CHAPTER 14

POST-CONSTRUCTION STORMWATER MANAGEMENT

14.0 INTRODUCTION

A. Overview. The purpose of this chapter is to provide design guidelines for post-construction stormwater management (PCSM) controls intended to manage stormwater after construction of a project is complete. The traditional design of storm drainage systems has been to collect and convey storm runoff as rapidly as possible to a suitable location where it may or may not have been detained, depending on the age and characteristics of the system, before it was discharged to the environment. The engineering community is now more aware of the effects of poor water quality upon the environment and the impact that uncontrolled increases in runoff can have on the environment and the public. This chapter provides general design criteria for detention/retention storage basins, procedures for sizing basins, procedures for performing routing calculations, and design guidelines for other post-construction stormwater management controls.

B. Background. The Department performs a broad spectrum of activities in order to maintain and improve the state's roadway system. Highway improvement projects involve, to varying degrees, altering the existing landscape through a combination of clearing, compaction, and impervious cover. These activities disrupt the natural hydrologic processes that reduce surface runoff, such as interception and infiltration. It has been well-documented that the development of land into less pervious areas generally leads to an increase in stormwater runoff volume, higher peak flows, higher average temperature of runoff, collection of a larger mass of pollutants (due to lack of infiltration capacity), and an increased flooding hazard for downstream waterways. All of these factors contribute to degradation – changes in the physical, chemical, and biological properties – of the receiving waters.

That being said, not all roadway improvement and land development projects are created equal in terms of their potential to impact receiving waters. Many land development projects involve the clearing of forests and meadows, and developing productive farmlands. On the other hand, the vast majority of Department projects involve improvements within an existing legal right-of-way, which has already been largely disturbed in order to construct the highway facility. Thus, the Department's improvement and maintenance projects tend to have less of an effect on runoff characteristics than other types of development projects. However, there are effects associated with most non-maintenance activities, and those effects are generally proportional to the amount of additional impervious area being proposed.

Among Pennsylvania's water quality standards are antidegradation requirements, which are described in Section 93.4a of the PA Code. The antidegradation requirements are aimed at protecting the existing instream uses of surface waters, in addition to maintaining and protecting the water quality of High Quality (HQ) and Exceptional Value (EV) waters. Stormwater runoff is considered a point source discharge which has the potential to impact existing uses and water quality, so it is regulated by PA DEP.

Three key measures are used to assess the potential for impacts from stormwater runoff – volume, rate, and quality. The goal of PCSM is to prevent or minimize any increase in the quantity (rate and volume) of runoff while also minimizing the factors affecting the quality. The best way to achieve antidegradation is to mimic the natural, pre-development hydrologic conditions, which are usually dominated by infiltration and evapotranspiration (ET – see definitions). This is a two-fold solution because stormwater management strategies that address quantity normally also address quality. However, the inherent characteristics of highway projects sometimes limit the options for volume reduction. Therefore, it is also important to have a combination of strategies that reduce the amount of runoff being generated.

PCSM is required whenever a project (1) requires an NPDES construction stormwater permit (see Section 12.1.B), or (2) is located in a watershed with an approved Act 167 stormwater management plan. The Department recognized that a policy on antidegradation and PCSM was needed in order to establish guidelines for addressing project-induced changes in runoff. The policy, which is outlined in Section 14.2, is a tool for achieving a target, which is consistent with Pennsylvania's antidegradation regulations and federal NPDES requirements. The guidelines that are provided were developed with the most common types of Department construction projects and circumstances in mind. However, it is important to keep in mind that there will be projects with circumstances that require considerations beyond those recommended for these typical situations.

14.1 HIGHWAY SPECIFIC STORMWATER ISSUES

In Pennsylvania, the three primary concerns related to the effects of runoff on water resources from roadway facilities are:

- Stream channel erosion and flooding resulting from increases in runoff rate and volume;
- Water quality impacts to streams and groundwater aquifers from particulates, floatables, hydrocarbons, and deicing materials; and
- Thermal impact on streams caused by heat transfer from pavement to runoff and loss of riparian buffer vegetation.

Chapter 7 of the *PA DEP Stormwater BMP Manual* (herein referred to as the "*BMP Manual*") lists a number of additional common pollutant constituents in highway runoff. Many, if not most of these constituents occur in relatively small concentrations and are usually addressed when the increases in the rate and volume of runoff are mitigated. The items listed above are the primary concerns related to potential water resources impacts and are discussed below in more detail.

A. Increases in Runoff Rate and Volume. It is well documented that a direct relationship exists between the imperviousness of a watershed and the impairment of its surface waters. Unmitigated increases in the rate and volume of runoff discharging from developing areas have a cumulative effect, which has been shown to cause flooding and erosion of streams. Increases in the rate and volume of runoff are mostly dependent on the amount of impervious area replacing pervious area, the amount of disturbance, and the time it takes for the runoff to concentrate and leave the site. Some types of projects add relatively little (or no) impervious area and require minimal disturbance, while other types of projects create large areas of impervious cover and disturbance. Increased discharges can often be prevented in the former case by implementing qualitative and non-structural measures; whereas the latter case usually requires structural measures for peak flow and volume mitigation. Because there is a wide range of activities affecting stormwater and an array of potential BMP solutions, it is necessary to group the activities and BMPs in order to create a standard approach that applies to most Department projects. This approach is described in detail in Section 14.2.B.

The peak rate and volume control achieved through application of the *BMP Manual* guidance results in treatment of a major fraction of pollutants associated with particulates from impervious surfaces, in addition to flood and stream channel protection during most storms. It should be noted, however, that solutes will continue to be transported in runoff throughout the storm, regardless of its magnitude.

B. Winter Maintenance Materials. Chlorides and other soluble chemicals in deicing materials and salts can spike concentrations in groundwater. In addition, the fine sediments that make up anti-skid materials can be carried into an adjacent stream or accumulate over and clog an infiltration facility. The *BMP Manual* and the Department's MS4 permit list several good housekeeping approaches that the Department uses to minimize pollutant loadings from winter maintenance materials, including

- Monitoring and minimizing the volume of winter maintenance materials used;
- Protecting salt storage and loading areas from weather influences; and
- Cleaning around the area where materials are dispensed immediately after deicing operations have ceased.

C. Thermal Impact. In warm months, heat transferred from stormwater runoff to cold-water streams can be a potential source of thermal impacts. This type of effect is pronounced in urban areas. Thermal energy stored in areas exposed to the sun's solar energy, such as asphalt and concrete pavement, is transferred to runoff as it passes over the surface. A few studies have shown that a combination of factors resulting from urbanization can have a pronounced effect on stream temperatures. These factors include base flow reduction (less infiltration and groundwater recharge), loss of riparian areas (i.e., vegetated buffer zones), and heat transfer from roofs, parking lots, roads, etc. It is important to note that this is a composite effect, and the relative contribution of each of these factors is unknown.

In addition to the effect of impervious surfaces, open water ponds or basins and loss of riparian areas expose water to direct sunlight. The cumulative effect over a large area creates a potential for increasing summer stream temperatures. Other studies have shown similar effects in the winter, except that impervious areas cool the runoff below the stream's ambient temperature. Thermal impacts are also particularly important for surface waters that have a fishery classification of Cold Water Fishes or Trout Stocking; this includes waters that are High Quality waters due to an existing or designated use as a Class A wild trout stream by the PA Fish and Boat Commission. PA DEP and PennDOT have developed strategies to reduce potential thermal impacts, which include the following:

- Limit the use of curb and gutter sections as much as practicable;
- Limit the use of storm sewers as much as practicable;
- Consider vegetative alternatives for slope and channel erosion protection;
- Discharge storm sewers into non-EV wetland areas or vegetated swales as much as practicable;
- Consider vegetated islands in-lieu of concrete islands; and
- Maintain naturally occurring vegetation (i.e., buffer zones, including wetland and riparian) along streams, rivers and other surface waters for shading and thermal protection.

