virginia	1948-1995	44	no	yes
Ren8893	Reno	Nevada	1988-1993	7	Yes	yes
Setl4895	Seattle	Washington	1948-1995	39	No	no
SFCA4895	San Francisco	California	1948-1995	19	No	no
SL8792	Salt Lake City	Utah	1987-1992	14	Yes	no
Stlo5292	St. Louis	Missouri	1952-1992	34	no	no

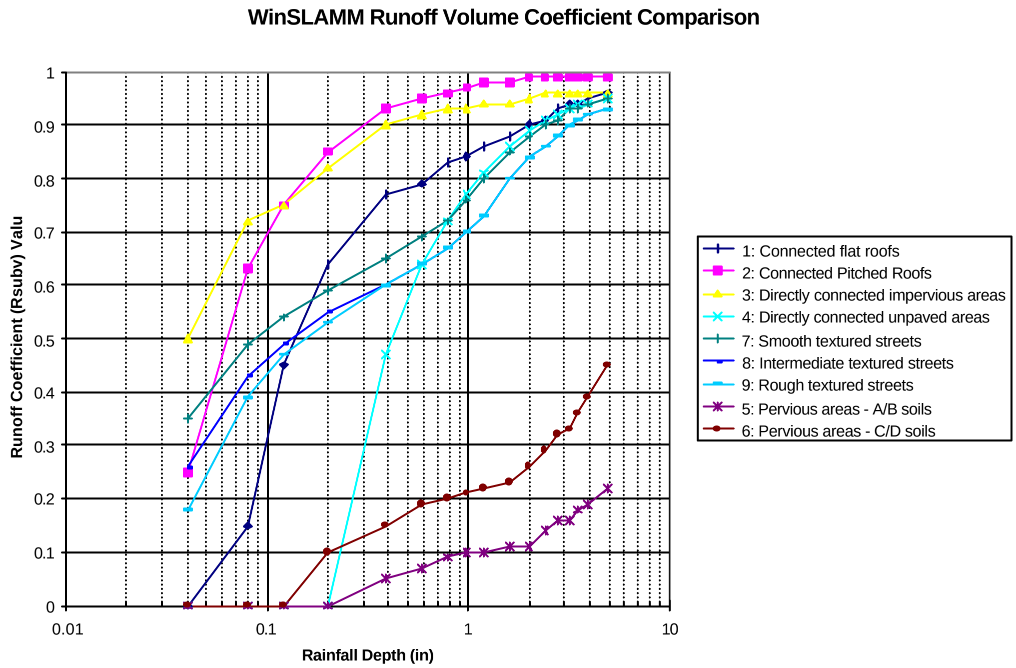
Appendix 5-C contains an example printout of the Bham76.ran rain file for the 1976 year in Birmingham, AL.

Runoff Coefficient Subprogram

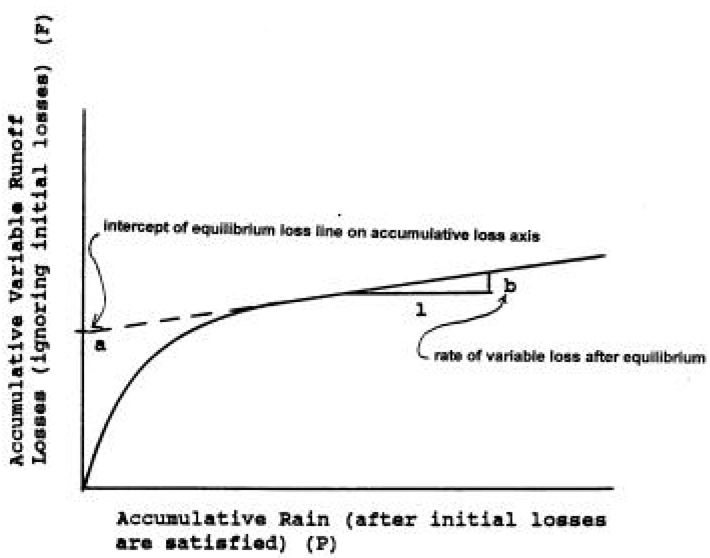
Runoff volume generation in WinSLA MM is accomplished with an RSV file. The included runoff.RSV file, named RUNOFF.RSV has undergone extensive calibration and verification and should not be destroyed. The runoff coefficients were calculated using general impervious and pervious area models. These models were then calibrated based on extensive Toronto data and were then verified using additional independent Toronto data, along with numerous Milwaukee and Madison data for a wide variety of land development and rain conditions. However, WinSLAMM was designed to allow the use of alternative runoff models, as desired. Alternative runoff coefficients for each source area type can be calculated using other models and saved as a different runoff.RSV file name.

Runoff coefficients, when multiplied by rain depths, land use source areas, and a conversion factor, determine the runoff volumes needed by SLAMM. The runoff coefficient subprogram creates the runoff coefficient file used in SLAMM and DETPOND. All runoff coefficient files have the extension ".RSV." Coefficients are required for nine area types which are listed in Table 5-9. Each area type requires a value for the 17 different rainfall depths listed in Table 5-10. The runoff coefficients are further reduced when the runoff from the areas drain across soils instead of being directly connected to the storm drainage system. These reduction factors are expressed as drainage efficiency factors (DEF). Table 5-11 lists the drainage efficiency factors. Disconnected paved area runoff coefficients in low density areas are similar to the runoff coefficients for the landscaped areas. All coefficient values must be less than 1.0.

The RUNOFF.RSV file contains the verified runoff coefficients, based on the small storm hydrology model. A typical runoff coefficient file is plotted below.



These data fit the general infiltration rate model developed by Pitt (1987) as follows:



$$F = bP + a(1 - e^{-gP})$$

where F = accumulative variable losses

g = exponential coefficient

P = accumulated rainfall

If b = 0, then a = total losses and no steady state losses occur (equivalent to SCS model)

Note: time since runoff started is not a factor (as implied by most users of Horton equation).

This figure plots cumulative variable runoff losses (F, inches or mm), ignoring the initial losses, versus cumulative rain (P, inches or mm), after runoff begins. The slope of this line is the instantaneous variable runoff loss (infiltration) occurring at a specific rain depth after runoff starts. A simple nonlinear model can be used to describe this relationship which is similar to many other infiltration models. For a constant rain intensity (i), total rain depth since the start of runoff (P), equals intensity times the time since the start of runoff (t). The small storm hydrology nonlinear model for this variable runoff loss (F) is therefore:

$$F = bit + a(1 - e^{-git}) \quad \text{or} \quad F = bP + a(1 - e^{-gP})$$

Three basic model parameters were used to define the model behavior, in addition to initial runoff losses and rain depth: "a", the intercept of the equilibrium loss line on the cumulative variable loss axis; "b", the rate of the variable losses after equilibrium; and "g", an exponential coefficient. If variable losses are zero at equilibrium, then "b" would be zero. Because this plot does not consider initial runoff losses, the variable loss line must pass through the origin. This model reduces to the SCS model when the "b" value is zero and "a" is S', and when Ia is 0.16 (80% of 0.2) of "a". This general model also reduces to the Horton equation when cumulative rain depth since the start of the event is used instead of just time since the start of rain. Observed runoff data from both small- and large-scale tests were fitted to this equation to determine the values for a, b, and g for observed i and t (or P), and F values. In addition, outfall runoff observations from many different heterogeneous land uses were used to verify the calibrated model (Pitt 1987). Below is a table showing the relationship between this model and the SCS and Horton parameters:

Curve Number	Fitted g from hypothesized model	SCS S' Value (ignores Ia) (mm)[1]	Initial Horton Infiltration Rate (Fo) (mm/hr)[2]	Horton Equation Decay Coefficient (k)[3] (1/hr)
99	0.22	2.03	0.45i	0.22i
95	0.042	10.7	0.45i	0.042i
90	0.022	22.6	0.50i	0.022i
85	0.016	35.8	0.57i	0.016i
80	0.012	50.8	0.61i	0.012i
75	0.010	67.8	0.67i	0.010i
70	0.0081	87.4	0.71i	0.0081i
60	0.0057	136	0.78i	0.0057i
50	0.0041	203	0.83i	0.0041i
40	0.0029	305	0.88i	0.0029i

(1) S' = 0.8S assumed by SCS. S' also equals a.
(2) Fo = S'gi, where i equals rain intensity (mm/hr).

Note: The SCS curve number procedure assumes that the final infil tration rate (Fc) is zero.

(3) K = gi, or Fo/S'

Table 5-9. Runoff Coefficient Area Types

1. Connected flat roofs
2. Connected pitched roofs
3. Directly connected impervious areas
4. Directly connected unpaved areas
5. Pervious area - sandy (A/B) soils
6. Pervious area - clayey (C/D) soils
7. Smooth textured streets
8. Intermediate textured streets
9. Rough textured streets

Table 5-10. Rain Depths Needed for Each Area Type

in:	0.04	0.08	0.12	0.20	0.39	0.59	0.79	0.98	1.2
mm:	1	2	3	5	10	15	20	25	30
in:	1.6	2.0	2.4	2.8	3.2	3.5	3.9	4.9	
mm:	40	50	60	70	80	90	100	125	

Table 5-11. Drainage Efficiency Factors

1. w/o alleys, medium to high density land use
2. w/ alleys, medium to high density land use
3. strip commercial and shopping center land use

Appendix 5-D contains an example printout of the Runoff.rsv runoff coefficient file.

Critical Particle Size Subprogram

The particle size distribution option prepares files containing the runoff particle size distribution for wet detention pond analyses. This information describes the size distribution of urban runoff particulates that enter a detention pond. These files have the extension ".CPZ." The particle size range is from 0 to 2000 microns.

To create a particle size file, enter the percentage of the particles in the runoff that are greater than the corresponding particle size for each particle size. The program will scroll from a particle size of 1 micron to a particle size of 2000 microns. The program will beep if a percentage value greater than the previous value is entered. Correct the error with the file-editor option.

Table 5-12 lists the particle sizes needed for a distribution. By definition, 100% of the particles are greater than 0 micrometers (μm) in size, and 0% of the particles are greater than 2000 μm. Data for each size can be easily determined from a standard particle size distribution plot developed from laboratory settling column tests or particle size analyses.

Table 5-12. Critical Particle Sizes for Detention Pond Analysis (■m)

0	6	12	30	100	1000
1	7	13	35	150	2000
2	8	14	40	200	
3	9	15	50	300	
4	10	20	60	500	
5	11	25	80	800	

The following example illustrates the creation of a particle size file:

Example 10: Create a Particle Size Distribution File

Create a particle distribution file from the MIDWEST data particle size distribution illustrated in Figure 10 on page 43 of the DETPOND manual.

Step Number	Command or Model Parameter	Enter Value:
1	Run the parameter module	DPPARA55
2	Select option 2: Particle Size data files	2
3	Select option 1: Create a new particle size distribution file	1
4	Enter the name of the new particle size distribution file	EX10
5	Enter the description of the new particle size distribution file	pg 43 dist
6	For each entry, enter the percent of the particles that are greater than the corresponding critical particle size	for 1 micron: 100 for 2 microns: 98 for 3 microns: 94 for 4 microns: 91 for 5 microns: 88 for 6 micron: 86 for 7 microns: 84 for 8 microns: 82 for 9 microns: 80 for 10 microns: 78 for 11 micron: 75 for 12 microns: 72 for 13 microns: 70 for 14 microns: 67 for 15 microns: 64 for 20 micron: 60 for 25 microns: 57 for 30 microns: 53 for 35 microns: 48 for 40 microns: 44 for 50 microns: 42 for 60 microns: 38 for 80 micron: 34 for 100 microns: 28 for 150 microns: 18 for 200 microns: 16 for 300 microns: 12 for 500 micron: 7 for 800 microns: 4 for 1000 microns: 3 for 2000 microns: 1
17	Exit the program	4 3

Description of Selected Critical Particle Size Files Included With The Program

The example size.CPZ files for wet detention analysis included in the disk were constructed using extensive urban runoff particle size data. However, these different size.CPZ files result in a wide range of potential wet detention pond performance (suspended solids percentage reduction) measurements. The particle size distributions for various source areas where wet detention ponds may be used can be expected to also vary widely. These size.CPZ files should therefore be used with caution, but they are expected to generally bracket particle size distributions in stormwater.

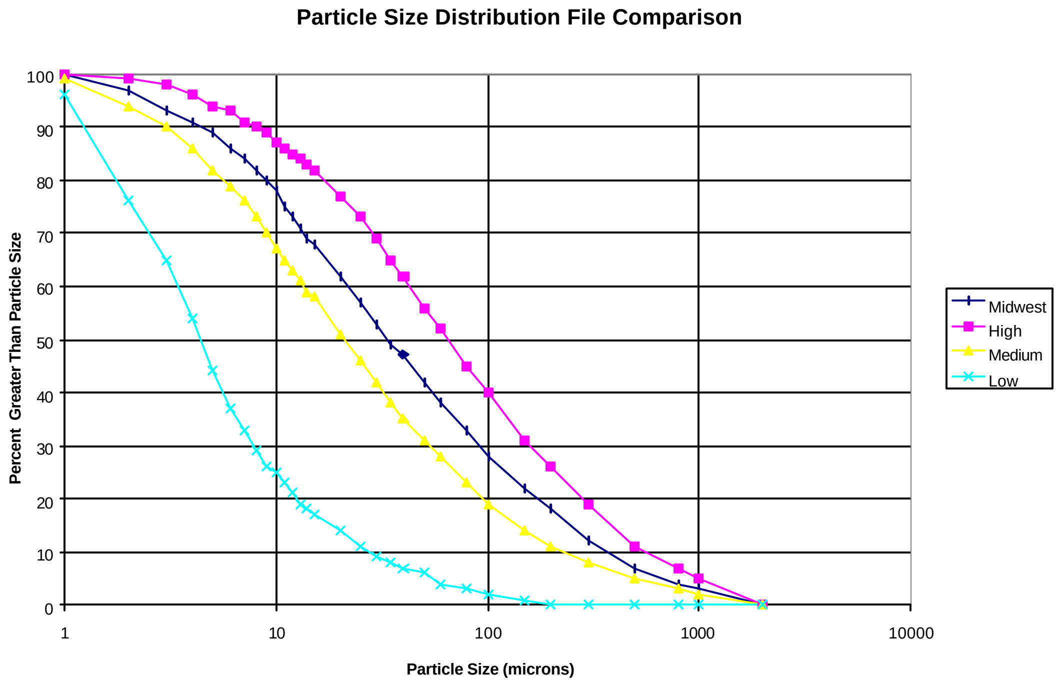
- LOW.CPZ is a particle size distribution corresponding to an urban runoff flow containing low concentrations of particulate residue (such as for roof runoff).
- MEDIUM.CPZ is a particle size distribution file for runoff containing "medium" particulate residue concentrations (such as for outfall locations).

• HIGH.CPZ is a particle size distribution file for runoff containing high concentrations of particulate residue (such as for construction sites).

• NURP.CPZ is an average of the available outfall particle size distribution data for all of the NURP projects.

• MIDWEST.CPZ summarizes the upper Midwest and Toronto outfall particle size data.

Below is a plot of the data in each of these files.



Also included on the distribution disk is an additional particle size file representing typical street dirt sizes (stretdrt.cpz). This file should not be used in stormwater treatment evaluations, but can be used to illustrate the misleading results when users incorrectly assume that the earlier reported street dirt particle distribution is the same as the particle size distribution in the runoff. Appendix 5-H includes an example file showing the medium.cpz distribution.

Particulate Solids Concentration Module

Particulate solids concentration values, when multiplied by source area runoff volumes and a conversion factor, calculate particulate solids loadings (lbs) in WinSLAMM. The particulate solids concentration subprogram creates the particulate solids concentration file used in WinSLAMM. All particulate solids concentration files have the extension ".PSC." Concentrations are required for thirteen area types in six land uses in WinSLAMM. These are listed in Table 5-13. Street areas are not included because WinSLAMM calculates street source area washoff directly. Each area type requires a value for the 14 different rain depths listed in Table 5-14.

Table 5-13. SLAMM Land Uses And Source Areas Listed In The Particulate Solids Concentration Subprogram

Land Uses:	Residential	Institutional
	Commercial	Industrial
	Open Spaces	Freeways

Source Areas:

Roofs	Undeveloped Areas
Paved Parking/Storage	Small Landscaped Areas
Unpaved Parking/Storage	Large Turf Areas
Playgrounds	Other Pervious Areas
Driveways	Other Impervious Areas
Sidewalks/Walks	Freeway Lanes/Shoulders
Large Landscaped Areas	

Table 5-14. Rain Depths Listed In The Particulate Solids Concentration Subprogram

in:	0.04	0.08	0.12	0.20	0.39	0.59	0.79	0.98	1.2
mm:	1	2	3	5	10	15	20	25	30
in:	1.6	2.0	2.4	2.8	3.2				
mm:	40	50	60	70	80				

The distribution disk contains a particulate residue (suspended solids) description file, BHAM.PSC. This file contains the summary of the calibrated and verified runoff particle solids concentration conditions found during Madison, Toronto, Birmingham and Milwaukee urban runoff research. Appendix 5-F lists the Bham.psc file.

Particulate Residue Reduction Subprogram

SLAMM uses the particulate residue reduction subprogram to create parameter files that describe the fraction of total particulates that remains in the drainage system (curbs and gutters, grass swales, and storm drainage) after rain events end due to deposition. The reduction of particulate residue at the outfall due to the delivery system is a function of the type of drainage system and rainfall depth. SLAMM calculates this deposition effect for three different drainage systems, based on the condition of the curb and gutter. The three drainage delivery systems are:

1. Grass swales
2. Undeveloped roadside
3. Curb and gutters, “valleys,” or sealed swales

The three condition options for curbs and gutters are:

1. Poor condition (or very flat)
2. Fair condition
3. Good condition (or very steep)

To create a particulate residue delivery reduction parameter file, enter the particulate residue reduction fraction for each of the drainage delivery types and, for curb and gutter system, conditions, described above. Enter a fractional value for each rainfall depth listed in Table 5-14. To edit a file, select a delivery system type, and condition option for curb and gutter systems, and the rain number. Enter the new fractional value at the prompt after entering the rain number. Particulate residue reduction parameter files have the extension “.PRR.” Appendix 5-E contains a printout of an example Delivery.prr file.

Pollutant Probability Distribution Subprogram

Data from a pollutant value file determine, when multiplied by either a source area runoff volume or source area particulate loading, the pollutant loading from a source area. This subprogram creates files that describe pollutant concentrations or loadings that are from source areas and land uses used in SLAMM. This data is generally based upon pollutant loading and concentration source area and land use data collected from the study area or region. For example, particulate phosphate source data, in units of milligrams of phosphate per kilogram of suspended solids loading in the runoff, must be entered for each source area and land use of concern. The land uses and source areas are described in Table 5-15.

To enter pollutant data in a new file, select the pollutant of concern from the "Pollutant Concentration Relative Values" menu. Then enter the geometric mean relative concentration value and the coefficient of variation of the selected pollutant for each source area and land use. To edit an existing pollutant parameter file, the user may either edit pollutant values for an entire source area, edit only a specified land use-source area pollutant value, or enter a multiplier factor for the mean pollutant value and coefficient of variation value of each of the source areas in a land use.

Table 5-15. SLAMM Land Uses and Source Areas Listed in the Pollutant Probability Distribution Subprogram

Land Uses:

Residential	Institutional	Commercial
Industrial	Open Spaces	Freeways

Source Areas:

Roofs	Undeveloped Areas
Paved Parking/Storage	Small Landscaped Areas
Unpaved Parking/Storage	Other Pervious Areas
Playgrounds	Other Impervious Areas
Driveways	Freeway Lanes/Shoulders
Sidewalks/Walks	Large Turf Areas
Street Areas	Large Landscaped Areas

The MADISON7.PPD file contains the filterable residue (dissolved solids) concentrations for each source area and for several pollutants. This file also contains COV values needed for the Monte Carlo evaluations. Table 5-16 shows the complete listing of pollutants available in SLAMM. In addition, the user may define up to six other pollutants in both particulate and filterable forms.

Table 5-16. Pollutants Available in SLAMM

Particulate Forms	Filterable Forms
Particulate Solids (kg/kg) (1)	Filterable Solids (mg/L)
Phosphorus (mg/kg)	Phosphate (mg/L)
	Nitrates (mg/L)
	Ammonia (mg/L)
Total Kjeldahl Nitrogen (mg/kg)	Total Kjeldahl Nitrogen (mg/L)
Chemical Oxygen Demand (mg/kg)	Chemical Oxygen Demand (mg/L)
Chromium (micrograms/kg)	Chromium (micrograms/L)
Copper (micrograms/kg)	Copper (micrograms/L)
Lead (micrograms/kg)	Lead (micrograms/L)
Zinc (micrograms/kg)	Zinc (micrograms/L)
	Fecal Coliform Bacteria (#/100 ml) (2)
Other pollutant #1	Other pollutant #1
Other pollutant #2	Other pollutant #2
Other pollutant #3	Other pollutant #3
Other pollutant #4	Other pollutant #4

Other pollutant #5	Other pollutant #5
Other pollutant #6	Other pollutant #6

[(1)] The particulate solids (suspended solids) data is obtained in the Particulate Solids Concentration subprogram described below.

[(2)] Fecal Coliform are retained on 0.45 micrometer filters, but generally behave like filterable pollutants in most urban runoff control practices.

Table 5-17. Units Available for Other Pollutants

Particulate Pollutant Units	Filterable Pollutant Units
1. nanograms/kg	1. nanograms/L (ng/L)
2. micrograms/kg	2. micrograms/L (µg/L)
3. milligrams /kg	3. milligrams /L (mg/L)
	4. #/100 ml (# ==> bacteria count)

To enter pollutants that are not listed in Table 5-16, select pollutants 11 -16 (Other particulate pollutants) or pollutants 27 - 32 (Other filterable pollutants). Enter the name of the pollutant and the units of the pollutant. Table 5-17 lists the available units. Apply the same procedures used to enter pollutants listed in Table 5-16 when entering "Other Pollutant" values. Table 5-18 is a blank coding form to organize the pollutant values.

Table 5-18. Blank Coding Form for Pollutant Probability Concentration File

Pollutant Probability Relative Concentration File (file.ppd)												
File name:												
Pollutant:												
filterable form (mg/L for COD, ug/L for nutrients and metals, and #/100 mL for bacteria)												
	Residential		Institutional		Commercial		Industrial		Open Space		Freeways	
	mean	COV	mean	COV	mean	COV	mean	COV	mean	COV	mean	COV
1. Roofs											n/a	n/a
2. Paved parking/storage											n/a	n/a
3. Unpaved parking/storage											n/a	n/a
4. Paved playground											n/a	n/a
5. Paved driveways											n/a	n/a
6. Paved walks											n/a	n/a
7. Paved streets											n/a	n/a
8. Large landscaped areas											n/a	n/a
9. Undeveloped areas											n/a	n/a
10. Small landscaped areas											n/a	n/a
11. Isolated areas	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
12. Other pervious areas												
13. Other directly connected impervious areas												
14. Other partially connected impervious areas												
15. Paved freeway lane and shoulder areas	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a		
16. Large turf areas												
particulate form (mg/kg)	Residential		Institutional		Commercial		Industrial		Open Space		Freeways	
	mean	COV	mean	COV	mean	COV	mean	COV	mean	COV	mean	COV
1. Roofs											n/a	n/a
2. Paved parking/storage											n/a	n/a
3. Unpaved parking/storage											n/a	n/a
4. Paved playground											n/a	n/a
5. Paved driveways											n/a	n/a
6. Paved walks											n/a	n/a
7. Paved streets											n/a	n/a
8. Large landscaped areas											n/a	n/a
9. Undeveloped areas											n/a	n/a
10. Small landscaped areas											n/a	n/a
11. Isolated areas	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
12. Other pervious areas												
13. Other directly connected impervious areas												
14. Other partially connected impervious areas												
15. Paved freeway lane and shoulder areas	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a		
16. Large turf areas												

Appendix 5-G contains the printout of the Bham.ppd file, showing the source area concentrations and variabilities used.

Example Input and Output Files

Printouts of the following example WinSLAMM files described below are presented in this section or in Appendices 5-C through 5-G:

- NEWRES.DAT . This is an example input file summarizing the characteristics of the area to be simulated. This file shows the areas for each source area, along with the associated “parameter” files also used. The rain simulation period examined, plus the source area and outfall controls are also shown.

- BHAM76.RAN (see Appendix 5-C). This is the 1976 rain file for Birmingham, AL. It contains 112 rains, although the example output file only includes a simulation for January. This file shows the beginning and end dates and times of the individual rains, plus the rainfall depth, the rainfall duration, the average rainfall intensity, and the interevent duration between the end of the indicated event and the following event.

- RUNOFF.RSV (see Appendix 5-D). This is the general runoff coefficient description file. The file is set up as a table of varying volumetric runoff coefficients for different rains and source areas.

- DELIVERY.PRR (see Appendix 5-E). This is the suspended solids “delivery” file reflecting the SS fractions that are trapped in the surface drainage system (swales and curbs) and in the sewerage. These values are quite large for small rains where sufficient energy is available to dislodge particulates from paved surfaces, but is insufficient to transport the solids to the outfall.

- BHAM.PSC (see Appendix 5-F). This is the suspended solids concentration file showing changes in SS concentrations for different rains and source areas (except for streets and freeway lanes which area calculated internally by WINSLAMM).

- BHAM.POL (see Appendix 5-G). This is the pollutant relative concentration file that describes the sheetflow concentrations of pollutants (other than suspended solids). Both particulate fractions (usually in mg/kg of SS) and filtered concentrations (usually in mg/L) are given for each source area and land use.

- NEWRES.OUT . This file is an example WINSLAMM output file for the above NEWRES.DAT input file and the associated parameter files. Summary tables are shown for runoff volume and suspended solids.

```
Data file name:  E:\slamm803\Newres.dat                      SLAMM Version V8.0
    Rain file name:  E:\SLAMM803\BHAM76.RAN                      Particulate Solids Concentration file name:  E:\SLAMM803\BHAM.PSC
    Runoff Coefficient file name:  E:\SLAMM803\RUNOFF.RSV         Particulate Residue Delivery file name:  E:\SLAMM803\DELIVERY.PRR
    Pollutant Relative Concentration file name:  E:\SLAMM803\POLL.PPD
                                                                 Seed for random number generator:   5
    Study period starting date:  01/02/76                        Study period ending date:  01/31/76
    Date:  03-08-1999                                            Time:  20:30:40
    Fraction of each type of Drainage System serving study area:
      1. Grass Swales 0
      2. Undeveloped roadside 0
          Curb and Gutters, `valleys', or sealed swales in:
           3. Poor condition (or very flat) 0
           4. Fair condition 1
           5. Good condition (or very steep) 0
    Site information:  MEDIUM DENSITY RESIDENTIAL 1961-1980, CURBS AND GUTTERS, CLAYEY SOILS, BASELINE CONTROLS (NONE)
```

Source Area	Resi-dential Areas	Institu-tional Areas	Commercial Areas	Industrial Areas	Open Spaces Areas
	|<===== Areas for each Source (acres) =====>|				
Roofs 1	2.60	0.00	0.00	0.00	0.00
Roofs 2	6.05	0.00	0.00	0.00	0.00
Roofs 3	0.00	0.00	0.00	0.00	0.00
Roofs 4	0.00	0.00	0.00	0.00	0.00
Roofs 5	0.00	0.00	0.00	0.00	0.00
Paved Parking/Storage 1	0.00	0.00	0.00	0.00	0.00
Paved Parking/Storage 2	0.00	0.00	0.00	0.00	0.00
Paved Parking/Storage 3	0.00	0.00	0.00	0.00	0.00
Unpaved Prkng/Storage 1	0.00	0.00	0.00	0.00	0.00
Unpaved Prkng/Storage 2	0.00	0.00	0.00	0.00	0.00
Playground 1	0.00	0.00	0.00	0.00	0.00
Playground 2	0.00	0.00	0.00	0.00	0.00
Driveways 1	1.19	0.00	0.00	0.00	0.00
Driveways 2	1.18	0.00	0.00	0.00	0.00
Driveways 3	0.00	0.00	0.00	0.00	0.00
Sidewalks/Walks 1	0.00	0.00	0.00	0.00	0.00
Sidewalks/Walks 2	0.00	0.00	0.00	0.00	0.00
Street Area 1	6.58	0.00	0.00	0.00	0.00
Street Area 2	0.65	0.00	0.00	0.00	0.00
Street Area 3	0.00	0.00	0.00	0.00	0.00
Large Landscaped Area 1	0.00	0.00	0.00	0.00	0.00
Large Landscaped Area 2	0.00	0.00	0.00	0.00	0.00
Undeveloped Area	4.59	0.00	0.00	0.00	0.00
Small Landscaped Area 1	50.94	0.00	0.00	0.00	0.00
Small Landscaped Area 2	26.22	0.00	0.00	0.00	0.00
Small Landscaped Area 3	0.00	0.00	0.00	0.00	0.00
Isolated Area	0.00	0.00	0.00	0.00	0.00
Other Pervious Area	0.00	0.00	0.00	0.00	0.00
Other Dir Cnctd Imp Area	0.00	0.00	0.00	0.00	0.00
Other Part Cnctd Imp Area	0.00	0.00	0.00	0.00	0.00
	--------	--------	--------	--------	--------
Total	100.00	0.00	0.00	0.00	0.00

Freeway Source Area	Area (acres)
Pavd Lane & Shldr Area 1	0.00
Pavd Lane & Shldr Area 2	0.00
Pavd Lane & Shldr Area 3	0.00
Pavd Lane & Shldr Area 4	0.00
Pavd Lane & Shldr Area 5	0.00
Large Turf Areas	0.00
Undeveloped Areas	0.00
Other Pervious Areas	0.00
Other Directly Conctd Imp	0.00
Other Partially Conctd Imp	0.00

Total	0.00

Total of All Source Areas 100.00

Total of All Source Areas
less All Isolated Areas 100.00

Source Area Control Practice Information

Land Use: Residential

Roofs 1 Source area number: 1

The roof is pitched

The Source Area is directly connected or draining to a directly conntected area

Roofs 2 Source area number: 2

The roof is pitched

The Source Area is draining to a pervious area (partially connected impervious area)

The SCS Hydrologic Soil Type is Clayey

The building density is medium or high

Alleys are not present

Driveways 1 Source area number: 13

The Source Area is directly connected or draining to a directly conntected area

```
   Driveways 2    Source area number:  14
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Clayey
         The building density is medium or high
         Alleys are not present
   Street Area 1    Source area number:  18
            1. Street Texture:  intermediate
            2. Total study area street length (curb-miles):  2.73
            3. Initial Street Dirt Loading (lbs/curb-mi):  default value
            4. Street Dirt Accumulation:
                  Default value used
   Street Area 2    Source area number:  19
            1. Street Texture:  rough
            2. Total study area street length (curb-miles):  0.27
            3. Initial Street Dirt Loading (lbs/curb-mi):  default value
            4. Street Dirt Accumulation:
                  Default value used
   Undeveloped Area    Source area number:  23
         The SCS Hydrologic Soil Type is Clayey
   Small Landscaped Area 1    Source area number:  24
         The SCS Hydrologic Soil Type is Clayey
   Small Landscaped Area 2    Source area number:  25
         The SCS Hydrologic Soil Type is Clayey

Pollutants to be Analyzed and Printed:
         Pollutant Name               Pollutant Type
         --------------               --------------
          Solids                      Particulate
          Chemical Oxygen Demand
```

Data File: Newres.DAT
Rain File: BHAM76.RAN
Date: 03-08-99 Time: 8:27:46 PM
Site Description: MEDIUM DENSITY RESIDENTIAL 1961-1980, CURBS AND GUTTERS, CLAYEY SOILS, BASELINE CONTROLS (NONE)

Residential Areas - Runoff Volume (cu. ft)

Start Date	Rain Total	Roofs 1	Roofs 2	Driveways 1	Driveways 2	Street Area 1	Street Area 2	Undeveloped Area	Small Landscaped Area 1	Small Landscaped Area 2	Land Use Totals	Rv	Total Losses (in.) *	Calculated CN
01/02/76	0.46	4067	1642	1927	332	6740	666	1253	13905	7157	37689	0.23	0.36	93.6
01/07/76	0.58	5194	2392	2430	477	8837	873	1815	20147	10370	52536	0.25	0.44	92.6
01/11/76	0.25	2057	591	1048	128	3365	324	473	5247	2701	15932	0.18	0.21	95.8
01/13/76	0.03	54	0	92	0	142	10	0	0	0	297	0.03	0.03	99.0
01/13/76	0.39	3418	1265	1634	258	5580	551	969	10750	5533	29957	0.21	0.31	94.3
01/16/76	0.01	6	0	10	0	16	1	0	0	0	33	0.01	0.01	99.6
01/20/76	0.05	166	0	203	0	365	28	0	0	0	762	0.04	0.05	98.5
01/24/76	0.03	54	0	92	0	142	10	0	0	0	297	0.03	0.03	99.0
01/25/76	2.33	21771	15073	9964	2940	47771	4719	11163	123888	63768	301056	0.36	1.50	81.1
Summary for Runoff Producing Events														
Minimum:	0.01	6.00	0.00	10.00	0.00	16.00	1.00	0.00	0.00	0.00	33.00	0.01	0.01	81.1
Maximum:	2.33	21771.00	15073.00	9964.00	2940.00	47771.00	4719.00	11163.00	123888.00	63768.00	301056.00	0.36	1.50	99.6
Average:	0.46	4087.44	2329.22	1933.33	459.44	8106.44	798.00	1741.44	19326.33	9947.67	48728.78	0.31	0.33	
Total:	4.13	36787	20963	17400	4135	72958	7182	15673	173937	89529	438559			

Total Area, with Drainage and Outfall Controls - Runoff Volume (cu. ft)

Start Date	Rain Total (inches)	Total Without Drainage Controls	Total With Drainage Controls	Catch basin Volume % Full	Total With Outfall Controls	Rv	Total Losses (in) *	Calculated CN	Peak Reduction Factor	Flushing Ratio	Det. Basin Out. Struct. Failed (l.u. #-src. area #)
01/02/76	0.46	37689	37689	0.00	37689	0.23	0.36	93.6			
01/07/76	0.58	52536	52536	0.00	52536	0.25	0.44	92.6			
01/11/76	0.25	15932	15932	0.00	15932	0.18	0.21	95.8			
01/13/76	0.03	297	297	0.00	297	0.03	0.03	99.0			
01/13/76	0.39	29957	29957	0.00	29957	0.21	0.31	94.3			
01/16/76	0.01	33	33	0.00	33	0.01	0.01	99.6			
01/20/76	0.05	762	762	0.00	762	0.04	0.05	98.5			
01/24/76	0.03	297	297	0.00	297	0.03	0.03	99.0			
01/25/76	2.33	301056	301056	0.00	301056	0.36	1.50	81.1			
Summary of Runoff Producing Events											
Number of Rains:	9	9	9	9	9						
Minimum:	0.01	33	33	0.0	33	0.01	0.01	81.1			
Maximum:	2.33	301056	301056	0.0	301056	0.36	1.50	99.6			
Average:	0.46	48729	48729	0.0	48729	0.32	0.33				
Total:	4.13	438559	438559	0.0	438559						

Data File: Newres.DAT											
Rain File: BHAM76.RAN											
Date: 03-08-99 Time: 8:27:46 PM											
Site Description: MEDIUM DENSITY RESIDENTIAL 1961-1980, CURBS AND GUTTERS, CLAYEY SOILS, BASELINE CONTROLS (NONE)											
Residential - Source Area Percentage Contributio											
Start Date	Rain Total	Roofs 1	Roofs 2	Driveways 1	Driveways 2	Street Area 1	Street Area 2	Undeveloped Area	Small Landscaped Area 1	Small Landscaped Area 2	Land Use Totals
01/02/76	0.46	0.11	0.04	0.05	0.01	0.18	0.02	0.03	0.37	0.19	1.00
01/07/76	0.58	0.10	0.05	0.05	0.01	0.17	0.02	0.03	0.38	0.20	1.00
01/11/76	0.25	0.13	0.04	0.07	0.01	0.21	0.02	0.03	0.33	0.17	1.00
01/13/76	0.03	0.18	0.00	0.31	0.00	0.48	0.03	0.00	0.00	0.00	1.00
01/13/76	0.39	0.11	0.04	0.05	0.01	0.19	0.02	0.03	0.36	0.18	1.00
01/16/76	0.01	0.18	0.00	0.31	0.00	0.48	0.03	0.00	0.00	0.00	1.00
01/20/76	0.05	0.22	0.00	0.27	0.00	0.48	0.04	0.00	0.00	0.00	1.00
01/24/76	0.03	0.18	0.00	0.31	0.00	0.48	0.03	0.00	0.00	0.00	1.00
01/25/76	2.33	0.07	0.05	0.03	0.01	0.16	0.02	0.04	0.41	0.21	1.00
Summary for Runoff Producing Events											
Minimum:	0.01	0.07	0.00	0.03	0.00	0.16	0.02	0.00	0.00	0.00	1.00
Maximum:	2.33	0.22	0.05	0.31	0.01	0.48	0.04	0.04	0.41	0.21	1.00
Average:	0.46	0.14	0.02	0.16	0.01	0.31	0.03	0.02	0.21	0.11	1.00

Data File: Newres.DAT

Rain File: BHAM76.RAN

Date: 03-08-99 Time: 8:27:46 PM

Site Description: MEDIUM DENSITY RESIDENTIAL 1961-1980, CURBS AND GUTTERS, CLAYEY SOILS, BASELINE CONTROLS (NONE)

Residential Areas - Concentration of PARTICULATE SOLIDS (mg/L)

Start Date	Rain Total	Roofs 1	Roofs 2	Driveways 1	Driveways 2	Street Area 1	Street Area 2	Undeveloped Area	Small Landscaped Area 1	Small Landscaped Area 2	Land Use Totals
01/02/76	0.46	5	5	73	73	211	97	965	965	965	616.0231
01/07/76	0.58	5	5	61	61	168	78	721	721	721	477.5421
01/11/76	0.25	5	5	175	175	449	218	1903	1903	1903	1118.625
01/13/76	0.03	4	0	785	0	3980	2838	0	0	0	2234.699
01/13/76	0.39	5	5	82	82	278	137	1121	1121	1121	705.5395
01/16/76	0.01	1	0	262	0	14780	10666	0	0	0	7481.86
01/20/76	0.05	5	0	900	0	2696	1662	0	0	0	1593
01/24/76	0.03	4	0	785	0	5106	3487	0	0	0	2793.458
01/25/76	2.33	5	5	60	60	41	20	600	600	600	406.1884
Summary for Runoff Producing Events											
Minimum:	0.01	1	0	60	0	41	20	0	0	0	406
Maximum:	2.33	5	5	900	175	14780	10666	1903	1903	1903	7482
Fl Wt Ave:	0.46	5	5	88	66	143	68	715	715	715	485

Total Area, with Drainage and Outfall Controls - Concentration of PARTICULATE SOLIDS (mg/L)

Start Date	Rain Total (inches)	Total Without Drainage Controls	Total With Drainage Controls	Catch basin Volume % Full	Total With Outfall Controls	Flow-wtd Min. Part. Size Controlled
01/02/76	0.46	616	354	0.00	354	
01/07/76	0.58	478	321	0.00	321	
01/11/76	0.25	1119	320	0.00	320	
01/13/76	0.03	2235	45	0.00	45	
01/13/76	0.39	706	363	0.00	363	
01/16/76	0.01	7483	150	0.00	150	
01/20/76	0.05	1593	45	0.00	45	
01/24/76	0.03	2794	56	0.00	56	
01/25/76	2.33	406	406	0.00	406	
Summary of Runoff Producing Events						
Number of Rains:	9	9	9	9	9	
Minimum:	0.01	406	45	0.0	45	
Maximum:	2.33	7483	406	0.0	406	
Fl Wt Ave:	0.46	1937	229	0.0	229	

Data File: Newres.DAT

Rain File: BHAM76.RAN

Date: 03-08-99 Time: 8:27:46 PM

Site Description: MEDIUM DENSITY RESIDENTIAL 1961-1980, CURBS AND GUTTERS, CLAYEY SOILS, BASELINE CONTROLS (NONE)

Residential Areas - Yield of PARTICULATE SOLIDS (lbs)

Start Date	Rain Total	Roofs 1	Roofs 2	Driveways 1	Driveways 2	Street Area 1	Street Area 2	Undeveloped Area	Small Landscaped Area 1	Small Landscaped Area 2	Land Use Totals
01/02/76	0.46	1	1	9	2	89	4	75	837	431	1449
01/07/76	0.58	2	1	9	2	92	4	82	907	467	1565
01/11/76	0.25	1	0	11	1	94	4	56	623	321	1112
01/13/76	0.03	0	0	4	0	35	2	0	0	0	41
01/13/76	0.39	1	0	8	1	97	5	68	751	387	1319
01/16/76	0.01	0	0	0	0	15	1	0	0	0	15
01/20/76	0.05	0	0	11	0	61	3	0	0	0	76
01/24/76	0.03	0	0	4	0	45	2	0	0	0	52
01/25/76	2.33	7	5	37	11	123	6	418	4637	2387	7630
Summary for Runoff Producing Events											
Minimum:	0.01	0	0	0	0	15	1	0	0	0	15
Maximum:	2.33	7	5	37	11	123	6	418	4637	2387	7630
Fl Wt Ave:	0.46	5	4	25	8	112	5	319	3540	1822	5680
Total:	4.13	12	7	93	17	651	31	699	7755	3993	13259

Total Area, with Drainage and Outfall Controls - Yield of PARTICULATE SOLIDS (lbs)

Start Date	Rain Total (inches)	Total Without Drainage Controls	Total With Drainage Controls	Catch basin Volume % Full	Total With Outfall Controls	Flow-wtd Min. Part. Size Controlled
01/02/76	0.46	1449	831	0.00	831	
01/07/76	0.58	1565	1051	0.00	1051	
01/11/76	0.25	1112	318	0.00	318	
01/13/76	0.03	41	1	0.00	1	
01/13/76	0.39	1319	678	0.00	678	
01/16/76	0.01	15	0	0.00	0	
01/20/76	0.05	76	2	0.00	2	
01/24/76	0.03	52	1	0.00	1	
01/25/76	2.33	7630	7630	0.00	7630	
Summary of Runoff Producing Events						
Number of Rains:	9	9	9	9	9	
Minimum:	0.01	15	0	0.0	0	
Maximum:	2.33	7630	7630	0.0	7630	
Fl Wt Ave:	0.46	1473	1168	0.0	1168	
Total:	4.13	13259	10512	0.0	10512	

Typical Land Use Descriptions

A significant investment of time should be spent to understand local development characteristics. These are the most important elements that affect stormwater quality and quantity. The following sections describe some typical land uses, plus provide some data used during SLAMM evaluations. Several examples are included in this section, with most of the information provided from the Little Shades Creek watershed, Birmingham, AL area, study. In this study, about 135 neighborhoods were surveyed to determine the critical development characteristics representing 18 major land use areas (schools, shopping centers, under development, apartments, multi-family, high-density residential, medium-density residential built prior to 1960, medium-density residential built from 1960 to 1980, medium-density residential built since 1980, low density residential, freeways, golf courses, cemeteries, parks, office parks, vacant or open space, churches, and light industrial areas). These surveys were used to develop the Birmingham area SLAMM files included on the distribution disk, and described in the attached appendix. Other example information included in this section is from the Toronto area, where an earlier, but similar, survey was conducted. The examples shown for Toronto are the excellent, but inexpensive, aerial photographs that were available. Several examples of single land use neighborhoods are presented in these aerials. In all cases, the needed aerials are obtained from the best sources. Local planning agencies (such as in the Milwaukee, WI area) typically have the needed photos, but may not be as good as we had to work with in Toronto. Also included are some information from Los Angeles County, CA, where a very large scale land use survey was recently conducted in a short period of time.

General Land Use Descriptions

The following are general land use descriptions used by the WI DNR, based on Southeast Wisconsin Regional Planning Commission (SEWRPC) data, and are indicative of typical planning agency definitions. In all cases, a stormwater/watershed study should use the locally available land use data and definitions. However, it may be necessary to slightly modify them. In this example, SEWRPC had all street areas in separate categories, so those areas were "added" back into the basic land use descriptions. In addition, local planning agencies typically do not separate the medium density residential areas into sub-categories, which may be necessary to represent different development trends that has occurred with time.

• Residential Land Uses

<u>High Density Residential without Alleys (HRNA):</u> Urban single family housing at a density of greater than 6 units/acre. Includes house, driveway, yards, sidewalks, and streets.

<u>High Density Residential with Alleys (HRWA):</u> Same as HRNA1, except alleys exist behind the houses.

<u>Medium Density without Alleys (MRNA):</u> Same as HRNA except the density is between 2 - 6 units/acre.

<u>Medium Density with Alleys (MRWA):</u> Same as HRWA, except alleys exists behind the houses.

<u>Low Density (LR):</u> Same as HRNA except the density is 0.7 to 2 units/acre.

<u>Duplexes (DUPLX)</u>: Housing having two separate units in a single building.

<u>Multiple Family (MF):</u> Housing for three or more families, from 1 - 3 stories in height. Units may be adjoined up-and-down, side-by-side; or front-and-rear. Includes building, yard, parking lot, and driveways.
High Rise (HIR): Same MF except buildings are

<u>High Rise Apartments (APTS)</u>: Multiple family units 4 or more stories in height.

<u>Trailer Parks (MOBR):</u> A mobile home or trailer park, includes all vehicle homes, the yard, driveway, and office area.

<u>Suburban (SUBR):</u> Same as HRNA except the density is between 0.2 and 0.6 units/acre.

• Commercial Land Uses

Strip Commercial (CST): Those buildings for which the primary function involves the sale of goods or services. This category includes some institutional lands found in commercial strips, such as post offices, court houses, and fire and police stations. This category does not include buildings used for the manufacture of goods or warehouses. This land use includes the buildings, parking lots, and streets. This land use does not include nursery, tree farms, or lumber yards.

Shopping Centers (SC): Commercial areas where the related parking lot is at least 2.5 times the area of the building roof area. The buildings in this land use are usually surrounded by the parking area. This land use includes the buildings, parking lot, and the streets.

Office Parks (OP): Land use where non-retail business takes place. The buildings are usually multi storied buildings surrounded by larger areas of lawn and other landscaping. This land use includes the buildings, lawn, and road areas. Types of establishments that may be in this category includes: insurance offices, government buildings, and company headquarters.

Downtown Central Business District (CBD): Highly impervious downtown areas of commercial and institutional land use.

- Industrial Land Uses

Manufacturing Industrial (HI): Those buildings and premises which are devoted to the manufacture of products, with many of the operations conducted outside, such as power plants, steel mills, and cement plants.

Medium Industrial (MI): This category includes businesses such as lumber yards, auto salvage yards, junk yards, grain elevators, agricultural coops, oil tank farms, coal and salt storage areas, slaughter houses, and areas for bulk storage of fertilizers.

Non-Manufacturing (LI): Those buildings which are used for the storage and/or distribution of goods awaiting further processing or sale to retailers. This category mostly includes warehouses, and wholesalers where all operations are conducted indoors, but with truck loading and transfer operations conducted outside.

- Institutional Land Uses

Hospitals (HOSP): Medical facilities that provide patient overnight care. Includes nursing homes, state, county, or private facilities. Includes the buildings, grounds, parking lots, and drives.

Education (SCH): Includes any public or private primary, secondary, or college educational institutional grounds. Includes buildings, playgrounds, athletic fields, roads, parking lots, and lawn areas.

Miscellaneous Institutional (MISC): Churches and large areas of institutional property not part of CST and CDT.

- Open Space Land Uses

Cemeteries (CEM): Includes cemetery grounds, roads, and buildings located on the grounds.

Parks (PARK): Outdoor recreational areas including municipal playgrounds, botanical gardens, arboretums, golf courses, and natural areas.

Undeveloped (OSUD): Lands that are private or publicly owned with no structures and have a complete vegetative cover. This includes vacant lots, transformer stations, radio and TV transmission areas, water towers, and railroad rights-of-way.

- Freeway Land Uses

Freeways (FREE): Limited access highways and the interchange areas, including any vegetated rights-of-ways.

Land Development Characteristics

Appendix 5-A contains detailed SLAMM *.DAT file descriptions for 17 land use sub-categories that were developed for the Little Shades Creek study area in the Birmingham, AL, area. This Little Shades Creek watershed study was part of a cooperative study conducted by the University of Alabama at Birmingham and the Jefferson County office of the U.S. Soil Conservation Service (now the U.S. Natural Resources Conservation Service). Other participants included the Jefferson County Office of Planning and Community Development, the U.S. Army Corps of Engineers, and various other city and county governments. The objective of the watershed study was to determine the sources of urban runoff and associated pollutants and to examine alternative controls in a rapidly developing area.

The Little Shades Creek watershed is about eight square miles in area and is about 70 percent developed, mostly with single family residential units. However, many different types of land development are represented in this area, from shopping centers to industrial areas. Current problems are mainly associated with frequent flooding during relatively small rains. This study, however, was a demonstration of how runoff water quality improvements can also be obtained in conjunction with drainage and flooding control. Local runoff quality data collected during EPA sponsored runoff projects (Pitt, *et al*. 1995) was used in conjunction with detailed development information collected during this watershed study, to calibrate SLAMM.

Site Surveys

Table 5-19 is the "Area Description" field sheet that was used to quantify the important characteristics of the study area. This sheet is a composite of earlier similar sheets and includes those characteristics thought to be of most importance in the study area. The following briefly explains the important elements of this sheet. Field training of the people responsible for collecting the information was carried out to assure data consistency.

• Location. The block number range and the street name were noted. A subarea name could also be used to describe the drainage area. Descriptions were made for homogeneous block segments in the study area. Specific blocks to be surveyed were randomly selected and located on the aerial photographs before the survey began. Each site had at least two photographs taken (color prints and slides): one was a general scene and the other was a close-up (showing about 25 by 40 centimeters of pavement). Additional photographs were usually taken to record unusual conditions. These photographs are very important to confirm the descriptions recorded on the sheets and to verify the consistency of information for the many areas. The photographs are also very important when additional site information is needed, but not recorded on the sheets.

• Land-use. The land-use type that best describes the block was circled. If more than one land-use was present the estimated distribution was shown. The approximate income level for residential areas was also circled. The specific types of industrial activities (warehouses, metal plating, bottling, electronics, gas station, etc.) for industrial and commercial areas was also written in. Also, the approximate age of development was circled.

• Roof drainage. The discharge location of the roof drains were shown by writing in. The approximate distribution was also noted if more than one discharge location was evident. The "underground" location may be to storm sewers, sanitary sewers, or dry wells. Some areas have the roof drains apparently directed underground but are actually discharged to the roadside gutter or drainage ditch. If they lead to the gutter, then the "to gutter" category was circled. Additionally, if the flow path length is less than about five feet over pervious ground, it is functionally directly connected to impervious areas, requiring circling the "to impervious" category. The roof types and building heights were also indicated (again, the approximate distributions were noted if more than one type were present). It was necessary to take an inventory of all visible roof drains in the study block by keeping tallies of each type of drain connection. The percentage distributions per connection type was put on the sheet. If other categories of characteristics varied in the study block (paved or unpaved driveway categories is another common variation), then these were also tallied.

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

• Street and Pavement. Traffic and parking characteristics were estimated. Pavement condition and texture are quite different. Condition implies the state of repair, specifically relating to cracks and holes in the pavement. Texture implies roughness. A rough street may be in excellent condition: many new street overlays result in very rough streets. Some very worn streets may also be quite smooth, but with many cracks. A close-up photograph of the street surface is needed to make final determinations of street texture. An overview photograph of the street was 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 street overly jobs are sloppy, resulting in a several centimeter ridge along the gutter/street interface. If the interface is in poor condition or uneven, an extra photograph was taken showing the interface close-up. The litter perception was also circled. Another photograph was taken of heavily littered areas.

Table 5-19. LITTLE SHADES CREEK CORRIDOR TEST AREA DESCRIPTIONS

Location: Site number:
Date: Time:
Photo numbers: Roll number:
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 1960-1980 >1980
Institutional: school hospital other (type):
Commercial: strip shop. center 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 other:
Sediment source nearby? No Yes (describe):
Treated wood near street? No telephone poles fence other:
Landscaping near road:
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: flat (<2%) medium (2-5%) steep (>5%)
Traffic speed: <25mph 25-40mph >40mph
Traffic density: Light moderate heavy
Parking density: none light moderate heavy
Width of street: number of parking lanes:
number of driving lanes:
Condition of street: good fair poor
Texture of street: smooth intermediate 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
Other paved areas (such as alleys and playgrounds),describe:
condition: good fair poor
texture: smooth intermediate rough
Notes:

The following illustrations are from the early analyses of the Little Shades Creek watershed (Rocky Ridge Corridor) and show the data collection steps describing the land uses, plus the initial source area contribution analyses and unit area yield data.

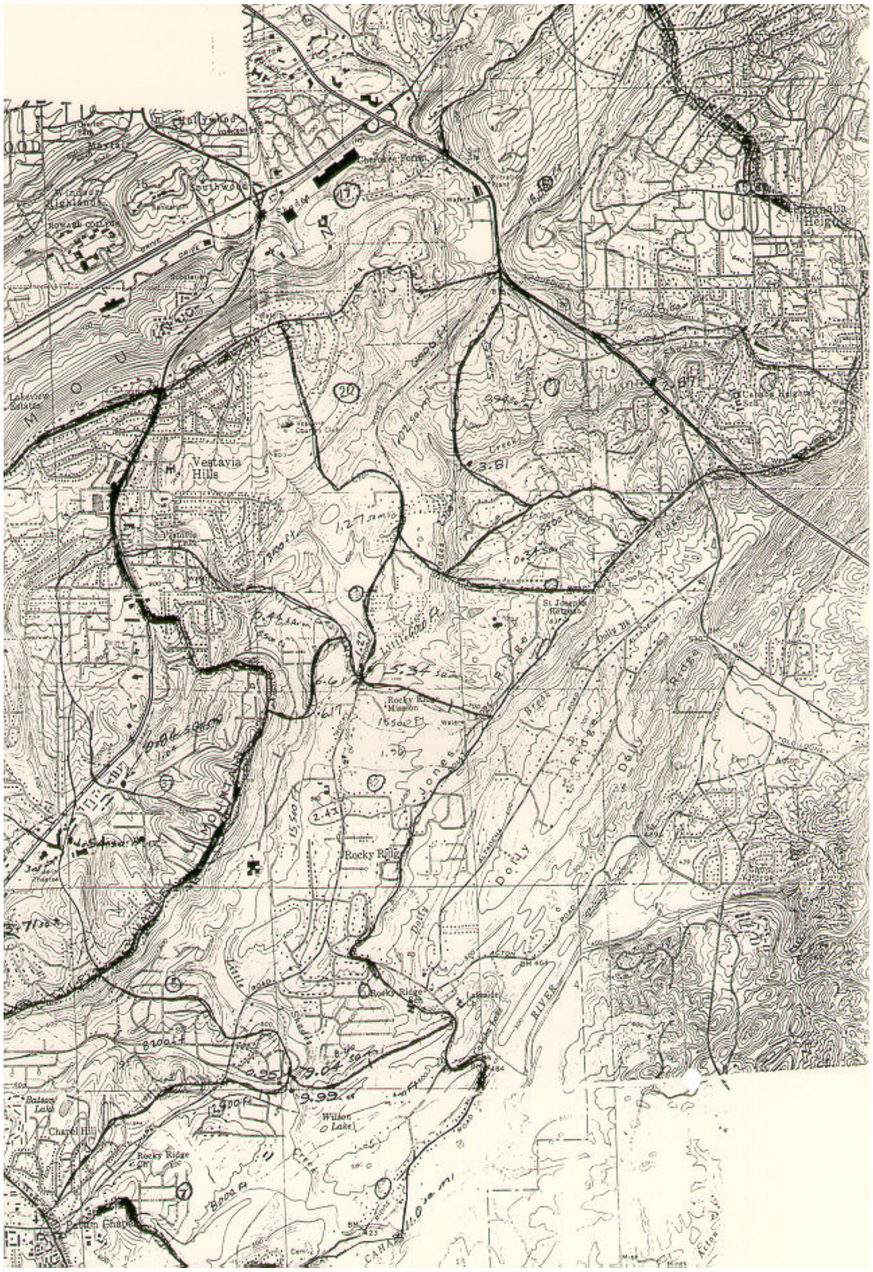


Figure 5-2. Map of Little Shades Creek watershed study area.

Table 5-20. Basic Land Uses in Each Sub-Watershed Area

Little Shades Creek Subwatershed Descriptions (acres)												
Land Use	1	2	3	4	5	6	7	8	9	10	11	Total
Single-family	339	448	676	401	194	112	253	355	615	186	31	3611
Town homes	0	20	8	0	0	0	0	0	87	0	7	122
Multi-family	0	47	13	0	9	0	0	0	19	0	0	87
School, church	0	0	38	13	28	0	0	7	4	0	19	109
Recreation	1	0	0	108	0	0	0	0	2	0	0	112
Public	0	0	1	2	0	0	0	0	2	0	0	5
Cemetery	0	0	0	0	0	0	0	0	0	0	3	3
Open space	0	0	0	0	0	0	0	0	26	0	0	26
Office	44	0	6	7	0	0	0	0	3	2	0	62
Commercial	8	8	17	7	0	0	0	0	20	5	16	82
Industrial	0	4	0	0	0	0	0	0	3	1	1	9
Utility	0	2	0	0	0	0	0	0	0	0	1	2
Vacant	24	147	191	47	18	47	177	59	99	0	178	989
Sum:	417	676	951	585	248	160	430	421	880	193	256	5218

Table 5-21. Land Use and Neighborhoods Surveyed and Corresponding Site Numbers

Categories		Site Numbers
1.	Schools	26, 27, 28, 29, 89, 93
2.	Shopping Center	2, 3, 45, 47, 48, 50, 51, 53, 55
3.	Under devel	44, 46, 54, 59, 121, 123, 124, 127
4.	Apartments	6, 60, 38, 39, 41, 42, 76, 81, 119
5.	Multi-Family	30,31,33,34,35,36,37,57,75,108
6.	High Den. Resd.	32,58,99,100,101,104,105,106,107,109 110,111
7.	Med. Den. Resd. <1960	52, 66, 67, 80, 112
8.	1960-1980	1,4,A1(5,7,9,10,11,12,16,17,18),19,102 103,114,116,117,120,122
9.	>1980	63, 84, 85, 86, 87, 90, 91, 92
10.	Low Den. Resd.	61, 62, 69, 70, 71, 72, 73, 74
Other:		
11.	Freeway	88, 96, 97, 98, 113
12.	Golf Course	65
13.	Cemetery	64, 95
14.	Park	56, 79
15.	Office Park	77, 78,82, 118, 125, 126
16.	Vacant or Open Space	8, 68,83
17.	Church	25, 43, 49, 94
18.	Industrial	129, 130, 131, 132, 133, 134, 135, 136

Figure 5-3. Example Site Photograph (Site 70, a new low density residential area).

Figure 5-4. Photograph of street texture at site 70 (intermediate texture).

Table 5-22. Site 70 Survey Form

LITTLE SHADES CREEK CORRIDOR TEST AREA DESCRIPTIONS

Location: Rocky brook DR Site number: 70
Date: 2/21/90 Time: 10:00
Photo numbers: 20-23 Roll number: 10
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: <1930 '30-'50 '51-'70 '71-'80 new
R-1 Institutional: school hospital other (type):
Commercial: strip shop. center 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 comp. shingle wood shingle other:
Sediment source nearby? No Yes (describe): undeveloped Land & New devel.
Treated wood near street? No telephone poles fence other:
Landscaping near road:
quantity: None some much
type: deciduous evergreen lawn
maintenance: excessive adequate poor
leafs on street: none some much 36/.1694
Topography: imp | pr | u.d
street slope: flat (<2%) medium (2-5%) steep (>5%)
land slope: flat (<2%) medium (2-5%) steep (>5%)
Traffic speed: <25 mph 25-40 mph >40 mph
Traffic density: light moderate heavy
Parking density: none light moderate heavy 4 | 7
Width of street: number of parking lanes: 0
number of driving lanes: 2
Condition of street: good fair poor
Texture of street: smooth intermediate 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
Other paved areas (such as alleys and playgrounds), describe:
condition: good fair poor
texture: smooth intermediate rough
Notes:

Table 5- 23a. Site 70 Example Aerial Photograph Area Measurements

Little Shades Creek Stormwater Study - Site Characteristics

Site #: 70 Land use: Single Fam. Zoning: R-1 Govt: Vest.

