Pennsylvania Stormwater Best Management Practices Manual

Chapter 3

Stormwater Management Principles and Recommended Control Guidelines

363-0300-002 / December 30, 2006

Chapter 3 Stormwater Management Principles and Recommended Control Guidelines

3.1 Introduction

This Chapter provides guidance for municipalities striving to improve their stormwater management programs. It presents stormwater management principles and recommends site control guidelines to address volume, water quality and flow rate. These guidelines can serve as the basis for municipal stormwater regulation. Pennsylvania laws and regulations do not directly manage stormwater at the state level, although some state level management occurs through the Stormwater Management Act and the NPDES permitting program. All municipalities, regardless of their specific setting, are encouraged to enact the most comprehensive stormwater management ordinances possible. They should also work with their watershed neighbors to integrate their individual municipal actions within the watershed as a whole.

The guidelines established in this chapter reflect the ten basic principles of stormwater management presented in the forward. The principles are listed below once more to emphasize their fundamental importance as the foundation for the control guidelines that will follow.

1. Managing stormwater as a resource;
2. Preserving and utilizing existing natural features and systems;
3. Managing stormwater as close to the source as possible;
4. Sustaining the hydrologic balance of surface and ground water;
5. Disconnecting, decentralizing and distributing sources and discharges;
6. Slowing runoff down, and not speeding it up;
7. Preventing potential water quality and quantity problems;
8. Minimizing problems that cannot be avoided;
9. Integrating stormwater management into the initial site design process; and
10. Inspecting and maintaining all BMPs.

3.2 Recommended Site Control Guidelines

Site control guidelines are designed to meet water volume and water quality requirements and to follow the ten principles previously listed. The control guidelines presented in this Chapter are comprehensive are consistent with the Pennsylvania Comprehensive Stormwater Management Policy, and are recommended to restore natural hydrology including velocity, current, cross-section, runoff volume, infiltration volume, and aquifer recharge volume. Following the guidelines will help sustain stream base flow and prevent increased frequency of damaging bank full flows. The guidelines also will help prevent increases in peak runoff rates for larger events (2-year through 100-year) on both a site-by-site and watershed basis. When applicable, Act 167 watershed plans may require additional rate controls to reduce cumulative flooding impacts downstream.

The site control guidelines are:

- **Effective** — The morphologic impacts on streams from increased volumes of runoff during smaller storms are prevented. The guidelines will be effective on a site-by-site basis, as well as on a broader watershed-wide scale;

- **Proportional** — The stormwater controls will produce approximately the same post-development stormwater discharge for all types of development in almost any location;

- **Equitable** — The requirements are based on project characteristics rather than project location so that physically similar projects will have similar storm water controls;

- **Flexible** — The diversity among Pennsylvania's 2,566 municipalities is accommodated by the guidelines. This diversity in physical conditions presents a major challenge that requires flexibility to achieve a uniform stormwater management program across the state.

3.3 Recommended Volume Control Guidelines

Regardless of where land development occurs, the impervious surfaces, the changes in vegetation, and the soil compaction associated with that development result in significant increases in runoff volume. When the balance of a developed site is cleared of existing vegetation, graded, and re-compacted, it produces an increase in runoff volume. While traditionally, if the original vegetation were replaced with natural vegetation, the runoff characteristics would be considered to be equivalent to the original natural vegetation. The disturbance and the compaction destroy the permeability of the natural soil.

The relative increase in runoff volume varies with event magnitude (return period). For example, the two-year rainfall of 3.27 inches/24 hours (SE PA) will result in an increase in runoff volume of 2.6 inches from every square foot of impervious surface placed on well-drained HSG B soil in woodland cover (Figure 3-1). For larger events, as the total rainfall increases, the net runoff also increases, but less than proportionately. For example, total rainfall for the 100-year storm is twice the rainfall for the 2-year storm (7.5 inches vs. 3.27 inches); however, the increase in runoff for the 100-year storm is only 1.7 inches more than the runoff for the 2-year storm (4.3 – 2.6 inches). This pattern holds true throughout the state.