Riprap application on roadway embankments and cut slopes has generally been limited to steep slopes (> 3:1), rocky soils, and groundwater springs. None of these conditions are conducive to vegetative establishment by seeding and mulching alone. Erosion protection and stabilization of steep roadway slopes may be achieved using a variety of products that aid vegetative establishment, and some even offer permanent reinforcement. The two recommended measures are rolled erosion control products (RECPs) and geocell slope confinement systems (filled with topsoil and seeded). Riprap has been a traditional approach for use in parallel roadway swales, collection ditches, and other types of stormwater channels. Typically, it has been the preferred lining for steep channels, where velocities and shear stresses exceed the limits that grass lining can resist. Advances in erosion control technologies in recent years has made it possible for vegetated lining to be used in channels that may experience moderate to high velocities and shear stresses. In fact, some products offer higher shear stress resistance than riprap lining. Vegetated channels also provide water quality benefits, such as filtering and adsorption of pollutants, which riprap channels do not. Riprap is more desirable where hydraulic conditions do not permit the use of simple seed and mulch stabilization.

Two additional factors that should be considered when evaluating a project's potential for thermal impacts are (1) the distance from the impervious areas to the surface water and (2) the size of the surface water relative to the amount of runoff generated by the impervious areas. Generally, the longer the travel time through vegetated or shaded areas, the cooler the runoff will be when it eventually reaches the surface water. Although the use of vegetated swales for stormwater conveyance is preferred, storm sewers are buried and generally stay cool; thus, a significant amount of heat loss can take place in a long sewer run before the runoff reaches the surface water. The size of the receiving surface water is an important factor due to mixing phenomena. Large highway projects that are adjacent to headwaters and other low order streams have the potential to have an adverse affect the temperature regime because runoff from the highway may produce a significant percentage of the total surface flow in the headwater. In this type of situation, it is particularly important to address potential thermal impacts using the strategies outlined above. However, it is more likely that the runoff produced by the road during a storm is insignificant compared to the flow in the receiving surface water. Additionally, the water quality criteria do not preclude the allowance of a reasonable mixing zone if there is no significant effect on the ambient temperature of the stream outside the mixing zone.

14.2 POLICY

A. Introduction. This Department's policy on antidegradation and post-construction stormwater management is a proactive approach to protecting the surface waters of the Commonwealth from degradation. Most of the information in this section is related to the implementation of a standardized approach for selecting PCSM best management practices (BMPs) on projects. However, this is just one component of an overall program to enable the Department to adapt to current practices and maintain consistency with evolving stormwater requirements. The Department will use a comprehensive "E^5" strategy for addressing stormwater management issues, which is consistent with the Department's MS4 permit. The goal is to integrate each of the E^5 components into the overall design process in order to achieve a program that is sustainable and efficient. The E^5 strategy includes:

- **E**ncouraging low impact practices for preventing runoff;

- **E**valuating site characteristics and BMP needs early in the design process;
- **E**ngaging PA DEP through pre-application meetings;
- **E**stablishing a process to evaluate new technologies, assess the performance of existing ones in the field, and update/expand the BMP toolbox; and
- **E**ducating PennDOT staff, consultants, and contractors on stormwater policy and implementation.

This comprehensive approach to stormwater management is needed in order to address the many challenges presented by runoff from the Department's facilities.

B. Project Categories. The most common types of construction projects that the Department engages in are grouped into three categories – bridges, highway restoration, and new construction – and presented in Table 14.1. Descriptions for each type of project are provided in the table. PCSM levels, which are located in the right-hand column of the table, are determined by:

- the potential for generating increased stormwater discharges (volume or rate) as a result of the activity;
- the potential for causing thermal impacts to receiving surface waters; and
- the potential for discharging high concentrations of pollutants (e.g., salt storage facilities).

The projects in Table 14.1 are assigned a PCSM level, from 1 to 3, which represents a scale of low potential (Level 1) to high potential (Level 3) for the items listed above. For example, a project involving a highway interchange reconfiguration (Level 3) has a greater potential for generating increased runoff than a project proposing to add a center turning lane to a local intersection (Level 2).

In addition to factors listed above, the sensitivity of the area or the watershed receiving runoff from the project is an important consideration in the analysis of increased runoff impacts. In fact, a project should be considered PSCM Level 4, regardless of the type of project it is, when it has the potential to discharge into one of the following sensitive areas, which are noted in Table 14.2:

- HQ or EV waters, or EV wetlands,
- stormwater-impaired surface waters,
- combined sewer systems, and
- surface waters containing threatened and endangered species and critical habitat for threatened and endangered species.

Each of the four PCSM levels corresponds to a different set of stormwater BMPs, which is called a "BMP toolbox." The BMPs within that toolbox may be used to prevent or control runoff from that particular project after the BMPs in the lower level toolboxes have been considered. The lower level BMPs are generally focused on minimizing the potential impacts from runoff by applying preventative design and construction measures, which are applicable on most projects. There may be circumstances that warrant the use of BMPs from a higher-level toolbox (e.g., a Level 2 project that uses BMPs in the Level 3 toolbox). In these cases, the District's project manager should be consulted.

Table 14.1 PCSM Levels for Projects Located in Non-sensitive Areas

Type of Project		Description	PCSM Level
Bridges	New or Replacement over Water	Total bridge length is 60 m (200 feet) or less, or at least 75% of total bridge length is over water for longer bridges.	1
		Bridges longer than 60 m (200 feet) and more than 25% of length over land.	2
	Replacement over Land	Similar to 3R widening.	2
	New over Land	Bridge over pervious area is similar to new road alignment; if new bridge over existing impervious, subtract impervious area below the bridge.	3
Highway Restoration (3R)	Pavement	Replace portions, overlay, or mill and resurface the roadway's surface.	1
	Widening	Increase the width of the existing travel lanes (no new lanes added) and shoulders, or extension of acceleration/deceleration ramps in existing shoulder areas.	2
	Shoulders	Resurface, stabilize, upgrade (dirt or gravel to paved), or widen the existing shoulders within the existing footprint.	1
	Intersection	Nominal channelization of intersections and addition of turning lanes.	2
	Alignment	Change the roadway by reducing or eliminating horizontal and vertical curves.	2
	Pull-offs	New, as part of a larger project or by itself.	2
	Other	Replace and/or repair guide rail, signs, traffic signals, and drainage systems to their original specifications; various minor safety improvements.	1
New Construction	Major Widening	Addition of one or more travel lanes, including acceleration and deceleration lanes, to an existing road.	3
	New Alignment	New roadway corridor.	3
	Interchange	Reconfiguration of ramps, lane modification within interchange area, etc.	3
	Facilities	New stockpile sites, park-and-ride lots, rest stops, etc.	3

Table 14.2 PCSM Levels for Projects Located in Sensitive Areas

Type of Area	Description	PCSM Level
HQ/EV waters or EV wetlands	Any portion of a project having a potential to discharge into waters with existing or designated HQ or EV uses per PA Code Title 25, Chapter 93, or EV wetlands per PA Code Title 25, Chapter 105.	4
Impaired watershed	Any portion of a project discharging into a watershed identified by DEP as having impairments due to stormwater.	4
Combined sewer systems	Any portion of a project discharging into a combined sewer system.	4
Threatened and endangered species and critical habitat	Any portion of a project that has the potential to have an adverse effect, either directly or indirectly, on threatened or endangered Federal or Pennsylvania species, or critical habitat for threatened or endangered species (e.g., bog turtle wetlands).	4

1. PCSM Level 1. These types of projects involve restoring an existing roadway to its original condition; pervious areas are generally not being converted into impervious areas. Level 1 projects do not measurably change the post-construction rate, volume, or quality (including temperature) of runoff from the site. The BMPs listed below should be employed and the designer should attempt to maintain pre-development stormwater conditions. Also refer to the E&S procedures and BMPs outlined in Chapter 12, *Erosion and Sediment Pollution Control*, for designing measures to prevent polluted discharges from the construction site. If one or more of these BMPs can be used for a substantial portion of a project, calculations for peak flow, volume, and water quality are usually not required for Level 1 projects.

Level 1 Target – Minimal disturbance.

The approved BMPs for Level 1, which are described in more detail in Section 14.5, include:

- **a.** Minimize compaction.
- **b.** Preserve trees and revegetate using native species.
- **c.** Maintain dual-purpose E&S/PCSM BMPs.
- **d.** Restore temporary staging areas.

2. PCSM Level 2. Level 2 projects typically involve a minor addition of impervious area relative to existing conditions and do not generally change the direction of runoff or the potential for pollutants in the runoff. For example, widening existing travel lanes or shoulders for improved safety does not increase the volume of traffic, thus, the amount of potential pollutants deposited and the amount of deicing materials used on the road are not expected to increase. A relatively small volume of additional runoff is generated by the new impervious area, in part because the pervious areas within the right-of-way are highly compacted and exhibit runoff qualities similar to impervious areas. The primary focus of a Level 2 project analysis should be to compare the existing and proposed runoff characteristics. In many cases, the existing road and right-of-way will contain very few, if any, BMPs that significantly contribute to improving water quality and reducing runoff volume. The additional runoff can often be dealt with using non-structural and restoration BMPs when the roadway runoff does not discharge directly to surface waters.