Description: Low Dens. area.

Location: Rocky brook DR.

Total area: 8.79 ha.

Total number of units in area: 9 Density: 1.02 /ha

Streets: Total street length: 665.5 m Street length density: 75.71 m/ha

Average street width: 6.05 m Street area: 4026.28 m^2

Street area density: 458.05 m^2/ha

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

area: ___ m^2 density: X m^2/ha

Sidewalk: width: ___ m length: ___ m area: ___ m^2 density: X m^2/ha

Front landscaping: average per unit 3018.45 m^2 x 9 # units = 27166.0 m^2

density: 3090.56 m^2/ha

Driveways: avg. per unit 44 m^2 x 9 # units = 396 m^2 density: 45.05 m^2/ha

100 % paved; 45.05 m^2/ha

0 % unpaved; 0 m^2/ha

Parking areas: ___ m^2 density: X m^2/ha

___ % paved; ✓ m^2/ha

___ % unpaved; ✓ m^2/ha

Storage areas: ___ m^2 density: ✓ m^2/ha

___ % paved; ✓ m^2/ha

___ % unpaved; ✓ m^2/ha

Playgrounds: ___ m^2 density: X m^2/ha

___ % paved; ✓ m^2/ha

___ % unpaved; X m^2/ha

Table 5-23b. Site 70 Example Aerial Photograph Area Measurements (cont)

Walkways: avg. per unit ______ m^2 x ______ # units = ______ m^2 density: X m^2/ha

Backyard Landscaping: average per unit 5944 m^2 x 9 # units = 53495 m^2

density: 6086 m^2/ha

Large Turf Areas: ______ m^2; density: X m^2/ha

Undeveloped areas: ______ m^2; density: X m^2/ha

Swimming pools: ______ m^2; density: X m^2/ha

Decks and small sheds: average per unit ______ m^2 x ______ # units = ______ m^2

density: X m^2/ha

Railroad row: width: ______ m; length: ______ m; area: ______ m^2;

density: X m^2/ha

Roof tops: average per unit: 238 m^2 x 9 # units = 2142 m^2

density: 243.69 m^2/ha

36 % direct connected to impervious; 87.73 m^2/ha

64 % to pervious areas; 156.0 m^2/ha

0 % underground; 0 m^2/ha

Total 10,000 m^2/ha (should be 10,000 m^2/ha)

Notes:

Table 5-24. Example Site Data Summary

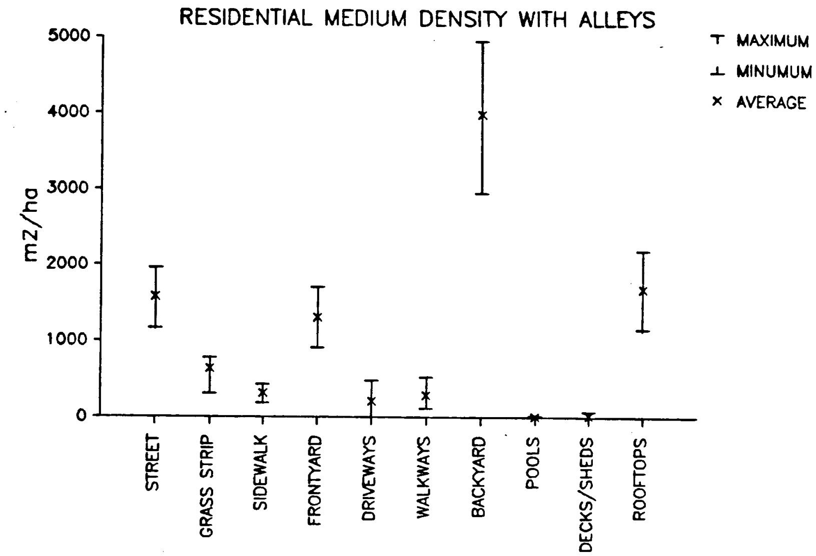
Land use classification	Width of Street: Number of Parking Lanes 0	1	2	Number of Driving Lanes 2	3	4	6	8	#Re
Residential:									
- High Density	12 100%			12 100%					12
- Med. Density <1960	5 100%			5 100%					5
- Med. Density 1961-1980	11 100%			11 100%					11
- Med. Density > 1980	8 100%			8 100%					8
- Low Density	8 100%			8 100%					8
- Apartments	9 100%			9 100%					9
- Multi-Family	12 100%			12 100%					12
All Residential:	65 100%			65 100%					65
Commercial:									
- Office	6 100%			5 100%	1 17%				6
- Shopping	9 100%			9 100%					9
Institutional:									
- Schools	6 100%			6 100%					6
- Church	4 100%			4 100%					4
Industrial:									8
- Medium Intensity	3.5 44%								
- Low intensity	4.5 56%								
Open Space:									
- Parks	2 100%			2 100%					2
- Cemetery	2 100%			2 100%					2
- Vacant	3 100%			3 100%					3
- Golf course	1 100%			1 100%					1
- Under construction	8 100%			8 100%					8
Freeway :	5 100%					2 40%	2 40%	1 20%	5
All areas combined :	111 100%			105 94%	1 1%	2 2%	2 2%	1 1%	III

Table 5-25a. Summary of Site Development Characteristics

Land Development Characteristics - Rocky Ridge Corridor (percentage of total area)	Residential Areas: low density	med. density pre 1960	med. density 1961-80	med. density since 1980	high den.	multi-family (duplexes)	apartments	Commercial: strip devel.	shopping center	office parks
Directly Connected Impervious Areas:										
roofs	1.17	3.26	2.6	5.35	5	10.9	4.25	23.4	21	17.58
parking/storage								40.9	29.62	27.06
playgrounds										
driveways		1.3	1.19	1.29	3	0.62	0.75	1.9	0.37	0.82
walks								4.3		
streets	4.94	4.42	7.23	6.8	7	7.4	9.66	20.1	16.04	14.73
other										
Sub Total:	6.11	8.98	11.02	13.44	15	18.92	14.66	90.6	67.03	60.19
Impervious Areas Draining to Pervious Areas:										
roofs	3.13	4.9	6.05	3.68	9	6.5	14.94		0.75	0.32
parking/storage						1.23	6.53			
playgrounds						0.16	0.82			
driveways	1.57	1.3	1.18	1.28		0.62	0.75		0.37	0.82
walks										
other										
Sub Total:	4.7	6.2	7.23	4.96	9	8.51	23.04	0	1.12	1.14
Pervious Areas:										
parking/storage						10		1.5		
large landscaped	39.49						51.69			
small landscaped	46.16	84.82	77.16	79.8	72	58.29		5.8	31.85	38.67
undeveloped	3.54		4.59	1.8	4	3	3.18	0.2		
other						1.28	7.43	1.9		
Sub Total:	89.19	84.82	81.75	81.6	76	72.57	62.3	9.4	31.85	38.67
Grand Total:	100	100	100	100	100	100	100	100	100	100

Table 5-25b. Summary of Site Development Characteristics (cont.)

Land Development Characteristics - Rocky Ridge Corridor (percentage of total area)	Institutional: schools	Industrial: light (ware-housing)	Open Space: golf course	cemetery	parks	undevel-oped	Freeways: freeways
Directly Connected Impervious Areas:							
roofs	6.02	23.8		1			
parking/storage	5.98	32.9		2.3	15.7		
playgrounds					8.15		
driveways	0.25	2.3		7.7	0.42		
walks		0.7					
streets	4.02	10.9	1.23	1.4	15.7	8	29.41
other							2.39
Sub Total:	16.27	70.6	1.23	12.4	39.97	8	31.8
Impervious Areas Draining to Pervious Areas:							
roofs	4.5	1.6	0.28	0.1			
parking/storage			0.67				
playgrounds	15.11		0.07		40.13		
driveways		0.3	1.17				
walks		0.7		0.1			
other							0.66
Sub Total:	19.61	2.6	2.19	0.2	40.13	0	0.66
Pervious Areas:							
parking/storage		6.3					
large landscaped	40.83	3.5	96.58	86.3			33.94
small landscaped	23.18	9.9		0.6	4.94		
undeveloped	0.11	4.3		0.5	14.96	92	33.6
other		2.8					
Sub Total:	64.12	26.8	96.58	87.4	19.9	92	67.54
Grand Total:	100	100	100	100	100	100	100



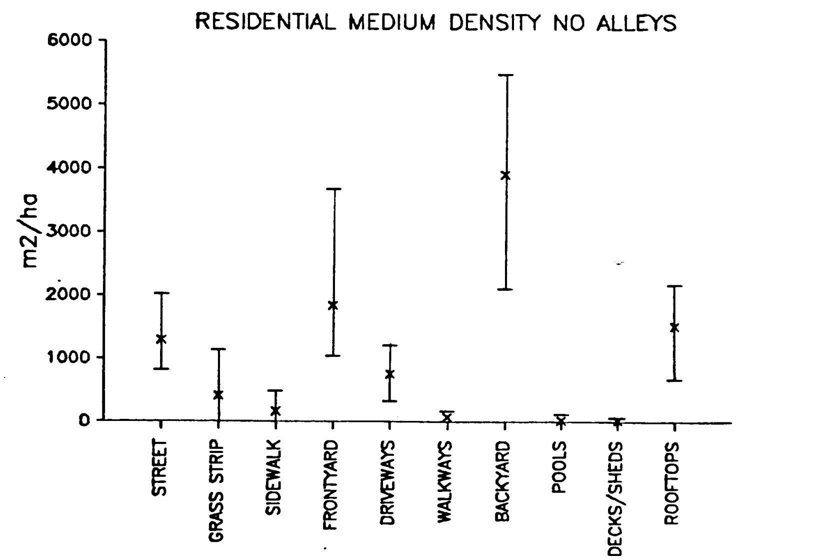


Figure 5-5. Source area measurement variations (Milwaukee data).

Area Measurements from Aerial Photographs

As noted above, an important aspect of the site surveys is the use of aerial photographs to measure the individual elements of each land use. Figure 5-6 is an example of a detailed aerial photograph used during the Humber River watershed study in Toronto, Ontario (Pitt and McLean 1986 and Pitt 1987). There photos were from original 9 in. by 9 in. negatives shot at 1 to 10,000 scale, and were enlarged 3.3 x to 30 in. by 30 in. prints having a 1 to 3,000 scale. This figure is less than 1/10th of the full print and the scale is represented by the map label (78-4351) which is about 530 ft long (0.1 mile). The above test area description sheet was filled out during each neighborhood surveyed. The corresponding aerial photographs were then examined for each neighborhood and the individual elements (roofs, parking areas, street areas, sidewalks, landscaping, etc.) were measured. These data were then summarized and used in the SLAMM files to describe each land use area. The following figures (various scales) are examples of aerial photographs of several different land use areas examined in the Toronto area.

Figure 5-6. General Aerial Photograph used to Measure Land Elements (Pitt and McLean 1986).

Figure 5-7. Medium Density Residential Area

Figure 5-8. Older Medium Density Residential Area


Figure 5-9. High Density Residential Area


Figure 5-10. High Rise Residential Area

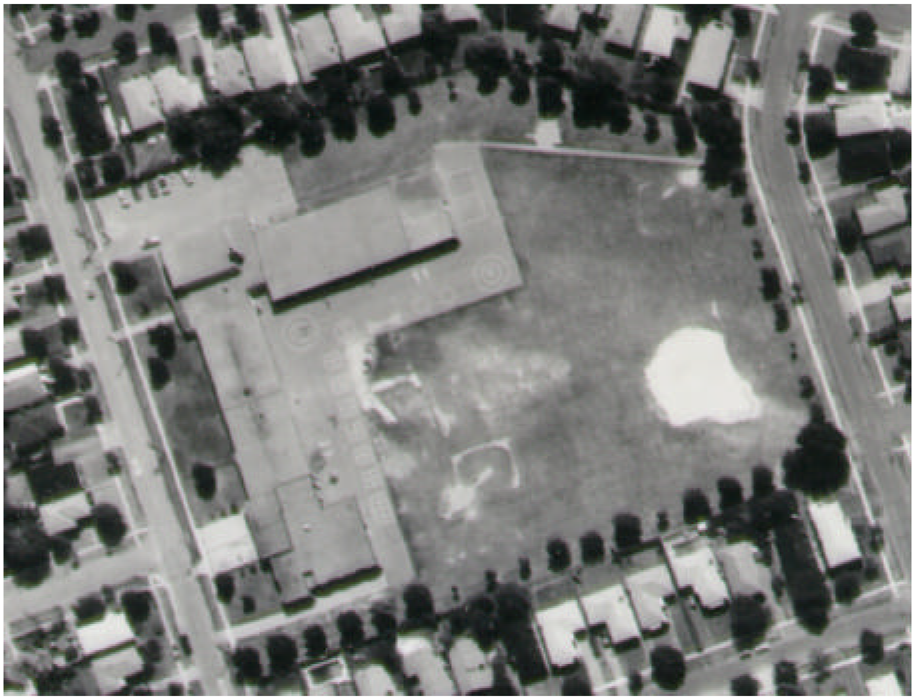


Figure 5-11. School

Figure 5-12. Strip Commercial Area


Figure 5-13. Light Industrial Area (Warehousing)

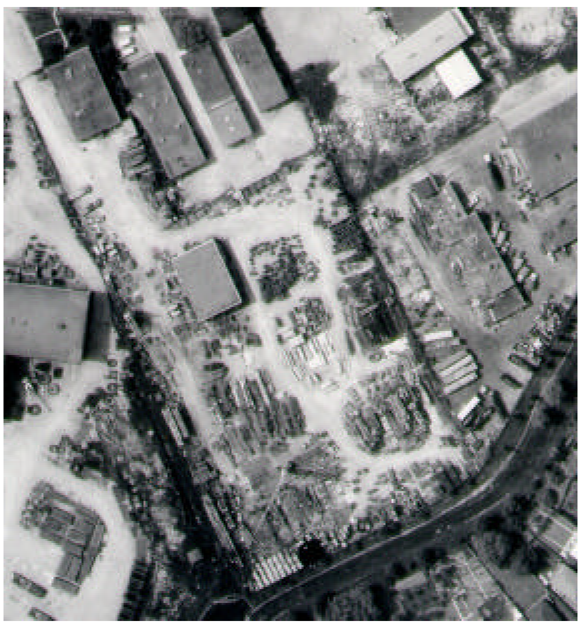


Figure 5-14. Scrap Yard/Storage Area


Figure 5-15. Freeway

Figure 5-16. Cemetery

Example Land Use Evaluations for Los Angeles County, California

A marginal benefit analysis was conducted by WWC and Psomas (1996) to identify land use monitoring sites to best represent the wide range of land uses in Los Angeles County. Table 5-26 lists the general land use categories for Los Angeles County, showing the percentage of each in the area covered by the NPDES stormwater discharge permit, plus the percentage of the total area estimated total suspended solids (TSS) and copper loadings. Detailed site surveys were conducted for the 12 most important land uses shown on this table (excluding vacant land), using methods developed by Pitt (1987). These 12 land uses comprised about 75% of the area of all land uses, excluding the vacant land. Seven to eight homogeneous areas representing each of these land use areas were surveyed during a five week period in the summer of 1996. Site survey information collected included detailed descriptions of the land use and age of the area, the nature and character of the buildings, the routing of on-site drainage (roof drainage and paved area drainage), the condition of the streets and other impervious areas, gutter types, the nature of the landscaping adjacent to the road, the presence of treated wood near the streets, and landscaping practices, as noted in the previous site survey form. In addition, measurements from maps and aerial photographs were made to determine the areas of each element of the development (roofs, streets, sidewalks, gutters, driveways, parking/storage areas, paved playgrounds, other paved areas, landscaped areas, and other pervious areas).

The individual land use categories are also ranked on Table 5-26 according to their total area contributions of these attributes. The estimated contributions for each land use category were based on measured site characteristics (especially imperviousness) of the most important land uses, plus the best estimates of runoff characteristics for these land uses. Analyses using other expected critical pollutants (especially bacteria) would have been informative, but preliminary data were not available. Similar analyses using runoff volume, COD and P were also conducted, with very similar results: the same land uses were always included in the group of the most important land uses. From marginal benefit analyses, a total of seven most important land uses were identified: high density single family residential, vacant land, light industrial, transportation, retail and commercial, multi-family residential, and educational facilities. Multi-family residential and educational facilities were added to the five land use areas previously selected for monitoring. It must be noted that heavy industrial land use data is being collected by the industrial component of the NPDES program and construction sites were not deemed an appropriate source to be included in this program by the county.

Table 5-26. Land Uses in Los Angeles County, and Estimated Pollutant Discharge Rankings

Land Use Category	% of area	Rank based on area	% of TSS load	Rank based on TSS load	% of copper load	Rank based on copper load
Vacant land	56.0	1	19.5	2	13.3	3
High density single family residential	18.6	2	22.9	1	32.5	1
Light industry	3.2	3	14.8	3	17.1	2
Multi-family residential	2.8	4	4.9	6	6.9	4
Retail and commercial	2.5	5	9.5	4	4.6	6
Transportation	1.7	6	5.6	5	6.5	5
Low density SFR	1.6	7	1.6	11	2.2	8
Educational facilities	1.6	8	3.6	7	1.7	11
Receiving waters	1.4	9	0.0	34	0.0	34
Open space/recreation	1.2	10	1.6	13	0.54	19
Mixed residential	1.1	11	1.5	14	2.1	10
Utility facilities	1.1	12	1.2	15	0.69	16
Natural resources extraction	0.73	13	2.1	8	2.4	7
Institutions	0.66	14	1.6	12	0.76	14
Urban vacant	0.64	15	0.26	24	0.14	26
Golf courses	0.64	16	0.46	21	0.16	25
Rural residential	0.62	17	0.29	23	0.40	22
Floodways and structures	0.62	18	0.85	17	0.29	23
Heavy industry	0.51	19	1.9	9	2.2	9
General office use	0.49	20	1.8	10	0.86	12
Agriculture	0.45	21	0.21	25	0.11	29
Under construction	0.41	22	0.56	19	0.65	17
Other commercial	0.33	23	1.2	16	0.58	18
Nurseries and vineyards	0.33	24	0.10	29	0.27	24
Mobile homes and trailer parks	0.25	25	0.50	20	0.71	15
Mixed transportation and utility	0.14	26	0.66	18	0.77	13
Animal husbandry	0.11	27	0.09	30	0.09	31
Military installations	0.10	28	0.12	27	0.13	27
Maintenance yards	0.08	29	0.38	22	0.44	21
Mixed commercial and industrial	0.04	30	0.07	31	0.09	30
Harbor facilities	0.04	31	0.12	26	0.52	20
Marina facilities	0.03	32	0.03	33	0.07	32
Mixed urban	0.03	33	0.05	32	0.06	33
Communication facilities	0.02	34	0.11	28	0.13	28

Further analyses were conducted to select smaller watershed areas for monitoring critical sources (WCC 1997). A list of industrial categories (by SIC codes), along with their ranking by their pollution potential and the number of the facilities is shown in Table 5-27. The pollution potential rank was determined based on the number of sources in the area, the relative size of the paved areas at each source, the likelihood of specific toxic pollutants and the exposure potential of the on-site sources. From this analysis, the following critical sources were selected for potential monitoring:

- wholesale trade (including scrap yards and auto dismantlers)
- automotive repair/parking (intend to stress repair facilities over parking areas in the monitoring program)
- fabricated metal products (including electroplating)
- motor freight (including trucking)
- chemical manufacturing

These source categories were found to be poorly represented in past stormwater studies with very little characterization data already available. Therefore, all of these categories were selected for further monitoring.

Table 5-27. Ranking of Candidate Critical Sources in Los Angeles County

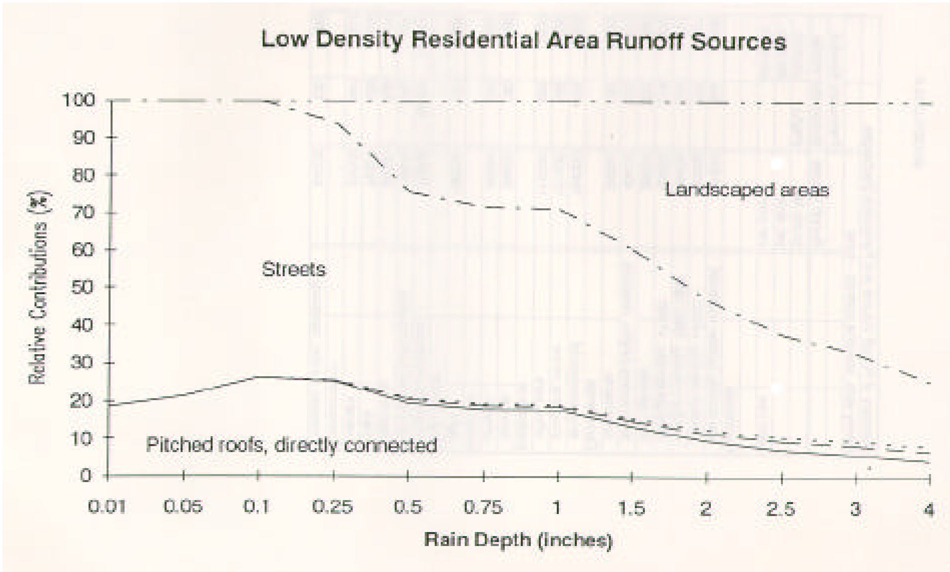
Industrial Category	SIC Code	Number of facilities in Los Angeles County study area	Ranking based on pollution potential
Wholesale trade (scrap, auto dismantling)	50	587	1
Automotive repair/parking	75	6,067	2
Fabricated metal products	34	3,283	3
Motor freight	42	872	4
Chemical manufacturing	28	1,069	5
Automotive dealers/gas stations	55	2,744	6
Primary metals products	33	703	7
Electric/gas/sanitary	49	2,001	8
Air transportation	45	431	9
Rubbers/miscellaneous plastics	30	1,034	10
Local/suburban transit	41	336	11
Railroad transportation	40	319	12
Oil and gas extraction	13	327	13
Lumber/wood products	24	905	14
Machinery manufacturing	35	4,223	15
Transportation equipment	37	1,838	16
Stone, clay, glass, concrete	32	733	17
Leather/leather products	31	163	18
Miscellaneous manufacturing	39	1,144	19
Food and kindred products	20	1,249	20
Petroleum refining	29	231	21
Mining of nonmetallic minerals	14	39	22
Printing and publishing	27	2,432	23
Electric/electronic	36	1,636	24
Paper and allied products	26	451	25
Furniture and fixtures	25	1,368	26
Personal services (laundries)	72	2,515	27
Instruments	38	1,029	28
Textile mills products	22	440	29
Apparel	23	1,900	30

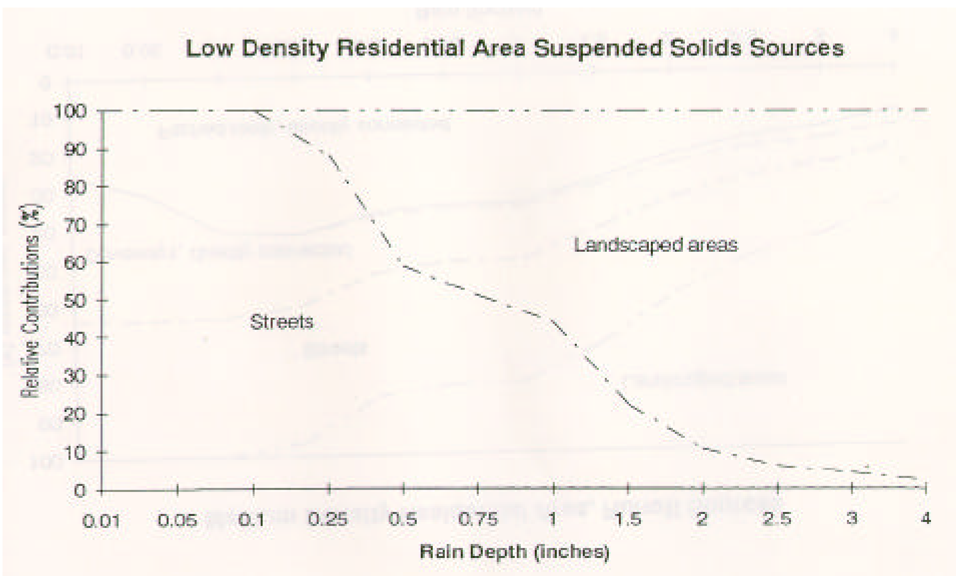
Little Shades Creek (Rocky Ridge Corridor) Preliminary SLAMM Analyses

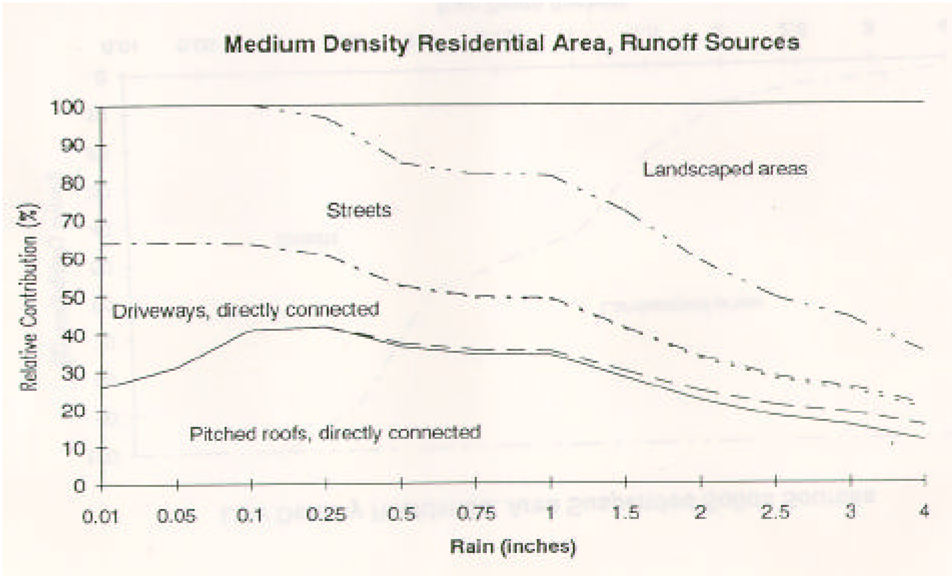
The following table and figures present the preliminary unit area loading calculations, and the relative source area evaluations, for the land uses studied in the Little Shades Creek watershed.

Table 5-28. Unit Area Loadings for Little Shades Creek Watershed Land Uses

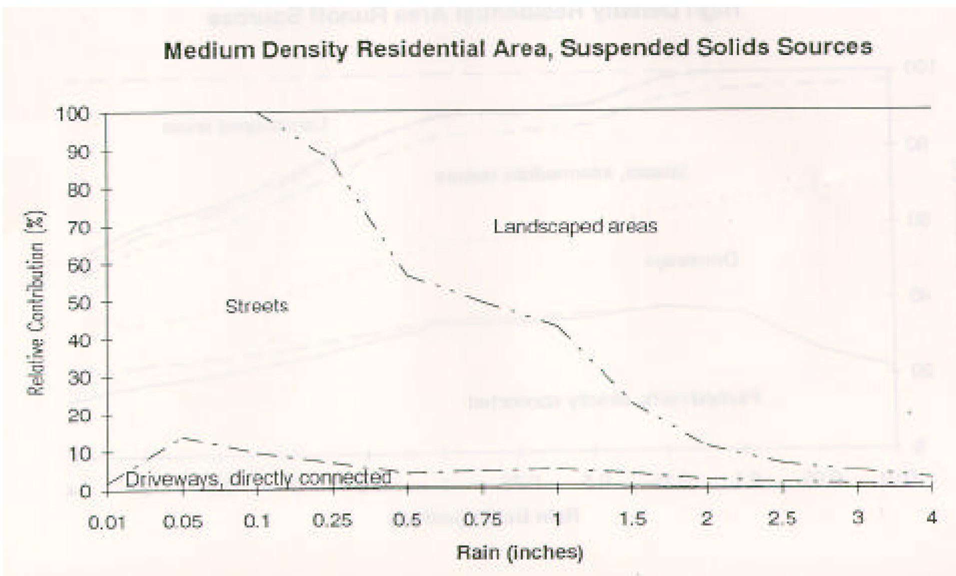
Summary of Runoff Volume and Particulate Discharges (sandy soils, baseline controls - none)			
		Particulate Residue	
	Runoff Volume	(suspended solids)	
Land Use	(cubic feet per acre per year)	(mg/L)	(pounds per acre per year)
Residential			
low density (undev. roadside)	21500	320	430
medium density, <1960	26900	270	450
medium density, 1960-1980	29400	240	450
medium density, >1980	33800	215	450
high density	36600	200	460
townhouses (undev. roadside)	43400	150	420
apartments	34800	170	370
Commercial			
strip commercial	164000	160	1600
shopping center	121000	190	1500
office park	116000	220	1600
Institutional			
schools	38800	160	380
church	40000	160	380
Industrial			
light	130000	160	1300
Open Space			
under development	70000	22000	100000
golf course (with swales)	8600	540	290
cemetery	34500	230	490
park	78500	100	500
vacant	23700	340	510
Transportation			
freeway (undev. raodside)	54000	100	350


Low Density Residential Area Runoff Sources
Relative Contributions (%)
100
90
80
70
60
50
40
30
20
10
0
Landscaped areas
Streets
Pitched roofs, directly connected
0.01
0.05
0.1
0.25
0.5
0.75
1
1.5
2
2.5
3
4
Rain Depth (inches)

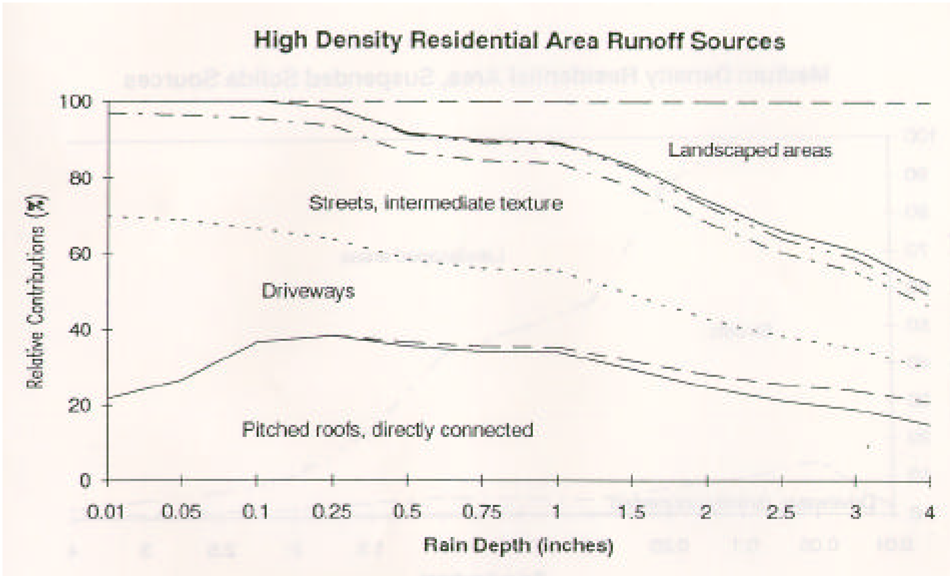

Low Density Residential Area Suspended Solids Sources
Relative Contributions (%)
100
90
80
70
60
50
40
30
20
10
0
Landscaped areas
Streets
0.01
0.05
0.1
0.25
0.5
0.75
1
1.5
2
2.5
3
4
Rain Depth (inches)

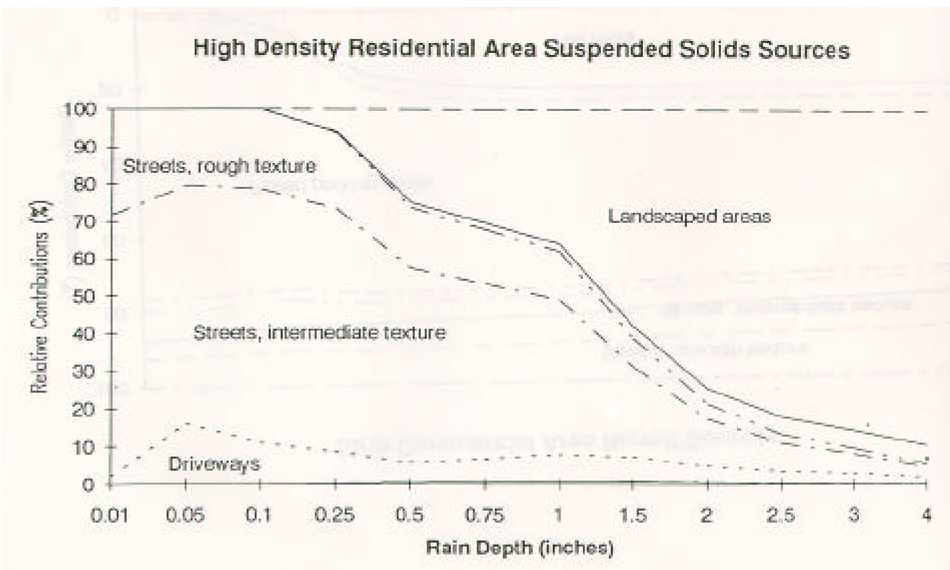


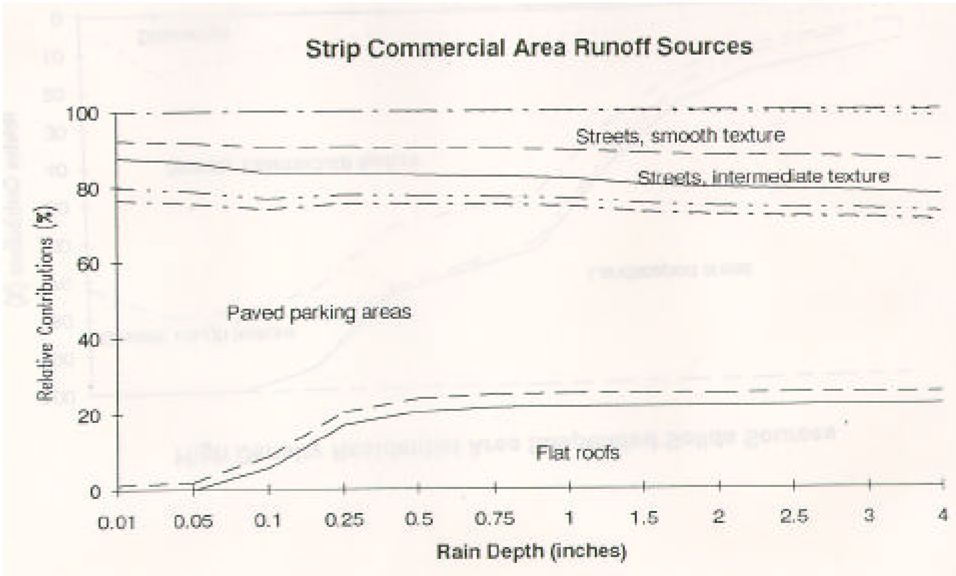
Medium Density Residential Area, Runoff Sources
Landscaped areas
Streets
Driveways, directly connected
Pitched roofs, directly connected
Relative Contribution (%)
100
90
80
70
60
50
40
30
20
10
0
0.01
0.05
0.1
0.25
0.5
0.75
1
1.5
2
2.5
3
4
Rain (inches)

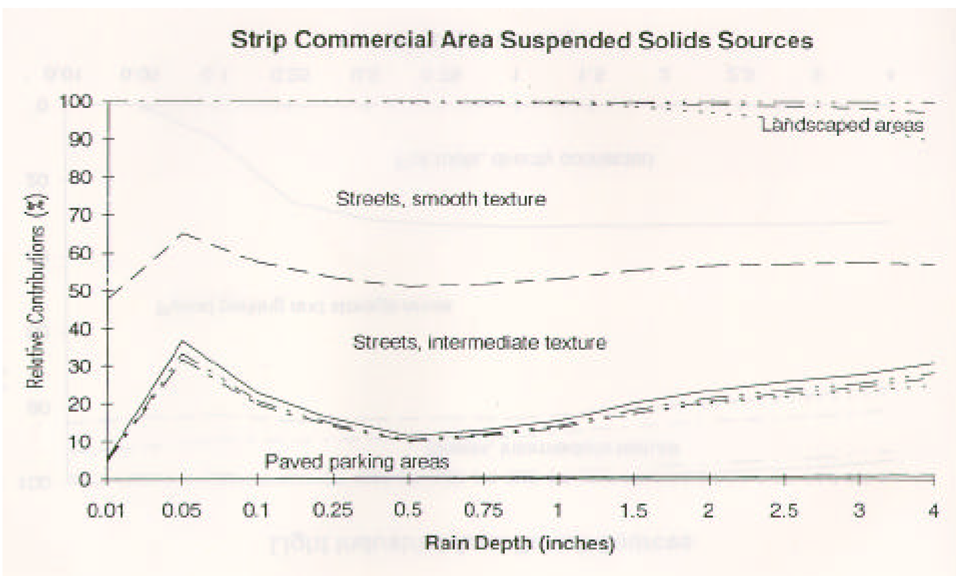


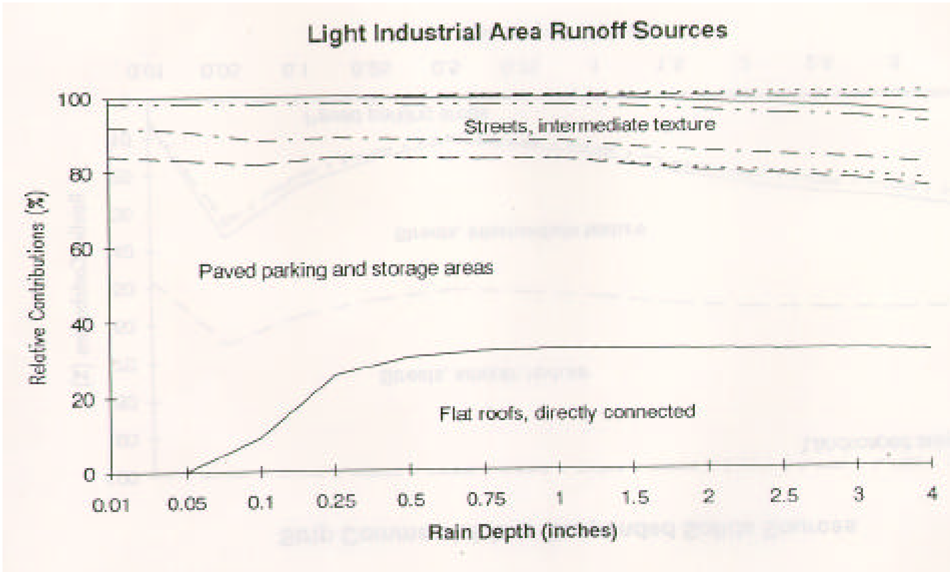
Medium Density Residential Area, Suspended Solids Sources
Landscaped areas
Streets
Driveways, directly connected
Relative Contribution (%)
100
90
80
70
60
50
40
30
20
10
0
0.01
0.05
0.1
0.25
0.5
0.75
1
1.5
2
2.5
3
4
Rain (inches)

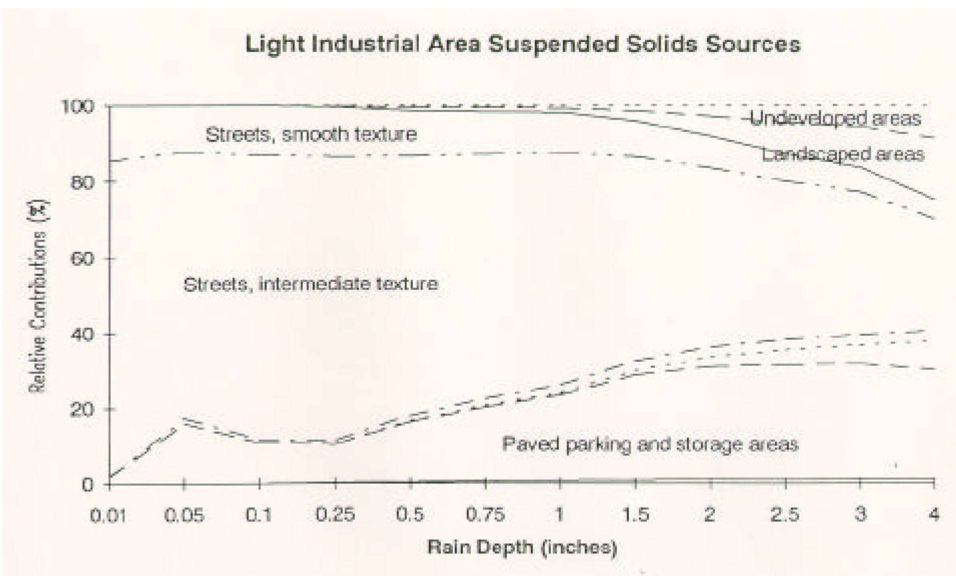

High Density Residential Area Runoff Sources
Landscaped areas
Streets, intermediate texture
Driveways
Pitched roofs, directly connected
Relative Contributions (%)
Rain Depth (inches)
0
20
40
60
80
100
0.01
0.05
0.1
0.25
0.5
0.75
1
1.5
2
2.5
3
4


High Density Residential Area Suspended Solids Sources
Streets, rough texture
Landscaped areas
Streets, intermediate texture
Driveways
Relative Contributions (%)
Rain Depth (inches)
0
10
20
30
40
50
60
70
80
90
100
0.01
0.05
0.1
0.25
0.5
0.75
1
1.5
2
2.5
3
4


Strip Commercial Area Runoff Sources
Streets, smooth texture
Streets, intermediate texture
Paved parking areas
Flat roofs
Relative Contributions (%)
100
80
60
40
20
0
0.01 0.05 0.1 0.25 0.5 0.75 1 1.5 2 2.5 3 4
Rain Depth (inches)


Strip Commercial Area Suspended Solids Sources
Landscaped areas
Streets, smooth texture
Streets, intermediate texture
Paved parking areas
Relative Contributions (%)
100
90
80
70
60
50
40
30
20
10
0
0.01 0.05 0.1 0.25 0.5 0.75 1 1.5 2 2.5 3 4
Rain Depth (inches)





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. Numerous individual rainfall-runoff events need to be sampled (using flow-weighted composite sampling). The best scenario is to collect all calibration information from one watershed and then verify the model using independent observations from another watershed. Another common approach is to collect calibration information for a series of events from one watershed, and then verify the calibrated model using additional data from other storms from the same watershed.

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

This section describes a general approach to calibrate WinSLAMM and describes the data sources for the additional parameter files used in WinSLAMM. The order for calibrating WinSLAMM is:

1) Runoff quantity
2) Annual suspended solids loading (and event mean concentration)
3) Event suspended solids loadings and concentrations
4) Annual total pollutant loadings (and event mean concentrations)
5) Partitioning of pollutants between particulate and filterable phases
6) Variations in pollutant concentrations

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 Coefficients

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

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

Initial Data Sources

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

R. Pitt. *Small Storm Urban Flow and Particulate Washoff Contributions to Outfall Discharges*. Ph.D. Dissertation, Civil and Environmental Engineering Department, University of Wisconsin, Madison, WI, November 1987.

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

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

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

Calibration Steps

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

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

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

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

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

2. Calculate the Rv for each event and observe the pattern. Plot rainfall depth vs. runoff depth and plot Rv vs. rainfall depth. The Rv values should be small for small rains and steadily increase as the rains increase. The Rv differences will not be great for mostly directly connected impervious areas (either paved or roofed areas), but the trend should be quite dramatic for areas having substantial unpaved areas, if a wide range of rains were monitored. The Rv values should look reasonable for moderate rains (0.25 to 0.5 inch rains): about 0.3 for medium density residential areas, about 0.8+ for commercial areas, etc. If the Rv values all appear to be too small or too large, suspect an error in the drainage area, or an error in the rainfall or flow monitoring calibrations. If several individual events look strange and the others appear to follow a reasonable trend, then investigate specific circumstances for the odd events. Unusual

rain intensities, snow/icing problems, debris at flow monitoring station, etc. are all transient problems that may periodically occur. If the unusual conditions cannot be explained, then a decision will have to be made concerning eliminating the data, or keeping it in the data set.

3. Hopefully, data from several watersheds are available for the calibration and verification process. If so, start with data from the simplest area (mostly directly connected paved areas and roofs, with little unpaved areas). This area probably represents commercial roofs and parking/storage areas alone. Therefore, these areas will 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.

4. Carefully prepare the WinSLAMM input file describing the watershed area and a rain file for the specific rains that occurred during the monitoring period. If rains occurred during the monitoring period that were not monitored, they must also be included in the rain file. It would be a good idea to include rains for about a month preceding the first monitored event because WinSLAMM is a quasi-continuous model and some preceding time is needed to reach equilibrium 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). This rain file (could be named SOURCE.RAN) should include about 12 rains spaced about two weeks apart, containing the following rain depths (sorted from small to large rains) and durations (modify durations based on typical durations for these rain depths for the area of interest):

0.01 inches	3 hours
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 for the two rain files, without any additional pollutants selected, using the available RUNOFF.RSV file and using the outfall total (at least) output option for the actual rains and the source area, by rains, output option for the source rain file. Compare the predicted runoff depths (in inches) with the measured runoff depths (in inches) for the monitored events by creating a scatter plot of observed vs. predicted runoff values. Calculate the percentage runoff depth errors: 100 x (observed-predicted)/observed, and plot these against the observed rain depths. The desired pattern for the observed vs. predicted runoff depth plot is a 45 degree line, with little deviation. The desired pattern for the residual error plot is an even, narrow band over the range of observed rain depths, centered on the zero residual error horizontal line. Also calculate the sum of the observed and predicted runoff depths for all monitored events. The percentage difference in the sum of depths should be small.

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

The model run using the SOURCE.RAN file is important in directing where the changes should be made. This run contains the percentage contribution of runoff for each rain, for each source area. This shows where WinSLAMM is generating the runoff for the different rain depths. It is doubtful if the monitored events cover the wide range of rains contained in this special rain file. Therefore, only look at the range of predicted data covering the actual monitored rains.

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

6. The above process is difficult if only one watershed is available for study and if the watershed area has much disconnected paved/roof areas. The preferred approach would be to start by evaluating an area having all directly connected impervious areas and making the basic changes in the Rv values for each source area and rain, as needed. Another area (preferably similar in character) having disconnected impervious areas would then be used to verify (or change) the coefficients in the RUNOFF.RSV that reduces the Rv values if the impervious areas are disconnected. The ten different watersheds used in preparing the initial RUNOFF.RSV file allowed this more rigorous approach.

Assuming the RUNOFF.RSV file Rv values are acceptable, the disconnection coefficients can be adjusted in a similar manner using the above described residual analysis: the runoff residual errors are plotted against rain depth and changes are made to the disconnection coefficients to minimize the total and individual errors.

Particulate Solids Concentrations

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

SLAMM uses another file (*.PRR) to calibrate the source predictions to outfall observations because the *.PSC file contains suspended solids data for only some of the source areas, while the streets and highway lanes are directly predicted. The mandatory delivery.PRR file accounts for the deposition of particulate pollutants in the storm drainage system, before the outfall, or before outfall controls. The DELIVERY.PRR file was originally calibrated for swales, curb and gutters, undeveloped roadsides, or combinations of drainage conditions.

Initial Data Sources

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

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

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

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

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

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

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

Calibration Steps

The suspended solids files can only be examined and modified after the runoff file is acceptable. The *.PSC file contains suspended solids concentrations (in mg/L) for each source area and land use for different rains, except for the street areas that use explicit accumulation and washoff algorithms based on land use, street texture, and rain conditions. Highway paved lane and shoulder areas also have explicit algorithms that calculate accumulation and washoff of suspended solids based on traffic volume and rains. Both of these areas have a great deal of research information available, allowing these direct calculations. Unfortunately, other source areas have little research data available to allow direct predictions of suspended solids runoff concentrations. This file is therefore used to account for the "first-flush" effects observed at specific source areas. Concentrations of suspended solids at the very beginning of rains at some paved areas (especially paved parking areas) are much greater than later in the same rain. This variation is highly dependent on rain energy and SLAMM uses a similar relationship to describe suspended solids variations for different rain depths. These data are based on observed conditions at the source areas. Runoff from some source areas (especially roofs and landscaped areas) typically do not indicate major concentration changes for different rains.

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

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

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

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

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

2. Run the watershed description SLAMM file prepared previously, using the DELIVERY.PRR file, the calibrated *.RSV file and the two rain files (one containing the monitored events and the other being the source.RAN file) without any additional pollutants selected. Select the output option giving results for each rain, by source area. Compare the predicted to the observed suspended solids concentrations for the monitored events by creating a scatter plot of observed vs. predicted runoff values. Calculate the percentage suspended solids concentration errors: 100 x (observed-predicted)/observed, and plot these against the observed suspended 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 suspended solids loadings (in lbs) for all monitored events. The percentage difference in the sum of loadings should be small and will indicate the general magnitude of the changes needed. It is likely that the largest discrepancies in suspended solids concentrations will be associated with small rain depths (SLAMM will probably over-estimate the concentrations), while the differences for the larger rains will be smaller.

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

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

If a constant percentage bias occurs (unlikely) over the range of events monitored, then modify all of the delivery fractions by the same amount. However, the residual error plot probably shows a bias, with some portions of the rain distribution having greater problems than others. As with the runoff calibration, it is possible to divide the residual error plot into different rain depth ranges, corresponding to different amounts of correction needed for suspended solids loads. Each rain depth range also has different source contributions. Therefore, the delivery corrections can be made to each source area for different rain ranges. After the changes are made, it is necessary to plot the new delivery values for each rain depth and to smooth the resulting relationships to remove any discontinuities. After these smoothing changes are made, re-run the program using the new *.PRR 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.

Pollutant Concentrations

The optional pollutant.PPD file describes the particulate pollutant strengths related to particulate residue and describes the filterable pollutant concentrations for each source area for each land use. This file is not needed if only runoff volume and particulate residue calculations are desired. This file also contains the COV values for each pollutant for Monte Carlo simulation in SLAMM. The POLL.PPD file was developed and verified using source area data from Toronto, Milwaukee and Birmingham during specific field tests. The following list shows the major published sources of the pollutant characteristic data used in developing this file:

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

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

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

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

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

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

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

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

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

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

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

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

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

Appendix 5-A: Shades Creek Land Use Descriptions

Residential Areas

Low Density (LDRCB.DAT and LDRSB.DAT)

```
Data file name:  C:\Program Files\WinSLAMM\LDRCB.DAT          SLAMM Version V8.1
    Rain file name:  C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN       Particulate Solids Concentration file name:  C:\PROGRAM
FILES\WINSLAMM\BHAM.PSC
    Runoff Coefficient file name:  C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
                                                                  Particulate Residue Delivery file name:  C:\PROGRAM
FILES\WINSLAMM\DELIVERY.PRR
    Pollutant Relative Concentration file name:  C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
                                                                  Seed for random number generator:   42
    Study period starting date:  01/01/53                         Study period ending date:  12/31/89
    Date:  07-23-2000                                             Time:  19:27:25
    Fraction of each type of Drainage System serving study area:
      1.  Grass Swales 0
      2.  Undeveloped roadside 1
          Curb and Gutters, `valleys', or sealed swales in:
           3.  Poor condition (or very flat) 0
           4.  Fair condition 0
           5.  Good condition (or very steep) 0
    Site information:  LOW DENISTY RESIDENTIAL, UNDEVELOPED ROADSIDES, CLAYEY SOILS, BASELINE CONTROLS (NONE)
                           |<===== Areas for each Source (acres) =====>|
                           Resi-   Institu- Commercial Industrial  Open
                          dential   tional     Areas      Areas   Spaces
Source Area                Areas    Areas                          Areas         Freeway Source Area                    Area
(acres)
12345678901234567890123456789012345678901234567890123456789012345678901234567890
Roofs 1                    1.17      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 1
0.00
Roofs 2                    3.13      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 2
0.00
Roofs 3                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 3
0.00
Roofs 4                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 4
0.00
Roofs 5                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 5
0.00
Paved Parking/Storage 1    0.00      0.00      0.00      0.00      0.00          Large Turf Areas
0.00
Paved Parking/Storage 2    0.00      0.00      0.00      0.00      0.00          Undeveloped Areas
0.00
Paved Parking/Storage 3    0.00      0.00      0.00      0.00      0.00          Other Pervious Areas
0.00
```

```
Unpaved Prkng/Storage 1    0.00      0.00      0.00      0.00      0.00          Other Directly Conctd Imp
0.00
Unpaved Prkng/Storage 2    0.00      0.00      0.00      0.00      0.00          Other Partially Conctd Imp
0.00
Playground 1               0.00      0.00      0.00      0.00      0.00                                                   -
-------
Playground 2               0.00      0.00      0.00      0.00      0.00          Total
0.00
Driveways 1                1.57      0.00      0.00      0.00      0.00
Driveways 2                0.00      0.00      0.00      0.00      0.00
Driveways 3                0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 1          0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 2          0.00      0.00      0.00      0.00      0.00
Street Area 1              4.94      0.00      0.00      0.00      0.00
Street Area 2              0.00      0.00      0.00      0.00      0.00
Street Area 3              0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 1    39.49     0.00      0.00      0.00      0.00
Large Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Undeveloped Area           3.54      0.00      0.00      0.00      0.00
Small Landscaped Area 1    46.16     0.00      0.00      0.00      0.00
Small Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Small Landscaped Area 3    0.00      0.00      0.00      0.00      0.00
Isolated Area              0.00      0.00      0.00      0.00      0.00
Other Pervious Area        0.00      0.00      0.00      0.00      0.00
Other Dir Cnctd Imp Area   0.00      0.00      0.00      0.00      0.00
Other Part Cnctd Imp Area  0.00      0.00      0.00      0.00      0.00
                        --------  --------  --------  --------  --------
Total                   100.00    0.00      0.00      0.00      0.00
Total of All Source Areas             100.00
                                      ---------
Total of All Source Areas
     less All Isolated Areas          100.00
                                      =========
                   Source Area Control Practice Information
Land Use:  Residential
   Roofs 1    Source area number:  1
         The roof is pitched
         The Source Area is directly connected or draining to a directly conntected area
   Roofs 2    Source area number:  2
         The roof is pitched
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Clayey
         The building density is low
   Driveways 1    Source area number:  13
```

```
        The Source Area is draining to a pervious area (partially connected impervious area)
        The SCS Hydrologic Soil Type is Clayey
        The building density is low
  Street Area 1    Source area number:  18
           1.  Street Texture:  intermediate
           2.  Total study area street length (curb-miles):  2.6
           3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
           4.  Street Dirt Accumulation:
                 Default value used
  Large Landscaped Area 1    Source area number:  21
        The SCS Hydrologic Soil Type is Clayey
  Undeveloped Area    Source area number:  23
        The SCS Hydrologic Soil Type is Clayey
  Small Landscaped Area 1    Source area number:  24
        The SCS Hydrologic Soil Type is Clayey

Pollutants to be Analyzed and Printed:
        Pollutant Name               Pollutant Type
         Solids                      Particulate
```

Data file name: C:\Program Files\WinSLAMM\LDRSB.DAT   SLAMM Version V8.1

Rain file name: C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN   Particulate Solids Concentration file name: C:\PROGRAM FILES\WINSLAMM\BHAM.PSC

Runoff Coefficient file name: C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV

Particulate Residue Delivery file name: C:\PROGRAM FILES\WINSLAMM\DELIVERY.PRR

Pollutant Relative Concentration file name: C:\PROGRAM FILES\WINSLAMM\BHAM.PPD

Seed for random number generator: 42

Study period starting date: 01/01/53   Study period ending date: 12/31/89

Date: 07-23-2000   Time: 19:27:38

Fraction of each type of Drainage System serving study area:

1. Grass Swales 0
2. Undeveloped roadside 0

Curb and Gutters, `valleys', or sealed swales in:

3. Poor condition (or very flat) 0
4. Fair condition 1
5. Good condition (or very steep) 0

Site information: Low Density resid., curbs and gutters, baseline controls (none)

|<===== Areas for each Source (acres) =====>|

12345678901234567890123456789012345678901234567890123456789012345678901234567890

Source Area	Resi-dential Areas	Institu-tional Areas	Commercial Areas	Industrial Areas	Open Spaces Areas	Freeway Source Area	Area (acres)
Roofs 1	1.17	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 1	0.00
Roofs 2	3.13	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 2	0.00
Roofs 3	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 3	0.00
Roofs 4	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 4	0.00
Roofs 5	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 5	0.00
Paved Parking/Storage 1	0.00	0.00	0.00	0.00	0.00	Large Turf Areas	0.00
Paved Parking/Storage 2	0.00	0.00	0.00	0.00	0.00	Undeveloped Areas	0.00
Paved Parking/Storage 3	0.00	0.00	0.00	0.00	0.00	Other Pervious Areas	0.00
Unpaved Prkng/Storage 1	0.00	0.00	0.00	0.00	0.00	Other Directly Conctd Imp	0.00

```
Unpaved Prkng/Storage 2    0.00      0.00      0.00      0.00      0.00          Other Partially Conctd Imp
0.00
Playground 1               0.00      0.00      0.00      0.00      0.00                                                -
-------
Playground 2               0.00      0.00      0.00      0.00      0.00          Total
0.00
Driveways 1                1.57      0.00      0.00      0.00      0.00
Driveways 2                0.00      0.00      0.00      0.00      0.00
Driveways 3                0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 1          0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 2          0.00      0.00      0.00      0.00      0.00
Street Area 1              4.94      0.00      0.00      0.00      0.00
Street Area 2              0.00      0.00      0.00      0.00      0.00
Street Area 3              0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 1    39.49     0.00      0.00      0.00      0.00
Large Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Undeveloped Area           3.54      0.00      0.00      0.00      0.00
Small Landscaped Area 1    46.16     0.00      0.00      0.00      0.00
Small Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Small Landscaped Area 3    0.00      0.00      0.00      0.00      0.00
Isolated Area              0.00      0.00      0.00      0.00      0.00
Other Pervious Area        0.00      0.00      0.00      0.00      0.00
Other Dir Cnctd Imp Area   0.00      0.00      0.00      0.00      0.00
Other Part Cnctd Imp Area  0.00      0.00      0.00      0.00      0.00
                        --------  --------  --------  --------  --------
Total                   100.00    0.00      0.00      0.00      0.00


Total of All Source Areas              100.00
                                       ---------
Total of All Source Areas
     less All Isolated Areas           100.00
                                       =========

                   Source Area Control Practice Information
Land Use:  Residential
   Roofs 1    Source area number:  1
         The roof is pitched
         The Source Area is directly connected or draining to a directly conntected area
   Roofs 2    Source area number:  2
         The roof is pitched
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Sandy
   Driveways 1    Source area number:  13
```

```
        The Source Area is draining to a pervious area (partially connected impervious area)
        The SCS Hydrologic Soil Type is Sandy
   Street Area 1    Source area number:  18
           1.  Street Texture:  intermediate
           2.  Total study area street length (curb-miles):  2.6
           3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
           4.  Street Dirt Accumulation:
                 Default value used
   Large Landscaped Area 1    Source area number:  21
        The SCS Hydrologic Soil Type is Sandy
   Undeveloped Area    Source area number:  23
        The SCS Hydrologic Soil Type is Sandy
   Small Landscaped Area 1    Source area number:  24
        The SCS Hydrologic Soil Type is Sandy

Pollutants to be Analyzed and Printed:
        Pollutant Name               Pollutant Type
        --------------               --------------
         Solids                      Particulate
```

