STATE OF MICHIGAN
DEPARTMENT OF ENVIRONMENTAL QUALITY
LANSING

JENNIFER M. GRANHOLM
GOVERNOR

STEVEN E. CHESTER
DIRECTOR

March 24, 2006

TO: Ralph Reznick, Nonpoint Source Unit
Water Bureau

FROM: Dave Fongers, Hydrologic Studies Unit
Land and Water Management Division

SUBJECT: 90-Percent Annual Non-Exceedance Storms

Michigan Department of Environmental Quality (MDEQ) Best Management Practice (BMP) guidelines recommend capture and treatment of 0.5 inches of runoff from a single site. The runoff is then released over 24 to 48 hours or is allowed to infiltrate into the ground within 72 hours. However, this is only applicable to a single site. Runoff from multiple or large sites may exhibit elevated pollutant concentrations longer, because the first flush runoff from some portions of the drainage area will take longer to reach the outlet. For multiple sites or watershed wide design, it is better to capture and treat 90 percent of the runoff producing storms (Claytor, 1996, pages 2-22 through 2-23, attached). This "90 percent rule" effectively treats storm runoff that could be reaching the treatment at different times during the storm event. It was designed to provide the greatest amount of treatment that is economically feasible. This criterion is being considered for inclusion in the MDEQ's BMP guidebook.

As requested, the Hydrologic Studies Unit of the Land and Water Management Division has completed an analysis of January 1948 through March 2005, National Oceanic and Atmospheric Administration climatological data, in order to statistically define 90-percent non-exceedance storms statewide. The 90-percent non-exceedance storm is the storm where 90 percent of the runoff-producing storm rainfalls are equal to or less than the specified value. The Center for Watershed Protection recommends using a runoff threshold of 0.10 inches, because impervious areas of the watershed are assumed to generate runoff beginning at approximately 0.10 inches of rainfall.

Data from 13 weather stations were evaluated, as shown in Figure 1. The selected weather stations include at least one station from within each of the ten Michigan climatic divisions, plus three additional stations to improve statewide coverage and comparability. Statistics for this analysis are shown in Table 1.

The limitations of this technique and methods to calculate water quality volumes and peak flows are further discussed by Claytor and Schueler in the attached reference. Although the goal of this memo is simply to statistically define the 90-percent non-exceedance storms statewide, the attached information, or an adaptation of it, will need to be combined with the 90-percent non-exceedance storm information if it is to be meaningful in the BMP manual.

