# Pennsylvania Stormwater Best Management Practices Manual

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## Section 9
## Stormwater Calculations and Methodology

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# Section 9 Stormwater Calculations and Methodology

## 9.1 Introduction to Stormwater Methodologies

There have been many methodologies developed to estimate the total runoff volume, the peak rate of runoff, and the runoff hydrograph from land surfaces under a variety of conditions. This section describes some of the methods that are most widely used in Pennsylvania and throughout the country. It is certainly not a complete list of procedures nor is it intended to discourage the use of new and better methods as they become available.

There also a wide variety of both public and private domain computer models available for performing stormwater calculations. The computer models use one or more calculation methodologies to estimate runoff characteristics. The procedures most commonly used in computer models are the same ones discussed below.

In order to facilitate a consistent and organized presentation of information throughout the state, assist design engineers in meeting the recommended control guidelines, and help reviewers analyze project data a series of Worksheets are provided in this Section for design professionals to complete and submit with their development applications.

## 9.2 Existing Methodologies for Runoff Volume Calculations and their Limitations

### 9.2.1 Runoff Curve Number Method

The runoff curve number method, developed by the Soil Conservation Service (now the Natural Resources Conservation Service), is perhaps the most commonly used tool for estimating runoff volumes. In this method, runoff is calculated based on precipitation, curve number, watershed storage, and initial abstraction. When rainfall is greater than the initial abstraction, runoff is given by (SCS, 1986):

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

where: Q = runoff (in.)
P = rainfall (in.)
$I_a$ = initial abstraction (in.)
S = potential maximum retention after runoff begins (in.)

Initial abstraction ($I_a$) includes all losses before the start of surface runoff: depression storage, interception, evaporation, and infiltration. $I_a$ can be highly variable but SCS has found that it can be empirically approximated by:

$$I_a = 0.2S$$

Therefore, the runoff equation becomes:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

Finally, S is a function of the watershed soil and cover conditions as represented by the runoff curve number (CN):

$$S = \frac{1000}{CN} - 10$$

Therefore, runoff can be calculated using only the curve number and rainfall. Curve numbers are determined by land cover type, hydrologic condition, antecedent moisture condition (AMC), and hydrologic soil group (HSG). Curve numbers for various land covers based on an average AMC for annual floods and $I_a$ = 0.2S can be found in Urban Hydrology for Small Watersheds (Soil Conservation Service, 1986) and various other references.

Often a single, area-weighted curve number is used to represent a watershed consisting of subareas with different curve numbers. While this approach is acceptable if the curve numbers are similar, if the difference in curve numbers is more than 5 the use of a weighted curve number significantly reduces the estimated amount of runoff from the watershed. This is especially problematic with pervious/impervious combinations: "combination of impervious areas with pervious areas can imply a significant initial loss that may not take place." (Soil Conservation Service, 1986) Therefore, the runoff from different subareas should be calculated separately and then combined or weighted appropriately. At a minimum, runoff from pervious and directly connected impervious areas should be estimated separately for storms less than approximately 4 inches. (NJDEP, 2004)

The curve number method is less accurate for storms that generate less than 0.5 inches of runoff and the Soil Conservation Service (1986) recommends using another procedure as a check for these situations. For example, the storm depth that results in 0.5 inches of runoff varies according to the CN; for impervious areas (CN of 98) it is a 0.7-inch storm, for "Open space" in good condition on C soils (CN of 74) it is 2.3 inches, for Woods in good condition on B soils (CN of 55) it is over 3.9 inches. An alternate method for calculating runoff from small storms is described below.

Recently, some researchers have suggested that the assumption that $I_a$ = 0.2S does not fit the observed rainfall-runoff data nearly as well as $I_a$ = 0.05S. Incorporating this assumption into the curve number method results in a new runoff equation and new curve numbers. Woodward et al. (2003) describe the new runoff equation and a procedure to convert from traditional CNs to new values based on $I_a$ = 0.05S. They also describe a plan to implement these changes into all appropriate NRCS documents and computer programs. The most notable differences in runoff modeling with these changes occur at lower curve numbers and lower rainfalls (using the traditional curve number assumption of $I_a$ = 0.2S results in higher initial abstraction and lower runoff volumes under these conditions). When utilized to predict runoff from developed sites in Pennsylvania during design storms the difference is likely to be insignificant.

### 9.2.2 Small Storm Hydrology Method

The Small Storm Hydrology Method was developed to estimate the runoff volume from urban and suburban land uses for relatively small storm events. Other common procedures, such as the runoff curve number method, are less accurate for small storms as described previously. The CN methodology can significantly underestimate the runoff generated from smaller storm events. (Claytor and Schueler, 1996 and Pitt, 2003) The SSHM is a straightforward procedure in which runoff is calculated using volumetric runoff coefficients. The runoff coefficients, $R_v$, are based on extensive field research from the Midwest, the Southeastern U.S., and Ontario, Canada over a wide range of land uses and storm events. The coefficients have also been tested and verified for numerous other U.S. locations. Runoff coefficients for individual land uses generally vary with the rainfall amount – larger storms have higher coefficients. Table 9-1 below lists SSHM runoff coefficients for seven land use scenarios for the 0.5 and 1.5 inch storms.

*Table 9-1. Runoff Coefficients for the Small Storm Hydrology Method (adapted from Pitt, 2003)*

| Rainfall (in.) | Volumetric Runoff Coefficients, $R_v$ | | | | | | |
|---|---|---|---|---|---|---|---|
| | Impervious Areas | | | | Pervious Areas | | |
| | Flat Roofs/ Large Unpaved Parking Areas | Pitched Roofs | Large Imperv. Areas | Small Imperv. Areas and Uncurbed Roads | Sandy Soils (HSG A) | Silty Soils (HSG B) | Clayey Soils (HSG C & D) |
| 0.5 | 0.75 | 0.94 | 0.97 | 0.62 | 0.02 | 0.09 | 0.17 |
| 1.5 | 0.88 | 0.99 | 0.99 | 0.77 | 0.05 | 0.15 | 0.24 |

Runoff is simply calculated by multiplying the rainfall amount by the appropriate runoff coefficient. Because the runoff relationship is linear for a given storm (unlike the curve number method), a single weighted runoff coefficient can be used for an area consisting of multiple land uses. Therefore, runoff is given by:

$$Q = P \times R_v$$

where: Q = runoff (in.)
P = rainfall (in.)
$R_v$ = area-weighted runoff coefficient

### 9.2.3 Infiltration Models for Runoff Calculations

Several computer packages offer the choice of using soil infiltration models as the basis of runoff volume and rate calculations. Horton developed perhaps the best-known infiltration equation – an empirical model that predicts an exponential decay in the infiltration capacity of soil towards an equilibrium value as a storm progresses over time. (Horton, 1940) Green-Ampt (1911) derived another equation describing infiltration based on physical soil parameters. As the original model applied only to infiltration after surface saturation, Mein and Larson (1973) expanded it to predict the infiltration that occurs up until saturation. (James et al., 2003) These infiltration models estimate the amount of precipitation excess occurring over time – excess must be transformed to runoff with other procedures to predict runoff volumes and hydrographs.

## 9.3 Existing Methodologies for Peak Rate/Hydrograph Estimations and their Limitations

### 9.3.1 The Rational Method

The Rational Method has been used for over 100 years to estimate peak runoff rates from relatively small, highly developed drainage areas. The peak runoff rate from a given drainage area is given by:

$$Q_y = C \times I \times A$$

where: $Q_y$ = peak runoff rate (cubic feet per second)
C = the runoff coefficient of the area (assumed to dimensionless)
I = the average rainfall intensity (in./hr) for a storm with a duration equal to the time of concentration of the area
A = the size of the drainage area (acres)

The runoff coefficient is usually assumed to be dimensionless because one acre-inch per hour is very close to one cubic foot per second (1 ac-in./hr = 1.008 cfs). Although it is a simple and straightforward method, estimating both the time of concentration and the runoff coefficient introduce considerable uncertainty in the calculated peak runoff rate. In addition, the method was developed for relatively frequent events so the peak rate as calculated above should be increased for more extreme events. (Viessman and Lewis, 2003) Because of these and other serious deficiencies, the Rational Method should only be used to predict the peak runoff rate for very small, highly impervious areas. (Linsley et. al, 1992)

Although the method has been adapted to include estimations of runoff hydrographs and volumes through the Modified Rational Method, it is further compromised by assumptions about the total storm duration and therefore should not be used to calculate water quality, infiltration, or capture volumes.

### 9.3.2 Modified Rational Method

The Rational Method, discussed in detail below, has been adapted to include estimations of runoff hydrographs and volumes through the Modified Rational Method. Due to the limitations of the Rational Method itself (see below) as well as assumptions in the Modified Rational Method about the total storm duration, this method should not be used to calculate water quality, infiltration, or capture volumes.

### 9.3.3 SCS (NRCS) Unit Hydrograph Method

In combination with the curve number method for calculating runoff depth, the Soil Conservation Service also developed a system to estimate peak runoff rates and runoff hydrographs using a dimensionless unit hydrograph derived from many natural unit hydrographs from diverse watersheds throughout the country. (NRCS Chapter 16, 1972) As discussed below, the SCS methodologies are available in several public domain computer models including TR-55 (WinTR-55) computer model (2003), Technical Release 20 (TR-20): Computer Program for Project Formulation Hydrology (1992), and is an option in the U.S. Army Corp of Engineers' Hydrologic Modeling System (HEC-HMS, 2003) and U.S. EPA's Storm Water Management Model (SWMM 5.0.003, 2004).

## 9.4 Computer Models

### 9.4.1 HEC Hydrologic Modeling System (HEC-HMS)

The U.S. Army Corp of Engineers' Hydrologic Modeling System (HEC-HMS, 2003) supersedes HEC-1 as "new-generation" rainfall-runoff simulation software. According to the Corp, HEC-HMS "is a significant advancement over HEC-1 in terms of both computer science and hydrologic engineering." (U.S. ACE, 2001) HEC-HMS was designed for use in a "wide range of geographic areas for solving the widest possible range of problems." The model incorporates several options for simulating precipitation excess (runoff curve number, Green & Ampt, etc.), transforming precipitation excess to runoff (SCS unit hydrograph, kinematic wave, etc.), and routing runoff (continuity, lag, Muskingum-Cunge, modified Puls, kinematic wave). HEC-HMS Version 2.2.2 (May 28, 2003) can be downloaded for free at: http://www.hec.usace.army.mil/software/hec-hms/hechms-hechms.html.

### 9.4.2 SCS/NRCS Models: TR-20 and TR-55

"Technical Release No. 20: Computer Program for Project Formulation Hydrology (TR-20) is a physically based watershed scale runoff event model" that "computes direct runoff and develops hydrographs resulting from any synthetic or natural rainstorm." (NRCS, 2004) Hydrographs can then be routed through stream/channel reaches and reservoirs. TR-20 applies the methodologies found in the Hydrology section of the National Engineering Handbook (NRCS, 1969-2001), specifically the runoff curve number method and the dimensionless unit hydrograph. (SCS, 1992) Version 2.04 was released in 1992 and can be downloaded for free at: http://www.wcc.nrcs.usda.gov/hydro/hydro-tools-models-tr20.html. A Beta test version for Windows, WinTR-20, has also been released in 2004.

Technical Release 55 (TR-55) was originally published in 1975 as a simple procedure to estimate runoff volume, peak rate, hydrographs, and storage volumes required for peak rate control. (NRCS, 2002) TR-55 was released as a computer program in 1986 and work began on a modernized Windows version in 1998. WinTR-55 generates hydrographs from urban and agricultural areas and routes them downstream through channels and/or reservoirs. WinTR-55 uses the TR-20 model for all of its hydrograph procedures. (NRCS, 2002) WinTR-55 Version 1 was officially released in 2002 and can be downloaded for free at: http://www.wcc.nrcs.usda.gov/hydro/hydro-tools-models-wintr55.html.

### 9.4.3 Storm Water Management Model (SWMM)

The U.S. Environmental Protection Agency (2004) describes its model as:

"a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. The runoff component of SWMM operates on a collection of subcatchment areas that receive precipitation and generate runoff and pollutant loads. The routing portion of SWMM transports this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators...

SWMM was first developed in 1971 and has since undergone several major upgrades… It continues to be widely used throughout the world for planning, analysis and design related to storm water runoff, combined sewers, sanitary sewers, and other drainage systems in urban areas, with many applications in non-urban areas as well. The current edition, Version 5, is a complete re-write of the previous release. Running under Windows, SWMM 5 provides an integrated environment for editing study area input data, running hydrologic, hydraulic and water quality simulations, and viewing the results in a variety of formats."

SWMM is a powerful model capable of simulating areas consisting of a single, uniform subcatchment to the drainage system of an entire city. Although typically not used to evaluate a single development site, the recently released Version 5 is more user-friendly and should promote an increase in use among design professionals.