Level 2 Target – Where existing swales and median areas can be retrofitted with structural BMPs without adversely affecting safety, BMPs should be designed to (1) capture 50 mm (2.0 in) of runoff from all impervious areas contributing to the BMPs; (2) permanently remove the first 25 mm (1.0 in) of runoff from new impervious areas by assimilating through infiltration and/or evapotranspiration; and (3) infiltrate the first 13 mm (0.5 in) of runoff from new impervious areas. Where retrofitting existing swales and medians is not feasible, the designer should maximize the use of non-structural and restoration-type BMPs that encourage and/or enhance evapotranspiration in order to attempt to maintain pre-development stormwater runoff conditions. Peak discharge rates should be calculated where the use of structural BMPs is not feasible and a measurable difference between pre- and post-construction rates is anticipated.

The Level 2 target is in alignment with Control Guideline 2 (CG-2) in the *BMP Manual*. Level 2 projects exceeding 0.40 hectare (1.0 acre) of disturbance should apply the above guidelines, even though the *BMP Manual* recommends limiting the application of CG-2 to one acre of disturbance. Disturbance to one acre of clustered land has a high potential to affect an adjacent surface water receiving runoff from the site. Given this scenario, the ratio of receiving waters to disturbed area is 1-to-1. On the other hand, a 3R project that proposes 0.6 m (2 ft) of shoulder widening on both sides of the road would have to be 3.2 km (2 mi) long to equal 0.40 hectare (1.0 acre) of disturbed area. Assuming that there are five small tributaries per 1.6 km (1 mi) for this particular project, the ratio of receiving waters to disturbed area (and added impervious area) is 10-to-1. Although the actual number of receiving waters varies from project to project, these types of ratios are typical and provide justification for the recommended PCSM target for Level 2 projects in this policy.

The approved BMPs for Level 2, which are described in more detail in Section 14.5, include:

- **a.** Street sweeping.
- **b.** Impervious disconnection.
- **c.** Slope roughening.
- **d.** Pavement width reduction.
- **e.** Riparian buffer reestablishment.
- **f.** Landscaping and planting.
- **g.** Soil amendments.
- **h.** Vegetated swale.
- **i.** Bioretention.

j. Vegetated filter strip.
k. Constructed wetland / wet pond (retrofit only).

The structural BMPs (items h through k above) can be used where they can be retrofitted within the existing footprint without affecting safety, and where the roadway facility would normally discharge directly into a conveyance system or surface water. Examples of swale retrofitting include: replacing earth material and/or vegetation in swales to encourage evapotranspiration and/or infiltration; adding an organic layer (i.e., compost) to encourage bioretention; replanting with species that offer greater evapotranspiration opportunities (i.e., larger root systems); and retrofitting ditches with check dams to provide storage in the channel. The vegetation for filter strips may be comprised of (1) turf grasses, (2) meadow grasses, shrubs, and native vegetation, including trees, and (3) indigenous areas of woods and vegetation. The BMP references should be consulted for information on increasing the capacity and efficiency of the structural BMPs. In addition, a combination of BMPs is preferred over a single BMP treatment because they can compliment each other and provide a more effective means of treatment.

3. PCSM Level 3. These projects typically involve a significant increase in an existing roadway's footprint or, as in a new alignment, significant changes in topography and cover. By altering the landscape, these projects generally produce higher volumes and rates of runoff.

Level 1 and 2 BMPs should be examined first before Level 3 BMPs are considered. In addition, incorporate low impact design concepts such as (1) maintaining natural drainage divides, (2) preserving naturally vegetated areas, (3) grading to encourage sheet flow, and (4) directing runoff into or across vegetated areas.

Level 3 Target – Reduce the post-construction runoff peak rate to the pre-construction peak rate for the 2-, 10-, 25-, 50-, and 100-year storm events. Reduce the post-construction runoff volume to the pre-construction runoff volume for the 2-year 24-hour storm event and smaller. The plans must also comply with the water quality requirements established by PA Code, Title 25, Chapter 93.

The approved BMPs for Level 3, which are described in more detail in Section 14.7, include:

a. Vegetated swale (Section 14.6).
b. Bioretention (Section 14.6).
c. Bioslope.
d. Dry extended detention basin.
e. Infiltration trench.
f. Infiltration basin.
g. Infiltration berm.

The structural BMPs above should be considered for integration into the design of the stormwater management and drainage systems. Most of these BMPs reduce runoff volume through a combination of infiltration and evapotranspiration, while all of the BMPs have some capacity for peak reduction and water quality.

4. PCSM Level 4. Level 2 or 3 projects that have the potential to discharge into surface waters that (1) have existing or designated HQ or EV uses (including EV wetlands), (2) have impairments due to stormwater, (3) are connected to combined sewer systems, or (4) have the potential to have an adverse effect on threatened or endangered species, or critical habitat for such species, are elevated to PCSM Level 4. Level 4 BMPs in Table 14.17 should be considered only after BMPs for Levels 1 through 3 are applied, where appropriate, to address the runoff from the additional impervious surfaces. Generally, PCSM BMPs that address quantity (rate and volume) also address quality. To demonstrate this determination, water quality requirements will be met when there is no net change in the pre- versus post-construction runoff volume comparison for the 2-year 24-hour storm event, rate is controlled for the 2-, 10-, 25-, 50-, and 100-year storm events, and the nitrate removal efficiency of the proposed BMPs has been documented.

Level 4 Target – Reduce the post-construction runoff peak rate to the pre-construction peak rate for the 2-, 10-, 25-, 50-, and 100-year storm events. Reduce the post-construction runoff volume to the pre-construction runoff volume for the 2-year 24-hour storm event and smaller. The plans must also comply with the water quality requirements established by PA Code, Title 25, Chapter 93.

The approved BMPs for Level 4, which are described in more detail in Section 14.8, include:

a. Constructed wetland.
b. Wet pond.
c. Permeable pavement.
d. Manufactured products, subsurface storage, water quality inlets, etc.

If the approved BMPs in this policy cannot accomplish the non-discharge alternative (a no net change in runoff for rate, volume, and quality), then Antidegradation Best Available Combination of Technologies (ABACT) BMPs need to be incorporated. ABACT BMPs include practices that, in combination, provide (1) cost-effective treatment, (2) land disposal, (3) pollution prevention, and (4) stormwater reuse technology approaches. In the Antidegradation Analysis Section of the NPDES permit, which applies only to Special Protection waters, the applicant must describe how these items have been satisfied. All but the last item, stormwater reuse technology approaches, can be satisfied using the BMPs described in this policy. Except for possibly Department buildings, park-and-ride lots, and maintenance facilities, stormwater reuse is not feasible for Department projects. Table 14.3 lists the BMPs in this policy according to which ABACT category they can be applied. Prior approval from the District project manager is required for using BMPs that are not listed in this table. Manufactured products, such as water quality inlets and underground detention units, require special approval from the Bureau of Design, Highway Quality Assurance Division, and will be assessed on a project-by-project basis.

Table 14.3 BMPs by ABACT Category

Treatment BMPs	Land Disposal	Pollution Prevention
Vegetated swale	Bioslope	Street sweeping
Bioretention	Bioretention	Impervious disconnection
Constructed wetland	Vegetated filter strip	Slope roughening
Wet pond	Impervious disconnection	Pavement width reduction
Infiltration trench		Riparian buffers
Infiltration basin		Landscaping and planting
Infiltration berm		Soil amendments
Permeable pavement		

C. Act 167 Plans and Municipal Ordinances. In Pennsylvania, Act 167 stormwater management plans provide a model set of ordinances to municipalities for regulating stormwater discharges from developing areas, which are based on extensive studies of the watershed's runoff characteristics. Because the watersheds being studied reach across many municipal boundaries, counties oversee the development of the plans. Once a plan is approved by PA DEP, the municipalities within that watershed must adopt and enforce ordinances that are at least as restrictive as the model ordinance in the Act 167 plan.