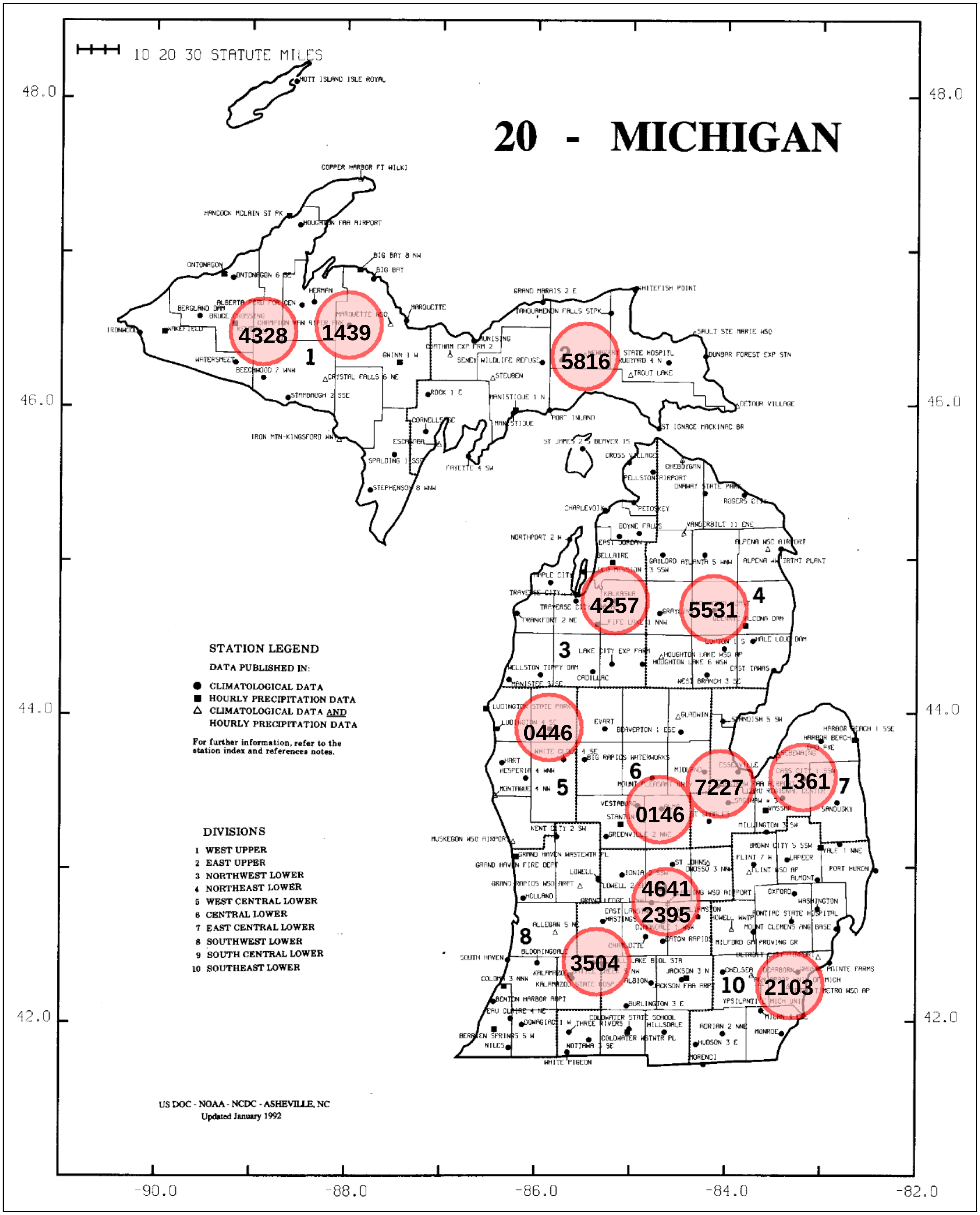


Figure 1: Selected Weather Stations

Table 1: Statistics for storms with more than 0.10" of rainfall at selected weather stations

Weather Station	Kenton	Champion Van Riper	Newberry	Kalkaska	Mio	Baldwin	Alma	Saginaw Airport	Cass City	Gull Lake	Lansing	East Lansing	Detroit Metro
Station Number	4328	1439	5816	4257	5531	0446	0146	7227	1361	3504	4641	2395	2103
Climatic Section	1		2	3	4	5	6	7		8	9		10
90-Percent Non-exceedance Storm	**0.95**	**0.87**	**0.84**	**0.77**	**0.78**	**0.93**	**0.93**	**0.92**	**0.87**	**1.00**	**0.90**	**0.91**	**0.90**
Period of Record	5/48-12/99	12/49-3/05	1/48-12/99	5/48-12/99	5/48-12/99	6/48-12/99	5/48-12/99	1/48-12/99	7/76-3/05	5/48-12/99	5/48-12/99	1/57-12/99	12/58-12/99
Number of Storms	3151	3943	3772	4219	3564	4007	3602	3453	1957	4071	3395	2939	3191
Minimum	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Median	0.30	0.29	0.29	0.26	0.27	0.30	0.30	0.31	0.30	0.32	0.29	0.30	0.30
Mean	0.44	0.41	0.41	0.39	0.38	0.43	0.45	0.44	0.43	0.46	0.42	0.44	0.43
Maximum	5.45	4.41	4.18	3.26	3.13	4.21	9.33	5.51	9.01	3.95	4.95	4.18	4.34

If you have any questions regarding our evaluation, please contact me at 517-373-0210.

Attachment: Claytor, R.A., and T.R. Schueler. 1996. *Design of Stormwater Filtering Systems*. The Center for Watershed Protection, Silver Spring, MD, pages 2-16 through 2-29.

cc: Steve Holden, WB
Ric Sorrell, LWMD

Design of Stormwater Filtering Systems

Prepared by

Richard A. Claytor and Thomas R. Schueler
The Center for Watershed Protection
8737 Colesville Road
Silver Spring, MD 20910
(301) 598-1890

Prepared for

Chesapeake Research Consortium, Inc.
P. O. Box 1280
Solomons, MD 20688
(410) 326-6700

with supplemental funding by

U.S. Environmental Protection Agency, Region 5

December 1996

Printed on Recycled Paper

PARTICLE SIZE DISTRIBUTION

One additional important aspect of stormwater runoff from different source areas is the relationship of particle size to pollutant load. Work done by Sartor and Boyd (1974) and Pitt (1987) starting in the early 1970's suggests that most of the total particulate load from urban runoff is made up by the coarser fractions, consisting of sand/gravel particle sizes greater than approximately 40 microns. Shaver and Baldwin (1991) reported that while nearly 94% of the urban runoff particulate load is from these coarser grained fractions, more than half of the phosphorus load and significant percentages of other pollutants are associated with fine grained silts and clays.

