3.0 General Stormwater BMP Design Considerations

3.1 The First Flush

The term "first flush" has become common nomenclature in the stormwater management field. The concept behind this term is that pollutants that have collected on impervious surfaces will wash off during the first portion of a storm event. Essentially, the first portion of a given rain event will "flush" the impervious surface of its pollutants, resulting in stormwater runoff that contains more pollutants than runoff produced later in the storm. This theory involves capturing and treating the first half inch of runoff (or, the first one inch of rainfall) in a stormwater practice. About 90% of the pollutants leaving the site would be treated in this scenario (Schueler, 2000). Thus, capturing the runoff associated with 1 inch of rainfall was previously considered the standard for capturing the first flush in non-coastal portions of the North Carolina.

A study was performed by BAE for NCDENR to evaluate the first flush (or water quality event) in various locations throughout North Carolina (Bean, 2005). For the basis of this study, the water quality storm event was defined as the event size (in depth) which 90% of all storms are equal to or less than. Prior to the study, the water quality storm was considered to be 1 inch in all areas of North Carolina excluding Coastal Area Management Act (CAMA) counties. In CAMA counties, the water quality storm was considered 1.5 inches. Figure 3.1 shows a map of the CAMA counties in North Carolina.

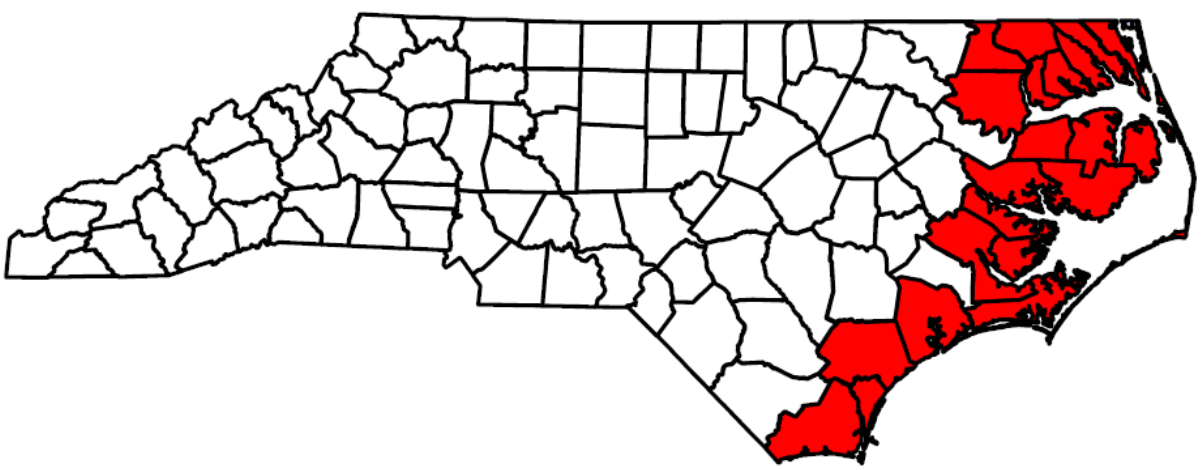

Figure 3.1 Map of CAMA counties in North Carolina.

Thirty years of rainfall data were analyzed from 9 locations in North Carolina. For most of North Carolina, capturing approximately 1 inch of rainfall would only result in capturing 80% of all the rainfall that fell on a given watershed. Likewise, in CAMA counties, 1.5 inches would result in capturing approximately 80% of all the rainfall. Because of the premise that the majority of pollution is carried in the earlier portions of the storm, it was assumed that at least 90% of pollution would be transported by the runoff produced by 80% of the rainfall. NCDENR considered these values to be acceptable based on this assumption, so the stormwater design standards remained the same. There are a few supporting studies in literature for this (Flint and Davis, 2007), but the theory has not been proven completely (Sansalone and Cristina, 2004).