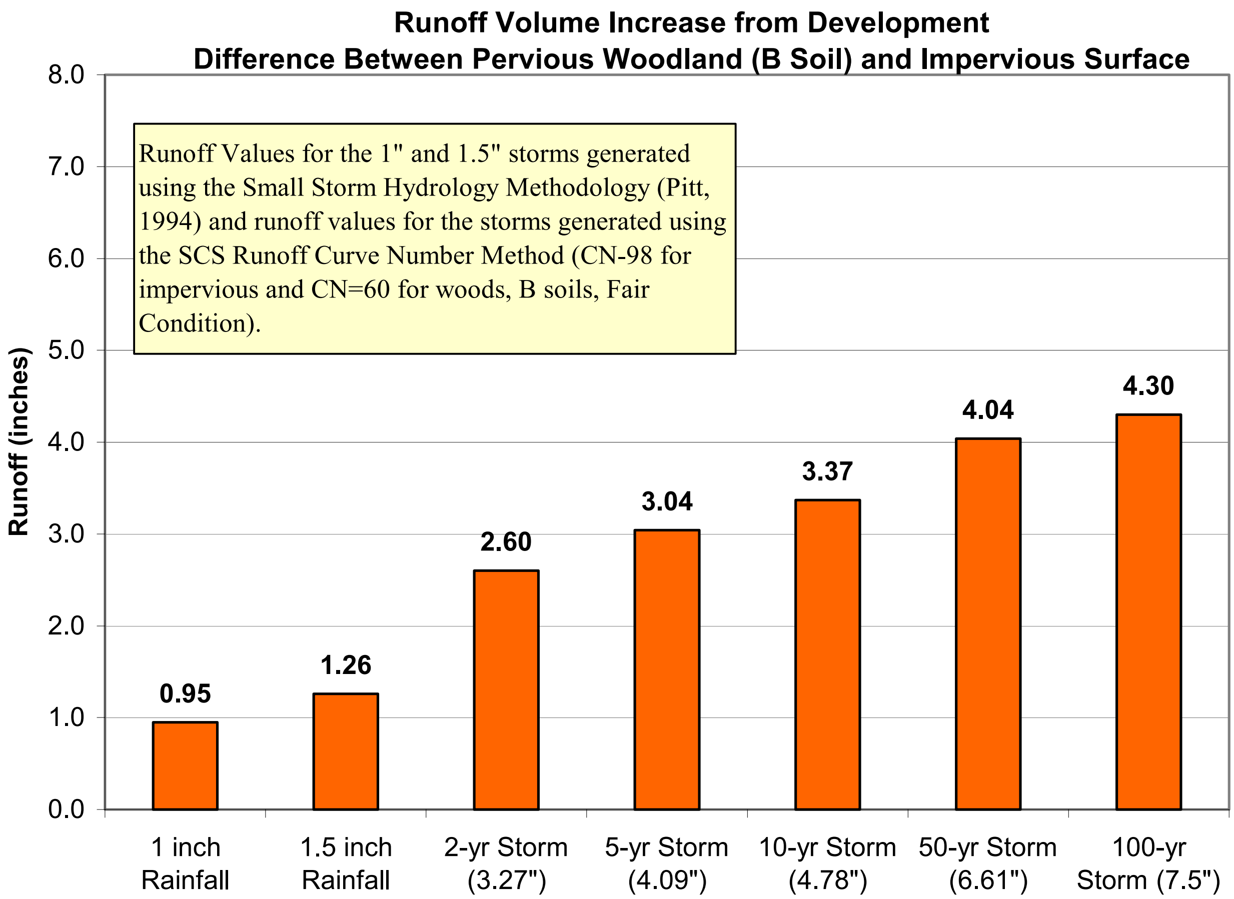

Figure 3-1. **Runoff Volume Increase from Impervious Surfaces - B Soils.**

For a specific site, the net increase in runoff volume during a given storm depends on both the pre-development permeability of the natural soil and the vegetative cover. Poorly drained soils result in a smaller increase of runoff volume because the volume of pre-development runoff is already high. Therefore, the amount of runoff resulting from development does not represent a large net increase. Using the same rainfall values, Figure 3-2 illustrates that the two-year rainfall of 3.27 inches/24 hours produces an increase of only 2.01 inches on a HSG C soil, while the better drained (B) soil in Figure 3-1 produces a 2.60-inch runoff volume increase. Thus a volume control guideline must be based on the net change in runoff volume for a given frequency rainfall to be equitable throughout the state on any given development site.