Rainfall excess is calculated in SWMM by subtracting infiltration (based on Horton or Green & Ampt) and/or evaporation from precipitation. Rainfall excess is converted to runoff by coupling Manning's equation with the continuity equation. (Rossman, 2004 and James et al., 2003) The newest version of SWMM also incorporates the runoff curve number method for estimating infiltration. (Rossman, 2004)

### 9.4.4 Source Loading and Management Model (SLAMM)

The Source Loading and Management Model (SLAMM) is designed to provide information about the sources of critical pollutants in urban runoff and the effectiveness of stormwater BMPs for controlling these pollutants. SLAMM was primarily developed as a planning level model to predict flow and pollutant discharges from a wide variety of development conditions using many combinations of common stormwater BMPs. Development of the model began in the mid 1970s and was supported by the U.S. Environmental Protection Agency, the Wisconsin Department of Natural Resources, and the Ontario (Canada) Ministry of the Environment. (Pitt and Voorhees, 2000) Because of their impact on pollutant loading, SLAMM places special emphasis on small storms and utilizes the Small Storm Hydrology Method to calculate surface runoff. According to Pitt and Voorhees (2000): "SLAMM also calculates correct NRCS curve numbers that reflect specific development and control characteristics. These curve numbers can then be used in conjunction with [other] available urban drainage procedures to reflect the water quantity reduction benefits of stormwater quality controls." The latest version of SLAMM, WinSLAMM, can be purchased through: http://www.winslamm.com/.

## 9.5 Precipitation Data for Stormwater Calculations

In 2004 the National Weather Service's Hydrometeorological Design Studies Center published updated precipitation estimates for much of the United States, including Pennsylvania. NOAA Atlas 14 supercedes previous precipitation estimates such as Technical Memorandum NWS Hydro 35 and Technical Papers 40 and 49 (TP-40 and TP-49) because the updates are based on more recent and expanded data, current statistical techniques, and enhanced spatial interpolation and mapping procedures. (Bonnin et al., 2003 and NWS, 2004) The "Precipitation-Frequency Atlas of the United States," NOAA Atlas 14, provides estimates of 2-year through 1000-year storm events for durations ranging from 5 minutes to 60 days as shown for Harrisburg in Table 9-2 (available online at http://hdsc.nws.noaa.gov/hdsc/pfds/). Users can select precipitation estimates for Pennsylvania from over 300 observation sites, by entering latitude/longitude coordinates, or by clicking on an interactive map on the Precipitation Frequency Data Server. These new rainfall estimates should be utilized for all applicable stormwater calculations.

*Table 9-2. Precipitation Frequency Estimates for "Harrisburg Capital Cit (36-3699)" from NOAA Atlas 14*

**Precipitation Frequency Estimates (inches)**

| ARI* (years) | 5 min | 10 min | 15 min | 30 min | 60 min | 120 min | 3 hr | 6 hr | 12 hr | 24 hr | 48 hr | 4 day | 7 day | 10 day | 20 day | 30 day | 45 day | 60 day |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 0.38 | 0.61 | 0.77 | 1.06 | 1.33 | 1.53 | 1.68 | 2.06 | 2.50 | 2.90 | 3.35 | 3.78 | 4.41 | 5.07 | 6.83 | 8.41 | 10.55 | 12.56 |
| 5 | 0.45 | 0.72 | 0.91 | 1.29 | 1.66 | 1.94 | 2.12 | 2.60 | 3.18 | 3.68 | 4.25 | 4.78 | 5.51 | 6.26 | 8.18 | 9.90 | 12.22 | 14.41 |
| 10 | 0.50 | 0.80 | 1.01 | 1.47 | 1.91 | 2.27 | 2.49 | 3.06 | 3.76 | 4.38 | 5.04 | 5.64 | 6.47 | 7.28 | 9.29 | 11.13 | 13.55 | 15.85 |
| 25 | 0.56 | 0.90 | 1.14 | 1.68 | 2.23 | 2.74 | 3.00 | 3.73 | 4.64 | 5.46 | 6.24 | 6.96 | 7.92 | 8.77 | 10.88 | 12.86 | 15.34 | 17.77 |
| 50 | 0.61 | 0.96 | 1.22 | 1.83 | 2.48 | 3.13 | 3.43 | 4.30 | 5.42 | 6.43 | 7.29 | 8.12 | 9.19 | 10.05 | 12.19 | 14.26 | 16.74 | 19.24 |
| 100 | 0.65 | 1.03 | 1.30 | 1.99 | 2.73 | 3.55 | 3.88 | 4.93 | 6.29 | 7.54 | 8.49 | 9.43 | 10.61 | 11.46 | 13.57 | 15.73 | 18.15 | 20.71 |
| 200 | 0.69 | 1.09 | 1.37 | 2.13 | 2.98 | 3.99 | 4.38 | 5.62 | 7.26 | 8.82 | 9.86 | 10.92 | 12.21 | 13.01 | 15.06 | 17.27 | 19.59 | 22.17 |
| 500 | 0.74 | 1.16 | 1.46 | 2.32 | 3.32 | 4.63 | 5.08 | 6.65 | 8.76 | 10.82 | 11.96 | 13.21 | 14.65 | 15.31 | 17.18 | 19.43 | 21.54 | 24.12 |
| 1000 | 0.78 | 1.22 | 1.52 | 2.46 | 3.59 | 5.16 | 5.67 | 7.52 | 10.06 | 12.62 | 13.81 | 15.23 | 16.78 | 17.28 | 18.92 | 21.18 | 23.04 | 25.61 |

** Average Recurrence Interval*

## 9.6 Water Quality

The purpose of this section is to assure compliance with the water quality requirements outlined in Section 3 for stormwater runoff from developed sites. Unlike the approach for volume and rate control, which considers the net change in hydrology resulting from land development, water quality evaluation begins by assuming that the built site will generate pollutants from the new or disturbed surfaces, and that the various BMPs can prevent or remove these pollutants from the resultant runoff. As discussed in Section 2, reduction of NPS pollutants by stormwater management is the primary issue of concern. If CG1 or CG2 are met for volume reduction, then it follows that the first flush of NPS pollutants have passed through one or more BMP and the resultant runoff meets the water quality criteria, except for solutes. There is no consideration of any transport of pollutants that might be generated from the site before development, and the undisturbed portions of the site are to be ignored as sources of NPS pollution.

The use of infiltration measures to meet water quality criteria as well as volume reduction has one potential constraint; solutes, specifically nitrate, cannot be assumed to be sufficiently reduced by infiltration alone. To further complicate the nitrate issue, it has been observed that the concentration of nitrate in runoff remains fairly constant over the entire hydrograph, with some reduction by dilution during the peak flow period. As a solute, this means that the nitrate is dissolved in runoff throughout the rainfall process, and continues to move throughout the entire storm. In effect, the "first flush" of particulate-associated pollutants does not apply, nor does the removal efficiency of the various BMP measures.

The non-structural measures discussed in Section 5 offer very efficient preventive answers to this issue, such as reduced fertilization, vegetative restoration and street sweeping. For the land development projects that apply these various non-structural measures, the overall pollutant load generated should be minimal for both particulates and solutes. If a project has preserved and restored the woodland vegetation on portions of the tract as an integral part of the development program, prevented compaction or restored permeability in disturbed soils, and kept to an absolute minimum the chemical maintenance required for new landscaping elements, the pollutant load generated should be minimal, from a water quality perspective, and should not warrant regulatory control. The determination of how successful a given site design is in meeting water quality compliance with non-structural measures will be guided by the loading data analysis described in this Section. The initial load estimate of NPS pollution generated by the proposed building program will provide insight into the relative impact of different built surfaces on ambient water quality in a watershed.

### 9.6.1 Analysis of Water Quality Impacts from Developed Land

Section 3 proposed criteria for three representative pollutants (Suspended Solids, Total Phosphorus and Nitrate) in terms of percent reduction of the load produced from new sources or surfaces. The specific values proposed for each pollutant are intended to reflect the potential efficiencies of the various BMPs considered, as well as the anticipated reduction required to sustain or restore water quality in receiving waters, although future study may suggest that different drainages may require greater or lesser reductions. The impacts of NPS pollution on surface water quality is well documented, but generally in terms of the receiving water body. A reduction in ambient water quality in many major riverine, lacustrine and estuarine systems has usually been associated with changes in land use within the contributing drainage, and in some cases, specific pollutants have been identified as “key” pollutants. The Lake Erie drainage in the mid-1960’s focused on phosphorus as the critical nutrient leading to trophic changes in the lake, and the resultant water quality strategy reduced this nutrient from both point sources and land runoff. The pattern of lake and estuary eutrophication has been repeated in countless water bodies across the US and throughout the world, and in virtually every drainage, phosphorus is the limiting nutrient.

In the Chesapeake drainage, which is largely provided by runoff from central PA, both phosphorus and nitrate are considered limiting nutrients. These pollutants contribute to diminishing water quality and a loss of both habitat and species by enrichment of the estuary waters. A major initiative has recent been undertaken by watershed states to significantly reduce both nutrients from wastewater effluent at over 350 treatment facilities, a process that will require an investment of hundreds of millions of dollars over the next decade (Chesapeake Bay Tributary Strategy, CEC, 8/12/04). In that program, PA must reduce nitrate by 48.2 million pounds and total phosphorus by 1.98 million pounds annually. Sediment has also played a major part in the reduction in water quality in the Bay, and so a companion effort of reducing nutrients and sediment from the land runoff must be required and included in any Bay recovery program, keeping in mind that the phosphorus is transported with the colloid fraction of sediments.

Thus all three of the selected NPS criteria are appropriate for water quality management of stormwater, in not only this portion of the state drainage, but throughout the state. Again, these pollutants serve as surrogates for a wide range of other pollutants that occur in lesser or trace concentrations which also contribute to degraded water quality. Many of these other pollutants are also solutes, and so the focus on nitrate serves a broader objective.

Table 2-2 summarizes the concentration of representative pollutants, both particulate and solute, that have been measured in the runoff from various built surfaces in a selected group of studies. In the preparation of this BMP Manual, a larger body of literature has been reviewed for comparative data, and is summarized in Appendix A. While this data is derived from numerous sources, the studies referenced were performed on very different sites, and measurement methods varied by investigator. The use of a value that represents the “mean” concentration of a pollutant in runoff is very dependent on the level of detail applied in the development of this data. For the purposes of evaluating the water quality impacts of land development and the benefits of a given BMP in reducing this pollution, the data was expanded to consider variations in land cover type, and is shown in Table 9-3.

It is possible that a proposed development may not conform exactly to the land cover categories shown in this Table. Independent sampling of representative stormwater chemistry from similar sites can be prepared by a developer or other interested party, if desired. It is recommended that any stormwater sampling be compiled by use of automated sampling equipment at flow measurement stations, where the record of chemical variability during runoff incidents can gathered, and that the program is approved by the Department prior to initiation. This new sampling data should allow the integration of hydrographs and chemographs to formulate mass transport loads and develop flow-weighted concentrations for analysis and substitution in lieu of Table 9-3.

In the absence of new sampling data prepared by a developer or other applicant, the values shown in Table 9-3 will be applied to the volume of runoff estimated from new development for completion of Worksheets. The concept of “Event Mean Concentration” was explained in Section 2, and represents the anticipated average concentration of a given pollutant that would be expected to be scoured from a given surface during a storm event of significant magnitude to produce surface runoff. No specific rainfall amount is applied to this term, and the body of data from which it is derived reflects very different hydrologic conditions.

*Table 9-3. Event Mean Concentrations (EMC)*

| | | POLLUTANT | | |
|---|---|---|---|---|
| | **LAND COVER CLASSIFICATION** | **Total Suspended Solids, EMC *(mg/l)*** | **Total Phosphorus, EMC *(mg/l)*** | **Nitrate-Nitrite EMC *(mg/l as N)*** |
| **Pervious Surfaces** | Forest | 39 | 0.15 | 0.17 |
| | Meadow | 47 | 0.19 | 0.3 |
| | Fertilized Planting Area | 55 | 1.34 | 0.73 |
| | Native Planting Area | 55 | 0.40 | 0.33 |
| | Lawn, Low-Input | 180 | 0.40 | 0.44 |
| | Lawn, High-Input | 180 | 2.22 | 1.46 |
| | Golf Course Fairway/Green | 305 | 1.07 | 1.84 |
| | Grassed Athletic Field | 200 | 1.07 | 1.01 |
| **Impervious Surfaces** | Rooftop | 21 | 0.13 | 0.32 |
| | High Traffic Street / Highway | 261 | 0.40 | 0.83 |
| | Medium Traffic Street | 113 | 0.33 | 0.58 |
| | Low Traffic / Residential Street | 86 | 0.36 | 0.47 |
| | Res. Driveway, Play Courts, etc. | 60 | 0.46 | 0.47 |
| | High Traffic Parking Lot | 120 | 0.39 | 0.60 |
| | Low Traffic Parking Lot | 58 | 0.15 | 0.39 |

### 9.6.2 Analysis of Water Quality Benefits from BMPs

Unlike the traditional approach to wastewater, the implementation of stormwater quality criteria is intended to change development practices and land management concepts, rather than to establish a series of treatment or pollutant removal methodologies. As a general rule, the removal of pollutants, both particulate and dissolved, from stormwater is a difficult and inefficient process. Because the rate of flow from a developed site, as well as the concentration of many pollutants, varies greatly during a storm, the use of traditional wastewater "unit operation" technologies is inappropriate. The intermittent nature of runoff also complicates the pollutant removal process. NPS pollution is produced in concentrated "slugs" of runoff, and not contained in a uniform flow that can be applied to a microbial based process in a medium or structure, such as a sewage treatment plant. Finally, the form of NPs pollutant, particulate or solute, determines the potential for removal by any physical BMP.