3.2 The Simple Method

The water quality storm can easily be used to calculate the anticipated volume of runoff that will leave a given catchment through the application of the Simple Method (Schueler, 1987). The required information is as follows: (1) area that will be draining to the proposed BMP location in square feet, (2) the percentage of the drainage area that is impervious, and (3) the desired depth of rainfall targeted for capture (normally the water quality event, which is 1 inch except in CAMA counties, where it is 1.5 inches). The Simple Method is described in equations 3-1 and 3-2 below.

Equation 3-1: Calculate Runoff Coefficient

$$Rv = 0.05 + (0.009 * I)$$

Equation 3-2: Calculate Runoff Volume

$$V = Rv * A * (P/12)$$

Where:

Rv = Runoff Coefficient (fraction of rainfall that will produce runoff)
I = Impervious percentage in watershed (%)
V = Volume of runoff (ft^3)
A = Area that drains to BMP (ft^2)
P = Depth of storm to be captured (in)

Please note: “I” includes the total impervious percentage in the watershed and does not differentiate between connected and disconnected impervious area.

Figures 3.2-3.5 use the Simple Method to calculate the volume of water that can be expected from a given watershed; these values are calculated using water quality events of either 1 inch or 1.5 inches (as defined in figure title).

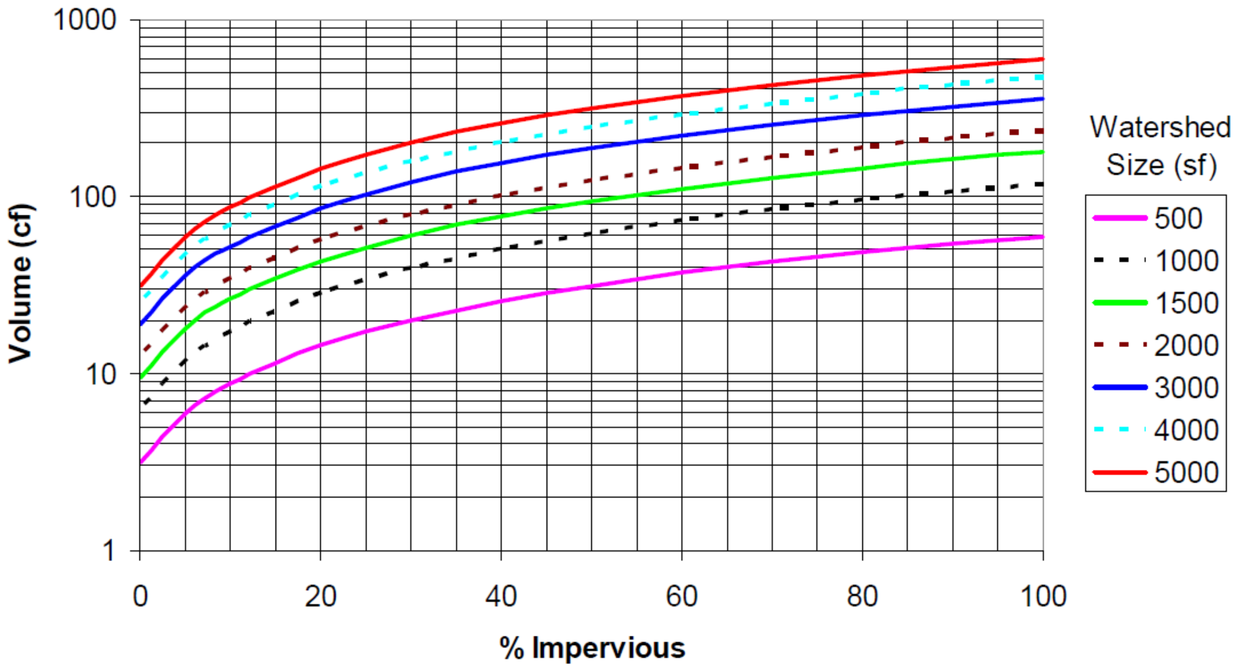

Figure 3.2 Estimated runoff volumes from watersheds <5000 ft^2 for 1-inch rainfall.