Medium Density, pre 1960 (MR6CB.DAT and MR6SB.DAT)

```
Data file name:  C:\Program Files\WinSLAMM\MR6CB.DAT          SLAMM Version V8.1
    Rain file name:  C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN       Particulate Solids Concentration file name:  C:\PROGRAM
FILES\WINSLAMM\BHAM.PSC
    Runoff Coefficient file name:  C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
                                                                  Particulate Residue Delivery file name:  C:\PROGRAM
FILES\WINSLAMM\DELIVERY.PRR
    Pollutant Relative Concentration file name:  C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
                                                                  Seed for random number generator:   42
    Study period starting date:  01/01/53                         Study period ending date:  12/31/89
    Date:  07-23-2000                                             Time:  19:29:32
    Fraction of each type of Drainage System serving study area:
      1.  Grass Swales 0
      2.  Undeveloped roadside 0
          Curb and Gutters, `valleys', or sealed swales in:
           3.  Poor condition (or very flat) 0
           4.  Fair condition 1
           5.  Good condition (or very steep) 0
    Site information:  MEDIUM DENSITY RESIDENTIAL PRE 1960, CURBS AND GUTTERS, CLAYEY SOILS, BASELINE CONTROLS (NONE)

                          |<===== Areas for each Source (acres) =====>|
                          Resi-   Institu- Commercial Industrial  Open
                         dential   tional     Areas      Areas   Spaces
```

```
Source Area                Areas    Areas                          Areas         Freeway Source Area                   Area
(acres)

1234567890123456789012345678901234567890123456789012345678901234567890
Roofs 1                    3.26      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 1
0.00
Roofs 2                    4.90      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 2
0.00
Roofs 3                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 3
0.00
Roofs 4                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 4
0.00
Roofs 5                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 5
0.00
Paved Parking/Storage 1    0.00      0.00      0.00      0.00      0.00          Large Turf Areas
0.00
Paved Parking/Storage 2    0.00      0.00      0.00      0.00      0.00          Undeveloped Areas
0.00
Paved Parking/Storage 3    0.00      0.00      0.00      0.00      0.00          Other Pervious Areas
0.00
Unpaved Prkng/Storage 1    0.00      0.00      0.00      0.00      0.00          Other Directly Conctd Imp
0.00
Unpaved Prkng/Storage 2    0.00      0.00      0.00      0.00      0.00          Other Partially Conctd Imp
0.00
Playground 1               0.00      0.00      0.00      0.00      0.00                                                  -
-------
Playground 2               0.00      0.00      0.00      0.00      0.00          Total
0.00
Driveways 1                1.30      0.00      0.00      0.00      0.00
Driveways 2                1.30      0.00      0.00      0.00      0.00
Driveways 3                0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 1          0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 2          0.00      0.00      0.00      0.00      0.00
Street Area 1              4.42      0.00      0.00      0.00      0.00
Street Area 2              0.00      0.00      0.00      0.00      0.00
Street Area 3              0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 1    0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Undeveloped Area           0.00      0.00      0.00      0.00      0.00
Small Landscaped Area 1    84.81     0.00      0.00      0.00      0.00
Small Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Small Landscaped Area 3    0.00      0.00      0.00      0.00      0.00
Isolated Area              0.00      0.00      0.00      0.00      0.00
Other Pervious Area        0.00      0.00      0.00      0.00      0.00
```

```
Other Dir Cnctd Imp Area   0.00      0.00      0.00      0.00      0.00
Other Part Cnctd Imp Area  0.00      0.00      0.00      0.00      0.00
                        --------  --------  --------  --------  --------
Total                   100.00    0.00      0.00      0.00      0.00

Total of All Source Areas               100.00
                                        ---------
Total of All Source Areas
     less All Isolated Areas            100.00
                                        =========
                   Source Area Control Practice Information
Land Use:  Residential
   Roofs 1    Source area number:  1
         The roof is pitched
         The Source Area is directly connected or draining to a directly conntected area
   Roofs 2    Source area number:  2
         The roof is pitched
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Clayey
         The building density is medium or high
         Alleys are not present
   Driveways 1    Source area number:  13
         The Source Area is directly connected or draining to a directly conntected area
   Driveways 2    Source area number:  14
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Clayey
         The building density is medium or high
         Alleys are not present
   Street Area 1    Source area number:  18
            1.  Street Texture:  intermediate
            2.  Total study area street length (curb-miles):  2.118
            3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
            4.  Street Dirt Accumulation:
                  Default value used
   Small Landscaped Area 1    Source area number:  24
         The SCS Hydrologic Soil Type is Clayey

      Control Practice 1 :  Catchbasin Cleaning Controls
       1.  Total sump volume (cubic feet)=  1
       2.  Area served by catchbasins (acres)=  100
       3.  Percent of sump volume full at beginning of study period=  60 %
       4.  Average sump depth (feet)=  0
       5.  Number of times catchbasins cleaned each year=  0
```

Pollutants to be Analyzed and Printed:

Pollutant Name	Pollutant Type
Solids	Particulate

Data file name: C:\Program Files\WinSLAMM\MR6SB.DAT   SLAMM Version V8.1
Rain file name: C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN   Particulate Solids Concentration file name: C:\PROGRAM FILES\WINSLAMM\BHAM.PSC
Runoff Coefficient file name: C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
Particulate Residue Delivery file name: C:\PROGRAM FILES\WINSLAMM\DELIVERY.PRR
Pollutant Relative Concentration file name: C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
Seed for random number generator: 42
Study period starting date: 01/01/53   Study period ending date: 12/31/89
Date: 07-23-2000   Time: 19:29:53
Fraction of each type of Drainage System serving study area:

1. Grass Swales 0
2. Undeveloped roadside 0

Curb and Gutters, `valleys', or sealed swales in:

3. Poor condition (or very flat) 0
4. Fair condition 1
5. Good condition (or very steep) 0

Site information: MEDIUM DENSITY RESIDENTIAL PRE 1960, CURB AND GUTTERS, SANDY SOILS, BASELINE CONTROLS (NONE)

	|<===== Areas for each Source (acres) =====>|					
Source Area	Resi-dential Areas	Institu-tional Areas	Commercial Areas	Industrial Areas	Open Spaces Areas	Freeway Source Area	Area (acres)
1234567890123456789012345678901234567890123456789012345678901234567890							
Roofs 1	3.26	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 1	0.00
Roofs 2	4.90	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 2	0.00
Roofs 3	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 3	0.00
Roofs 4	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 4	0.00
Roofs 5	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 5	0.00
Paved Parking/Storage 1	0.00	0.00	0.00	0.00	0.00	Large Turf Areas	0.00
Paved Parking/Storage 2	0.00	0.00	0.00	0.00	0.00	Undeveloped Areas	0.00
Paved Parking/Storage 3	0.00	0.00	0.00	0.00	0.00	Other Pervious Areas	0.00
Unpaved Prkng/Storage 1	0.00	0.00	0.00	0.00	0.00	Other Directly Conctd Imp	0.00

```
Unpaved Prkng/Storage 2    0.00      0.00      0.00      0.00      0.00          Other Partially Conctd Imp
0.00
Playground 1               0.00      0.00      0.00      0.00      0.00                                                  -
-------
Playground 2               0.00      0.00      0.00      0.00      0.00          Total
0.00
Driveways 1                1.30      0.00      0.00      0.00      0.00
Driveways 2                1.30      0.00      0.00      0.00      0.00
Driveways 3                0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 1          0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 2          0.00      0.00      0.00      0.00      0.00
Street Area 1              4.42      0.00      0.00      0.00      0.00
Street Area 2              0.00      0.00      0.00      0.00      0.00
Street Area 3              0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 1    0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Undeveloped Area           0.00      0.00      0.00      0.00      0.00
Small Landscaped Area 1    84.81     0.00      0.00      0.00      0.00
Small Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Small Landscaped Area 3    0.00      0.00      0.00      0.00      0.00
Isolated Area              0.00      0.00      0.00      0.00      0.00
Other Pervious Area        0.00      0.00      0.00      0.00      0.00
Other Dir Cnctd Imp Area   0.00      0.00      0.00      0.00      0.00
Other Part Cnctd Imp Area  0.00      0.00      0.00      0.00      0.00
                        --------  --------  --------  --------  --------
Total                   100.00    0.00      0.00      0.00      0.00

Total of All Source Areas              100.00
                                       ---------
Total of All Source Areas
     less All Isolated Areas           100.00
                                       =========
                   Source Area Control Practice Information
Land Use:  Residential
   Roofs 1    Source area number:  1
         The roof is pitched
         The Source Area is directly connected or draining to a directly conntected area
   Roofs 2    Source area number:  2
         The roof is pitched
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Sandy
   Driveways 1    Source area number:  13
         The Source Area is directly connected or draining to a directly conntected area
   Driveways 2    Source area number:  14
```

```
        The Source Area is draining to a pervious area (partially connected impervious area)
        The SCS Hydrologic Soil Type is Sandy
   Street Area 1    Source area number:  18
           1.  Street Texture:  intermediate
           2.  Total study area street length (curb-miles):  2.118
           3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
           4.  Street Dirt Accumulation:
                 Default value used
   Small Landscaped Area 1    Source area number:  24
        The SCS Hydrologic Soil Type is Sandy
     Control Practice 1 :  Catchbasin Cleaning Controls
      1.  Total sump volume (cubic feet)=  1
      2.  Area served by catchbasins (acres)=  100
      3.  Percent of sump volume full at beginning of study period=  60 %
      4.  Average sump depth (feet)=  0
      5.  Number of times catchbasins cleaned each year=  0

Pollutants to be Analyzed and Printed:
        Pollutant Name                Pollutant Type
         Solids                       Particulate
```

Medium Density, 1961 – 1980 (MR68CB.DAT and MR68SB.DAT)

```
    Data file name:  C:\Program Files\WinSLAMM\MR68CB.DAT         SLAMM Version V8.1
    Rain file name:  C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN       Particulate Solids Concentration file name:  C:\PROGRAM
FILES\WINSLAMM\BHAM.PSC
    Runoff Coefficient file name:  C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
                                                                  Particulate Residue Delivery file name:  C:\PROGRAM
FILES\WINSLAMM\DELIVERY.PRR
    Pollutant Relative Concentration file name:  C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
                                                                  Seed for random number generator:   42
    Study period starting date:  01/01/53                         Study period ending date:  12/31/89
    Date:  07-23-2000                                             Time:  19:28:54
    Fraction of each type of Drainage System serving study area:
      1.  Grass Swales 0
      2.  Undeveloped roadside 0
          Curb and Gutters, `valleys', or sealed swales in:
           3.  Poor condition (or very flat) 0
           4.  Fair condition 1
           5.  Good condition (or very steep) 0
    Site information:  MEDIUM DENSITY RESIDENTIAL 1961-1980, CURBS AND GUTTERS, CLAYEY SOILS, BASELINE CONTROLS (NONE)

                           |<===== Areas for each Source (acres) =====>|
                           Resi-   Institu- Commercial Industrial  Open
                          dential   tional     Areas      Areas   Spaces
Source Area                Areas    Areas                          Areas         Freeway Source Area                   Area
(acres)

12345678901234567890123456789012345678901234567890123456789012345678901234567890
Roofs 1                    2.60      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 1
0.00
Roofs 2                    6.05      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 2
0.00
Roofs 3                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 3
0.00
Roofs 4                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 4
0.00
Roofs 5                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 5
0.00
Paved Parking/Storage 1    0.00      0.00      0.00      0.00      0.00          Large Turf Areas
0.00
Paved Parking/Storage 2    0.00      0.00      0.00      0.00      0.00          Undeveloped Areas
0.00
```

```
Paved Parking/Storage 3    0.00      0.00      0.00      0.00      0.00          Other Pervious Areas
0.00
Unpaved Prkng/Storage 1    0.00      0.00      0.00      0.00      0.00          Other Directly Conctd Imp
0.00
Unpaved Prkng/Storage 2    0.00      0.00      0.00      0.00      0.00          Other Partially Conctd Imp
0.00
Playground 1               0.00      0.00      0.00      0.00      0.00                                                  -
-------
Playground 2               0.00      0.00      0.00      0.00      0.00          Total
0.00
Driveways 1                1.19      0.00      0.00      0.00      0.00
Driveways 2                1.18      0.00      0.00      0.00      0.00
Driveways 3                0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 1          0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 2          0.00      0.00      0.00      0.00      0.00
Street Area 1              6.58      0.00      0.00      0.00      0.00
Street Area 2              0.65      0.00      0.00      0.00      0.00
Street Area 3              0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 1    0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Undeveloped Area           4.59      0.00      0.00      0.00      0.00
Small Landscaped Area 1    50.94     0.00      0.00      0.00      0.00
Small Landscaped Area 2    26.22     0.00      0.00      0.00      0.00
Small Landscaped Area 3    0.00      0.00      0.00      0.00      0.00
Isolated Area              0.00      0.00      0.00      0.00      0.00
Other Pervious Area        0.00      0.00      0.00      0.00      0.00
Other Dir Cnctd Imp Area   0.00      0.00      0.00      0.00      0.00
Other Part Cnctd Imp Area  0.00      0.00      0.00      0.00      0.00
                        --------  --------  --------  --------  --------
Total                   100.00    0.00      0.00      0.00      0.00


Total of All Source Areas              100.00
                                       ---------
Total of All Source Areas
     less All Isolated Areas           100.00
                                       =========

                   Source Area Control Practice Information
Land Use:  Residential
   Roofs 1    Source area number:  1
         The roof is pitched
         The Source Area is directly connected or draining to a directly conntected area
   Roofs 2    Source area number:  2
```

```
        The roof is pitched
        The Source Area is draining to a pervious area (partially connected impervious area)
        The SCS Hydrologic Soil Type is Clayey
        The building density is medium or high
        Alleys are not present
  Driveways 1    Source area number:  13
        The Source Area is directly connected or draining to a directly conntected area
  Driveways 2    Source area number:  14
        The Source Area is draining to a pervious area (partially connected impervious area)
        The SCS Hydrologic Soil Type is Clayey
        The building density is medium or high
        Alleys are not present
  Street Area 1    Source area number:  18
           1.  Street Texture:  intermediate
           2.  Total study area street length (curb-miles):  2.73
           3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
           4.  Street Dirt Accumulation:
                 Default value used
  Street Area 2    Source area number:  19
           1.  Street Texture:  rough
           2.  Total study area street length (curb-miles):  0.27
           3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
           4.  Street Dirt Accumulation:
                 Default value used
  Undeveloped Area    Source area number:  23
        The SCS Hydrologic Soil Type is Clayey
  Small Landscaped Area 1    Source area number:  24
        The SCS Hydrologic Soil Type is Clayey
  Small Landscaped Area 2    Source area number:  25
        The SCS Hydrologic Soil Type is Clayey


     Control Practice 1 :  Catchbasin Cleaning Controls
      1.  Total sump volume (cubic feet)=  1
      2.  Area served by catchbasins (acres)=  100
      3.  Percent of sump volume full at beginning of study period=  60 %
      4.  Average sump depth (feet)=  0
      5.  Number of times catchbasins cleaned each year=  0



Pollutants to be Analyzed and Printed:

        Pollutant Name               Pollutant Type
```

--------------	--------------
Solids	Particulate

```
    Data file name:  C:\Program Files\WinSLAMM\MR68SB.DAT         SLAMM Version V8.1
    Rain file name:  C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN       Particulate Solids Concentration file name:  C:\PROGRAM
FILES\WINSLAMM\BHAM.PSC
    Runoff Coefficient file name:  C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
                                                                 Particulate Residue Delivery file name:  C:\PROGRAM
FILES\WINSLAMM\DELIVERY.PRR
    Pollutant Relative Concentration file name:  C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
                                                                  Seed for random number generator:   42
    Study period starting date:  01/01/53                         Study period ending date:  12/31/89
    Date:  07-23-2000                                             Time:  19:29:17
    Fraction of each type of Drainage System serving study area:
      1.  Grass Swales 0
      2.  Undeveloped roadside 0
          Curb and Gutters, `valleys', or sealed swales in:
           3.  Poor condition (or very flat) 0
           4.  Fair condition 1
           5.  Good condition (or very steep) 0
    Site information:  MEDIUM DENSITY RESIDENTIAL 1961-1980, CURBS AND GUTTERS, SANDY SOILS, BASELINE CONTROLS (NONE)
                           |<===== Areas for each Source (acres) =====>|
                           Resi-   Institu- Commercial Industrial  Open
                          dential   tional     Areas      Areas   Spaces
Source Area                Areas    Areas                          Areas         Freeway Source Area                  Area
(acres)

1234567890123456789012345678901234567890123456789012345678901234567890123456780
Roofs 1                    2.60      0.00      0.00      0.00      0.00         Pavd Lane & Shldr Area 1
0.00
Roofs 2                    6.05      0.00      0.00      0.00      0.00         Pavd Lane & Shldr Area 2
0.00
Roofs 3                    0.00      0.00      0.00      0.00      0.00         Pavd Lane & Shldr Area 3
0.00
Roofs 4                    0.00      0.00      0.00      0.00      0.00         Pavd Lane & Shldr Area 4
0.00
Roofs 5                    0.00      0.00      0.00      0.00      0.00         Pavd Lane & Shldr Area 5
0.00
Paved Parking/Storage 1    0.00      0.00      0.00      0.00      0.00         Large Turf Areas
0.00
Paved Parking/Storage 2    0.00      0.00      0.00      0.00      0.00         Undeveloped Areas
0.00
Paved Parking/Storage 3    0.00      0.00      0.00      0.00      0.00         Other Pervious Areas
0.00
Unpaved Prkng/Storage 1    0.00      0.00      0.00      0.00      0.00         Other Directly Conctd Imp
0.00
```

```
Unpaved Prkng/Storage 2    0.00      0.00      0.00      0.00      0.00          Other Partially Conctd Imp
0.00
Playground 1               0.00      0.00      0.00      0.00      0.00                                              -
-------
Playground 2               0.00      0.00      0.00      0.00      0.00          Total
0.00
Driveways 1                1.19      0.00      0.00      0.00      0.00
Driveways 2                1.18      0.00      0.00      0.00      0.00
Driveways 3                0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 1          0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 2          0.00      0.00      0.00      0.00      0.00
Street Area 1              6.58      0.00      0.00      0.00      0.00
Street Area 2              0.65      0.00      0.00      0.00      0.00
Street Area 3              0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 1    0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Undeveloped Area           4.59      0.00      0.00      0.00      0.00
Small Landscaped Area 1    50.94     0.00      0.00      0.00      0.00
Small Landscaped Area 2    26.22     0.00      0.00      0.00      0.00
Small Landscaped Area 3    0.00      0.00      0.00      0.00      0.00
Isolated Area              0.00      0.00      0.00      0.00      0.00
Other Pervious Area        0.00      0.00      0.00      0.00      0.00
Other Dir Cnctd Imp Area   0.00      0.00      0.00      0.00      0.00
Other Part Cnctd Imp Area  0.00      0.00      0.00      0.00      0.00
                        --------  --------  --------  --------  --------
Total                   100.00    0.00      0.00      0.00      0.00
Total of All Source Areas              100.00
                                       ---------
Total of All Source Areas
     less All Isolated Areas           100.00
                                       =========
                   Source Area Control Practice Information
Land Use:  Residential
   Roofs 1    Source area number:  1
         The roof is pitched
         The Source Area is directly connected or draining to a directly conntected area
   Roofs 2    Source area number:  2
         The roof is pitched
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Sandy
   Driveways 1    Source area number:  13
         The Source Area is directly connected or draining to a directly conntected area
   Driveways 2    Source area number:  14
         The Source Area is draining to a pervious area (partially connected impervious area)
```

```
        The SCS Hydrologic Soil Type is Sandy
   Street Area 1    Source area number:  18
            1.  Street Texture:  intermediate
            2.  Total study area street length (curb-miles):  2.73
            3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
            4.  Street Dirt Accumulation:
                  Default value used
   Street Area 2    Source area number:  19
            1.  Street Texture:  rough
            2.  Total study area street length (curb-miles):  0.27
            3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
            4.  Street Dirt Accumulation:
                  Default value used
   Undeveloped Area    Source area number:  23
        The SCS Hydrologic Soil Type is Sandy
   Small Landscaped Area 1    Source area number:  24
        The SCS Hydrologic Soil Type is Sandy
   Small Landscaped Area 2    Source area number:  25
        The SCS Hydrologic Soil Type is Sandy
      Control Practice 1 :  Catchbasin Cleaning Controls
       1.  Total sump volume (cubic feet)=  1
       2.  Area served by catchbasins (acres)=  100
       3.  Percent of sump volume full at beginning of study period=  60 %
       4.  Average sump depth (feet)=  0
       5.  Number of times catchbasins cleaned each year=  0

Pollutants to be Analyzed and Printed:
         Pollutant Name               Pollutant Type
         --------------               --------------
          Solids                      Particulate
```

Medium Density, since 1980 (MR8CB.DAT and MR8SB.DAT)

```
Data file name:  C:\Program Files\WinSLAMM\MR8CB.DAT          SLAMM Version V8.1
    Rain file name:  C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN       Particulate Solids Concentration file name:  C:\PROGRAM
FILES\WINSLAMM\BHAM.PSC
    Runoff Coefficient file name:  C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
                                                                  Particulate Residue Delivery file name:  C:\PROGRAM
FILES\WINSLAMM\DELIVERY.PRR
    Pollutant Relative Concentration file name:  C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
                                                                  Seed for random number generator:   42
    Study period starting date:  01/01/53                         Study period ending date:  12/31/89
    Date:  07-23-2000                                             Time:  19:30:12
    Fraction of each type of Drainage System serving study area:
      1.  Grass Swales 0
      2.  Undeveloped roadside 0
          Curb and Gutters, `valleys', or sealed swales in:
           3.  Poor condition (or very flat) 0
           4.  Fair condition 1
           5.  Good condition (or very steep) 0
    Site information:  MEDIUM DENSITY RESIDENTIAL SINCE 1980, CURBS AND GUTTERS, CLAYEY SOILS, BASELINE CONTROLS (NONE)

                           |<===== Areas for each Source (acres) =====>|
                           Resi-   Institu- Commercial Industrial  Open
                          dential   tional     Areas      Areas   Spaces
Source Area                Areas    Areas                          Areas         Freeway Source Area                   Area
(acres)

12345678901234567890123456789012345678901234567890123456789012345678901234567890
Roofs 1                    5.35      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 1
0.00
Roofs 2                    3.68      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 2
0.00
Roofs 3                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 3
0.00
Roofs 4                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 4
0.00
Roofs 5                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 5
0.00
Paved Parking/Storage 1    0.00      0.00      0.00      0.00      0.00          Large Turf Areas
0.00
Paved Parking/Storage 2    0.00      0.00      0.00      0.00      0.00          Undeveloped Areas
0.00
```

```
Paved Parking/Storage 3    0.00      0.00      0.00      0.00      0.00          Other Pervious Areas
0.00
Unpaved Prkng/Storage 1    0.00      0.00      0.00      0.00      0.00          Other Directly Conctd Imp
0.00
Unpaved Prkng/Storage 2    0.00      0.00      0.00      0.00      0.00          Other Partially Conctd Imp
0.00
Playground 1               0.00      0.00      0.00      0.00      0.00                                                -
-------
Playground 2               0.00      0.00      0.00      0.00      0.00          Total
0.00
Driveways 1                1.29      0.00      0.00      0.00      0.00
Driveways 2                1.28      0.00      0.00      0.00      0.00
Driveways 3                0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 1          0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 2          0.00      0.00      0.00      0.00      0.00
Street Area 1              6.80      0.00      0.00      0.00      0.00
Street Area 2              0.00      0.00      0.00      0.00      0.00
Street Area 3              0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 1    0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Undeveloped Area           1.80      0.00      0.00      0.00      0.00
Small Landscaped Area 1    56.50     0.00      0.00      0.00      0.00
Small Landscaped Area 2    23.30     0.00      0.00      0.00      0.00
Small Landscaped Area 3    0.00      0.00      0.00      0.00      0.00
Isolated Area              0.00      0.00      0.00      0.00      0.00
Other Pervious Area        0.00      0.00      0.00      0.00      0.00
Other Dir Cnctd Imp Area   0.00      0.00      0.00      0.00      0.00
Other Part Cnctd Imp Area  0.00      0.00      0.00      0.00      0.00
                        --------  --------  --------  --------  --------
Total                   100.00    0.00      0.00      0.00      0.00

Total of All Source Areas             100.00
                                     ---------
Total of All Source Areas
     less All Isolated Areas          100.00
                                      =========
                   Source Area Control Practice Information
Land Use:  Residential
   Roofs 1    Source area number:  1
         The roof is pitched
         The Source Area is directly connected or draining to a directly conntected area
   Roofs 2    Source area number:  2
         The roof is pitched
         The Source Area is draining to a pervious area (partially connected impervious area)
```

```
        The SCS Hydrologic Soil Type is Clayey
        The building density is medium or high
        Alleys are not present
  Driveways 1    Source area number:  13
        The Source Area is directly connected or draining to a directly conntected area
  Driveways 2    Source area number:  14
        The Source Area is draining to a pervious area (partially connected impervious area)
        The SCS Hydrologic Soil Type is Clayey
        The building density is medium or high
        Alleys are not present
  Street Area 1    Source area number:  18
           1.  Street Texture:  intermediate
           2.  Total study area street length (curb-miles):  3.17
           3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
           4.  Street Dirt Accumulation:
                 Default value used
  Undeveloped Area    Source area number:  23
        The SCS Hydrologic Soil Type is Clayey
  Small Landscaped Area 1    Source area number:  24
        The SCS Hydrologic Soil Type is Clayey
  Small Landscaped Area 2    Source area number:  25
        The SCS Hydrologic Soil Type is Clayey
     Control Practice 1 :  Catchbasin Cleaning Controls
      1.  Total sump volume (cubic feet)=  1
      2.  Area served by catchbasins (acres)=  100
      3.  Percent of sump volume full at beginning of study period=  60 %
      4.  Average sump depth (feet)=  0
      5.  Number of times catchbasins cleaned each year=  0

Pollutants to be Analyzed and Printed:
        Pollutant Name               Pollutant Type
        --------------               --------------
         Solids                      Particulate
```

Data file name: C:\Program Files\WinSLAMM\MR8SB.DAT SLAMM Version V8.1
Rain file name: C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN Particulate Solids Concentration file name: C:\PROGRAM FILES\WINSLAMM\BHAM.PSC
Runoff Coefficient file name: C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
Particulate Residue Delivery file name: C:\PROGRAM FILES\WINSLAMM\DELIVERY.PRR
Pollutant Relative Concentration file name: C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
Seed for random number generator: 42
Study period starting date: 01/01/53 Study period ending date: 12/31/89
Date: 07-23-2000 Time: 19:30:29
Fraction of each type of Drainage System serving study area:

1. Grass Swales 0
2. Undeveloped roadside 0

Curb and Gutters, `valleys', or sealed swales in:

3. Poor condition (or very flat) 0
4. Fair condition 1
5. Good condition (or very steep) 0

Site information: MEDIUM DENSITY RESIDENTIAL SINCE 1980, CURB AND GUTTERS, SANDY SOILS, BASELINE CONTROLS (NONE)

|<===== Areas for each Source (acres) =====>|

1234567890123456789012345678901234567890123456789012345678901234567890

Source Area	Resi-dential Areas	Institu-tional Areas	Commercial Areas	Industrial Areas	Open Spaces Areas	Freeway Source Area	Area (acres)
Roofs 1	5.35	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 1	0.00
Roofs 2	3.68	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 2	0.00
Roofs 3	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 3	0.00
Roofs 4	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 4	0.00
Roofs 5	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 5	0.00
Paved Parking/Storage 1	0.00	0.00	0.00	0.00	0.00	Large Turf Areas	0.00
Paved Parking/Storage 2	0.00	0.00	0.00	0.00	0.00	Undeveloped Areas	0.00
Paved Parking/Storage 3	0.00	0.00	0.00	0.00	0.00	Other Pervious Areas	0.00
Unpaved Prkng/Storage 1	0.00	0.00	0.00	0.00	0.00	Other Directly Conctd Imp	0.00

Other Partially Conctd Imp
0.00

Total
0.00

Unpaved Prkng/Storage 2	0.00	0.00	0.00	0.00	0.00
Playground 1	0.00	0.00	0.00	0.00	0.00
Playground 2	0.00	0.00	0.00	0.00	0.00
Driveways 1	1.29	0.00	0.00	0.00	0.00
Driveways 2	1.28	0.00	0.00	0.00	0.00
Driveways 3	0.00	0.00	0.00	0.00	0.00
Sidewalks/Walks 1	0.00	0.00	0.00	0.00	0.00
Sidewalks/Walks 2	0.00	0.00	0.00	0.00	0.00
Street Area 1	6.80	0.00	0.00	0.00	0.00
Street Area 2	0.00	0.00	0.00	0.00	0.00
Street Area 3	0.00	0.00	0.00	0.00	0.00
Large Landscaped Area 1	0.00	0.00	0.00	0.00	0.00
Large Landscaped Area 2	0.00	0.00	0.00	0.00	0.00
Undeveloped Area	1.80	0.00	0.00	0.00	0.00
Small Landscaped Area 1	56.50	0.00	0.00	0.00	0.00
Small Landscaped Area 2	23.30	0.00	0.00	0.00	0.00
Small Landscaped Area 3	0.00	0.00	0.00	0.00	0.00
Isolated Area	0.00	0.00	0.00	0.00	0.00
Other Pervious Area	0.00	0.00	0.00	0.00	0.00
Other Dir Cnctd Imp Area	0.00	0.00	0.00	0.00	0.00
Other Part Cnctd Imp Area	0.00	0.00	0.00	0.00	0.00
	--------	--------	--------	--------	--------
Total	100.00	0.00	0.00	0.00	0.00

Total of All Source Areas 100.00

Total of All Source Areas
less All Isolated Areas 100.00
=========

Source Area Control Practice Information

Land Use: Residential

Roofs 1 Source area number: 1
The roof is pitched
The Source Area is directly connected or draining to a directly conntected area

Roofs 2 Source area number: 2
The roof is pitched
The Source Area is draining to a pervious area (partially connected impervious area)
The SCS Hydrologic Soil Type is Sandy

Driveways 1 Source area number: 13

```
        The Source Area is directly connected or draining to a directly conntected area
  Driveways 2    Source area number:  14
        The Source Area is draining to a pervious area (partially connected impervious area)
        The SCS Hydrologic Soil Type is Sandy
  Street Area 1    Source area number:  18
           1.  Street Texture:  intermediate
           2.  Total study area street length (curb-miles):  3.17
           3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
           4.  Street Dirt Accumulation:
                 Default value used
  Undeveloped Area    Source area number:  23
        The SCS Hydrologic Soil Type is Sandy
  Small Landscaped Area 1    Source area number:  24
        The SCS Hydrologic Soil Type is Sandy
  Small Landscaped Area 2    Source area number:  25
        The SCS Hydrologic Soil Type is Sandy

     Control Practice 1 :  Catchbasin Cleaning Controls
      1.  Total sump volume (cubic feet)=  1
      2.  Area served by catchbasins (acres)=  100
      3.  Percent of sump volume full at beginning of study period=  60 %
      4.  Average sump depth (feet)=  0
      5.  Number of times catchbasins cleaned each year=  0

Pollutants to be Analyzed and Printed:
        Pollutant Name              Pollutant Type
        --------------              --------------
         Solids                     Particulate
```

High Density (HDRCB.DAT and HDRSB.DAT)

```
Data file name:  C:\Program Files\WinSLAMM\HDRCB.DAT          SLAMM Version V8.1
    Rain file name:  C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN       Particulate Solids Concentration file name:  C:\PROGRAM
FILES\WINSLAMM\BHAM.PSC
    Runoff Coefficient file name:  C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
                                                                  Particulate Residue Delivery file name:  C:\PROGRAM
FILES\WINSLAMM\DELIVERY.PRR
    Pollutant Relative Concentration file name:  C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
                                                                  Seed for random number generator:   42
    Study period starting date:  01/01/53                         Study period ending date:  12/31/89
    Date:  07-23-2000                                             Time:  19:26:57
    Fraction of each type of Drainage System serving study area:
      1.  Grass Swales 0
      2.  Undeveloped roadside 0
          Curb and Gutters, `valleys', or sealed swales in:
           3.  Poor condition (or very flat) 0
           4.  Fair condition 1
           5.  Good condition (or very steep) 0
    Site information:  HIGH DENSITY RESIDENTIAL, CURBS AND GUTTERS, CLAYEY SOILS, BASELINE CONTROLS (NONE)

                           |<===== Areas for each Source (acres) =====>|
                           Resi-   Institu- Commercial Industrial  Open
                          dential   tional     Areas      Areas   Spaces
Source Area                Areas    Areas                          Areas         Freeway Source Area                   Area
(acres)

12345678901234567890123456789012345678901234567890123456789012345678901234567890
Roofs 1                    5.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 1
0.00
Roofs 2                    9.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 2
0.00
Roofs 3                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 3
0.00
Roofs 4                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 4
0.00
Roofs 5                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 5
0.00
Paved Parking/Storage 1    0.00      0.00      0.00      0.00      0.00          Large Turf Areas
0.00
Paved Parking/Storage 2    0.00      0.00      0.00      0.00      0.00          Undeveloped Areas
0.00
```

```
Paved Parking/Storage 3    0.00      0.00      0.00      0.00      0.00          Other Pervious Areas
0.00
Unpaved Prkng/Storage 1    0.00      0.00      0.00      0.00      0.00          Other Directly Conctd Imp
0.00
Unpaved Prkng/Storage 2    0.00      0.00      0.00      0.00      0.00          Other Partially Conctd Imp
0.00
Playground 1               0.00      0.00      0.00      0.00      0.00                                              -
-------
Playground 2               0.00      0.00      0.00      0.00      0.00          Total
0.00
Driveways 1                3.00      0.00      0.00      0.00      0.00
Driveways 2                0.00      0.00      0.00      0.00      0.00
Driveways 3                0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 1          0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 2          0.00      0.00      0.00      0.00      0.00
Street Area 1              6.00      0.00      0.00      0.00      0.00
Street Area 2              1.00      0.00      0.00      0.00      0.00
Street Area 3              0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 1    0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Undeveloped Area           4.00      0.00      0.00      0.00      0.00
Small Landscaped Area 1    40.00     0.00      0.00      0.00      0.00
Small Landscaped Area 2    32.00     0.00      0.00      0.00      0.00
Small Landscaped Area 3    0.00      0.00      0.00      0.00      0.00
Isolated Area              0.00      0.00      0.00      0.00      0.00
Other Pervious Area        0.00      0.00      0.00      0.00      0.00
Other Dir Cnctd Imp Area   0.00      0.00      0.00      0.00      0.00
Other Part Cnctd Imp Area  0.00      0.00      0.00      0.00      0.00
                        --------  --------  --------  --------  --------
Total                   100.00    0.00      0.00      0.00      0.00

Total of All Source Areas             100.00
                                      ---------
Total of All Source Areas
     less All Isolated Areas          100.00
                                      =========
                   Source Area Control Practice Information
Land Use:  Residential
   Roofs 1    Source area number:  1
         The roof is pitched
         The Source Area is directly connected or draining to a directly conntected area
   Roofs 2    Source area number:  2
         The roof is pitched
         The Source Area is draining to a pervious area (partially connected impervious area)
```

```
        The SCS Hydrologic Soil Type is Clayey
        The building density is medium or high
        Alleys are not present
  Driveways 1    Source area number:  13
        The Source Area is directly connected or draining to a directly conntected area
  Street Area 1    Source area number:  18
           1.  Street Texture:  intermediate
           2.  Total study area street length (curb-miles):  3.1
           3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
           4.  Street Dirt Accumulation:
                 Default value used
  Street Area 2    Source area number:  19
           1.  Street Texture:  rough
           2.  Total study area street length (curb-miles):  2.7
           3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
           4.  Street Dirt Accumulation:
                 Default value used
  Undeveloped Area    Source area number:  23
        The SCS Hydrologic Soil Type is Clayey
  Small Landscaped Area 1    Source area number:  24
        The SCS Hydrologic Soil Type is Clayey
  Small Landscaped Area 2    Source area number:  25
        The SCS Hydrologic Soil Type is Clayey
     Control Practice 1 :  Catchbasin Cleaning Controls
      1.  Total sump volume (cubic feet)=  1
      2.  Area served by catchbasins (acres)=  100
      3.  Percent of sump volume full at beginning of study period=  60 %
      4.  Average sump depth (feet)=  0
      5.  Number of times catchbasins cleaned each year=  0
Pollutants to be Analyzed and Printed:
        Pollutant Name              Pollutant Type
        --------------              --------------
         Solids                     Particulate
```

```
    Data file name:  C:\Program Files\WinSLAMM\HDRSB.DAT          SLAMM Version V8.1
    Rain file name:  C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN       Particulate Solids Concentration file name:  C:\PROGRAM
FILES\WINSLAMM\BHAM.PSC
    Runoff Coefficient file name:  C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
                                                                  Particulate Residue Delivery file name:  C:\PROGRAM
FILES\WINSLAMM\DELIVERY.PRR
    Pollutant Relative Concentration file name:  C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
                                                                  Seed for random number generator:   42
    Study period starting date:  01/01/53                         Study period ending date:  12/31/89
    Date:  07-23-2000                                             Time:  19:27:12
    Fraction of each type of Drainage System serving study area:
      1.  Grass Swales 0
      2.  Undeveloped roadside 0
          Curb and Gutters, `valleys', or sealed swales in:
           3.  Poor condition (or very flat) 0
           4.  Fair condition 1
           5.  Good condition (or very steep) 0
    Site information:  HIGH DENSITY RESIDENTIAL, CURB AND GUTTERS, SANDY, BASELINE CONTROLS (NONE)

                           |<===== Areas for each Source (acres) =====>|
                           Resi-   Institu- Commercial Industrial  Open
                          dential   tional     Areas      Areas   Spaces
Source Area                Areas    Areas                          Areas         Freeway Source Area                   Area
(acres)
12345678901234567890123456789012345678901234567890123456789012345678901234567890
Roofs 1                    5.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 1
0.00
Roofs 2                    9.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 2
0.00
Roofs 3                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 3
0.00
Roofs 4                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 4
0.00
Roofs 5                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 5
0.00
Paved Parking/Storage 1    0.00      0.00      0.00      0.00      0.00          Large Turf Areas
0.00
Paved Parking/Storage 2    0.00      0.00      0.00      0.00      0.00          Undeveloped Areas
0.00
Paved Parking/Storage 3    0.00      0.00      0.00      0.00      0.00          Other Pervious Areas
0.00
Unpaved Prkng/Storage 1    0.00      0.00      0.00      0.00      0.00          Other Directly Conctd Imp
0.00
```

```
Unpaved Prkng/Storage 2    0.00      0.00      0.00      0.00      0.00          Other Partially Conctd Imp
0.00
Playground 1               0.00      0.00      0.00      0.00      0.00                                                   -
-------
Playground 2               0.00      0.00      0.00      0.00      0.00          Total
0.00
Driveways 1                3.00      0.00      0.00      0.00      0.00
Driveways 2                0.00      0.00      0.00      0.00      0.00
Driveways 3                0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 1          0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 2          0.00      0.00      0.00      0.00      0.00
Street Area 1              6.00      0.00      0.00      0.00      0.00
Street Area 2              1.00      0.00      0.00      0.00      0.00
Street Area 3              0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 1    0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Undeveloped Area           4.00      0.00      0.00      0.00      0.00
Small Landscaped Area 1    40.00     0.00      0.00      0.00      0.00
Small Landscaped Area 2    32.00     0.00      0.00      0.00      0.00
Small Landscaped Area 3    0.00      0.00      0.00      0.00      0.00
Isolated Area              0.00      0.00      0.00      0.00      0.00
Other Pervious Area        0.00      0.00      0.00      0.00      0.00
Other Dir Cnctd Imp Area   0.00      0.00      0.00      0.00      0.00
Other Part Cnctd Imp Area  0.00      0.00      0.00      0.00      0.00
                        --------  --------  --------  --------  --------
Total                   100.00    0.00      0.00      0.00      0.00

Total of All Source Areas              100.00
                                       ---------
Total of All Source Areas
     less All Isolated Areas           100.00
                                       =========
                   Source Area Control Practice Information
Land Use:  Residential
   Roofs 1    Source area number:  1
         The roof is pitched
         The Source Area is directly connected or draining to a directly conntected area
   Roofs 2    Source area number:  2
         The roof is pitched
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Sandy
   Driveways 1    Source area number:  13
         The Source Area is directly connected or draining to a directly conntected area
   Street Area 1    Source area number:  18
```

```
            1.  Street Texture:  intermediate
            2.  Total study area street length (curb-miles):  3.1
            3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
            4.  Street Dirt Accumulation:
                  Default value used
   Street Area 2    Source area number:  19
            1.  Street Texture:  rough
            2.  Total study area street length (curb-miles):  2.7
            3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
            4.  Street Dirt Accumulation:
                  Default value used
   Undeveloped Area    Source area number:  23
         The SCS Hydrologic Soil Type is Sandy
   Small Landscaped Area 1    Source area number:  24
         The SCS Hydrologic Soil Type is Sandy
   Small Landscaped Area 2    Source area number:  25
         The SCS Hydrologic Soil Type is Sandy

      Control Practice 1 :  Catchbasin Cleaning Controls
       1.  Total sump volume (cubic feet)=  1
       2.  Area served by catchbasins (acres)=  100
       3.  Percent of sump volume full at beginning of study period=  60 %
       4.  Average sump depth (feet)=  0
       5.  Number of times catchbasins cleaned each year=  0

Pollutants to be Analyzed and Printed:
         Pollutant Name               Pollutant Type
         --------------               --------------
          Solids                      Particulate
```

Multi-Family (Duplexes) (MFRCB.DAT and MFRSB.DAT)

Data file name: C:\Program Files\WinSLAMM\MFRCB.DAT   SLAMM Version V8.1

Rain file name: C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN   Particulate Solids Concentration file name: C:\PROGRAM FILES\WINSLAMM\BHAM.PSC

Runoff Coefficient file name: C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV

Particulate Residue Delivery file name: C:\PROGRAM FILES\WINSLAMM\DELIVERY.PRR

Pollutant Relative Concentration file name: C:\PROGRAM FILES\WINSLAMM\BHAM.PPD

Seed for random number generator: 42

Study period starting date: 01/01/53   Study period ending date: 12/31/89

Date: 07-23-2000   Time: 19:28:22

Fraction of each type of Drainage System serving study area:

1. Grass Swales 0
2. Undeveloped roadside 1

Curb and Gutters, `valleys', or sealed swales in:

3. Poor condition (or very flat) 0
4. Fair condition 0
5. Good condition (or very steep) 0

Site information: MULTI-FAMILY RESIDENTIAL, UNDEVELOPED ROADSIDE, CLAYEY SOILS, BASELINE CONTROLS (NONE)

	|<===== Areas for each Source (acres) =====>|						
Source Area	Resi-dential Areas	Institu-tional Areas	Commercial Areas	Industrial Areas	Open Spaces Areas	Freeway Source Area	Area (acres)
12345678901234567890123456789012345678901234567890123456789012345678901234567890							
Roofs 1	10.90	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 1	0.00
Roofs 2	6.50	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 2	0.00
Roofs 3	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 3	0.00
Roofs 4	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 4	0.00
Roofs 5	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 5	0.00
Paved Parking/Storage 1	1.23	0.00	0.00	0.00	0.00	Large Turf Areas	0.00
Paved Parking/Storage 2	0.00	0.00	0.00	0.00	0.00	Undeveloped Areas	0.00

```
Paved Parking/Storage 3    0.00      0.00      0.00      0.00      0.00          Other Pervious Areas
0.00
Unpaved Prkng/Storage 1    10.00     0.00      0.00      0.00      0.00          Other Directly Conctd Imp
0.00
Unpaved Prkng/Storage 2    0.00      0.00      0.00      0.00      0.00          Other Partially Conctd Imp
0.00
Playground 1               0.16      0.00      0.00      0.00      0.00                                                -
-------
Playground 2               0.00      0.00      0.00      0.00      0.00          Total
0.00
Driveways 1                0.62      0.00      0.00      0.00      0.00
Driveways 2                0.62      0.00      0.00      0.00      0.00
Driveways 3                0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 1          0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 2          0.00      0.00      0.00      0.00      0.00
Street Area 1              6.36      0.00      0.00      0.00      0.00
Street Area 2              0.67      0.00      0.00      0.00      0.00
Street Area 3              0.37      0.00      0.00      0.00      0.00
Large Landscaped Area 1    0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Undeveloped Area           3.00      0.00      0.00      0.00      0.00
Small Landscaped Area 1    28.20     0.00      0.00      0.00      0.00
Small Landscaped Area 2    30.09     0.00      0.00      0.00      0.00
Small Landscaped Area 3    0.00      0.00      0.00      0.00      0.00
Isolated Area              0.00      0.00      0.00      0.00      0.00
Other Pervious Area        1.28      0.00      0.00      0.00      0.00
Other Dir Cnctd Imp Area   0.00      0.00      0.00      0.00      0.00
Other Part Cnctd Imp Area  0.00      0.00      0.00      0.00      0.00
                        --------  --------  --------  --------  --------
Total                   100.00    0.00      0.00      0.00      0.00


Total of All Source Areas             100.00
                                      ---------
Total of All Source Areas
     less All Isolated Areas          100.00
                                      =========

                   Source Area Control Practice Information
Land Use:  Residential
   Roofs 1    Source area number:  1
         The roof is pitched
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Clayey
```

```
      The building density is medium or high
      Alleys are not present
Roofs 2    Source area number:  2
      The roof is pitched
      The Source Area is draining to a pervious area (partially connected impervious area)
      The SCS Hydrologic Soil Type is Clayey
      The building density is medium or high
      Alleys are not present
Paved Parking/Storage 1    Source area number:  6
      The Source Area is draining to a pervious area (partially connected impervious area)
      The SCS Hydrologic Soil Type is Clayey
      The building density is medium or high
      Alleys are not present
Unpaved Prkng/Storage 1    Source area number:  9
      The Source Area is draining to a pervious area (partially connected impervious area)
      The SCS Hydrologic Soil Type is Clayey
      The building density is medium or high
      Alleys are not present
Playground 1    Source area number:  11
      The Source Area is draining to a pervious area (partially connected impervious area)
      The SCS Hydrologic Soil Type is Clayey
      The building density is medium or high
      Alleys are not present
Driveways 1    Source area number:  13
      The Source Area is directly connected or draining to a directly conntected area
Driveways 2    Source area number:  14
      The Source Area is draining to a pervious area (partially connected impervious area)
      The SCS Hydrologic Soil Type is Clayey
      The building density is medium or high
      Alleys are not present
Street Area 1    Source area number:  18
         1.  Street Texture:  intermediate
         2.  Total study area street length (curb-miles):  2.85
         3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
         4.  Street Dirt Accumulation:
               Default value used
Street Area 2    Source area number:  19
         1.  Street Texture:  smooth
         2.  Total study area street length (curb-miles):  2.85
         3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
         4.  Street Dirt Accumulation:
               Default value used
Street Area 3    Source area number:  20
         1.  Street Texture:  rough
```

```
          2.  Total study area street length (curb-miles):  2.85
          3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
          4.  Street Dirt Accumulation:
                Default value used
   Undeveloped Area    Source area number:  23
         The SCS Hydrologic Soil Type is Clayey
   Small Landscaped Area 1    Source area number:  24
         The SCS Hydrologic Soil Type is Clayey
   Small Landscaped Area 2    Source area number:  25
         The SCS Hydrologic Soil Type is Clayey
   Other Pervious Area    Source area number:  28
         The SCS Hydrologic Soil Type is Clayey
```

Pollutants to be Analyzed and Printed:

Pollutant Name	Pollutant Type
Solids	Particulate

Data file name: C:\Program Files\WinSLAMM\MFRSB.DAT
SLAMM Version V8.1
Rain file name: C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN
Particulate Solids Concentration file name: C:\PROGRAM FILES\WINSLAMM\BHAM.PSC
Runoff Coefficient file name: C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
Particulate Residue Delivery file name: C:\PROGRAM FILES\WINSLAMM\DELIVERY.PRR
Pollutant Relative Concentration file name: C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
Seed for random number generator: 42
Study period starting date: 01/01/53
Study period ending date: 12/31/89
Date: 07-23-2000
Time: 19:28:37

Fraction of each type of Drainage System serving study area:

1. Grass Swales 0
2. Undeveloped roadside 1

Curb and Gutters, `valleys', or sealed swales in:

3. Poor condition (or very flat) 0
4. Fair condition 0
5. Good condition (or very steep) 0

Site information: MULTI-FAMILY RESIDENTIAL, UNDEVELOPED ROADSIDE, SANDY SOILS, BASELINE CONTROLS (NONE)

	|<===== Areas for each Source (acres) =====>|						
Source Area	Residential Areas	Institutional Areas	Commercial Areas	Industrial Areas	Open Spaces Areas	Freeway Source Area	Area (acres)
1234567890123456789012345678901234567890123456789012345678901234567890123456789							
Roofs 1	10.90	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 1	0.00
Roofs 2	6.50	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 2	0.00
Roofs 3	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 3	0.00
Roofs 4	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 4	0.00
Roofs 5	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 5	0.00
Paved Parking/Storage 1	1.23	0.00	0.00	0.00	0.00	Large Turf Areas	0.00
Paved Parking/Storage 2	0.00	0.00	0.00	0.00	0.00	Undeveloped Areas	0.00
Paved Parking/Storage 3	0.00	0.00	0.00	0.00	0.00	Other Pervious Areas	0.00
Unpaved Prkng/Storage 1	10.00	0.00	0.00	0.00	0.00	Other Directly Conctd Imp	0.00

Unpaved Prkng/Storage 2	0.00	0.00	0.00	0.00	0.00	Other Partially Conctd Imp	0.00
Playground 1	0.16	0.00	0.00	0.00	0.00		--------
Playground 2	0.00	0.00	0.00	0.00	0.00	Total	0.00
Driveways 1	0.62	0.00	0.00	0.00	0.00		
Driveways 2	0.62	0.00	0.00	0.00	0.00		
Driveways 3	0.00	0.00	0.00	0.00	0.00		
Sidewalks/Walks 1	0.00	0.00	0.00	0.00	0.00		
Sidewalks/Walks 2	0.00	0.00	0.00	0.00	0.00		
Street Area 1	6.36	0.00	0.00	0.00	0.00		
Street Area 2	0.67	0.00	0.00	0.00	0.00		
Street Area 3	0.37	0.00	0.00	0.00	0.00		
Large Landscaped Area 1	0.00	0.00	0.00	0.00	0.00		
Large Landscaped Area 2	0.00	0.00	0.00	0.00	0.00		
Undeveloped Area	3.00	0.00	0.00	0.00	0.00		
Small Landscaped Area 1	28.20	0.00	0.00	0.00	0.00		
Small Landscaped Area 2	30.09	0.00	0.00	0.00	0.00		
Small Landscaped Area 3	0.00	0.00	0.00	0.00	0.00		
Isolated Area	0.00	0.00	0.00	0.00	0.00		
Other Pervious Area	1.28	0.00	0.00	0.00	0.00		
Other Dir Cnctd Imp Area	0.00	0.00	0.00	0.00	0.00		
Other Part Cnctd Imp Area	0.00	0.00	0.00	0.00	0.00		
	--------	--------	--------	--------	--------		
Total	100.00	0.00	0.00	0.00	0.00		

```
Total of All Source Areas              100.00
                                       ---------
Total of All Source Areas
     less All Isolated Areas           100.00
                                       =========
```

Source Area Control Practice Information

```
Land Use:  Residential
   Roofs 1    Source area number:  1
         The roof is pitched
         The Source Area is directly connected or draining to a directly conntected area
         The SCS Hydrologic Soil Type is Sandy
   Roofs 2    Source area number:  2
         The roof is pitched
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Sandy
```

```
Paved Parking/Storage 1    Source area number:  6
      The Source Area is draining to a pervious area (partially connected impervious area)
      The SCS Hydrologic Soil Type is Sandy
Unpaved Prkng/Storage 1    Source area number:  9
      The Source Area is draining to a pervious area (partially connected impervious area)
      The SCS Hydrologic Soil Type is Sandy
Playground 1    Source area number:  11
      The Source Area is draining to a pervious area (partially connected impervious area)
      The SCS Hydrologic Soil Type is Sandy
Driveways 1    Source area number:  13
      The Source Area is directly connected or draining to a directly conntected area
Driveways 2    Source area number:  14
      The Source Area is draining to a pervious area (partially connected impervious area)
      The SCS Hydrologic Soil Type is Sandy
Street Area 1    Source area number:  18
         1.  Street Texture:  intermediate
         2.  Total study area street length (curb-miles):  2.85
         3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
         4.  Street Dirt Accumulation:
               Default value used
Street Area 2    Source area number:  19
         1.  Street Texture:  smooth
         2.  Total study area street length (curb-miles):  2.85
         3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
         4.  Street Dirt Accumulation:
               Default value used
Street Area 3    Source area number:  20
         1.  Street Texture:  rough
         2.  Total study area street length (curb-miles):  2.85
         3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
         4.  Street Dirt Accumulation:
               Default value used
Undeveloped Area    Source area number:  23
      The SCS Hydrologic Soil Type is Sandy
Small Landscaped Area 1    Source area number:  24
      The SCS Hydrologic Soil Type is Sandy
Small Landscaped Area 2    Source area number:  25
      The SCS Hydrologic Soil Type is Sandy
Other Pervious Area    Source area number:  28
      The SCS Hydrologic Soil Type is Sandy
```

Pollutants to be Analyzed and Printed:

Pollutant Name	Pollutant Type
Solids	Particulate

Apartments (APTCB.DAT and APTSB.DAT)

```
Data file name:  C:\Program Files\WinSLAMM\APTCB.DAT          SLAMM Version V8.1
    Rain file name:  C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN       Particulate Solids Concentration file name:  C:\PROGRAM
FILES\WINSLAMM\BHAM.PSC
    Runoff Coefficient file name:  C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
                                                                  Particulate Residue Delivery file name:  C:\PROGRAM
FILES\WINSLAMM\DELIVERY.PRR
    Pollutant Relative Concentration file name:  C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
                                                                  Seed for random number generator:   42
    Study period starting date:  01/01/53                         Study period ending date:  12/31/89
    Date:  07-23-2000                                             Time:  19:15:28
    Fraction of each type of Drainage System serving study area:
      1.  Grass Swales 0
      2.  Undeveloped roadside 0
          Curb and Gutters, `valleys', or sealed swales in:
           3.  Poor condition (or very flat) 0
           4.  Fair condition 1
           5.  Good condition (or very steep) 0
    Site information:  APARTMENTS, CURBS AND GUTTERS, CLAYEY SOILS, BASELINE CONTROLS (NONE)
```

Source Area	|<===== Areas for each Source (acres) =====>| Resi-dential Areas	Institu-tional Areas	Commercial Areas	Industrial Areas	Open Spaces Areas	Freeway Source Area	Area (acres)
1234567890123456789012345678901234567890123456789012345678901234567890							
Roofs 1	14.94	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 1	0.00
Roofs 2	4.25	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 2	0.00
Roofs 3	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 3	0.00
Roofs 4	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 4	0.00
Roofs 5	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 5	0.00
Paved Parking/Storage 1	6.53	0.00	0.00	0.00	0.00	Large Turf Areas	0.00
Paved Parking/Storage 2	0.00	0.00	0.00	0.00	0.00	Undeveloped Areas	0.00

Paved Parking/Storage 3	0.00	0.00	0.00	0.00	0.00	Other Pervious Areas
0.00						
Unpaved Prkng/Storage 1	0.00	0.00	0.00	0.00	0.00	Other Directly Conctd Imp
0.00						
Unpaved Prkng/Storage 2	0.00	0.00	0.00	0.00	0.00	Other Partially Conctd Imp
0.00						
Playground 1	0.82	0.00	0.00	0.00	0.00	-

Playground 2	0.00	0.00	0.00	0.00	0.00	Total
0.00						
Driveways 1	0.75	0.00	0.00	0.00	0.00	
Driveways 2	0.75	0.00	0.00	0.00	0.00	
Driveways 3	0.00	0.00	0.00	0.00	0.00	
Sidewalks/Walks 1	0.00	0.00	0.00	0.00	0.00	
Sidewalks/Walks 2	0.00	0.00	0.00	0.00	0.00	
Street Area 1	9.66	0.00	0.00	0.00	0.00	
Street Area 2	0.00	0.00	0.00	0.00	0.00	
Street Area 3	0.00	0.00	0.00	0.00	0.00	
Large Landscaped Area 1	28.73	0.00	0.00	0.00	0.00	
Large Landscaped Area 2	22.96	0.00	0.00	0.00	0.00	
Undeveloped Area	3.18	0.00	0.00	0.00	0.00	
Small Landscaped Area 1	0.00	0.00	0.00	0.00	0.00	
Small Landscaped Area 2	0.00	0.00	0.00	0.00	0.00	
Small Landscaped Area 3	0.00	0.00	0.00	0.00	0.00	
Isolated Area	0.00	0.00	0.00	0.00	0.00	
Other Pervious Area	7.43	0.00	0.00	0.00	0.00	
Other Dir Cnctd Imp Area	0.00	0.00	0.00	0.00	0.00	
Other Part Cnctd Imp Area	0.00	0.00	0.00	0.00	0.00	
	--------	--------	--------	--------	--------	
Total	100.00	0.00	0.00	0.00	0.00	

Total of All Source Areas	100.00

Total of All Source Areas less All Isolated Areas	100.00
	=========

Source Area Control Practice Information

Land Use: Residential

Roofs 1 Source area number: 1

The roof is pitched

The Source Area is draining to a pervious area (partially connected impervious area)

The SCS Hydrologic Soil Type is Clayey

```
      The building density is medium or high
      Alleys are not present
Roofs 2    Source area number:  2
      The roof is pitched
      The Source Area is directly connected or draining to a directly conntected area
Paved Parking/Storage 1    Source area number:  6
      The Source Area is draining to a pervious area (partially connected impervious area)
      The SCS Hydrologic Soil Type is Clayey
      The building density is medium or high
      Alleys are not present
Playground 1    Source area number:  11
      The Source Area is draining to a pervious area (partially connected impervious area)
      The SCS Hydrologic Soil Type is Clayey
      The building density is medium or high
      Alleys are not present
Driveways 1    Source area number:  13
      The Source Area is directly connected or draining to a directly conntected area
Driveways 2    Source area number:  14
      The Source Area is draining to a pervious area (partially connected impervious area)
      The SCS Hydrologic Soil Type is Clayey
      The building density is medium or high
      Alleys are not present
Street Area 1    Source area number:  18
         1.  Street Texture:  intermediate
         2.  Total study area street length (curb-miles):  3.48
         3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
         4.  Street Dirt Accumulation:
               Default value used
Large Landscaped Area 1    Source area number:  21
      The SCS Hydrologic Soil Type is Clayey
Large Landscaped Area 2    Source area number:  22
      The SCS Hydrologic Soil Type is Clayey
Undeveloped Area    Source area number:  23
      The SCS Hydrologic Soil Type is Clayey
Other Pervious Area    Source area number:  28
      The SCS Hydrologic Soil Type is Clayey


   Control Practice 1 :  Catchbasin Cleaning Controls
    1.  Total sump volume (cubic feet)=  1
    2.  Area served by catchbasins (acres)=  100
    3.  Percent of sump volume full at beginning of study period=  60 %
    4.  Average sump depth (feet)=  0
    5.  Number of times catchbasins cleaned each year=  0
```

Pollutants to be Analyzed and Printed:

Pollutant Name	Pollutant Type
Solids	Particulate

Data file name: C:\Program Files\WinSLAMM\APTSB.DAT   SLAMM Version V8.1
Rain file name: C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN   Particulate Solids Concentration file name: C:\PROGRAM FILES\WINSLAMM\BHAM.PSC
Runoff Coefficient file name: C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
Particulate Residue Delivery file name: C:\PROGRAM FILES\WINSLAMM\DELIVERY.PRR
Pollutant Relative Concentration file name: C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
Seed for random number generator: 42
Study period starting date: 01/01/53   Study period ending date: 12/31/89
Date: 07-23-2000   Time: 19:15:46

Fraction of each type of Drainage System serving study area:

1. Grass Swales 0
2. Undeveloped roadside 0

   Curb and Gutters, `valleys', or sealed swales in:

3. Poor condition (or very flat) 0
4. Fair condition 1
5. Good condition (or very steep) 0

Site information: APARTMENTS, CURBS AND GUTTERS, SANDY SOILS, BASELINE CONTROLS (NONE)

|<===== Areas for each Source (acres) =====>|

1234567890123456789012345678901234567890123456789012345678901234567890123456789 0

Source Area	Resi-dential Areas	Institu-tional Areas	Commercial Areas	Industrial Areas	Open Spaces Areas	Freeway Source Area	Area (acres)
Roofs 1	14.94	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 1	0.00
Roofs 2	4.25	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 2	0.00
Roofs 3	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 3	0.00
Roofs 4	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 4	0.00
Roofs 5	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 5	0.00
Paved Parking/Storage 1	6.53	0.00	0.00	0.00	0.00	Large Turf Areas	0.00
Paved Parking/Storage 2	0.00	0.00	0.00	0.00	0.00	Undeveloped Areas	0.00
Paved Parking/Storage 3	0.00	0.00	0.00	0.00	0.00	Other Pervious Areas	0.00
Unpaved Prkng/Storage 1	0.00	0.00	0.00	0.00	0.00	Other Directly Conctd Imp	0.00

```
Unpaved Prkng/Storage 2    0.00      0.00      0.00      0.00      0.00          Other Partially Conctd Imp
0.00
Playground 1               0.82      0.00      0.00      0.00      0.00                                                           -
-------
Playground 2               0.00      0.00      0.00      0.00      0.00          Total
0.00
Driveways 1                0.75      0.00      0.00      0.00      0.00
Driveways 2                0.75      0.00      0.00      0.00      0.00
Driveways 3                0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 1          0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 2          0.00      0.00      0.00      0.00      0.00
Street Area 1              9.66      0.00      0.00      0.00      0.00
Street Area 2              0.00      0.00      0.00      0.00      0.00
Street Area 3              0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 1    28.73     0.00      0.00      0.00      0.00
Large Landscaped Area 2    22.96     0.00      0.00      0.00      0.00
Undeveloped Area           3.18      0.00      0.00      0.00      0.00
Small Landscaped Area 1    0.00      0.00      0.00      0.00      0.00
Small Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Small Landscaped Area 3    0.00      0.00      0.00      0.00      0.00
Isolated Area              0.00      0.00      0.00      0.00      0.00
Other Pervious Area        7.43      0.00      0.00      0.00      0.00
Other Dir Cnctd Imp Area   0.00      0.00      0.00      0.00      0.00
Other Part Cnctd Imp Area  0.00      0.00      0.00      0.00      0.00
                        --------  --------  --------  --------  --------
Total                   100.00    0.00      0.00      0.00      0.00

Total of All Source Areas              100.00
                                       ---------
Total of All Source Areas
     less All Isolated Areas           100.00
                                       =========
                   Source Area Control Practice Information
Land Use:  Residential
   Roofs 1    Source area number:  1
         The roof is pitched
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Sandy
   Roofs 2    Source area number:  2
         The roof is pitched
         The Source Area is directly connected or draining to a directly conntected area
   Paved Parking/Storage 1    Source area number:  6
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Sandy
```

```
   Playground 1    Source area number:  11
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Sandy
   Driveways 1    Source area number:  13
         The Source Area is directly connected or draining to a directly conntected area
   Driveways 2    Source area number:  14
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Sandy
   Street Area 1    Source area number:  18
            1.  Street Texture:  intermediate
            2.  Total study area street length (curb-miles):  3.48
            3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
            4.  Street Dirt Accumulation:
                  Default value used
   Large Landscaped Area 1    Source area number:  21
         The SCS Hydrologic Soil Type is Sandy
   Large Landscaped Area 2    Source area number:  22
         The SCS Hydrologic Soil Type is Sandy
   Undeveloped Area    Source area number:  23
         The SCS Hydrologic Soil Type is Sandy
   Other Pervious Area    Source area number:  28
         The SCS Hydrologic Soil Type is Sandy
      Control Practice 1 :  Catchbasin Cleaning Controls
       1.  Total sump volume (cubic feet)=  1
       2.  Area served by catchbasins (acres)=  100
       3.  Percent of sump volume full at beginning of study period=  60 %
       4.  Average sump depth (feet)=  0
       5.  Number of times catchbasins cleaned each year=  0
Pollutants to be Analyzed and Printed:
         Pollutant Name                Pollutant Type
         --------------                --------------
          Solids                       Particulate
```

Commercial Areas

Strip Development (STRCB.DAT and STRSB.DAT)

```
    Data file name:  C:\Program Files\WinSLAMM\STRCB.DAT          SLAMM Version V8.1
    Rain file name:  C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN       Particulate Solids Concentration file name:  C:\PROGRAM
FILES\WINSLAMM\BHAM.PSC
    Runoff Coefficient file name:  C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
                                                                  Particulate Residue Delivery file name:  C:\PROGRAM
FILES\WINSLAMM\DELIVERY.PRR
    Pollutant Relative Concentration file name:  C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
                                                                  Seed for random number generator:   42
    Study period starting date:  01/01/53                         Study period ending date:  12/31/89
    Date:  07-23-2000                                             Time:  19:32:30
    Fraction of each type of Drainage System serving study area:
      1.  Grass Swales 0
      2.  Undeveloped roadside 0
          Curb and Gutters, `valleys', or sealed swales in:
           3.  Poor condition (or very flat) 0
           4.  Fair condition 1
           5.  Good condition (or very steep) 0
    Site information:  STRIP COMMERCIAL, CURBS AND GUTTERS, CLAYEY SOILS, BASELINE CONTROLS (NONE)

                           |<===== Areas for each Source (acres) =====>|
                           Resi-   Institu- Commercial Industrial  Open
                          dential   tional     Areas      Areas   Spaces
Source Area                Areas    Areas                          Areas         Freeway Source Area                    Area
(acres)

1234567890123456789012345678901234567890123456789012345678901234567890123456789 0
Roofs 1                    0.00      0.00      20.60     0.00      0.00          Pavd Lane & Shldr Area 1
0.00
Roofs 2                    0.00      0.00      2.80      0.00      0.00          Pavd Lane & Shldr Area 2
0.00
Roofs 3                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 3
0.00
Roofs 4                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 4
0.00
Roofs 5                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 5
0.00
Paved Parking/Storage 1    0.00      0.00      40.90     0.00      0.00          Large Turf Areas
0.00
```

```
Paved Parking/Storage 2    0.00      0.00      0.00      0.00      0.00         Undeveloped Areas
0.00
Paved Parking/Storage 3    0.00      0.00      0.00      0.00      0.00         Other Pervious Areas
0.00
Unpaved Prkng/Storage 1    0.00      0.00      1.50      0.00      0.00         Other Directly Conctd Imp
0.00
Unpaved Prkng/Storage 2    0.00      0.00      0.00      0.00      0.00         Other Partially Conctd Imp
0.00
Playground 1               0.00      0.00      0.00      0.00      0.00                                               -
-------
Playground 2               0.00      0.00      0.00      0.00      0.00         Total
0.00
Driveways 1                0.00      0.00      1.90      0.00      0.00
Driveways 2                0.00      0.00      0.00      0.00      0.00
Driveways 3                0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 1          0.00      0.00      4.30      0.00      0.00
Sidewalks/Walks 2          0.00      0.00      0.00      0.00      0.00
Street Area 1              0.00      0.00      8.90      0.00      0.00
Street Area 2              0.00      0.00      11.20     0.00      0.00
Street Area 3              0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 1    0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Undeveloped Area           0.00      0.00      0.20      0.00      0.00
Small Landscaped Area 1    0.00      0.00      5.80      0.00      0.00
Small Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Small Landscaped Area 3    0.00      0.00      0.00      0.00      0.00
Isolated Area              0.00      0.00      0.00      0.00      0.00
Other Pervious Area        0.00      0.00      1.90      0.00      0.00
Other Dir Cnctd Imp Area   0.00      0.00      0.00      0.00      0.00
Other Part Cnctd Imp Area  0.00      0.00      0.00      0.00      0.00
                        --------  --------  --------  --------  --------
Total                   0.00      0.00      100.00    0.00      0.00


Total of All Source Areas              100.00
                                       ---------
Total of All Source Areas
     less All Isolated Areas           100.00
                                       =========

                   Source Area Control Practice Information
Land Use:  Commercial
   Roofs 1    Source area number:  61
         The roof is flat
```

```
        The Source Area is directly connected or draining to a directly conntected area
  Roofs 2    Source area number:  62
        The roof is pitched
        The Source Area is directly connected or draining to a directly conntected area
  Paved Parking/Storage 1    Source area number:  66
        The Source Area is directly connected or draining to a directly conntected area
  Unpaved Prkng/Storage 1    Source area number:  69
        The Source Area is draining to a pervious area (partially connected impervious area)
        The SCS Hydrologic Soil Type is Clayey
  Driveways 1    Source area number:  73
        The Source Area is directly connected or draining to a directly conntected area
  Sidewalks/Walks 1    Source area number:  76
        The Source Area is directly connected or draining to a directly conntected area
  Street Area 1    Source area number:  78
           1.  Street Texture:  intermediate
           2.  Total study area street length (curb-miles):  3.5
           3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
           4.  Street Dirt Accumulation:
                 Default value used
  Street Area 2    Source area number:  79
           1.  Street Texture:  smooth
           2.  Total study area street length (curb-miles):  4.3
           3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
           4.  Street Dirt Accumulation:
                 Default value used
  Undeveloped Area    Source area number:  83
        The SCS Hydrologic Soil Type is Clayey
  Small Landscaped Area 1    Source area number:  84
        The SCS Hydrologic Soil Type is Clayey
  Other Pervious Area    Source area number:  88
        The SCS Hydrologic Soil Type is Clayey


     Control Practice 1 :  Catchbasin Cleaning Controls
      1.  Total sump volume (cubic feet)=  1
      2.  Area served by catchbasins (acres)=  100
      3.  Percent of sump volume full at beginning of study period=  60 %
      4.  Average sump depth (feet)=  0
      5.  Number of times catchbasins cleaned each year=  0



Pollutants to be Analyzed and Printed:
```

Pollutant Name	Pollutant Type
Solids	Particulate

```
    Data file name:  C:\Program Files\WinSLAMM\STRSB.DAT          SLAMM Version V8.1
    Rain file name:  C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN       Particulate Solids Concentration file name:  C:\PROGRAM
FILES\WINSLAMM\BHAM.PSC
    Runoff Coefficient file name:  C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
                                                                  Particulate Residue Delivery file name:  C:\PROGRAM
FILES\WINSLAMM\DELIVERY.PRR
    Pollutant Relative Concentration file name:  C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
                                                                  Seed for random number generator:   42
    Study period starting date:  01/01/53                         Study period ending date:  12/31/89
    Date:  07-23-2000                                             Time:  19:32:44
    Fraction of each type of Drainage System serving study area:
      1.  Grass Swales 0
      2.  Undeveloped roadside 0
          Curb and Gutters, `valleys', or sealed swales in:
           3.  Poor condition (or very flat) 0
           4.  Fair condition 1
           5.  Good condition (or very steep) 0
    Site information:  STRIP COMMERCIAL, CURB AND GUTTERS, SANDY SOILS, BASELINE CONTROLS (NONE)

                           |<===== Areas for each Source (acres) =====>|
                           Resi-   Institu- Commercial Industrial  Open
                          dential   tional     Areas      Areas   Spaces
Source Area                Areas    Areas                          Areas         Freeway Source Area                   Area
(acres)
12345678901234567890123456789012345678901234567890123456789012345678901234567890
Roofs 1                    0.00      0.00      20.60     0.00      0.00          Pavd Lane & Shldr Area 1
0.00
Roofs 2                    0.00      0.00      2.80      0.00      0.00          Pavd Lane & Shldr Area 2
0.00
Roofs 3                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 3
0.00
Roofs 4                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 4
0.00
Roofs 5                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 5
0.00
Paved Parking/Storage 1    0.00      0.00      40.90     0.00      0.00          Large Turf Areas
0.00
Paved Parking/Storage 2    0.00      0.00      0.00      0.00      0.00          Undeveloped Areas
0.00
Paved Parking/Storage 3    0.00      0.00      0.00      0.00      0.00          Other Pervious Areas
0.00
Unpaved Prkng/Storage 1    0.00      0.00      1.50      0.00      0.00          Other Directly Conctd Imp
0.00
```

Unpaved Prkng/Storage 2	0.00	0.00	0.00	0.00	0.00	Other Partially Conctd Imp
0.00						
Playground 1	0.00	0.00	0.00	0.00	0.00	-

Playground 2	0.00	0.00	0.00	0.00	0.00	Total
0.00						
Driveways 1	0.00	0.00	1.90	0.00	0.00	
Driveways 2	0.00	0.00	0.00	0.00	0.00	
Driveways 3	0.00	0.00	0.00	0.00	0.00	
Sidewalks/Walks 1	0.00	0.00	4.30	0.00	0.00	
Sidewalks/Walks 2	0.00	0.00	0.00	0.00	0.00	
Street Area 1	0.00	0.00	8.90	0.00	0.00	
Street Area 2	0.00	0.00	11.20	0.00	0.00	
Street Area 3	0.00	0.00	0.00	0.00	0.00	
Large Landscaped Area 1	0.00	0.00	0.00	0.00	0.00	
Large Landscaped Area 2	0.00	0.00	0.00	0.00	0.00	
Undeveloped Area	0.00	0.00	0.20	0.00	0.00	
Small Landscaped Area 1	0.00	0.00	5.80	0.00	0.00	
Small Landscaped Area 2	0.00	0.00	0.00	0.00	0.00	
Small Landscaped Area 3	0.00	0.00	0.00	0.00	0.00	
Isolated Area	0.00	0.00	0.00	0.00	0.00	
Other Pervious Area	0.00	0.00	1.90	0.00	0.00	
Other Dir Cnctd Imp Area	0.00	0.00	0.00	0.00	0.00	
Other Part Cnctd Imp Area	0.00	0.00	0.00	0.00	0.00	
	--------	--------	--------	--------	--------	
Total	0.00	0.00	100.00	0.00	0.00	

Total of All Source Areas 100.00

Total of All Source Areas
less All Isolated Areas 100.00
=========

Source Area Control Practice Information

Land Use: Commercial

Roofs 1 Source area number: 61
The roof is flat
The Source Area is directly connected or draining to a directly conntected area

Roofs 2 Source area number: 62
The roof is pitched
The Source Area is directly connected or draining to a directly conntected area

Paved Parking/Storage 1 Source area number: 66
The Source Area is directly connected or draining to a directly conntected area

Unpaved Prkng/Storage 1 Source area number: 69
The Source Area is draining to a pervious area (partially connected impervious area)

```
         The SCS Hydrologic Soil Type is Sandy
   Driveways 1    Source area number:  73
         The Source Area is directly connected or draining to a directly conntected area
   Sidewalks/Walks 1    Source area number:  76
         The Source Area is directly connected or draining to a directly conntected area
   Street Area 1    Source area number:  78
            1.  Street Texture:  intermediate
            2.  Total study area street length (curb-miles):  3.5
            3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
            4.  Street Dirt Accumulation:
                  Default value used
   Street Area 2    Source area number:  79
            1.  Street Texture:  smooth
            2.  Total study area street length (curb-miles):  4.3
            3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
            4.  Street Dirt Accumulation:
                  Default value used
   Undeveloped Area    Source area number:  83
         The SCS Hydrologic Soil Type is Sandy
   Small Landscaped Area 1    Source area number:  84
         The SCS Hydrologic Soil Type is Sandy
   Other Pervious Area    Source area number:  88
         The SCS Hydrologic Soil Type is Sandy
      Control Practice 1 :  Catchbasin Cleaning Controls
       1.  Total sump volume (cubic feet)=  1
       2.  Area served by catchbasins (acres)=  100
       3.  Percent of sump volume full at beginning of study period=  60 %
       4.  Average sump depth (feet)=  0
       5.  Number of times catchbasins cleaned each year=  0
Pollutants to be Analyzed and Printed:
         Pollutant Name                Pollutant Type
         --------------                --------------
          Solids                       Particulate
```

Shopping Centers (SHPCB.DAT and SHPSB.DAT)

```
Data file name:  C:\Program Files\WinSLAMM\SHPCB.DAT          SLAMM Version V8.1
    Rain file name:  C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN       Particulate Solids Concentration file name:  C:\PROGRAM
FILES\WINSLAMM\BHAM.PSC
    Runoff Coefficient file name:  C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
                                                                  Particulate Residue Delivery file name:  C:\PROGRAM
FILES\WINSLAMM\DELIVERY.PRR
    Pollutant Relative Concentration file name:  C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
                                                                  Seed for random number generator:   42
    Study period starting date:  01/01/53                         Study period ending date:  12/31/89
    Date:  07-23-2000                                             Time:  19:31:47
    Fraction of each type of Drainage System serving study area:
      1.  Grass Swales 0
      2.  Undeveloped roadside 0
          Curb and Gutters, `valleys', or sealed swales in:
           3.  Poor condition (or very flat) 0
           4.  Fair condition 1
           5.  Good condition (or very steep) 0
    Site information:  SHOPPING CENTER, CURBS AND GUTTERS, CLAYEY SOILS, BASELINE CONTROLS (NONE)
                            |<===== Areas for each Source (acres) =====>|
                           Resi-   Institu- Commercial Industrial  Open
                          dential   tional     Areas      Areas   Spaces
Source Area                Areas    Areas                          Areas         Freeway Source Area                   Area
(acres)
12345678901234567890123456789012345678901234567890123456789012345678901234567890
Roofs 1                    0.00      0.00      21.00     0.00      0.00          Pavd Lane & Shldr Area 1
0.00
Roofs 2                    0.00      0.00      0.75      0.00      0.00          Pavd Lane & Shldr Area 2
0.00
Roofs 3                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 3
0.00
Roofs 4                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 4
0.00
Roofs 5                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 5
0.00
Paved Parking/Storage 1    0.00      0.00      29.62     0.00      0.00          Large Turf Areas
0.00
Paved Parking/Storage 2    0.00      0.00      0.00      0.00      0.00          Undeveloped Areas
0.00
Paved Parking/Storage 3    0.00      0.00      0.00      0.00      0.00          Other Pervious Areas
0.00
Unpaved Prkng/Storage 1    0.00      0.00      0.00      0.00      0.00          Other Directly Conctd Imp
0.00
```

```
Unpaved Prkng/Storage 2    0.00      0.00      0.00      0.00      0.00          Other Partially Conctd Imp
0.00
Playground 1               0.00      0.00      0.00      0.00      0.00                                                         -
-------
Playground 2               0.00      0.00      0.00      0.00      0.00          Total
0.00
Driveways 1                0.00      0.00      0.37      0.00      0.00
Driveways 2                0.00      0.00      0.37      0.00      0.00
Driveways 3                0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 1          0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 2          0.00      0.00      0.00      0.00      0.00
Street Area 1              0.00      0.00      1.76      0.00      0.00
Street Area 2              0.00      0.00      14.28     0.00      0.00
Street Area 3              0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 1    0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Undeveloped Area           0.00      0.00      0.00      0.00      0.00
Small Landscaped Area 1    0.00      0.00      31.85     0.00      0.00
Small Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Small Landscaped Area 3    0.00      0.00      0.00      0.00      0.00
Isolated Area              0.00      0.00      0.00      0.00      0.00
Other Pervious Area        0.00      0.00      0.00      0.00      0.00
Other Dir Cnctd Imp Area   0.00      0.00      0.00      0.00      0.00
Other Part Cnctd Imp Area  0.00      0.00      0.00      0.00      0.00
                        --------  --------  --------  --------  --------
Total                   0.00      0.00      100.00    0.00      0.00
Total of All Source Areas             100.00
Total of All Source Areas
     less All Isolated Areas          100.00
                                      =========
                   Source Area Control Practice Information
Land Use:  Commercial
   Roofs 1    Source area number:  61
         The roof is flat
         The Source Area is directly connected or draining to a directly conntected area
   Roofs 2    Source area number:  62
         The roof is flat
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Clayey
   Paved Parking/Storage 1    Source area number:  66
         The Source Area is directly connected or draining to a directly conntected area
   Driveways 1    Source area number:  73
         The Source Area is directly connected or draining to a directly conntected area
   Driveways 2    Source area number:  74
```

```
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Clayey
   Street Area 1    Source area number:  78
            1.  Street Texture:  intermediate
            2.  Total study area street length (curb-miles):  0.7
            3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
            4.  Street Dirt Accumulation:
                  Default value used
   Street Area 2    Source area number:  79
            1.  Street Texture:  intermediate
            2.  Total study area street length (curb-miles):  5.5
            3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
            4.  Street Dirt Accumulation:
                  Default value used
   Small Landscaped Area 1    Source area number:  84
         The SCS Hydrologic Soil Type is Clayey
      Control Practice 1 :  Catchbasin Cleaning Controls
       1.  Total sump volume (cubic feet)=  1
       2.  Area served by catchbasins (acres)=  100
       3.  Percent of sump volume full at beginning of study period=  60 %
       4.  Average sump depth (feet)=  0
       5.  Number of times catchbasins cleaned each year=  0

Pollutants to be Analyzed and Printed:
         Pollutant Name               Pollutant Type
         --------------               --------------
          Solids                      Particulate
```

```
    Data file name:  C:\Program Files\WinSLAMM\SHPSB.DAT          SLAMM Version V8.1
    Rain file name:  C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN       Particulate Solids Concentration file name:  C:\PROGRAM
FILES\WINSLAMM\BHAM.PSC
    Runoff Coefficient file name:  C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
                                                                  Particulate Residue Delivery file name:  C:\PROGRAM
FILES\WINSLAMM\DELIVERY.PRR
    Pollutant Relative Concentration file name:  C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
                                                                  Seed for random number generator:   42
    Study period starting date:  01/01/53                         Study period ending date:  12/31/89
    Date:  07-23-2000                                             Time:  19:32:12
    Fraction of each type of Drainage System serving study area:
      1.  Grass Swales 0
      2.  Undeveloped roadside 0
          Curb and Gutters, `valleys', or sealed swales in:
           3.  Poor condition (or very flat) 0
           4.  Fair condition 1
           5.  Good condition (or very steep) 0
    Site information:  SHOPPING CENTER, CURB AND GUTTERS, SANDY SOILS, BASELINE CONTROLS (NONE)
                           |<===== Areas for each Source (acres) =====>|
                           Resi-   Institu- Commercial Industrial  Open
                          dential   tional     Areas      Areas   Spaces
Source Area                Areas    Areas                          Areas         Freeway Source Area                   Area
(acres)
12345678901234567890123456789012345678901234567890123456789012345678901234567890
Roofs 1                    0.00      0.00      21.00     0.00      0.00          Pavd Lane & Shldr Area 1
0.00
Roofs 2                    0.00      0.00      0.75      0.00      0.00          Pavd Lane & Shldr Area 2
0.00
Roofs 3                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 3
0.00
Roofs 4                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 4
0.00
Roofs 5                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 5
0.00
Paved Parking/Storage 1    0.00      0.00      29.62     0.00      0.00          Large Turf Areas
0.00
Paved Parking/Storage 2    0.00      0.00      0.00      0.00      0.00          Undeveloped Areas
0.00
Paved Parking/Storage 3    0.00      0.00      0.00      0.00      0.00          Other Pervious Areas
0.00
Unpaved Prkng/Storage 1    0.00      0.00      0.00      0.00      0.00          Other Directly Conctd Imp
0.00
Unpaved Prkng/Storage 2    0.00      0.00      0.00      0.00      0.00          Other Partially Conctd Imp
0.00
```

Playground 1	0.00	0.00	0.00	0.00	0.00	-

Playground 2	0.00	0.00	0.00	0.00	0.00	Total
0.00						
Driveways 1	0.00	0.00	0.37	0.00	0.00	
Driveways 2	0.00	0.00	0.37	0.00	0.00	
Driveways 3	0.00	0.00	0.00	0.00	0.00	
Sidewalks/Walks 1	0.00	0.00	0.00	0.00	0.00	
Sidewalks/Walks 2	0.00	0.00	0.00	0.00	0.00	
Street Area 1	0.00	0.00	1.76	0.00	0.00	
Street Area 2	0.00	0.00	14.28	0.00	0.00	
Street Area 3	0.00	0.00	0.00	0.00	0.00	
Large Landscaped Area 1	0.00	0.00	0.00	0.00	0.00	
Large Landscaped Area 2	0.00	0.00	0.00	0.00	0.00	
Undeveloped Area	0.00	0.00	0.00	0.00	0.00	
Small Landscaped Area 1	0.00	0.00	31.85	0.00	0.00	
Small Landscaped Area 2	0.00	0.00	0.00	0.00	0.00	
Small Landscaped Area 3	0.00	0.00	0.00	0.00	0.00	
Isolated Area	0.00	0.00	0.00	0.00	0.00	
Other Pervious Area	0.00	0.00	0.00	0.00	0.00	
Other Dir Cnctd Imp Area	0.00	0.00	0.00	0.00	0.00	
Other Part Cnctd Imp Area	0.00	0.00	0.00	0.00	0.00	
	--------	--------	--------	--------	--------	
Total	0.00	0.00	100.00	0.00	0.00	

Total of All Source Areas 100.00

Total of All Source Areas
less All Isolated Areas 100.00
=========

Source Area Control Practice Information

Land Use: Commercial

Roofs 1 Source area number: 61
The roof is flat
The Source Area is directly connected or draining to a directly conntected area

Roofs 2 Source area number: 62
The roof is flat
The Source Area is draining to a pervious area (partially connected impervious area)
The SCS Hydrologic Soil Type is Sandy

Paved Parking/Storage 1 Source area number: 66
The Source Area is directly connected or draining to a directly conntected area

Driveways 1 Source area number: 73
The Source Area is directly connected or draining to a directly conntected area

Driveways 2 Source area number: 74

```
        The Source Area is draining to a pervious area (partially connected impervious area)
        The SCS Hydrologic Soil Type is Sandy
  Street Area 1    Source area number:  78
           1.  Street Texture:  intermediate
           2.  Total study area street length (curb-miles):  0.7
           3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
           4.  Street Dirt Accumulation:
                 Default value used
  Street Area 2    Source area number:  79
           1.  Street Texture:  intermediate
           2.  Total study area street length (curb-miles):  5.5
           3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
           4.  Street Dirt Accumulation:
                 Default value used
  Small Landscaped Area 1    Source area number:  84
        The SCS Hydrologic Soil Type is Sandy

     Control Practice 1 :  Catchbasin Cleaning Controls
      1.  Total sump volume (cubic feet)=  1
      2.  Area served by catchbasins (acres)=  100
      3.  Percent of sump volume full at beginning of study period=  60 %
      4.  Average sump depth (feet)=  0
      5.  Number of times catchbasins cleaned each year=  0

Pollutants to be Analyzed and Printed:
        Pollutant Name                Pollutant Type
        --------------                --------------
         Solids                       Particulate
```

Office Parks (OFFCB.DAT and OFFSB.DAT)

```
Data file name:  C:\Program Files\WinSLAMM\OFFCB.DAT          SLAMM Version V8.1
    Rain file name:  C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN       Particulate Solids Concentration file name:  C:\PROGRAM
FILES\WINSLAMM\BHAM.PSC
    Runoff Coefficient file name:  C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
                                                                  Particulate Residue Delivery file name:  C:\PROGRAM
FILES\WINSLAMM\DELIVERY.PRR
    Pollutant Relative Concentration file name:  C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
                                                                  Seed for random number generator:   42
    Study period starting date:  01/01/53                         Study period ending date:  12/31/89
    Date:  07-23-2000                                             Time:  19:30:50
    Fraction of each type of Drainage System serving study area:
      1.  Grass Swales 0
      2.  Undeveloped roadside 0
          Curb and Gutters, `valleys', or sealed swales in:
           3.  Poor condition (or very flat) 0
           4.  Fair condition 1
           5.  Good condition (or very steep) 0
    Site information:  OFFICE PARK, CURBS AND GUTTERS, CLAYEY SOILS, BASELINE CONTROLS (NONE)

                           |<===== Areas for each Source (acres) =====>|
                           Resi-   Institu- Commercial Industrial  Open
                          dential   tional     Areas      Areas   Spaces
Source Area                Areas    Areas                          Areas         Freeway Source Area                   Area
(acres)

12345678901234567890123456789012345678901234567890123456789012345678901234567890
Roofs 1                    0.00      0.00      17.58     0.00      0.00          Pavd Lane & Shldr Area 1
0.00
Roofs 2                    0.00      0.00      0.32      0.00      0.00          Pavd Lane & Shldr Area 2
0.00
Roofs 3                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 3
0.00
Roofs 4                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 4
0.00
Roofs 5                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 5
0.00
Paved Parking/Storage 1    0.00      0.00      27.06     0.00      0.00          Large Turf Areas
0.00
Paved Parking/Storage 2    0.00      0.00      0.00      0.00      0.00          Undeveloped Areas
0.00
```

Paved Parking/Storage 3	0.00	0.00	0.00	0.00	0.00	Other Pervious Areas 0.00
Unpaved Prkng/Storage 1	0.00	0.00	0.00	0.00	0.00	Other Directly Conctd Imp 0.00
Unpaved Prkng/Storage 2	0.00	0.00	0.00	0.00	0.00	Other Partially Conctd Imp 0.00
Playground 1	0.00	0.00	0.00	0.00	0.00	--------
Playground 2	0.00	0.00	0.00	0.00	0.00	Total 0.00
Driveways 1	0.00	0.00	0.82	0.00	0.00	
Driveways 2	0.00	0.00	0.82	0.00	0.00	
Driveways 3	0.00	0.00	0.00	0.00	0.00	
Sidewalks/Walks 1	0.00	0.00	0.00	0.00	0.00	
Sidewalks/Walks 2	0.00	0.00	0.00	0.00	0.00	
Street Area 1	0.00	0.00	8.54	0.00	0.00	
Street Area 2	0.00	0.00	6.19	0.00	0.00	
Street Area 3	0.00	0.00	0.00	0.00	0.00	
Large Landscaped Area 1	0.00	0.00	0.00	0.00	0.00	
Large Landscaped Area 2	0.00	0.00	0.00	0.00	0.00	
Undeveloped Area	0.00	0.00	0.00	0.00	0.00	
Small Landscaped Area 1	0.00	0.00	23.93	0.00	0.00	
Small Landscaped Area 2	0.00	0.00	14.74	0.00	0.00	
Small Landscaped Area 3	0.00	0.00	0.00	0.00	0.00	
Isolated Area	0.00	0.00	0.00	0.00	0.00	
Other Pervious Area	0.00	0.00	0.00	0.00	0.00	
Other Dir Cnctd Imp Area	0.00	0.00	0.00	0.00	0.00	
Other Part Cnctd Imp Area	0.00	0.00	0.00	0.00	0.00	
	--------	--------	--------	--------	--------	
Total	0.00	0.00	100.00	0.00	0.00	

Total of All Source Areas 100.00

Total of All Source Areas
less All Isolated Areas 100.00

=========

Source Area Control Practice Information

Land Use: Commercial

Roofs 1 Source area number: 61

The roof is flat

The Source Area is directly connected or draining to a directly conntected area

Roofs 2 Source area number: 62

The roof is pitched

The Source Area is draining to a pervious area (partially connected impervious area)

The SCS Hydrologic Soil Type is Clayey

```
   Paved Parking/Storage 1    Source area number:  66
         The Source Area is directly connected or draining to a directly conntected area
   Driveways 1    Source area number:  73
         The Source Area is directly connected or draining to a directly conntected area
   Driveways 2    Source area number:  74
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Clayey
   Street Area 1    Source area number:  78
            1.  Street Texture:  intermediate
            2.  Total study area street length (curb-miles):  3.29
            3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
            4.  Street Dirt Accumulation:
                  Default value used
   Street Area 2    Source area number:  79
            1.  Street Texture:  intermediate
            2.  Total study area street length (curb-miles):  2.38
            3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
            4.  Street Dirt Accumulation:
                  Default value used
   Small Landscaped Area 1    Source area number:  84
         The SCS Hydrologic Soil Type is Clayey
   Small Landscaped Area 2    Source area number:  85
         The SCS Hydrologic Soil Type is Clayey
      Control Practice 1 :  Catchbasin Cleaning Controls
       1.  Total sump volume (cubic feet)=  1
       2.  Area served by catchbasins (acres)=  100
       3.  Percent of sump volume full at beginning of study period=  60 %
       4.  Average sump depth (feet)=  0
       5.  Number of times catchbasins cleaned each year=  0
Pollutants to be Analyzed and Printed:
         Pollutant Name               Pollutant Type
         --------------               --------------
          Solids                      Particulate
```

```
    Data file name:  C:\Program Files\WinSLAMM\OFFSB.DAT          SLAMM Version V8.1
    Rain file name:  C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN       Particulate Solids Concentration file name:  C:\PROGRAM
FILES\WINSLAMM\BHAM.PSC
    Runoff Coefficient file name:  C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
                                                                  Particulate Residue Delivery file name:  C:\PROGRAM
FILES\WINSLAMM\DELIVERY.PRR
    Pollutant Relative Concentration file name:  C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
                                                                  Seed for random number generator:   42
    Study period starting date:  01/01/53                         Study period ending date:  12/31/89
    Date:  07-23-2000                                             Time:  19:31:03
    Fraction of each type of Drainage System serving study area:
      1.  Grass Swales 0
      2.  Undeveloped roadside 0
          Curb and Gutters, `valleys', or sealed swales in:
           3.  Poor condition (or very flat) 0
           4.  Fair condition 1
           5.  Good condition (or very steep) 0
    Site information:  OFFICE PARK, CURB AND GUTTERS, SANDY SOILS, BASELINE CONTROLS (NONE)
                           |<===== Areas for each Source (acres) =====>|
                           Resi-   Institu- Commercial Industrial  Open
                          dential   tional     Areas      Areas   Spaces
Source Area                Areas    Areas                          Areas         Freeway Source Area                   Area
(acres)
12345678901234567890123456789012345678901234567890123456789012345678901234567890
Roofs 1                    0.00      0.00      17.58     0.00      0.00          Pavd Lane & Shldr Area 1
0.00
Roofs 2                    0.00      0.00      0.32      0.00      0.00          Pavd Lane & Shldr Area 2
0.00
Roofs 3                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 3
0.00
Roofs 4                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 4
0.00
Roofs 5                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 5
0.00
Paved Parking/Storage 1    0.00      0.00      27.06     0.00      0.00          Large Turf Areas
0.00
Paved Parking/Storage 2    0.00      0.00      0.00      0.00      0.00          Undeveloped Areas
0.00
Paved Parking/Storage 3    0.00      0.00      0.00      0.00      0.00          Other Pervious Areas
0.00
Unpaved Prkng/Storage 1    0.00      0.00      0.00      0.00      0.00          Other Directly Conctd Imp
0.00
Unpaved Prkng/Storage 2    0.00      0.00      0.00      0.00      0.00          Other Partially Conctd Imp
0.00
```

Playground 1	0.00	0.00	0.00	0.00	0.00	-

Playground 2	0.00	0.00	0.00	0.00	0.00	Total
0.00						
Driveways 1	0.00	0.00	0.82	0.00	0.00	
Driveways 2	0.00	0.00	0.82	0.00	0.00	
Driveways 3	0.00	0.00	0.00	0.00	0.00	
Sidewalks/Walks 1	0.00	0.00	0.00	0.00	0.00	
Sidewalks/Walks 2	0.00	0.00	0.00	0.00	0.00	
Street Area 1	0.00	0.00	8.54	0.00	0.00	
Street Area 2	0.00	0.00	6.19	0.00	0.00	
Street Area 3	0.00	0.00	0.00	0.00	0.00	
Large Landscaped Area 1	0.00	0.00	0.00	0.00	0.00	
Large Landscaped Area 2	0.00	0.00	0.00	0.00	0.00	
Undeveloped Area	0.00	0.00	0.00	0.00	0.00	
Small Landscaped Area 1	0.00	0.00	23.93	0.00	0.00	
Small Landscaped Area 2	0.00	0.00	14.74	0.00	0.00	
Small Landscaped Area 3	0.00	0.00	0.00	0.00	0.00	
Isolated Area	0.00	0.00	0.00	0.00	0.00	
Other Pervious Area	0.00	0.00	0.00	0.00	0.00	
Other Dir Cnctd Imp Area	0.00	0.00	0.00	0.00	0.00	
Other Part Cnctd Imp Area	0.00	0.00	0.00	0.00	0.00	
	--------	--------	--------	--------	--------	
Total	0.00	0.00	100.00	0.00	0.00	

Total of All Source Areas 100.00

Total of All Source Areas
less All Isolated Areas 100.00

=========

Source Area Control Practice Information

Land Use: Commercial

Roofs 1 Source area number: 61
The roof is flat
The Source Area is directly connected or draining to a directly conntected area

Roofs 2 Source area number: 62
The roof is flat
The Source Area is draining to a pervious area (partially connected impervious area)
The SCS Hydrologic Soil Type is Sandy

Paved Parking/Storage 1 Source area number: 66
The Source Area is directly connected or draining to a directly conntected area

Driveways 1 Source area number: 73
The Source Area is directly connected or draining to a directly conntected area

Driveways 2 Source area number: 74

```
        The Source Area is draining to a pervious area (partially connected impervious area)
        The SCS Hydrologic Soil Type is Sandy
   Street Area 1    Source area number:  78
           1.  Street Texture:  intermediate
           2.  Total study area street length (curb-miles):  3.29
           3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
           4.  Street Dirt Accumulation:
                 Default value used
   Street Area 2    Source area number:  79
           1.  Street Texture:  intermediate
           2.  Total study area street length (curb-miles):  2.38
           3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
           4.  Street Dirt Accumulation:
                 Default value used
   Small Landscaped Area 1    Source area number:  84
        The SCS Hydrologic Soil Type is Sandy
   Small Landscaped Area 2    Source area number:  85
        The SCS Hydrologic Soil Type is Clayey
     Control Practice 1 :  Catchbasin Cleaning Controls
      1.  Total sump volume (cubic feet)=  1
      2.  Area served by catchbasins (acres)=  100
      3.  Percent of sump volume full at beginning of study period=  60 %
      4.  Average sump depth (feet)=  0
      5.  Number of times catchbasins cleaned each year=  0
Pollutants to be Analyzed and Printed:
        Pollutant Name               Pollutant Type
           Solids                      Particulate
```

Institutional Areas

Schools (SCHCB.DAT and SCHSB.DAT)

```
  Data file name:  C:\Program Files\WinSLAMM\SCHCB.DAT          SLAMM Version V8.1
    Rain file name:  C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN       Particulate Solids Concentration file name:  C:\PROGRAM
FILES\WINSLAMM\BHAM.PSC
    Runoff Coefficient file name:  C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
                                                                  Particulate Residue Delivery file name:  C:\PROGRAM
FILES\WINSLAMM\DELIVERY.PRR
    Pollutant Relative Concentration file name:  C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
                                                                  Seed for random number generator:   42
    Study period starting date:  01/01/53                         Study period ending date:  12/31/89
    Date:  07-23-2000                                             Time:  19:31:17
    Fraction of each type of Drainage System serving study area:
      1.  Grass Swales 0
      2.  Undeveloped roadside 0
          Curb and Gutters, `valleys', or sealed swales in:
           3.  Poor condition (or very flat) 0
           4.  Fair condition 1
           5.  Good condition (or very steep) 0
    Site information:  SCHOOLS, CURBS AND GUTTERS, CLAYEY SOILS, BASELINE CONTROLS (NONE)

                           |<===== Areas for each Source (acres) =====>|
                           Resi-   Institu- Commercial Industrial  Open
                          dential   tional     Areas      Areas   Spaces
Source Area                Areas    Areas                          Areas         Freeway Source Area                     Area
(acres)

1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
Roofs 1                    0.00      0.13      0.00      0.00      0.00          Pavd Lane & Shldr Area 1
0.00
Roofs 2                    0.00      4.37      0.00      0.00      0.00          Pavd Lane & Shldr Area 2
0.00
Roofs 3                    0.00      6.02      0.00      0.00      0.00          Pavd Lane & Shldr Area 3
0.00
Roofs 4                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 4
0.00
Roofs 5                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 5
0.00
Paved Parking/Storage 1    0.00      5.98      0.00      0.00      0.00          Large Turf Areas
0.00
Paved Parking/Storage 2    0.00      0.00      0.00      0.00      0.00          Undeveloped Areas
0.00
Paved Parking/Storage 3    0.00      0.00      0.00      0.00      0.00          Other Pervious Areas
0.00
```

Unpaved Prkng/Storage 1	0.00	0.00	0.00	0.00	0.00	Other Directly Conctd Imp
0.00						
Unpaved Prkng/Storage 2	0.00	0.00	0.00	0.00	0.00	Other Partially Conctd Imp
0.00						
Playground 1	0.00	15.11	0.00	0.00	0.00	-

Playground 2	0.00	0.00	0.00	0.00	0.00	Total
0.00						
Driveways 1	0.00	0.25	0.00	0.00	0.00	
Driveways 2	0.00	0.00	0.00	0.00	0.00	
Driveways 3	0.00	0.00	0.00	0.00	0.00	
Sidewalks/Walks 1	0.00	0.00	0.00	0.00	0.00	
Sidewalks/Walks 2	0.00	0.00	0.00	0.00	0.00	
Street Area 1	0.00	0.32	0.00	0.00	0.00	
Street Area 2	0.00	3.70	0.00	0.00	0.00	
Street Area 3	0.00	0.00	0.00	0.00	0.00	
Large Landscaped Area 1	0.00	40.83	0.00	0.00	0.00	
Large Landscaped Area 2	0.00	0.00	0.00	0.00	0.00	
Undeveloped Area	0.00	0.11	0.00	0.00	0.00	
Small Landscaped Area 1	0.00	23.18	0.00	0.00	0.00	
Small Landscaped Area 2	0.00	0.00	0.00	0.00	0.00	
Small Landscaped Area 3	0.00	0.00	0.00	0.00	0.00	
Isolated Area	0.00	0.00	0.00	0.00	0.00	
Other Pervious Area	0.00	0.00	0.00	0.00	0.00	
Other Dir Cnctd Imp Area	0.00	0.00	0.00	0.00	0.00	
Other Part Cnctd Imp Area	0.00	0.00	0.00	0.00	0.00	
	--------	--------	--------	--------	--------	
Total	0.00	100.00	0.00	0.00	0.00	

```
Total of All Source Areas               100.00
                                        ---------
Total of All Source Areas
     less All Isolated Areas            100.00
                                        =========
```

Source Area Control Practice Information

Land Use: Institutional

Roofs 1 Source area number: 31

The roof is pitched

The Source Area is draining to a pervious area (partially connected impervious area)

The SCS Hydrologic Soil Type is Clayey

The building density is low

Roofs 2 Source area number: 32

```
        The roof is flat
        The Source Area is draining to a pervious area (partially connected impervious area)
        The SCS Hydrologic Soil Type is Clayey
        The building density is low
  Roofs 3    Source area number:  33
        The roof is flat
        The Source Area is directly connected or draining to a directly conntected area
  Paved Parking/Storage 1    Source area number:  36
        The Source Area is directly connected or draining to a directly conntected area
  Playground 1    Source area number:  41
        The Source Area is draining to a pervious area (partially connected impervious area)
        The SCS Hydrologic Soil Type is Sandy
  Driveways 1    Source area number:  43
        The Source Area is directly connected or draining to a directly conntected area
  Street Area 1    Source area number:  48
           1.  Street Texture:  smooth
           2.  Total study area street length (curb-miles):  0.127
           3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
           4.  Street Dirt Accumulation:
                 Default value used
  Street Area 2    Source area number:  49
           1.  Street Texture:  intermediate
           2.  Total study area street length (curb-miles):  1.46
           3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
           4.  Street Dirt Accumulation:
                 Default value used
  Large Landscaped Area 1    Source area number:  51
        The SCS Hydrologic Soil Type is Clayey
  Undeveloped Area    Source area number:  53
        The SCS Hydrologic Soil Type is Clayey
  Small Landscaped Area 1    Source area number:  54
        The SCS Hydrologic Soil Type is Clayey


     Control Practice 1 :  Catchbasin Cleaning Controls
      1.  Total sump volume (cubic feet)=  1
      2.  Area served by catchbasins (acres)=  100
      3.  Percent of sump volume full at beginning of study period=  60 %
      4.  Average sump depth (feet)=  0
      5.  Number of times catchbasins cleaned each year=  0



Pollutants to be Analyzed and Printed:
```

Pollutant Name	Pollutant Type
Solids	Particulate

Data file name: C:\Program Files\WinSLAMM\SCHSB.DAT
SLAMM Version V8.1
Rain file name: C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN
Particulate Solids Concentration file name: C:\PROGRAM FILES\WINSLAMM\BHAM.PSC
Runoff Coefficient file name: C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
Particulate Residue Delivery file name: C:\PROGRAM FILES\WINSLAMM\DELIVERY.PRR
Pollutant Relative Concentration file name: C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
Seed for random number generator: 42
Study period starting date: 01/01/53
Study period ending date: 12/31/89
Date: 07-23-2000
Time: 19:31:32

Fraction of each type of Drainage System serving study area:

1. Grass Swales 0
2. Undeveloped roadside 0

Curb and Gutters, `valleys', or sealed swales in:

3. Poor condition (or very flat) 0
4. Fair condition 1
5. Good condition (or very steep) 0

Site information: SCHOOLS, CURB AND GUTTER, SANDY SOILS, BASELINE CONTROLS (NONE)

Source Area	Residential Areas	Institutional Areas	Commercial Areas	Industrial Areas	Open Spaces Areas	Freeway Source Area	Area (acres)
	|<===== Areas for each Source (acres)			=====>|			
1234567890123456789012345678901234567890123456789012345678901234567890							
Roofs 1	0.00	0.13	0.00	0.00	0.00	Pavd Lane & Shldr Area 1	0.00
Roofs 2	0.00	4.37	0.00	0.00	0.00	Pavd Lane & Shldr Area 2	0.00
Roofs 3	0.00	6.02	0.00	0.00	0.00	Pavd Lane & Shldr Area 3	0.00
Roofs 4	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 4	0.00
Roofs 5	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 5	0.00
Paved Parking/Storage 1	0.00	5.98	0.00	0.00	0.00	Large Turf Areas	0.00
Paved Parking/Storage 2	0.00	0.00	0.00	0.00	0.00	Undeveloped Areas	0.00
Paved Parking/Storage 3	0.00	0.00	0.00	0.00	0.00	Other Pervious Areas	0.00
Unpaved Prkng/Storage 1	0.00	0.00	0.00	0.00	0.00	Other Directly Conctd Imp	0.00

```
Unpaved Prkng/Storage 2    0.00      0.00      0.00      0.00      0.00          Other Partially Conctd Imp
0.00
Playground 1               0.00      15.11     0.00      0.00      0.00                                           -
-------
Playground 2               0.00      0.00      0.00      0.00      0.00          Total
0.00
Driveways 1                0.00      0.25      0.00      0.00      0.00
Driveways 2                0.00      0.00      0.00      0.00      0.00
Driveways 3                0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 1          0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 2          0.00      0.00      0.00      0.00      0.00
Street Area 1              0.00      0.32      0.00      0.00      0.00
Street Area 2              0.00      3.70      0.00      0.00      0.00
Street Area 3              0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 1    0.00      40.83     0.00      0.00      0.00
Large Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Undeveloped Area           0.00      0.11      0.00      0.00      0.00
Small Landscaped Area 1    0.00      23.18     0.00      0.00      0.00
Small Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Small Landscaped Area 3    0.00      0.00      0.00      0.00      0.00
Isolated Area              0.00      0.00      0.00      0.00      0.00
Other Pervious Area        0.00      0.00      0.00      0.00      0.00
Other Dir Cnctd Imp Area   0.00      0.00      0.00      0.00      0.00
Other Part Cnctd Imp Area  0.00      0.00      0.00      0.00      0.00
                        --------  --------  --------  --------  --------
Total                   0.00      100.00    0.00      0.00      0.00


Total of All Source Areas             100.00
                                      ---------
Total of All Source Areas
     less All Isolated Areas          100.00
                                      =========

                   Source Area Control Practice Information
Land Use:  Institutional
   Roofs 1    Source area number:  31
         The roof is pitched
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Sandy
   Roofs 2    Source area number:  32
         The roof is flat
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Sandy
```

```
Roofs 3    Source area number:  33
      The roof is flat
      The Source Area is directly connected or draining to a directly conntected area
Paved Parking/Storage 1    Source area number:  36
      The Source Area is directly connected or draining to a directly conntected area
Playground 1    Source area number:  41
      The Source Area is draining to a pervious area (partially connected impervious area)
      The SCS Hydrologic Soil Type is Sandy
Driveways 1    Source area number:  43
      The Source Area is directly connected or draining to a directly conntected area
Street Area 1    Source area number:  48
         1.  Street Texture:  smooth
         2.  Total study area street length (curb-miles):  0.127
         3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
         4.  Street Dirt Accumulation:
               Default value used
Street Area 2    Source area number:  49
         1.  Street Texture:  intermediate
         2.  Total study area street length (curb-miles):  1.46
         3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
         4.  Street Dirt Accumulation:
               Default value used
Large Landscaped Area 1    Source area number:  51
      The SCS Hydrologic Soil Type is Sandy
Undeveloped Area    Source area number:  53
      The SCS Hydrologic Soil Type is Sandy
Small Landscaped Area 1    Source area number:  54
      The SCS Hydrologic Soil Type is Sandy


   Control Practice 1 :  Catchbasin Cleaning Controls
    1.  Total sump volume (cubic feet)=  1
    2.  Area served by catchbasins (acres)=  100
    3.  Percent of sump volume full at beginning of study period=  60 %
    4.  Average sump depth (feet)=  0
    5.  Number of times catchbasins cleaned each year=  0



Pollutants to be Analyzed and Printed:

         Pollutant Name               Pollutant Type
         --------------               --------------
```

Solids	Particulate

Industrial Areas

Light Industry (Warehousing) (LIDCB.DAT and LIDSB.DAT)

```
Data file name:  C:\Program Files\WinSLAMM\LIDCB.DAT          SLAMM Version V8.1
    Rain file name:  C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN       Particulate Solids Concentration file name:  C:\PROGRAM
FILES\WINSLAMM\BHAM.PSC
    Runoff Coefficient file name:  C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
                                                                  Particulate Residue Delivery file name:  C:\PROGRAM
FILES\WINSLAMM\DELIVERY.PRR
    Pollutant Relative Concentration file name:  C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
                                                                  Seed for random number generator:   42
    Study period starting date:  01/01/53                         Study period ending date:  12/31/89
    Date:  07-23-2000                                             Time:  19:27:55
    Fraction of each type of Drainage System serving study area:
      1.  Grass Swales 0
      2.  Undeveloped roadside 0
          Curb and Gutters, `valleys', or sealed swales in:
           3.  Poor condition (or very flat) 0
           4.  Fair condition 1
           5.  Good condition (or very steep) 0
    Site information:  LIGHT INDUSTRIAL AREA, CURBS AND GUTTERS, CLAYEY SOILS, BASELINE CONTROLS (NONE)

                           |<===== Areas for each Source (acres) =====>|
                           Resi-   Institu- Commercial Industrial  Open
                          dential   tional     Areas      Areas   Spaces
Source Area                Areas    Areas                          Areas         Freeway Source Area                    Area
(acres)

1234567890123456789012345678901234567890123456789012345678901234567890123456789890
Roofs 1                    0.00      0.00      0.00      23.80     0.00          Pavd Lane & Shldr Area 1
0.00
Roofs 2                    0.00      0.00      0.00      1.60      0.00          Pavd Lane & Shldr Area 2
0.00
Roofs 3                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 3
0.00
Roofs 4                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 4
0.00
Roofs 5                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 5
0.00
Paved Parking/Storage 1    0.00      0.00      0.00      32.90     0.00          Large Turf Areas
0.00
```

Paved Parking/Storage 2	0.00	0.00	0.00	0.00	0.00	Undeveloped Areas
0.00						
Paved Parking/Storage 3	0.00	0.00	0.00	0.00	0.00	Other Pervious Areas
0.00						
Unpaved Prkng/Storage 1	0.00	0.00	0.00	6.30	0.00	Other Directly Conctd Imp
0.00						
Unpaved Prkng/Storage 2	0.00	0.00	0.00	0.00	0.00	Other Partially Conctd Imp
0.00						
Playground 1	0.00	0.00	0.00	0.00	0.00	-

Playground 2	0.00	0.00	0.00	0.00	0.00	Total
0.00						
Driveways 1	0.00	0.00	0.00	2.30	0.00	
Driveways 2	0.00	0.00	0.00	0.30	0.00	
Driveways 3	0.00	0.00	0.00	0.00	0.00	
Sidewalks/Walks 1	0.00	0.00	0.00	0.70	0.00	
Sidewalks/Walks 2	0.00	0.00	0.00	0.70	0.00	
Street Area 1	0.00	0.00	0.00	9.00	0.00	
Street Area 2	0.00	0.00	0.00	1.90	0.00	
Street Area 3	0.00	0.00	0.00	0.00	0.00	
Large Landscaped Area 1	0.00	0.00	0.00	3.50	0.00	
Large Landscaped Area 2	0.00	0.00	0.00	0.00	0.00	
Undeveloped Area	0.00	0.00	0.00	4.30	0.00	
Small Landscaped Area 1	0.00	0.00	0.00	9.90	0.00	
Small Landscaped Area 2	0.00	0.00	0.00	0.00	0.00	
Small Landscaped Area 3	0.00	0.00	0.00	0.00	0.00	
Isolated Area	0.00	0.00	0.00	0.00	0.00	
Other Pervious Area	0.00	0.00	0.00	2.80	0.00	
Other Dir Cnctd Imp Area	0.00	0.00	0.00	0.00	0.00	
Other Part Cnctd Imp Area	0.00	0.00	0.00	0.00	0.00	
	--------	--------	--------	--------	--------	
Total	0.00	0.00	0.00	100.00	0.00	

```
Total of All Source Areas               100.00
                                        ---------
Total of All Source Areas
     less All Isolated Areas            100.00
                                        =========
```

Source Area Control Practice Information

Land Use: Industrial

Roofs 1 Source area number: 91

The roof is flat

```
      The Source Area is directly connected or draining to a directly conntected area
Roofs 2    Source area number:  92
      The roof is flat
      The Source Area is draining to a pervious area (partially connected impervious area)
      The SCS Hydrologic Soil Type is Clayey
      The building density is medium or high
      Alleys are not present
Paved Parking/Storage 1    Source area number:  96
      The Source Area is directly connected or draining to a directly conntected area
Unpaved Prkng/Storage 1    Source area number:  99
      The Source Area is draining to a pervious area (partially connected impervious area)
      The SCS Hydrologic Soil Type is Clayey
      The building density is medium or high
      Alleys are not present
Driveways 1    Source area number:  103
      The Source Area is directly connected or draining to a directly conntected area
Driveways 2    Source area number:  104
      The Source Area is draining to a pervious area (partially connected impervious area)
      The SCS Hydrologic Soil Type is Clayey
      The building density is medium or high
      Alleys are not present
Sidewalks/Walks 1    Source area number:  106
      The Source Area is directly connected or draining to a directly conntected area
Sidewalks/Walks 2    Source area number:  107
      The Source Area is draining to a pervious area (partially connected impervious area)
      The SCS Hydrologic Soil Type is Clayey
      The building density is medium or high
      Alleys are not present
Street Area 1    Source area number:  108
         1.  Street Texture:  intermediate
         2.  Total study area street length (curb-miles):  4.3
         3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
         4.  Street Dirt Accumulation:
               Default value used
Street Area 2    Source area number:  109
         1.  Street Texture:  smooth
         2.  Total study area street length (curb-miles):  0.75
         3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
         4.  Street Dirt Accumulation:
               Default value used
Large Landscaped Area 1    Source area number:  111
      The SCS Hydrologic Soil Type is Clayey
Undeveloped Area    Source area number:  113
      The SCS Hydrologic Soil Type is Clayey
```

```
   Small Landscaped Area 1    Source area number:  114
         The SCS Hydrologic Soil Type is Clayey
   Other Pervious Area    Source area number:  118
         The SCS Hydrologic Soil Type is Clayey


      Control Practice 1 :  Catchbasin Cleaning Controls
       1.  Total sump volume (cubic feet)=  1
       2.  Area served by catchbasins (acres)=  100
       3.  Percent of sump volume full at beginning of study period=  60 %
       4.  Average sump depth (feet)=  0
       5.  Number of times catchbasins cleaned each year=  0



Pollutants to be Analyzed and Printed:

         Pollutant Name                Pollutant Type
         --------------                --------------
          Solids                       Particulate
```

Data file name: C:\Program Files\WinSLAMM\LIDSB.DAT
SLAMM Version V8.1
Rain file name: C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN
Particulate Solids Concentration file name: C:\PROGRAM FILES\WINSLAMM\BHAM.PSC
Runoff Coefficient file name: C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
Particulate Residue Delivery file name: C:\PROGRAM FILES\WINSLAMM\DELIVERY.PRR
Pollutant Relative Concentration file name: C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
Seed for random number generator: 42
Study period starting date: 01/01/53
Study period ending date: 12/31/89
Date: 07-23-2000
Time: 19:28:08

Fraction of each type of Drainage System serving study area:

1. Grass Swales 0
2. Undeveloped roadside 0

   Curb and Gutters, `valleys', or sealed swales in:

3. Poor condition (or very flat) 0
4. Fair condition 1
5. Good condition (or very steep) 0

Site information: LIGHT INDUSTRIAL AREA, CURB AND GUTTERS, SANDY SOILS, BASELINE CONTROLS (NONE)

|<===== Areas for each Source (acres) =====>|

Source Area	Residential Areas	Institutional Areas	Commercial Areas	Industrial Areas	Open Spaces Areas	Freeway Source Area	Area (acres)
1234567890123456789012345678901234567890123456789012345678901234567890123456789							
Roofs 1	0.00	0.00	0.00	23.80	0.00	Pavd Lane & Shldr Area 1	0.00
Roofs 2	0.00	0.00	0.00	1.60	0.00	Pavd Lane & Shldr Area 2	0.00
Roofs 3	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 3	0.00
Roofs 4	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 4	0.00
Roofs 5	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 5	0.00
Paved Parking/Storage 1	0.00	0.00	0.00	32.90	0.00	Large Turf Areas	0.00
Paved Parking/Storage 2	0.00	0.00	0.00	0.00	0.00	Undeveloped Areas	0.00
Paved Parking/Storage 3	0.00	0.00	0.00	0.00	0.00	Other Pervious Areas	0.00
Unpaved Prkng/Storage 1	0.00	0.00	0.00	6.30	0.00	Other Directly Conctd Imp	0.00

Unpaved Prkng/Storage 2	0.00	0.00	0.00	0.00	0.00	Other Partially Conctd Imp
0.00						
Playground 1	0.00	0.00	0.00	0.00	0.00	-