The BMPs described in detail in Sections 5 and 6 represent a variety of measures that, generally speaking, have not been broadly applied during the past twenty-five years for water quality mitigation on land development projects throughout the state. A number of wet extended detention basins have been built, as a variation on the conventional detention basin, but most of these have not been subject to detailed monitoring that would quantify water quality benefits. Infiltration BMPs have also seen limited application in PA, but again virtually none have had through scientific monitoring measures included in their design. Several dozen porous pavement systems have been built since 1981, largely in the southeast area of the state, but even these systems have had little water quality monitoring data developed, simply because the site owner declined to participate in and support such a program. Other infiltration measures, including trenches, rain gardens and cisterns, have been built on a limited number of sites, but these have also not been designed to provide sample collection from the unsaturated zone or groundwater beneath the BMP. Thus the scientific basis for pollutant removal efficiency is derived from other relevant literature, especially the soil sciences and agriculture.

The most complete record of pollutant removal efficiency for BMPs is based on surface detention basins, as modified to include standing water, vegetation, multiple pond systems and the like. While simple detention structures can provide significant reduction of Suspended Solids, especially the larger particulate fraction, the NPS pollutant removal process is greatly enhanced by these modifications. For the other BMPs, the evaluation process is largely a work in progress. A review of the available literature, included in Appendix A, suggests a range of benefits from BMPs, including their relative efficiency of pollutant reduction, removal or prevention, as summarized in Table 9-4.

The available water quality data demonstrates that the roof areas of structures will not contribute a significant fraction of the total pollutant load, and can generally be ignored, since much of the pollution washed from rooftops is comprised of atmospheric deposition. For "big box" projects this may not necessarily be true because of the relative size and proportion, and the potential loading analysis should guide the designer in this step. The estimate of NPS pollution produced by a built site can be simplified by ignoring rooftop runoff and undisturbed land areas as NPS sources. The analysis effectively limits the contributing surfaces to two major categories; impervious pavements and chemically maintained landscapes. Both of these types of surfaces can vary in their pollutant contribution, as illustrated by Table 9-3. In many if not most new developments, the evaluation and reduction of pollutant impacts will focus on these two types of sources.

All infiltration BMPs shown in Table 9-4 assume the NPS pollutant removal efficiency for both TSS and TP is 85%, although an efficiency of close to 100% is reasonable for all infiltrated runoff. Any runoff greater than the design storms of CG-1 and CG-2 will probably overflow or bypass these

*Table 9-4. Summary of Pollutant Removal Percent Efficiencies of Stormwater BMP,*

| COMPREHENSIVE BMP LIST | | | | |
|---|---|---|---|---|
| | | Pollutant Removal Efficiency % | | |
| | | TSS | TP | $NO_3$ |
| ***Non-Structural BMP*** | | | | |
| 5.1 | Protect Sensitive / Special Value Features | SC | SC | SC |
| 5.2 | Protect / Conserve / Enhance Riparian Areas | SC | SC | SC |
| 5.3 | Protect / Utilize Natural Flow Pathways in Overall Stormwater Planning and Design | 30 | 20 | 0 |
| 5.4 | Cluster Uses at Each Site; Build on the Smallest Area Possible | SC | SC | SC |
| 5.5 | Concentrate Uses Areawide through Smart Growth Practices | SC | SC | SC |
| 5.6 | Minimize Total Disturbed Area - Grading | 40 | 0 | 0 |
| 5.7 | Minimize Soil Compaction in Disturbed Areas | 30 | 0 | 0 |
| 5.8 | Re-vegetate and Re-forest Disturbed Areas using Native Species | 85 | 85 | 50 |
| 5.9 | Reduce Street Imperviousness | SC | SC | SC |
| 5.10 | Reduce Parking Imperviousness | SC | SC | SC |
| 5.11 | Rooftop Disconnection | 30 | 0 | 0 |
| 5.12 | Disconnection from Storm Sewers | 30 | 0 | 0 |
| 5.13 | Streetsweeping | 85 | 85 | 50 |
| ***Structural BMP*** | | | | |
| 6.1 | Porous Pavement with Infiltration Bed | 85 | 85 | 30 |
| 6.2 | Infiltration Basin | 85 | 85 | 30 |
| 6.3 | Subsurface Infiltration Bed | 85 | 85 | 30 |
| 6.4 | Infiltration Trench | 85 | 85 | 30 |
| 6.5 | Rain Garden / Bioretention | 85 | 85 | 30 |
| 6.6 | Dry Well / Seepage Pit | 85 | 85 | 30 |
| 6.7 | Constructed Filter | 85 | 85 | 30 |
| 6.8 | Vegetated Swale | 50 | 50 | 20 |
| 6.9 | Vegetated Filter Strip | 30 | 20 | 10 |
| 6.10 | Infiltration Berm and Retentive Grading | 60 | 50 | 40 |
| 6.11 | Vegetated Roof | 85 | 85 | 30 |
| 6.12 | Rooftop Runoff - Capture and Reuse | 100 | 100 | 100 |
| 6.13 | Constructed Wetland | 85 | 85 | 30 |
| 6.14 | Wet Pond / Retention Basin | 70 | 60 | 30 |
| 6.15 | Dry Extended Detention Basin | 60 | 40 | 20 |
| 6.16 | Water Quality Filter | 60 | 50 | 20 |
| 6.17 | Riparian Buffer Restoration | 65 | 50 | 50 |
| 6.18 | Landscape Restoration | 85 | 85 | 50 |
| 6.19 | Soils Amendment and Restoration | 85 | 85 | 50 |
| 6.20 | Level Spreader | 20 | 10 | 5 |
| 6.21 | Special Detention Areas - Parking Lot, Rooftop | 0 | 0 | 0 |

*SC, Self Crediting: The BMP reduces the pollutant load, thus is self-crediting. BMPs with this designation are labeled as "**Preventive**" in Section 5.*

*** All values shown represent professional interpretation, based on best available data as provided in Appendix A.***

BMPs, and so some NPS load during major storms will discharge to surface waters. The 85% efficiency is reasonable as an overall performance standard of pollutant removal from runoff, and can be revised as and if new data is gathered. For solutes, it will be assumed that the removal efficiency by infiltration is as shown, but this removal may prove to be greater than current studies suggest. For the situation where an infiltration BMP is in close proximity to a potable water supply well, the potential for contamination by solutes must be considered, and additional BMPs applied if the site conditions warrant (groundwater concentration exceeds 10 mg/l).

Compliance with CG1 or CG-2 will require that the site design team initially configure the site plan to optimize runoff capture, ideally with distributed BMPs. If they consist of a single measure or multiple measures distributed across the site, the first question is the amount of total built surface that drains to one or more BMP. This “capture efficiency” of the stormwater management system determines not only hydraulic capacity of any given measure, but also how much of the site is controlled in terms of pollutant containment. It is recognized that most site designs do not allow total capture of all runoff, no matter how flat the parcel may be. Completion of the Worksheets for either CG will result in a design capacity for the selected BMPs, which can usually be aggregated by type for analysis of water quality impacts. That is, multiple small measures such as rain gardens in a residential development can be treated as a single measure in terms of pollutant reduction.

### 9.6.3 Water Quality Analysis

Confirmation that the BMP program has been successful in meeting the water quality criteria assumes that CG-1 or CG-2 have been met, and that at least 90% of the parcel is conveyed or mitigated by a BMP (Flow Chart D). Compliance with the volume criteria assumes that the major portion of particulate pollutants have been removed from runoff by one or more BMP, and so the only additional demonstration required for compliance with water quality criteria is to confirm that one or more of the BMPs that are most effective in solute reduction have been included in the stormwater management program. Worksheet 10 is a simple checklist of those measures, and is divided into two categories, primary and secondary. Without performing a detailed loading analysis, the inclusion of a combination of these measures should provide adequate demonstration that the site design has considered this issue and incorporated the best feasible solution.

Worksheet 11 is intended for those sites where volume reduction cannot be met. This form estimates the total pollutant load produced from all built surfaces, so that the designer can appreciate the relative magnitude of the problem created by the proposed design. Where the site design provides insufficient capture by BMPs, the designer must revisit the overall program and apply additional measures to meet water quality criteria. That is, even if site constraints prevent compliance with CG-1 and CG-2, water quality criteria must still be met.

In many site designs where NPS reduction is a concern, it is usually obvious that the greatest pollutant impact is from two surfaces; impervious pavements and fertilized landscapes. As designers focus attention on the uncontrolled runoff from streets and fertilized landscapes and revisit the water quality impacts, the value of non-structural measures, including street sweeping and the use of native plantings for landscape design, should become apparent.

Worksheets 12 and 13 indicate the uncontrolled load from built surfaces and gives credit for load reduction and source omissions by using the full array of non-structural and structural BMPs. It is likely that if compliance with CG-1 or CG-2 is not feasible, no additional structural measures can be included without major site plan redesign. That option is not excluded, but if non-structural measures can be incorporated, then the answer is simple, and additional structural measures may not be required. The designer can turn to land management measures that can be incorporated in the finished building program without any structural alterations. Clearly, it will require creative design to meet the recommended water quality goals, but it is well within the capabilities of the BMPs described in this Manual.

## 9.7 Guidance for Stormwater Calculations for CG1 and CG2

Stormwater management in Pennsylvania has traditionally focused on flow rate control for large storm events. Stormwater management has traditionally required that there be no increase in the rate of runoff from development as compared to the rate of runoff before development for storm events ranging from the 2-year, 24-hour event to the 100-year, 24-hour event. The *Pennsylvania Stormwater Best Management Practices Manual* is recommending that stormwater management be expanded to include:

- Rate of flow
- Volume of flow
- Groundwater recharge
- Water quality
- Stream channel protection

Control Guideline 1 and Control Guideline 2 provide recommended guidelines to achieve these stormwater management elements.

It should be noted that control of the rate of flow of stormwater runoff remains an important part of stormwater management. This criteria is generally based on larger storm events of limited frequency (i.e., the 1-year through the 100-year storm events).

By contrast, the additional elements of stormwater management – volume, groundwater recharge, water quality, and stream channel protection – are based on the smaller, more frequent storm events. Effective stormwater management includes rate control and the additional elements of volume, groundwater recharge, water quality, and stream channel protection.

Engineers and regulatory officials are familiar with the engineering methods and models used to evaluate the rate of runoff for large storm events. There is general consistency in the calculation methodologies used across the state, with the Cover Complex Method or the Rational Method being the two most common methodologies applied to estimate rate of runoff.

In order to manage stormwater for volume, ground water recharge, quality, and channel protection, additional or expanded analytical methods are needed. The following sections provide guidance on recommended procedures and methodologies to improve stormwater management, and include worksheets and flow charts intended to assist in this process.

### 9.7.1 Stormwater Calculation Process

Flow Chart A (page 9-60) is provided to guide the user in the first step of the stormwater calculation process (*Stormwater Calculation Process Non-structural BMPs*).

- Step 1: Provide General Site information (**Worksheet 1**)

- Step 2: Identify sensitive natural resources, and if applicable, identify which areas will be protected (**Worksheet 2**).

- Step 3: Incorporate Non-structural BMPs into the stormwater design. Quantify the volume benefits of Non-structural BMPs (**Worksheet** 3).

Proceed to either Flow Chart B, Control Guideline 1 or Flow Chart C, Control Guideline 2.

**For Control Guideline 1 (Flow Chart B)**

- Step 4: Estimate the increased volume of runoff for the 2-Year storm event, using the Cover Complex Curve Number method. The use of a weighted curve number is NOT acceptable. Runoff volume should be calculated based on major land use types and soil types (**Worksheet 4**).

- Step 5: Design and incorporate Structural and Non-Structural BMPs that provide volume control for the 2-Year volume increase indicated on Worksheet 4. Provide calculations and documentation to support the volume estimate provided by BMPs. For Non-structural BMPs, provide Non-structural BMP checklists to demonstrate that BMPs are appropriate. Indicate the volume reduction provided by BMPs (**Worksheet 5)**. *Note: if the designer is unable to incorporate the 2-year volume increase after all feasible BMP options have been considered, the designer proceeds to Control Guideline 2.*

- Step 6: Determine if the site is exempt from peak rate calculations (**Worksheet 6**).