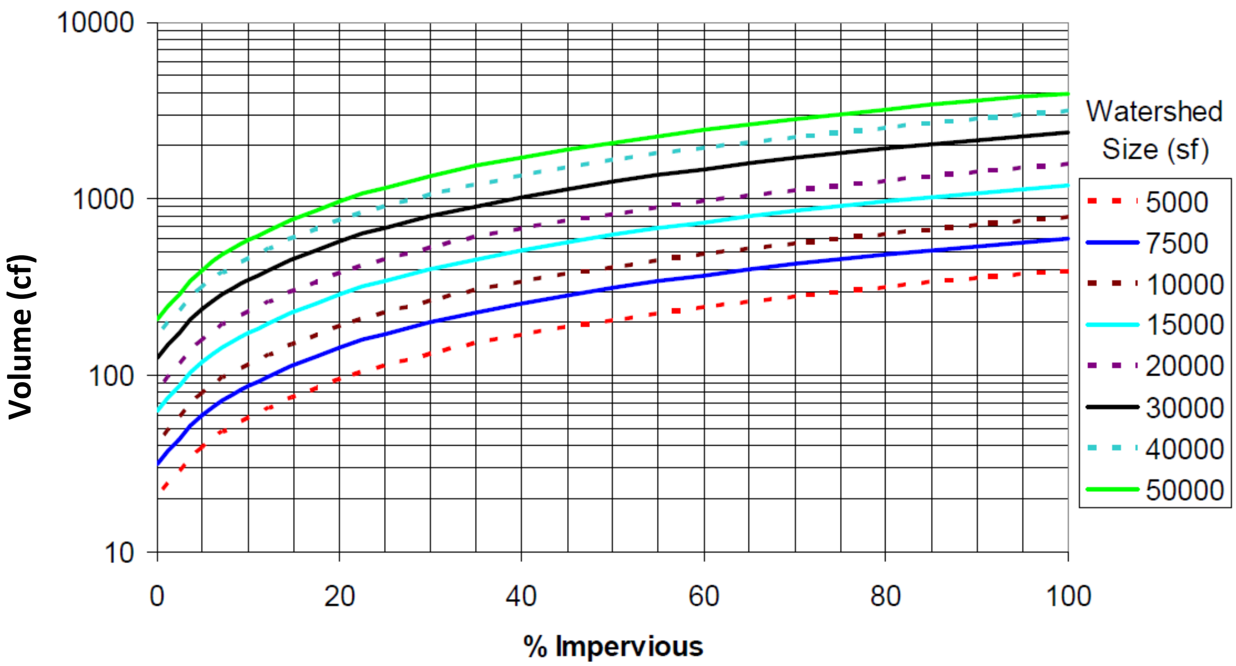

Figure 3.3 Estimated runoff volumes from watersheds >5000 ft^2 for 1-inch rainfall.