Particle size distribution is an important consideration for sizing the sedimentation chamber of a filter system. Shaver and Baldwin (1991) and Bell et al. (1995) specify that sand filters should only be used to treat runoff from impervious, or nearly-impervious surfaces. They argue that the larger percentage of particulates from impervious surfaces are in the coarser fractions, and therefore, filtering systems will be less prone to clogging. The logic follows that the sedimentation chamber will capture the coarser grained material, and the filter chamber will capture and treat the relatively small amount of finer grained material. Therefore, filters designed to treat runoff from purely impervious surfaces require less sedimentation area and volume than those designed to treat runoff from more pervious surfaces.

The City of Austin (1988) allows the use of sand filters for a range of land uses and drainage areas. They use a smaller, silt size particle (20 microns) as the target for sizing the sedimentation chamber, probably recognizing that more pervious areas are likely to contribute more fine grained particles In order to quantify and resolve the apparent discrepancy between the above criteria, this manual recommends that for drainage areas less than 75% impervious, the target particle size for designing the sedimentation chamber be set at 20 microns. For drainage areas with imperviousness greater than 75%, the target particle size should be set at 40 microns. See Chapter 5 for discussion and application of these sizing principles.

2.3 *SMALL STORM HYDROLOGY*

Small storms are responsible for most annual urban runoff and likewise are responsible for most pollutant washoff from urban surfaces. Therefore, the small storms are of most concern for water quality resource protection.

Large storms occur infrequently, and although they may contain significant pollutant loads (Chang, G., et al., 1990), their contribution to the annual average pollutant load is really quite small (due to the infrequency of their occurrence). In addition, there are longer periods of recovery available to receiving waters between larger storm events allowing systems to flush themselves and the aquatic environment to recover.

The runoff **volume** is the most important hydrologic variable for water quality protection and design because water quality is a function of the capture and treatment of the mass load of pollutants. The runoff **peak rate** is the most important hydrologic variable for drainage system design and flooding analysis. Water quality facilities are designed to treat a specified quantity or volume of runoff for the full duration of a storm event as opposed to accommodating only an instantaneous peak at the most severe portion of a storm event.

To design effective BMPs and evaluate water quality impacts in urban watersheds, it is necessary to predict the amount of rainfall converted to runoff. The amount of rainfall which is converted to runoff is a function of storm characteristics such as rainfall amount, storm duration, rainfall intensity, and the urban land surface. These surfaces can be broken down into two main categories, pervious and impervious surfaces.

Impervious surfaces are traditionally thought to convert almost all rainfall into runoff, with pervious surfaces contributing much less runoff. In urban areas, particularly for small storms, this is not necessarily the case. Pervious surfaces can be heavily compacted and can have a surprisingly high runoff potential. Impervious surfaces, with minor cracks and expansion joints can have a remarkably high infiltration capability.

Impervious surfaces have five main components which contribute to rainfall losses:

- Interception of rainfall by over-hanging vegetation
- Flash evaporation
- Depression storage
- Sorption by dirt particles
- Infiltration through cracks and seams

The first four processes predominately occur immediately after the start of a rainfall event and dissipate within a relatively short time period and are therefore often referred to as initial abstractions. Infiltration through cracks and seams continues throughout the storm event and depending on the amount of rainfall, can account for significant losses. Many runoff models incorrectly estimate initial abstractions by holding them constant, and few consider infiltration through impervious surfaces for the duration of the storm event (Pitt, 1994).

The amount of runoff generated by pervious surfaces is related to the size of the pervious area, the relationship to impervious surfaces, the permeability of the underlying soils and the condition and type of vegetative cover.