- Step 7: If the site is NOT exempt from peak rate calculations, provide detailed routing analysis to demonstrate peak rate control for the 1-year through 100-year storm events. This routing should consider the benefits of BMPs. Provide additional detention capacity if needed.

Proceed to Flow Chart D, Water Quality Calculations

**For Control Guideline 2 (Flow Chart C)**

- Step 4: Estimate Runoff Volume for infiltration (0.5 inches rainfall) and for Volume Control (1.5 inches rainfall) (**Worksheet 7**).

- Step 5: Design and incorporate Structural and Non-Structural BMPs that provide infiltration for the first ½-inch of rainfall, and provide volume control for the next 1-inch of rainfall (**Worksheet 8**). Provide calculations and documentation to support the volume estimate and infiltration estimate provided by BMPs. For Non-structural BMPs, provide Non-structural BMP checklists to demonstrate that BMPs are appropriate. Indicate the volume reduction provided by BMPs on Worksheet 8.

- Step 6: Provide detailed routing analysis to demonstrate peak rate control for the 1-year through 100-year storm events. This routing should consider the benefits of BMPs.

- Step 7: Determine Flow Target requirement for extended detention requirement for channel protection (**Worksheet 9**).

Proceed to Flow Chart D, Water Quality Calculations

### 9.7.2 Water Quality Calculations (Flow Chart D)

- Step 8: Determine if the stormwater management design complies with either Control Guideline 1 or 2 for volume control. If volume compliance is achieved under either of these guidelines, proceed to Step 9. If compliance is not achieved, proceed to Step 11.

- Step 9: Determine if at least 90% of the disturbed site area is controlled by a BMP (maximum disturbed, uncontrolled area of 10%). To be considered "controlled" by a BMP, the disturbed area must either drain to a structural BMP (or series of BMPs) or be off-set by a preventive BMP, such as reduced imperviousness or landscape restoration. If at least 90% of the disturbed area is controlled, proceed to Step 10; else proceed to Step 12.

- Step 10: TSS and TP requirements are considered met. Demonstrate use of specific nitrate prevention/reduction BMPs (**Worksheet 10**). If the required BMPs (2 primary or 4 secondary or 1 primary and 2 secondary) are proposed within the stormwater management plan, then the water quality requirement for nitrate is achieved. If the required BMPs are not proposed, proceed to Step 11.

- Step 11: If neither Control Guideline is met for volume control, demonstrate use of specific BMPs for pollutant prevention (**Worksheet 11**).

- Step 12: Estimate pollutant load from disturbed areas of the site, excluding preventive measures (if proposed). (**Worksheet 12**).

- Step 13: Calculate pollutant load reductions with the proposed structural BMPs (**Worksheet 13**). If target load reductions are achieved for TSS, TP, and nitrate, then the water quality requirements are met.

## 9.8 Non-structural BMP Credits

The use of Non-structural BMPs is an important part of a project's stormwater management system. However, the BMPs must be correctly implemented to be effective. The use of these credits shall be documented at the municipal and NPDES permit level and verified with "as-built" certifications provided to the municipality. *(copied from MD manual*)

For the Non-Structural BMPs applied, use the appropriate checklists to demonstrate that BMPs are applicable to project.

Worksheet 3 determines the amount of Volume credit or Peak Rate credit associated with Non-structural BMPs.

The following BMPs are "self-crediting" in that the use of these BMPs automatically provides a reduction in impervious area and a corresponding reduction in stormwater impacts. Additionally, the use of these BMPs may be regulated by local ordinances. Local governments and reviewing agencies are encouraged to promote the use of these BMPs where feasible:

| | |
|---|---|
| BMP 5.4 | Cluster Uses |
| BMP 5.5 | Concentrate Uses through SmartGrowth |
| BMP 5.9 | Reduce Street Imperviousness |
| BMP 5.10 | Reduce Parking Imperviousness |

The following BMPs provide a quantitative runoff volume reduction:

| | |
|---|---|
| BMP 5.1 | Protect Sensitive/Special Value Features |
| BMP 5.2 | Protect/Conserve/Enhance Riparian Areas |
| BMP 5.3 | Protect/Utilize Natural Flow Pathways |
| BMP 5.6 | Minimize Disturbed Area |
| BMP 5.7 | Minimize Soil Compaction in Disturbed Areas |
| BMP 5.8 | Re-Vegetate and Re-Forest Disturbed Areas |
| BMP 5.11 | Rooftop Disconnection |
| BMP 5.12 | Disconnection from Storm Sewers |

References that support the quantitative BMP volume reduction are provided at the end of this section. **No more than 25% of the Volume Reduction may be met through Non-Structural BMP credits**.

## Criteria and Credits for BMP 5.1 Protect Sensitive/Special Value Features

To receive credit, the proposed areas:

- ☐ Shall include natural areas of floodplains, mapped wetlands, mapped woodlands, and natural slopes over 15% and 25%.
- ☐ May include other areas of significant natural resources that the applicant demonstrates are of special natural value.
- ☐ Shall not be disturbed during project construction (i.e., cleared or graded) except for temporary impacts associated with mitigation and reforestation efforts. Utility disturbance is discouraged and should be kept to a minimum.
- ☐ Shall be protected by having the limits of disturbance clearly shown on all construction drawings and delineated in the field.
- ☐ Shall be located within an acceptable land preservation/protection agreement or other enforceable instrument, such as a deed restriction, that ensures perpetual protection of the proposed areas. The preservation agreement shall clearly specify how the natural area shall be managed and boundaries will be marked with permanent survey markers.
- ☐ Managed turf is not considered an acceptable form of vegetation management.
- ☐ Shall be located on the development project.

### CREDITS

**Volume and Quality**

Protected Area is not to be included in Runoff Volume calculation

*Stormwater Management Area = (Total Area – Protected Area)*

**Peak Rate and Channel Protection**

Runoff from the Protected Area may be excluded from Peak Rate calculations and Channel Protection calculations for rate control, provided that the runoff from the protected area is not conveyed to and/or through stormwater management control structures. If necessary, runoff from Protected Areas should be directed around BMPs and stormwater pipes and inlets by means of vegetated swales or low berms that direct flow to natural drainageways.

## Criteria and Credits for BMP 5.2 Protect/Conserve/Enhance Riparian Areas

To receive credit, the Riparian Buffer Protection areas:

- ☐ Shall include a minimum width of 25 feet from each streambank for Zone 1. Smaller widths do not receive credit.
- ☐ Shall include a minimum width of 75 feet from each streambank for Zone 2. Smaller widths do not receive credit.
- ☐ Shall not be disturbed during project construction (i.e., cleared or graded) except for temporary impacts associated with mitigation and afforestation efforts. Utility disturbance is discouraged and should be kept to a minimum.
- ☐ Areas disturbed for stream crossings (temporary or permanent) do not receive credit.
- ☐ Shall be protected by having the limits of disturbance clearly shown on all construction drawings and delineated in the field.
- ☐ Shall be located within an acceptable land preservation/protection agreement or other enforceable instrument, such as a deed restriction, that ensures perpetual protection of the proposed areas. The preservation agreement shall clearly specify how the Riparian Buffer shall be managed and boundaries will be marked with permanent survey markers.
- ☐ Managed turf is not considered an acceptable form of vegetation management within Zone 1 or Zone 2.
- ☐ Zone 1 shall not be subject to point discharges for the entire length of Zone 1. Zone 2 shall not be subject to point discharges unless the use of a level spreader or similar device is implemented.
- ☐ Shall be located on the development project.
- ☐ Forested Buffers are encouraged. See BMP 3.3 for Tree Planting Credit.

**CREDITS**

**Volume and Quality**

Protected Area in Zone 1 and/or Zone 2 is not to be included in Runoff Volume calculation or Water Quality volume

Mitigation Area = (Total Area – Protected Area)

**Peak Rate and Channel Protection**

Runoff from the Protected Area may be excluded from Peak Rate calculations and Channel Protection calculations for rate control, provided that the runoff from the protected area is not conveyed to and/or through stormwater management control structures. If necessary, runoff from Protected Areas should be directed around BMPs and stormwater pipes and inlets by means of vegetated swales or low berms that direct flow to natural drainageways.

## Criteria and Credits for BMP 5.3 Protect/Utilize Natural Flow Pathways in Overall Stormwater Planning and Design

To receive credit, the proposed natural Drainage Features:

- ☐ Shall include natural swales and drainage pathways that existed prior to development and that will receive runoff from developed areas, including intermittent drainage areas and intermittent wetland depressions. Manmade drainage features are not included.
- ☐ May use check dams, low berms, native vegetation, and limited grading to improve natural drainage features.
- ☐ Shall be designed to receive runoff such that flows after development are non-erosive. Care must be taken to maintain the non-erosive conditions and natural systems should not be overloaded.
- ☐ Shall be protected from compaction or unintended disturbance during construction by having the limits of disturbance clearly shown on all construction drawings and delineated in the field.
- ☐ Shall be noted on stormwater management plans as part of stormwater management system and included in any municipal easement requirements for stormwater systems. Such areas shall be noted on parcel deeds and protected from future encroachment or disturbance by deed restrictions.
- ☐ Shall be located on the development project.
- ☐ May not include perennial streams.
- ☐ Does not include Constructed Vegetated Swales and Vegetated Filter Strips

### CREDITS

#### Volume and Quality

A Volume Reduction may be credited based upon the area of the Natural Drainage Feature that is vegetated.

Volume Reduction ($ft^3$) = Area x ¼-inch runoff
= Vegetated Area of Natural Drainage Feature ($ft^2$) x ¼” / 12

*Note: A greater volume credit may be requested by the applicant if calculations support a greater numerical value to Minimizing Soil Compaction*.

#### Peak Rate and Channel Protection

The Peak Rate is reduced by a longer travel time of runoff through Natural Drainage Features. The Time of Travel (Tt) after development may be considered the same as the Tt before development for flows through Natural Drainage Features.
When calculating flow rates:

$$Tt_{BEFORE} = Tt_{AFTER}$$

## Criteria and Credits for BMP 5.6 Minimize Total Disturbed Area - Grading

To receive credit, areas of Minimized Disturbance/Grading must meet the following criteria:

- ☐ Area shall not be subject to grading or movement of existing soils.
- ☐ Existing native vegetation in a healthy condition may not be removed.
- ☐ Invasive non-native vegetation may be removed.
- ☐ Pruning or other required maintenance of vegetation is permitted. Additional planting is permitted.
- ☐ Area shall be protected by having the limits of disturbance clearly shown on all construction drawings and delineated in the field.
- ☐ The area not subject to grading shall be clearly delineated on the Stormwater Management Plan. If future grading or disturbance of this area occurs, subsequent stormwater management must be provided to address disturbance.
- ☐ Shall be located on the development project.

### CREDITS

#### Volume and Quality

Protected Area is not to be included in Runoff Volume calculation or Water Quality volume

Mitigation Area = (Total Area – Protected Area)

#### Peak Rate and Channel Protection

Runoff from the Protected Area (area not subject to grading) may be excluded from Peak Rate calculations and Channel Protection calculations for rate control, provided that the runoff from the protected area is not conveyed to and/or through stormwater management control structures. If necessary, runoff from Protected Areas should be directed around BMPs and stormwater pipes and inlets by means of vegetated swales or low berms that direct flow to natural drainageways.

## Criteria and Credits for BMP 5.7 Minimize Soil Compaction in Disturbed Areas

To receive credit, areas of Minimal Soil Compaction must meet the following criteria:

- ☐ Area shall NOT be stripped of existing topsoil.
- ☐ Area shall not be subject to excessive equipment movement. Vehicles movement, storage, or equipment/material laydown shall not be permitted in areas of Minimized Disturbance/ Grading.
- ☐ The area shall be protected by having the limits of disturbance and access clearly shown on the Stormwater Management Plan, all construction drawings and delineated in the field.
- ☐ The use of soil amendments and additional topsoil is permitted. Light grading may be done with tracked vehicles that prevent compaction.
- ☐ Lawn and turf grass are acceptable uses. Planted Meadow is an encouraged use.
- ☐ Area shall be located on the development project.

### CREDITS

**Volume and Quality**

A Volume Reduction may be credited based upon the area of Minimal Soil Compaction.

For Lawn Areas:
Volume Reduction ($ft^3$) = Area of Min. Soil Compaction ($ft^2$) x ¼" / 12

*For Meadow Areas*:
Volume Reduction ($ft^3$) = Area of Min. Soil Compaction ($ft^2$) x 1/3" / 12

Note: A greater volume credit may be requested by the applicant if calculations support a greater numerical value to Minimizing Soil Compaction.

**Peak Rate and Channel Protection**

The Peak Rate for flood protection and channel protection will be reduced by the reduction in runoff volume provided above.