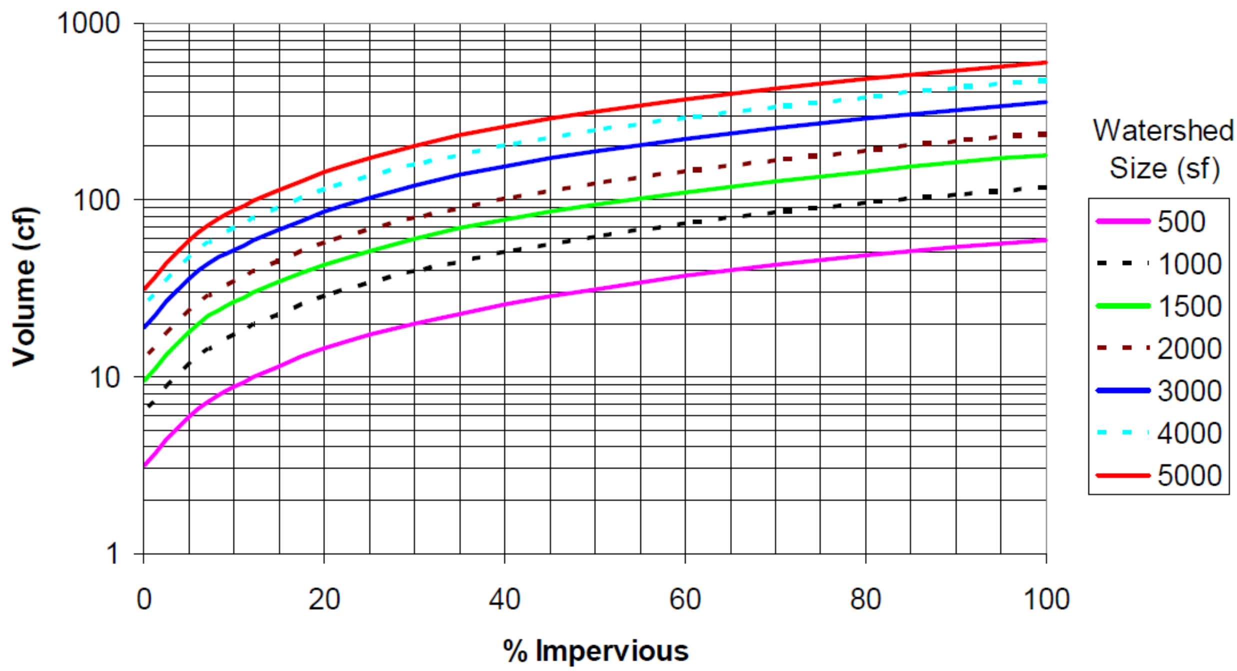

Figure 3.4 Estimated runoff volumes from watersheds <5000 ft^2 for 1.5-inch rainfall.