Playground 2	0.00	0.00	0.00	0.00	0.00	Total
0.00						
Driveways 1	0.00	0.00	0.00	2.30	0.00	
Driveways 2	0.00	0.00	0.00	0.30	0.00	
Driveways 3	0.00	0.00	0.00	0.00	0.00	
Sidewalks/Walks 1	0.00	0.00	0.00	0.70	0.00	
Sidewalks/Walks 2	0.00	0.00	0.00	0.70	0.00	
Street Area 1	0.00	0.00	0.00	9.00	0.00	
Street Area 2	0.00	0.00	0.00	1.90	0.00	
Street Area 3	0.00	0.00	0.00	0.00	0.00	
Large Landscaped Area 1	0.00	0.00	0.00	3.50	0.00	
Large Landscaped Area 2	0.00	0.00	0.00	0.00	0.00	
Undeveloped Area	0.00	0.00	0.00	4.30	0.00	
Small Landscaped Area 1	0.00	0.00	0.00	9.90	0.00	
Small Landscaped Area 2	0.00	0.00	0.00	0.00	0.00	
Small Landscaped Area 3	0.00	0.00	0.00	0.00	0.00	
Isolated Area	0.00	0.00	0.00	0.00	0.00	
Other Pervious Area	0.00	0.00	0.00	2.80	0.00	
Other Dir Cnctd Imp Area	0.00	0.00	0.00	0.00	0.00	
Other Part Cnctd Imp Area	0.00	0.00	0.00	0.00	0.00	
	--------	--------	--------	--------	--------	
Total	0.00	0.00	0.00	100.00	0.00	

Total of All Source Areas	100.00

Total of All Source Areas less All Isolated Areas	100.00
	=========

Source Area Control Practice Information

Land Use: Industrial

Roofs 1 Source area number: 91

The roof is flat

The Source Area is directly connected or draining to a directly conntected area

Roofs 2 Source area number: 92

The roof is flat

The Source Area is draining to a pervious area (partially connected impervious area)

The SCS Hydrologic Soil Type is Sandy

Paved Parking/Storage 1 Source area number: 96

```
      The Source Area is directly connected or draining to a directly conntected area
Unpaved Prkng/Storage 1    Source area number:  99
      The Source Area is draining to a pervious area (partially connected impervious area)
      The SCS Hydrologic Soil Type is Sandy
Driveways 1    Source area number:  103
      The Source Area is directly connected or draining to a directly conntected area
Driveways 2    Source area number:  104
      The Source Area is draining to a pervious area (partially connected impervious area)
      The SCS Hydrologic Soil Type is Sandy
Sidewalks/Walks 1    Source area number:  106
      The Source Area is directly connected or draining to a directly conntected area
Sidewalks/Walks 2    Source area number:  107
      The Source Area is draining to a pervious area (partially connected impervious area)
      The SCS Hydrologic Soil Type is Sandy
Street Area 1    Source area number:  108
         1.  Street Texture:  intermediate
         2.  Total study area street length (curb-miles):  4.3
         3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
         4.  Street Dirt Accumulation:
               Default value used
Street Area 2    Source area number:  109
         1.  Street Texture:  smooth
         2.  Total study area street length (curb-miles):  0.75
         3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
         4.  Street Dirt Accumulation:
               Default value used
Large Landscaped Area 1    Source area number:  111
      The SCS Hydrologic Soil Type is Sandy
Undeveloped Area    Source area number:  113
      The SCS Hydrologic Soil Type is Sandy
Small Landscaped Area 1    Source area number:  114
      The SCS Hydrologic Soil Type is Sandy
Other Pervious Area    Source area number:  118
      The SCS Hydrologic Soil Type is Sandy


   Control Practice 1 :  Catchbasin Cleaning Controls
    1.  Total sump volume (cubic feet)=  1
    2.  Area served by catchbasins (acres)=  100
    3.  Percent of sump volume full at beginning of study period=  60 %
    4.  Average sump depth (feet)=  0
    5.  Number of times catchbasins cleaned each year=  0
```

Pollutants to be Analyzed and Printed:

Pollutant Name	Pollutant Type
Solids	Particulate

Open Space

Golf Courses (GLFCB.DAT and GLFSB.DAT)

```
Data file name:  C:\Program Files\WinSLAMM\GLFCB.DAT          SLAMM Version V8.1
    Rain file name:  C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN       Particulate Solids Concentration file name:  C:\PROGRAM
FILES\WINSLAMM\BHAM.PSC
    Runoff Coefficient file name:  C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
                                                                  Particulate Residue Delivery file name:  C:\PROGRAM
FILES\WINSLAMM\DELIVERY.PRR
    Pollutant Relative Concentration file name:  C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
                                                                  Seed for random number generator:   42
    Study period starting date:  01/01/53                         Study period ending date:  12/31/89
    Date:  07-23-2000                                             Time:  19:26:24
    Fraction of each type of Drainage System serving study area:
      1.  Grass Swales 1
      2.  Undeveloped roadside 0
          Curb and Gutters, `valleys', or sealed swales in:
           3.  Poor condition (or very flat) 0
           4.  Fair condition 0
           5.  Good condition (or very steep) 0
    Site information:  GOLF COURSE, SWALE DRAINAGE, CLAYEY SOILS, BASELILNE CONTROLS (SWALES)
                            |<===== Areas for each Source (acres) =====>|
                            Resi-   Institu- Commercial Industrial  Open
                           dential   tional     Areas      Areas   Spaces
Source Area                 Areas    Areas                           Areas         Freeway Source Area                    Area
(acres)
12345678901234567890123456789012345678901234567890123456789012345678901234567890
Roofs 1                     0.00      0.00      0.00      0.00      0.28          Pavd Lane & Shldr Area 1
0.00
Roofs 2                     0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 2
0.00
Roofs 3                     0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 3
0.00
Roofs 4                     0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 4
0.00
Roofs 5                     0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 5
0.00
Paved Parking/Storage 1     0.00      0.00      0.00      0.00      0.67          Large Turf Areas
0.00
Paved Parking/Storage 2     0.00      0.00      0.00      0.00      0.00          Undeveloped Areas
0.00
Paved Parking/Storage 3     0.00      0.00      0.00      0.00      0.00          Other Pervious Areas
0.00
```

```
Unpaved Prkng/Storage 1    0.00      0.00      0.00      0.00      0.00          Other Directly Conctd Imp
0.00
Unpaved Prkng/Storage 2    0.00      0.00      0.00      0.00      0.00          Other Partially Conctd Imp
0.00
Playground 1               0.00      0.00      0.00      0.00      0.07                                                 -
-------
Playground 2               0.00      0.00      0.00      0.00      0.00          Total
0.00
Driveways 1                0.00      0.00      0.00      0.00      1.17
Driveways 2                0.00      0.00      0.00      0.00      0.00
Driveways 3                0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 1          0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 2          0.00      0.00      0.00      0.00      0.00
Street Area 1              0.00      0.00      0.00      0.00      1.23
Street Area 2              0.00      0.00      0.00      0.00      0.00
Street Area 3              0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 1    0.00      0.00      0.00      0.00      96.58
Large Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Undeveloped Area           0.00      0.00      0.00      0.00      0.00
Small Landscaped Area 1    0.00      0.00      0.00      0.00      0.00
Small Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Small Landscaped Area 3    0.00      0.00      0.00      0.00      0.00
Isolated Area              0.00      0.00      0.00      0.00      0.00
Other Pervious Area        0.00      0.00      0.00      0.00      0.00
Other Dir Cnctd Imp Area   0.00      0.00      0.00      0.00      0.00
Other Part Cnctd Imp Area  0.00      0.00      0.00      0.00      0.00
                        --------  --------  --------  --------  --------
Total                   0.00      0.00      0.00      0.00      100.00

Total of All Source Areas             100.00
                                      ---------
Total of All Source Areas
     less All Isolated Areas          100.00
                                      =========
                   Source Area Control Practice Information
Land Use:  Open Space
   Roofs 1    Source area number:  121
         The roof is pitched
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Clayey
   Paved Parking/Storage 1    Source area number:  126
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Clayey
   Playground 1    Source area number:  131
```

```
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Clayey
   Driveways 1    Source area number:  133
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Clayey
   Street Area 1    Source area number:  138
            1.  Street Texture:  intermediate
            2.  Total study area street length (curb-miles):  0.65
            3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
            4.  Street Dirt Accumulation:
                  Default value used
   Large Landscaped Area 1    Source area number:  141
         The SCS Hydrologic Soil Type is Clayey
      Control Practice 1 :  Grass Swale
         1.  Swale infiltration rate (inches per hour)=  0.1
         2.  Wetted swale width (feet)=  3
         3.  Swale density (feet per acre)=  17.16
         4.  Area served by swales (acres)=  100
Pollutants to be Analyzed and Printed:
         Pollutant Name                Pollutant Type
          Solids                       Particulate
```

```
    Data file name:  C:\Program Files\WinSLAMM\GLFSB.DAT          SLAMM Version V8.1
    Rain file name:  C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN       Particulate Solids Concentration file name:  C:\PROGRAM
FILES\WINSLAMM\BHAM.PSC
    Runoff Coefficient file name:  C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
                                                                  Particulate Residue Delivery file name:  C:\PROGRAM
FILES\WINSLAMM\DELIVERY.PRR
    Pollutant Relative Concentration file name:  C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
                                                                  Seed for random number generator:   42
    Study period starting date:  01/01/53                         Study period ending date:  12/31/89
    Date:  07-23-2000                                             Time:  19:26:41
    Fraction of each type of Drainage System serving study area:
      1.  Grass Swales 1
      2.  Undeveloped roadside 0
          Curb and Gutters, `valleys', or sealed swales in:
           3.  Poor condition (or very flat) 0
           4.  Fair condition 0
           5.  Good condition (or very steep) 0
    Site information:  GOLF COURSE, SWALE DRAINAGE, SANDY SOILS, BASELINE CONTROLS (SWALES)

                           |<===== Areas for each Source (acres) =====>|
                           Resi-   Institu- Commercial Industrial  Open
                          dential   tional     Areas      Areas   Spaces
Source Area                Areas    Areas                          Areas         Freeway Source Area                   Area
(acres)

12345678901234567890123456789012345678901234567890123456789012345678901234567890
Roofs 1                    0.00      0.00      0.00      0.00      0.28         Pavd Lane & Shldr Area 1
0.00
Roofs 2                    0.00      0.00      0.00      0.00      0.00         Pavd Lane & Shldr Area 2
0.00
Roofs 3                    0.00      0.00      0.00      0.00      0.00         Pavd Lane & Shldr Area 3
0.00
Roofs 4                    0.00      0.00      0.00      0.00      0.00         Pavd Lane & Shldr Area 4
0.00
Roofs 5                    0.00      0.00      0.00      0.00      0.00         Pavd Lane & Shldr Area 5
0.00
Paved Parking/Storage 1    0.00      0.00      0.00      0.00      0.67         Large Turf Areas
0.00
Paved Parking/Storage 2    0.00      0.00      0.00      0.00      0.00         Undeveloped Areas
0.00
Paved Parking/Storage 3    0.00      0.00      0.00      0.00      0.00         Other Pervious Areas
0.00
Unpaved Prkng/Storage 1    0.00      0.00      0.00      0.00      0.00         Other Directly Conctd Imp
0.00
```

```
Unpaved Prkng/Storage 2    0.00      0.00      0.00      0.00      0.00          Other Partially Conctd Imp
0.00
Playground 1               0.00      0.00      0.00      0.00      0.07                                                          -
-------
Playground 2               0.00      0.00      0.00      0.00      0.00          Total
0.00
Driveways 1                0.00      0.00      0.00      0.00      1.17
Driveways 2                0.00      0.00      0.00      0.00      0.00
Driveways 3                0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 1          0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 2          0.00      0.00      0.00      0.00      0.00
Street Area 1              0.00      0.00      0.00      0.00      1.23
Street Area 2              0.00      0.00      0.00      0.00      0.00
Street Area 3              0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 1    0.00      0.00      0.00      0.00      96.58
Large Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Undeveloped Area           0.00      0.00      0.00      0.00      0.00
Small Landscaped Area 1    0.00      0.00      0.00      0.00      0.00
Small Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Small Landscaped Area 3    0.00      0.00      0.00      0.00      0.00
Isolated Area              0.00      0.00      0.00      0.00      0.00
Other Pervious Area        0.00      0.00      0.00      0.00      0.00
Other Dir Cnctd Imp Area   0.00      0.00      0.00      0.00      0.00
Other Part Cnctd Imp Area  0.00      0.00      0.00      0.00      0.00
                        --------  --------  --------  --------  --------
Total                   0.00      0.00      0.00      0.00      100.00


Total of All Source Areas               100.00
                                        ---------
Total of All Source Areas
     less All Isolated Areas            100.00
                                        =========

                   Source Area Control Practice Information
Land Use:  Open Space
   Roofs 1    Source area number:  121
         The roof is pitched
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Sandy
   Paved Parking/Storage 1    Source area number:  126
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Sandy
   Playground 1    Source area number:  131
```

```
        The Source Area is draining to a pervious area (partially connected impervious area)
        The SCS Hydrologic Soil Type is Sandy
  Driveways 1    Source area number:  133
        The Source Area is draining to a pervious area (partially connected impervious area)
        The SCS Hydrologic Soil Type is Sandy
  Street Area 1    Source area number:  138
           1.  Street Texture:  intermediate
           2.  Total study area street length (curb-miles):  0.65
           3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
           4.  Street Dirt Accumulation:
                 Default value used
  Large Landscaped Area 1    Source area number:  141
        The SCS Hydrologic Soil Type is Sandy


     Control Practice 1 :  Grass Swale
        1.  Swale infiltration rate (inches per hour)=  2.5
        2.  Wetted swale width (feet)=  3
        3.  Swale density (feet per acre)=  17.16
        4.  Area served by swales (acres)=  100



Pollutants to be Analyzed and Printed:

        Pollutant Name               Pollutant Type
        --------------               --------------
         Solids                      Particulate
```

Cemeteries (CEMCB.DAT and CEMSB.DAT)

```
  Data file name:  C:\Program Files\WinSLAMM\CEMCB.DAT          SLAMM Version V8.1
    Rain file name:  C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN       Particulate Solids Concentration file name:  C:\PROGRAM
FILES\WINSLAMM\BHAM.PSC
    Runoff Coefficient file name:  C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
                                                                  Particulate Residue Delivery file name:  C:\PROGRAM
FILES\WINSLAMM\DELIVERY.PRR
    Pollutant Relative Concentration file name:  C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
                                                                  Seed for random number generator:   42
    Study period starting date:  01/01/53                         Study period ending date:  12/31/89
    Date:  07-23-2000                                             Time:  19:15:59
    Fraction of each type of Drainage System serving study area:
      1.  Grass Swales 0
      2.  Undeveloped roadside 0
          Curb and Gutters, `valleys', or sealed swales in:
           3.  Poor condition (or very flat) 0
           4.  Fair condition 1
           5.  Good condition (or very steep) 0
    Site information:  CEMETERY, CURBS AND GUTTERS, CLAYEY SOILS, BASELINE CONTROLS (NONE)
                           |<===== Areas for each Source (acres) =====>|
                           Resi-   Institu- Commercial Industrial  Open
                          dential   tional     Areas      Areas   Spaces
Source Area                Areas    Areas                          Areas         Freeway Source Area                   Area
(acres)
1234567890123456789012345678901234567890123456789012345678901234567890
Roofs 1                    0.00      0.00      0.00      0.00      1.00          Pavd Lane & Shldr Area 1
0.00
Roofs 2                    0.00      0.00      0.00      0.00      0.10          Pavd Lane & Shldr Area 2
0.00
Roofs 3                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 3
0.00
Roofs 4                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 4
0.00
Roofs 5                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 5
0.00
Paved Parking/Storage 1    0.00      0.00      0.00      0.00      2.30          Large Turf Areas
0.00
Paved Parking/Storage 2    0.00      0.00      0.00      0.00      0.00          Undeveloped Areas
0.00
Paved Parking/Storage 3    0.00      0.00      0.00      0.00      0.00          Other Pervious Areas
0.00
```

```
Unpaved Prkng/Storage 1    0.00      0.00      0.00      0.00      0.00          Other Directly Conctd Imp
0.00
Unpaved Prkng/Storage 2    0.00      0.00      0.00      0.00      0.00          Other Partially Conctd Imp
0.00
Playground 1               0.00      0.00      0.00      0.00      0.00                                              -
-------
Playground 2               0.00      0.00      0.00      0.00      0.00          Total
0.00
Driveways 1                0.00      0.00      0.00      0.00      7.70
Driveways 2                0.00      0.00      0.00      0.00      0.00
Driveways 3                0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 1          0.00      0.00      0.00      0.00      0.10
Sidewalks/Walks 2          0.00      0.00      0.00      0.00      0.00
Street Area 1              0.00      0.00      0.00      0.00      0.70
Street Area 2              0.00      0.00      0.00      0.00      0.70
Street Area 3              0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 1    0.00      0.00      0.00      0.00      86.30
Large Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Undeveloped Area           0.00      0.00      0.00      0.00      0.50
Small Landscaped Area 1    0.00      0.00      0.00      0.00      0.60
Small Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Small Landscaped Area 3    0.00      0.00      0.00      0.00      0.00
Isolated Area              0.00      0.00      0.00      0.00      0.30
Other Pervious Area        0.00      0.00      0.00      0.00      0.00
Other Dir Cnctd Imp Area   0.00      0.00      0.00      0.00      0.00
Other Part Cnctd Imp Area  0.00      0.00      0.00      0.00      0.00
                        --------  --------  --------  --------  --------
Total                   0.00      0.00      0.00      0.00      100.30

Total of All Source Areas              100.30
                                       ---------
Total of All Source Areas
     less All Isolated Areas           100.00
                                       =========
                   Source Area Control Practice Information
Land Use:  Open Space
   Roofs 1    Source area number:  121
         The roof is flat
         The Source Area is directly connected or draining to a directly conntected area
   Roofs 2    Source area number:  122
         The roof is pitched
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Clayey
   Paved Parking/Storage 1    Source area number:  126
```

```
        The Source Area is directly connected or draining to a directly conntected area
    Driveways 1    Source area number:  133
        The Source Area is directly connected or draining to a directly conntected area
    Sidewalks/Walks 1    Source area number:  136
        The Source Area is draining to a pervious area (partially connected impervious area)
        The SCS Hydrologic Soil Type is Clayey
    Street Area 1    Source area number:  138
          1.  Street Texture:  smooth
          2.  Total study area street length (curb-miles):  0.38
          3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
          4.  Street Dirt Accumulation:
                Default value used
    Street Area 2    Source area number:  139
          1.  Street Texture:  intermediate
          2.  Total study area street length (curb-miles):  0.38
          3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
          4.  Street Dirt Accumulation:
                Default value used
    Large Landscaped Area 1    Source area number:  141
        The SCS Hydrologic Soil Type is Clayey
    Undeveloped Area    Source area number:  143
        The SCS Hydrologic Soil Type is Clayey
    Small Landscaped Area 1    Source area number:  144
        The SCS Hydrologic Soil Type is Clayey
      Control Practice 1 :  Catchbasin Cleaning Controls
       1.  Total sump volume (cubic feet)=  1
       2.  Area served by catchbasins (acres)=  100
       3.  Percent of sump volume full at beginning of study period=  60 %
       4.  Average sump depth (feet)=  0
       5.  Number of times catchbasins cleaned each year=  0
Pollutants to be Analyzed and Printed:
         Pollutant Name               Pollutant Type
          Solids                      Particulate
```

```
    Data file name:  C:\Program Files\WinSLAMM\CEMSB.DAT          SLAMM Version V8.1
    Rain file name:  C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN       Particulate Solids Concentration file name:  C:\PROGRAM
FILES\WINSLAMM\BHAM.PSC
    Runoff Coefficient file name:  C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
                                                                  Particulate Residue Delivery file name:  C:\PROGRAM
FILES\WINSLAMM\DELIVERY.PRR
    Pollutant Relative Concentration file name:  C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
                                                                  Seed for random number generator:   42
    Study period starting date:  01/01/53                         Study period ending date:  12/31/89
    Date:  07-23-2000                                             Time:  19:16:13
    Fraction of each type of Drainage System serving study area:
      1.  Grass Swales 0
      2.  Undeveloped roadside 0
          Curb and Gutters, `valleys', or sealed swales in:
           3.  Poor condition (or very flat) 0
           4.  Fair condition 1
           5.  Good condition (or very steep) 0
    Site information:  CEMETERY, CURBS AND GUTTERS, SANDY SOILS, BASELINE CONTROLS (NONE)

                           |<===== Areas for each Source (acres) =====>|
                           Resi-   Institu- Commercial Industrial  Open
                          dential   tional     Areas      Areas   Spaces
Source Area                Areas    Areas                          Areas         Freeway Source Area                   Area
(acres)

1234567890123456789012345678901234567890123456789012345678901234567890
Roofs 1                    0.00      0.00      0.00      0.00      1.00          Pavd Lane & Shldr Area 1
0.00
Roofs 2                    0.00      0.00      0.00      0.00      0.10          Pavd Lane & Shldr Area 2
0.00
Roofs 3                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 3
0.00
Roofs 4                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 4
0.00
Roofs 5                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 5
0.00
Paved Parking/Storage 1    0.00      0.00      0.00      0.00      2.30          Large Turf Areas
0.00
Paved Parking/Storage 2    0.00      0.00      0.00      0.00      0.00          Undeveloped Areas
0.00
Paved Parking/Storage 3    0.00      0.00      0.00      0.00      0.00          Other Pervious Areas
0.00
Unpaved Prkng/Storage 1    0.00      0.00      0.00      0.00      0.00          Other Directly Conctd Imp
0.00
```

```
Unpaved Prkng/Storage 2    0.00      0.00      0.00      0.00      0.00          Other Partially Conctd Imp
0.00
Playground 1               0.00      0.00      0.00      0.00      0.00                                                      -
-------
Playground 2               0.00      0.00      0.00      0.00      0.00          Total
0.00
Driveways 1                0.00      0.00      0.00      0.00      7.70
Driveways 2                0.00      0.00      0.00      0.00      0.00
Driveways 3                0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 1          0.00      0.00      0.00      0.00      0.10
Sidewalks/Walks 2          0.00      0.00      0.00      0.00      0.00
Street Area 1              0.00      0.00      0.00      0.00      0.70
Street Area 2              0.00      0.00      0.00      0.00      0.70
Street Area 3              0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 1    0.00      0.00      0.00      0.00      86.30
Large Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Undeveloped Area           0.00      0.00      0.00      0.00      0.50
Small Landscaped Area 1    0.00      0.00      0.00      0.00      0.60
Small Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Small Landscaped Area 3    0.00      0.00      0.00      0.00      0.00
Isolated Area              0.00      0.00      0.00      0.00      0.30
Other Pervious Area        0.00      0.00      0.00      0.00      0.00
Other Dir Cnctd Imp Area   0.00      0.00      0.00      0.00      0.00
Other Part Cnctd Imp Area  0.00      0.00      0.00      0.00      0.00
                        --------  --------  --------  --------  --------
Total                   0.00      0.00      0.00      0.00      100.30

Total of All Source Areas             100.30
                                      ---------
Total of All Source Areas
     less All Isolated Areas          100.00
                                      =========
                   Source Area Control Practice Information
Land Use:  Open Space
   Roofs 1    Source area number:  121
         The roof is flat
         The Source Area is directly connected or draining to a directly conntected area
   Roofs 2    Source area number:  122
         The roof is pitched
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Sandy
   Paved Parking/Storage 1    Source area number:  126
         The Source Area is directly connected or draining to a directly conntected area
   Driveways 1    Source area number:  133
```

```
         The Source Area is directly connected or draining to a directly conntected area
   Sidewalks/Walks 1    Source area number:  136
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Sandy
   Street Area 1    Source area number:  138
            1.  Street Texture:  smooth
            2.  Total study area street length (curb-miles):  0.38
            3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
            4.  Street Dirt Accumulation:
                  Default value used
   Street Area 2    Source area number:  139
            1.  Street Texture:  intermediate
            2.  Total study area street length (curb-miles):  0.38
            3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
            4.  Street Dirt Accumulation:
                  Default value used
   Large Landscaped Area 1    Source area number:  141
         The SCS Hydrologic Soil Type is Sandy
   Undeveloped Area    Source area number:  143
         The SCS Hydrologic Soil Type is Sandy
   Small Landscaped Area 1    Source area number:  144
         The SCS Hydrologic Soil Type is Sandy

      Control Practice 1 :  Catchbasin Cleaning Controls
       1.  Total sump volume (cubic feet)=  1
       2.  Area served by catchbasins (acres)=  100
       3.  Percent of sump volume full at beginning of study period=  60 %
       4.  Average sump depth (feet)=  0
       5.  Number of times catchbasins cleaned each year=  0
Pollutants to be Analyzed and Printed:
         Pollutant Name                Pollutant Type
          Solids                       Particulate
```

Parks (PRKCB.DAT and PRKSB.DAT)

```
  Data file name:  C:\Program Files\WinSLAMM\PRKCB.DAT          SLAMM Version V8.1
    Rain file name:  C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN       Particulate Solids Concentration file name:  C:\PROGRAM
FILES\WINSLAMM\BHAM.PSC
    Runoff Coefficient file name:  C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
                                                                  Particulate Residue Delivery file name:  C:\PROGRAM
FILES\WINSLAMM\DELIVERY.PRR
    Pollutant Relative Concentration file name:  C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
                                                                  Seed for random number generator:   42
    Study period starting date:  01/01/53                         Study period ending date:  12/31/89
    Date:  07-23-2000                                             Time:  19:35:59
    Fraction of each type of Drainage System serving study area:
      1.  Grass Swales 0
      2.  Undeveloped roadside 0
          Curb and Gutters, `valleys', or sealed swales in:
           3.  Poor condition (or very flat) 0
           4.  Fair condition 1
           5.  Good condition (or very steep) 0
    Site information:  PARKS, CURBS AND GUTTERS, CLAYEY SOILS, BASELINE CONTROLS (NONE)

                           |<===== Areas for each Source (acres) =====>|
                           Resi-   Institu- Commercial Industrial  Open
                          dential   tional     Areas      Areas   Spaces
Source Area                Areas    Areas                          Areas         Freeway Source Area                   Area
(acres)
1234567890123456789012345678901234567890123456789012345678901234567890
Roofs 1                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 1
0.00
Roofs 2                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 2
0.00
Roofs 3                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 3
0.00
Roofs 4                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 4
0.00
Roofs 5                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 5
0.00
Paved Parking/Storage 1    0.00      0.00      0.00      0.00      15.70         Large Turf Areas
0.00
Paved Parking/Storage 2    0.00      0.00      0.00      0.00      0.00          Undeveloped Areas
0.00
Paved Parking/Storage 3    0.00      0.00      0.00      0.00      0.00          Other Pervious Areas
0.00
```

```
Unpaved Prkng/Storage 1    0.00      0.00      0.00      0.00      0.00          Other Directly Conctd Imp
0.00
Unpaved Prkng/Storage 2    0.00      0.00      0.00      0.00      0.00          Other Partially Conctd Imp
0.00
Playground 1               0.00      0.00      0.00      0.00      8.15                                       -
-------
Playground 2               0.00      0.00      0.00      0.00      40.13         Total
0.00
Driveways 1                0.00      0.00      0.00      0.00      0.21
Driveways 2                0.00      0.00      0.00      0.00      0.21
Driveways 3                0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 1          0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 2          0.00      0.00      0.00      0.00      0.00
Street Area 1              0.00      0.00      0.00      0.00      15.70
Street Area 2              0.00      0.00      0.00      0.00      0.00
Street Area 3              0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 1    0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Undeveloped Area           0.00      0.00      0.00      0.00      14.96
Small Landscaped Area 1    0.00      0.00      0.00      0.00      4.94
Small Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Small Landscaped Area 3    0.00      0.00      0.00      0.00      0.00
Isolated Area              0.00      0.00      0.00      0.00      0.00
Other Pervious Area        0.00      0.00      0.00      0.00      0.00
Other Dir Cnctd Imp Area   0.00      0.00      0.00      0.00      0.00
Other Part Cnctd Imp Area  0.00      0.00      0.00      0.00      0.00
                        --------  --------  --------  --------  --------
Total                   0.00      0.00      0.00      0.00      100.00
Total of All Source Areas             100.00
                                     ---------
Total of All Source Areas
     less All Isolated Areas          100.00
                                      =========
                   Source Area Control Practice Information
Land Use:  Open Space
   Paved Parking/Storage 1    Source area number:  126
         The Source Area is directly connected or draining to a directly conntected area
   Playground 1    Source area number:  131
         The Source Area is directly connected or draining to a directly conntected area
   Playground 2    Source area number:  132
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Clayey
   Driveways 1    Source area number:  133
         The Source Area is directly connected or draining to a directly conntected area
```

```
   Driveways 2    Source area number:  134
         The Source Area is directly connected or draining to a directly conntected area
   Street Area 1    Source area number:  138
            1.  Street Texture:  intermediate
            2.  Total study area street length (curb-miles):  11.913
            3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
            4.  Street Dirt Accumulation:
                  Default value used
   Undeveloped Area    Source area number:  143
         The SCS Hydrologic Soil Type is Clayey
   Small Landscaped Area 1    Source area number:  144
         The SCS Hydrologic Soil Type is Clayey
      Control Practice 1 :  Catchbasin Cleaning Controls
       1.  Total sump volume (cubic feet)=  1
       2.  Area served by catchbasins (acres)=  100
       3.  Percent of sump volume full at beginning of study period=  60 %
       4.  Average sump depth (feet)=  0
       5.  Number of times catchbasins cleaned each year=  0


Pollutants to be Analyzed and Printed:
         Pollutant Name                Pollutant Type
         --------------                --------------
          Solids                       Particulate
```

```
    Data file name:  C:\Program Files\WinSLAMM\PRKSB.DAT          SLAMM Version V8.1
    Rain file name:  C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN       Particulate Solids Concentration file name:  C:\PROGRAM
FILES\WINSLAMM\BHAM.PSC
    Runoff Coefficient file name:  C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
                                                                  Particulate Residue Delivery file name:  C:\PROGRAM
FILES\WINSLAMM\DELIVERY.PRR
    Pollutant Relative Concentration file name:  C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
                                                                  Seed for random number generator:   42
    Study period starting date:  01/01/53                         Study period ending date:  12/31/89
    Date:  07-23-2000                                             Time:  19:36:14
    Fraction of each type of Drainage System serving study area:
      1.  Grass Swales 0
      2.  Undeveloped roadside 0
          Curb and Gutters, `valleys', or sealed swales in:
           3.  Poor condition (or very flat) 0
           4.  Fair condition 1
           5.  Good condition (or very steep) 0
    Site information:  PARKS, CURB AND GUTTERS, SANDY SOILS, BASELINE CONDITIONS (NONE)

                           |<===== Areas for each Source (acres) =====>|
                           Resi-   Institu- Commercial Industrial  Open
                          dential   tional     Areas      Areas   Spaces
Source Area                Areas    Areas                          Areas         Freeway Source Area                   Area
(acres)

12345678901234567890123456789012345678901234567890123456789012345678901234567890
Roofs 1                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 1
0.00
Roofs 2                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 2
0.00
Roofs 3                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 3
0.00
Roofs 4                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 4
0.00
Roofs 5                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 5
0.00
Paved Parking/Storage 1    0.00      0.00      0.00      0.00      15.70         Large Turf Areas
0.00
Paved Parking/Storage 2    0.00      0.00      0.00      0.00      0.00          Undeveloped Areas
0.00
Paved Parking/Storage 3    0.00      0.00      0.00      0.00      0.00          Other Pervious Areas
0.00
Unpaved Prkng/Storage 1    0.00      0.00      0.00      0.00      0.00          Other Directly Conctd Imp
0.00
```

```
Unpaved Prkng/Storage 2    0.00      0.00      0.00      0.00      0.00          Other Partially Conctd Imp
0.00
Playground 1               0.00      0.00      0.00      0.00      8.15                                                  -
-------
Playground 2               0.00      0.00      0.00      0.00      40.13         Total
0.00
Driveways 1                0.00      0.00      0.00      0.00      0.21
Driveways 2                0.00      0.00      0.00      0.00      0.21
Driveways 3                0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 1          0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 2          0.00      0.00      0.00      0.00      0.00
Street Area 1              0.00      0.00      0.00      0.00      15.70
Street Area 2              0.00      0.00      0.00      0.00      0.00
Street Area 3              0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 1    0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Undeveloped Area           0.00      0.00      0.00      0.00      14.96
Small Landscaped Area 1    0.00      0.00      0.00      0.00      4.94
Small Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Small Landscaped Area 3    0.00      0.00      0.00      0.00      0.00
Isolated Area              0.00      0.00      0.00      0.00      0.00
Other Pervious Area        0.00      0.00      0.00      0.00      0.00
Other Dir Cnctd Imp Area   0.00      0.00      0.00      0.00      0.00
Other Part Cnctd Imp Area  0.00      0.00      0.00      0.00      0.00
                        --------  --------  --------  --------  --------
Total                   0.00      0.00      0.00      0.00      100.00
Total of All Source Areas             100.00
     less All Isolated Areas          100.00
                                      =========
                   Source Area Control Practice Information
Land Use:  Open Space
   Paved Parking/Storage 1    Source area number:  126
         The Source Area is directly connected or draining to a directly conntected area
   Playground 1    Source area number:  131
         The Source Area is directly connected or draining to a directly conntected area
   Playground 2    Source area number:  132
         The Source Area is draining to a pervious area (partially connected impervious area)
         The SCS Hydrologic Soil Type is Sandy
   Driveways 1    Source area number:  133
         The Source Area is directly connected or draining to a directly conntected area
   Driveways 2    Source area number:  134
         The Source Area is directly connected or draining to a directly conntected area
   Street Area 1    Source area number:  138
            1.  Street Texture:  intermediate
```

```
           2.  Total study area street length (curb-miles):  11.913
           3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
           4.  Street Dirt Accumulation:
                 Default value used
   Undeveloped Area    Source area number:  143
         The SCS Hydrologic Soil Type is Sandy
   Small Landscaped Area 1    Source area number:  144
         The SCS Hydrologic Soil Type is Sandy
      Control Practice 1 :  Catchbasin Cleaning Controls
       1.  Total sump volume (cubic feet)=  1
       2.  Area served by catchbasins (acres)=  100
       3.  Percent of sump volume full at beginning of study period=  60 %
       4.  Average sump depth (feet)=  0
       5.  Number of times catchbasins cleaned each year=  0

Pollutants to be Analyzed and Printed:

         Pollutant Name                Pollutant Type
          Solids                       Particulate
```

Undeveloped (UNVCB.DAT and UNVSB.DAT)

Data file name: C:\Program Files\WinSLAMM\UDVCB.DAT   SLAMM Version V8.1
Rain file name: C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN   Particulate Solids Concentration file name: C:\PROGRAM FILES\WINSLAMM\BHAM.PSC
Runoff Coefficient file name: C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
Particulate Residue Delivery file name: C:\PROGRAM FILES\WINSLAMM\DELIVERY.PRR
Pollutant Relative Concentration file name: C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
Seed for random number generator: 42
Study period starting date: 01/01/53   Study period ending date: 12/31/89
Date: 07-23-2000   Time: 19:33:00
Fraction of each type of Drainage System serving study area:
1. Grass Swales 0
2. Undeveloped roadside 0
Curb and Gutters, `valleys', or sealed swales in:
3. Poor condition (or very flat) 0
4. Fair condition 1
5. Good condition (or very steep) 0
Site information: UNDEVELOPED LAND, CURBS AND GUTTERS, CLAYEY SOILS, BASELINE CONTROLS (NONE)

	|<===== Areas for each Source (acres) =====>|						
Source Area	Resi- dential Areas	Institu- tional Areas	Commercial Areas	Industrial Areas	Open Spaces Areas	Freeway Source Area	Area (acres)
1234567890123456789012345678901234567890123456789012345678901234567890							
Roofs 1	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 1	0.00
Roofs 2	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 2	0.00
Roofs 3	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 3	0.00
Roofs 4	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 4	0.00
Roofs 5	0.00	0.00	0.00	0.00	0.00	Pavd Lane & Shldr Area 5	0.00
Paved Parking/Storage 1	0.00	0.00	0.00	0.00	0.00	Large Turf Areas	0.00
Paved Parking/Storage 2	0.00	0.00	0.00	0.00	0.00	Undeveloped Areas	0.00
Paved Parking/Storage 3	0.00	0.00	0.00	0.00	0.00	Other Pervious Areas	0.00

```
Unpaved Prkng/Storage 1    0.00      0.00      0.00      0.00      0.00          Other Directly Conctd Imp
0.00
Unpaved Prkng/Storage 2    0.00      0.00      0.00      0.00      0.00          Other Partially Conctd Imp
0.00
Playground 1               0.00      0.00      0.00      0.00      0.00                                                 -
-------
Playground 2               0.00      0.00      0.00      0.00      0.00          Total
0.00
Driveways 1                0.00      0.00      0.00      0.00      0.00
Driveways 2                0.00      0.00      0.00      0.00      0.00
Driveways 3                0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 1          0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 2          0.00      0.00      0.00      0.00      0.00
Street Area 1              0.00      0.00      0.00      0.00      7.00
Street Area 2              0.00      0.00      0.00      0.00      1.00
Street Area 3              0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 1    0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Undeveloped Area           0.00      0.00      0.00      0.00      92.00
Small Landscaped Area 1    0.00      0.00      0.00      0.00      0.00
Small Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Small Landscaped Area 3    0.00      0.00      0.00      0.00      0.00
Isolated Area              0.00      0.00      0.00      0.00      0.00
Other Pervious Area        0.00      0.00      0.00      0.00      0.00
Other Dir Cnctd Imp Area   0.00      0.00      0.00      0.00      0.00
Other Part Cnctd Imp Area  0.00      0.00      0.00      0.00      0.00
                        --------  --------  --------  --------  --------
Total                   0.00      0.00      0.00      0.00      100.00


Total of All Source Areas              100.00
                                       ---------
Total of All Source Areas
     less All Isolated Areas           100.00
                                       =========

                   Source Area Control Practice Information
Land Use:  Open Space
   Street Area 1    Source area number:  138
            1.  Street Texture:  intermediate
            2.  Total study area street length (curb-miles):  2.7
            3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
            4.  Street Dirt Accumulation:
                  Default value used
```

```
   Street Area 2    Source area number:  139
            1.  Street Texture:  smooth
            2.  Total study area street length (curb-miles):  0.5
            3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
            4.  Street Dirt Accumulation:
                  Default value used
   Undeveloped Area    Source area number:  143
         The SCS Hydrologic Soil Type is Clayey

      Control Practice 1 :  Catchbasin Cleaning Controls
       1.  Total sump volume (cubic feet)=  1
       2.  Area served by catchbasins (acres)=  100
       3.  Percent of sump volume full at beginning of study period=  60 %
       4.  Average sump depth (feet)=  0
       5.  Number of times catchbasins cleaned each year=  0

Pollutants to be Analyzed and Printed:

         Pollutant Name               Pollutant Type
         --------------               --------------
          Solids                      Particulate
```

```
    Data file name:  C:\Program Files\WinSLAMM\UDVSB.DAT          SLAMM Version V8.1
    Rain file name:  C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN       Particulate Solids Concentration file name:  C:\PROGRAM
FILES\WINSLAMM\BHAM.PSC
    Runoff Coefficient file name:  C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
                                                                  Particulate Residue Delivery file name:  C:\PROGRAM
FILES\WINSLAMM\DELIVERY.PRR
    Pollutant Relative Concentration file name:  C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
                                                                  Seed for random number generator:   42
    Study period starting date:  01/01/53                         Study period ending date:  12/31/89
    Date:  07-23-2000                                             Time:  19:33:17
    Fraction of each type of Drainage System serving study area:
      1.  Grass Swales 0
      2.  Undeveloped roadside 0
          Curb and Gutters, `valleys', or sealed swales in:
           3.  Poor condition (or very flat) 0
           4.  Fair condition 1
           5.  Good condition (or very steep) 0
    Site information:  UNDEVELOPED LAND, CURB AND GUTTERS, SANDY SOILS, BASELINE CONTROLS (NONE)

                           |<===== Areas for each Source (acres) =====>|
                           Resi-   Institu- Commercial Industrial  Open
                          dential   tional     Areas      Areas   Spaces
Source Area                Areas    Areas                          Areas         Freeway Source Area                   Area
(acres)

12345678901234567890123456789012345678901234567890123456789012345678901234567890
Roofs 1                    0.00      0.00      0.00      0.00      0.00         Pavd Lane & Shldr Area 1
0.00
Roofs 2                    0.00      0.00      0.00      0.00      0.00         Pavd Lane & Shldr Area 2
0.00
Roofs 3                    0.00      0.00      0.00      0.00      0.00         Pavd Lane & Shldr Area 3
0.00
Roofs 4                    0.00      0.00      0.00      0.00      0.00         Pavd Lane & Shldr Area 4
0.00
Roofs 5                    0.00      0.00      0.00      0.00      0.00         Pavd Lane & Shldr Area 5
0.00
Paved Parking/Storage 1    0.00      0.00      0.00      0.00      0.00         Large Turf Areas
0.00
Paved Parking/Storage 2    0.00      0.00      0.00      0.00      0.00         Undeveloped Areas
0.00
Paved Parking/Storage 3    0.00      0.00      0.00      0.00      0.00         Other Pervious Areas
0.00
Unpaved Prkng/Storage 1    0.00      0.00      0.00      0.00      0.00         Other Directly Conctd Imp
0.00
```

```
Unpaved Prkng/Storage 2    0.00      0.00      0.00      0.00      0.00          Other Partially Conctd Imp
0.00
Playground 1               0.00      0.00      0.00      0.00      0.00                                                  -
-------
Playground 2               0.00      0.00      0.00      0.00      0.00          Total
0.00
Driveways 1                0.00      0.00      0.00      0.00      0.00
Driveways 2                0.00      0.00      0.00      0.00      0.00
Driveways 3                0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 1          0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 2          0.00      0.00      0.00      0.00      0.00
Street Area 1              0.00      0.00      0.00      0.00      7.00
Street Area 2              0.00      0.00      0.00      0.00      1.00
Street Area 3              0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 1    0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Undeveloped Area           0.00      0.00      0.00      0.00      92.00
Small Landscaped Area 1    0.00      0.00      0.00      0.00      0.00
Small Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Small Landscaped Area 3    0.00      0.00      0.00      0.00      0.00
Isolated Area              0.00      0.00      0.00      0.00      0.00
Other Pervious Area        0.00      0.00      0.00      0.00      0.00
Other Dir Cnctd Imp Area   0.00      0.00      0.00      0.00      0.00
Other Part Cnctd Imp Area  0.00      0.00      0.00      0.00      0.00
                        --------  --------  --------  --------  --------
Total                   0.00      0.00      0.00      0.00      100.00


Total of All Source Areas             100.00
                                      ---------
Total of All Source Areas
     less All Isolated Areas          100.00
                                      =========

                   Source Area Control Practice Information
Land Use:  Open Space
   Street Area 1    Source area number:  138
            1.  Street Texture:  intermediate
            2.  Total study area street length (curb-miles):  2.7
            3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
            4.  Street Dirt Accumulation:
                  Default value used
   Street Area 2    Source area number:  139
            1.  Street Texture:  smooth
```

```
          2.  Total study area street length (curb-miles):  0.5
          3.  Initial Street Dirt Loading (lbs/curb-mi):  default value
          4.  Street Dirt Accumulation:
                Default value used
   Undeveloped Area    Source area number:  143
         The SCS Hydrologic Soil Type is Sandy

      Control Practice 1 :  Catchbasin Cleaning Controls
       1.  Total sump volume (cubic feet)=  1
       2.  Area served by catchbasins (acres)=  100
       3.  Percent of sump volume full at beginning of study period=  60 %
       4.  Average sump depth (feet)=  0
       5.  Number of times catchbasins cleaned each year=  0

Pollutants to be Analyzed and Printed:

         Pollutant Name               Pollutant Type
         --------------               --------------
          Solids                      Particulate
```

Freeway Areas

Freeways (FRYCB.DAT and FRYSB.DAT)

```
Data file name:  C:\Program Files\WinSLAMM\FRYCB.DAT          SLAMM Version V8.1
    Rain file name:  C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN       Particulate Solids Concentration file name:  C:\PROGRAM
FILES\WINSLAMM\BHAM.PSC
    Runoff Coefficient file name:  C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
                                                                  Particulate Residue Delivery file name:  C:\PROGRAM
FILES\WINSLAMM\DELIVERY.PRR
    Pollutant Relative Concentration file name:  C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
                                                                  Seed for random number generator:   42
    Study period starting date:  01/01/53                         Study period ending date:  12/31/89
    Date:  07-23-2000                                             Time:  19:25:53
    Fraction of each type of Drainage System serving study area:
      1.  Grass Swales 0
      2.  Undeveloped roadside 1
          Curb and Gutters, `valleys', or sealed swales in:
           3.  Poor condition (or very flat) 0
           4.  Fair condition 0
           5.  Good condition (or very steep) 0
    Site information:  FREEWAYS, UNDEVELOPED ROADSIDE, CLAYEY SOILS, BASELINE CONTROLS (NONE)

                           |<===== Areas for each Source (acres) =====>|
                           Resi-   Institu- Commercial Industrial  Open
                          dential   tional     Areas      Areas   Spaces
Source Area                Areas    Areas                          Areas         Freeway Source Area                     Area
(acres)

1234567890123456789012345678901234567890123456789012345678901234567890123456789O
Roofs 1                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 1
11.76
Roofs 2                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 2
17.65
Roofs 3                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 3
0.00
Roofs 4                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 4
0.00
Roofs 5                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 5
0.00
Paved Parking/Storage 1    0.00      0.00      0.00      0.00      0.00          Large Turf Areas
33.94
```

Paved Parking/Storage 2	0.00	0.00	0.00	0.00	0.00	Undeveloped Areas
33.60						
Paved Parking/Storage 3	0.00	0.00	0.00	0.00	0.00	Other Pervious Areas
0.00						
Unpaved Prkng/Storage 1	0.00	0.00	0.00	0.00	0.00	Other Directly Conctd Imp
2.39						
Unpaved Prkng/Storage 2	0.00	0.00	0.00	0.00	0.00	Other Partially Conctd Imp
0.66						
Playground 1	0.00	0.00	0.00	0.00	0.00	-

Playground 2	0.00	0.00	0.00	0.00	0.00	Total
100.00						
Driveways 1	0.00	0.00	0.00	0.00	0.00	
Driveways 2	0.00	0.00	0.00	0.00	0.00	
Driveways 3	0.00	0.00	0.00	0.00	0.00	
Sidewalks/Walks 1	0.00	0.00	0.00	0.00	0.00	
Sidewalks/Walks 2	0.00	0.00	0.00	0.00	0.00	
Street Area 1	0.00	0.00	0.00	0.00	0.00	
Street Area 2	0.00	0.00	0.00	0.00	0.00	
Street Area 3	0.00	0.00	0.00	0.00	0.00	
Large Landscaped Area 1	0.00	0.00	0.00	0.00	0.00	
Large Landscaped Area 2	0.00	0.00	0.00	0.00	0.00	
Undeveloped Area	0.00	0.00	0.00	0.00	0.00	
Small Landscaped Area 1	0.00	0.00	0.00	0.00	0.00	
Small Landscaped Area 2	0.00	0.00	0.00	0.00	0.00	
Small Landscaped Area 3	0.00	0.00	0.00	0.00	0.00	
Isolated Area	0.00	0.00	0.00	0.00	0.00	
Other Pervious Area	0.00	0.00	0.00	0.00	0.00	
Other Dir Cnctd Imp Area	0.00	0.00	0.00	0.00	0.00	
Other Part Cnctd Imp Area	0.00	0.00	0.00	0.00	0.00	
	--------	--------	--------	--------	--------	
Total	0.00	0.00	0.00	0.00	0.00	

Total of All Source Areas 100.00

Total of All Source Areas
less All Isolated Areas 100.00
=========

Source Area Control Practice Information

Land Use: Freeways

Pavd Lane & Shldr Area 1 Source area number: 151

1. Pavement texture: smooth

```
          2.  Average daily traffic (# vehicles/day):   15000
          3.  Highway length (miles):   2.43
          4.  Initial street dirt loading (lbs/curb-mi):  default value:  620.1882 lbs.
   Pavd Lane & Shldr Area 2    Source area number:  152
          1.  Pavement texture:  intermediate
          2.  Average daily traffic (# vehicles/day):   15000
          3.  Highway length (miles):   3.62
          4.  Initial street dirt loading (lbs/curb-mi):  default value:  923.9018 lbs.
   Large Turf Areas    Source area number:  156
       The SCS Hydrologic Soil Type is Clayey
```

Pollutants to be Analyzed and Printed:

Pollutant Name	Pollutant Type
Solids	Particulate

```
    Data file name:  C:\Program Files\WinSLAMM\FRYSB.DAT          SLAMM Version V8.1
    Rain file name:  C:\PROGRAM FILES\WINSLAMM\BHAM5289.RAN       Particulate Solids Concentration file name:  C:\PROGRAM
FILES\WINSLAMM\BHAM.PSC
    Runoff Coefficient file name:  C:\PROGRAM FILES\WINSLAMM\RUNOFF.RSV
                                                                  Particulate Residue Delivery file name:  C:\PROGRAM
FILES\WINSLAMM\DELIVERY.PRR
    Pollutant Relative Concentration file name:  C:\PROGRAM FILES\WINSLAMM\BHAM.PPD
                                                                  Seed for random number generator:   42
    Study period starting date:  01/01/53                         Study period ending date:  12/31/89
    Date:  07-23-2000                                             Time:  19:26:07
    Fraction of each type of Drainage System serving study area:
      1.  Grass Swales 0
      2.  Undeveloped roadside 1
          Curb and Gutters, `valleys', or sealed swales in:
           3.  Poor condition (or very flat) 0
           4.  Fair condition 0
           5.  Good condition (or very steep) 0
    Site information:  FREEWAYS, UNDEVELOPED ROADSIDE, SANDY SOILS, BASELINE CONTROLS (NONE)

                          |<===== Areas for each Source (acres) =====>|
                           Resi-   Institu- Commercial Industrial  Open
                          dential   tional     Areas      Areas   Spaces
Source Area                Areas    Areas                          Areas         Freeway Source Area                   Area
(acres)

1234567890123456789012345678901234567890123456789012345678901234567890
Roofs 1                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 1
11.76
Roofs 2                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 2
17.65
Roofs 3                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 3
0.00
Roofs 4                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 4
0.00
Roofs 5                    0.00      0.00      0.00      0.00      0.00          Pavd Lane & Shldr Area 5
0.00
Paved Parking/Storage 1    0.00      0.00      0.00      0.00      0.00          Large Turf Areas
33.94
Paved Parking/Storage 2    0.00      0.00      0.00      0.00      0.00          Undeveloped Areas
33.60
Paved Parking/Storage 3    0.00      0.00      0.00      0.00      0.00          Other Pervious Areas
0.00
Unpaved Prkng/Storage 1    0.00      0.00      0.00      0.00      0.00          Other Directly Conctd Imp
2.39
```

```
Unpaved Prkng/Storage 2    0.00      0.00      0.00      0.00      0.00          Other Partially Conctd Imp
0.66
Playground 1               0.00      0.00      0.00      0.00      0.00                                           -
-------
Playground 2               0.00      0.00      0.00      0.00      0.00          Total
100.00
Driveways 1                0.00      0.00      0.00      0.00      0.00
Driveways 2                0.00      0.00      0.00      0.00      0.00
Driveways 3                0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 1          0.00      0.00      0.00      0.00      0.00
Sidewalks/Walks 2          0.00      0.00      0.00      0.00      0.00
Street Area 1              0.00      0.00      0.00      0.00      0.00
Street Area 2              0.00      0.00      0.00      0.00      0.00
Street Area 3              0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 1    0.00      0.00      0.00      0.00      0.00
Large Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Undeveloped Area           0.00      0.00      0.00      0.00      0.00
Small Landscaped Area 1    0.00      0.00      0.00      0.00      0.00
Small Landscaped Area 2    0.00      0.00      0.00      0.00      0.00
Small Landscaped Area 3    0.00      0.00      0.00      0.00      0.00
Isolated Area              0.00      0.00      0.00      0.00      0.00
Other Pervious Area        0.00      0.00      0.00      0.00      0.00
Other Dir Cnctd Imp Area   0.00      0.00      0.00      0.00      0.00
Other Part Cnctd Imp Area  0.00      0.00      0.00      0.00      0.00
                        --------  --------  --------  --------  --------
Total                   0.00      0.00      0.00      0.00      0.00


Total of All Source Areas               100.00
                                        ---------
Total of All Source Areas
     less All Isolated Areas            100.00
                                        =========

                   Source Area Control Practice Information
Land Use:  Freeways
   Pavd Lane & Shldr Area 1    Source area number:  151
            1.  Pavement texture:  smooth
            2.  Average daily traffic (# vehicles/day):   15000
            3.  Highway length (miles):   2.43
            4.  Initial street dirt loading (lbs/curb-mi):  default value:  620.1882 lbs.
   Pavd Lane & Shldr Area 2    Source area number:  152
            1.  Pavement texture:  intermediate
            2.  Average daily traffic (# vehicles/day):   15000
```

3. Highway length (miles): 3.62
4. Initial street dirt loading (lbs/curb-mi): default value: 923.9018 lbs.

Large Turf Areas   Source area number: 156

The SCS Hydrologic Soil Type is Sandy

Pollutants to be Analyzed and Printed:

Pollutant Name	Pollutant Type
Solids	Particulate

Appendix 5-B: WinSLAMM Algorithm Documentation

Introduction

This discussion describes how the program is structured. The following subsection discusses the input data requirements of the program. The last two subsections describe how the model calculates runoff and pollutant loadings, and the output formats available.

Data Entry

The graphical user interface allows you to create, edit, and print WinSLAMM data files. This subsection discusses the kinds of information needed to create a WinSLAMM data file. This includes information on both the different source area parameters, as well as a brief discussion of the control devices available in the model. Five main areas of data are needed to run WinSLAMM. They are the “Land Uses”, the “Catchbasin or Drainage Controls”, the “Outfall Controls”, the “Other Pollutant Analysis Selection”, and the “File Name Information”, and are described in the following discussion.

Table 5-29 lists the six land uses. Each one of these land uses, except Freeways, contains 14 source area types. Most of the source area types are listed more than once to account for different characteristics in a land use. The Freeways land use description has six source area types and a total of 10 available source areas. Table 5-30 lists the source areas and the number of each of the source areas available in each land use.

Table 5-29. SLAMM5 Land Uses

1. Residential Areas
2. Institutional Areas
3. Commercial Areas
4. Industrial Areas
5. Open Space Areas
6. Freeways

Table 5-30. Source Areas

Source Area	Number Available in Each Land Use
Roofs	5
Paved Parking/Storage	3
Unpaved Parking/Storage	2
Playgrounds	2
Driveways	3
Sidewalks	2
Street Areas/Alleys	3
Large Landscaped Areas	2
Undeveloped Areas	1
Small Landscaped Areas	3
Isolated Areas	1
Other Pervious Area	1
Other Directly Connected Impervious Area	1
Other Partially Connected Impervious Area	1
Paved Freeway and Shoulder Area (F)	5
Large Turf Area (F)	1

(F) indicates available in Freeway Land Use area only

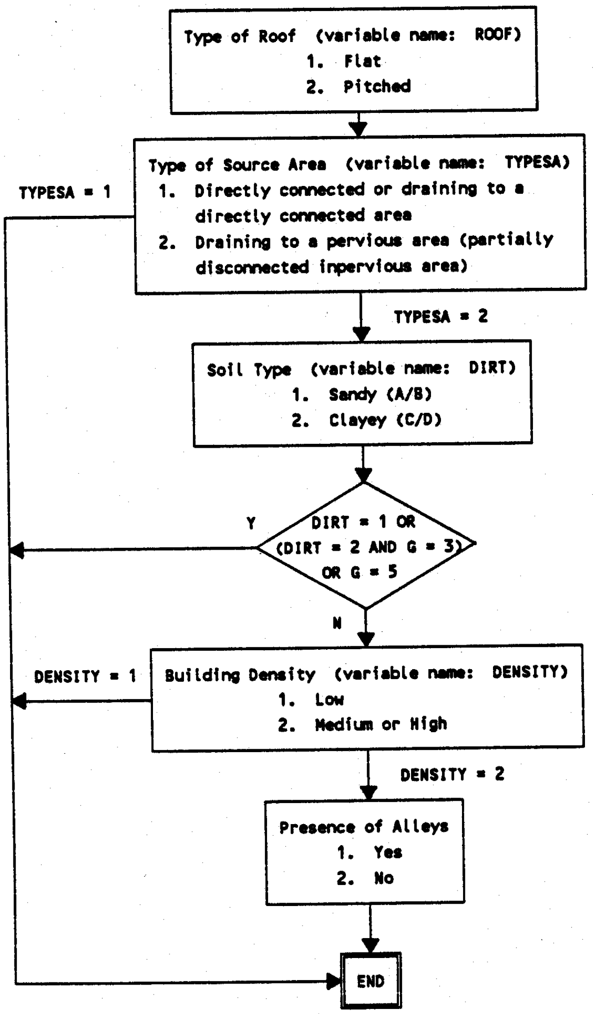
There are two kinds of information required for each source area: the source area (in acres), and specific information about the characteristics, or parameters, of the source area. The various parameters are listed in Table 5-31. Each source area might need none, some, or all of this information. Figures 5-17 to 5-22 are flow charts that completely describe which parameters the model needs for each source area. The directly connected impervious areas are completely described by the name and no other information is required by the model for those source areas.

Table 5-31. "Other Information" Needed in a Source Area

1. Type of roof - pitched or flat
2. Source area connection to pavement drainage – directly connected, or unconnected/draining to a pervious area
3. Soil type - Sandy (A/B) or Clayey (C/D)
4. Building density - low or medium/high
5. Presence of alleys - yes or no
6. Pavement texture - smooth to very rough
7. Total street length - curb-miles
8. Street dirt accumulation equation coefficients (or let SLAMM5 determine based on land use)
9. Initial street dirt loading (or let SLAMM5 determine based on street texture and street cleaning frequency)
10. Average daily traffic - vehicles/day (freeway source area only)

"Catchbasin or Drainage Controls" are runoff and particulate residue loading control devices, and include infiltration devices, grass swales, and catchbasins. These devices modify the quantity of runoff and particulate residue after they are calculated for each source area and combined, but before they reach the outfall. "Outfall Controls" are runoff and suspended solids reduction devices. They are used to reduce runoff volumes and loadings at the outfall. These devices include wet detention ponds and infiltration devices. The "Other Pollutant Analysis" section allows the user to identify the other pollutants that are evaluated by WinSLAMM.