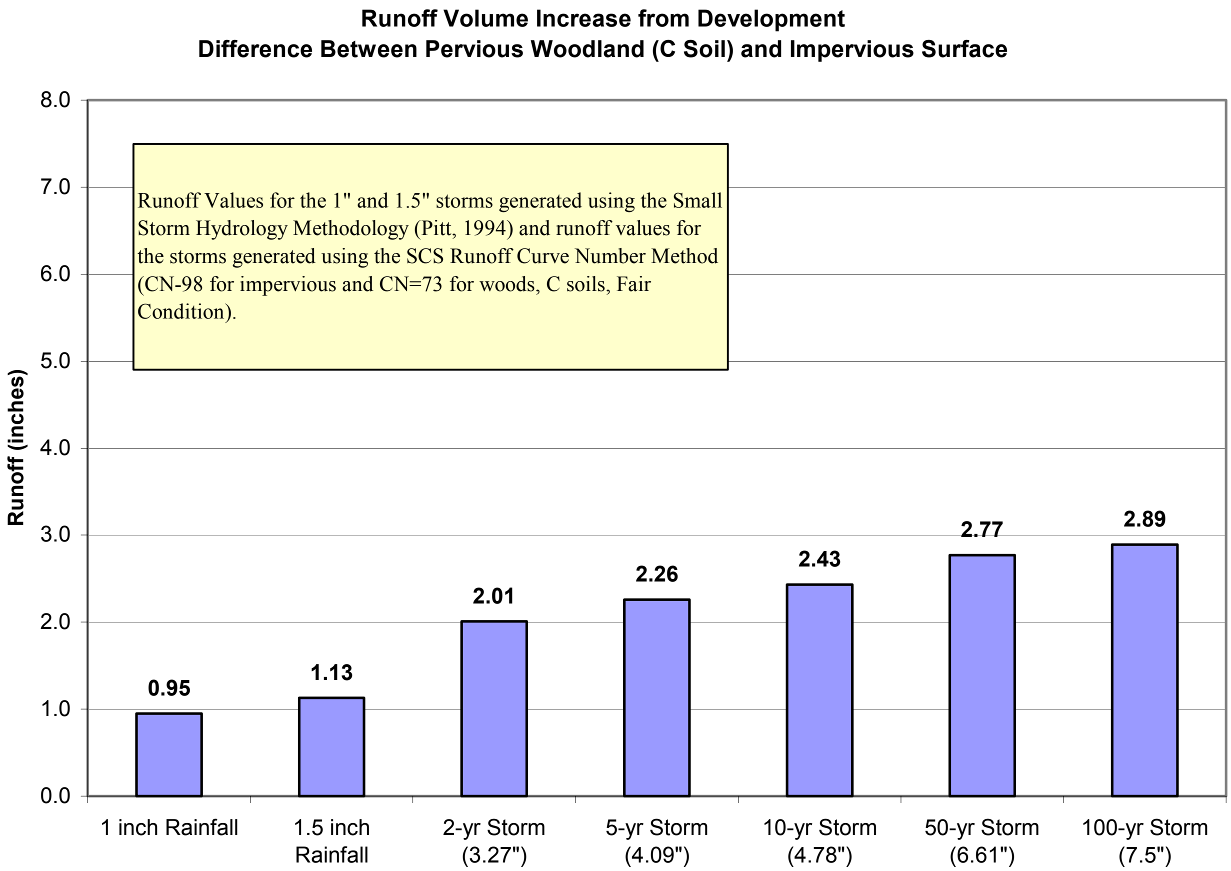

***Figure 3-2*. Runoff Volume Increase from Impervious Surfaces - C Soils**

Consideration of a volume control guideline has focused on providing stream channel protection and water quality protection from the frequent rainfalls that comprise a major portion of runoff events in any part of the state. On the basis of these factors, the 2-year event has been chosen as the stormwater management design storm for Volume Control Guideline 1.