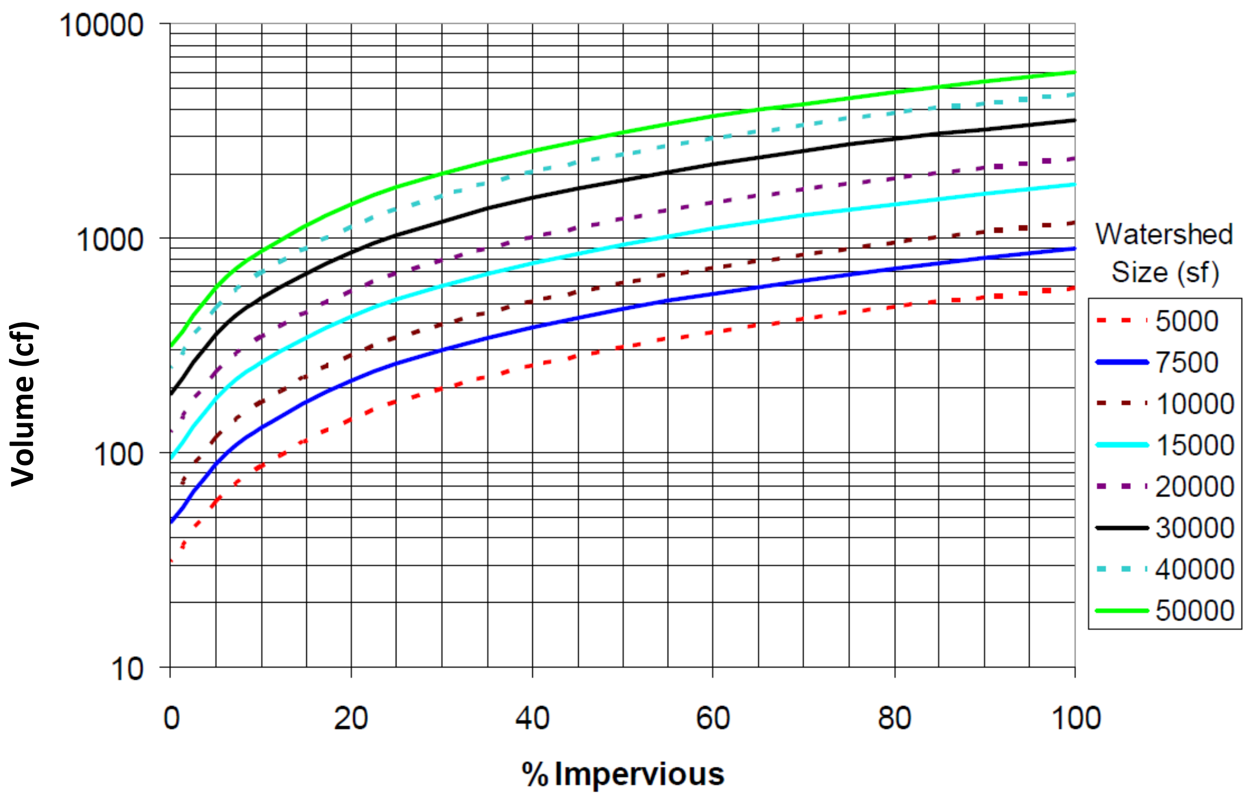

Figure 3.5 Estimated runoff volumes from watersheds >5000 ft^2 for 1.5-inch rainfall.

3.3 Peak Flow Rate

Determining the peak flow rate leaving a watershed during a design storm is important when designing many best management practices. The peak flow is the largest flow that leaves the watershed through the course of a storm event. Figure 3.6 shows a sample flow versus time relationship and the associated peak flow. The depth of rain that falls throughout the event can be observed as a bar graph with the rainfall depth on the secondary vertical axis.