## Criteria and Credits for BMP 5.8 Re-Vegetate and Re-Forest Disturbed Areas, Using Native Species

This BMP includes both Protection of Existing Trees and Re-forestation:

### Part 1 Protect Existing Trees

To receive credit for protecting existing trees **NOT** located within Sensitive/Special Value areas, the following criteria must be met:

- ☐ Trees shall be protected by having the limits of disturbance clearly shown on all construction drawings and delineated in the field.
- ☐ Protection during construction shall entail minimizing disruption of the root system; construction shall not encroach within a space measured 10 feet outside of the drip line to the tree trunk.
- ☐ Trees credited for stormwater management shall be clearly labeled on the construction drawings and recorded on Record Plan for project.
- ☐ Trees shall be maintained and protected for the life of the project (50 years) or until redevelopment occurs.
- ☐ No more than 25% of the runoff volume can be mitigated through the use of trees.
- ☐ Pruning or other required maintenance of existing vegetation is permitted for safety purposed only, unless near a building.
- ☐ Escrow shall be provided for the replacement of any protected trees used for stormwater credit that die within 5 years of construction. Dead trees shall be replaced within 6 months.
- ☐ Shall be located on the development project.
- ☐ Existing tree canopy must be within 100 feet of impervious surfaces to gain credit.
- ☐ Only applies for trees outside Sensitive/Special Value areas
- ☐ Applies to existing trees of 4-inch caliper or larger. Non-native species are not applicable.

**CREDITS**
**Volume and Quality**
A Volume Reduction may be credited based upon the existing tree canopy.

*For Trees within 20 feet of impervious cover:*
Volume Reduction ($ft^3$) = Existing Tree Canopy ($ft^2$) x 1” / 12

*For Trees within 20 to 100 feet of impervious cover*:
Volume Reduction ($ft^3$) = Existing Tree Canopy ($ft^2$) x 1/2” / 12

**Peak Rate and Channel Protection**
The Peak Rate for flood protection and channel protection will be reduced by the reduction in runoff volume provided above.

**Part 2 Revegetate and Reforest**

To receive credit for planting trees, the following criteria must be met:

- ☐ Trees must be native species (see Appendix), minimum 2" caliper. Minimum tree height is 6 feet.
- ☐ Trees shall be adequately protected during construction.
- ☐ Trees credited for stormwater management shall be clearly labeled on the construction drawings and recorded on Record Plan for project.
- ☐ Trees shall be maintained and protected for the life of the project (50 years) or until redevelopment occurs.
- ☐ No more than 25% of the runoff volume can be mitigated through the use of trees.
- ☐ Escrow shall be provided for the replacement of any protected trees used for stormwater credit that die within 5 years of construction. Dead trees shall be replaced within 6 months.
- ☐ Shall be located on the development project.
- ☐ May be applied for trees required under Street Tree or Landscaping requirements.
- ☐ May be applied for trees planted as part of Riparian Buffer improvement.
- ☐ Non-native species are not applicable.

**CREDITS**
**Volume and Quality**

A Volume Reduction may be credited based upon the existing tree canopy.

*For Deciduous Trees:*
Volume Reduction ($ft^3$) = 6 $ft^3$

*For EvergreenTrees:*
Volume Reduction ($ft^3$) = 10 $ft^3$

**Peak Rate and Channel Protection**

The Peak Rate for flood protection and channel protection will be reduced by the reduction in runoff volume provided above.

## Criteria and Credits for BMP 5.11 Rooftop Disconnection

To receive credit, Rooftop Disconnection Areas must meet the following criteria:

- ☐ Roof leaders are directed to a pervious area where runoff can either infiltrate into the soil or filter over it.
- ☐ Shall be located on the development project.
- ☐ The use of soil amendments and additional topsoil is permitted.
- ☐ Lawn and turf grass are acceptable uses. Planted Meadow is an encouraged use.
- ☐ Shall be noted on stormwater management plans as part of stormwater management system and included in any municipal easement requirements for stormwater systems.
- ☐ Rooftop cannot be within a designated hotspot.
- ☐ Disconnection shall not cause basement seepage.
- ☐ The contributing rooftop area to each disconnection point shall be 500 sf or less. For greater areas, see BMP 6.20 Level Spreader.
- ☐ The length of the disconnection shall be 75 feet or greater.
- ☐ Dry wells, french drains, recharge gardens, infiltration trenches/beds, or other similar storage devices may be utilized to compensate for areas with disconnection lengths less than 75 feet. (Do not credit BMP 5.11)
- ☐ In residential development applications, disconnections will only be credited for lot sizes greater than 6000 sf.
- ☐ The entire vegetated "disconnection" area shall have a maximum slope of 5%.
- ☐ The disconnection must drain continuously through a vegetated swale or filter strip to the property line or BMP.
- ☐ Roof downspouts shall be at least 10 feet away from the nearest impervious surface to discourage "re-connections"
- ☐ For rooftops draining directly to a buffer, only the rooftop disconnection credit of the buffer credit may be used, not both.

**CREDITS**

**Volume and Quality**

Volume Reduction ($ft^3$) = Contributing Rooftop Area ($ft^2$) x 1/4" / 12

*Note: A greater volume credit may be requested by the applicant if calculations support a greater numerical value to Minimizing Soil Compaction.*

**Peak Rate and Channel Protection**

The Peak Rate for flood protection and channel protection will be reduced by the reduction in runoff volume provided above.

## Criteria and Credits for BMP 5.12 Disconnection from Storm Sewers

To receive credit, the following must be met:

- ☐ Runoff from the non-rooftop impervious cover shall be directed to pervious areas where it is infiltrated into the soil.
- ☐ May include Vegetated Swales as outlined in BMP 6.8.
- ☐ May include check dams, low berms, native vegetation, and limited grading to improve natural drainage features.
- ☐ Shall be designed such that flows after development are non-erosive.
- ☐ Shall be protected from compaction or unintended disturbance during construction by having the limits of disturbance clearly shown on all construction drawings and delineated in the field.
- ☐ Shall be noted on stormwater management plans as part of stormwater management system and included in any municipal easement requirements for stormwater systems.
- ☐ Shall be located on the development project.
- ☐ Runoff cannot originate from a designated hotspot.
- ☐ The maximum contributing impervious flow path length shall be 75 feet.
- ☐ The disconnection shall drain continuously through a vegetated swale or filter strip, or planted area to the property line or BMP.
- ☐ The length of the disconnection area must be at the least the length of the contributing area.
- ☐ The entire vegetated "disconnection" area shall have a maximum slope of 5%.
- ☐ The contributing impervious area to any one discharge point shall not exceed 1000 $ft^2$.
- ☐ Disconnections are encouraged on relatively well-draining soils (HSG A & B).
- ☐ If the site cannot meet the required disconnect length, a level-spreading device, recharge garden, infiltration trench, or other storage device may be needed for compensation.

**CREDITS**

**Volume and Quality**

Volume Reduction ($ft^3$) = Contributing Rooftop Area ($ft^2$) x 1/4" / 12

*Note: A greater volume credit may be requested by the applicant if calculations support a greater numerical value to Minimizing Soil Compaction.*

**Peak Rate and Channel Protection**

The Peak Rate for flood protection and channel protection will be reduced by the reduction in runoff volume provided above.

**Supporting Documentation**

**Natural Drainage Swales (BMP 5.3)**

"Headwater streams and wetlands have a particularly important role to play in recharge. These smallest upstream components of a river network have the largest surface area of soil in contact with available water, thereby providing the greatest opportunity for recharge of groundwater. Moreover, water level in headwater streams is often higher than the water table, allowing water to flow through the channel bed and banks into soil and groundwater. Such situations occur when water levels are high, such as during spring snowmelt or rainy seasons."

"Headwaters can be intermittent streams that flow briefly when snow melts or after rain, but shrink in dry times to become individual pools filled with water…wetlands are depressions in the ground that hold water whether from rainwater, snowmelt, or groundwater welling up to the surface."

The scientific Imperative for Defending Small streams and Wetlands" Judy L. Meyer, PhD, et al, American Rivers, September 2003

**Trees (BMP 5.8)**

"Besides taking in carbon dioxide and putting out oxygen, trees have an enormous impact on temperature. As much as 90 percent of the solar energy is absorbed. Trees also cool by transpiration, the evaporation of water from their leaves. A medium sized tree can move more than 500 gallons of water into the air on a hot day, thereby reducing air temperature."

The Natural Habitat Garden by Ken Druse with Margaret Roach, Timber Press 2004.

500 gal = 66.8 cf

**Volume Credits (BMPs 5.3, 5.7, 5.11, 5.12)**

Protect natural drainageways, avoiding compaction, and disconnecting impervious areas all contribute to a reduction in the volume of runoff and the rate of runoff. The amount of reduction will vary depending on the site-specific conditions, including soil type, cover, etc. The designer may request additional volume credit by providing supporting calculations. The following table compares the difference in runoff volume for protected versus disturbed area for three storm events (1.5-inch, 2.7-inch, and 3.3-inch) for different soil types using the Cover Complex Method.

***For 1.5" Rainfall***

| | **A soil** | **B soil** | **C soil** | **D soil** |
|---|---|---|---|---|
| **Runoff Before** | 0 | 0.00 | 0.10 | 0.23 |
| **Runoff After** | 0.00 | 0.07 | 0.26 | 0.41 |
| **Difference** | ***0.00*** | ***0.07*** | ***0.16*** | ***0.18*** |

***For 2.7" Rainfall***

| | **A soil** | **B soil** | **C soil** | **D soil** |
|---|---|---|---|---|
| **Runoff Before** | 0 | 0 | 0.59 | 0.92 |
| **Runoff After** | 0.03 | 0.52 | 0.97 | 1.27 |
| **Difference** | ***0.03*** | ***0.52*** | ***0.38*** | ***0.35*** |

***For 3.3" Rainfall***

| | **A soil** | **B soil** | **C soil** | **D soil** |
|---|---|---|---|---|
| **Runoff Before** | 0 | 0.38 | 0.94 | 1.35 |
| **Runoff After** | 0.13 | 0.84 | 1.41 | 1.77 |
| **Difference** | ***0.13*** | ***0.46*** | ***0.47*** | ***0.42*** |

# FLOW CHART A
# Stormwater Calculation Process

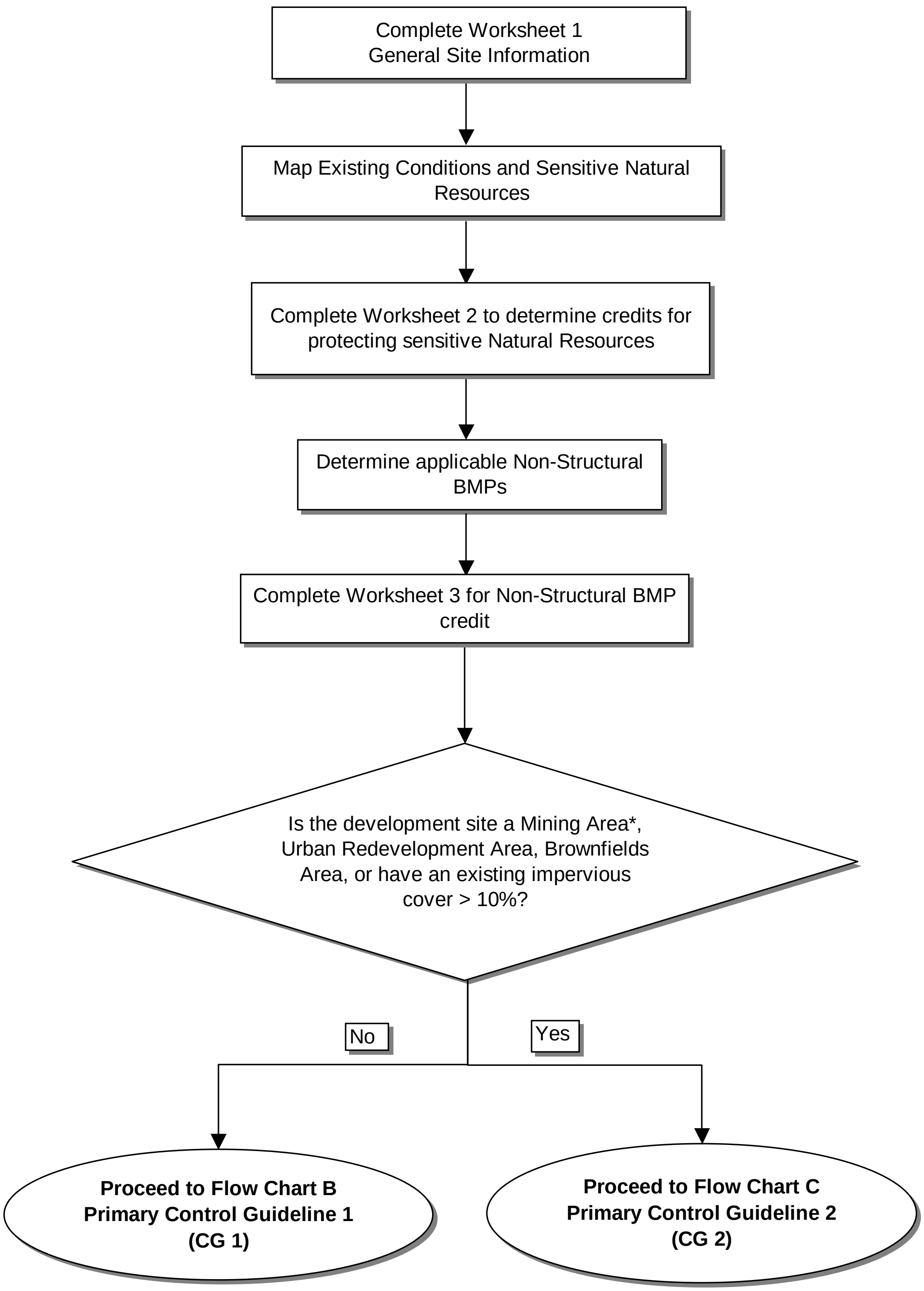



*Figure 9-1. Stormwater Calculation Process*

## Worksheet 1. General Site Information

**INSTRUCTIONS: Fill out Worksheet 1 for each watershed**

**Date:** ______________________________

**Project Name:** ______________________________

**Municipality:** ______________________________

**County:** ______________________________

**Total Area (acres):** ______________________________

**Major River Basin:** ______________________________

http://www.dep.state.pa.us/dep/deputate/watermgt/wc/default.htm#newtopics

**Watershed:** ______________________________

**Sub-Basin:** ______________________________

**Nearest Surface Water(s) to Receive Runoff:** ____________________

**Chapter 93 - Designated Water Use:** ____________________

http://www.pacode.com/secure/data/025/chapter93/chap93toc.html

**Impaired according to Chapter 303(d) List?** Yes ☐ No ☐

http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/303d-Report.htm

**List Causes of Impairment:**

***Is project subject to, or part of:***

**Municipal Separate Storm Sewer System (MS4) Requirements?** Yes ☐ No ☐

http://www.dep.state.pa.us/dep/deputate/watermgt/wc/Subjects/StormwaterManagement/GeneralPermits/default.htm

