Small Storm Hydrology and BMP Modeling with SWMM5

Gilles Rivard

Stormwater management practices increasingly are required to meet not only peak flowrate restrictions but also are required to include measures that can minimize the impacts on base flow, water quality in receiving waters and erosion in watercourses. The best management practices (BMPs) and low impact development (LID) techniques that are specifically designed to reduce these impacts generally consider small to moderate rainfall events and the hydrologic modeling of these events is in some respect different from the modeling for the larger storms that are typically used in control of peak flowrates.

Small storm hydrology features have been defined and studied for the past 20 y (Pitt, 1987; 1999a) to examine the specific elements that should be taken into account for the design of BMPs used for recharge, quality and erosion control. After a discussion of characteristics of rainfall events and design criteria, this chapter reviews small storm hydrology concepts and the main findings as they are currently applied in different stormwater management guides.

The chapter subsequently describes how SWMM5 (Stormwater Management Model, V5—as implemented in PCSWMM.NET) could be used to reproduce results obtained empirically in small storm hydrology research, with a specific discussion of design storms. Finally, the use of SWMM5 for the analysis of filter strip, infiltration trench, porous pavement and bioretention is discussed.

Rivard, G. 2010. "Small Storm Hydrology and BMP Modeling with SWMM5." *Journal of Water Management Modeling* R236-10. doi: 10.14796/JWMM.R236-10.

© CHI 2010 www.chijournal.org ISSN: 2292-6062 (Formerly in Dynamic Modeling of Urban Water Systems. ISBN: 978-0-9808853-3-0)

10.1 Introduction

Most of the recently available guides for stormwater management typically require that the criteria retained for stormwater management should be defined for the entire rainfall event spectrum, from very frequent events up to the very rare events (MDE, 2000; MOE, 2003; MPCA, 2005). While the rare events are controlled because of the potential for surcharge and flooding, it is now recognized that the more frequent events should also be specifically controlled as it has been demonstrated that they have a significant impact on groundwater recharge, water quality and watercourse erosion.

Analysis of the specific hydrological features of more frequent runoff events was reported in the pioneering work of Robert Pitt and other researchers at the end of the 1970s and in the 1980s (Heaney et al., 1977; EPA, 1983; Pitt, 1987). This has led to the concept of small storm hydrology (Pitt, 1999a; Pitt and Voorhes, 2000) and associated computations that are now being included in recent stormwater guides (DEP, 2006; Iowa, 2008). Essentially, the so-called small storm hydrology method was developed to estimate the runoff volume from urban and suburban land uses for relatively small storm events, based on field research in the Midwest, the Southeastern U.S. and Ontario. A specific program, WinSlamm (Source Loading and Management Model) has also been developed to plan stormwater quality controls (Pitt and Voorhes, 2000).

This chapter discusses small storm hydrology concepts and illustrates the use of SWMM5 to model typical BMPs. After an analysis of the rainfall event spectrum and the design criteria using the Montréal area as an example, the small storm hydrology results are presented as they are currently applied in recent guides. A sensitivity analysis for the characteristics of a design storm for water quality control is then subsequently presented. Finally, the last section describes the use of SWMM5 to model different BMPs, including a filter strip, an infiltration trench, a porous pavement and a bioretention unit. Even though SWMM5 cannot actually model infiltration processes in a canal or a basin, it will be shown that different artifices can be used to model these BMPs.

10.2 Rainfall Event Spectrum and Design Criteria

10.2.1 Characterization of Rainfall Events

As pointed out by Pitt (1999a), frequent rainfall events are responsible for most of the runoff and mass pollutant discharges and they should therefore be used as

the basis for water quality control. An analysis of hourly rainfall events for the Dorval airport in Montréal is shown in Figure 10.1; a minimum interevent time of 6 h has been used to define separate rainfall events. All the rainfall events for the period 1943–1992 and with a rainfall quantity >1 mm were considered.

Figure 10.1 Analysis of hourly rainfall events at Dorval airport, Montreal, for the period 1943–1992.

The analysis clearly shows that most of the events are relatively small and that they could be separated in different categories:

- Very frequent rainfall events (<10 mm);
- Common rainfall (80% and 90% of the events have a quantity <14 mm and <22 mm respectively); and
- Rainfall events ≥ 32 mm represent <5% of the total number of events.