Regardless of the volume reduction goal desired, it is considered unreasonable to design any stormwater BMP for greater than a 2-year event. The increase in runoff volume from the 100-year rainfall after site development is so large that it is impractical to require management of the total increase in volume. During such extreme events, the runoff simply overwhelms the natural and human-made conveyance elements of pipes and stream channels. In practice, a BMP sized for the increase in the 100-year runoff volume would be empty most of the time and would have a 1% probability of functioning at capacity in any one year. Of course, large storms need to be managed in terms of flooding and peak rate control, to the extent practicable.

3.3.1 Volume Control Criteria

A volume control guideline is essential to mitigate the consequences of increased runoff. To do this, the volume reduction BMP must:

1. Protect stream channel morphology;
2. Maintain groundwater recharge;
3. Prevent downstream increases in flooding; and
4. Replicate the natural hydrology on site before development to the greatest extent possible.

Protect Stream Channel Morphology: Increased volume of runoff results in an increase in the frequency of bank full or near bank full flow conditions in stream channels. The increased presence of high flow conditions in riparian sections has a detrimental effect on stream shaping, including stream channel and overall stream morphology. Stream bank erosion is greatly accelerated. As banks are eroded and undercut and as stream channels are gouged and straightened; meanders, pools, riffles, and other essential elements of habitat are lost or diminished. Research has demonstrated that bank-full stream flow typically occurs between the 1-year and the 2-year storm event (often around the 1.5-year storm). Urbanization can cause the natural bankfull stream flows to occur far more often. Strategies employed by the CG's include a combination of volume reduction and extended detention to reduce the bankfull flow occurances.

Maintain Groundwater Recharge: Over 80 percent of the annual precipitation infiltrates into the soil mantle in Pennsylvania's watersheds under natural conditions. More than half of this is taken up by vegetation and transpired. Part of this infiltrated water moves down gradient to emerge as springs and seeps, feeding local wetlands and surface streams. The rest enters deep groundwater aquifers that supply drinking water wells. Without groundwater recharge, surface stream flows and supplies of groundwater for wells will diminish or disappear during drought periods. Certain land areas recharge more groundwater than others; therefore, protecting the critical recharge areas is important in maintaining the water cycle's balance. In round numbers, an estimate of the annual water balance is: surface water runoff, 20%; evapotranspiration (ET), 45%; groundwater recharge, 35%.

Prevent Downstream Increases in Runoff Volume and Flooding: Although site-based rate control measures may help protect the area immediately downstream from a development site, the increased volume of runoff and the prolonged duration of runoff from multiple development sites can increase peak flow rates and duration of flooding from runoff caused by relatively small rain events. Replicating pre-development runoff volumes for small storms will usually substantially reduce the problem of frequent flooding that plague many communities. Although control of runoff volumes from small storms almost always helps to reduce flooding during large storms, additional measures are necessary to provide adequate relief from the serious flooding that occurs during such events.

Replicate the Surface Water Hydrology On-site Before Development: The objective for stormwater management is to develop a program that replicates the natural hydrologic conditions of watersheds to the maximum extent practicable. However, the very process of clearing the existing vegetation from the site removes the single largest component of the natural hydrologic regime, evapotranspiration (ET). Unless the ET component is replaced, the runoff increase will be substantial. Several of the BMPs described in this manual, such as infiltration, tree planting, vegetated roof systems and rain gardens, can help replace a portion of the ET function.

3.3.2 Volume Control Alternatives

While the volume control guideline alternatives are quite specific concerning the volume of runoff to be controlled from a development site, they do not specify the methods by which this can be accomplished. The selection of a BMP, or combination of BMPs, is left to the design process. But in all instances, minimizing the volume increase from existing and future development is the goal. The BMPs described in this manual place emphasis on infiltration of precipitation as an important solution; however, three methods are provided to reduce the volume of runoff from land development:

1. Infiltration;
2. Capture and Reuse; and
3. Vegetation systems that provide ET, returning rainfall to the atmosphere.

It is anticipated that many of the stormwater management systems used in Pennsylvania will include one or more of these methods, depending on specific site conditions that constrain stormwater management opportunities**.** Inherent in these guidelines is the assumption that all soils allow some infiltration. Where this is not possible, a vegetated roof, or bioretention combined with capture-and-reuse systems, or other forms of runoff volume control will be necessary to achieve the required capture and removal volumes.