**Existing or planned drinking water supply?** Yes ☐ No ☐

**If yes, distance from proposed discharge (miles):** ____________

**Approved Act 167 Plan?** Yes ☐ No ☐

http://www.dep.state.pa.us/dep/deputate/watermgt/wc/Subjects/StormwaterManagement/Approved_1.html

**Existing River Conservation Plan?** Yes ☐ No ☐

http://www.dcnr.state.pa.us/brc/rivers/riversconservation/planningprojects/

## Worksheet 2. Sensitive Natural Resources

**INSTRUCTIONS:**

1. Provide Sensitive Resources Map according to non-structural BMP 1.1 in Section 5.0 Non-Structural BMPs. This map should identify waterbodies, floodplains, riparian areas, wetlands, woodlands, natural drainage ways, steep slopes, and other sensitive natural features.

2. Summarize the existing extent of each sensitive resource in the Existing Sensitive Resources Table (below, using Acres).

3. Summarize Total Protected Area as defined under BMPs in Section 5.0.

4. Do not count any area twice. For example, an area that is both a floodplain and a wetland may only be considered once.

| EXISTING NATURAL SENSITIVE RESOURCE | MAPPED? yes/no/n/a | TOTAL AREA (Ac.) | PROTECTED AREA (Ac.) |
|---|---|---|---|
| Waterbodies | | | |
| Floodplains | | | |
| Riparian Areas | | | |
| Wetlands | | | |
| Woodlands | | | |
| Natural Drainage Ways | | | |
| Steep Slopes, 15% - 25% | | | |
| Steep Slopes, over 25% | | | |
| Other: | | | |
| Other: | | | |
| **TOTAL EXISTING:** | | | |

## Worksheet 3. Nonstructural BMP Credits

### PROTECTED AREA

| | | |
|---|---|---|
| **5.1 Area of Protected Sensitive/Special Value Features (see WS 2)** | ______ | **Ac.** |
| **5.2 Area of Riparian Forest Buffer Protection** | ______ | **Ac.** |
| **5.6 Area of Minimum Disturbance/Reduced Grading** | ______ | **Ac.** |
| **TOTAL** | ______ | **Ac.** |

| Site Area | *minus* | Protected Area | = | Stormwater Management Area |
|---|---|---|---|---|
| | - | | = | |

*This is the area that requires stormwater management*

### VOLUME CREDITS

**5.3 Protect/Utilize Natural Flow Paths**

| | | | | | | |
|---|---|---|---|---|---|---|
| Flow Path/Depression | ______ ft² | x 1/4" | x 1/12 | = | ______ | **ft³** |

**5.7 Minimum Soil Compaction**

| | | | | | | |
|---|---|---|---|---|---|---|
| Lawn | ______ ft² | x 1/4" | x 1/12 | = | ______ | **ft³** |
| Meadow | ______ ft² | x 1/3" | x 1/12 | = | ______ | **ft³** |

**5.8 Protect Existing Trees**

*For Trees within 100 feet of impervious area:*

| | | | | | | |
|---|---|---|---|---|---|---|
| Tree Canopy | ______ ft² | x 1/2" | x 1/12 | = | ______ | **ft³** |

*For Trees within 20 feet of impervious area:*

| | | | | | | |
|---|---|---|---|---|---|---|
| Tree Canopy | ______ ft² | x 1" | x 1/12 | = | ______ | **ft³** |

**5.11 Disconnect Roof Leaders to Vegetated Areas**

*For Runoff directed to areas protected under 3.1 and 3.2*

| | | | | | | |
|---|---|---|---|---|---|---|
| Roof Area | ______ ft² | x 1/3" | x 1/12 | = | ______ | **ft³** |

*For all other disconnected roof areas*

| | | | | | | |
|---|---|---|---|---|---|---|
| Roof Area | ______ ft² | x 1/4" | x 1/12 | = | ______ | **ft³** |

**5.12 Disconnect Non-Roof impervious to Vegetated Areas**

*For Runoff directed to areas protected under 3.1 and 3.2*

| | | | | | | |
|---|---|---|---|---|---|---|
| Impervious Area | ______ ft² | x 1/3" | x 1/12 | = | ______ | **ft³** |

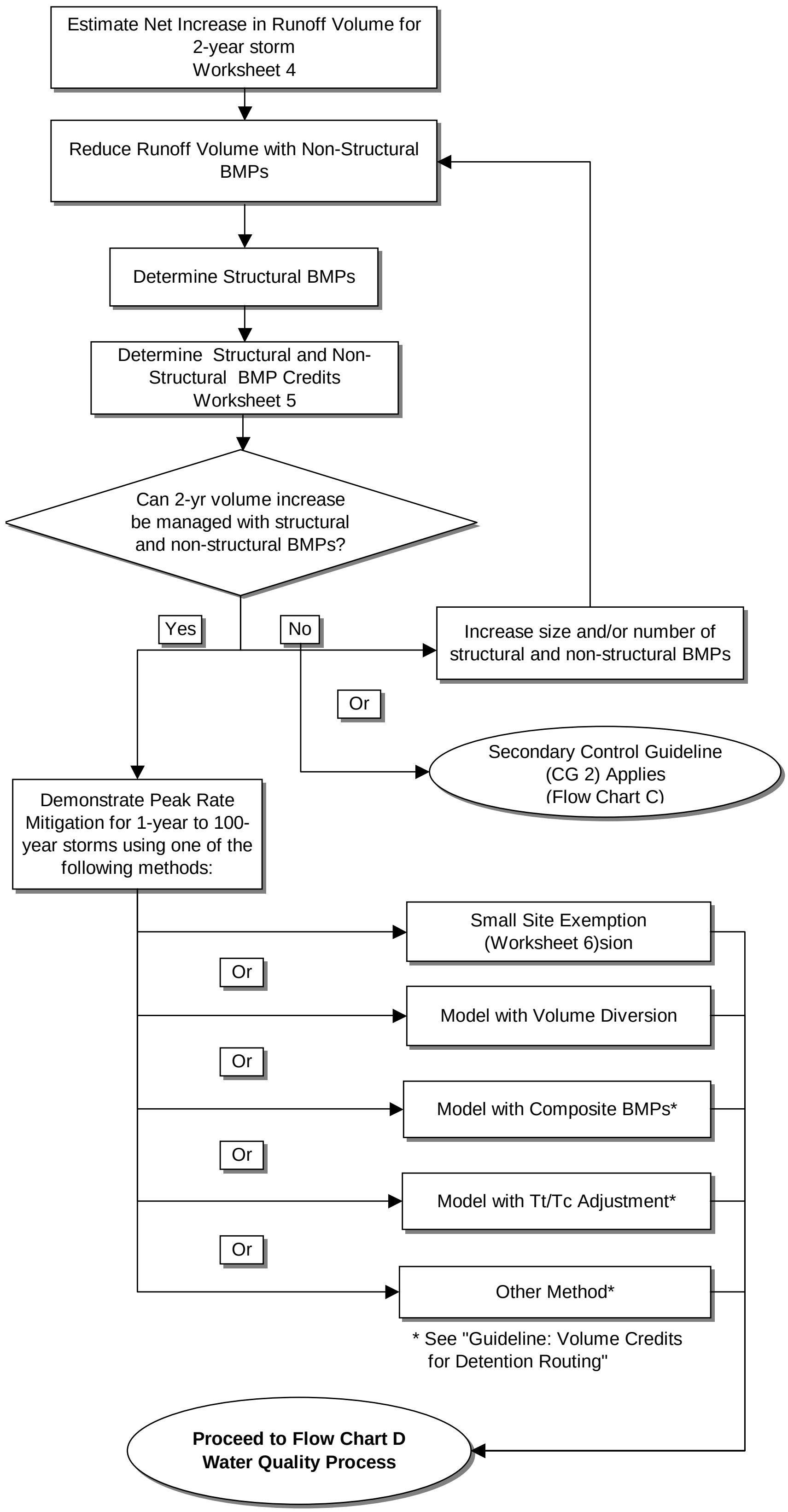
*For all other disconnected roof areas*

| | | | | | | |
|---|---|---|---|---|---|---|
| Impervious Area | ______ ft² | x 1/4" | x 1/12 | = | ______ | **ft³** |

**TOTAL NON-STRUCTURAL VOLUME CREDIT*** ______ **ft³**

** For use on Worksheet 5*

# FLOW CHART B
# Control Guideline 1 Process



## WORKSHEET 4 . CHANGE IN RUNOFF VOLUME FOR 2-YR STORM EVENT

**PROJECT:** ____________________
**DA:** ____________________
**2-Year Rainfall:** ________ **in**

**Total Site Area:** ________ **acres**
**Protected Site Area:** ________ **acres**
**Managed Area** ________ **acres**

**Existing Conditions:**

| Cover Type | Soil Type | Area (sf) | Area (ac) | CN | S | Ia | Q Runoff[1] (in) | Runoff Volume[2] ($ft^3$) |
|---|---|---|---|---|---|---|---|---|
| Woodland | | | | | | | | |
| Meadow | | | | | | | | |
| Impervious | | | | | | | | |
| **TOTAL:** | | | | | | | | |

**Developed Conditions:**

| Cover Type | Soil Type | Area (sf) | Area (ac) | CN | S | Ia | Q Runoff[1] (in) | Runoff Volume[2] ($ft^3$) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| **TOTAL:** | | | | | | | | |

| **2-Year Volume Increase (ft3):** |
|---|

**2-Year Volume Increase = Developed Conditions Runoff Volume - Existing Conditions Runoff Volume**

1. Runoff (in) = Q = $(P - 0.2S)^2 / (P + 0.8S)$ where

P = 2-Year Rainfall (in)

S = 1000/ CN

2. Runoff Volume (CF) = Q x Area x 1/12

Q = Runoff (in)

Area = Land use area (in)

**Note: Runoff Volume must be calculated for EACH land use type and soil.**
**The use of a weighted CN value for volume calculations is not acceptable.**

# WORKSHEET 5 . STRUCTURAL BMP VOLUME CREDITS

**PROJECT:** ______________________________

**SUB-BASIN:** ______________________________

**Required Control Volume ($ft^3$) - *from Worksheet 4*:** ____________

**Non-structural Volume Credit ($ft^3$) - *from Worksheet 3*:** - ____________

**Structural Volume Reqmt ($ft^3$)** ____________

***(Required Control Volume minus Non-structural Credit)***

| Proposed BMP* | | Area ($ft^2$) | Storage Volume ($ft^3$) |
|---|---|---|---|
| 6.1 | Porous Pavement w. Infiltration Bed | | |
| 6.2 | Infiltration Basin | | |
| 6.3 | Subsurface Infiltration Bed | | |
| 6.4 | Infiltration Trench | | |
| 6.5 | Rain Garden/Bioretention | | |
| 6.6 | Dry Well / Seepage Pit | | |
| 6.7 | Constructed Filter | | |
| 6.8 | Vegetated Swale | | |
| 6.9 | Vegetated Filter Strip | | |
| 6.10 | Infiltration Berm & Retentive Grading | | |
| 6.11 | Vegetated Roof | | |
| 6.12 | Capture and Re-use | | |
| 6.13 | Constructed Wetlands | | |
| 6.14 | Wet Pond / Retention Basin | | |
| 6.15 | Dry Extended Detention Basin | | |
| 6.16 | Water Quality Filters | | |
| 6.17 | Riparian Buffer Restoration | | |
| 6.18 | Landscape Restoration | | |
| 6.19 | Soil Amendment & Restoration | | |
| 6.20 | Level Spreader | | |
| 6.21 | Special Storage Areas | | |
| | | | |