The Department must be consistent with the standards of watershed-based stormwater management plans approved by PA DEP and implemented under the Stormwater Management Act (1978 Act 167); however, the Department is not required to comply with individual local ordinances, including ordinances adopted under an Act 167 plan. The Department does, however, strive to maintain good relations with local municipalities and, at the Department's discretion, wishes to be consistent with local ordinances when feasible and practicable. Municipal stormwater ordinances should not be used to design stormwater facilities on a project unless specifically directed by the Department's project manager.

Consistency with an Act 167 plan does not necessarily mean that the antidegradation requirements for an NPDES permit have been satisfied. From 1980 to 2003, Act 167 plans that were developed focused on controlling the peak rate of discharge to protect downstream persons and property. Act 167 plans developed since 2003 have targeted a broader range of stormwater runoff issues related to development including: minimizing increases in runoff volume, controlling peak discharge rates, maintaining groundwater recharge, and protecting water quality. The former addresses one component of antidegradation and PCSM, while the latter addresses most of the issues. Volume control and water quality requirements of the NPDES permit will usually govern because the majority of existing plans do not include volume and water quality standards. On the other hand, the peak discharge standards in an Act 167 plan may be more restrictive than NPDES requirements and would thereby govern. In any case, the more restrictive requirements between the NPDES permit and the PA DEP-approved Act 167 plan govern the design of PCSM for Department projects.

D. Limitations. A number of factors may preclude the use of a BMP, even if it otherwise appears to be applicable. The most common factors limiting their use include karst topography, high groundwater table, limiting soil zones, shallow depth to bedrock, and compacted soils. A few of these factors are described below. It should be noted that the presence of limiting factors does not exempt a project from analyzing the post-construction stormwater conditions and potential impacts to receiving waters.

1. Structural Infiltration BMPs. The use of structural infiltration systems is challenging in cold-climate states such as Pennsylvania. Frozen soils can dramatically reduce, or stop, the rate of infiltration, chlorides may pose a risk to groundwater, and sand used as abrasives on roads may clog infiltration practices. Consequently, designers need to make modifications to these BMPs to make them effective in cold climates. Minimum soil infiltration rates should be increased (from base criteria) to account for the clogging potential from road abrasives and somewhat for the reduced infiltration rates during the winter season. Additional design guidelines for infiltration systems can be found in Appendix C of the *BMP Manual*. When infiltration practices are used next to a road or pavement, they should be set back in order to avoid potential frost heave conditions. Infiltrated water can contribute to ice lenses that form beneath the road surface, aggravating frost heave and potentially causing damage. The maximum ponding elevation in a facility should be no higher than the minimum subgrade elevation of the road. Setback restrictions can be avoided by using other measures to protect pavement. For example, pavement can be insulated or underlain with a very thick gravel to protect against frost damage.

Roadway runoff generates high levels of suspended solids and should not be discharged directly to infiltration systems without first reducing sediment loads. Structural infiltration BMPs are appropriate for roadway systems but must be designed in conjunction with a pre-treatment measure (structural or non-structural) that reduces the amount of sediment and other particulate matter in roadway runoff prior to infiltration. Sediment loads can be reduced by:

- Vegetated systems such as grassed swales, filter strips, and bioretention;
- During construction, sediment filter bags on inlets and various other E&S BMPs; and
- Maintenance measures such as street sweeping and vacuuming.

Using one or more of these measures before discharging to an infiltration BMP will minimize the accumulation of sediment that could lead to failure of an infiltration BMP. All measures for sediment reduction require regular maintenance.

2. Karst Topography. Karst terrain is characterized by sinkholes, depressions, caves, and underground drainage, and is generally underlain by soluble rocks such as limestone and dolomite. Thick sequences of carbonate bedrock underlie a sizeable area in central and southeastern Pennsylvania. Because natural filtration through soil is limited in karst areas, pollutants in highway stormwater runoff can directly infiltrate underground sources of drinking water and environments that are habitats for sensitive species. Although there is an abundance of literature concerning karst groundwater quality, relatively little research has been conducted addressing the specific impacts of highway runoff to groundwater in karst areas.

It is important to evaluate the appropriateness of structural infiltration BMPs in karst areas on a project-by-project basis. In general, areas with less than 4 feet of soil over carbonate bedrock should be avoided, and ponding depths in infiltration systems should be shallow. Infiltration trenches are not recommended in areas with pronounced karst topography due to the potential for sinkhole formation and groundwater contamination. These limitations should not preclude infiltration altogether. Structural infiltration BMPs may be provided where runoff can be spread over a large area with a shallow maximum ponding depth. This should be done on existing grades, if possible, to avoid excavation and maintain sufficient soil depth above the bedrock. Where infiltration is not feasible, maximize the use of non-structural BMPs and consider structural BMPs with high evapotranspiration characteristics, such as bioretention. Additional information on the use of BMPs in karst areas can be found in Chapter 7 of the *BMP Manual*.

E. Special Considerations.

1. Building and Maintenance Facilities. The Department should consider alternative stormwater solutions at administrative buildings and maintenance facilities, since these areas have less limiting factors than roadway systems. For example, porous pavement and other subsurface infiltration methodologies may be considered on park-and-ride sites and parking areas. Dry wells and other subsurface infiltration methodologies may be considered for building roof drains.

2. Combined Sewer Systems. Combined sewer systems (CSSs) can be found in cities and towns throughout Pennsylvania, including Pittsburgh, Harrisburg, and Philadelphia. These systems were designed to collect stormwater runoff, domestic sewage, and industrial wastewater all in the same pipe. Most of the time, combined sewer systems transport all of their wastewater to a sewage treatment plant. However, during periods of heavy rainfall or melting snow the volume of wastewater can exceed the capacity of the CSS pipes, and excess wastewater empties directly into nearby streams, rivers, or other water bodies. New construction of CSS systems is prohibited, and the old CSS infrastructure in Pennsylvania is gradually being replaced with separate stormwater and sewer systems. The volume and quality of highway stormwater discharges to CSSs can contribute to water quality impacts to receiving surface waters. At a minimum, peak discharge rates into a CSS should not increase because of a project, and practicable alternatives that reduce discharges into a CSS should be considered. Department designs should evaluate conditions and alternatives that facilitate the removal of headwater streams from local collection and conveyance systems. Department projects located in CSS communities should evaluate and incorporate, where feasible, water quality improvement designs to minimize runoff volume and pollutant content, including solids, floatables, and oil/grease. The Department will coordinate and evaluate its project design proposals to be consistent with local Long Term Control Plans and its objectives.

14.3 LEGAL

There are many important laws and regulations both directly and indirectly related to post-construction stormwater management and the size and breadth of these documents do not allow for a short explanation of each. Therefore, this section describes only a partial list of key laws and regulations related to post-construction stormwater management. Some of these laws and regulations contain specific permitting requirements which directly impact post-construction stormwater management whereas other laws and regulations involve permitting programs, such as 25 PA Code § 105, which indirectly affect post-construction stormwater management. Additional information regarding these laws and regulations as they relate to post-construction stormwater management should be obtained from the agencies responsible for the programs (i.e., Environmental Protection Agency (EPA), United States Army Corps of Engineers (USACE), and PA DEP).

A. The Federal Clean Water Act, 33 U.S.C. § 1251 et seq. The Clean Water Act, which was enacted in 1972, was formerly known as the Federal Water Pollution Control Act. Its purpose is to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters." The Clean Water Act sets requirements for water quality standards for the discharge of pollutants into waterways.

The three primary sections of this Act pertaining to stormwater management regulations are Sections 401, 402, and 404 (33 U.S.C. §§ 1341, 1342, and 1344 respectively).

1. Section 401. Section 401 is triggered if the construction or operation of a facility (1) requires a Federal license or approval (e.g. a Section 404 Permit from the U.S. Army Corps of Engineers) and (2) the construction or operation of the facility will cause a discharge into navigable waters. Section 401 requires that an individual applying for a Federal license or permit to discharge into navigable waters provide the permitting agency with a certification from the State (from PA DEP; in Pennsylvania) indicating that the discharge will comply with provisions in Sections 301, 302, 303, 306, and 307 of the Clean Water Act. The aforementioned sections provide the effluent limitations, water quality standards, and performance standards for certain types of activities and discharges. The PA DEP approves this certification, which is commonly referred to as a "401 Water Quality Certification" or 40 CFR Part 121.