These categories can be in turn associated with different design criteria, as highlighted in Figure 10.2: the very small events that could be in principle totally infiltrated for groundwater recharge, the common rainfall events (≤ 22 mm) for quality control, the rainfall event of about 32 mm (which is approximately associated with a return period of 1 y and is associated with erosion control) and finally the rarer events, which are to be used for the design of the conveyance systems (minor and major) to minimize flooding. These four design criteria, which are now typically included in many North American guidelines

for stormwater management programs (MDE, 2000; MPCA, 2005), are all related to each other as shown in Figure 10.2. A pond could therefore be designed in such a way with an appropriate outlet structure that each of these controls could be met with different control mechanisms in order to minimize environmental and flooding impacts.

Figure 10.2 Integration of stormwater design criteria (adapted from MPCA, 2005).

Average years, considering the number of rainfall events, the average rainfall quantities and the average intensities, can also be selected to further analyze the different categories. Figures 10.3 and 10.4 respectively show such an analysis for 1980 and 1983, at the same station. It can again be seen that most of the rainfall events are relatively small and that a threshold of 25 mm, as has been adopted in many stormwater management guidelines, will be sufficient to capture annually a high percentage of the runoff and pollutant discharges.

Most of the hydrology models have been developed historically to analyze runoff generated from large rainfall events in order to design conveyance systems. As discussed by Pitt and Voorhes (2000), these procedures and their underlying assumptions could incorrectly predict flows and runoff volumes from small rains in urban areas and this is why the small storm hydrology approach has been developed empirically using field measurements.

Figure 10.3 Rainfall events for 1980 (May–December)—Dorval airport, Montréal.

Figure 10.4 Rainfall events for 1983 (May–November)—Dorval airport, Montréal.

10.3 Small Storm Hydrology Features

Pitt (1999a) summarized the main elements that become particularly significant when runoff generated by small rainfall events is analyzed:

- For paved surfaces, initial abstractions are dependent on pavement texture and slope, while infiltration is dependent on pavement porosity and pavement cracks. Typical urban street pavements are relatively porous, in contrast to the much thicker and denser pavements for freeways and airport runways. Initial abstractions may be about 1 mm and the infiltration may be >5 mm and <10 mm. High infiltration rates are associated with high rainfall intensities; and
- For pervious surface (disturbed urban soils), as shown on Figure 10.5 from Pitt (1999b), less rain infiltrates through soils in pervious areas in disturbed urban soils than typically assumed; areas experiencing substantial disturbances or traffic could have very low infiltration rates; compaction has the greatest impact on infiltration rates in sandy soils while clay soils are affected by both compaction and soilwater content; very large errors in infiltration rates can be made if published soil maps and typical models are used for typically disturbed urban soils.

Therefore, for small to moderate rainfall events, it has been observed that more rain infiltrates through pavement surfaces and less rain infiltrates through pervious surfaces than it is generally assumed.

Figure 10.5 Measured in situ infiltration rate for sandy soils (Pitt, 1999b).

Considering these specific features of small storm hydrology, Pitt (1987) has developed volumetric runoff coefficients for urban runoff flow calculations, based on actual field measurements. A summary of these coefficients is provided in Table 10.1. As can be seen for different types of impervious surfaces, the coefficients are similar for relatively large quantities of rainfall (>80 mm) but the differences could be much larger for small rains that are of most concern in water quality evaluation (Pitt, 1999a).

Table 10.1 Summary of volumetric runoff coefficients for urban flow calculations (for directly connected areas) (Pitt, 1987).

Rain depth (mm)	Flat roofs (or large unpaved parking areas) ¹	Pitched roofs ¹	Large impervious areas ¹	Small impervious areas and streets	Sandy soils	Typical urban soils	Clayey soils
1	0	0.25	0.93	0.26	0	0	0
3	0.3	0.75	0.96	0.49	0	0	0
5	0.54	0.85	0.97	0.55	0	0.05	0.1
10	0.72	0.93	0.97	0.6	0.01	0.08	0.15
15	0.79	0.95	0.97	0.64	0.02	0.1	0.19
20	0.83	0.96	0.97	0.67	0.02	0.11	0.2
30	0.86	0.98	0.98	0.73	0.03	0.12	0.22
50	0.9	0.99	0.99	0.84	0.07	0.17	0.26
80	0.94	0.99	0.99	0.9	0.15	0.24	0.33
125	0.96	0.99	0.99	0.93	0.25	0.35	0.45

¹If these impervious areas drain for a significant length across sandy soils, the sandy soil runoff coefficients will usually be applied to these areas. If, however these areas drain across clayey soils, the runoff coefficients will be reduced, depending on the land use and rain depth, according to Table 10.1(a).