**Total Structural Volume ($ft^3$):** ____________

**Structural Volume Requirement ($ft^3$):** ____________

**DIFFERENCE** ____________

* Complete BMP Design Checklist each measure proposed

# WORKSHEET 6 . SMALL SITE / SMALL IMPERVIOUS AREA EXCEPTION FOR PEAK RATE MITIGATION CALCULATIONS

***The following conditions must be met for exemption from peak rate analysis for small sites under CG-1:***

______ The 2-Year Runoff Volume increase must be met in BMPs designed in accordance with Manual Standards

______ Total Site Impervious Area may not exceed **1 acre.**

______ Maximum Development Area is **10 acres**.

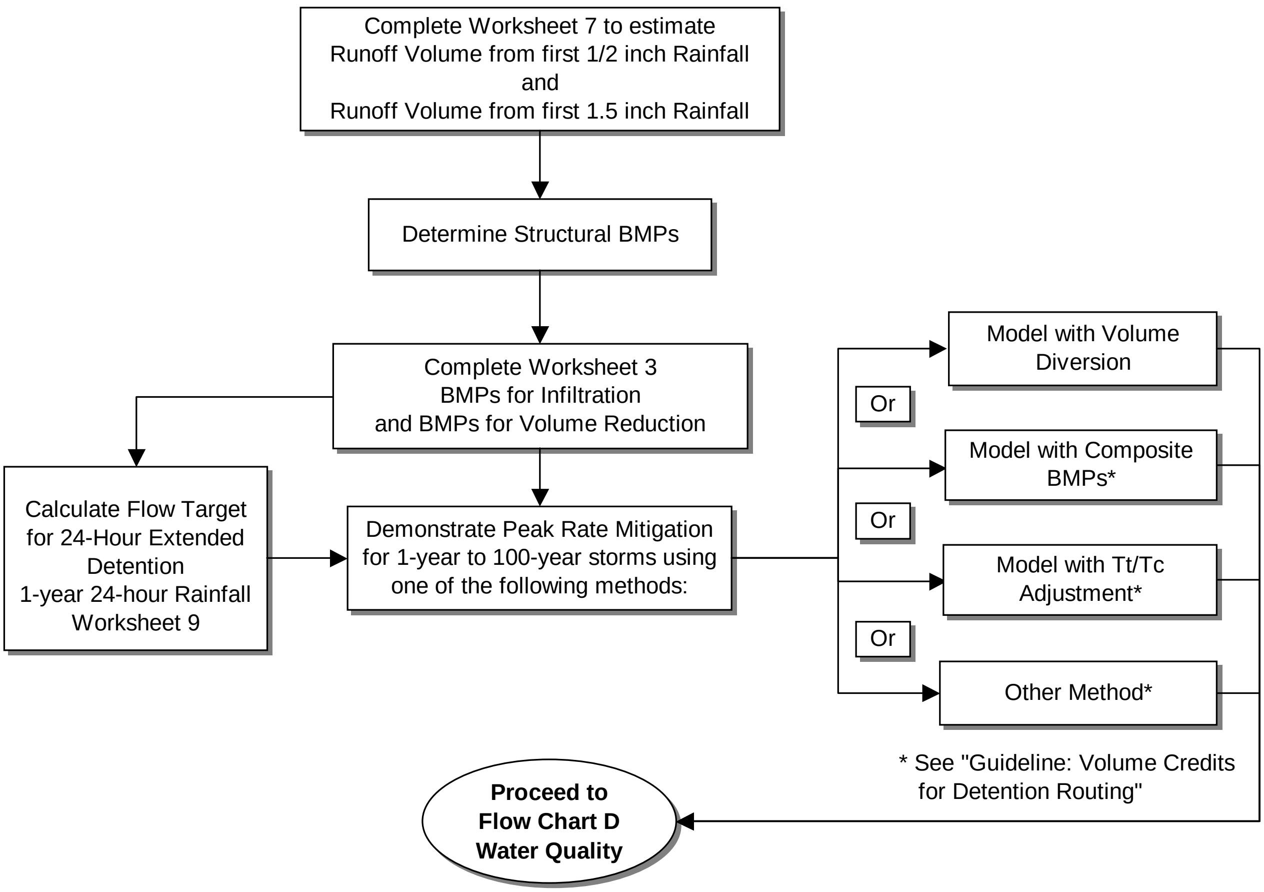
______ Maximum site impervious cover is 50%.

______ No more than 25% Volume Control can be in Non-structural BMPs

______ Infiltration BMPs must have an infiltration rate of 0.5 in/hr.

| Site Area | Percent Impervious | Total Impervious |
|---|---|---|
| 10 acre | 10% | 1 acre |
| 5 acre | 20% | 1 acre |
| 2 acre | 50% | 1 acre |
| 1 acre | 50% | 0.5 acre |
| 0.5 acre | 50% | 0.25 acre |

# FLOW CHART C
# Control Guideline 2 Process



## WORKSHEET 7 . CHANGE IN RUNOFF VOLUME FOR 2-YR STORM EVENT

**PROJECT:** ____________
**DA:**

**Total Site Area:** ________ **acres**
**Protected Site Area:** ________ **acres**
**Managed Area** ________ **acres**

**0.5 Inch Rainfall - Multiply impervious area by 0.5 inch**

| Cover Type | Area (sf) | Area (ac) | Runoff Volume[1] ($ft^3$) |
|---|---|---|---|
| Roof | | | |
| Pavement | | | |
| Other Impervious | | | |
| **TOTAL:** | | | |

**1.5 Inch Rainfall -**

| Cover Type | Soil Type | Area (sf) | Area (ac) | CN | S | Ia | Q Runoff[2] (in) | Runoff Volume[3] ($ft^3$) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| **TOTAL:** | | | | | | | | |

1. Runoff Volume ($ft^3$) = Impervious Area ($ft^2$) x 0.5 inch x 1/12

2. Runoff (in) = Q = $(P - 0.2S)^2 / (P + 0.8S)$ where

P = 2-Year Rainfall (in)

S = 1000/ CN

3. Runoff Volume (CF) = Q x Area x 1/12

Q = Runoff (in)

Area = Land use area (in)

**Note: Runoff Volume must be calculated for EACH land use type and soil.**
**The use of a weighted CN value for volume calculations is not acceptable.**

# WORKSHEET 8 . STRUCTURAL BMP VOLUME CREDITS

**PROJECT:** ______________________________

**SUB-BASIN:** ______________________________

**Required Control Volume ($ft^3$) - *from Worksheet 7*:** ______________

**Non-structural Volume Credit ($ft^3$) - *from Worksheet 3*:** - ______________

**Structural Volume Reqmt ($ft^3$)** ______________

***(Required Control Volume minus Non-structural Credit)***

| Proposed BMP* | | Area ($ft^2$) | Storage Volume ($ft^3$) |
|---|---|---|---|
| 6.1 | Porous Pavement w/ infiltration Bed | | |
| 6.2 | Infiltration Basin | | |
| 6.3 | Subsurface Infiltration Bed | | |
| 6.4 | Infiltration Trench | | |
| 6.5 | Rain Garden/Bioretention | | |
| 6.6 | Dry Well / Seepage Pit | | |
| 6.7 | Constructed Filter | | |
| 6.8 | Vegetated Swale | | |
| 6.9 | Vegetated Filter Strip | | |
| 6.10 | Infiltration Berm | | |
| 6.11 | Vegetated Roof | | |
| 6.12 | Capture and Re-use | | |
| 6.13 | Constructed Wetlands | | |
| 6.14 | Wet Pond / Retention Basin | | |
| 6.15 | Dry Extended Detention Basin | | |
| 6.16 | Water Quality Filters | | |
| 6.17 | Riparian Buffer Restoration | | |
| 6.18 | Landscape Restoration | | |
| 6.19 | Soil Amendment & Restoration | | |
| 6.20 | Level Spreader | | |
| 6.21 | Special Storage Areas | | |
| | | | |

**Total Structural Volume ($ft^3$):** ______________

**Structural Volume Requirement ($ft^3$):** ______________

**DIFFERENCE** ______________

* Complete BMP Design Checklist each measure proposed

# WORKSHEET 9 . FLOW TARGET FOR 24-HOUR EXTENDED DETENTION (CG-2 ONLY)

**PROJECT:** ______________________

**Drainage Area:** ______________________

**1-year, 24-hour Rainfall (in.):** [ ]

**Site Area (ac.):** [ ]

**Post-Development Runoff from 1-year, 24-hour Rainfall:**

| Cover Type | Soil Type | Area (sf) | Area (ac) | CN | S | Ia | Runoff (in) | Runoff (CF) |
|---|---|---|---|---|---|---|---|---|
| Impervious | | | | | | | | |
| Vegetated Open Space | | | | | | | | |
| Meadow | | | | | | | | |
| Woods | | | | | | | | |
| Other | | | | | | | | |
| Other | | | | | | | | |
| **TOTAL:** | --- | | | --- | --- | --- | --- | |

**1-Year Runoff Volume (cf):**

**Flow Target for 24-hour Extended Detention of 1-year, 24-hour Rainfall: ****

| Total Post-Dev. 1-year Runoff, $Q_{1\text{-}yr}$ (cf) | Ext. Det. Time (hr.) | Adjustment Factor, F | E.D. Flow Target (cfs) |
|---|---|---|---|
| | 24 | 1.3 | |

** Flow Target is calculated by (with appropriate unit conversions): This is based on a simple triangular approximation of the hydrograph. The Adjustment Factor, F, accounts for the fact that the hydrograph will not actually be triangular. F can reasonably range from 1 to approximately 1.6 for typical sites.

$$Flow.Target = \frac{Q_{1-yr}}{Time/2} * F$$

## Guidelines: Volume Credits for Detention Routing

### (For projects required to demonstrate peak rate control / extended detention for 1-year through 100-year storm events)

The utilization of volume reduction BMPs as part of either CG-1 or CG-2 will obviously reduce the amount of storage required for peak rate mitigation because less runoff is ultimately discharged. As quantifying the peak rate mitigation benefits of volume control BMPs can be difficult and cumbersome with common stormwater models, applicants are strongly encouraged to use these or other approaches to give credit for volume control when demonstrating peak rate control:

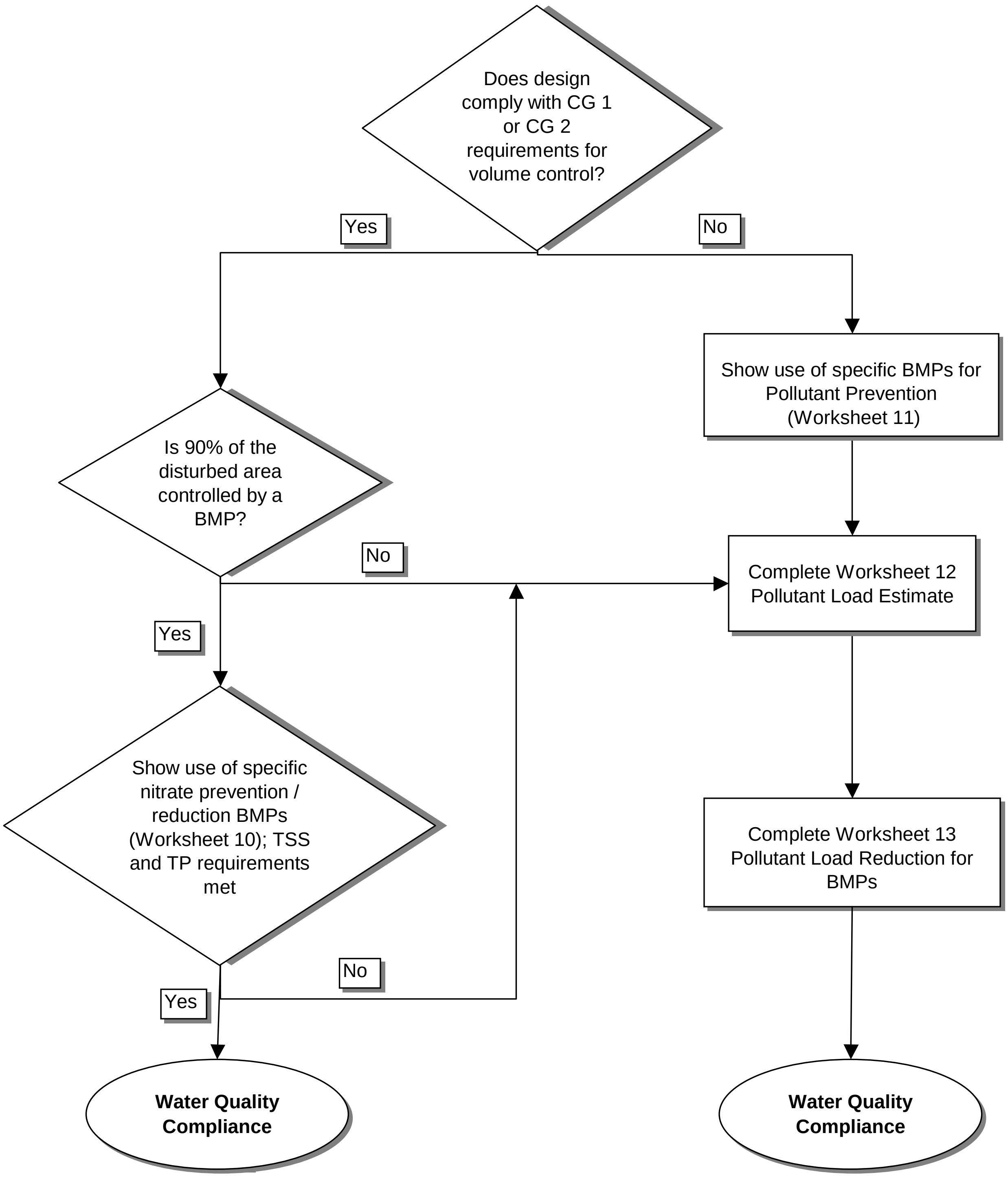
**1) Volume Diversion.** Many computers models have components that allow a "diversion" or "abstraction". The total volume reduction provided by the applicable structural and non-structural BMPs can be diverted or abstracted from the modeled runoff before it is routed to the detention system(s). This approach is very conservative because it does not give any credit to the increased time of travel, ongoing infiltration, etc. associated with the BMPs. For example, Figure X shows a schematic HEC-HMS setup with and without the "diversion" included. As shown in Table X, incorporating the CG-2 capture volume in the model reduces the required detention storage by about 22% for this example.