Figure 5-17. Source Area Information: Roofs



G: Land Use Numbers

1. Residential Areas
2. Institutional Areas
3. Commercial Areas
4. Industrial Areas
5. Open Space Areas
6. Freeways

Figure 5-18. Source Area Information: Paved parking/storage; unpaved parking/storage; playgrounds; driveways; and sidewalks

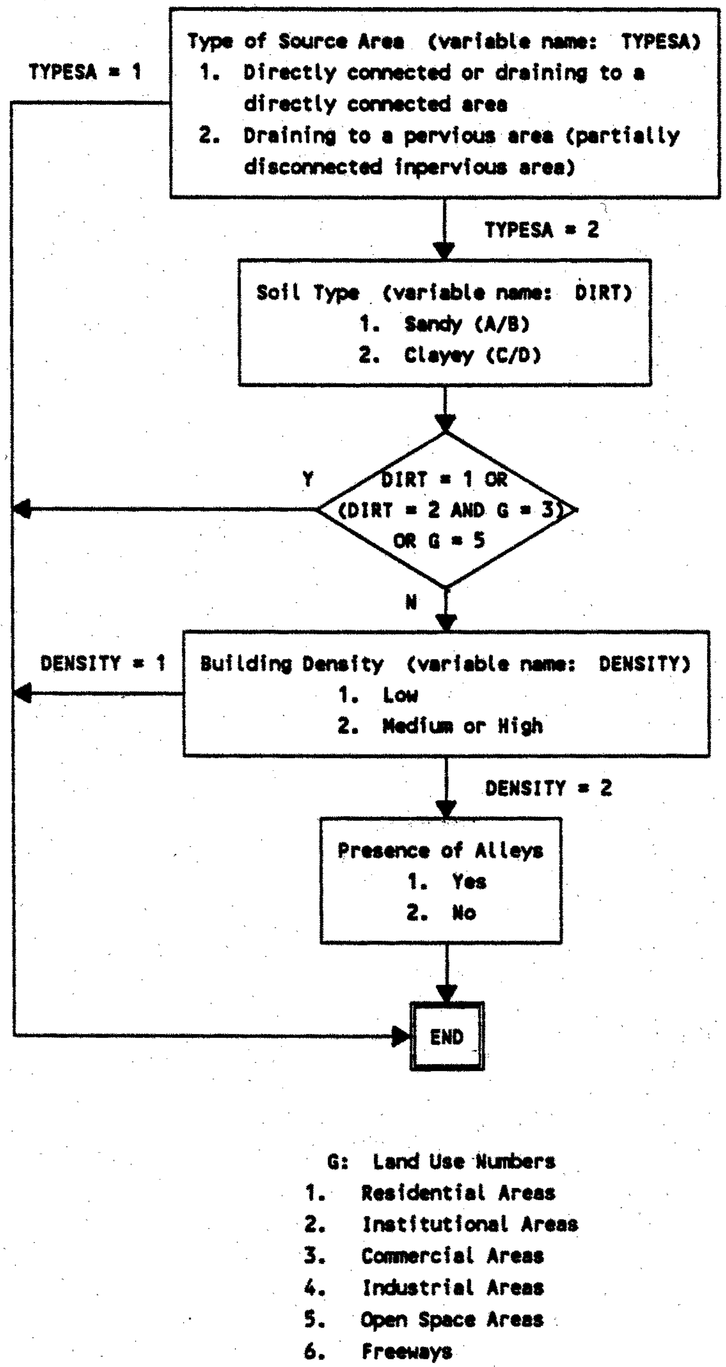


Figure 5-19. Source Area Information: Streets and alleys

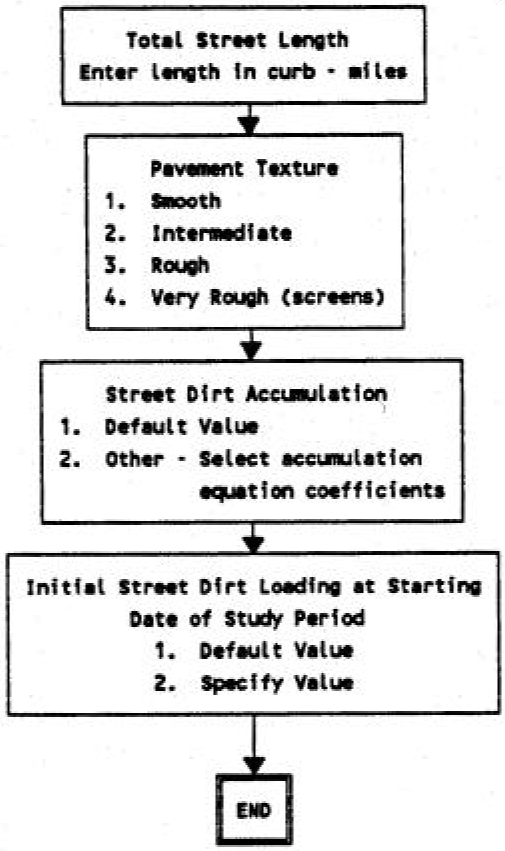


Figure 5-20. Source Area Information: Unpaved areas; other pervious areas; large landscaped areas; large turf areas; and undeveloped areas

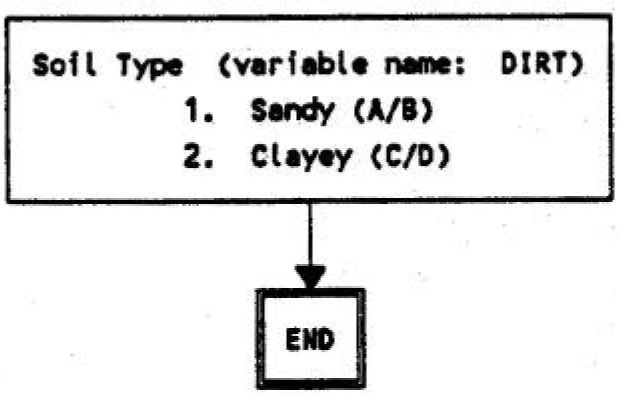


Figure 5-21. Source Area Information: Other area: partially connected impervious areas

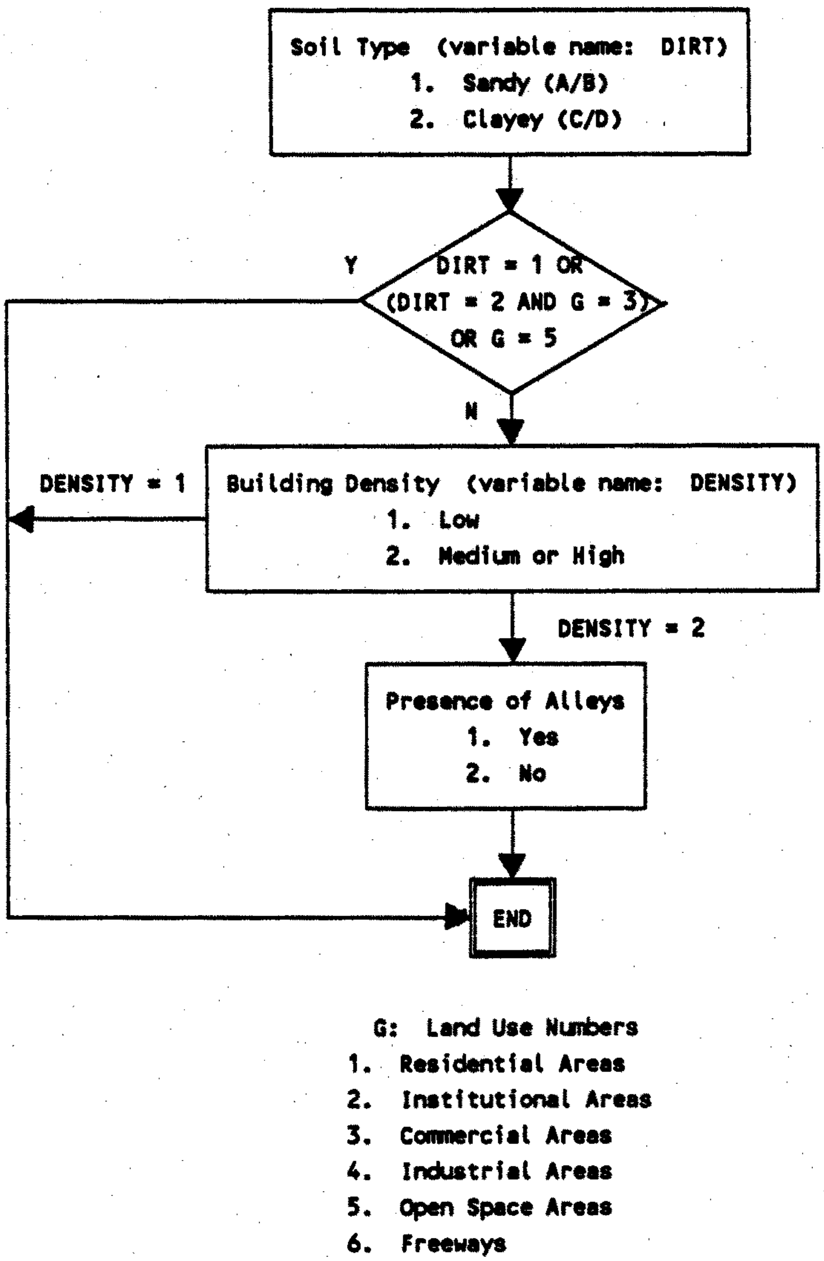
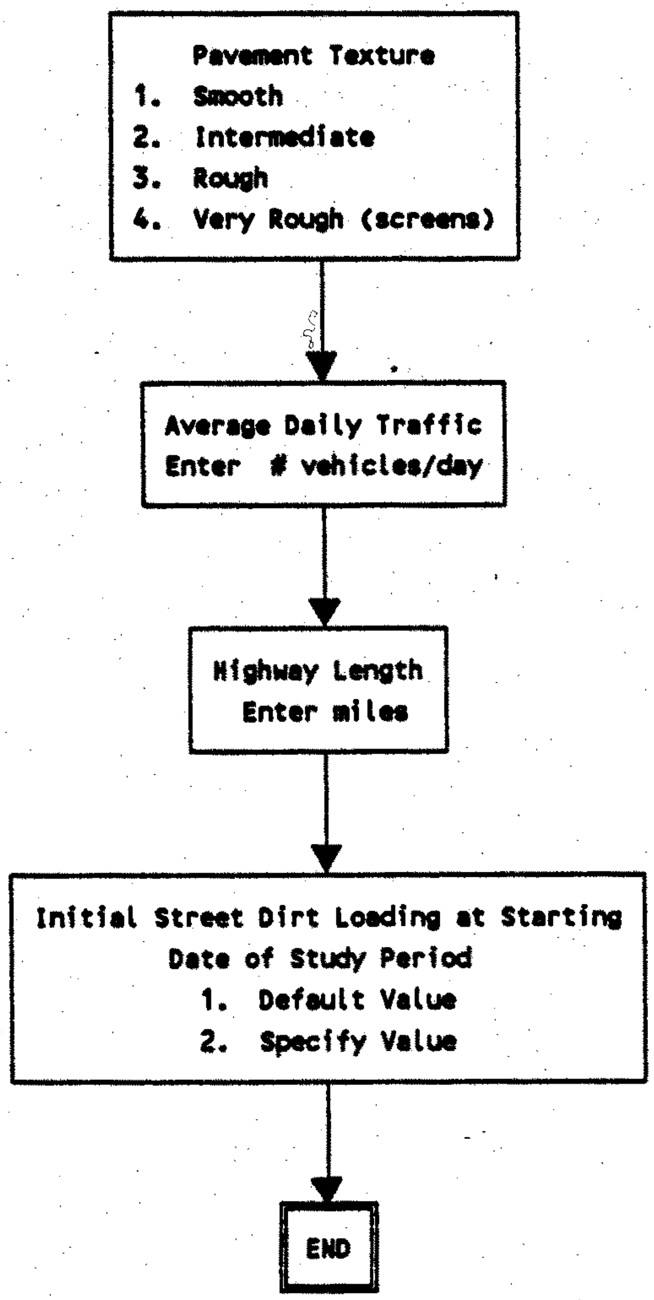


Figure 5-22. Source Area Information: Paved lane and shoulder areas (freeways)



Control Devices

There are seven different major categories of control devices available within SLAMM5 to reduce runoff volume and pollutant loadings. The following paragraphs describe each device. The algorithms for each device are described in detail later in this section. The control devices included in SLAMM5 are:

1. Wet Detention Ponds
2. Porous Pavement
3. Infiltration Devices
4. Other Devices (source areas)
5. Street Cleaning
6. Catchbasin Cleaning
7. Grass Swales
8. Other Devices (outfall)

Wet detention ponds. The wet detention ponds are the most complex control devices in the model. The design for each pond includes an outlet device description and a stage-area curve describing the incremental pond volume. The algorithm is based on the storage-indication reservoir routing subroutine in HE5-1 and in TR-20 and is summarized by McCuen (1982). The governing storage equation is:

Inflow - Outflow = Change in Storage/Change in Time

The inflow is calculated from a triangular hydrograph developed from the depth and duration of the runoff from each rain. The outflow is calculated from the outfall structure and the combined rating curve. The connection between the two is made through a storage indication curve.

The incremental upflow velocities are calculated from the incremental pond area and outflow values. These velocities are then used to find the quantity of particulates which settle in the pond. These values are based on the particle sizes entered in the critical particle size parameter file using the Parameter Module. If any detention pond should overflow ("fail") during a rain event, the output will list the land use and source area where the overflow occurred.

Porous pavement. Porous Pavement flow volume reductions are based solely on the infiltration rate through the pavement times the duration of the event (compared to the rain intensity). The algorithm calculates the fraction of the total rain which is infiltrated into the ground by the pavement.

Infiltration devices. Infiltration device flow volume reductions are due to infiltration from both the bottom and sides of an infiltration device. The amount of infiltration is a function of the device area and the runoff volume and duration.

Other controls. The "Other" volume and loading reduction device only allows the user to enter a fixed fraction (from 0 to 1) as a runoff volume or particulate reduction value. This fraction is not a function of any other parameter except at the outfall, where the loading reduction may be entered as a function of rain depth.

Street cleaning. Street cleaning is part of the street loading subroutine. It is applied by setting street cleaning frequencies and durations in the input module for each street source area. The subroutine assumes that there are two possible street events which could occur over time: 1) street cleaning, and 2) washoff. Street dirt accumulates during the time between each street event. Then, when the time period between any two street events is up, the algorithm makes the appropriate street cleaning or street washoff event calculation.

Catchbasin cleaning. The catchbasin cleaning routine is used immediately before the outfall calculations and removes particulate loadings from the runoff. The user must enter the size of the basin as well as cleaning dates. The device will remove solids from the indicated source areas until it is full. At that point, no more solids are removed until the device is cleaned. The solids removal process then begins again.

Grass swales. Grass swales reduce runoff through infiltration. The reduction is a function of the dynamic percolation rate, the rain duration, the volume of runoff entering the swale, and the area of the swale .

Data File Format

WinSLAMM Version 8.0 creates either one or two input data files for use in the calculation module. It will always create a file with the extension .DAT. This file includes the source area, control device (except detention pond), and parameter file name information. If there are any detention ponds used as control devices, it also creates another input data file with the extension . SDP. Version 8.1 will combine the two files into one .DAT file.

Calculation/Output Module – Calculations

Calculation/Output Module Overview

The subprograms for WinSLAMM calculations calculate the runoff volumes and particulate loadings for all source areas and at the outfall and evaluate the effects of any control devices at the source areas and at the outfall.

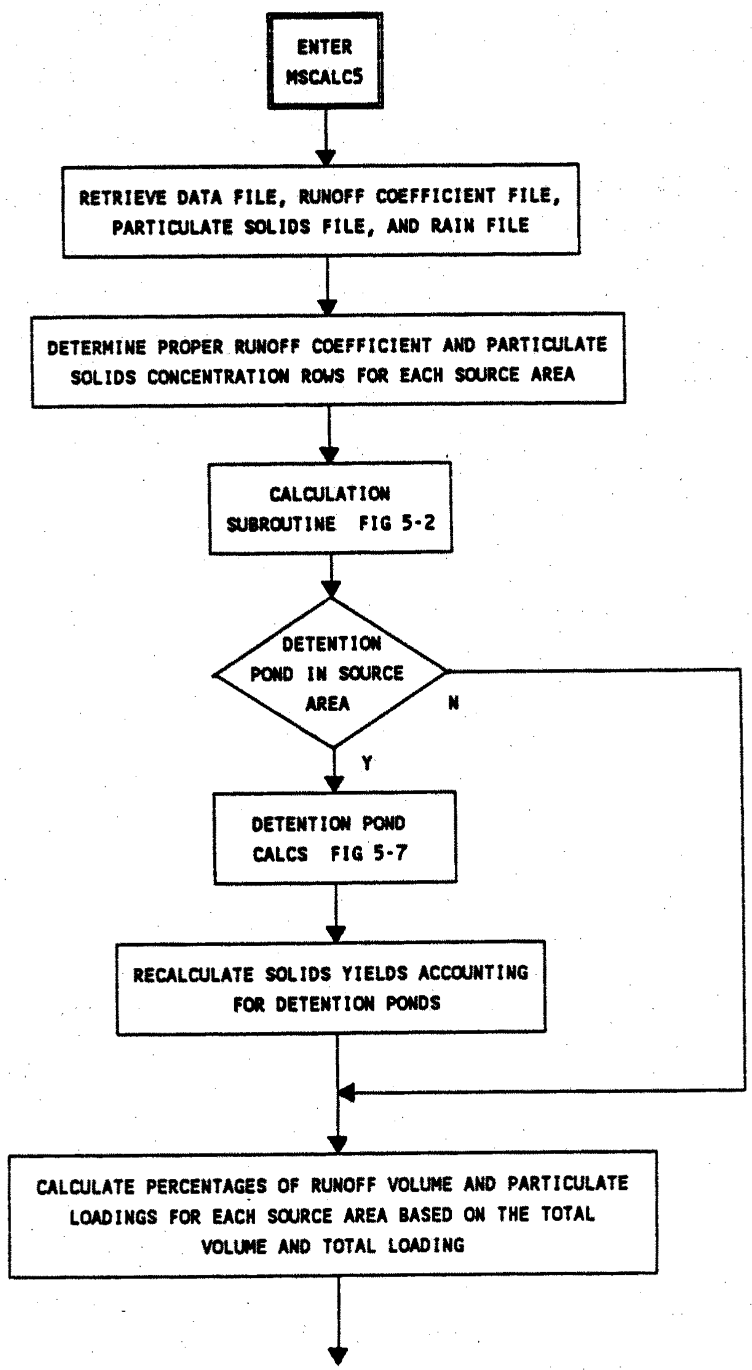
Once all calculations are completed, WinSLAMM produces a number of temporary output variables. These variables contain the runoff volumes, particulate loadings, and other information generated by the model. They are used to calculate the loadings for other pollutants (besides suspended solids) and print or save the results of the calculations in the desired format.

The following flow charts describe the calculations module algorithms and equations. Figure 5-23 is the main flow chart for the calculations program of the main module. All the other flow charts in this section are connected to this main flow chart. Figure 5-24 illustrates the main calculation subroutines. This subroutine calculates runoff volumes and directs the program to the appropriate control device subroutines for infiltration, porous pavement, or "other" control methods (Figures 5-25 to 5- 27). It also routes the program to the paved lane and shoulder subroutine and to the street and alley loading subroutine. The street and alley loading subroutine can route program control to either the street cleaning subroutine or the washoff subroutine.

WinSLAMM calculates the effects of detention ponds after completing the main calculation subroutines. This process is developed as a control device in Figure 5-28. After adjusting the loading results for the detention pond particulate reductions, WinSLAMM determines the effects of grass swales (Figure 5-29) and catchbasins (Figure 5-30). It then calculates the effects of infiltration, detention ponds, and the "other" control device (which is, for the outfall, a function of rain depth) at the outfall.

The variables in each flow chart are defined in the variable list on the facing page. The flow charts are not intended to give a detailed description of the program structure. They should, however, help the user to understand how the calculation algorithms are structured in the code. Most of the variable subscripts have been eliminated to simplify the flow chart. Double lined boxes with a RETURN inside indicate the end of a subroutine. You should return to the box that sent you to the subroutine and continue from there.

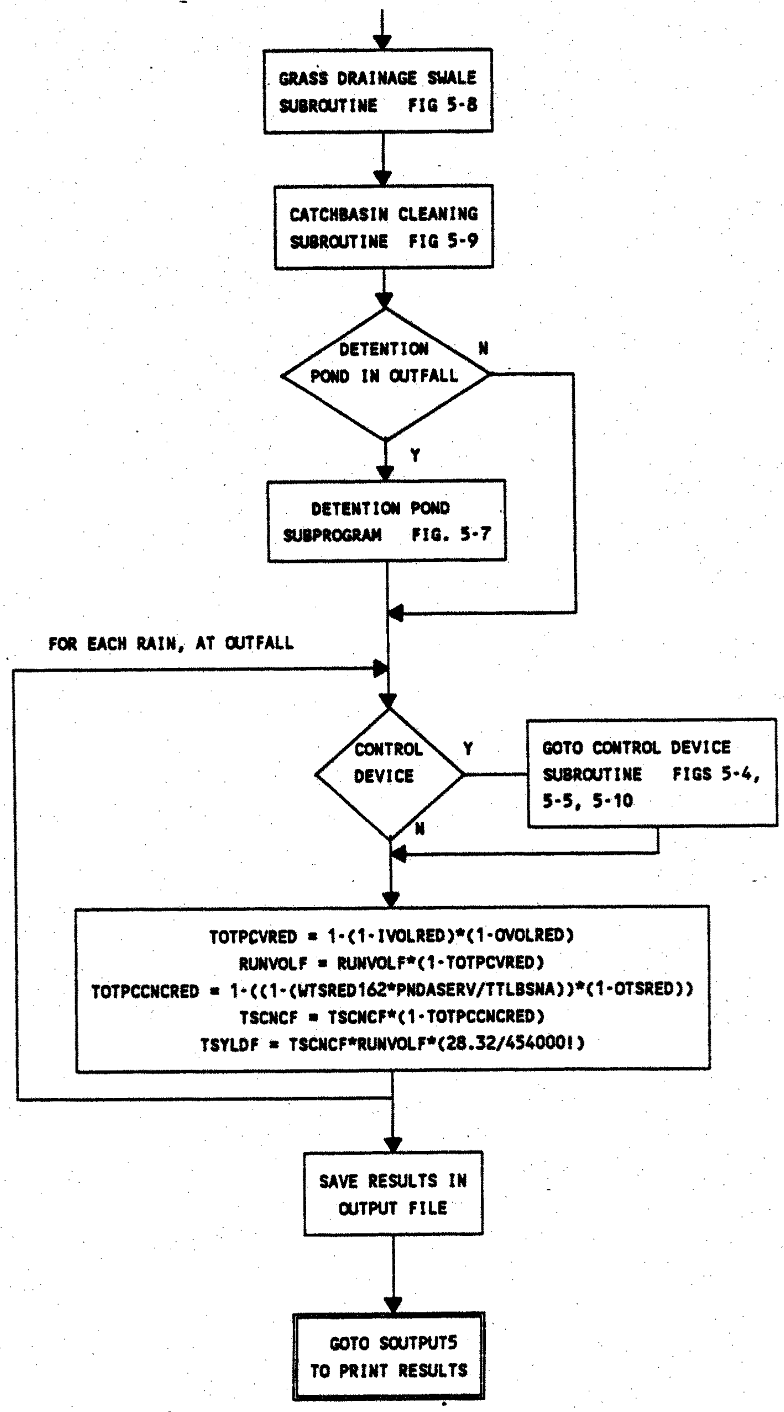
Figure 5-23. MSCALC program module flow chart (referred to as Figure 5-1 in some flow charts).



Variable Definitions for Figure 5-23:

IVOLRED	Infiltration device volume reduction [fraction]
OVOLRED	Other control device volume reduction [fraction]
PNDASERV	Area served by detention pond [acres]
RUNVOLF	Source area runoff volume for a rain event [cu ft]
SOUTPUT5	Output program which prints the SLAMM5 calculation module results
TOTPCCNCRED	Total percentage reduction in concentration
TOTPCVRED	Total percentage volume reduction
TTLBSNA	Total basin area, the sum of source areas 1 to 160
TSCNCF	Particulate solid concentration [mg/L]
TSYLDF	Particulate solid yield [lbs]
WTSRED162	Weighted average total particulate solid reduction at outfall. Equivalent to WTSRED(a,s) for outfall from Figure 5-14

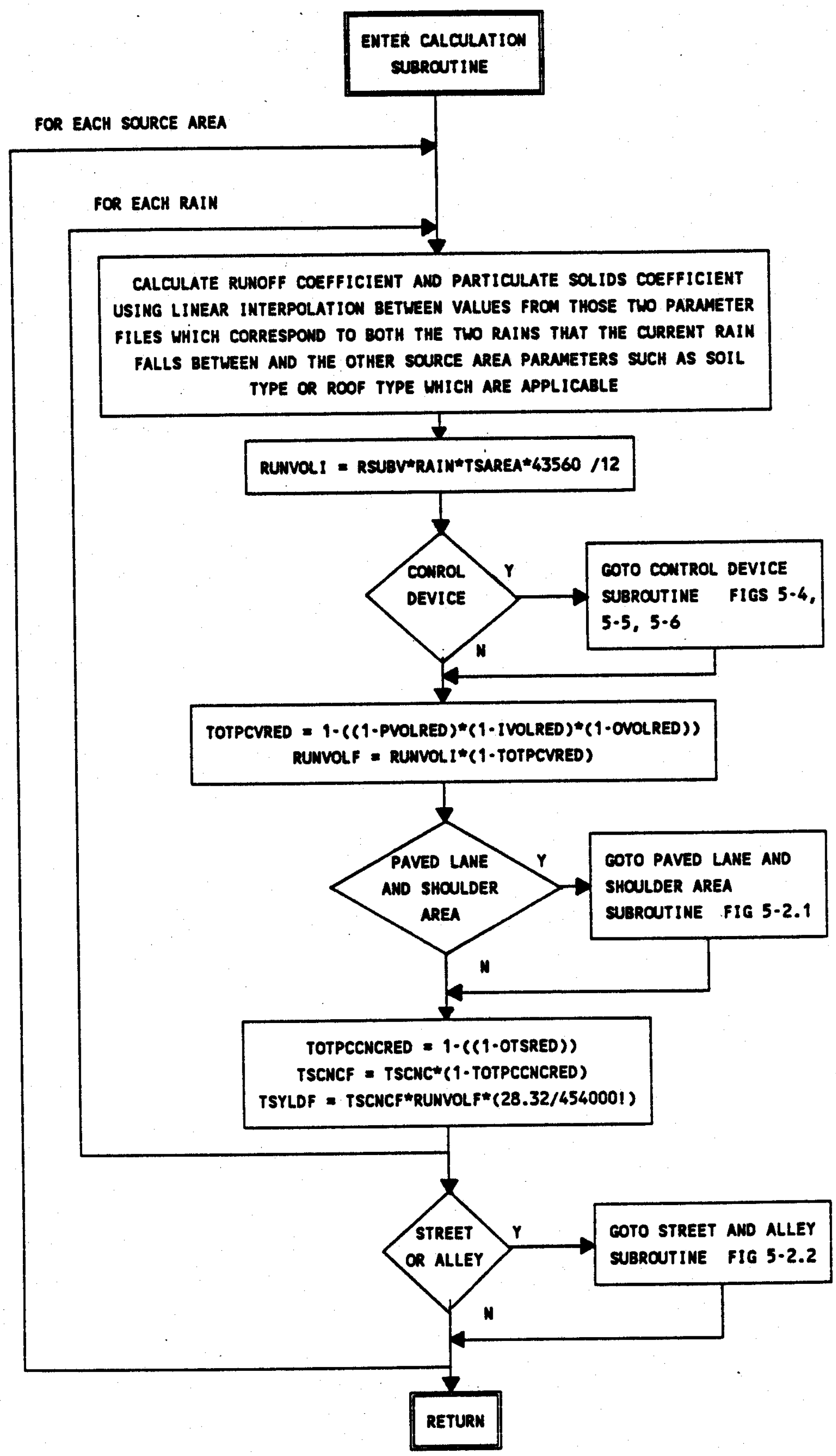
Continuation of Figure 5-23 (referred to as Figure 5-1 in some flow charts).



Variable Definitions for Figure 5-24:

IVOLRED	Infiltration device flow volume reduction [fraction]
OTSRED	Other control device particulate solids reduction [fraction]
OVOLRED	Other control device volume reduction [fraction]
PVOLRED	Porous pavement control device flow volume reduction [fraction]
RAIN	Rain depth [in]
RSUBV	Runoff coefficient for source area and rain depth
RUNVOLF	Source area runoff volume for a rain event [cu ft]
TOTPCCNCRED	Total percentage reduction in concentration
TOTPCVRED	Total percentage volume reduction
TSAREA	Total source area [acres]
TSCNCF	Particulate solid concentration [mg/L]
TSYLDF	Particulate solid yield [lbs]

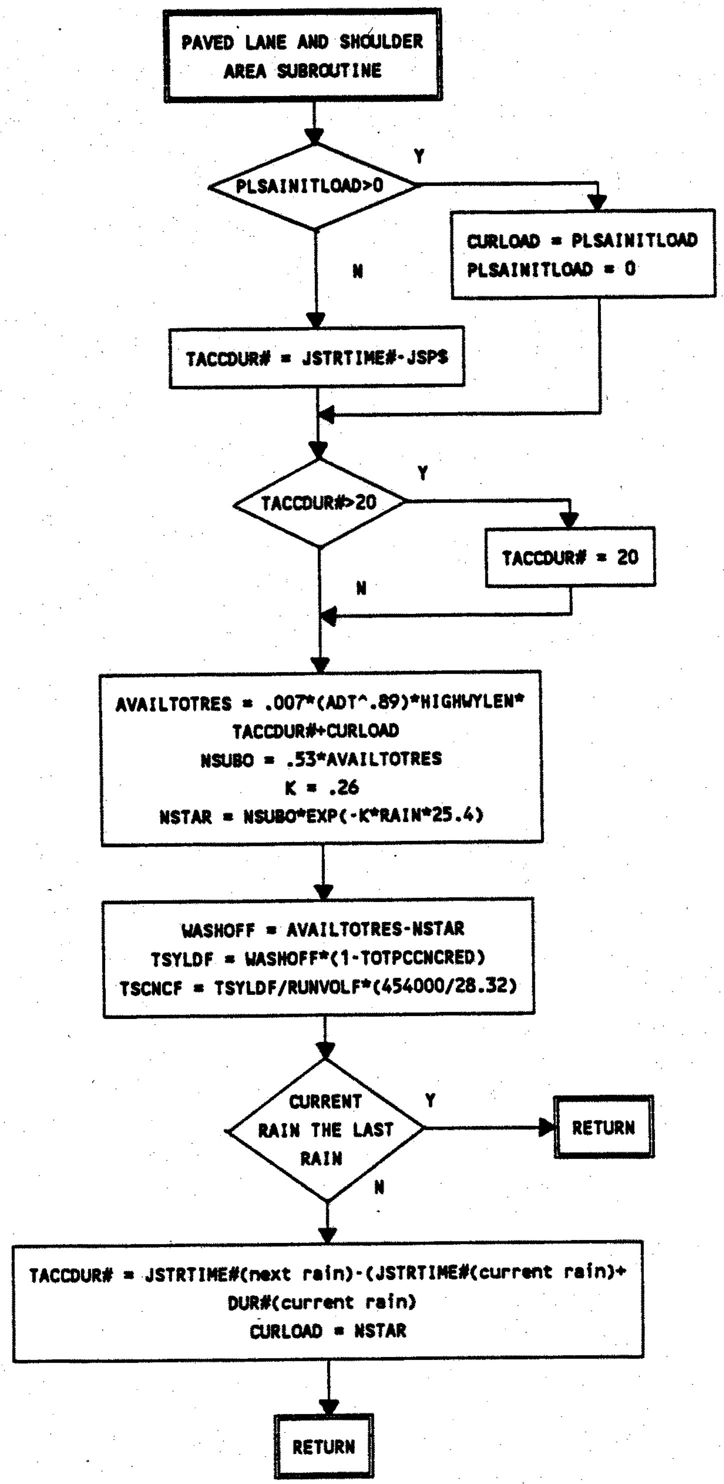
Figure 5-24. Calculations subroutine (referred to as Figure 5-2 in some flow charts).



Variable Definitions for Figure 5-25:

ADT	Average daily traffic [vehicles/day]
AVAILTOTRES	Total residue available for washoff
CURLOAD	The street loading which occurs immediately after a rain event.
DUR	Duration of rain event [days]
HIGHWYLEN	Highway length [curb miles]
JSP	The study period starting date in terms of the Julian calendar
JSTRTIME	The starting time of a rain event in terms of the Julian calendar
K	Proportionality constant used in loading calculations [l/mm]. Its a function of total street loading and rain intensity.
PLSAINITLOAD	Paved lane and shoulder area initial load [lbs]
RAIN	Rain event depth [in].
RUNVOLF	Source area runoff volume for a rain event [cu ft]
TACCDUR	Street loading accumulation time: the time between the end of one rain and the beginning of the next.
TOTPCCNCRED	Total percentage reduction in concentration
TSCNCF	Source area particulate solids concentration [mg/L]
TSYLDF	Source area particulate solids yield [lbs].
UNAVAILAFTRAIN	Total loading unavailable for washoff after a rain
WASHOFF	Street dirt contained in runoff.

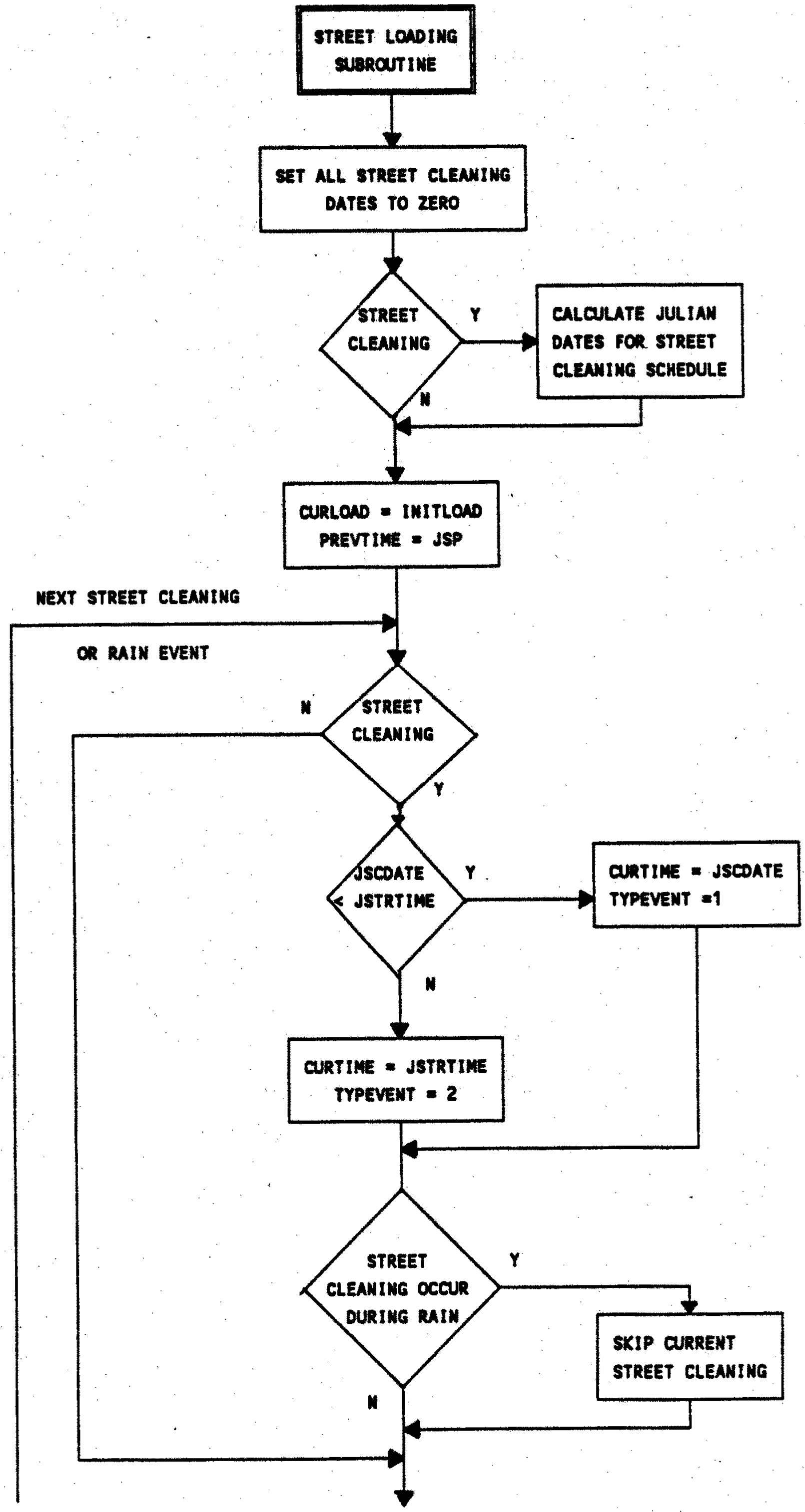
Figure-5-25 Paved lane and shoulder area flow chart (referred to as Figure 5-2.1 in some flow charts).



Variable Definitions for Figure 5-26:

CURLOAD	The street loading which occurs immediately after a rain event.
CURTIME	The time of the current rain event
INITLOAD	Initial street dirt loading value [lbs/curb mi].
JSCDATE	The time a street cleaning event occurs in terms of the Julian calendar.
JSP	The study period starting date in terms of the Julian calendar.
JSTRTIME	The starting time of a rain event in terms of the Julian calendar.
PREVTIME	Julian date of the event before the current event.
RAIN	Rain event depth [in] .
TYPEVENT	Marker to indicate type of event. 1: street cleaning; 2: rain event

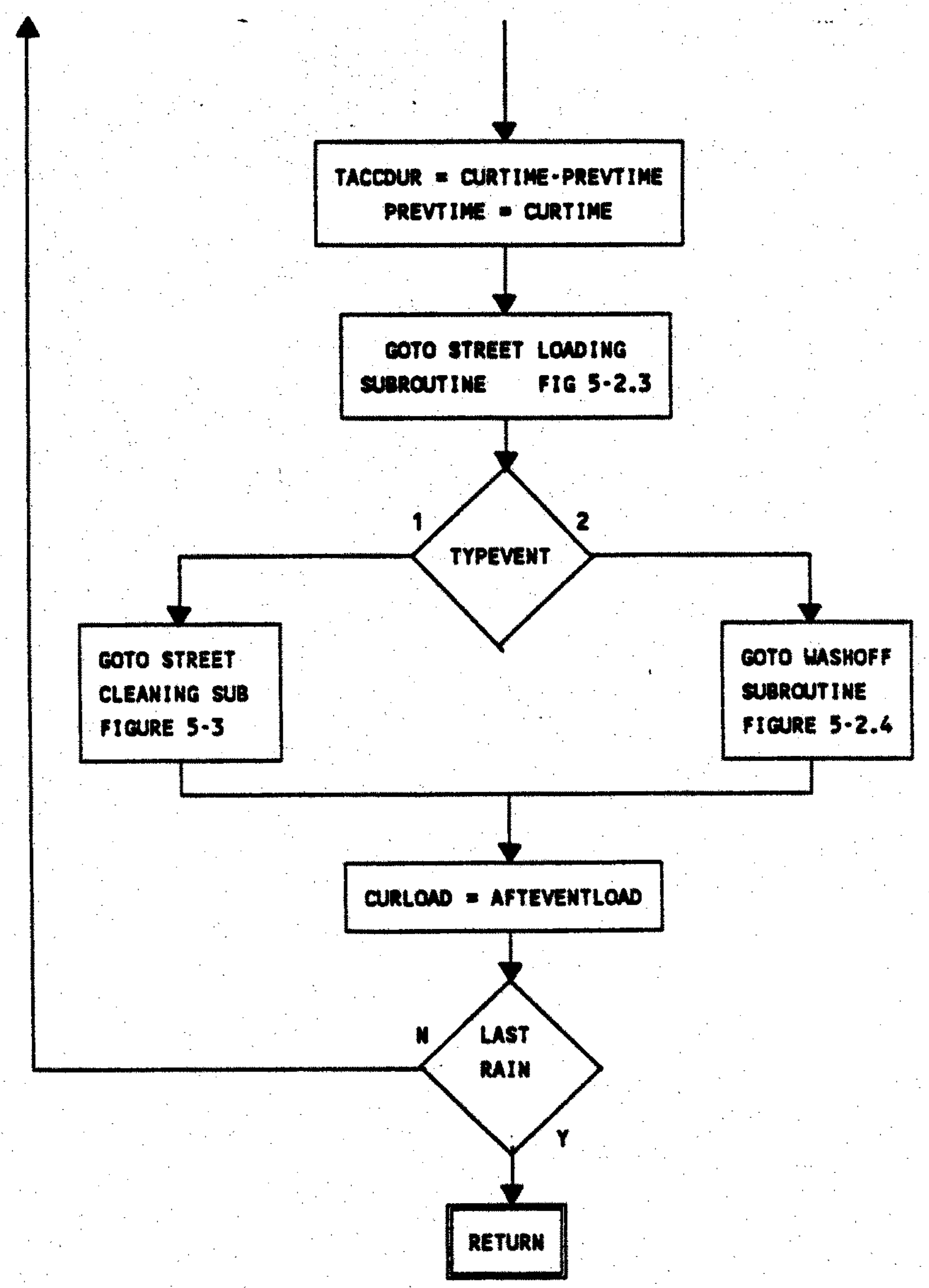
Figure 5-26. Street and alley subroutine flow chart (referred to as Figure 5-2.2 in some flow charts).



Variable Definitions for Figure 5-26 (Continued):

AFTFVENTLOAD	Total loading after the event [lbs].
CURLOAD	The street loading which occurs immediately after a rain event.
CURTIME	The time of the current rain event.
INITLOAD	Initial street dirt loading value [lbs/curb mi].
PREVTIME	Julian date of the event before the current event.
RAIN	Rain event depth [in].
TACCDUR	Street loading accumulation time: the time between the end of one rain and the beginning of the next.
TYPEVENT	Marker to indicate type of event. 1: street cleaning: 2: rain event.

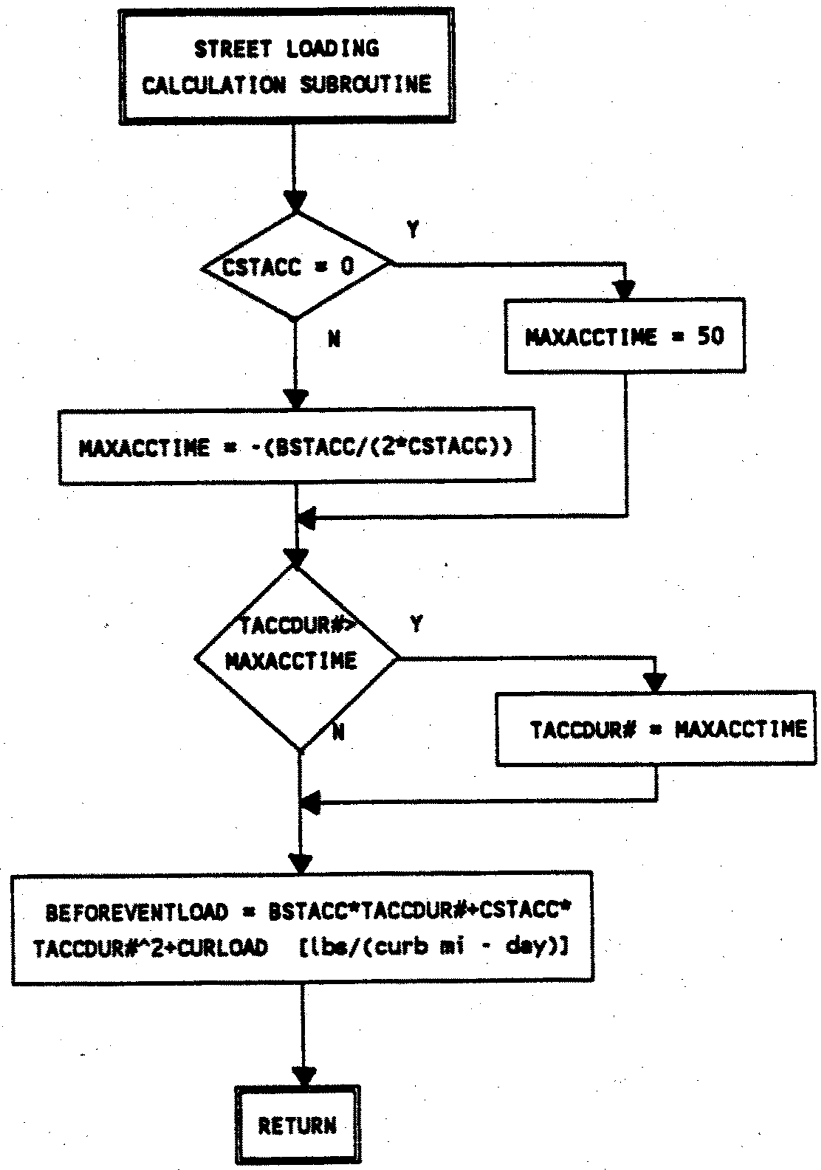
Continuation of Figure 5-26 (referred to as Figure 5-2.2 in some flow charts).



Variable Definitions for Figure 5-27:

BEFOREVENTLOAD	Street dirt loading [lbs/curb-mi - day] on the street immediately before the rain or street cleaning event.
BSTACC	First order coefficient in quadratic equation describing street dirt accumulation (y=ASTACC + BASTACC*x + CASTACC *x*x)
CSTACC	Second order coefficient in quadratic equation describing street dirt accumulation (y=ASTACC + BASTACC*x + CASTACC *x*x)
CURLOAD	The street loading which occurs immediately after a rain event.
MAXACCTIME	Maximum allowable time for street dirt loading accumulation. Equation is the derivative of the loading equation that calculated BEFORAINLOAD.
TACCDUR	Street loading accumulation time: the time between the end of one rain and the beginning of the next.

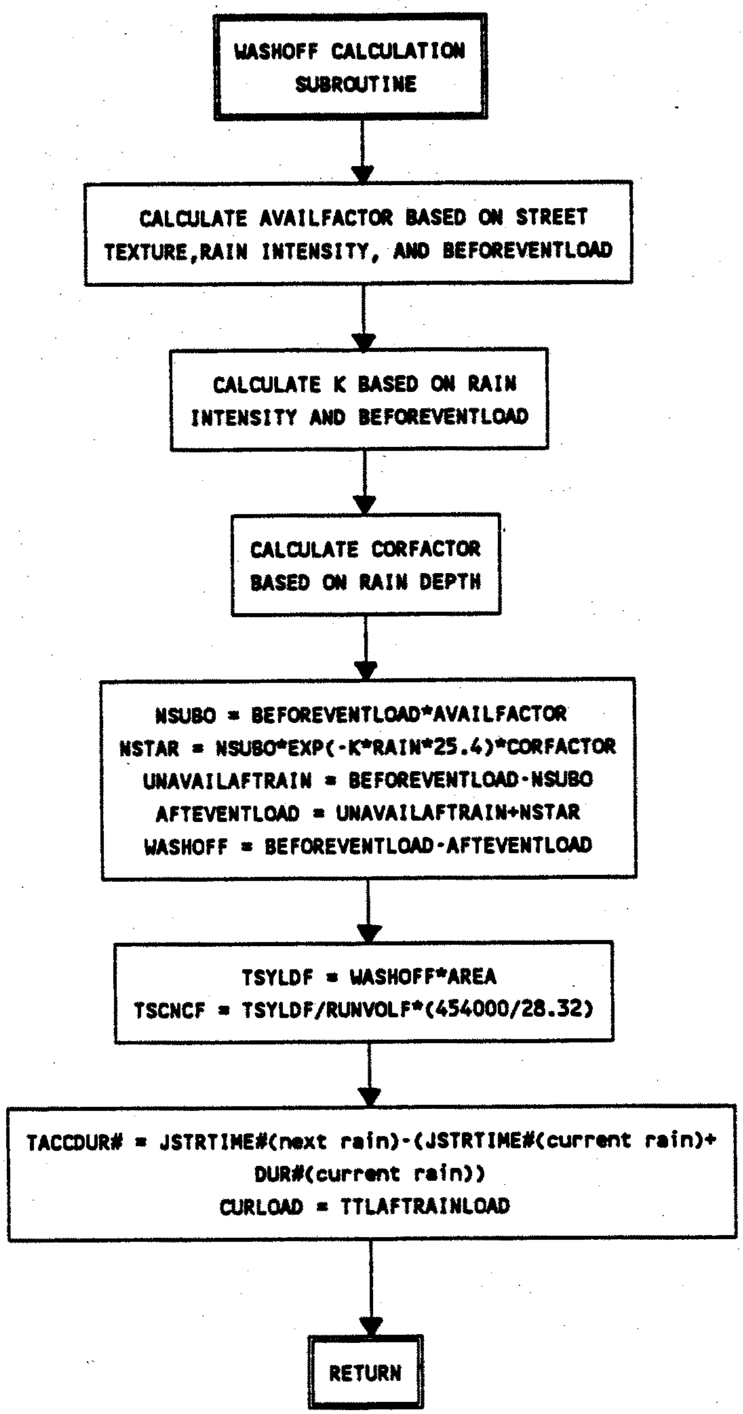
Figure 5-27. Street dirt loadings calculation subroutine (referred to as Figure 5-2.3 in some flow charts).



Variable Definitions for Figure 5-28:

AFTEVENTLOAD	Total loading on the street after the event [lbs].
AREA	The length of curb in a street (curb-mi/acre). If there are 2 miles of street per acre of land, then there are 4 curb-miles per acre. If the street is divided by an island, then there area 8 curb-miles per acre.
AVAILFACTOR	Availability factor which makes the initial adjustment on the street loading value immediately before the rain. It is calculated as a function of street texture, rain intensity, and street loading.
BEFOREVENTLOAD	Street dirt loading [lbs/(curb-mi)] on the street immediately before the rain or street cleaning event.
CORFACTOR	Correction factor to adjust street dirt washoff for short rains of relatively high duration. It is a function of street texture, rain depth, rain intensity, and street loading.
CURLOAD	The street loading which occurs immediately after a rain event.
DUR	Rain duration [days]
JSTRTIME	The starting time of a rain event in terms of the Julian calendar.
K	Proportionality constant used in loading calculations [l/mm]. Its a function of total street loading and rain intensity.
RAIN	Rain event depth [in].
RUNVOLF	Source area runoff volume for a rain event [cu ft]
TACCDUR	Street loading accumulation time: the time between the end of one rain and the beginning of the next.
TSCNCF	Source area particulate solids concentration [mg/L]
TSYLDF	Source area particulate solids yield [lbs].
UNAVAILAFTRAIN	Total loading unavailable for washoff after a rain
WASHOFF	Street dirt contained in runoff.

Figure 5-28. Washoff calculation subroutine (referred to as Figure 5-2.4 in some flow charts).



Variable Definitions for Figure 5-29:

AFTEVENTLOAD	Total loading after the event [lbs].
B	Y intercept term in first order equation describing street cleaning (y = m* x + B).
BEFOREVENTLOAD	Street dirt loading [lbs/(curb-mi)] on the street immediately before the rain or street cleaning event.
M	Slope term in first order equation describing street dirt cleaning (y = M *x + b).

Variable Definitions for Figure 5-30:

DUR	Rainfall duration [days]
IDAREA	Infiltration device area [sq ft]
IDASERV	Area served by infiltration device [acres]
IDPRATE	Infiltration device percolation rate [in/hr]
IDWTOD	Infiltration device width to depth ratio
IVOLRED	Water volume reduction from infiltration device
RAIN	Event rain depth [in]
RSUBV	Runoff coefficient for source area and rain depth
TSAREA	Total source area [acres]

Figure 5-29. Street cleaning flow chart (referred to as Figure 5-3 in some flow charts).

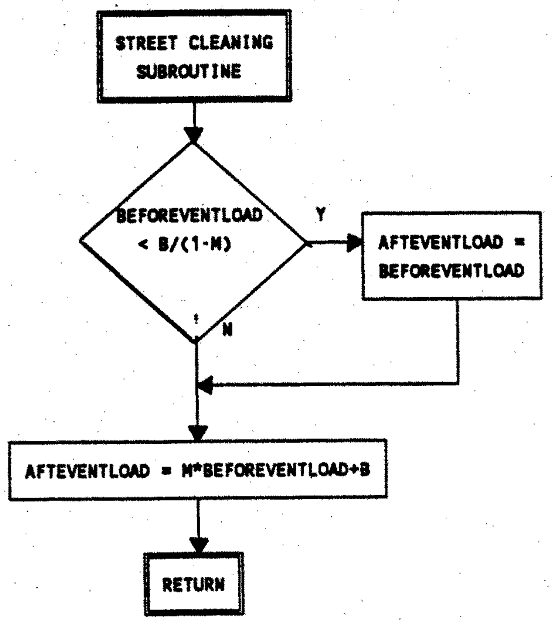
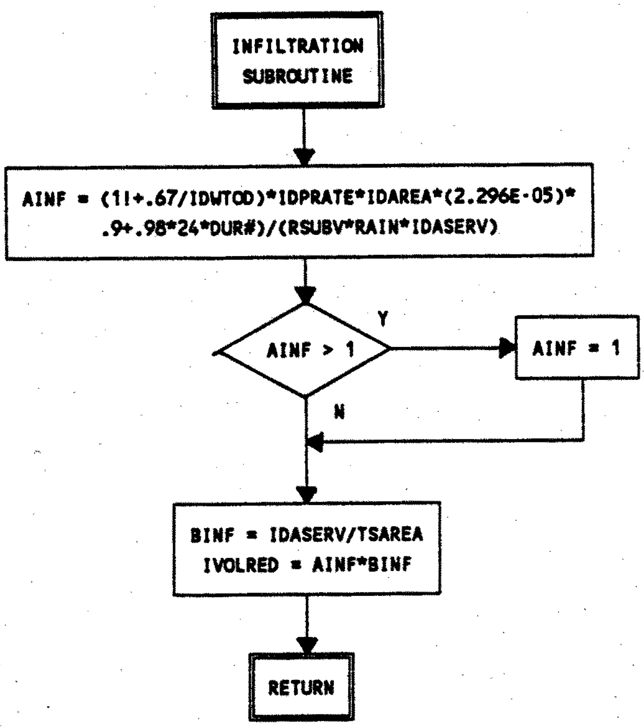


Figure 5-30. Infiltration device subroutine flow chart (referred to as Figure 5-4 in some flow charts).



Variable Definitions for Figure 5-31:

DUR	Rainfall duration [days]
PAVAREA	Porous pavement area [sq ft]
PAVPRATE	Porous pavement percolation rate [in/hr]
PVOLRED	Porous pavement volume reduction [fraction]
RAIN	Event rain depth [in]
TSAREA	Total source area [acres]

Variable Definitions for Figure 5-32:

AOTH	Percent flow reduction for “Other” control device.
BOTH	Proportion of the total area served by the “Other” control device.
CONASERV	Area served (acres) by the “Other” control device.
FLOWRED	Percent flow reduction for “Other” control device.
OTSRED	Particulate solids reduction percentage for that part of source area served by the “Other” control device.
OVOLRED	Volume reduction percentage for the source area.
POLRED	Particulate solids reduction percentage for the source area.
TSAREA	Total source area [acres]

Figure 5-31. Porous pavement subroutine flow chart (referred to as Figure 5-5 in some flow charts).

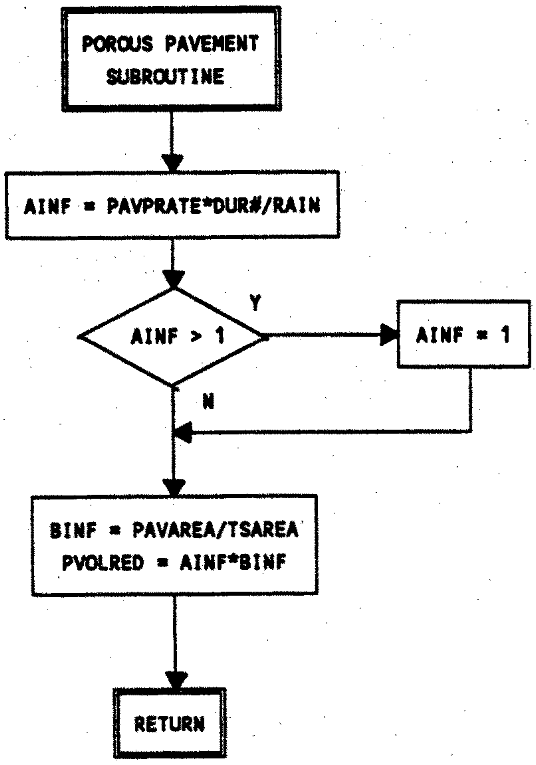
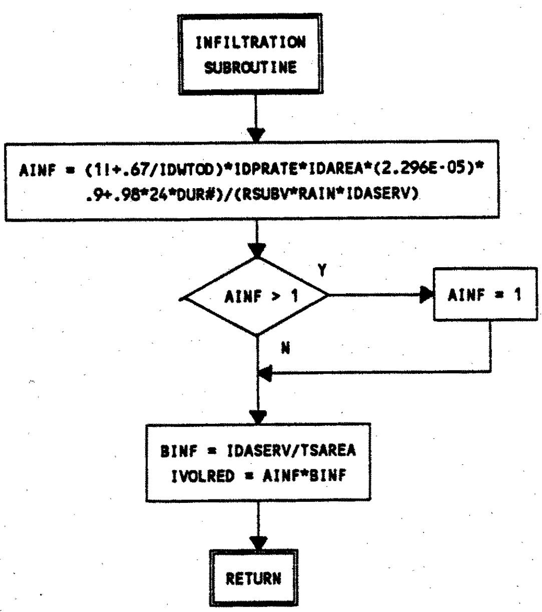


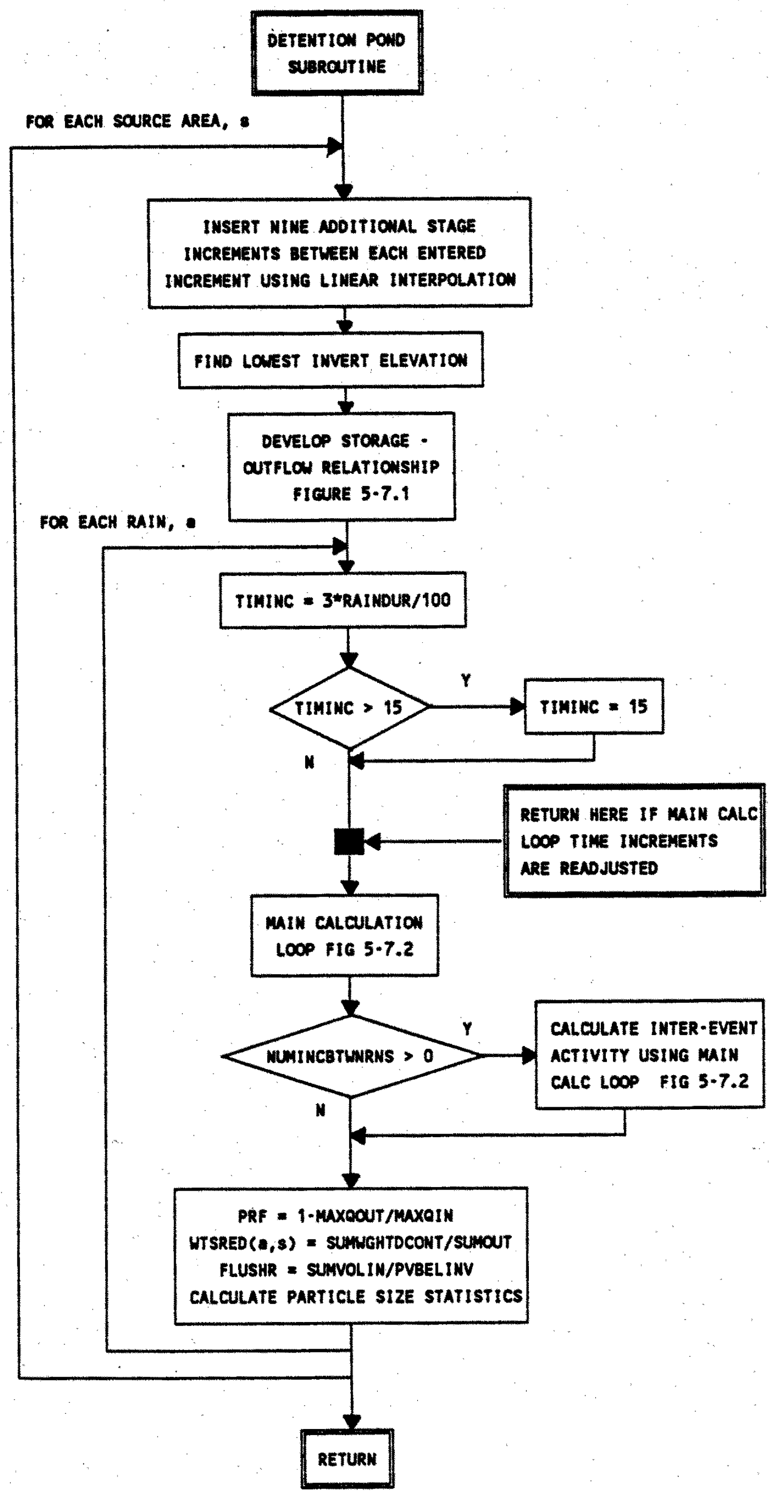
Figure 5-32. Other volume and solids reduction flow chart (referred to as Figure 5-6 in some flow charts).