For Regulated Activities equal or less than one acre that do not require design of stormwater storage facilities, the applicant may select either Control Guideline 1 or Control Guideline 2 on the basis of economic considerations, applicability and limitations of the analytic procedures and other factors. Control Guideline 1 may require more complex and detailed analyses while providing a greater opportunity to select stormwater controls that require fewer resources to construct and operate. For all Regulated Activities larger than one acre and for all projects that require design of stormwater storage facilities, Control Guideline 2 may not be used.

3.3.3 Volume Control Guideline 1

The Control Guideline 1 is applicable to any size of the Regulated Activity. Use of Control Guideline 1 (CG-1) is recommended where site conditions offer the opportunity to reduce the increase in runoff volume as follows:

> **Do not increase the post-development total runoff volume for all storms equal to or less than the 2-year/24-hour event**.
>
> **Existing (pre-development) non-forested pervious areas must be considered meadow (good condition) or its equivalent.**
>
> **Twenty (20) percent of existing impervious area, when present, shall be considered meadow (good condition) in the model for existing conditions for redevelopment.**

The scientific basis for Volume Control Guideline 1 is as follows:

- The 2-year event provides stream channel protection and water quality protection for the relatively frequent runoff events across the state;
- Volume reduction BMPs based on this standard will provide a storage capacity to help reduce the increase in peak flow rates for larger runoff events;
- In a natural stream system in Mid-Atlantic States, the bank full stream flow occurs with a period of approximately 1.5 years. If the runoff volume from storms less than the 2-year event are not increased, the fluvial impacts on streams will be reduced;
- The 2-year storm is well defined and data are readily accessible for use in stormwater management calculations.

3.3.4 Volume Control Guideline 2

Control Guideline 2 (CG-2) is independent of site constraints and should be used if CG-1 is not followed. This method is not applicable to Regulated Activities greater than one (1) acre or for projects that require design of stormwater storage facilities. For new impervious surfaces:

> **Stormwater facilities shall be sized to capture at least the first two inches (2") of runoff from all contributing impervious surfaces.**
>
> **At least the first one inch (1.0") of runoff from new impervious surfaces shall be permanently removed from the runoff flow — i.e. it shall not be released into the surface Waters of this Commonwealth. Removal options include reuse, evaporation, transpiration, and infiltration.**
>
> **Wherever possible, infiltration facilities should be designed to accommodate infiltration of the entire permanently removed runoff; however, in all cases at least the first one-half inch (0.5") of the permanently removed runoff should be infiltrated.**

The scientific basis for Volume Control Guideline 2 is as follows:

- Groundwater recharge will be maintained;
- The permanently removed volume will reduce the runoff;
- The combined permanently removed volume and extended detention volume will provide water quality protection by:
    - Capture / treatment of 95+/-% of the yearly water budget, and a higher volume of pollutants (first flush);
    - Capture / treatment of 99+/-% of the yearly storm events from paved areas. Example: for over 50 years of data on the Brandywine, 2.6 storms per year on average exceed 2";
- Volume reduction BMPs based on this standard will provide a storage capacity to reduce the increase in peak flow rates;
- In many of Pennsylvania's natural streams, the bank full stream flow occurs with a period of approximately 1.5 years. The combination of volume reduction and extended detention will reduce the depth and frequency of flows for all events less than the 2-year event, therefore, the fluvial impacts on streams will be reduced.

3.3.5 Retention and Detention Considerations

Infiltration areas should be spread out and located in the sections of the site that are most suitable for infiltration.

In all cases, retention and detention facilities should be designed to completely drain water quality volumes including both the permanently removed volume and the extended detention volume over a period of time not less than 24 hours and not more than 72 hours from the end of the design storm.

3.4 Recommended Peak Rate Control Guideline

Peak rate control for large storms, up to the 100-year event, is essential to protect against immediate downstream erosion and flooding. Most designs achieve peak rate control through the use of detention structures. Peak rate control can also be integrated into volume control BMPs in ways that eliminate the need for additional peak rate control detention systems. Non-Structural BMPs also can contribute to rate control, as discussed in Chapters 5 and 8.