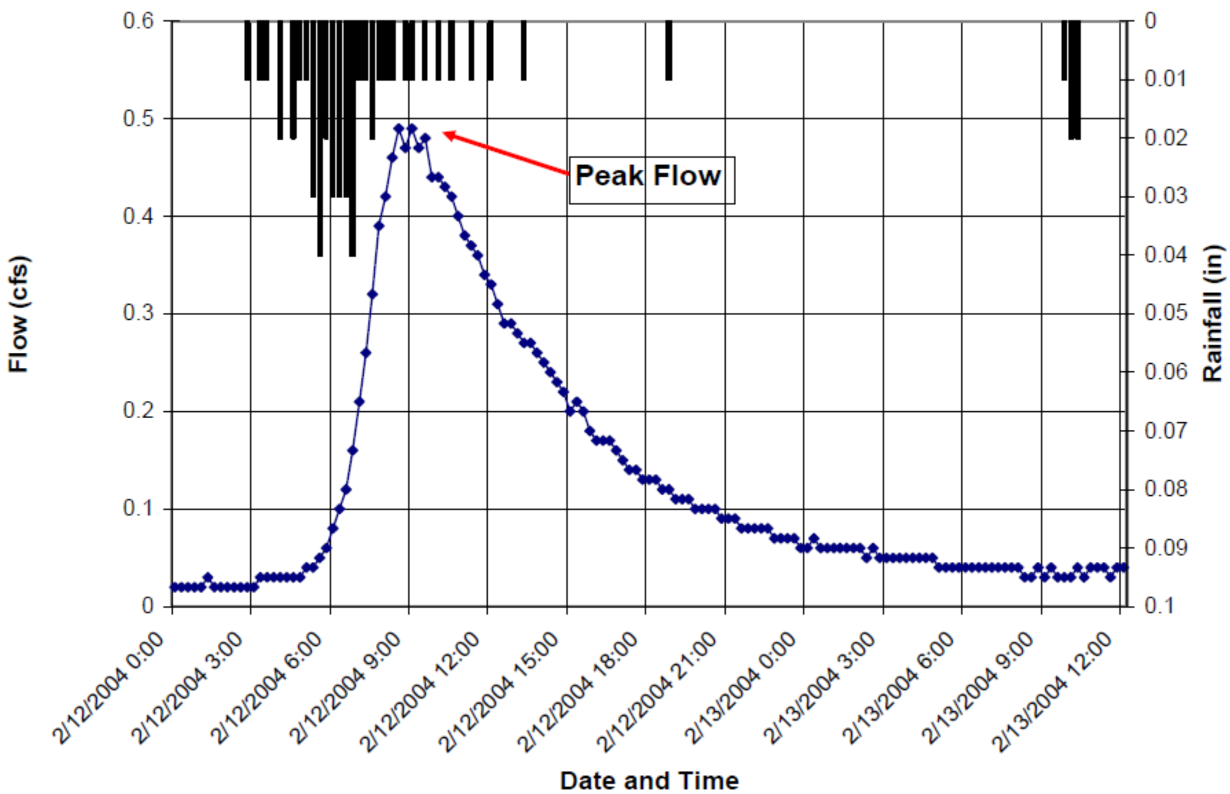

Figure 3.6 Hydrograph with peak flow rate emphasized.

The peak flow is used to determine the proper size of conveyances such as swales and drainage pipes and can also be used to determine the proper size of high flow bypass devices. Peak flow can be calculated easily using the Rational Method (Bedient and Huber, 1992). The Rational Method is a simple model used to estimate the peak flow from a given watershed. For applications such as backyard stormwater practices, where small, highly impervious watersheds will be treated, the Rational Method offers a somewhat coarse, but adequate, estimate of peak flow. The Rational Method is as follows:

Equation 3-3: Rational Method

$$Q = C \times I \times A$$

Where:

Q = Peak flow (ft^3/s)

C = Runoff Coefficient (dimensionless) – varies based on land use
A = Watershed area being treated (acres)
I = Intensity of storm event to be captured (in/hr)
(Note: There are 43,560 ft^2 in 1 acre)

3.3.1 Storm Intensity

The Rational Method is highly adaptable to various land uses, storm events, and watershed characteristics. For the purpose of this manual, some generalizations can be made to simplify the calculation. Rainfall intensity varies throughout the course of a storm. For small watersheds (those being treated by the backyard BMPs constructed as part of this program) stormwater from the far end of the connected impervious area does not have a large distance to travel to the BMP; thus, the time it takes stormwater to reach the BMP from all parts of the watershed is short. With these watershed characteristics, the peak flow from the watershed will be produced by the most intense portion of the storm. A short duration of high intensity rainfall is the most intense part of the storm; therefore, the amount of rainfall that falls during the most intense 5 minutes of the storm will be chosen as the intensity used in the Rational Method calculation. Table 3.1 shows the 5-minute peak intensity for various North Carolina cities for the 2, 5, 10, and 25-year storm events. Data from the city closest to the proposed BMP location can be used (Table 3.1) or further information can be gathered for a specific city by visiting the National Weather Service's Hydrometeorological Design Studies Center (http://hdsc.nws.noaa.gov/hdsc/pfds/orb/nc_pfds.html).

Table 3.1 Peak Intensity (in/hr) for Various Storm Events (5-minute duration).

Location	2-yr	5-yr	10-yr	25-yr
Asheville	4.78	5.75	6.48	7.45
Boone	5.71	6.64	7.42	8.46
Charlotte	5.66	6.59	7.26	8.03
Durham	5.69	6.53	7.25	7.97
Elizabeth City	6.11	7.02	7.96	8.98
Fayetteville	6.11	7.14	7.92	8.89
Greensboro	5.41	6.29	6.86	7.49
Greenville	6.18	7.12	8.04	9.07
Hickory	5.22	6.18	6.91	7.82
Raleigh	5.53	6.36	7.04	7.75
Wilmington	7.39	8.65	9.64	10.88
Winston-Salem	5.32	6.24	6.86	7.58

Source: National Weather Service.