Table 10.1(a) Reduced volumetric runoff coefficients for certain areas.

Rain depth (mm)	Strip commercial and shopping centers	Other medium to high intensity land uses, with alleys	Other medium to high density land uses, without alleys
1	0	0	0
3	0	0.08	0
5	0.47	0.11	0.11
10	0.9	0.16	0.16
15	0.99	0.2	0.2
20	0.99	0.29	0.21
30	0.99	0.46	0.22
50	0.99	0.81	0.27
80	0.99	0.99	0.34
125	0.99	0.99	0.46

These results have been incorporated in different recent stormwater guidelines (DEP–Pennsylvania, 2006; Iowa DNR, 2008) to determine the volumetric runoff coefficient for water quality control of small events. Table 10.2 gives an example of the recommended coefficients.

Table 10.2 Runoff coefficients for the small storm hydrology method (adapted from Pitt, 2000) (DEP–Pennsylvania, 2006).

Rainfall (mm)	Impervious areas				Pervious areas		
	Flat roofs (or large unpaved parking areas) ¹	Pitched roofs ¹	Large imper- vious areas ¹	Small im- pervious areas and streets	Sandy soils (Type A)	Silty soils (Type B)	Clayey soils (Types C and D)
12.5	0.75	0.94	0.97	0.62	0.02	0.09	0.17
38.1	0.88	0.99	0.99	0.77	0.05	0.15	0.24

¹If these impervious areas drain for a significant length across sandy soils, the sandy soil runoff coefficients will usually be applied to these areas. If, however, these areas drain across clayey soils, the runoff coefficients will be reduced, depending on the land use and rain depth, according to Table 10.1(a) above.

As pointed out by Pitt (1999a), runoff volume is the important hydraulic parameter for most water quality studies (peak flow rate and time of concentration being the most important parameters for most flooding and drainage studies). The small storm hydrology approach described in most BMP manuals is therefore to calculate a water quality volume using a simple equation:

$$WQV = R_v \times P \tag{10.1}$$

where:

- WQV = Water quality volume,
- R_v = volumetric runoff coefficient (from Table 10.2), and
- P = rain amount for 90% of the storms.

For the Montréal area, this rainfall quantity would be 22 mm but it has been recommended for the province of Québec to use a general value of 25 mm (a similar analysis having shown that the 90% quantity for Québec City is 26 mm). Therefore, interpolating in Tables 10.1 and 10.2 to obtain the coefficients for a 25 mm rainfall, the water quality volume for a 1 ha area with different land uses would be as given in Table 10.3. For mixed land uses, a weighted runoff coefficient could be defined to compute the water quality volume in this case. An example for a medium density residential area is provided in Table 10.4.

Table 10.3 Runoff coefficient (R_v) and water quality volume (WQV , m^3) for 0.5 ha areas with different land uses (calculated with the small storm hydrology method and 25 mm rainfall event).

	Impervious areas				Pervious areas		
	Flat roofs (or large unpaved parking areas)	Pitched roofs	Large impervious areas	Small impervious areas and streets	Sandy soils (Type A)	Typical urban soils	Clayey soils (Types C and D)
R_v	0.83	0.96	0.97	0.67	0.02	0.11	0.20
$WQV (m^3)$	104	120	121	84	2.5	14	25

Table 10.4 Weighted runoff coefficient R_v for a medium density residential area and a 20 mm rainfall (adapted from Pitt and Voorhes, 2003).

Area	%	R_v	Weighted R_v
Roofs	6	0.96	0.058
Driveways	5	0.67	0.034
Sidewalks	3	0.67	0.020
Streets	12	0.67	0.080
Frontyards	45	0.20	0.090
Backyards	29	0.20	0.058
Total	100		0.34

The following section will discuss the use of design storms to reproduce with SWMM5 the results obtained with small storm hydrology.

10.4 Design Storms for Small Storm Hydrology

Different design storms have been proposed in the literature to model frequent rainfall events for BMP design. The New Jersey stormwater manual (NJDEP, 2004) recommends using a 2 h mass curve for a 31.8 mm quantity (1.25 in.), as shown on Figure 10.6. The Province of Ontario recommends on the other hand a 25 mm 4 h Chicago storm.