2. Section 402. This section of the Clean Water Act requires a permit for the discharge of any pollutant, or combination of pollutants into waters of the United States. This permit is referred to as the National Pollutant Discharge and Elimination System (NPDES) Permit. The purpose of the permit is to ensure that necessary actions are taken to protect water quality and quantity. This section provides for permits for discharges associated with industrial activity and permits for discharges from municipal storm sewers (stormwater). This section defines stormwater associated with construction activity as "industrial activity." EPA has enacted regulations defining the NPDES Permit process. 40 CFR Part 122. PA DEP's NPDES program has been approved by EPA; therefore PA DEP is responsible for the issuance of NPDES Permits.

3. Section 404. This section of the Clean Water Act prohibits the discharge of dredged or fill material into waters of the United States without a permit from the USACE. This permit is referred to as a "Section 404 Permit". As part of the Section 404 Permit, a 401 Water Quality Certification is required from DEP.

The USACE provides for two types of Section 404 permits, general and individual, depending upon the project's complexity, environmental impacts, and location. (It should be noted that general permits include nationwide, regional, and programmatic Section 404 permits). For projects that require a Section 404 Permit and a PA DEP Chapter 105 Permit (as discussed below), a Joint Permit Application is available through the PA DEP, and may be used and submitted to satisfy both the Section 404 and Chapter 105 Permit requirements (the use of the Joint Permit is restricted depending upon certain project conditions). The USACE regulations 33 CFR Parts 325, 320, 323, 330 and EPA regulations 40 CFR Part 122 also apply.

Details regarding Section 404 Permits can be obtained by contacting the USACE, or through their website at www.usace.army.mil. Details regarding the NPDES Permits and Section 401 Water Quality Certification can be obtained from the PA DEP through their website at www.dep.state.pa.us/efacts.

B. Pennsylvania's Clean Streams Law, Act of June 22, 1937 (P.L. 1987, No. 394) as amended 35 P.S. § 691.1 et seq. The Clean Streams Law was enacted in 1937 in order to "preserve and improve the purity of the waters of the Commonwealth for the protection of public health, animal and aquatic life, and for industrial consumption, and recreation..." This law provides for protection of water supplies and water quality, regulates discharges of sewage and industrial waste, regulates mine operations and their impact on water quality, supply and quantity, and regulates stormwater associated with construction activities. Therefore, construction activities fall under the Clean Streams Law. Through this law, the PA DEP is given the power to "establish policies for effective water quality control and water quality management in the Commonwealth of Pennsylvania and coordinate and be responsible for the development and implementation of comprehensive public water supply, waste management, and other water quality plans." This law requires permit approval for discharges from mines, discharge of sewage or industrial waste, and discharge of any other substance that would result in pollution, both directly and indirectly, into waters of the Commonwealth.

Several PA DEP permit processes have been generated through regulations promulgated in part or in whole, pursuant to the Clean Streams Law. Of these, the following list includes, but is not limited to, those permits that have a link to erosion and sediment control and stormwater management:

- NPDES Permit for Stormwater Discharges Associated With Construction Activities.
- NPDES Phase II MS4 Permit.
- E&S Control Permit.

Details regarding these permits can be obtained from the PA DEP through their website at www.dep.state.pa.us/efacts. Select the link to the "Guide to DEP Permits and Other Authorizations."

C. Pennsylvania's Stormwater Management Act, Act of October 4, 1978, P.L. 864 No. 167, 32 P.S. § 680.1 et seq. (as amended by Act 63). The purpose of Act 167 is to encourage planning and management of storm water runoff in each watershed, authorize a comprehensive program of storm water management designated to preserve and restore the flood carrying capacity of Commonwealth streams, and to encourage local administration and management of storm water consistent with the Commonwealth's duty as trustee of natural resources.

The county stormwater management plans are commonly referred to as "Act 167 Plans." The plans evaluate both the hydrologic and hydraulic characteristics of the drainage basins, and are designed to manage stormwater from a quantity and quality perspective. Act 167 Plans are adopted by counties and approved by PA DEP. After an Act 167 Plan is adopted and approved, each municipality is required to adopt and implement ordinances necessary to regulate development and activities within the municipality in a manner consistent with the Act 167 Plan. Moreover, construction using Commonwealth funds within a watershed with an approved Act 167 plan shall be completed in a manner consistent with the plan.

The Pennsylvania Stormwater Management Act (Act 167) is the legislative basis for stormwater management. Section 11 (a) of the Act states that "after adoption and approval of a watershed storm water plan in accordance with this act, the location, design and construction within the watershed of storm water management systems, obstructions, flood control projects, subdivision and major land developments, highways and transportation facilities, facilities for the provision of public utility services and facilities owned or financed in whole or part in by funds from the Commonwealth shall be conducted in a manner consistent with the watershed storm water plan." Thus, wherever an adopted and approved Act 167 plan exists, consistency with that plan is a statutory requirement for PennDOT.

Often, these Act 167 Plans overlap with requirements from the NPDES Construction Stormwater Permit. For NPDES Construction Permits, the Post Construction Stormwater Management (PCSM) Plan always needs to be consistent with the approved Act 167 Plan. PCSM plans also need to meet the design requirements contained in the NPDES construction stormwater permit application. In the rare case that the design requirements in the NPDES construction permit application directly conflict with the requirements in an approved Act 167 plan, the requirements in the approved Act 167 plan take precedence; however, all requirements can usually be satisfied.

This Act also requires any land developer to implement measures: (1) "to assure that the maximum rate of stormwater runoff is no greater after development than prior to development activities;" or (2) "to manage the quantity, velocity and direction of the resulting stormwater in a manner which otherwise adequately protects health and property from possible injury."

D. Federal National Pollutant Discharge Elimination System Phase II. The NPDES Phase II MS4 Program is designed to ensure that government entities located within designated urbanized areas take actions to control/manage stormwater runoff and associated discharges into surface waters. An MS4 is a "municipal separate storm sewer system." Any municipality operating an MS4 within a designated urbanized area must obtain an NPDES Phase II MS4 Permit from DEP. Included within the requirements of this permit process are the development and implementation of a plan to meet six minimum control measures (MCMs); with a time schedule, series of BMPs, and measurable goals required for each MCM. The MCMs include the following:

- Public Education and Outreach.
- Public Participation and Involvement.
- Illicit Discharge Detection and Elimination.
- Construction Site Runoff Control.
- Post-Construction Stormwater Management.
- Pollution Prevention and Good Housekeeping for Municipal Operations and Maintenance.

PennDOT has an NPDES Phase II MS4 Permit which permits the discharge of stormwater from PennDOT facilities to surface waters within the designated urbanized areas. Under the MS 4 Permit, part of PennDOT's compliance with the six minimum control measures described above is to renew and update PCSM and E&S design guidance periodically. Therefore, the designer is not responsible for updating the permit, but following the design guidance provided by PennDOT.

E. Pennsylvania's Dam Safety and Encroachments Act (Act of November 26, 1978 (P.L. 1375 No. 325) as amended, 32 P.S. § 693.1 et seq.) This Act provides for the regulation and safety of dams, reservoirs, water obstructions, and encroachments in the Commonwealth of Pennsylvania. It requires that regulations be developed establishing: 1) standards and criteria for the location and design of dams, water obstructions and encroachments; 2) requirements for operation of dams; 3) requirements for monitoring, inspection, and reporting of conditions affecting the safety of dams, water obstructions, and encroachments; and 4) requirements for emergency warning and action plans, etc. It applies to dams as well as other water obstructions and encroachments located in, along, across, or projecting into any watercourse, floodway, or body of water. Types of activities under this Act's jurisdiction include, but are not limited to, placing fill in waters of the Commonwealth (e.g. wetlands and streams) or the construction of bridges, culverts, or pipes in waters of the Commonwealth. Based on this statute, the construction, operation, maintenance, modification, enlargement, or abandonment of any dam, water obstruction, or encroachment is prohibited without a permit from the PA DEP. This permit is known as either a Chapter 105 Dam Safety Permit or Water Obstruction and Encroachment Permit as described in the following heading for PA Code, Title 25, Chapter 105. The Dam Safety Permit is specific to the design, construction, maintenance, operation, modification, and/or abandonment of dams, while the Water Obstruction and Encroachment Permit is specific to the construction, maintenance, operation, modification, and/or abandonment of water obstructions and encroachments.

F. Commonwealth of Pennsylvania, PA Code, Title 25, Chapter 105: Dam Safety and Waterway Management. Chapter 105 of PA Code, Title 25 is part of the regulatory mechanism for Pennsylvania's implementation of the Dam Safety and Encroachments Act. The Chapter 105 regulations serve to "provide for the comprehensive regulation and supervision of dams, reservoirs, water obstructions and encroachments in the Commonwealth in order to protect the health, safety, welfare and property of the people" by requiring a permit for the construction, operation, maintenance, modification, enlargement, or abandonment of a dam, water obstruction, or encroachment. This permit is typically referred to as a "Chapter 105 Permit."