The primary hydrologic methods to estimate storm runoff peak discharges in the Chesapeake Bay Watershed are the Rational Formula and SCS Methods, particularly, TR-55, "Urban Hydrology for Small Watersheds" (USDA, 1986). Several computer models, including SCS, TR-20, "Project Formulation, Hydrology" (USDA, 1982) and the U.S. Army Corps of Engineers', HEC-1 (U.S. Army, COE 1982) also utilize SCS methods to compute discharge rates. These methods are valuable for estimating peak discharge rates for large storms (i.e., >2") and larger drainage areas (> 10 to 25 acres), but can significantly underestimate the runoff from small storm events.

The limiting factors for the Rational Formula are in the computation of the time of concentration (usually set at a minimum of 5 minutes, which is hard to achieve on many small sites), the selection of "C" values for urban developments which do not address soil infiltration capability, and the equal weight placed on drainage area. The rational method is ideally suited for drainage design where peak rates of runoff are required, but does not estimate storm volume and therefore should not be used for water quality design.

Urban Hydrology For Small Watersheds (TR-55), as the title suggests, is recommended for urban watersheds with small drainage basins. This methodology has been used extensively for stormwater management design for quantity control (i.e., 2, 10, and 100 year management). TR-55 relies on a Curve Number (CN) instead of the "C" to reflect the percentage of rainfall converted to runoff. The TR-55 methodology also has the same limitations associated with computing the time of concentration for extremely small drainage areas.

One of the principal short comings of TR-55 is that the methodology assumes a constant CN for a large range of rainfall events. While this assumption does not significantly affect the accuracy of the model for larger storm events (> 2"), smaller rainfall events produce more runoff than are predicted by the SCS procedure (Pitt, 1994). This chapter presents a method for estimating the volume of runoff and peak discharge from small storms. Standard SCS methods should be used by designers for computing volumes and peak discharges for larger storm events (i.e., 2, 10 and 100 year storms).

Dr. Robert Pitt and his colleagues, have conducted several years of research on small storm hydrology, in several diverse geographic regions, over a wide range of land uses with remarkable consistency between simulated and observed results. The results of Pitt's research are described in Table 2.10.

TABLE 2.10: PRINCIPLES OF SMALL STORM HYDROLOGY (ADAPTED FROM PITT, 1994)

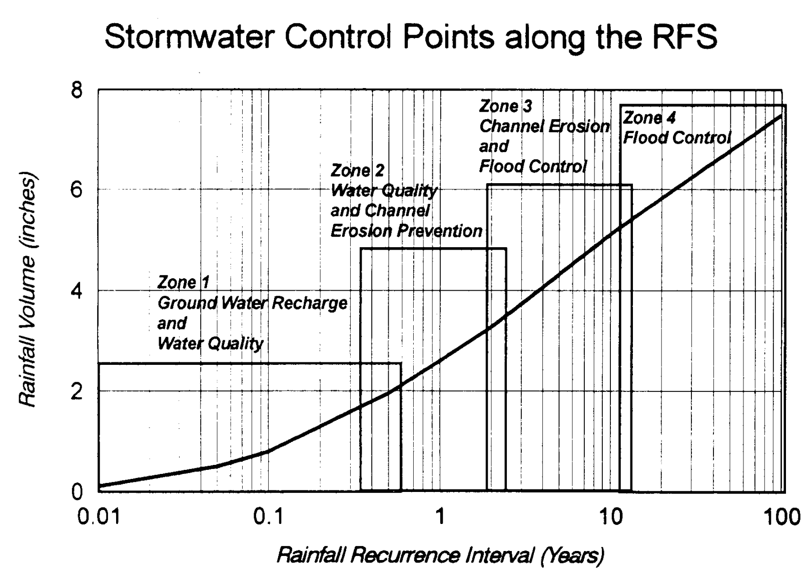
Larger rainfall events correspond reasonably well with SCS CN procedures.
Smaller rainfall events produce more runoff than is predicted by SCS CN procedures.
For strictly pervious surfaces, published CN's are much lower than observed CN's for small storm events. Therefore, less runoff is predicted from pervious areas during small storm events and SCS methodology incorrectly attributes more flow to impervious surfaces. This translates into inaccurate pollutant loading estimates from both pervious and impervious surfaces.
For impervious surfaces, the type of surface (i.e., rooftop, large paved surface, narrow street) has a significant impact on the amount of runoff for small storm events. The infiltration characteristics of these surfaces vary greatly. Remarkably, narrow streets can have a higher infiltration capability than some compacted urban pervious surfaces (such as ballfields).
Disconnecting impervious surfaces can significantly reduce the volume of runoff. The relative amount of reduction is a function of the pervious area flow path, the amount of impervious area draining to pervious areas, and the infiltration capacity of the pervious surfaces. Substantial reductions in runoff are observed for a wide range of land uses when impervious surfaces are disconnected and drained through permeable soils (SCS, Hydrologic Soil Groups (A and B). Reductions are only slight for relatively low density land uses when impervious surfaces are disconnected and drained through relatively impermeable soils (HSG's - C and D). Not surprisingly, disconnecting paved surfaces and rooftops for commercial areas does not result in significant reductions in runoff.