Variable Definitions for Figure 5-33:

a	Rain number counter
FLUSHR	Flushing ratio: inflow volume/pond volume below invert
MAXQIN	Maximum event pond inflow [cfs]
MAXQOUT	Maximum event pond outflow [cfs]
NUMINCBTWNRAINS	Number of time steps for an interevent period
PRF	Peak reduction factor: 1 - (maximum pond outflow rate/maximum pond inflow rate)
PVBELINV	Pond volume below lowest invert [cu ft]
RAIN	Event rain depth [in]
RAINDUR	Event rain duration [hrs]
s	Source area number
SUMOUT	Total event outflow [cfs]
SUMVOLIN	Total event inflow volume [cu ft]
SUMWGHTDCONT	Sum of flow weighted percentage of particle sizes controlled
TIMINC	Time step increment [min]
WTSRED(a,s)	Weighted average total particulate solid reduction

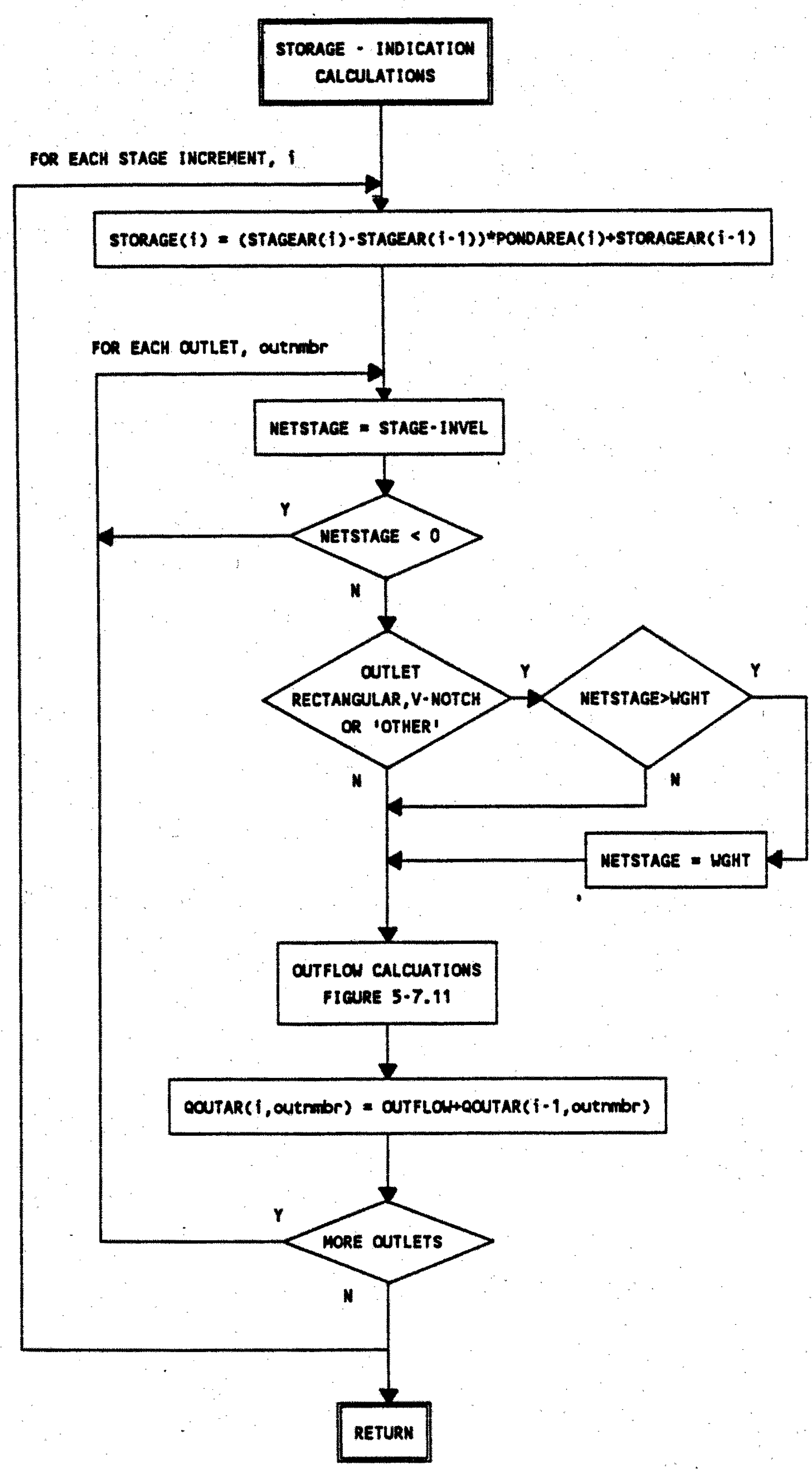
Figure 5-33. Detention pond flow chart (referred to as Figure 5-7 in some flow charts).



Variable Definitions for Figure 5-34:

i	Stage increment counter
INVEL	Invert elevation of outlet [ft]
NETSTAGE	Net stage value [ft]
OUTFLOW	Outflow [cfs]
Outnumber	Outlet number counter
PONDAREA	Pond area for a time step [sq ft]
QOUTAR	Total pond outflow from all outlets for each defined stage elevation [cfs]
STAGE	pond stage level [ft]
STAGEAR	Model or user defined stage elevation [ft]
STORAGE	Total storage volume in pond for a time step [cu ft]
STORAGEAR	Total storage volume in pond at each stage level [cu ft]
WGHT	Weir height [ft]

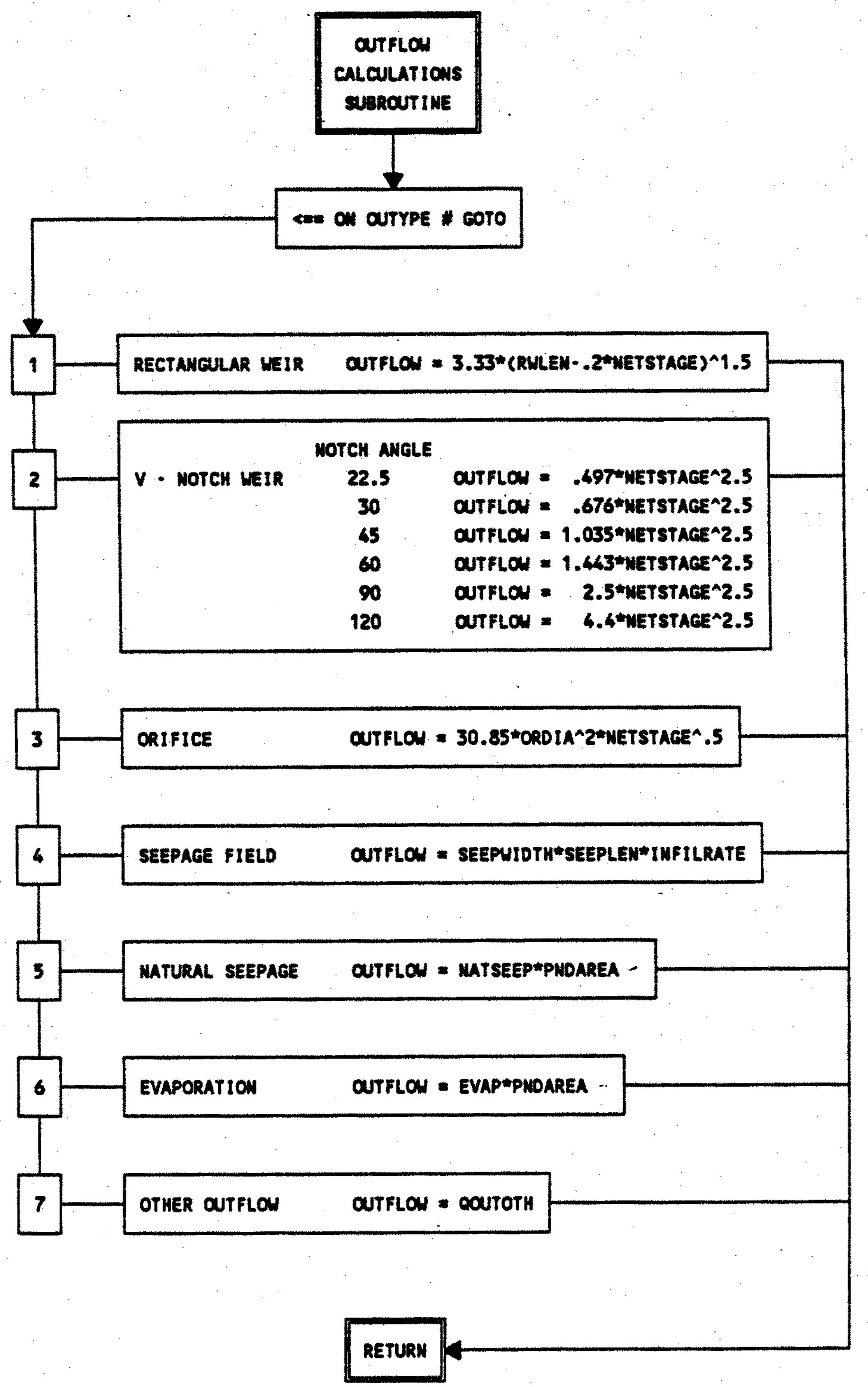
Figure 5-34. Storage indication curve flow chart (referred to as Figure 5-7.1 in some flow charts).



Variable Definitions for Figure 5-35:

EVAP	Evaporation [in/day]
INFILRATE	Seepage field infiltration rate [in/hr]
NATSEEP	Natural seepage rate for a time step [in/hr]
NETSTAGE	Net stage value [ft]
ORDIA	Orifice diameter [ft]
OUTFLOW	Outflow [cfs]
OUTYPE	Outlet type
PNDAREA	Pond area for a time step [sq ft]
QOUTOTH	User defined hydrograph outflow rate [cfs]
RWLEN	Rectangular weir length [ft]
SEEPLEN	Seepage field length [ft]
SEEPWIDTH	Seepage field width [ft]

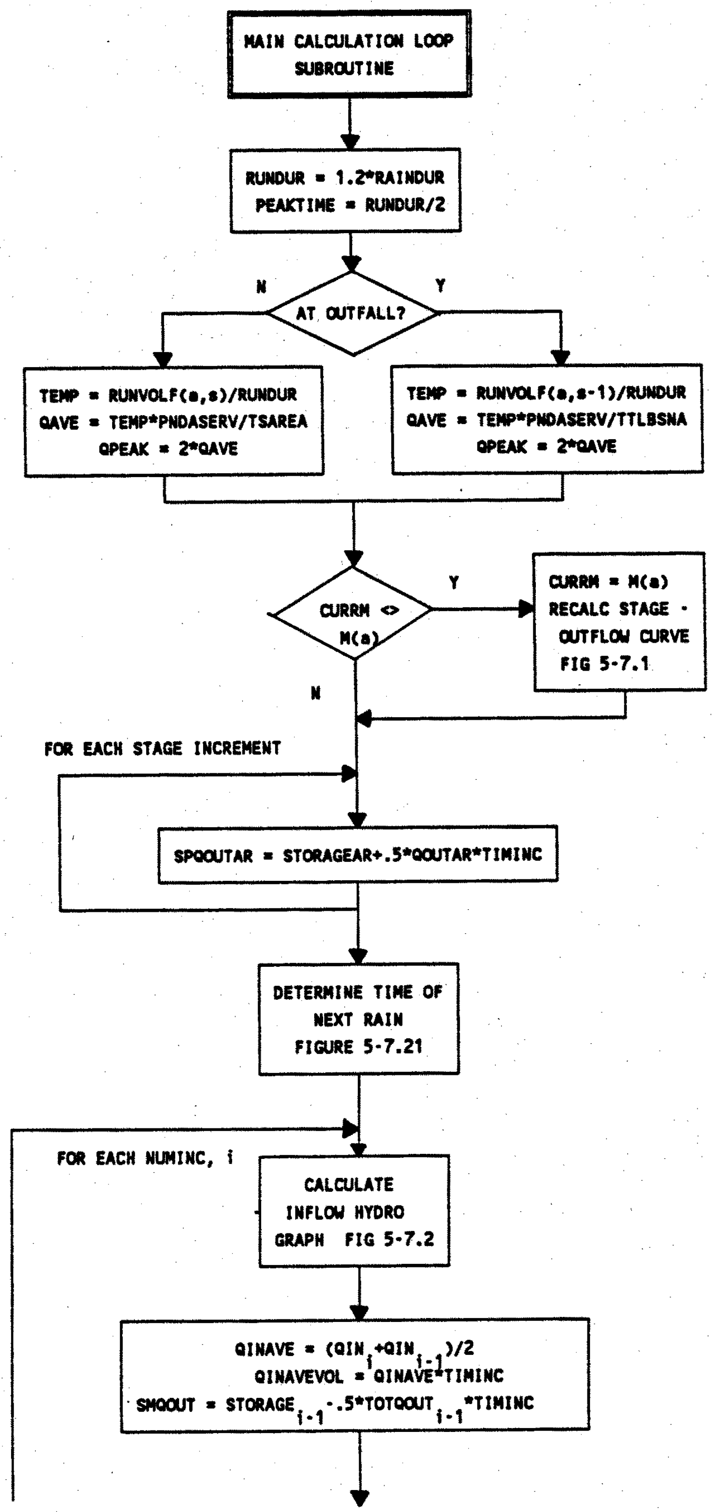
Figure 5-35. Outflow calculation flow chart (referred to as Figure 5-7.11 in some flow charts).



Variable Definitions for Figure 5-36:

a	Rain number counter
CURR	Current month
M	Month number (1 to 12)
NUMINC	Number of time step increments for an event
PEAKTIME	Time of peak inflow for an event
PNDASERV	Area served by detention pond [sq ft]
QAVE	Average event inflow rate [cfs]
QIN	Inflow for a time step [cfs]
QINAVE	Average inflow rate between two time steps [cu ft]
QINAVEVOL	Average inflow volume between two time steps [cu ft]
QOUTAR	Total pond outflow from all outlets for each defined stage elevation [cfs]
QPEAK	Peak inflow rate [cfs]
RAINDUR	Event rain duration [hrs]
RUNDUR	Event runoff duration (1.2 times rain duration)
RUNVOLF	Source area runoff volume for a rain event [cu ft]
SMQOUT	Previous time step storage volume minus previous time step outflow for current time step
SPQOUTAR	Storage plus 1/2 outflow for each stage increment
STORAGE	Total storage volume in pond for a time step [cu ft]
STORAGEAR	Total storage volume in pond at each stage level [cu ft]
TIMINC	Time step increment [min]
TOTQOUT	Total outflow per time step [cfs]
TSAREA	Total source area [acres]
TTLBSNA	Total basin area [acres]

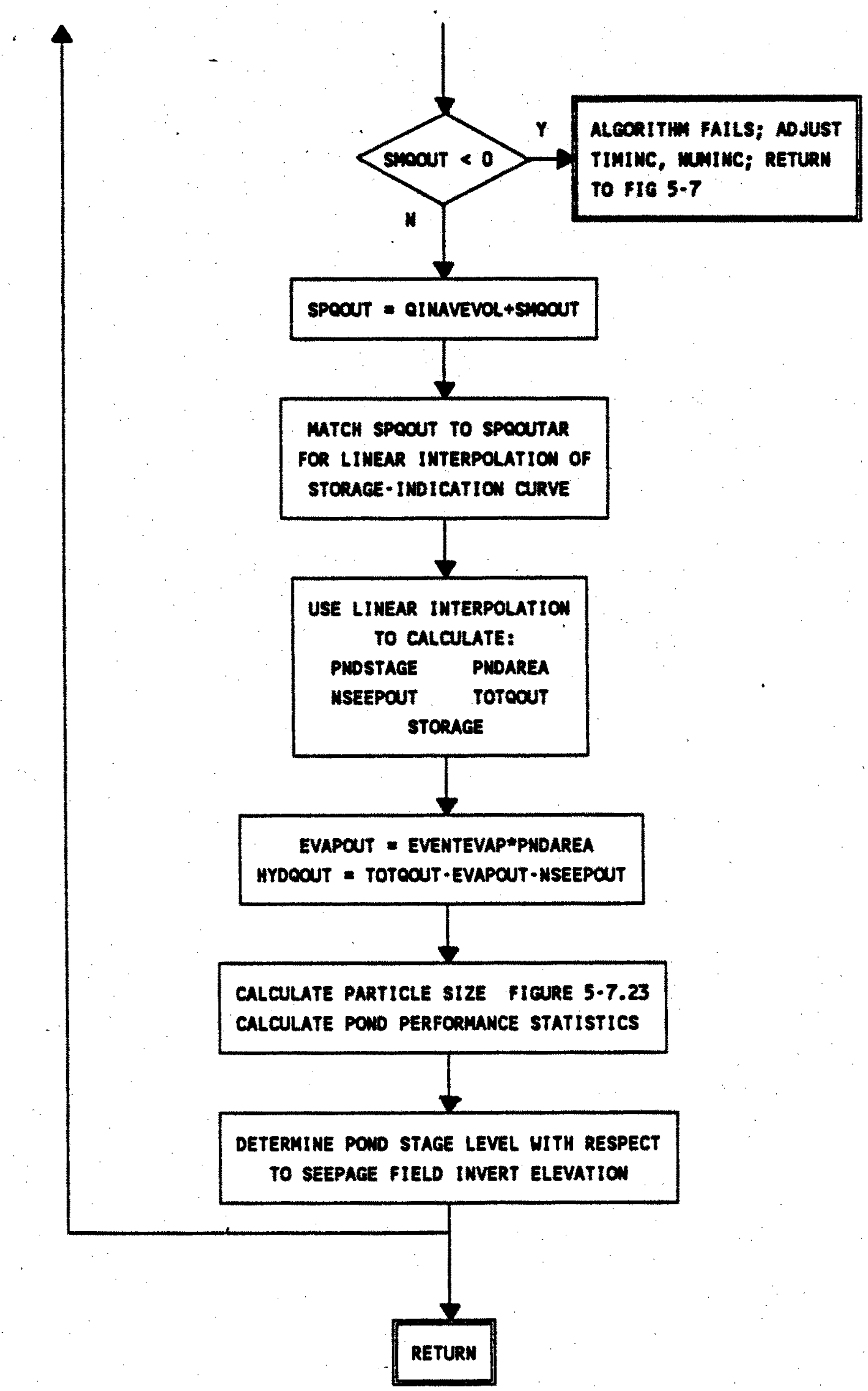
Figure 5-36. Main calculation loop flow chart (referred to as Figure 5-7.2 in some flow charts).



Variable Definitions for Figure 5-36 (Continued):

EVAPOUT	Outflow due to evaporation [cfs]
EVENTEVAP	Event evaporation
HYDQOUT	hydraulic outflow for a time step [cfs]
NSEEPOUT	Natural seepage for a time step [cfs]
PNDAREA	Pond area for a time step [sq ft]
PNDSTAGE	Pond stage for a time step [ft]
QINAVEVOL	Average inflow volume between two time steps [cu ft]
SMQOUT	Previous time step storage volume minus previous time step outflow for current time step
SPQOUT	Inflow volume for current time step plus SMQOUT for current time step
STORAGE	Total storage volume in pond for a time step [cu ft]
TOTQOUT	Total outflow per time step [cfs]

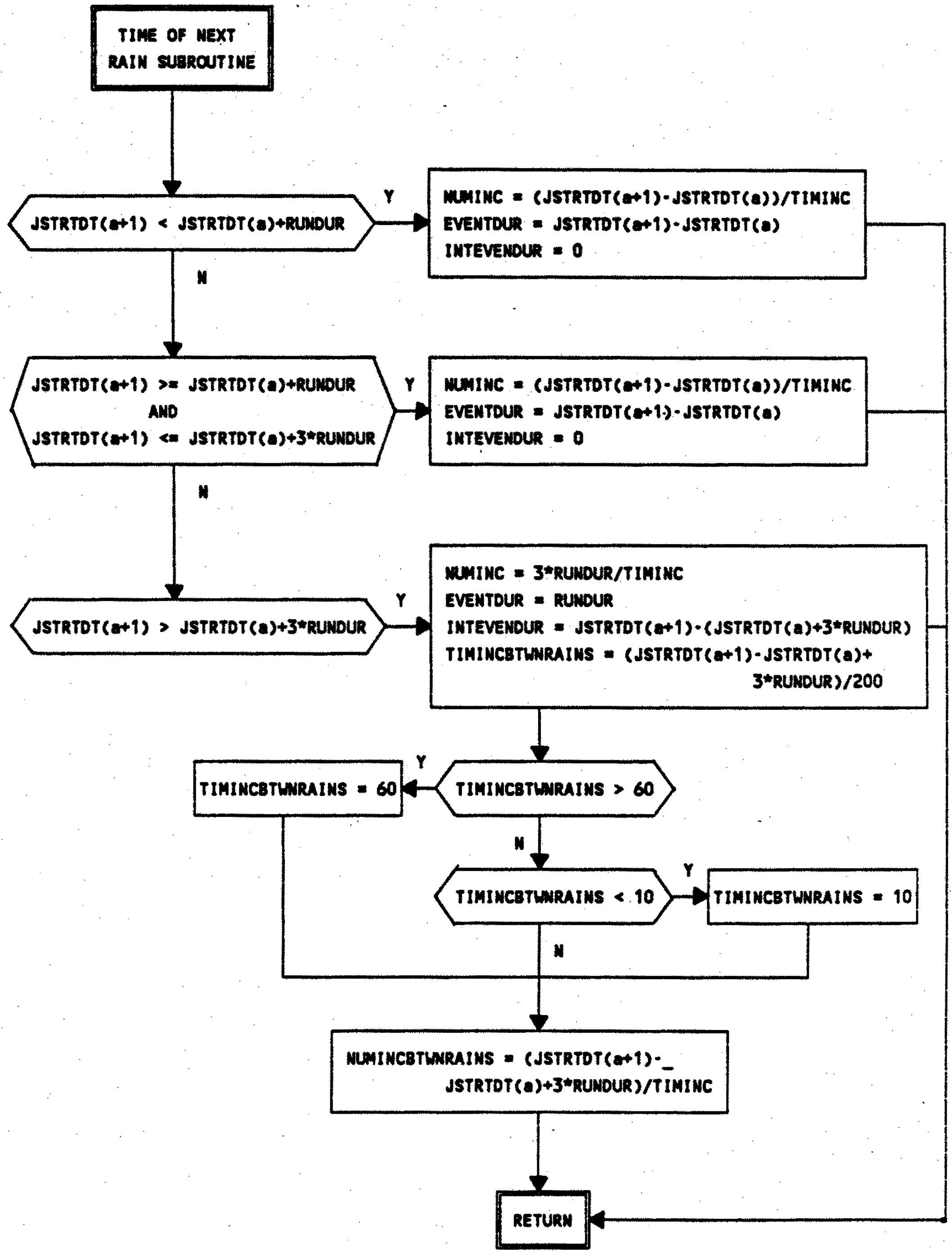
Continuation of Figure 5-36 (referred to as Figure 5-7.2 in some flow charts).



Variable Definitions for Figure 5-37:

a	Rain number counter
EVENTDUR	Event duration
INTEVENTDUR	Interevent duration time period [days]
JSTRTDT	Starting date and time for a model run (Julian calendar)
NUMINC	Number of time step increments for an event
NUMINCBTWNRAINS	Number of time steps for an interevent period
RUNDUR	Event runoff duration (1.2 times rain duration)
TIMINC	Time step increment [min]
TIMINCBTWNRAINS	Time step increment between rain events from stochastic rain file [days]

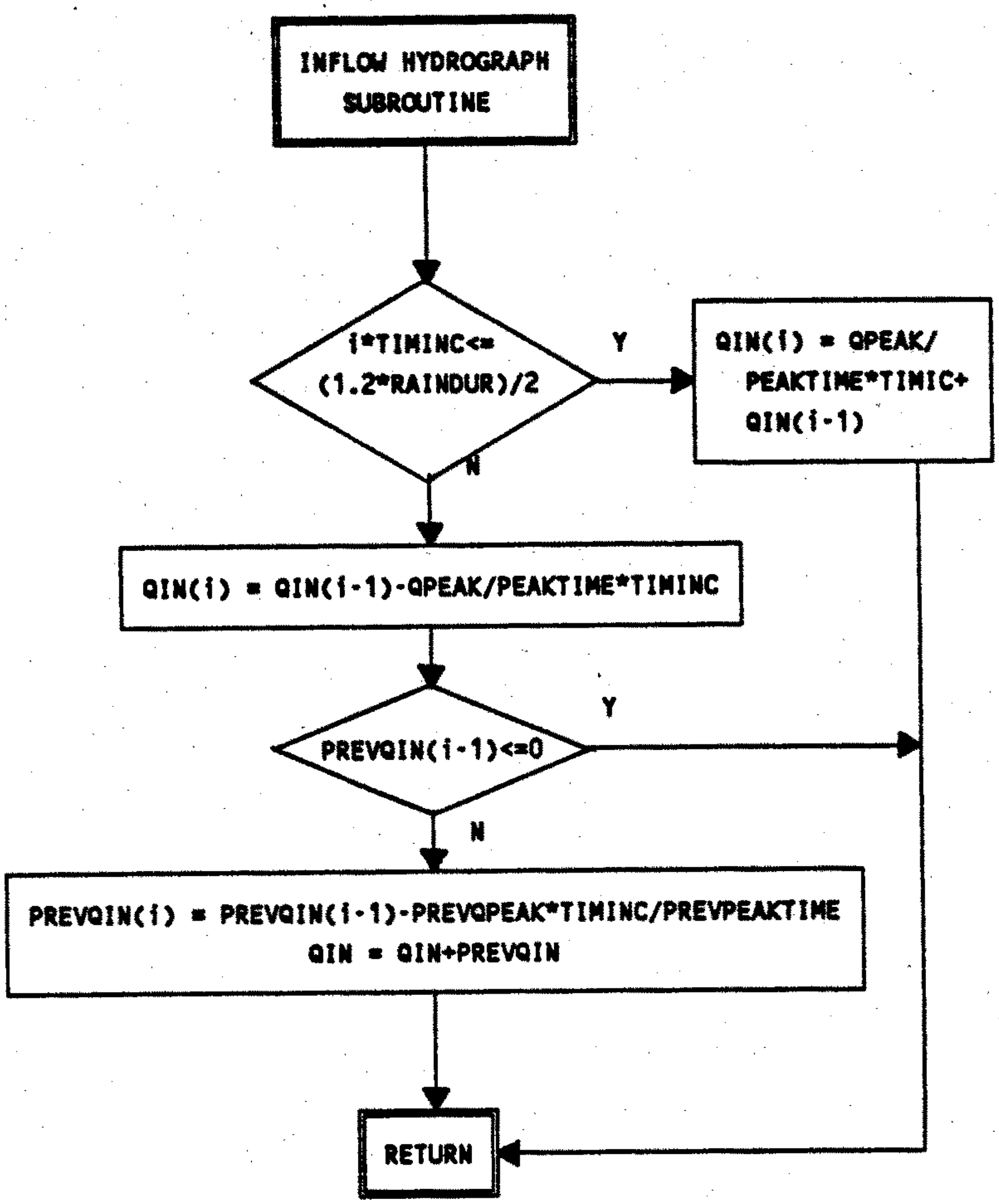
Figure 5-37. Time of next rain calculation flow chart (referred to as Figure 5-7.21 in some flow charts).



Variable Definitions for Figure 5-38:

i	Stage increment counter
PEAKTIME	Time of peak inflow for an event
PREVPEAKTIME	Peak inflow time used to calculate previous event inflow when a new event begins before runoff from the previous event has ended.
PREVQIN	Previous inflow value used as part of total inflow when a new event begins before runoff from the previous event has ended.
PREVQPEAK	Peak inflow value used to calculate previous event inflow when a new event begins before runoff from the previous event has ended.
QIN	Inflow for a time step [cfs]
QPEAK	Peak inflow rate [cfs]
RAINDUR	Event rain duration [hrs]
TIMINC	Time step increment [mind

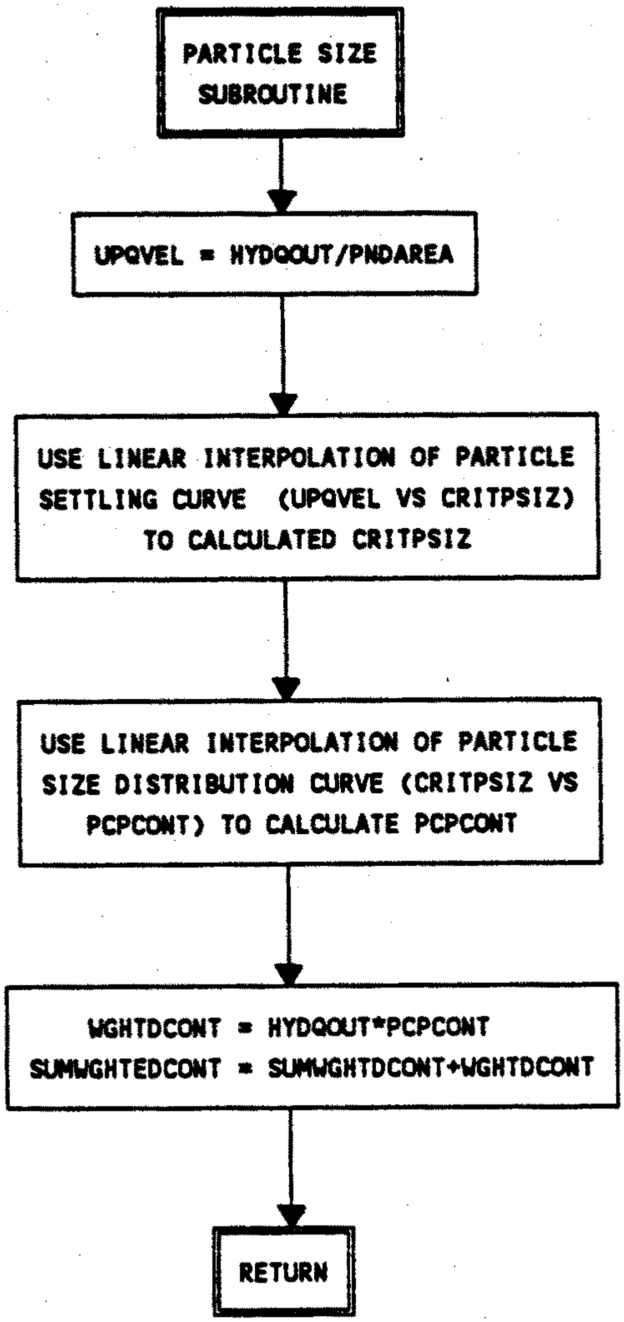
Figure 5-38. Inflow hydrograph flow chart (referred to as Figure 5-7.22 in some flow charts).



Variable Definitions for Figure 5-39:

CRITPSIZ	Time step critical particle size [micrometers]
HYDQOUT	hydraulic outflow for a time step [cfs]
PCPCONT	Percent particle control for a time step
PNDAREA	Pond area for a time step [sq ft]
SUMWGHTDCONT	Sum of flow weighted percentage of particle sizes controlled
UPQVEL	Upflow velocity for a time step [ft/hr]
WGHTDCONT	Flow weighted percent of particle sizes controlled for a time step

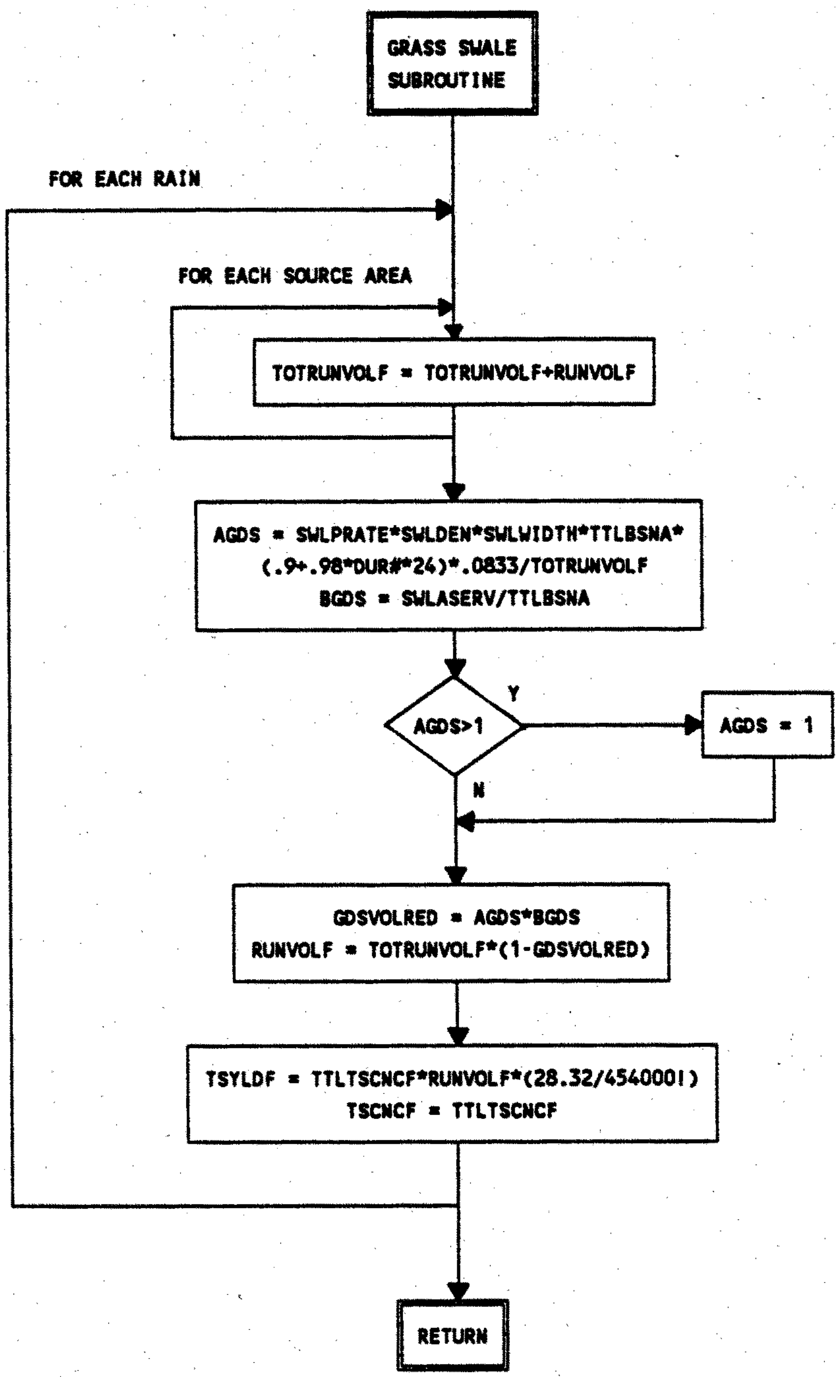
Figure 5-39. Particle size calculation flow chart (referred to as Figure 5-7.23 in some flow charts)



Variable Definitions for Figure 40:

DUR	Event duration [days]
GDSVOLRED	Grass drainage swale volume reduction [fraction]
RUNVOLF	Source area runoff volume for a rain event [cu ft]
SWLASERV	Area served by grass swales [acres]
SWLDEN	Grass swale density
SWLPRATE	Grass swale percolation rate
SWLWIDTH	Grass swale width
TOTRUNVOLF	Total runoff volume from all source areas [cu ft]
TSCNCF	Source area particulate solids concentration [mg/L]
TSYLDF	Source area particulate solids yield [lbs]
TTLBSNA	Total basin area [acres]
TTLTSCNCF	Total solids concentration from entire basin [mg/L]

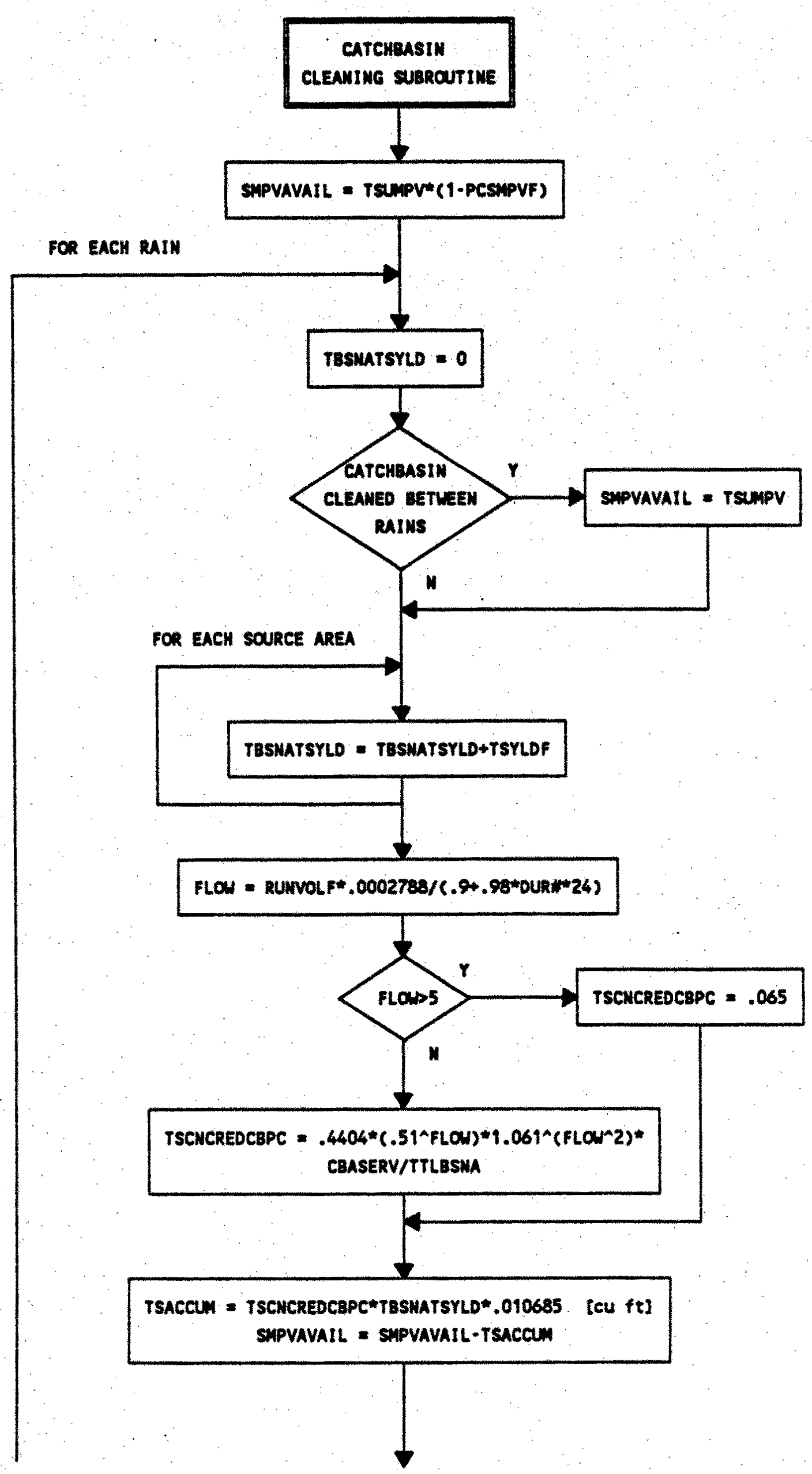
Figure 5-40. Grass swale subroutine flow chart (referred to as Figure 5-8 in some flow charts).



Variable Definitions for Figure 5-41:

CBASERV	Area served by catchbasin [acres]
DUR	Rain duration [days]
FLOW	Flow into catchbasin
PCSMPVF	Percent of sump volume full
RUNVOLF	Source area runoff volume for a rain event [cu ft]
SMPVAVAIL	Sump volume available for particulate solids [cu ft]
TBSNATSYLD	Total basin area particulate solids yield [lbs]
TSACCUM	Particulate solids accumulated in catchbasin [cu ft]
TSCNCREDCBPC	Percentage particulate solids reduction from catchbasin
TSUMPV	Total sump volume [cu ft]
TSYLDF	Source area particulate solids yield [lbs]
TTLBSNA	Total basin area [acres]

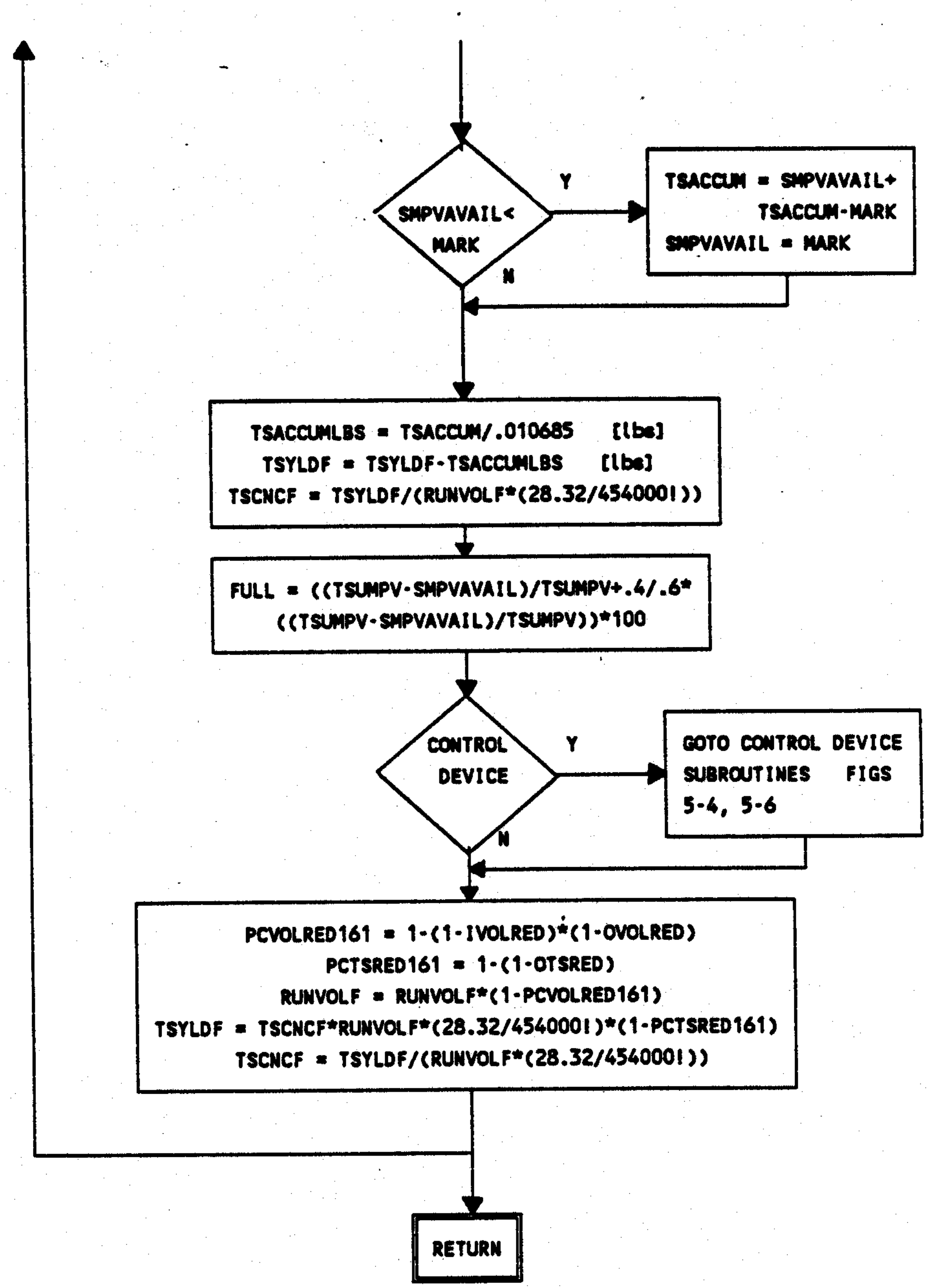
Figure 5-41. Catchbasin cleaning flow chart (referred to as Figure 5-9 in some flow charts).



Variable Definitions for Figure 5-41 (continued):

CBASERV	Area served by catchbasin [acres]
DUR	Rain duration [days]
FULL	Percent of catchbasin full
FLOW	Flow into catchbasin
IVOLRED	Infiltration device volume reduction [fraction]
MARK	Minimum sump volume available for solids storage (40 percent of total sump volume) [cu ft]
OVOLRED	Other control device volume reduction [fraction]
PCSMPVF	Percent of sump volume full
PCTSRED161	Percent particulate solids reduction due to drainage controls before catchbasins
PCVOLRED161	Percent flow volume reduction due to drainage controls before catchbasins
RUNVOLF	Source area runoff volume for a rain event [cu ft]
SMPVAVAIL	Sump volume available for particulate solids [cu ft] .
TBSNATSYLD	Total basin area particulate solids yield [lbs]
TSACCUM	Particulate solids accumulated in catchbasin [cu ft]
TSACCUMLBS	Particulate solids accumulated in catchbasin[lbs]
TSCNCF	Particulate solids concentration [mg/L]
TSCNCREDCBPC	Percentage particulate solids reduction from catchbasin
TSUMPV	Total sump volume [cu ft]
TSYLDF	Source area particulate solids yield [lbs].
TTLBSNA	Total basin area [acres]

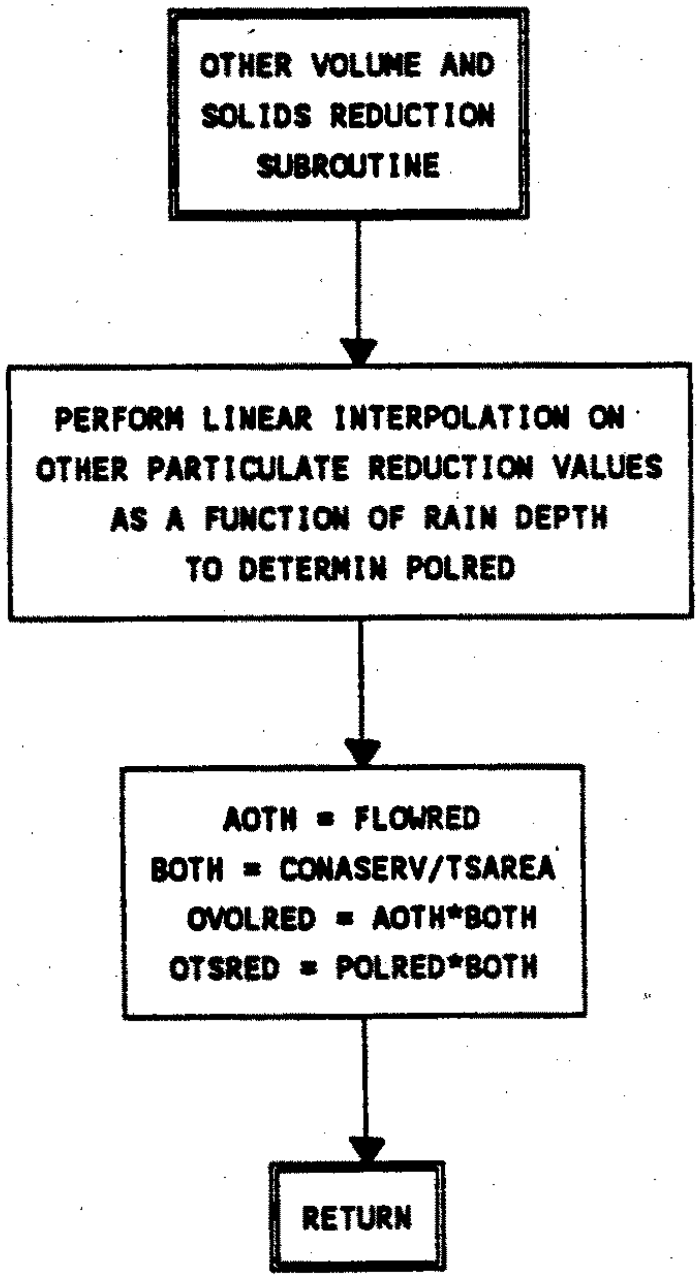
Figure 5-41 continued (referred to as Figure 5-9 in some flow charts).



Variable Definitions for Figure 5-42:

AOTH	Percent flow reduction for "Other" control device.
BOTH	Proportion of the total area served by the "Other" control device.
CONASERV	Area served (acres) by the "Other" control device.
FLOWRED	Percent flow reduction for "Other" control device.
OTSRED	Particulate solids reduction percentage for that part of source area served by the "Other" control device.
OVOLRED	Volume reduction percentage for the source area.
POLRED	Particulate solids reduction percentage for the source area.
TSAREA	Total source area [acres]

Figure 5-42. Other volume and solids reduction flow chart (referred to as Figure 5-10 in some flow charts).



Calculation/Output Module - Output

The program uses flow volumes and particulate loadings to calculate the pollutant concentrations and loadings.

The variables in the flow chart are defined in the variable list on the facing page. The flow charts are not intended to give you a detailed description of the program structure. They should, however, help you understand how the calculations are structured in the code. To make the flow charts clearer, the variable subscripts have been eliminated.

Output from WinSLAMM is in both disk file and hard copy form.

There are four printing options. You select the desired option in the input module. The printing options are:

1. Print source areas by land use and outfall for each rain - complete printout. -

2. Print outfall data only for each rain.

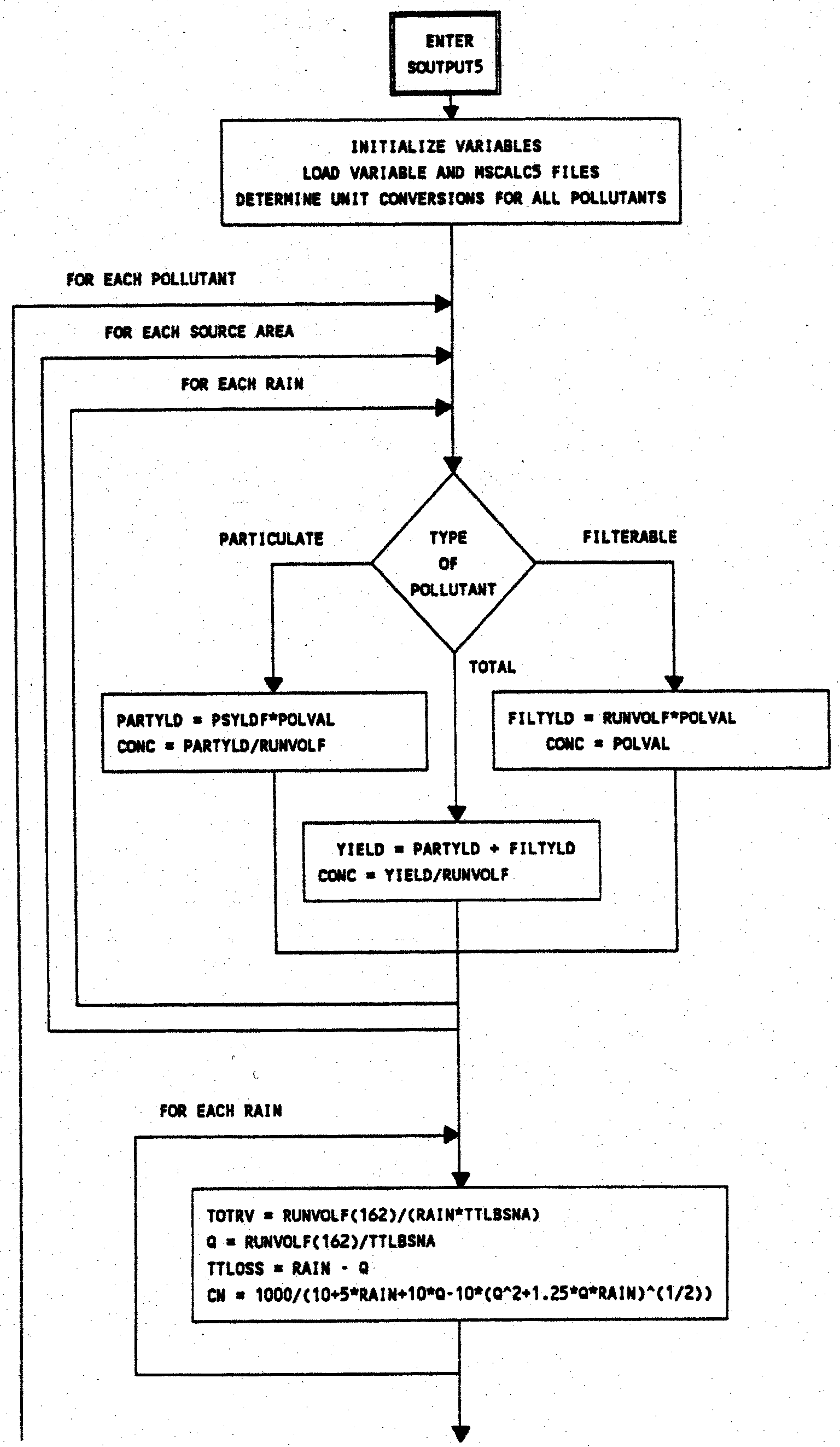
3. Print summary totals of each source area category for all land uses and print outfall data for each rain.

4. Default option - print outfall summaries only.

Variable Definitions for Figure 5-43:

CONC	Concentration of a pollutant from a source area for a rain
FILTYLD	Filterable yield of a pollutant from a source area for a rain
MSCALC5	Calculation Module program which determined runoff volumes, particulate concentrations, and particulate yields for each source area for each rain
PARTYLD	Particulate yield of a pollutant from a source area for a rain
POLVAL	The concentration of a pollutant from a source area and land use. For particulate pollutants, the units are: mass of pollutant/kg particulate solids. For filterable pollutants, the units are: mass of pollutant/Liter of runoff.
PSYLDF	Particulate solids yield [lbs]. Determined for each source area for each rain in the "MSCALC5. EXE" program.
RUNOFF	Source area runoff volume for a rain event [cu ft]
s	Source area number
TTLBSNA	Total basin area [acres]

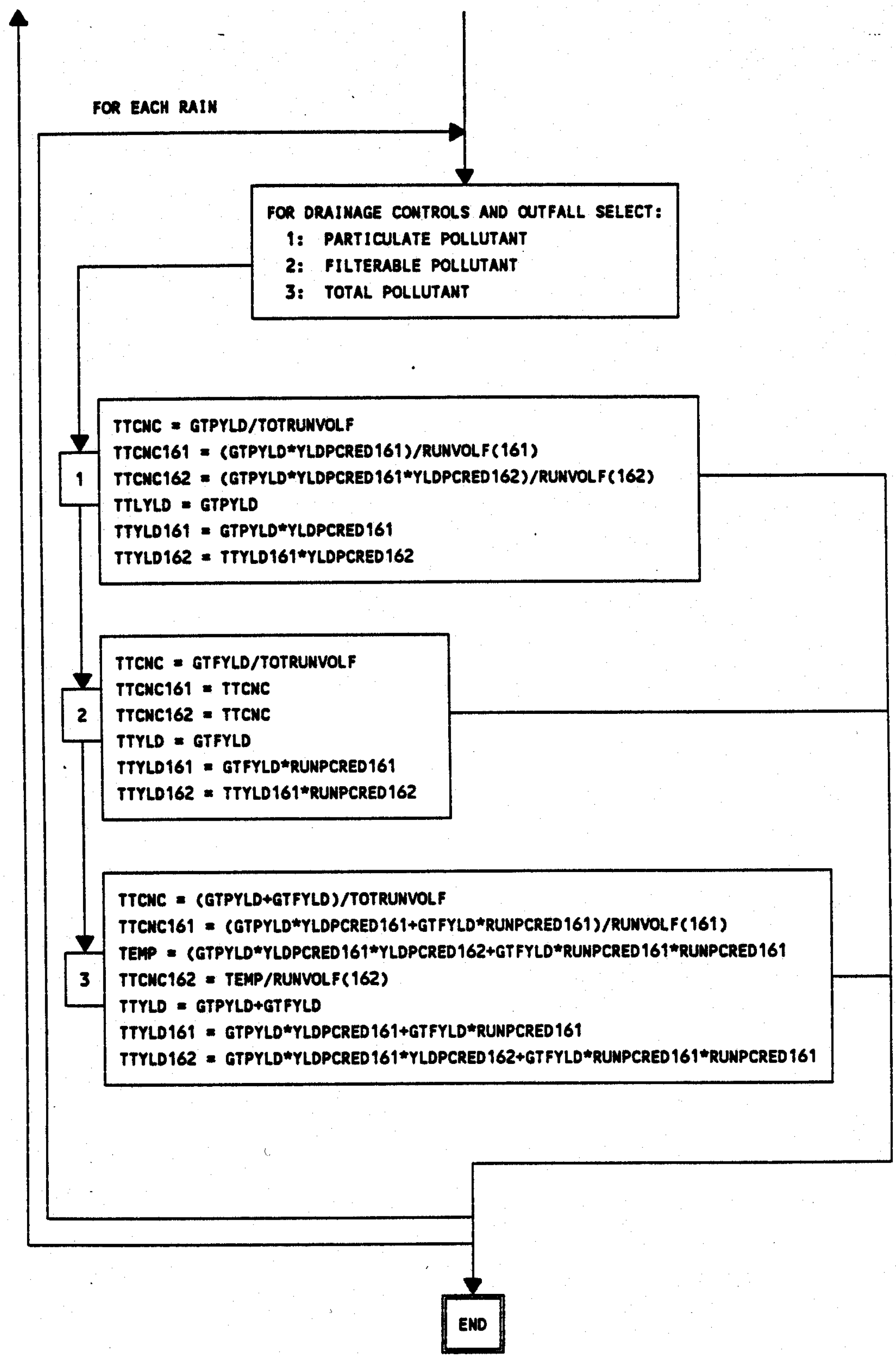
Figure 5-43. Output program main flow chart.



Variable Definitions for Figure 5-43 (continued):

CN	SCS Curve Number
GTFYLD	Total filterable yield of a pollutant from all source areas for a rain [lbs]
GTPYLD	Total particulate yield of a pollutant from all source areas for a rain [lbs]
PCTSRED161	Percent particulate solids reduction due to drainage controls for a rain
PCVOLRED161	Percent flow volume reduction due to drainage controls for a rain
Q	Runoff [in]
RAIN	Rain depth for an event [in]
RUNVOLF	Source area runoff volume for a rain event. (161)==> runoff volume from all source areas after drainage controls. (162)==> runoff volume from all source areas after outfall controls. [cu ft]
RUNPCRED161	Percent reduction of runoff due to drainage controls for a rain
RUNPCRED162	Percent reduction of runoff due to outfall controls for a rain
TOTRUNVOLF	Total runoff volume from all source areas for a rain
TOTRV	Ratio of runoff volume to rain volume for a rain event
TTCNC	Total concentration (particulate if yield is GTPYLD, filterable if yield is GTFYLD) from all the source areas for a rain
TTCNC161	Total concentration (particulate if yield is GTPYLD, filterable if yield is GTFYLD) from all the source areas for a rain after drainage controls
TTCNC162	Total concentration (particulate if yield is GTPYLD, filterable if yield is GTFYLD) from all the source areas for a rain after drainage and outfall controls
TTLBSNA	Total basin area t acres]
TTLOSS	Total precipitation lost due to evaporation, infiltration, and other processes
TTLYLD	Total yield (particulate if yield is GTPYLD, filterable if yield is GTFYLD) from all the source areas for a rain
TTLYLD161	Total yield (particulate if yield is GTPYLD, filterable if yield is GTFYLD) from all the source areas for a rain after drainage controls
TTLYLD162	Total yield (particulate if yield is GTPYLD, filterable if yield is GTFYLD) from all the source areas for a rain after drainage and outfall controls
YLDPCRED161	Percent reduction of yield due to drainage controls for a rain
YLDPCRED162	Percent reduction of yield due to outfall controls for a rain

Figure 5-43 (continued).