3.3.2 Runoff Coefficient

Although it is assumed that the BMPs implemented as part of the CCAP will treat catchments that are primarily impervious (rooftops, driveways, parking lots), there will likely be other land uses associated with each watershed, such as landscaped areas, lawns, and other pervious areas. The rational method is versatile enough to account for both the impervious and pervious areas of each watershed.

that can be applied to a given watershed, a C value of 0.95 should be applied to all impervious areas, and a C value of 0.25 should be applied to all pervious areas. Equation 3-4 can be used to determine a C value that can be applied to the whole watershed.

Equation 3-4: Determine the Composite Runoff Coefficient

$$C = [((\text{Impervious Area}) \times 0.95) + ((\text{Pervious Area}) \times 0.25)]/\text{Watershed Area}$$

3.4 Routing Water to the BMP

In certain situations, a small "shoulder berm", "water bar" or similar mechanism may be required to route more water to a practice. These are earthen structures that are designed to intercept and direct stormwater to the BMP. They can increase the effectiveness of the BMP by allowing it to treat a larger watershed.

The side slopes should not be graded steeper than 2:1, and the height should not exceed 1 foot. If greater than a 1 foot height is required, PE approval is required. These installations can be covered with grass or mulch depending on the landscape and the expected runoff velocities. Erosion control matting should be used for cover while vegetation is being established.

Please contact a DSWC engineer for more information.

3.5 Determining Outlet Size

3.5.1 Determining Outlet Size

The outlet weir rectangular notch should be sized such that the berm is not overtopped during a 10-year storm event. The weir notch must be long enough to allow the peak flow associated with the 10-year storm to pass without the water rising high enough that the top of the berm is reached. To determine the appropriate length of weir notch to pass the 10-year storm, the weir equation can be applied. The weir equation is as follows:

Equation 3-9: Weir Equation

$$Q = C_W \times L \times H^{1.5}$$

Where:

Q = Flow (ft^3/s) – *Use peak flow from 10-year event*
C_W = Weir Coefficient (dimensionless) – *Use 3.0*
L = Length of Weir (ft)
H = Height of Water Over Top of Weir (ft) – *Use 0.5 feet*

The flow that should be passed is the flow associated with the 10-year event as determined using the Rational Method (Section 3.4). The weir coefficient is set to 3.0, and the height of the water over the top of the weir should be no higher than 6 inches (0.5 feet), so the water will not flow over the containment berm. As a result, the only unknown in the equation is the length of the weir. This equation can be rearranged to solve for the weir length:

Equation 3-10: Weir Equation

$$L = Q \div (C_w \times H^{1.5})$$

Sample 10-year peak flow calculations for various watershed scenarios are shown in Appendix A. Included is a required weir length for each watershed scenario.

3.5.2 Outlet installation

Appendix B shows a diagram of a wooden weir structure that could be used for an outlet control structure on large systems. For any type of outlet used, concentrated flows should only pass over a structure or undisturbed and vegetated soil. All wooden weir structures should be tied into the underlying soils. Soils filled around structures should be compacted and protected.

Note: *The engineers are working on consistent guidance regarding the use of an earthen vs wooden weir. It appears that the maximum velocities possible from a backyard practice's maximum drainage area would not require the need for a wooden weir. An earthen weir should be appropriate for most backyard practices.*

The one exception is that an earthen weir is only appropriate on natural ground where vegetation establishment is possible. A wooden structure may be required on some areas with fill material.

Proposed guidance for sizing of an earthen weir include:

- Always use a H (height of water over top of the weir) = 0.5 ft
- The minimum size (L) of a weir should be = 2 ft
- Always use temporary matting to assure vegetation establishment