From a stormwater runoff standpoint, a Chapter 105 Permit requires an analysis of the project's impact on Act 167 Stormwater Management Plans and a letter from the municipality commenting on the analysis. If the stormwater analysis reveals increases in peak rates of runoff or flood elevations, the permit application must also include a description of property that may be affected and an analysis of the degree of risk to the property. Finally, except for small projects, proof of an application for an erosion and sedimentation plan must be included.

There are three types of PA DEP Chapter 105 Permits. They include general permits, small project permits, and individual permits. There are several general permits, each containing specific limits and restrictions. Copies of these permits and their conditions can be obtained from the PA DEP website at www.dep.state.pa.us. Applicants for these general permits need only register their intent to construct the project in accordance with the conditions of the permit. No additional application information is required.

A small project application is required for projects that do not qualify for a general permit, but are considered to have an "insignificant impact" on safety and protection of life, health, property and the environment as defined in Chapter 105.1 of the regulations, and that do not impact wetlands. All other projects require an Individual Chapter 105 Permit.

For projects that require both a PA DEP Chapter 105 Permit (small project or individual permit) and a USACE Section 404 Permit (as discussed above), a Joint Permit Application is available through the PA DEP, and may be used and submitted to satisfy both the Section 404 and Chapter 105 Permit requirements (the use of the Joint Permit is restricted depending upon certain project conditions).

G. Pennsylvania's Flood Plain Management Act, Act of October 4, 1978, P.L. 851, No. 166, 32 P.S. § 679.101 et seq. This Act provides for the regulation of land and water use for flood control purposes. It authorizes a comprehensive and coordinated program, based upon the National Flood Insurance Program, to preserve and restore the efficiency and carrying capacity of streams and floodplains in Pennsylvania. The adoption and administration of floodplain management regulations necessary to comply with the National Flood Insurance Program is governed by the provisions in the Pennsylvania Municipalities Planning Code.

H. Commonwealth of Pennsylvania, PA Code, Title 25, Chapter 106: Floodplain Management. Chapter 106 is part of the regulatory mechanism for implementation of the Flood Plain Management Act. It requires individuals to obtain a permit to construct, modify, remove, destroy, or abandon a highway obstruction or an obstruction in a floodplain. Its primary purpose is to prevent flooding and protect people and property from such flooding, by encouraging planning and development in floodplains that are consistent with sound land use practices. This permit is obtained (for highway projects) from the Pennsylvania PA DEP under the Chapter 105 Program.

I. Commonwealth of Pennsylvania, PA Code, Title 25, Chapter 92: National Pollutant Discharge Elimination System (NPDES) Permitting, Monitoring and Compliance. Chapter 92 was issued under Section 5 and 402 of the Clean Streams Law. Chapter 92 sets forth permitting, monitoring and compliance requirements with regard to the PA DEP implementation of the NPDES program. As part of this process all construction projects with greater than 2.0 ha (5 ac) of earth disturbance are required to obtain an individual NPDES permit to construct the project. Those projects between 0.4 - 2.0 ha (1 - 5 ac) of earth disturbance, which also have a point source of discharge are required to obtain a general NPDES permit. According the PA DEP, a point source discharge is defined as "any discernible, confined and discrete conveyance, including but not limited to, any pipe, ditch, channel, tunnel, well, discrete fissure, or container from which pollutants are or may be discharged."

If applicants meet either of the aforementioned criteria then the project is required to address post-construction stormwater management as part of the permit application package. When completing the supporting documentation for the NPDES permit and preparing a post-construction stormwater management plan applicants must consider the following items.

1. DEP's policy strives for a no net change in stormwater runoff in terms of volume, rate, and water quality comparing pre-construction with post-construction runoff conditions. For runoff rate, DEP's policy calls for the evaluation of the 1- through 100-year storm events. For runoff volume, DEP's policy calls for the evaluation of the 2-year 24-hour storm event or smaller.

2. Consistency with the standards of watershed-based stormwater management plans approved and implemented under the Stormwater Management Act (Act 167).

3. Application of both rate control and also volume control of stormwater runoff in High Quality or Exceptional Value watersheds. Volume increases may be permitted, if justified, in High Quality Watersheds but any increase in post-construction stormwater runoff volume must be mitigated in Exceptional Value watersheds. For a map or listing of High Quality or Exceptional Values watersheds in Pennsylvania contact the Pennsylvania Department of Environmental Protection (PA DEP). As the performance standards for post construction stormwater management controls in HQ or EV watersheds are frequently changing, designers should review current PA DEP requirements and contact the District Environmental Manager for current performance standards for a project prior to initiating the design.

For further description of the NPDES application process and how it relates to PennDOT projects refer to Publication 13M, Design Manual, Part 2, *Highway Design*, Section 13.5.B.2.

J. Commonwealth of Pennsylvania, PA Code, Title 25, Chapter 93: Water Quality Standards. The provisions of this chapter were issued under sections 5 and 402 of the Clean Streams Law. Chapter 93 sets forth water quality standards for waters of the Commonwealth, including wetlands. In addition, this chapter provides for the implementation of antidegradation requirements to protect existing use of waters of the Commonwealth. In watersheds designated as High Quality (HQ) or Exceptional Value (EV), Chapter 93 requires that nondischarge alternatives be considered. Where no environmentally sound and cost-effective nondischarge alternatives exist, Chapter 93 requires that the applicant demonstrate that the discharge will maintain and protect the existing quality of receiving surface waters. For High Quality Waters, DEP may allow a reduction in water quality (1) if necessary to accommodate important economic or social development in the area; and (2) a demonstration is made that said reduction will support applicable existing and designated uses, e.g. WWF, TSF, CWF. For a list of special protection watersheds, contact the PA DEP.

K. Commonwealth of Pennsylvania, PA Code, Title 25, Chapter 102: Erosion and Sediment Control. Chapter 102 of PA Code, Title 25, does not deal directly with long-term stormwater management but addresses the application of the National Pollution Discharge Elimination System as it relates to construction and maintenance projects in the state of Pennsylvania. The focus of Chapter 102 is to implement and maintain BMPs to minimize potential for accelerated erosion and sedimentation during construction activities. The Erosion and Sedimentation Pollution Control (E&SPC) Plan is the product of the Chapter 102 process. The E&SPC plan is normally reviewed and approved by the County Conservation Districts.

Table 14.4 Relationship of Activities, Regulations, and Permits for Stream Work

Activity*	Regulations	Requirements/Permits
Discharging Stormwater Into Surface Waters	PA Clean Streams Law Federal Clean Water Act, Sections 402 Federal NPDES Regulations at 40 CFR Part 122 PA Stormwater Management Act PA Code, Title 25, Chapter 92: NPDES Permitting, Monitoring, and Compliance PA Code, Title 25, Chapter 102: Erosion and Sediment Control	The NPDES regulations (40 CFR § 122), and Chapter 92 require that construction activities with disturbances of 5 or more acres, or those that disturb between 1 and 5 acres with a point source discharge be permitted, as per the NPDES Permit for Stormwater Discharges Associated With Construction Activities. Stormwater is then managed by NPDES after construction through the NPDES Phase II Permit.
Stream Encroachment or Obstruction	Federal Clean Water Act, Sections 401 and 404 PA Dam Safety and Encroachments Act PA Code, Title 25, Chapter 105: Dam Safety and Waterway Management PA Code, Title 25, Chapter 102: Erosion and Sediment Control Federal NPDES Regulations at 40 CFR Part 122 PA Code, Title 25, Chapter 92: NPDES Permitting, Monitoring, and Compliance	Work that creates or allows water runoff, effluent, or other pollutants to be discharged into navigable waters requires a Section 401 Water Quality Certification to ensure water quality standards are met. A USACE Section 404 Permit is required to allow for the discharge of dredged or fill material into navigable waterways. A Chapter 105 Permit is needed for any structure or activity that changes, expands, or diminishes the course, current, or cross section of a watercourse, floodway, or body of water. In addition, these activities will likely involve earth disturbance activities and discharges into waters, thereby requiring permits as described above in this table and an E&S Plan as per Chapter 102. The NPDES regulations (40 CFR § 122), and Chapter 92 require that construction activities with disturbances of 5 or more acres, or those that disturb between 1 and 5 acres with a point source discharge be permitted, as per the NPDES Permit for Stormwater Discharges Associated With Construction Activities. Structures that require less than 1 acre of earth disturbance will not require an NPDES permit.
Dam Construction / Removal	PA Dam Safety and Encroachments Act PA Code, Title 25, Chapter 105: Dam Safety and Waterway Management	Dam construction or removal will require a Dam Safety Permit, as well as a PA DEP Chapter 105 Permit (or qualify for a waiver). In addition, this activity may involve earth disturbance activities and discharges into waters, thereby requiring permits as described above in this table.