To investigate the influence of the rainfall duration, Chicago design storms of different durations for a total rainfall depth of 25 mm in all cases were derived, as shown in Figure 10.7. These Chicago design storms and the New Jersey design storm (with total quantity of 25 mm instead of 31.8 mm) were subsequently used to model SWMM5 (as implemented in PCSWMM.NET) two types of generic areas:

- Small 0.5 ha areas with different types of imperviousness areas.

- Medium density residential area of 5 ha.

Table 10.5 gives the characteristics of each type of areas. The results of the modeling are summarized in Table 10.6, along with the volumes computed with a small storm hydrology approach.

Figure 10.6 Mass curve for the design storm recommended in New Jersey (NJDEP, 2004).

Figure 10.7 Chicago design storms with different durations and a 25 mm rain quantity.

Table 10.5 Characteristics of generic areas.

Type of area	Area (ha)	Width (m)	% Impervious	Depression storage	
				Impervious area (mm)	Pervious area (mm)
Flat roof	0.5	100	80	1	5
Large impervious area	0.5	100	100	1	5
Medium density residential area	5	1 430	30	1	5

Table 10.6 Results of SWMM5 modeling for generic areas and different design storms (25 mm in all cases).

Type of area	Area (ha)	Peak discharge for different design storms ¹ (L/s)	Runoff volume for different design storms ¹ (m ³)	Runoff coefficient with SWMM for different design storms ¹	Volume with small storm hydrology approach (m ³)
Flat roof	0.5	72.3	114	0.792	104 ²
		39.0	93	0.789	
		37.3	93	0.788	
		38.4	92	0.787	
		68.6	98	0.783	
Large impervious area	0.5	91.0	143	0.989	121 ³
		50.0	116	0.986	
		47.3	116	0.984	
		48.0	115	0.983	
		86.0	122	0.979	
Medium density residential area	5	561.0	860	0.295	425 ⁴
		312.7	685	0.294	
		293.9	688	0.294	
		289.0	685	0.294	
		529.8	735	0.294	

¹ The different values are respectively for Chicago design storms of 2 h, 3 h, 4 h and 6 h and for a New Jersey mass curve of 2 h duration; all the design storms have a total rainfall quantity of 25 mm.

² Calculated with a runoff coefficient of 0.83.

³ Calculated with a runoff coefficient of 0.97.

⁴ Calculated with a runoff coefficient of 0.34.

Some conclusions could be drawn from the values in Table 10.6 regarding the characteristics of the generic areas and the different design storms:

- For flat roof and large impervious areas, a Chicago design storm of 2 h gives a volume too high as compared with the volumes obtained with small storm hydrology results; the New Jersey design storm mass curve (2 h duration) gives on the other hand very close agreement with the small storm hydrology results.

- For medium density residential area the New Jersey design storm gives much larger volumes than the small storm hydrology approach. In this case, a 6 h Chicago design storm is closer but still overestimate the runoff volume by a significant amount. Using a percentage of imperviousness of 20% (instead of 30%) and depression storages of 3 mm and 7.5 mm for the impervious and pervious areas (instead of 1 mm and 5 mm) produces a runoff volume of 425 m³, similar to the small storm hydrology result.

From this analysis, it can be concluded that using the New Jersey 2 h design storm gives, for impervious surfaces, results similar to the small storm hydrology approach for the runoff volumes. For medium density residential area, using either the New Jersey design storm or the Chicago design storms gives much higher runoff volumes. This could be considered appropriate for a design situation but the volume could be reduced if deemed necessary by reducing the percentage of directly connected impervious surface (here reduced from 30% to 20%, which could be considered to be relatively low for a typical design situation).

Finally, another approach could be used to put the results obtained with design storms in perspective. A series of historical rainfall events for an average year would provide a comparison for the results obtained with the design storms. Referring to Figure 10.3, it can be seen for example for the year 1980 that 14 rainfall events had a total quantity of ≥15 mm rainfall. A selection of these rainfall events has therefore been run for the same three generic areas as before. Table 10.7 gives the results for this analysis.

Table 10.7 Results of SWMM5 modeling (peak discharge Q and runoff volumes V) for generic areas and historical rainfall events for 1980 (events close to a rainfall quantity of 25 mm).