2.4 RAINFALL FREQUENCY SPECTRUM (RFS)

The effectiveness of any stormwater water quality treatment practice is a function of how much stormwater runoff is treated by the system and how much bypasses the practice. Since storms vary dramatically in magnitude, stormwater best management practices must be sized to capture a reasonable percentage of all runoff but bypass excessively large events. The rainfall frequency spectrum or RFS, which is defined as the distribution of all rainfall events, is a useful tool for establishing water quality treatment volume sizing criteria. This distribution is the cumulative volume from all storm events ranging from the smallest most frequent events in any given year to the largest most extreme events over a long duration, say, the 100 year frequency event.

The RFS consists of classes of frequencies often broken down by return interval, such as the two year storm return interval. Four principle classes are typically targeted for control by stormwater management practices. The two smallest, most frequent, classes are often referred to as water quality storms, where the control objectives are groundwater recharge, pollutant load reduction, and to some extent, control of channel erosion producing events. The two larger classes are typically referred to as quantity storms, where the control objectives are channel erosion control, overbank control, and flood control. Figure 2.5 illustrates a theoretical representation of these four classes.

FIGURE 2.5: FOUR CLASSES OF RAINFALL DISTRIBUTION



The distribution and magnitude of the RFS varies from region to region and to some extent, from year to year. Therefore, in order to establish a reasonable water quality treatment design volume for stormwater filtering practices it is necessary to define the RFS for the region of application. Within the Chesapeake Bay Watershed the average precipitation characteristics vary somewhat. This manual presents a sizing criteria based on an in-depth analysis conducted for the Washington, DC metropolitan area, compared with three other locations within the Bay and makes recommendations for establishing the RFS for other locations within the Bay Watershed.

Schueler (1987 and 1992), conducted a detailed evaluation of 50 years of hourly rainfall data in the Washington D.C. area. The recorded precipitation data from Washington National Airport consisted of all storm events separated by at least 3 hours from the next event. The base data collected at National Airport included minor storm events which normally do not produce measurable runoff. These minor events make up approximately 10% of all annual rainfall, are usually less than 0.1 inches, and are therefore excluded from the RFS analysis.

Table 2.11 outlines the RFS for the Washington D.C. metropolitan area and illustrates that the vast majority of all annual runoff is produced from the small frequent storm events.

TABLE 2.11: RAINFALL FREQUENCY SPECTRUM WASHINGTON, DC AREA[a]
SOURCE: DESIGN OF STORWATER WETLAND SYSTEMS (SCHUELER, 1992)

Percent of All Storm Events [b]	*Return Interval*	*Rainfall[c] Volume*
30	7 days	0.25
50	14 days	0.40
70	Monthly	0.75
85	Bi-monthly	1.05
90	Quarterly	1.25
95	Semi-annually	1.65
98	Annually	2.40
99	Two-year	2.90

a. 50 year analysis of hourly rainfall record at Washington National Airport, excluding all storms less than 0.10 inches that were separated by three consecutive hours from the next storm. These small storms seldom produce measurable stormwater runoff, yet are numerically the most common rainfall event.

b. Equal to or less than given rainfall volume

c. Watershed inches

2.5 THE 90% RULE-CUMULATIVE RAINFALL VOLUME FOR WATER QUALITY TREATMENT

A careful examination of Table 2.11 suggests that a BMP which is sized to capture and treat the three month storm frequency storm (or 1.25" rainfall) will effectively treat 90% of the annual average rainfall. While this is true, such a practice will also capture and at least partially treat the first 1.25" of larger rainfall events. Therefore treating the 1.25" rainfall will result in a capture efficiency of greater than 90%.