Appendix 5-C. Bham76.ran File Printout

Rain File name: bham76.RAN
Printout Date: 08-09-2000

Rain Number	Beginning Rain Date	Beginning Rain Time	Ending Rain Date	Ending Rain Time	Rainfall Depth (in)	Rainfall Duration (days)	Intensity (in/hr)	Interevent Duration (days)
1	01/02/76	22:00	01/03/76	07:00	0.46	0.3750	0.0511	3.7917
2	01/07/76	02:00	01/08/76	13:00	0.58	1.4583	0.0166	2.8333
3	01/11/76	09:00	01/11/76	21:00	0.25	0.5000	0.0208	1.1667
4	01/13/76	01:00	01/13/76	03:00	0.03	0.0833	0.0150	0.2500
5	01/13/76	09:00	01/13/76	21:00	0.39	0.5000	0.0325	2.8333
6	01/16/76	17:00	01/17/76	03:00	0.01	0.4167	0.0010	3.2083
7	01/20/76	08:00	01/20/76	14:00	0.05	0.2500	0.0083	3.7500
8	01/24/76	08:00	01/24/76	19:00	0.03	0.4583	0.0027	0.7083
9	01/25/76	12:00	01/26/76	22:00	2.33	1.4167	0.0685	5.4167
10	02/01/76	08:00	02/01/76	10:00	0.01	0.0833	0.0050	0.3333
11	02/01/76	18:00	02/01/76	20:00	0.01	0.0833	0.0050	3.5417
12	02/05/76	09:00	02/06/76	10:00	0.51	1.0417	0.0204	4.8750
13	02/11/76	07:00	02/11/76	18:00	0.01	0.4583	0.0009	6.0000
14	02/17/76	18:00	02/17/76	19:00	0.01	0.0417	0.0100	0.3750
15	02/18/76	04:00	02/18/76	12:00	0.67	0.3333	0.0837	3.0833
16	02/21/76	14:00	02/21/76	23:00	0.61	0.3750	0.0678	0.5000
17	02/22/76	11:00	02/22/76	14:00	0.01	0.1250	0.0033	12.0000
18	03/05/76	14:00	03/06/76	15:00	0.85	1.0417	0.0340	1.5417
19	03/08/76	04:00	03/08/76	08:00	0.01	0.1667	0.0025	0.4583
20	03/08/76	19:00	03/09/76	14:00	1.02	0.7917	0.0537	0.2500
21	03/09/76	20:00	03/09/76	23:00	0.01	0.1250	0.0033	2.2917
22	03/12/76	06:00	03/12/76	23:00	1.48	0.7083	0.0871	0.6250
23	03/13/76	14:00	03/13/76	15:00	0.01	0.0417	0.0100	0.5000
24	03/14/76	03:00	03/14/76	13:00	0.01	0.4167	0.0010	0.5000

25	03/15/76	01:00	03/16/76	12:00	3.64	1.4583	0.1040	3.7083
26	03/20/76	05:00	03/20/76	13:00	0.04	0.3333	0.0050	0.2500
27	03/20/76	19:00	03/21/76	05:00	1.14	0.4167	0.1140	3.5417
28	03/24/76	18:00	03/25/76	09:00	0.04	0.6250	0.0027	0.9167
29	03/26/76	07:00	03/27/76	06:00	1.54	0.9583	0.0670	2.4167
30	03/29/76	16:00	03/30/76	04:00	2.20	0.5000	0.1833	0.3333
31	03/30/76	12:00	03/31/76	15:00	2.08	1.1250	0.0770	3.8333
32	04/04/76	11:00	04/04/76	12:00	0.01	0.0417	0.0100	7.3333
33	04/11/76	20:00	04/11/76	25:00	0.21	0.2083	0.0420	1.9167
34	04/13/76	23:00	04/14/76	13:00	0.04	0.5833	0.0029	6.8333
35	04/21/76	09:00	04/21/76	11:00	0.01	0.0833	0.0050	3.1250
36	04/24/76	14:00	04/25/76	07:00	0.84	0.7083	0.0494	4.2500
37	04/29/76	13:00	05/01/76	05:00	1.03	1.6667	0.0258	5.4583
38	05/06/76	16:00	05/07/76	19:00	1.71	1.1250	0.0633	0.2500
39	05/08/76	01:00	05/08/76	12:00	0.30	0.4583	0.0273	2.0417
40	05/10/76	13:00	05/11/76	15:00	0.26	1.0833	0.0100	1.7917
41	05/13/76	10:00	05/14/76	24:00	3.84	1.5833	0.1011	0.4583
42	05/15/76	11:00	05/15/76	13:00	0.01	0.0833	0.0050	0.7917
43	05/16/76	08:00	05/16/76	11:00	0.07	0.1250	0.0233	1.6667
44	05/18/76	03:00	05/18/76	05:00	0.01	0.0833	0.0050	4.6250
45	05/22/76	20:00	05/24/76	02:00	2.31	1.2500	0.0770	2.5833
46	05/26/76	16:00	05/28/76	13:00	0.27	1.8750	0.0060	0.4583
47	05/28/76	24:00	05/29/76	07:00	0.05	0.2917	0.0071	3.1667
48	06/01/76	11:00	06/01/76	22:00	0.48	0.4583	0.0436	0.3333
49	06/02/76	06:00	06/02/76	14:00	0.01	0.3333	0.0012	2.3750
50	06/04/76	23:00	06/05/76	02:00	0.01	0.1250	0.0033	4.6667
51	06/09/76	18:00	06/09/76	20:00	0.01	0.0833	0.0050	6.7917
52	06/16/76	15:00	06/16/76	19:00	0.01	0.1667	0.0025	1.7083
53	06/18/76	12:00	06/18/76	19:00	0.03	0.2917	0.0043	0.3750
54	06/19/76	04:00	06/20/76	06:00	1.78	1.0833	0.0685	7.3333

55	06/27/76	14:00	06/27/76	15:00	0.01	0.0417	0.0100	2.6250
56	06/30/76	06:00	06/30/76	10:00	0.46	0.1667	0.1150	3.5417
57	07/03/76	23:00	07/04/76	24:00	1.17	1.0417	0.0468	8.6250
58	07/13/76	15:00	07/13/76	16:00	0.26	0.0417	0.2600	3.0000
Rain Number	Beginning Rain Date	Beginning Rain Time	Ending Rain Date	Ending Rain Time	Rainfall Depth (in)	Rainfall Duration (days)	Intensity (in/hr)	Interevent Duration (days)
59	07/16/76	16:00	07/17/76	08:00	0.03	0.6667	0.0019	0.3333
60	07/17/76	16:00	07/17/76	17:00	0.01	0.0417	0.0100	3.9167
61	07/21/76	15:00	07/21/76	17:00	0.09	0.0833	0.0450	1.9583
62	07/23/76	16:00	07/23/76	18:00	0.26	0.0833	0.1300	3.7083
63	07/27/76	11:00	07/27/76	24:00	1.01	0.5417	0.0777	0.4167
64	07/28/76	10:00	07/28/76	17:00	1.63	0.2917	0.2329	1.0000
65	07/29/76	17:00	07/29/76	20:00	0.17	0.1250	0.0567	0.4167
66	07/30/76	06:00	07/30/76	12:00	0.23	0.2500	0.0383	1.0000
67	07/31/76	12:00	07/31/76	14:00	0.07	0.0833	0.0350	5.9583
68	08/06/76	13:00	08/06/76	20:00	0.30	0.2917	0.0429	0.7500
69	08/07/76	14:00	08/07/76	16:00	0.54	0.0833	0.2700	8.0000
70	08/15/76	16:00	08/15/76	19:00	0.06	0.1250	0.0200	0.7917
71	08/16/76	14:00	08/16/76	17:00	0.93	0.1250	0.3100	7.9167
72	08/24/76	15:00	08/25/76	04:00	0.86	0.5417	0.0662	1.1667
73	08/26/76	08:00	08/26/76	14:00	0.01	0.2500	0.0017	0.6667
74	08/27/76	06:00	08/27/76	20:00	0.34	0.5833	0.0243	0.2500
75	08/28/76	02:00	08/28/76	15:00	0.28	0.5417	0.0215	2.8333
76	08/31/76	11:00	08/31/76	13:00	0.01	0.0833	0.0050	0.4167
77	08/31/76	23:00	09/01/76	20:00	1.41	0.8750	0.0671	1.3333
78	09/03/76	04:00	09/03/76	07:00	0.01	0.1250	0.0033	0.2500
79	09/03/76	13:00	09/03/76	24:00	0.25	0.4583	0.0227	0.2500
80	09/04/76	06:00	09/04/76	14:00	0.04	0.3333	0.0050	0.2917
81	09/04/76	21:00	09/05/76	18:00	0.44	0.8750	0.0210	0.9167

82	09/06/76	16:00	09/06/76	20:00	0.04	0.1667	0.0100	0.7083
83	09/07/76	13:00	09/07/76	17:00	0.11	0.1667	0.0275	1.8750
84	09/09/76	14:00	09/09/76	15:00	0.01	0.0417	0.0100	0.4167
85	09/10/76	01:00	09/10/76	03:00	0.01	0.0833	0.0050	6.8333
86	09/16/76	23:00	09/16/76	24:00	0.01	0.0417	0.0100	3.9583
87	09/20/76	23:00	09/21/76	06:00	0.06	0.2917	0.0086	4.8333
88	09/26/76	02:00	09/26/76	03:00	0.01	0.0417	0.0100	0.3333
89	09/26/76	11:00	09/26/76	15:00	0.12	0.1667	0.0300	0.6667
90	09/27/76	07:00	09/27/76	09:00	0.03	0.0833	0.0150	0.2500
91	09/27/76	15:00	09/27/76	18:00	0.01	0.1250	0.0033	1.1250
92	09/28/76	21:00	09/29/76	22:00	2.39	1.0417	0.0956	6.1250
93	10/06/76	01:00	10/07/76	05:00	0.05	1.1667	0.0018	0.7083
94	10/07/76	22:00	10/08/76	24:00	0.16	1.0833	0.0062	7.7500
95	10/16/76	18:00	10/17/76	03:00	0.05	0.3750	0.0056	2.9583
96	10/20/76	02:00	10/20/76	06:00	0.15	0.1667	0.0375	4.0000
97	10/24/76	06:00	10/24/76	17:00	0.01	0.4583	0.0009	0.2500
98	10/24/76	23:00	10/25/76	22:00	0.64	0.9583	0.0278	3.9167
99	10/29/76	20:00	10/30/76	16:00	0.54	0.8333	0.0270	11.8333
100	11/11/76	12:00	11/12/76	02:00	0.23	0.5833	0.0164	1.9583
101	11/14/76	01:00	11/15/76	05:00	0.96	1.1667	0.0343	4.3750
102	11/19/76	14:00	11/19/76	19:00	0.01	0.2083	0.0020	0.5833
103	11/20/76	09:00	11/20/76	19:00	0.22	0.4167	0.0220	5.4167
104	11/26/76	05:00	11/26/76	18:00	0.12	0.5417	0.0092	0.6667
105	11/27/76	10:00	11/27/76	15:00	0.02	0.2083	0.0040	0.4167
106	11/28/76	01:00	11/29/76	12:00	0.72	1.4583	0.0206	6.9583
107	12/06/76	11:00	12/07/76	15:00	0.57	1.1667	0.0204	2.5833
108	12/10/76	05:00	12/11/76	20:00	1.09	1.6250	0.0279	3.0417
109	12/14/76	21:00	12/15/76	05:00	0.25	0.3333	0.0312	4.5417
110	12/19/76	18:00	12/20/76	13:00	0.87	0.7917	0.0458	4.7917
111	12/25/76	08:00	12/25/76	24:00	1.35	0.6667	0.0844	4.5000

112	12/30/76	12:00	12/31/76	06:00	0.20	0.7500	0.0111

**

Appendix 5-D. Runoff.rsv File Printout

```
Runoff Coefficient file name:  RUNOFF.RSV
Runoff Coefficient file description:  CALIBRATED RUNOFF COEFFICIENT FILE
Date:  08-09-2000

    Area Types:
 1: Connected flat roofs
 2: Connected Pitched Roofs
 3: Directly connected impervious areas
 4: Directly connected unpaved areas
 5: Pervious areas - A/B soils
 6: Pervious areas - C/D soils
 7: Smooth textured streets
 8: Intermediate textured streets
 9: Rough textured streets

Drainage efficiency coefficients (fractions)
 10: C/D soils, w/o alleys, medium to high density land use
 11: C/D soils, w/ alleys, medium to high density land use
 12: C/D soils for strip commercial and shopping center land use

     |           Volumetric Runoff Coefficients for Rains (in & mm)
Area | in:   .01  .08  .12  .20  .39  .59  .79  .98  1.2  1.6  2.0  2.4  2.8  3.2  3.5
3.9  4.9
Type | mm:     1    2    3    5   10   15   20   25   30   40   50   60   70   80   90
100  125
 No  |Rain #:  1    2    3    4    5    6    7    8    9   10   11   12   13   14   15
16   17

 1 :        0.00 0.00 0.30 0.54 0.72 0.79 0.83 0.84 0.86 0.88 0.90 0.91 0.93 0.94 0.94
0.95 0.96
 2 :        0.25 0.63 0.75 0.85 0.93 0.95 0.96 0.97 0.98 0.98 0.99 0.99 0.99 0.99 0.99
0.99 0.99
 3 :        0.93 0.96 0.96 0.97 0.97 0.97 0.97 0.97 0.98 0.98 0.99 0.99 0.99 0.99 0.99
0.99 0.99
 4 :        0.00 0.00 0.00 0.00 0.47 0.64 0.72 0.77 0.81 0.86 0.89 0.91 0.92 0.93 0.94
0.94 0.95
 5 :        0.00 0.00 0.00 0.00 0.01 0.02 0.02 0.02 0.03 0.04 0.07 0.10 0.13 0.15 0.20
0.22 0.25
 6 :        0.00 0.00 0.00 0.10 0.15 0.19 0.20 0.21 0.22 0.23 0.26 0.29 0.32 0.33 0.36
0.39 0.45
 7 :        0.35 0.49 0.54 0.59 0.65 0.69 0.72 0.76 0.80 0.85 0.88 0.90 0.91 0.93 0.93
0.94 0.95
 8 :        0.26 0.43 0.49 0.55 0.60 0.64 0.67 0.67 0.73 0.80 0.84 0.86 0.88 0.90 0.91
0.92 0.93
 9 :        0.18 0.39 0.47 0.53 0.60 0.64 0.67 0.70 0.73 0.80 0.84 0.86 0.88 0.90 0.91
0.92 0.93

Drainage efficiency coefficients (fractions):
10 :        0.00 0.00 0.00 0.11 0.16 0.20 0.21 0.22 0.22 0.24 0.27 0.30 0.33 0.34 0.37
0.40 0.46
11 :        0.00 0.05 0.08 0.11 0.16 0.20 0.29 0.38 0.46 0.64 0.81 0.93 0.99 0.99 0.99
0.99 0.99
12 :        0.00 0.00 0.00 0.47 0.90 0.99 0.99 0.99 0.99 0.99 0.99 0.99 0.99 0.99 0.99
0.99 0.99
```

Appendix 5-E. Delivery.prr File Printout

```
Particulate Residue Reduction due to Delivery file name:  delivery.PRR
Size distribution file description:  example delivery
Date:  08-09-2000

             Particulate Residue Reduction due to Delivery (fraction) for Rains (in & mm)
             Rain (in) :.04  .08  .12  .20  .39  .59  .79  .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

       For 1.  Grass Swales:
                       0.99 0.98 0.97 0.94 0.85 0.74 0.61 0.44 0.25 0.07 0.02 0.00 0.00
0.00
       For 2.  Undeveloped roadside:
                       0.99 0.98 0.97 0.94 0.85 0.74 0.61 0.44 0.25 0.07 0.02 0.00 0.00
0.00
       For 3.  Curb and Gutters, `valleys', or sealed swales in poor condition (or very
flat):
                       0.98 0.96 0.92 0.85 0.61 0.46 0.31 0.22 0.13 0.04 0.01 0.00 0.00
0.00
       For 3.  Curb and Gutters, `valleys', or sealed swales in fair condition:
                       0.98 0.95 0.90 0.80 0.48 0.32 0.16 0.11 0.07 0.02 0.00 0.00 0.00
0.00
       For 3.  Curb and Gutters, `valleys', or sealed swales in good condition (or very
steep):
                       0.98 0.95 0.88 0.75 0.36 0.18 0.00 0.00 0.00 0.00 0.00 0.00 0.00
0.00
```

Appendix 5-F. Bham.psc File Printout

Particulate Solids Concentration file name: BHAM.PSC
Particulate Solids Concentration file description: Particulate residue concentrations for source areas.
Date: 08-09-2000

Area Types:
A : Roofs
B : Paved Parking
C : Unpaved parking, driveways, and walkways
D : Paved playgrounds
E : Paved driveways
F : Paved sidewalks and walks
G : Large landscaped areas
H : Small landscaped areas
I : Undeveloped areas
J : Other pervious areas
K : Other directly connected impervious areas
L : Other partially connected impervious areas
M : Paved lane and shoulder areas

Row No	Area Type	Particulate Solids (mg/l) for Rains (in & mm)														
		.04	.08	.12	.20	.39	.59	.79	.98	1.2	1.6	2.0	2.4	2.8	3.2	:in
		1	2	3	5	10	15	20	25	30	40	50	60	70	80	:mm
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	:Rain
#																
Residential Areas																
1	A	5	5	5	5	5	5	5	5	5	5	5	5	5	5	
2	B	1030	550	370	210	80	60	60	60	60	60	60	60	60	60	
3	C	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600	
4	D	1030	550	370	210	80	60	60	60	60	60	60	60	60	60	
5	E	1030	550	370	210	80	60	60	60	60	60	60	60	60	60	
6	F	1030	550	370	210	80	60	60	60	60	60	60	60	60	60	
7	G	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600	
8	H	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600	
9	I	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600	
10	J	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600	
11	K	1030	550	370	210	80	60	60	60	60	60	60	60	60	60	
12	L	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600	
Institutional Areas																
13	A	5	5	5	5	5	5	5	5	5	5	5	5	5	5	
14	B	1030	550	370	210	80	60	60	60	60	60	60	60	60	60	
15	C	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600	
16	D	1030	550	370	210	80	60	60	60	60	60	60	60	60	60	
17	E	1030	550	370	210	80	60	60	60	60	60	60	60	60	60	
18	F	1030	550	370	210	80	60	60	60	60	60	60	60	60	60	
19	G	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600	
20	H	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600	
21	I	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600	
22	J	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600	
23	K	1030	550	370	210	80	60	60	60	60	60	60	60	60	60	
24	L	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600	

Commercial Areas															
25	A	5	5	5	5	5	5	5	5	5	5	5	5	5	5
26	B	1030	550	370	210	80	60	60	60	60	60	60	60	60	60
27	C	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600
28	D	1030	550	370	210	80	60	60	60	60	60	60	60	60	60
29	E	1030	550	370	210	80	60	60	60	60	60	60	60	60	60
30	F	1030	550	370	210	80	60	60	60	60	60	60	60	60	60
31	G	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600
32	H	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600
33	I	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600
34	J	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600
35	K	1030	550	370	210	80	60	60	60	60	60	60	60	60	60
36	L	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600
Industrial Areas															
37	A	5	5	5	5	5	5	5	5	5	5	5	5	5	5
38	B	300	200	150	100	100	100	100	100	100	100	100	100	100	100
39	C	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600
40	D	300	200	150	100	100	100	100	100	100	100	100	100	100	100
41	E	300	200	150	100	100	100	100	100	100	100	100	100	100	100
42	F	300	200	150	100	100	100	100	100	100	100	100	100	100	100
43	G	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600
44	H	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600
45	I	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600
46	J	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600
47	K	300	200	150	100	100	100	100	100	100	100	100	100	100	100
48	L	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600
Open Space Areas															
49	A	5	5	5	5	5	5	5	5	5	5	5	5	5	5
50	B	1030	550	370	210	80	60	60	60	60	60	60	60	60	60
51	C	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600
52	D	1030	550	370	210	80	60	60	60	60	60	60	60	60	60
53	E	1030	550	370	210	80	60	60	60	60	60	60	60	60	60
54	F	1030	550	370	210	80	60	60	60	60	60	60	60	60	60
55	G	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600
56	H	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600
57	I	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600
58	J	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600
59	K	1030	550	370	210	80	60	60	60	60	60	60	60	60	60
60	L	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600
Freeways															
61	M	5800	4200	3100	2000	1200	1100	1100	1100	1100	1100	1100	1100	1100	1100
62	G	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600
63	I	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600
64	J	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600
65	K	1030	550	370	210	100	100	100	100	100	100	100	100	100	100
66	L	5000	4000	3300	2200	1100	700	600	600	600	600	600	600	600	600

Appendix 5-G. Bham.ppd File Printout

```
Pollutant Probability Relative Concentration file name:  bham.PPD
File description:  Modified PPD File 05/22/00, Para Mod. Version 6.7
Date:  08-09-2000
```

```
Source: 1: Roofs                    7: Street Area            13: Other Dir Conctd Imperv Area
 Areas: 2: Paved Parking/Storage    8: Large Landscaped Area  14: Othr Partially Conctd Imperv Area
        3: Unpaved Parking/Storage  9: Undeveloped Area       15: Paved Lane & Shoulder Area
        4: Playground               10: Small Landscaped Area 16: Large Turf Areas
        5: Driveways                11: Isolated Area
        6: Sidewalks/Walks          12: Other Pervious Area
```

Source Area #	Residential Land Uses	Institutional Land Uses	Commercial Land Uses	Industrial Land Uses	Open Spcs Land Use	Freeway Land Use

Particulate Pollutant: Phosphorus (mg/kg)

1-AVE :	5319.00	12033.00	12033.00	1600.00	1600.00	0.00
1-COV :	1.00	1.00	1.00	1.00	1.00	0.00
2-AVE :	1847.00	1847.00	1847.00	580.00	580.00	0.00
2-COV :	1.00	1.00	1.00	1.00	1.00	0.00
3-AVE :	1847.00	1847.00	1847.00	570.00	570.00	0.00
3-COV :	1.00	1.00	1.00	1.00	1.00	0.00
4-AVE :	7825.00	7825.00	7825.00	500.00	500.00	0.00
4-COV :	1.00	1.00	1.00	1.00	1.00	0.00
5-AVE :	3384.00	3384.00	3384.00	580.00	580.00	0.00
5-COV :	1.00	1.00	1.00	1.00	1.00	0.00
6-AVE :	3384.00	3384.00	3384.00	995.00	995.00	0.00
6-COV :	1.00	1.00	1.00	1.00	1.00	0.00
7-AVE :	809.00	809.00	809.00	650.00	650.00	0.00
7-COV :	1.00	1.00	1.00	1.00	1.00	0.00
8-AVE :	7825.00	7825.00	7825.00	2800.00	2800.00	2800.00
8-COV :	1.00	1.00	1.00	1.00	1.00	1.00
9-AVE :	5000.00	5000.00	5000.00	695.00	695.00	695.00
9-COV :	1.00	1.00	1.00	1.00	1.00	1.00
10-AVE :	7825.00	7825.00	7825.00	1250.00	1250.00	1250.00
10-COV :	1.00	1.00	1.00	1.00	1.00	1.00
11-AVE :	0.00	0.00	0.00	0.00	0.00	0.00
11-COV :	0.00	0.00	0.00	0.00	0.00	0.00
12-AVE :	7825.00	7825.00	7825.00	1600.00	1600.00	1600.00
12-COV :	1.00	1.00	1.00	1.00	1.00	1.00
13-AVE :	1847.00	1847.00	1847.00	500.00	500.00	500.00
13-COV :	1.00	1.00	1.00	1.00	1.00	1.00
14-AVE :	3304.00	3304.00	3304.00	500.00	500.00	500.00
14-COV :	1.00	1.00	1.00	1.00	1.00	1.00
15-AVE :	0.00	0.00	0.00	0.00	0.00	1000.00
15-COV :	0.00	0.00	0.00	0.00	0.00	1.00
16-AVE :	7825.00	7825.00	7825.00	2800.00	2800.00	2800.00
16-COV :	1.00	1.00	1.00	1.00	1.00	1.00

Particulate Pollutant: Total Kjeldahl Nitrogen (mg/kg)

1-AVE :	3340.00	10000.00	10000.00	3340.00	3340.00	0.00
1-COV :	1.00	1.00	1.00	1.00	1.00	0.00
2-AVE :	911.00	6400.00	6400.00	911.00	911.00	0.00
2-COV :	1.00	1.00	1.00	1.00	1.00	0.00
3-AVE :	620.00	620.00	620.00	620.00	620.00	0.00
3-COV :	1.00	1.00	1.00	1.00	1.00	0.00
4-AVE :	600.00	600.00	600.00	600.00	600.00	0.00
4-COV :	1.00	1.00	1.00	1.00	1.00	0.00
5-AVE :	911.00	911.00	911.00	911.00	911.00	0.00
5-COV :	1.00	1.00	1.00	1.00	1.00	0.00
6-AVE :	2770.00	2770.00	2770.00	2770.00	2770.00	0.00
6-COV :	1.00	1.00	1.00	1.00	1.00	0.00
7-AVE :	630.00	630.00	1910.00	940.00	630.00	0.00
7-COV :	1.00	1.00	1.00	1.00	1.00	0.00
8-AVE :	2200.00	2200.00	2200.00	2200.00	2200.00	2200.00
8-COV :	1.00	1.00	1.00	1.00	1.00	1.00
9-AVE :	1760.00	1760.00	1760.00	1760.00	1760.00	1760.00
9-COV :	1.00	1.00	1.00	1.00	1.00	1.00
10-AVE :	1760.00	1760.00	1760.00	1760.00	1760.00	1760.00
10-COV :	1.00	1.00	1.00	1.00	1.00	1.00
11-AVE :	0.00	0.00	0.00	0.00	0.00	0.00
11-COV :	0.00	0.00	0.00	0.00	0.00	0.00
12-AVE :	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00
12-COV :	1.00	1.00	1.00	1.00	1.00	1.00
13-AVE :	600.00	600.00	600.00	600.00	600.00	600.00
13-COV :	1.00	1.00	1.00	1.00	1.00	1.00
14-AVE :	600.00	600.00	600.00	600.00	600.00	600.00
14-COV :	1.00	1.00	1.00	1.00	1.00	1.00
15-AVE :	0.00	0.00	0.00	0.00	0.00	1100.00
15-COV :	0.00	0.00	0.00	0.00	0.00	1.00
16-AVE :	2200.00	2200.00	2200.00	2200.00	2200.00	2200.00
16-COV :	1.00	1.00	1.00	1.00	1.00	1.00

Particulate Pollutant: Chemical Oxygen Demand (mg/kg)

1-AVE :	913000.00	1520000.00	1520000.00	913000.00	913000.00	0.00
1-COV :	1.00	1.00	1.00	1.00	1.00	0.00
2-AVE :	512000.00	512000.00	512000.00	540000.00	512000.00	0.00
2-COV :	1.00	1.00	1.00	1.00	1.00	0.00
3-AVE :	695000.00	695000.00	695000.00	733000.00	695000.00	0.00
3-COV :	1.00	1.00	1.00	1.00	1.00	0.00
4-AVE :	507000.00	507000.00	507000.00	535000.00	507000.00	0.00
4-COV :	1.00	1.00	1.00	1.00	1.00	0.00
5-AVE :	512000.00	512000.00	512000.00	535000.00	507000.00	0.00
5-COV :	1.00	1.00	1.00	1.00	1.00	0.00
6-AVE :	664000.00	659000.00	659000.00	701000.00	659000.00	0.00
6-COV :	1.00	1.00	1.00	1.00	1.00	0.00
7-AVE :	304000.00	304000.00	304000.00	428000.00	304000.00	0.00
7-COV :	1.00	1.00	1.00	1.00	1.00	0.00
8-AVE :	1115000.00	1115000.00	1115000.00	1180000.00	1115000.00	1115000.00
8-COV :	1.00	1.00	1.00	1.00	1.00	1.00
9-AVE :	276000.00	276000.00	276000.00	292000.00	276000.00	284000.00
9-COV :	1.00	1.00	1.00	1.00	1.00	1.00
10-AVE :	507000.00	507000.00	507000.00	535000.00	507000.00	507000.00
10-COV :	1.00	1.00	1.00	1.00	1.00	1.00
11-AVE :	0.00	0.00	0.00	0.00	0.00	0.00
11-COV :	0.00	0.00	0.00	0.00	0.00	0.00
12-AVE :	761000.00	761000.00	761000.00	803000.00	761000.00	782000.00
12-COV :	1.00	1.00	1.00	1.00	1.00	1.00
13-AVE :	304000.00	304000.00	304000.00	321000.00	304000.00	313000.00
13-COV :	1.00	1.00	1.00	1.00	1.00	1.00
14-AVE :	304000.00	304000.00	304000.00	321000.00	304000.00	313000.00
14-COV :	1.00	1.00	1.00	1.00	1.00	1.00
15-AVE :	0.00	0.00	0.00	0.00	0.00	464000.00
15-COV :	0.00	0.00	0.00	0.00	0.00	1.00
16-AVE :	1115000.00	1115000.00	1115000.00	1115000.00	1115000.00	1150000.00
16-COV :	1.00	1.00	1.00	1.00	1.00	1.00

Particulate Pollutant: Copper (mg/kg)

1-AVE :	106.00	121.00	121.00	324.00	106.00	0.00
1-COV :	1.38	1.49	1.49	1.26	1.49	0.00
2-AVE :	139.00	408.00	408.00	822.00	139.00	0.00
2-COV :	0.23	1.06	0.74	0.42	1.06	0.00
3-AVE :	151.00	151.00	151.00	461.00	151.00	0.00
3-COV :	0.86	0.86	0.86	1.12	0.86	0.00
4-AVE :	82.00	82.00	82.00	249.00	82.00	0.00
4-COV :	1.06	1.06	1.06	1.06	1.06	0.00
5-AVE :	139.00	139.00	139.00	423.00	139.00	0.00
5-COV :	1.06	1.06	1.06	1.06	1.06	0.00
6-AVE :	131.00	131.00	131.00	398.00	131.00	0.00
6-COV :	1.06	1.06	1.06	1.06	1.06	0.00
7-AVE :	375.00	375.00	143.00	423.00	375.00	0.00
7-COV :	1.06	0.69	1.06	1.16	1.06	0.00
8-AVE :	41.00	41.00	41.00	125.00	41.00	0.00
8-COV :	2.00	1.10	1.10	1.10	1.10	0.00
9-AVE :	73.00	73.00	73.00	224.00	73.00	150.00
9-COV :	1.10	1.10	1.10	1.10	1.10	1.10
10-AVE :	16.00	16.00	16.00	50.00	16.00	0.00
10-COV :	1.10	1.10	1.10	1.10	1.10	0.00
11-AVE :	0.00	0.00	0.00	0.00	0.00	0.00
11-COV :	0.00	0.00	0.00	0.00	0.00	0.00
12-AVE :	41.00	41.00	41.00	125.00	41.00	82.00
12-COV :	1.10	1.10	1.10	1.10	1.10	1.10
13-AVE :	82.00	82.00	82.00	249.00	82.00	165.00
13-COV :	1.06	1.06	2.02	0.88	1.06	1.06
14-AVE :	82.00	82.00	82.00	249.00	82.00	165.00
14-COV :	2.00	1.06	2.02	0.88	1.06	1.06
15-AVE :	0.00	0.00	0.00	0.00	0.00	1100.00
15-COV :	0.00	0.00	0.00	0.00	0.00	1.06
16-AVE :	0.00	0.00	0.00	0.00	0.00	150.00
16-COV :	0.00	0.00	0.00	0.00	0.00	1.10

Particulate Pollutant: Lead (mg/kg)

1-AVE :	3518.00	3518.00	26995.00	11778.00	3518.00	0.00
1-COV :	1.21	1.21	1.68	0.87	1.21	0.00
2-AVE :	7235.00	1289.00	1223.00	1157.00	7235.00	0.00
2-COV :	1.41	1.15	1.21	1.27	1.41	0.00
3-AVE :	94.00	94.00	94.00	1020.00	94.00	0.00
3-COV :	1.18	1.18	1.18	0.60	1.18	0.00
4-AVE :	1289.00	1289.00	1289.00	1289.00	1289.00	0.00
4-COV :	1.15	1.15	1.15	1.15	1.15	0.00
5-AVE :	1289.00	1289.00	1289.00	1289.00	1289.00	0.00
5-COV :	1.15	1.15	1.15	1.15	1.15	0.00
6-AVE :	1289.00	1289.00	1289.00	1289.00	1289.00	0.00
6-COV :	1.15	1.15	1.15	1.15	1.15	0.00
7-AVE :	1861.00	1861.00	3580.00	722.00	1861.00	0.00
7-COV :	1.41	1.41	1.41	0.81	1.41	0.00
8-AVE :	1358.00	1358.00	1358.00	1358.00	1358.00	1358.00
8-COV :	1.84	1.84	1.84	1.84	1.84	1.84
9-AVE :	1358.00	1358.00	1358.00	1358.00	1358.00	121.00
9-COV :	1.84	1.84	1.84	1.84	1.84	1.84
10-AVE :	1358.00	1358.00	1358.00	1358.00	1358.00	121.00
10-COV :	1.84	1.84	1.84	1.84	1.84	1.84
11-AVE :	0.00	0.00	0.00	0.00	0.00	0.00
11-COV :	0.00	0.00	0.00	0.00	0.00	0.00
12-AVE :	1358.00	1358.00	1358.00	1358.00	1358.00	134.00
12-COV :	1.84	1.84	1.84	1.84	1.84	1.84
13-AVE :	1289.00	1289.00	2911.00	1398.00	1289.00	447.00
13-COV :	1.15	1.15	0.79	0.63	1.15	1.15
14-AVE :	1289.00	1289.00	2911.00	1398.00	1289.00	447.00
14-COV :	1.15	1.15	0.79	0.63	1.15	1.15
15-AVE :	0.00	0.00	0.00	0.00	0.00	8630.00
15-COV :	0.00	0.00	0.00	0.00	0.00	1.41
16-AVE :	1358.00	1358.00	1358.00	1358.00	1358.00	240.00
16-COV :	1.84	1.84	1.84	1.84	1.84	1.84

Particulate Pollutant: Zinc (mg/kg)

1-AVE :	980.00	980.00	53333.00	4000.00	980.00	0.00
1-COV :	1.10	1.10	1.73	1.06	1.10	0.00
2-AVE :	944.00	1031.00	754.00	477.00	944.00	0.00
2-COV :	1.41	1.19	1.06	0.93	1.41	0.00
3-AVE :	85.00	85.00	85.00	308.00	85.00	0.00
3-COV :	1.41	1.41	1.41	1.00	1.41	0.00
4-AVE :	944.00	944.00	944.00	944.00	944.00	0.00
4-COV :	1.41	1.41	1.41	1.41	1.41	0.00
5-AVE :	944.00	944.00	944.00	944.00	944.00	0.00
5-COV :	1.41	1.41	1.41	1.41	1.41	0.00
6-AVE :	944.00	944.00	944.00	944.00	944.00	0.00
6-COV :	1.41	1.41	1.41	1.41	1.41	0.00
7-AVE :	384.00	447.00	876.00	1300.00	384.00	0.00
7-COV :	1.00	1.00	1.00	1.06	1.00	0.00
8-AVE :	1327.00	1327.00	1327.00	1327.00	1327.00	450.00
8-COV :	2.24	2.24	2.24	2.24	2.24	1.00
9-AVE :	1327.00	1327.00	1327.00	1327.00	1327.00	450.00
9-COV :	2.24	2.24	2.24	2.24	2.24	2.24
10-AVE :	1327.00	1327.00	1327.00	1327.00	1327.00	450.00
10-COV :	2.24	2.24	2.24	2.24	2.24	2.24
11-AVE :	0.00	0.00	0.00	0.00	0.00	0.00
11-COV :	0.00	0.00	0.00	0.00	0.00	0.00
12-AVE :	1327.00	1327.00	1327.00	1327.00	1327.00	340.00
12-COV :	2.24	2.24	2.24	2.24	2.24	2.24
13-AVE :	944.00	944.00	1691.00	385.00	944.00	510.00
13-COV :	1.41	1.41	1.73	1.03	1.41	2.24
14-AVE :	944.00	944.00	1691.00	385.00	944.00	510.00
14-COV :	1.41	1.41	1.73	1.03	1.41	2.24
15-AVE :	0.00	0.00	0.00	0.00	0.00	1730.00
15-COV :	0.00	0.00	0.00	0.00	0.00	1.00
16-AVE :	1327.00	1327.00	1327.00	1327.00	1327.00	450.00
16-COV :	2.24	2.24	2.24	2.24	2.24	2.24

Filterable Pollutant: Filterable Solids (mg/L)

1-AVE :	116.00	386.00	386.00	148.00	116.00	0.00
1-COV :	1.00	1.00	1.00	1.00	1.00	0.00
2-AVE :	223.00	223.00	223.00	157.00	223.00	0.00
2-COV :	1.00	1.00	1.00	1.00	1.00	0.00
3-AVE :	1240.00	1240.00	1240.00	585.00	1240.00	0.00
3-COV :	1.00	1.00	1.00	1.00	1.00	0.00
4-AVE :	223.00	223.00	223.00	105.00	223.00	0.00
4-COV :	1.00	1.00	1.00	1.00	1.00	0.00
5-AVE :	223.00	223.00	223.00	105.00	223.00	0.00
5-COV :	1.00	1.00	1.00	1.00	1.00	0.00
6-AVE :	318.00	318.00	318.00	150.00	318.00	0.00
6-COV :	1.00	1.00	1.00	1.00	1.00	0.00
7-AVE :	151.00	151.00	151.00	263.00	151.00	0.00
7-COV :	1.00	1.00	1.00	1.00	1.00	0.00
8-AVE :	861.00	861.00	861.00	406.00	861.00	861.00
8-COV :	1.00	1.00	1.00	1.00	1.00	1.00
9-AVE :	846.00	846.00	846.00	400.00	846.00	846.00
9-COV :	1.00	1.00	1.00	1.00	1.00	1.00
10-AVE :	861.00	861.00	861.00	406.00	861.00	861.00
10-COV :	1.00	1.00	1.00	1.00	1.00	1.00
11-AVE :	0.00	0.00	0.00	0.00	0.00	0.00
11-COV :	0.00	0.00	0.00	0.00	0.00	0.00
12-AVE :	861.00	861.00	861.00	406.00	861.00	638.00
12-COV :	1.00	1.00	1.00	1.00	1.00	1.00
13-AVE :	223.00	223.00	223.00	105.00	223.00	165.00
13-COV :	1.00	1.00	1.00	1.00	1.00	1.00
14-AVE :	223.00	223.00	223.00	105.00	223.00	165.00
14-COV :	1.00	1.00	1.00	1.00	1.00	1.00
15-AVE :	0.00	0.00	0.00	0.00	0.00	352.00
15-COV :	0.00	0.00	0.00	0.00	0.00	1.00
16-AVE :	861.00	861.00	861.00	861.00	861.00	638.00
16-COV :	1.00	1.00	1.00	1.00	1.00	1.00

Filterable Pollutant: Nitrates (mg/L)

1-AVE :	18.30	0.61	0.61	0.23	0.61	0.00
1-COV :	1.00	1.00	1.00	1.00	1.00	0.00
2-AVE :	0.61	0.61	0.61	26.10	0.61	0.00
2-COV :	1.00	1.00	1.00	1.00	1.00	0.00
3-AVE :	6.10	6.10	6.10	63.00	6.10	0.00
3-COV :	1.00	1.00	1.00	1.00	1.00	0.00
4-AVE :	0.61	0.61	0.61	0.61	0.61	0.00
4-COV :	1.00	1.00	1.00	1.00	1.00	0.00
5-AVE :	0.37	0.61	0.61	64.35	0.35	0.00
5-COV :	1.00	1.00	1.00	1.00	1.00	0.00
6-AVE :	0.61	0.61	0.61	16.20	0.61	0.00
6-COV :	1.00	1.00	1.00	1.00	1.00	0.00
7-AVE :	0.35	0.35	0.37	27.90	0.35	0.00
7-COV :	1.00	1.00	1.00	1.00	1.00	0.00
8-AVE :	1.28	1.28	1.28	9.45	1.28	1.28
8-COV :	1.00	1.00	1.00	1.00	1.00	1.00
9-AVE :	1.28	1.28	1.28	9.45	1.28	1.28
9-COV :	1.00	1.00	1.00	1.00	1.00	1.00
10-AVE :	1.28	1.28	1.28	9.45	1.28	1.28
10-COV :	1.00	1.00	1.00	1.00	1.00	1.00
11-AVE :	0.00	0.00	0.00	0.00	0.00	0.00
11-COV :	0.00	0.00	0.00	0.00	0.00	0.00
12-AVE :	1.28	1.28	1.28	9.45	1.28	5.46
12-COV :	1.00	1.00	1.00	1.00	1.00	1.00
13-AVE :	0.61	0.61	0.61	4.50	0.61	2.60
13-COV :	1.00	1.00	1.00	1.00	1.00	1.00
14-AVE :	0.61	0.61	0.61	4.50	0.61	2.60
14-COV :	1.00	1.00	1.00	1.00	1.00	1.00
15-AVE :	0.00	0.00	0.00	0.00	0.00	1.56
15-COV :	0.00	0.00	0.00	0.00	0.00	1.00
16-AVE :	1.28	1.28	1.28	9.45	1.28	5.46
16-COV :	1.00	1.00	1.00	1.00	1.00	1.00

Filterable Pollutant: Total Kjeldahl Nitrogen (mg/L)

1-AVE :	0.78	4.30	4.30	1.63	0.78	0.00
1-COV :	1.00	1.00	1.00	1.00	1.00	0.00
2-AVE :	1.42	1.40	1.40	0.29	1.40	0.00
2-COV :	1.00	1.00	1.00	1.00	1.00	0.00
3-AVE :	2.00	2.00	2.00	2.00	2.00	0.00
3-COV :	1.00	1.00	1.00	1.00	1.00	0.00
4-AVE :	1.40	1.40	1.40	1.40	1.40	0.00
4-COV :	1.00	1.00	1.00	1.00	1.00	0.00
5-AVE :	1.40	1.40	1.40	1.40	1.40	0.00
5-COV :	1.00	1.00	1.00	1.00	1.00	0.00
6-AVE :	3.30	3.30	3.30	3.30	3.30	0.00
6-COV :	1.00	1.00	1.00	1.00	1.00	0.00
7-AVE :	1.50	1.50	2.20	2.70	1.50	0.00
7-COV :	1.00	1.00	1.00	1.00	1.00	0.00
8-AVE :	1.60	1.60	1.60	1.60	1.60	1.60
8-COV :	1.00	1.00	1.00	1.00	1.00	1.00
9-AVE :	1.10	1.10	1.10	1.10	1.10	1.10
9-COV :	1.00	1.00	1.00	1.00	1.00	1.00
10-AVE :	1.60	1.60	1.60	1.60	1.60	1.60
10-COV :	1.00	1.00	1.00	1.00	1.00	1.00
11-AVE :	0.00	0.00	0.00	0.00	0.00	0.00
11-COV :	0.00	0.00	0.00	0.00	0.00	0.00
12-AVE :	1.60	1.60	1.60	1.60	1.60	1.60
12-COV :	1.00	1.00	1.00	1.00	1.00	1.00
13-AVE :	1.40	1.40	1.40	1.40	1.40	1.40
13-COV :	1.00	1.00	1.00	1.00	1.00	1.00
14-AVE :	1.40	1.40	1.40	1.40	1.40	1.40
14-COV :	1.00	1.00	1.00	1.00	1.00	1.00
15-AVE :	0.00	0.00	0.00	0.00	0.00	2.30
15-COV :	0.00	0.00	0.00	0.00	0.00	1.00
16-AVE :	1.60	1.60	1.60	1.60	1.60	1.60
16-COV :	1.00	1.00	1.00	1.00	1.00	1.00

Filterable Pollutant: Chemical Oxygen Demand (mg/L)

1-AVE :	23.00	84.00	84.00	38.00	23.00	0.00
1-COV :	1.00	1.00	1.00	1.00	1.00	0.00
2-AVE :	22.00	22.00	55.00	52.00	22.00	0.00
2-COV :	1.00	1.00	1.00	1.00	1.00	0.00
3-AVE :	107.00	107.00	107.00	113.00	107.00	0.00
3-COV :	1.00	1.00	1.00	1.00	1.00	0.00
4-AVE :	17.00	17.00	17.00	17.00	17.00	0.00
4-COV :	1.00	1.00	1.00	1.00	1.00	0.00
5-AVE :	22.00	22.00	22.00	22.00	22.00	0.00
5-COV :	1.00	1.00	1.00	1.00	1.00	0.00
6-AVE :	22.00	22.00	22.00	22.00	22.00	0.00
6-COV :	1.00	1.00	1.00	1.00	1.00	0.00
7-AVE :	40.00	40.00	101.00	191.00	40.00	0.00
7-COV :	1.00	1.00	1.00	1.00	1.00	0.00
8-AVE :	17.00	17.00	17.00	17.00	17.00	17.00
8-COV :	1.00	1.00	1.00	1.00	1.00	1.00
9-AVE :	20.00	20.00	20.00	20.00	20.00	20.00
9-COV :	1.00	1.00	1.00	1.00	1.00	1.00
10-AVE :	17.00	17.00	17.00	17.00	17.00	17.00
10-COV :	1.00	1.00	1.00	1.00	1.00	1.00
11-AVE :	0.00	0.00	0.00	0.00	0.00	0.00
11-COV :	0.00	0.00	0.00	0.00	0.00	0.00
12-AVE :	17.00	17.00	17.00	17.00	17.00	17.00
12-COV :	1.00	1.00	1.00	1.00	1.00	1.00
13-AVE :	22.00	22.00	22.00	22.00	22.00	22.00
13-COV :	1.00	1.00	1.00	1.00	1.00	1.00
14-AVE :	22.00	22.00	22.00	22.00	22.00	22.00
14-COV :	1.00	1.00	1.00	1.00	1.00	1.00
15-AVE :	0.00	0.00	0.00	0.00	0.00	78.00
15-COV :	0.00	0.00	0.00	0.00	0.00	1.00
16-AVE :	18.00	18.00	18.00	18.00	18.00	18.00
16-COV :	1.00	1.00	1.00	1.00	1.00	1.00

Filterable Pollutant: Fecal Coliform Bact. (#/100 ml)

1-AVE :	5030.00	80.00	80.00	5010.00	5030.00	0.00
1-COV :	1.00	1.00	1.00	1.00	1.00	0.00
2-AVE :	100000.00	100000.00	48000.00	9800.00	100000.00	0.00
2-COV :	1.00	1.00	1.00	1.00	1.00	0.00
3-AVE :	200000.00	200000.00	200000.00	200000.00	200000.00	0.00
3-COV :	1.00	1.00	1.00	1.00	1.00	0.00
4-AVE :	18000.00	18000.00	18000.00	18000.00	18000.00	0.00
4-COV :	1.00	1.00	1.00	1.00	1.00	0.00
5-AVE :	300000.00	300000.00	300000.00	300000.00	300000.00	0.00
5-COV :	1.00	1.00	1.00	1.00	1.00	0.00
6-AVE :	170000.00	170000.00	170000.00	170000.00	170000.00	0.00
6-COV :	1.00	1.00	1.00	1.00	1.00	0.00
7-AVE :	43000.00	43000.00	43000.00	170000.00	43000.00	0.00
7-COV :	1.00	1.00	1.00	1.00	1.00	0.00
8-AVE :	30000.00	30000.00	30000.00	30000.00	30000.00	30000.00
8-COV :	1.00	1.00	1.00	1.00	1.00	1.00
9-AVE :	30000.00	30000.00	30000.00	30000.00	30000.00	30000.00
9-COV :	1.00	1.00	1.00	1.00	1.00	1.00
10-AVE :	30000.00	30000.00	30000.00	30000.00	30000.00	30000.00
10-COV :	1.00	1.00	1.00	1.00	1.00	1.00
11-AVE :	0.00	0.00	0.00	0.00	0.00	0.00
11-COV :	0.00	0.00	0.00	0.00	0.00	0.00
12-AVE :	30000.00	30000.00	30000.00	30000.00	30000.00	30000.00
12-COV :	1.00	1.00	1.00	1.00	1.00	1.00
13-AVE :	18000.00	18000.00	18000.00	18000.00	18000.00	18000.00
13-COV :	1.00	1.00	1.00	1.00	1.00	1.00
14-AVE :	18000.00	18000.00	18000.00	18000.00	18000.00	18000.00
14-COV :	1.00	1.00	1.00	1.00	1.00	1.00
15-AVE :	0.00	0.00	0.00	0.00	0.00	43000.00
15-COV :	0.00	0.00	0.00	0.00	0.00	1.00
16-AVE :	30000.00	30000.00	30000.00	30000.00	30000.00	30000.00
16-COV :	1.00	1.00	1.00	1.00	1.00	1.00

Filterable Pollutant: Copper (microgram/L)

1-AVE :	2.82	0.85	0.85	1.60	0.85	0.00
1-COV :	1.18	0.72	0.72	0.94	0.72	0.00
2-AVE :	2.05	15.79	8.36	0.93	2.05	0.00
2-COV :	0.52	1.37	0.90	0.43	0.52	0.00
3-AVE :	2.28	2.28	2.28	154.00	2.28	0.00
3-COV :	0.20	0.20	0.20	1.64	0.20	0.00
4-AVE :	2.28	2.28	2.28	2.28	2.28	0.00
4-COV :	0.20	0.20	0.20	0.20	0.20	0.00
5-AVE :	2.28	2.28	2.28	2.28	2.28	0.00
5-COV :	0.20	0.20	0.20	0.20	0.20	0.00
6-AVE :	2.28	2.28	2.28	2.28	2.28	0.00
6-COV :	0.20	0.20	0.20	0.20	0.20	0.00
7-AVE :	1.34	1.34	1.34	4.23	1.34	0.00
7-COV :	0.39	0.39	0.39	1.16	0.39	0.00
8-AVE :	3.30	3.30	3.30	3.30	3.30	3.30
8-COV :	0.90	0.90	0.90	0.90	0.90	0.90
9-AVE :	3.30	3.30	3.30	3.30	3.30	3.30
9-COV :	0.90	0.90	0.90	0.90	0.90	0.90
10-AVE :	3.30	3.30	3.30	3.30	3.30	3.30
10-COV :	0.90	0.90	0.90	0.90	0.90	0.90
11-AVE :	0.00	0.00	0.00	0.00	0.00	0.00
11-COV :	0.00	0.00	0.00	0.00	0.00	0.00
12-AVE :	3.30	3.30	3.30	3.30	3.30	3.30
12-COV :	0.90	0.90	0.90	0.90	0.90	0.90
13-AVE :	2.28	2.28	7.00	5.94	2.28	2.28
13-COV :	0.20	0.20	1.45	1.29	0.20	0.20
14-AVE :	2.28	2.28	6.81	5.94	2.28	2.28
14-COV :	0.20	0.20	1.45	1.29	0.20	0.20
15-AVE :	0.00	0.00	0.00	0.00	0.00	1.34
15-COV :	0.00	0.00	0.00	0.00	0.00	0.39
16-AVE :	3.30	3.30	3.30	3.30	3.30	3.30
16-COV :	0.90	0.90	0.90	0.90	0.90	0.90

Filterable Pollutant: Lead (microgram/L)

1-AVE :	0.05	0.05	0.05	1.00	0.05	0.05
1-COV :	0.00	0.00	0.00	0.48	0.00	0.00
2-AVE :	1.00	1.48	1.57	1.66	1.00	0.00
2-COV :	0.71	1.13	0.60	0.07	0.71	0.00
3-AVE :	0.25	0.25	0.25	2.23	0.25	0.00
3-COV :	0.00	0.00	0.00	0.56	0.00	0.00
4-AVE :	1.00	1.00	1.00	1.00	1.00	0.00
4-COV :	0.71	0.71	0.71	0.71	0.71	0.00
5-AVE :	1.00	1.00	1.00	1.00	1.00	0.00
5-COV :	0.71	0.71	0.71	0.71	0.71	0.00
6-AVE :	1.00	1.00	1.00	1.00	1.00	0.00
6-COV :	0.71	0.71	0.71	0.71	0.71	0.00
7-AVE :	4.00	4.00	21.00	12.00	4.00	0.00
7-COV :	0.63	0.63	0.63	0.55	0.63	0.00
8-AVE :	0.73	0.73	0.73	0.73	0.73	2.00
8-COV :	0.70	0.70	0.70	0.70	0.70	0.70
9-AVE :	0.73	0.73	0.73	0.73	0.73	2.00
9-COV :	0.70	0.70	0.70	0.70	0.70	0.70
10-AVE :	0.73	1.00	0.73	0.73	0.73	2.00
10-COV :	0.70	0.70	0.70	0.70	0.70	0.70
11-AVE :	0.00	0.00	0.00	0.00	0.00	0.00
11-COV :	0.00	0.00	0.00	0.00	0.00	0.00
12-AVE :	0.70	0.73	0.73	0.73	0.73	2.00
12-COV :	0.70	0.70	0.70	0.70	0.70	0.70
13-AVE :	1.00	1.00	1.26	1.11	1.00	2.00
13-COV :	0.71	0.71	0.71	0.95	0.71	0.71
14-AVE :	1.00	1.00	1.26	1.11	1.00	2.00
14-COV :	0.71	0.71	1.00	0.95	0.71	0.71
15-AVE :	0.00	0.00	0.00	0.00	0.00	130.00
15-COV :	0.00	0.00	0.00	0.00	0.00	0.63
16-AVE :	0.73	0.73	0.73	0.73	0.73	2.00
16-COV :	0.70	0.70	0.70	0.70	0.70	0.70

Filterable Pollutant: Zinc (microgram/L)

1-AVE :	438.00	128.00	128.00	21.80	128.00	0.00
1-COV :	1.43	0.90	0.90	0.90	0.90	0.00
2-AVE :	55.50	144.00	92.00	39.20	55.50	0.00
2-COV :	0.83	1.38	1.40	1.42	0.83	0.00
3-AVE :	18.00	18.00	18.00	13.40	18.00	0.00
3-COV :	0.39	0.39	0.39	0.54	0.39	0.00
4-AVE :	55.50	55.50	55.50	55.50	55.50	0.00
4-COV :	0.83	0.83	0.83	0.83	0.83	0.00
5-AVE :	55.50	55.50	55.50	55.50	55.50	0.00
5-COV :	0.83	0.83	0.83	0.83	0.83	0.00
6-AVE :	55.50	55.50	55.50	55.50	55.50	0.00
6-COV :	0.83	0.83	0.83	0.83	0.83	0.00
7-AVE :	72.00	72.00	97.00	237.00	72.00	0.00
7-COV :	0.77	0.77	0.77	1.23	0.77	0.00
8-AVE :	165.00	165.00	165.00	165.00	165.00	19.00
8-COV :	1.71	1.71	1.71	1.71	1.71	1.71
9-AVE :	165.00	165.00	165.00	165.00	165.00	19.00
9-COV :	1.71	1.71	1.71	1.71	1.71	1.71
10-AVE :	165.00	165.00	165.00	165.00	165.00	19.00
10-COV :	1.71	1.71	1.71	1.71	1.71	1.71
11-AVE :	0.00	0.00	0.00	0.00	0.00	0.00
11-COV :	0.00	0.00	0.00	0.00	0.00	0.00
12-AVE :	165.00	165.00	165.00	165.00	165.00	2.00
12-COV :	1.71	1.71	1.71	1.71	1.71	1.71
13-AVE :	55.50	55.50	72.80	22.20	55.50	22.00
13-COV :	0.83	0.83	1.30	1.56	0.83	0.83
14-AVE :	55.50	55.50	72.80	22.20	55.50	22.00
14-COV :	0.83	0.83	1.30	1.56	0.83	0.83
15-AVE :	0.00	0.00	0.00	0.00	0.00	204.00
15-COV :	0.00	0.00	0.00	0.00	0.00	0.77
16-AVE :	165.00	165.00	165.00	165.00	165.00	2.00
16-COV :	1.71	1.71	1.71	1.71	1.71	1.71

Filterable Pollutant: Other 1 Ammonia (mg/L)

1-AVE :	0.50	1.10	1.10	0.40	0.50	0.00
1-COV :	1.00	1.00	1.00	1.00	1.00	0.00
2-AVE :	0.20	0.38	0.38	0.30	0.20	0.00
2-COV :	1.00	1.00	1.00	1.00	1.00	0.00
3-AVE :	0.05	0.05	0.05	0.05	0.05	0.00
3-COV :	1.00	1.00	1.00	1.00	1.00	0.00
4-AVE :	0.20	0.38	0.38	0.30	0.20	0.00
4-COV :	1.00	1.00	1.00	1.00	1.00	0.00
5-AVE :	0.05	0.05	0.05	0.05	0.05	0.00
5-COV :	1.00	1.00	1.00	1.00	1.00	0.00
6-AVE :	0.30	0.30	0.30	0.05	0.30	0.00
6-COV :	1.00	1.00	1.00	1.00	1.00	0.00
7-AVE :	0.42	0.05	0.05	0.05	0.42	0.00
7-COV :	1.00	1.00	1.00	1.00	1.00	0.00
8-AVE :	0.80	0.80	0.80	0.80	0.80	0.80
8-COV :	1.00	1.00	1.00	1.00	1.00	1.00
9-AVE :	0.05	0.05	0.05	0.05	0.05	0.05
9-COV :	1.00	1.00	1.00	1.00	1.00	1.00
10-AVE :	0.80	0.80	0.80	0.80	0.80	0.80
10-COV :	1.00	1.00	1.00	1.00	1.00	1.00
11-AVE :	0.00	0.00	0.00	0.00	0.00	0.00
11-COV :	0.00	0.00	0.00	0.00	0.00	0.00
12-AVE :	0.80	0.80	0.80	0.80	0.80	0.80
12-COV :	1.00	1.00	1.00	1.00	1.00	1.00
13-AVE :	0.20	0.38	0.38	0.30	0.20	0.30
13-COV :	1.00	1.00	1.00	1.00	1.00	1.00
14-AVE :	0.20	0.38	0.38	0.30	0.20	0.30
14-COV :	1.00	1.00	1.00	1.00	1.00	1.00
15-AVE :	0.42	0.05	0.05	0.05	0.42	0.05
15-COV :	1.00	1.00	1.00	1.00	1.00	1.00
16-AVE :	0.05	0.05	0.05	0.05	0.05	0.50
16-COV :	1.00	1.00	1.00	1.00	1.00	1.00

Appendix 5-H. Medium.cpz File Printout

Size distribution file name: MEDIUM.CPZ
Size distribution file description: PARTICLE SIZE DISTRIBUTION FOR URBAN RUNOFF HAVING MEDIUM TOTAL RESIDUE CONCENTRATIONS
Date: 03-08-1999

Entry Number	Critical Size (microns)	Percent > Critical Size
0	0	100.0
1	1	99.0
2	2	94.0
3	3	90.0
4	4	86.0
5	5	82.0
6	6	79.0
7	7	76.0
8	8	73.0
9	9	70.0
10	10	67.0
11	11	65.0
12	12	63.0
13	13	61.0
14	14	59.0
15	15	58.0
16	20	51.0
17	25	46.0
18	30	42.0
19	35	38.0
20	40	35.0
21	50	31.0
22	60	28.0
23	80	23.0
24	100	19.0
25	150	14.0
26	200	11.0
27	300	8.0
28	500	5.0
29	800	3.0
30	1000	2.0
31	2000	0.0