The recommended control guideline for peak rate control is:

Do not increase the peak rate of discharge for the 1-year through 100-year events (at minimum); as necessary, provide additional peak rate control as required by applicable and approved Act 167 plans.

Where Act 167 plans apply, hydrologic modeling may have been performed to provide the basis for establishing more stringent release rate controls on sub-districts within the watershed. As volume reduction BMPs are incorporated into stormwater management on a watershed basis, release rate values will require re-evaluation. Use of the control guidelines will reduce or perhaps even eliminate the increase in peak rate and runoff volume for some storms.

3.5 Recommended Water Quality Control Guideline

The volume control achieved through applying CG-1 and CG-2 may also remove a major fraction of particulate associated pollutants from impervious surfaces during most storms. Pervious surfaces such as “lawnscapes” subject to continuing fertilization may generate NPS pollutants throughout a major storm, as may stream banks subjected to severe flows. While infiltration BMPs and landscape BMPs are very effective in NPS reduction, if the volume control measures simply overflow during severe storms then they will not achieve the control anticipated. Solutes will continue to be transported in runoff throughout the storm, regardless of magnitude.

CG-1 will provide water quality control and stream channel protection as well as flood control protection for most storms if the BMPs drain reasonably well and are adequately sized and distributed. CG-2 will not fully mitigate the peak rate for larger storms, and will require the addition of secondary BMPs for peak rate control. These secondary BMPs could also provide water quality control. In the event that this secondary BMP is added to assure rate mitigation during severe storms, the incorporation of vegetation could provide effective water quality controls.

The recommended control guideline for *total water quality control* is:

> Achieve an 85 percent reduction in post-development particulate associated pollutant load (as represented by Total Suspended Solids), an 85 percent reduction in post-development total phosphorus loads, and a 50 percent reduction in post-development solute loads (as represented by NO3-N), all based on post-development land use.

The recommended water quality control guideline is a set of performance-based goals. The guideline does not represent specific effluent limitations but presents composite efficiency expectations that can be used to select appropriate BMPs.

These reductions may be estimated based on the pollutant load for each land use type and the pollutant removal effectiveness of the proposed BMPs, as shown in Chapters 5 and 6 and discussed in Chapter 8. The inclusion of total phosphorus as a parameter is in recognition of the fact that much of the phosphorus in transit with stormwater is attached to the small (colloidal) particles, which are not subject to gravity settlement in conventional detention structures, except over extended periods. With infiltration or vegetative treatment, however, the removal of both suspended solids and total phosphorus should be very high.

New impervious surfaces, such as rooftops, that produce relatively little additional pollutants can be left out of the water quality impact site evaluation under most circumstances. Rainfall has some latent concentration of nitrate (1 to 2 mg/l) as the result of air pollution, but it would be unreasonable to require the removal of this pollutant load from stormwater runoff. The control of nitrate from new development should focus on reduction of fertilizer applications rather than removal from runoff.

When the proposed development plan for a site is measured by type of surface (roof, parking lot, driveway, lawn, etc.), an estimate of potential pollutant load can be made based on the volume of runoff from those surfaces, with a flow-weighted pollutant concentration applied. The total potential non-point source load can then be estimated for the parcel, and the various BMPs, both Structural and Non-Structural, can be considered for their effectiveness. This method is described in detail in Chapter 8. In general, the Non-Structural BMPs are most beneficial for the reduction of solutes, with Structural BMPs most useful for particulate reduction. Because soluble pollutants are extremely difficult to remove, prevention or reduction on the land surface, as achieved through Non-Structural BMPs described in Chapter 5, are the most effective methods for reducing them.

3.6 Stormwater Standards for Special Management Areas

CG-1 and CG-2 may require modification, on a case-by-case basis, before they are applied to Special Management Areas around the Commonwealth. Special Areas include highways and roads, existing urban or developed sites, contaminated or brownfield sites, sites situated in karst topography, sites located in public water supply protection areas, sites situated in High Quality or Exceptional Value watersheds, sites situated on old mining lands, etc. These are areas where BMP application of any type may be limited. Stormwater management for these Special Management Areas is discussed in more detail in Chapter 7.