Rainfall event	Duration (h)	Total rainfall quantity (mm)	Results for different generic areas					
			Large impervious area		Medium density residential area		Flat roof	
			Q	V	Q	V	Q	V
			(L/s)	(m ³)	(L/s)	(m ³)	(L/s)	(m ³)
May 18	16	28.4	7.6	136	52	811	6	109
July 17	4	25.8	94.3	148	598	892	74	118
July 21	6	27.0	32.8	136	200	832	26.1	109
July 28	18.5	23.4	15.9	116	99	702	12.6	92
Aug. 12	17	17.0	9.6	89	63	527	7.5	71

One of the elements that stand out in Table 10.7 is that runoff volumes and peak discharges are two distinct runoff parameters and that ordering of the values for each parameter would produce different orderings. It could also be seen that for rainfalls within the same range of quantity (the first four events in Table 10.7 for example) the range of results for the peak discharges could be quite large but that it is much narrower for runoff volumes. This finding is similar to what Pitt has reported (1987; 1999a), stating that estimates of runoff volume could be made with only rain depth information. Finally, recalling that the volumes computed with the small storm hydrology were 121 m^3 , 425 m^3 and 104 m^3 respectively for the large impervious area, the medium density residential area and the flat roof, it can be seen that the ranges of values in Table 10.7 for large impervious area and flat roof are quite close to the values computed with the small storm hydrology approach. However, for the medium density residential area, the simulated volumes are much higher than the value indicated with the simple small storm hydrology computation.

10.5 Quantitative BMP Modeling with SWMM5

BMP modeling is in a sense directly related to small storm hydrology as it normally involves modeling the runoff associated with relatively frequent and small rainfalls. Both quantity and quality aspects have also to be considered in order to assess the performance of most BMPs and, in recent years, a number of software packages have been developed to analyze specifically BMPs. These include for example SLAMM (Pitt and Voorhes, 2000), P8 (Walker, 1990; 2002), MUSIC (Wong et al., 2002), WWHM3 (Clear Creek Solutions, 2006), HSPF BMP Toolkit (EPA, 2008) and LIFE (Graham et al., 2004). Many of these programs can be better categorized as planning tools to evaluate BMPs globally, and most lack complete dynamic flow routing. Huber et al. (2006) provide a critical discussion on the capabilities of some of these programs.

As noted by Huber et al. (2006), SWMM has the capability to properly account for losses (hydrologic abstractions such as infiltration, depression storage, and evapotranspiration) for low rainfall depths. It is also a dynamic rainfall-runoff simulation with flow routing performed for surface and sub-surface conveyance and groundwater systems; nonpoint source runoff quality and routing may also be simulated. Huber et al. (2006) have described the current SWMM simulation capabilities for BMP modeling:

- Storage may occur on the ground surface, in the drainage system and in specific storage devices (ponds, tanks, secondary flow removal devices). Pollutant removal occurs primarily through

sedimentation and decay. Modeling of storage is quite flexible with different types of hydraulic controls and time-dependant regulators.

- Infiltration into the soil is currently simulated only for overland flow planes. There is however a capability to route overland flow from one overland flow plane to another (Figure 10.8), which enables to simulate easily infiltration of runoff diverted to large surfaces such as lawns and vegetated buffers. Many BMPs could be modeled using this basic capability. One other possibility is to use the *Subarea Routing* and *Percentage Routed* parameters, which are now included in SWMM5. For a given catchment, Subarea Routing directs surface flow from pervious land or vice versa; The parameter controls how much flow is transferred between compartments. Huber and Cannon (2002) and Chen et al. (2008) have discussed the use of this capability to represent non-directly connected impervious area in SWMM modeling.

Even if SWMM does not have the capability to model infiltration in channels or basins (which could however become available features in SWMM5 in the near future), different approaches can be used to model most BMPs, at least from a quantitative point of view (quality aspects will not be discussed here). These approaches will be described in the following sections.

10.5.1 Filter strips and Grass Swales

Filter strips correspond to the situation illustrated on Figure 10.8, with essentially the runoff from an impervious surface (a road or a parking lot) directed to another pervious surface. As shown on Figure 10.9, two approaches can be used in SWMM: using Subarea Routing and Percentage Routed or directing the out-flow of the impervious catchment to another pervious catchment. The results for the two approaches are shown in Figure 10.10: first for a 1 ha impervious surface (ParkingNoRunon) 100 m wide draining towards a 0.5 ha pervious surface (FilterStrip) 100 m wide; secondly, using Subarea Routing and Percentage Routed for a 2 ha surface with 50% imperviousness and 100% of the impervious surface draining internally towards the pervious surface. It could be seen that there is a slight difference in the results between the two approaches.