* Activities that occur within EV or HQ Watersheds, as per PA Code, Title 25 Chapter 93, require an Individual NPDES Permit for Stormwater Discharges Associated With Construction Activities.

14.4 LEVEL 1 TOOLBOX

Information about each of the stormwater BMPs for Level 1 projects is provided in this section. Any of these BMPs may be used for higher-level projects as well.

A. Minimize Compaction. The post-construction runoff from a project can be reduced by minimizing the amount of area that is compacted. Compaction of a previously undisturbed area can significantly reduce the infiltration capacity of that soil. This non-structural BMP can be applied to almost every project. Compaction is normally a planned construction activity, but it can also occur unintentionally, such as by the weight of construction vehicles. Well-planned staging of construction activities can reduce the need to disturb uncompacted areas outside of the construction footprint. Areas specifically designated for staging and temporary construction measures should be described in the E&S plans and clearly marked in the field by the contractor.

B. Preserve Trees and Re-vegetate Using Native Species. Clearing of forested areas, including riparian buffers, should be limited to only those areas that are essential for construction operations. Well-planned staging of construction activities can reduce the need to disturb wooded areas outside of the construction footprint. Similar to minimizing compaction, this non-structural BMP can be applied to almost every project. Highway projects involving new alignments sometimes involve abandoning existing sections of highway. These areas may provide opportunities to offset the stormwater-related impacts of the new alignment. By removing pavement and planting the abandoned areas with native vegetation, the abandoned areas can be made to resemble pre-existing conditions.

C. Maintenance of Dual-Purpose E&S/PCSM BMPs. Temporary E&S facilities, such as sediment traps and basins, are often converted into permanent stormwater management facilities, such as detention or infiltration basins. Similarly, existing stormwater basins may be retrofit with temporary flow control devices to provide E&S functions during construction. Maintenance of these facilities during construction is critical in ensuring that the infiltration capacity at the bottom of the facility is preserved. E&S plans should specify that heavy equipment is to be kept off of the bottom of the facility, and accumulated sediments must be removed upon stabilization of the contributing drainage areas.

D. Restoration of Temporary Staging Areas. Temporary staging areas are a necessary part of most roadway projects. Construction materials and equipment are often stored in medians, open areas in interchanges, or just off shoulder areas. This activity often result in soil compaction and loss of vegetation within the staging area. Areas designated for staging should be returned to their pre-construction condition when use of the staging area is no longer needed.

E. Summary. See table below.

Table 14.5 Level 1 BMP Toolbox Summary

Stormwater BMP	**Reference**	**Application**
Minimize compaction	Ch 5.6.2 [a]	Designate areas for construction vehicle traffic to prevent unintended compaction
Preserve trees and re-vegetate using native species	Ch 5.6.3 [a]	Preserve trees by clearing only those that are safety hazards and that are necessary for construction; preserve riparian buffers; clearly mark overall limits of disturbance; re-vegetation of abandoned alignment; re-vegetate temporary staging areas
Maintenance of dual-purpose E&S/PCSM BMPs	Ch 12 [b]	Proper maintenance and conversion of E&S control facilities, such as sediment basins, into permanent PCSM facilities, such as infiltration basins
Restoration of temporary staging areas	Ch 6.7.3 [a]	Restore areas used for temporary staging or storage of materials by replacing or supplementing the soil and re-vegetating the disturbed areas

[a] *BMP Manual*, 2006; [b] PennDOT PDM, Current Edition.

14.5 LEVEL 2 TOOLBOX

Information about each of the stormwater BMPs for Level 2 projects is provided in this section. Any of these BMPs may be used for higher-level projects as well.

A. Street Sweeping. Street sweeping is an effective non-structural BMP for removing pollutants before they are carried away by runoff into storm sewers or an adjacent stream. Applications may be limited to projects with highly impervious surroundings and few opportunities for vegetative or structural BMPs. It is effective in removing all three of the representative pollutants in the *BMP Manual*: TSS, TP, and TN. Sweeping frequencies and cleaning routes should be chosen to optimize overall sweeping efficiencies. For example, sweeping should be assessed before any regional wet season to remove accumulated sediments. Certain conditions, such as streets with high traffic volumes and streets with high erosion zones, may also warrant increased sweeping frequencies. The maintenance manager in the District where the project is located should be consulted prior to submitting a permit where this BMP is proposed.

B. Impervious Disconnection. A number of potential stormwater impacts can be reduced or eliminated by installing BMPs in between impervious areas and storm sewers. Direct connection is primarily an issue with curbed roadways, where runoff is forced into catch basins, which are part of the storm sewer collection system. This common type of design quickly and efficiently removes runoff from the roadway to prevent ponding hazards. The problem with this system is that it usually results in (1) a decreased time of concentration, (2) an increase the peak flow rate, (3) an increase in the total runoff volume, and (4) no removal of pollutants from the runoff. Two ways to achieve disconnection are to (1) eliminate curbs and gutters, and (2) redirect road and driveway runoff into grassed swales or other vegetated systems designed to receive stormwater. Where curb and gutter cannot be eliminated for safety, right-of-way, or other practical reasons, carefully designed curb cuts may be used to allow runoff to spill into an adjacent vegetated BMP.

C. Slope Roughening. Known as a time of concentration (T_c) practice, slope roughening increases the time it takes for runoff to flow across a site to the drainage point or a BMP. Slowing runoff velocity potentially reduces erosion and increases the potential for infiltration. This BMP can include slope terracing, surface roughening, contouring, benching, and other similar methods of creating stabilized irregularities in graded slopes. Instead of allowing runoff to sheet flow down an embankment, these surface features (1) reduce erosion potential by slowing down the flow, (2) create pockets of small depressions that capture and reduce the total volume of runoff, and (3) encourage infiltration on the slope. When applied to slopes at bridge sites, the turbulence that this BMP creates aids in oxygenating the runoff before it discharges into the stream. Surface roughening has traditionally been used as an E&S measure to reduce erosion potential and prepare a slope to receive vegetation. Slopes steeper than 2:1 may be benched or stepped.

D. Pavement Width Reduction. The Department has standard pavement widths for various road classifications. Whenever a proposed design uses shoulder or lane widths that are less than the design standards, it should be noted in the PCSM plan. This is a self-crediting BMP, meaning that by not using the additional pavement width, the total volume of runoff is proportionally reduced. It is a good idea to document the amount of additional runoff that was not generated by using a design exception in the PCSM plan.

E. Riparian Buffer Restoration. Riparian buffers are areas adjacent to streams, ponds, etc., that protect those water resources from pollution, prevent bank erosion, provide wildlife food and cover, and shade the adjacent water, moderating temperatures for aquatic species. Buffers are transition areas between aquatic and upland environments. Department projects that are adjacent to bodies of water with depleted riparian buffers may consider restoration as a structural BMP. Riparian buffers are complicated natural features that require a diverse group of expertise to effectively design restoration strategies. Restoration design should be coordinated with PA DEP early in project development.

F. Landscaping and Planting. Landscape restoration is the general term used for actively sustainable landscaping practices that are implemented outside riparian (or other specially protected) buffer areas. Landscape restoration includes the restoration of forest (i.e., reforestation) and/or meadow and the conversion of turf to meadow. In a truly sustainable site design process, this BMP should be considered only after the areas of development that require landscaping and/or revegetation are minimized. The remaining areas that do require landscaping and/or revegetation should be driven by the selection and use of vegetation (i.e., native species) that does not require significant chemical maintenance by fertilizers, herbicides, and pesticides.