**2) Composite BMPs.** For optimal stormwater management, this manual suggests widely distributed BMPs for volume, rate, and quality control. This approach, however, can be very cumbersome to evaluate in detail with common computer models. To facilitate modeling, similar types of BMPs can be combined within the model. For modeling purposes, the storage of the combined BMP is simply the sum of the BMP capacities that it represents. A stage-storage-discharge relationship can be developed for the combined BMP based on the configuration of the individual systems. The combined BMP(s) can then be routed normally and the results submitted.

**3) Travel Time/ Time of Concentration Adjustment.** The use of widely-distributed, volume-reducing BMPs can significantly increase the post-development runoff travel time and therefore decrease the peak rate of discharge. The Delaware Urban Runoff Management Model (DURMM) calculates the extended travel time through storage elements, even at flooded depths, to adjust peak flow rates (Lucas, 2001). The extended travel time is essentially the residence time of the storage elements, found by dividing the total storage by the 2-year peak flow rate. This increased travel time can be added to the time of concentration of the area to account for the slowing effect of the volume-reducing BMPs. This can reduce the amount of detention storage required for peak rate control. Table Y shows the results of adjusting the time of concentration of the same example used in approach 1 above. The detention storage requirements are reduced by almost 40% by the CG-2 capture volume.

**4) Other Methods.** Other methods, such as adjusting runoff curve numbers based on the runoff volume left after BMP application, or reducing net precipitation based on the volume captured, can be applied as appropriate.

# Flow Chart D
## Water Quality Process



## WORKSHEET 10. WATER QUALITY COMPLIANCE FOR NITRATE

***Does the site design incorporate the following BMPs to address nitrate pollution? A summary "yes" rating is achieved if at least 2 Primary BMPs for nitrate are provided across the site or 4 secondary BMPs for nitrate are provided across the site (or the equivalent). "Provided across the site" is taken to mean that the specifications for that BMP set forward in Sections 5 and 6 are satisfied.***

***PRIMARY BMPs FOR NITRATE:***

| BMP | YES | NO |
|---|---|---|
| **NS BMP 5.2 - Protect / Conserve / Enhance Riparian Buffers** | | |
| **NS BMP 5.4 - Cluster Uses at Each Site** | | |
| **NS BMP 5.6 - Minimize Total Disturbed Area** | | |
| **NS BMP 5.8 - Re-Vegetate / Re-Forest Disturbed Areas (Native Species)** | | |
| **NS BMP 5.13 - Street Sweeping / Vacuuming** | | |
| **Structural BMP 6.17 - Riparian Buffer Restoration** | | |
| **Structural BMP 6.18 - Landscape Restoration** | | |

***SECONDARY BMPs FOR NITRATE:***

| BMP | YES | NO |
|---|---|---|
| **NS BMP 5.1 - Protect Sensitive / Special Value Features** | | |
| **NS BMP 5.3 - Protect / Utilize Natural Drainage Features** | | |
| **NS BMP 5.7 - Minimize Soil Compaction** | | |
| **Structural BMP 6.5 - Rain Garden / Bioretention** | | |
| **Structural BMP 6.8 - Vegetated Swale** | | |
| **Structural BMP 6.9 - Vegetated Filter Strip** | | |
| **Structural BMP 6.13 - Constructed Wetland** | | |
| **Structural BMP 6.17 - Soils Amendment / Restoration** | | |
| **Structural BMP 6.18 - Landscape Restoration** | | |
| **Structural BMP 6.19 - Soils Amendment and Restoration** | | |

# WORKSHEET 11. BMPS FOR POLLUTION PREVENTION

***Does the site design incorporate the following BMPs to address pollution? A summary "yes" rating is achieved if at least 2 BMPs are provided across the site. "Provided across the site" is taken to mean that the specifications for that BMP set forward in Sections 5 and 6 are satisfied.***

***<u>BMPs FOR POLLUTANT PREVENTION:</u>***

| BMP | YES | NO |
|---|---|---|
| NS BMP 5.1 - Protect Sensitive / Special Value Features | | |
| NS BMP 5.2 - Protect / Conserve / Enhance Riparian Buffers | | |
| NS BMP 5.3 - Protect / Utilize Natural Flow Pathways in Overall Stormwater Planning and Design | | |
| NS BMP 5.4 - Cluster Uses at Each Site; Build on the Smallest Area Possible | | |
| NS BMP 5.6 - Minimize Total Disturbed Area - Grading | | |
| NS BMP 5.7 - Minimize Soil Compaction in Disturbed Areas | | |
| NS BMP 5.8 - Re-Vegetate / Re-Forest Disturbed Areas (Native Species) | | |
| NS BMP 5.9 - Reduce Street Imperviousness | | |
| NS BMP 5.10 - Reduce Parking Imperviousness | | |
| NS BMP 5.11 - Rooftop Disconnection | | |
| NS BMP 5.12 - Disconnection from Storm Sewers | | |
| NS BMP 5.13 - Street Sweeping | | |
| Structural BMP 6.17 - Riparian Buffer Restoration | | |
| Structural BMP 6.18 - Landscape Restoration | | |
| Structural BMP 6.19 - Soils Amendment and Restoration | | |

# WORKSHEET 12. WATER QUALITY ANALYSIS OF POLLUTANT LOADING FROM ALL DISTURBED AREAS

| | |
|---|---|
| **TOTAL SITE AREA (AC)** | |
| **TOTAL DISTURBED AREA (AC)** | |
| **DISTURBED AREA CONTROLLED BY BMPs (AC)** | |

**TOTAL DISTURBED AREAS:**

| | | **POLLUTANT** | | | | | **POLLUTANT LOAD** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **LAND COVER CLASSIFICATION** | **TSS EMC *(mg/l)*** | **TP EMC *(mg/l)*** | **Nitrate-Nitrite EMC *(mg/l as N)*** | **COVER (Acres)** | **RUNOFF VOLUME (AF)** | **TSS** (LBS)** | **TP** (LBS)** | **$NO_3$ (LBS)** |
| **Pervious Surfaces** | Forest | 39 | 0.15 | 0.17 | | | | | |
| | Meadow | 47 | 0.19 | 0.3 | | | | | |
| | Fertilized Planting Area | 55 | 1.34 | 0.73 | | | | | |
| | Native Planting Area | 55 | 0.40 | 0.33 | | | | | |
| | Lawn, Low-Input | 180 | 0.40 | 0.44 | | | | | |
| | Lawn, High-Input | 180 | 2.22 | 1.46 | | | | | |
| | Golf Course Fairway/Green | 305 | 1.07 | 1.84 | | | | | |
| | Grassed Athletic Field | 200 | 1.07 | 1.01 | | | | | |
| **Impervious Surfaces** | Rooftop | 21 | 0.13 | 0.32 | | | | | |
| | High Traffic Street / Highway | 261 | 0.40 | 0.83 | | | | | |
| | Medium Traffic Street | 113 | 0.33 | 0.58 | | | | | |
| | Low Traffic / Residential Street | 86 | 0.36 | 0.47 | | | | | |
| | Res. Driveway, Play Courts, etc. | 60 | 0.46 | 0.47 | | | | | |
| | High Traffic Parking Lot | 120 | 0.39 | 0.60 | | | | | |
| | Low Traffic Parking Lot | 58 | 0.15 | 0.39 | | | | | |
| | | | | | | **TOTAL LOAD** | | | |
| | | | | | | **REQUIRED REDUCTION (%)** | **85%** | **85%** | **50%** |
| | | | | | | ***REQUIRED REDUCTION (LBS)*** | | | |

* Pollutant Load = [EMC, mg/l] X [Volume, AF] X [2.7, Unit Conversion]
** TSS and TP calculations only required for projects not meeting CG1/CG2 or not controlling less than 90% of the disturbed area

## WORKSHEET 13. POLLUTANT REDUCTION THROUGH BMP APPLICATIONS*

** FILL THIS WORKSHEET OUT FOR EACH BMP TYPE WITH DIFFERENT POLLUTANT REMOVAL EFFICIENCIES. SUM POLLUTANT REDUCTION ACHIEVED FOR ALL BMP TYPES ON FINAL SHEET.*

**BMP TYPE:** ______________________________

| **DISTURBED AREA CONTROLLED BY THIS BMP TYPE (AC)** | |
|---|---|

**DISTURBED AREAS CONTROLLED BY THIS BMP TYPE:**

| | | POLLUTANT | | | | | POLLUTANT LOAD** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **LAND COVER CLASSIFICATION** | **TSS EMC *(mg/l)*** | **TP EMC *(mg/l)*** | **Nitrate-Nitrite EMC *(mg/l as N)*** | **COVER (Acres)** | **RUNOFF VOLUME (AF)** | **TSS*** (LBS)** | **TP*** (LBS)** | **$NO_3$ (LBS)** |
| **Pervious Surfaces** | Forest | 39 | 0.15 | 0.17 | | | | | |
| | Meadow | 47 | 0.19 | 0.3 | | | | | |
| | Fertilized Planting Area | 55 | 1.34 | 0.73 | | | | | |
| | Native Planting Area | 55 | 0.40 | 0.33 | | | | | |
| | Lawn, Low-Input | 180 | 0.40 | 0.44 | | | | | |
| | Lawn, High-Input | 180 | 2.22 | 1.46 | | | | | |
| | Golf Course Fairway/Green | 305 | 1.07 | 1.84 | | | | | |
| | Grassed Athletic Field | 200 | 1.07 | 1.01 | | | | | |
| **Impervious Surfaces** | Rooftop | 21 | 0.13 | 0.32 | | | | | |
| | High Traffic Street / Highway | 261 | 0.40 | 0.83 | | | | | |
| | Medium Traffic Street | 113 | 0.33 | 0.58 | | | | | |
| | Low Traffic / Residential Street | 86 | 0.36 | 0.47 | | | | | |
| | Res. Driveway, Play Courts, etc. | 60 | 0.46 | 0.47 | | | | | |
| | High Traffic Parking Lot | 120 | 0.39 | 0.60 | | | | | |
| | Low Traffic Parking Lot | 58 | 0.15 | 0.39 | | | | | |
| | | | | | | **TOTAL LOAD TO THIS BMP TYPE** | | | |
| | | | | | | **POLLUTANT REMOVAL EFFICIENCIES FROM TABLE 9-3 (%)** | | | |
| | | | | | | **POLLUTANT REDUCTION ACHIEVED BY THIS BMP TYPE (LBS)** | | | |

| | | | |
|---|---|---|---|
| ***POLLUTANT REDUCTION ACHIEVED BY ALL BMP TYPES (LBS)*** | | | |
| ***REQUIRED REDUCTION FROM WS12 (LBS)*** | | | |

** Pollutant Load = [EMC, mg/l] X [Volume, AF] X [2.7, Unit Conversion]
*** TSS and TP calculations only required for projects not meeting CG1/CG2 or not controlling less than 90% of the disturbed area

## 9.8 References and Additional Information Sources

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