For grass swales, the best option would be to model them as a channel where infiltration could be taken into account. Unfortunately, this is not currently possible in SWMM but a grass swale could nevertheless be modeled in

Figure 10.8 Conceptual routing from the impervious sub-area of a catchment to the pervious sub-area of a catchment (Huber et al., 2006).

Figure 10.9 Options for the modeling of filter strips.

SWMM5 in various ways. Depending on the configuration, a grass swale could have or not have small dams to maximize the retention and infiltration of part of the runoff. Therefore, they could be modeled as a storage node with an outlet device with a calculated depth-outflow relation and a pump that would simulate

the infiltration process (pumping to a storage node). Another option (Huber et al., 2006) would be to consider a negative hydrograph upstream of the channel to simulate infiltration outflows. The channel could also be simulated as a catchment, but then it would not be possible to have the infiltration vary with flow depth. Finally, a grass swale could be simulated with the storage with treatment node if the quality aspects are to be considered (Huber et al., 2006).

10.5.2 Infiltration Trench and Bioretention

For infiltration trench (and also for bioretention), there is a component of storage and a component of outflow dependent on infiltration processes. Huber et al. (2006) have recommended the following procedure:

1. Simulate subcatchment runoff by usual procedures and route it downstream to the infiltration trench subcatchment;
2. Simulate the infiltration trench as 100% pervious catchment of width w and length l (trench dimensions). Set depression storage to the trench depth;
3. Infiltration is simulated by Horton or Green–Ampt method; if a outflow constant rate is desired, the parameter in Horton could be adjusted accordingly (maximum infiltration rate = minimum infiltration rate); and
4. A combination of low slope, high Manning's n or very small conceptual width to eliminate horizontal outflow out of the trench.

Drainage from the infiltration trench subcatchment can be directed to a groundwater component if further tracking is desired. Another option would be to use a pump or an outlet link to simulate the infiltration and/or an outflow from the subdrain if one is used. The discharges pumped or getting out of the system with an outlet link could be directed to a storage node, which could also be emptied slowly to simulate recovery.

10.5.3 Porous Pavement

Porous or permeable pavement is a hard surface that can support a certain amount of activity, while still allowing water to pass through. Several different types of porous pavement exist (Pitt and Voorhes, 2000). James et al. (2001) demonstrate how SWMM can be used, treating porous pavement as a pervious surface and using the subsurface flow routines.

10.6 Conclusion

Criteria for BMP design and LID measures are based on frequent and common rainfall events that have a relatively small quantity of rainfall. Modeling of these measures should take into account the small storm hydrology features that have been identified notably by Pitt (1987) and other researchers. Specifically, design storms of different durations have been shown to give results with SWMM5 that are similar to what is obtained with the small storm hydrology approach. Most BMPs can be modeled with SWMM5 with the use of simple artifices. This type of modeling, involving in many cases the tracking of infiltrated runoff, would however be more efficient if direct modeling of infiltration in channels or storage node was possible.