Given the economic considerations of capturing and storing a reasonably large water quality volume, and the realization that stormwater filters tend to lose efficiency as pollutant load input concentrations decrease (Bell, et. al, 1995), a smaller storm event was investigated to evaluate the effectiveness of an alternative treatment criteria. Many jurisdictions require storage of the first one-half inch of runoff from impervious surfaces. While this volume appears to have gained widespread acceptance, there has been little research on the cumulative pollutant load bypassing facilities sized on this principle. One notable exception, is a study conducted in Texas by Chang and his colleagues (1990), where the annual total solids load captured using the half-inch rule showed significant drop-off when imperviousness approached 70%.

To balance the desire to capture and treat as much cumulative rainfall as possible while avoiding an overly burdensome sizing criteria, additional rainfall data was evaluated throughout Chesapeake Bay watershed. In addition to Washington, DC, Three other locations were selected to evaluate longer term rainfall characteristics.

Daily precipitation data was analyzed for an 11 year period (January 1980 through December 1990) at four locations within the Chesapeake Bay Watershed. Norfolk VA, Washington, DC, Frederick MD, and Harrisburg, PA were selected as representative of the bay-wide watershed where new development activity is occurring. In addition locations are separated by 100 to 150 miles and represent a distribution from coastal to inland, and south to north.

The one-inch rainfall was evaluated to assess whether this value could be used to effectively capture 90% of the annual runoff. The average capture percentage using the 1.0" rainfall ranges from approximately 85% to 91% for the four locations. The analysis included the first one-inch of larger rainfall events which will be captured, but probably not completely treated. It is recognized that during these large events treatment conditions may be less than ideal. But it is safe to say that approximately 90% of the annual average rainfall events will be captured and treated using a **one-inch rainfall criteria**.

The results presented in Table 2.12 provide justification for using the 1.0" rainfall event for sizing stormwater filtering practices throughout the Chesapeake Bay Watershed. It must be emphasized that regional rainfall characteristics will differ from specific location to location. Additional rainfall frequency analysis is required for more complete reliance on this value. If a particular jurisdiction has the resources and long term data, a complete RFS should be conducted and the 90% rule applied to establish a local water quality precipitation value. In addition a longer data-set (say 50 years) will make some of the extreme rainfall events or drought periods less statistically significant and may have a minor effect on the capture value derived herein.

TABLE 2.12: COMPARISON OF PRECIPITATION DATA FOR FOUR LOCATIONS WITHIN THE CHESAPEAKE BAY WATERSHED 1980 - 1991 (DAILY ANALYSIS)

	Norfolk, VA	*Washington, DC*	*Harrisburg, PA*	*Frederick, MD*
Annual average precipitation	43.4 inches	37.9 inches	39.6 inches	37.0 inches
Annual average snowfall	7.7 inches	17.2 inches	31.3 inches	Not Obtained
Annual average # of precipitation days *	76 days	67 days	71 days	68 days
Annual average # of precipitation days more than 1.0"	10.5 days	9.5 days	9.5 days	7.7 Days
Annual average # of precipitation days less than 0.1"	39.0 days	45.4 days	55.1 days	Not Obtained
Percent of annual average rainfall ≤ 1.0" *	85.3%	91.4%	86.8%	89.9%
Percent of annual precipitation days ≤ 1.0" *	86.2%	85.9%	86.7%	88.6%

* adjusted to exclude rainfall events ≤ 0.1 (assumed to produce no runoff)

2.6 *STORMWATER FILTERING SYSTEMS - SIZING CONSIDERATIONS*

In general, stormwater filtering systems should be sized based on the **volume** of runoff to be filtered. All practices identified in this manual utilize the volume based sizing criteria, except for the grass channel practice, where a peak rate is utilized. It is necessary, however, to utilize a peak rate of discharge for sizing off-line flow diversion structures.

As presented earlier in this chapter, the target rainfall event for estimating the Water Quality Volume (WQV) for sizing all filtering devices is based on the **90% Rule** for capturing annual runoff volume. For the Mid-Atlantic region and much of the Chesapeake Bay Watershed, a rainfall value of **1.0 inches** is suggested.