References

- Chen, M., S. Shyamprasad, M.C. Heineman and C.S. Carter. 2008. "Representation of Non-Directly Connected Impervious Area in SWMM Runoff Modeling." *Journal of Water Management Modeling* R228-18. doi: 10.14796/JWMM.R228-18.
- DEP (Department of Environmental Protection)–Pennsylvania, 2006. Pennsylvania Stormwater Best Management Practices Manual, Document 363-0300-002, Pennsylvania.
- EPA (Environmental Protection Agency), 1983. Results of Nationwide Urban Runoff Program. EPA-PB/84-185552.
- EPA (Environmental Protection Agency) 2009. HSPF BMP Toolkit. Web-based HSPF tool, Ecosystems Research Division, <http://www.epa.gov/ATHENS/research/modeling/HSPFWebTools>.
- Graham, P., Maclean, L., Medina, D., Patwardhan, A. and Vasarhelyi, G. 2004. The role of water balance modeling in the transition to low impact development. *Water Quality Research Journal of Canada*, Volume 39, No. 4, pp 331-342, Burlington, On.
- Heaney, J.P., Huber, W.C., Medina, M.A., Jr., Murphy, M.P., Nix, S.J. and Hasan, S.M. 1977. Nationwide Evaluation of Combined Sewer Overflows and Urban Stormwater Discharges, Volume II: Cost Assessment and Impacts. EP2-600/2-77-064b. NTIS PB-266005, USEPA. Cincinnati, OH. March.
- Huber, W.C., 2001. "New Options for Overland Flow Routing in SWMM," *Urban Drainage Modeling*, R.W. Brashear and C. Maksimovic, eds., Proc. of the Specialty Symposium of the World Water and Environmental Resources Conference, ASCE, Environmental and Water Resources Institute, Orlando, FL, May, pp. 22-29.
- Huber, W.C. and Cannon, L., 2002. "Modeling Non-Directly Connected Impervious Areas in Dense Neighborhoods," In *Global Solutions for Urban Drainage*, Proc. Ninth International Conference on Urban Drainage, E.W. Strecker and W.C. Huber, eds., Portland, OR, ASCE, Reston, VA, CD-ROM.

- Huber, W.C., Cannon, L. and Stouder, M., 2006. "BMP Modeling Concepts and Simulation," EPA Contract No. 68-C-01-020, report EPA/600/R-06/033, Office of Research and Development, EPA, Washington, DC.
- Iowa DNR (Department of Natural Resources), 2008. Iowa Stormwater Manual. Download from <http://www.ctre.iastate.edu/pubs/stormwater/index.cfm> (Iowa State University - Institute for Transportation), Iowa.
- James, R., W. James and H. von Langsdorff. 2001. "Stormwater Management Model for Environmental Design of Permeable Pavement." *Journal of Water Management Modeling* R207-26. doi: 10.14796/JWMM.R207-26.
- Maryland Department of the Environment (MDE) 2000. Maryland Stormwater Design Manual: Vols 1 & 2. Maryland Department of the Environment, Annapolis, Md.
- MOE, 2003. *Stormwater Management Planning and Design Manual*. Ministry of Ontario Environment, Toronto, On.
- MPCA (Minnesota Pollution Control Agency), 2005. Minnesota Stormwater Manual. Minnesota Stormwater Steering Committee, Minnesota.
- NJED (New Jersey Department of Environmental Protection), 2004. New Jersey Stormwater Best Management Practices, New Jersey Department of Environmental Protection, Division of Watershed Management, Trenton, NJ.
- Pitt, R.E., 1987. Small Storm Flow and Particulate Washoff Contributions to Outfall Discharges. Ph.D. dissertation, Department of Civil and Environmental Engineering, the University of Wisconsin – Madison.
- Pitt, R.E. 1999a. "Small Storm Hydrology and Why it is Important for the Design of Stormwater Control Practices." *Journal of Water Management Modeling* R204-04. doi: 10.14796/JWMM.R204-04.
- Pitt, R.E., Lantrip, J., Harrison, R., Henry, C.L. and Xue, D., 1999b. Infiltration Through Disturbed Urban Soils and Compost-Amended Soil Effects on Runoff Quality and Quantity, EPA/600/R-00/016, Environmental Protection Agency, Cincinnati, OH.
- Pitt, R. E. and Voorhes, J., 2000. The Source Loading and Management Model (SLAMM), A Water Quality Management Planning Model for Urban Stormwater Runoff. University of Alabama, Department of Civil and Environmental Engineering, Tuscaloosa, AL.
- Walker, W.W., 1990. P8 Urban Catchment model Program Documentation Version 1.1, Prepared for IEP, Inc. and Narragansett Bay Project, October. (<http://www.walker.net/p8/>).
- Walker, W.W. and Kadlec, R.H., 2002. Dynamic Model for Stormwater Treatment Areas, Sponsored by U.S. Department of the Interior. (<http://www.walker.net/dmsta/>).
- Wong, T.H.F., Fletcher, T.D., Duncan, J.P., Coleman, J. and Jenkins, G.A., 2002. "A Model for Urban Stormwater Improvement Conceptualisation," In Global Solutions for Urban Drainage, Proc. Ninth International Conference on Urban Drainage, E.W. Strecker and W.C. Huber, eds., Portland, OR, ASCE, Reston, VA, CD-ROM.