Some jurisdictions may elect to use other sizing guidelines, such as the ½ inch rule (measured in watershed inches). This criteria may be acceptable for lower imperviousness but will have decreased pollutant capture efficiencies for a higher imperviousness and a lower capture percentage of the annual runoff volume. The individual practice sizing principles contained in this manual are applicable for alternative treatment volumes so a reliance on the 90% Rule is not mandatory. In addition, several filtering practices are ideally suited for retrofit applications where full storage is often constrained. Designers and regulators should recognize that the 90% Rule is targeted mainly at new construction and is based on maximizing pollutant load capture. Practices sized for smaller treatment volumes are certainly acceptable in many situations.

2.7 *ESTIMATING WATER QUALITY VOLUME (WQV)*

Two methods can be utilized to estimate the Water Quality Volume (WQV). Both rely on computing a volumetric runoff coefficient (R_v) and multiplying this by the rainfall volume to obtain a runoff volume in watershed inches.

The first method, or what we call the **Short Cut Method,** utilizes equation 2.1 to estimate the volumetric runoff coefficient R_v, (Schueler, 1987). It is recommended that the Short Cut Method be utilized where the site consists of predominately one type of land surface or for quick calculations to obtain a reasonably accurate estimate of treatment volume.

$$R_v = 0.05 + 0.009(I)$$ **Equation 2.1**

where I = site percent impervious

Therefore, the required treatment volume for a site will be equal to:

$WQV = P * R_v$ **Equation 2.2**

P = rainfall, in inches
and WQV = Water Quality Volume, in watershed inches

EXAMPLE CALCULATION
Assume a 3.0 acre shopping center which is 87% impervious, for a 1.0 inch rainfall event. $R_v = 0.05 + 0.009(87\%)$ $R_v = 0.83$ for P = 1.0 inches WQV = (1.0")(.83) = .83 watershed inches WQV = .83"(1/12 "/ft)(3.0 ac)(43,560 ft^2/ac) = 9,039 ft^3

The second method, or **Small Storm Hydrology Method** utilizes the work done by Pitt and others, to compute a volumetric runoff coefficient (R_v) based on the specific characteristics of the pervious and impervious surfaces of the drainage catchment. This method presents a relatively simple relationship between rainfall amount, land surface, and runoff volume. The R_vs used to compute the volume of runoff are identified in Table 2.13. The small storm hydrology model involves the following:

- For a given rainfall depth, the runoff coefficients for land surfaces present on the subject site are selected.
- A weighted runoff coefficient for the entire site is computed.
- If a portion of the site has disconnected impervious surfaces, reduction factors are applied to R_v. The reduction factors (from Table 2.14) are multiplied by the computed R_v for connected impervious areas to obtain the corrected value.
- For the given rainfall, the runoff volume (in watershed inches) is computed. WQV is equal to the rainfall times the R_v (same as equation 2.2 above).

TABLE 2.13: VOLUMETRIC COEFFICIENTS FOR URBAN RUNOFF
(DIRECTLY CONNECTED IMPERVIOUS AREAS, ADAPTED FROM PITT, 1994)

Rainfall (inches)	Flat roofs and large unpaved parking lots	Pitched roofs and large impervious areas (large parking lots)	Small impervious areas and narrow streets	Sandy soils HSG-A	Silty soils HSG-B	Clayey soils HSG-C & D
0.75	.82	.97	.66	.02	.11	.20
1.00	.84	.97	.70	.02	.11	.21
1.25	.86	.98	.74	.03	.13	.22
1.50	.88	.99	.77	.05	.15	.24

TABLE 2.14: REDUCTION FACTORS TO VOLUMETRIC RUNOFF COEFFICIENTS FOR DISCONNECTED IMPERVIOUS SURFACES (ADAPTED FROM PITT, 1994)

Rainfall (inches)	Strip commercial and shopping center	Medium to high density residential with paved alleys	Medium to high density residential without alleys	Low density residential
0.75	.99	.27	.21	.20
1.00	.99	.38	.22	.21
1.25	.99	.48	.22	.22
1.50	.99	.59	.24	.24

In order to use the reduction factors for disconnected impervious surfaces, as general guidance, the impervious area above the pervious surface area should be less than one-half of the pervious surface and the flowpath through the pervious area should be at least twice the impervious surface flowpath.

The Small Storm Hydrology method has the advantage of evaluating the precise elements of a particular site and should be utilized for most design applications to estimate accurate runoff volumes. The method requires somewhat more effort to identify the specific land surface area ratios and additional effort is needed to assess the disconnections of impervious areas. The method rewards site designs which utilize disconnections of impervious surfaces by lowering the computed R_v and the required WQV.

EXAMPLE CALCULATION

Assume a 3.0 acre small shopping center having a 1.0 acre flat roof, 1.6 acres of parking and a 0.4 acre open space (sandy soil), for a 1.0 inch rainfall event and no disconnection of impervious surfaces. The weighted volumetric runoff coefficient is:

flat roof:	1.0 acre x .84 = 0.84
parking:	1.6 acres x .97 = 1.55
open space:	0.4 acre x .02 = 0.01
total:	3.0 acres = 2.40

weighted volumetric runoff coefficient R_v = 2.40/3.0 = .80

for P = 1.0 inches
Water Quality Volume (WQV) = (1.0")(.80) = .80 watershed inches
= (.80") (1 ft/12") (3.0 ac) (43,560 ft^2/ac)
= 8,712 ft^3

2.8 ESTIMATING PEAK DISCHARGE FOR THE WATER QUALITY STORM (Q_P)

The peak rate of discharge is needed for the sizing of off-line diversion structures and to design grass channels. As discussed earlier in this chapter, conventional SCS methods underestimate the volume and rate of runoff for rainfall events less than 2". This discrepancy in estimating runoff and discharge rates can lead to situations where a significant amount of runoff by-passes the filtering treatment practice due to an inadequately sized diversion structure or leads to the design of undersized grass channels.

The following procedure can be used to estimate peak discharges for small storm events. It relies on the volume of runoff computed using the Small Storm Hydrology Method and utilizes SCS, TR-55 Graphical Peak Discharge Method.

- Using the water quality volume (WQV), computed using the methods previously presented, a corresponding Curve Number (CN) is computed utilizing equation 2.3.

$$CN = 1000/[10 + 5P + 10Q - 10(Q^2 + 1.25\ QP)^{1/2}]$$ **Equation 2.3**

where P = rainfall, in inches (use 1.0" for the Water Quality Storm)
and Q = runoff volume, in inches (equal to WQV)

Note: Equation 2.3 above, is derived from the SCS Runoff Curve Number method described in detail in NEH-4, Hydrology (SCS 1985) and SCS TR-55 Chapter 2: Estimating Runoff. The CN can also be obtained graphically (also from TR-55).

- Once a CN is computed, the time of concentration (t_c) is computed (based on the methods identified in TR-55, Chapter 3: "Time of concentration and travel time"). The t_c for small sites is often small based on relatively short flow paths; however, a minimum value of 0.1 hours should be used.

- Using the computed CN, t_c and drainage area (A), in acres; the peak discharge (Q_p) for the Water Quality Storm is computed (based on the procedures identified in TR-55, Chapter 4: "Graphical Peak Discharge Method"). For the Chesapeake Bay Watershed use Rainfall distribution type II.

  - Read initial abstraction (I_a), compute I_a/P
  - Read the unit peak discharge (q_u) from Exhibit 4-II for appropriate t_c
  - Using the water quality volume (WQV), compute the peak discharge (Q_p)

$$Q_p = q_u * A * WQV$$ **Equation 2.4**

where Q_p = the peak discharge, in cfs
q_u = the unit peak discharge, in cfs/mi²/inch
A = drainage area, in square miles
and WQV = Water Quality Volume, in watershed inches

EXAMPLE CALCULATION

Using the previous example:

where WQV = .80"

CN = 1000/[10+5*1.0"+10*.80"-10((0.80")²+1.25*.80"*1.0")^½]

CN = 98

assume t_c = 10 minutes = .17 hours

I_a = 0.041 for CN = 98, I_a/P = 0.041/1.25" = .03

read q_u = 950 csm/in (TR-55 Exhibit 4-II)

A = 3.0 acres/640ac/mi² = .0047mi²

Q_p = 950 csm/in* .0047mi²* .80" =3.6 cfs

For computing runoff volume and peak rate for storms larger than the Water Quality Storm (i.e., 2, 10 and 100 year storms), use the published CN's from TR-55 and follow the prescribed procedure in TR-55.

In some cases the Rational Formula may be used to compute peak discharges associated with the Water Quality Storm. The designer must have available reliable intensity, duration, frequency (IDF) tables or curves for the storm and region of interest. This information may not be available for many locations and therefore the TR-55 method described above is recommended.