G. Soil Amendments. Soil amendments, which include both soil conditioners and fertilizers, make the soil more suitable for the growth of plants and increase water retention capabilities. Compost amendments and soils for water quality enhancement are also used to enhance native or disturbed and compacted soils. These measures change the physical, chemical, and biological characteristics of the soil allowing it to more effectively reduce runoff volume and filter pollutants. Vegetated swales and grass filter strips can be treated with soil amendments to improve performance and increase their permeability. A variety of techniques are included as potential soil amendments including aerating, fertilizing, and adding compost, other organic matter, or lime to the soil. Appropriate application of fertilizers and other soil amendments is important to prevent the discharge of excess of nutrients (loading) into nearby surface waters.

H. Vegetated Swale. Vegetated swales are one of the most commonly used BMPs along roads because of their ability to fit within limited right-of-way space while providing both drainage and PCSM functions. Vegetated swales are broad, shallow, typically trapezoidal channels that receive runoff from adjacent impervious surfaces and are designed to slow it down, promote infiltration, and filter pollutants and sediments in the process of conveying the runoff. Vegetated swales can receive runoff from concentrated sources (e.g., pipe outfalls), as well as from lateral sheet flow along the length of the channel. They are well suited for use along roads, either as swales in a cut section of a shoulder or in the median receiving runoff from both sides of a divided highway. They can also be used for storm sewer outlet channels and top of cut ditches.

The simplest form of a vegetated swale consists of a band of dense vegetation that can include a variety of trees, shrubs, and/or grasses. Under the vegetated surface layer is approximately 600 mm (24 in) of permeable soil (minimum 13 mm/hr (0.5 in/hr) infiltration rate) containing a high level of organic matter. An acceptable variation is known as a dry swale, which is essentially a vegetated swale with an infiltration trench. Check dams can also be used to reduce velocities in channels that have a longitudinal slope greater than 3 percent. Turf reinforcement mats can be used to provide enhanced stabilization within the channel to prevent erosion. Salt-tolerant vegetation, such as creeping bentgrass and switchgrass, should be considered in areas with regular deicing of roads in the winter.

Examples of retrofitting existing swales (Level 2 toolbox) include: replacing or modifying poorly draining soils in the swale; adding an organic layer (i.e., compost) to encourage bioretention; replanting with species that offer greater evapotranspiration opportunities; and retrofitting ditches with check dams to provide storage in the channel. A rock-lined ditch that discharges directly into a surface water may be a good candidate for retrofitting with a turf reinforcement mat and vegetation. If it is not practicable to construct swales on both sides of road, the capacity of the swale can be increased to capture more runoff on one side of the road while releasing all of the runoff from the other side.

Table 14.6 Vegetated Swale Summary

Location	Median Swale in cut section Top of slope ditch	
Effectiveness	Water quality High Volume Medium Peak discharge Medium	
Key Design Elements	• DA ≤ 2 ha (5 ac) • Min. 600 mm (24 in) between bottom and bedrock/seasonal high GWT • Longitudinal slopes from 1%-6% • Use 150-300 mm (6-12 in) high check dams to increase retention • Side slopes from 3:1 to 5:1 • Bottom width 0.6-2.4 m (2-8 ft)	Vegetated swale along roadside

I. Bioretention. Bioretention is a method of treating stormwater by pooling water on the surface and allowing filtering and settling of suspended solids and sediment at the mulch layer, prior to entering the plant/soil/microbe complex media for infiltration and pollutant removal. Bioretention cells, also called raingardens, cause retention of runoff through exfiltration into the subsoil (if subsoil has adequate permeability), subsurface storage below the underdrain (if present), and evapotranspiration by vegetation. Detention storage is provided through a combination of surface ponding with control structures and subsurface storage in soil and gravel layers above the underdrain. Common areas of application for highway projects include medians, areas adjacent to local/urban roads and intersections, and parking or median islands. Several examples of road and parking application are shown in the *BMP Manual*.

Table 14.7 Bioretention Summary

Location	Median Swale in cut section Top of slope ditch	
Effectiveness	Water quality High Volume Medium Peak discharge Medium	
Key Design Elements	• DA ≤ 0.2 ha (0.5 ac) • Min. 600 mm (24 in) between bottom and bedrock/seasonal high GWT • Native, perennial vegetation • Provide overflow system	Bioretention along roadside

J. Vegetated Filter Strip. Vegetated filter strips are a common and often overlooked BMP. They are gently sloping, densely vegetated areas that filter, slow, and infiltrate sheet flowing stormwater. They are essentially buffers between runoff from impervious areas and a receiving body of water. Filter strips can be best utilized along roads and next to parking areas where runoff flows off the pavement via sheet flow and into a filter strip. This scenario is possible for roads at grade or in a fill condition; it does not work for a section in cut. The effectiveness of filter strips can be improved by adding a pervious berm at the toe of the slope. Check dams can also be implemented on filter strip slopes exceeding 5 percent. Level spreaders can be used to spread flow over a larger area so as not to create a point-source discharge.

Table 14.8 Vegetated Filter Strip Summary

Location	Adjacent to road/shoulder or parking lot	
Effectiveness	Water quality High Volume Low/Medium Peak discharge Low	
Key Design Elements	• Contrib. DA slope ≤ 5% • Filter strip slope < 5% preferred; 8% max. • Min. width should be ≥ width of DA • Effectiveness is a function of slope, vegetative cover, and soil type • Check dams can be used on slopes > 5%	Vegetated filter strip in median

K. Constructed Wetland / Wet Pond. Retrofit of existing stormwater basins only. Refer to Section 14.8.A and Section 14.8.B for additional information on constructed wetlands and wet ponds, respectively.

L. Summary. See Table 14.9.

Table 14.9 Level 2 BMP Toolbox Summary

Stormwater BMP		Reference	Application
Non-Structural	Street sweeping	Ch 11 [b] Ch 5.9.1 [a]	Most effective in urban areas for removing debris and sediment on roads; bridges over HQ/EV waters
	Impervious disconnection	Ch 5.8.2 [a]	Disconnect road from storm sewer; eliminate curb/gutter where possible and provide curb cuts to allow flow into parallel BMPs
	Slope roughening	N/A	Includes surface roughening, grooving, tracking, stepping, etc.; use on slopes to reduce erosion potential and increase ET
	Pavement width reduction	Ch 5.7.1 [a]	Use minimum allowable pavement widths; consider design exceptions where adjacent road sections are narrow
Structural – Restoration	Riparian buffers	Ch 6.7.1 [a]	Reestablish buffer areas along stream; minimum 10.5 m (35 ft) width from top of bank
	Landscaping and planting	Ch 6.7.2 [a]	Use non-invasive native species vegetation in lawn areas and on slopes, to enhance water uptake and the storage of certain pollutants in plant tissue. Use sod-forming grasses adjacent to the roadway shoulders and for vegetated swales to serve as filters for suspended solids and metals.
	Soil amendments	Ch 13 [b] Ch 6.7.3 [a]	Replace poorly draining soils in swales or other areas receiving runoff with a permeable/organic mix of soil
Structural – Retrofitting	Vegetated swales	Ch 14 [b]	Convert ordinary shoulder swales and rock-lined ditches to vegetated swales (see BMP descriptions); use check dams; supplement with subsurface storage if necessary
	Bioretention	Ch 5 [b] Ch 6.4.5 [a]	Convert median areas on low-volume roads and intersections to vegetated areas or replant existing vegetated areas with species that offer greater ET
	Vegetated filter strip	Ch 6.4.9 [a]	Receives sheet flow directly from pavement edge; used on embankment slopes of fill sections and adjacent to flat sections
	Constructed wetlands / Wet ponds	Ch 6.6.1 [a] Ch 6.6.2 [a]	Retrofitting an existing dry detention basin only

[a] *BMP Manual*, 2006; [b] TRB Evaluation of BMPs for Highway Runoff Control, 2006

14.6 LEVEL 3 TOOLBOX

Information about each of the stormwater BMPs for Level 3 projects is provided in this section. Any of these BMPs may be used for higher-level projects as well.

A. Bioslope. Bioslopes (also called "ecology embankments") are embankments that treat runoff by rapid filtering through an engineered soil media commonly known as an ecology mix. Bioslopes use a variety of physical, chemical, and biological processes to improve water quality. Bioslopes are similar to vegetated filter strips, but instead of filtering runoff via sheet flow through thatch and surface soils, runoff is rapidly infiltrated into a gravel trench and then filtered via subsurface flow through the ecology mix. A bioslope is usually indistinguishable from ordinary embankments, and its footprint is usually contained within the embankment.

Bioslopes cause retention of runoff through exfiltration into the subsoil (if subsoil has adequate permeability), storage in the gravel trench below the underdrain (if present), and evapotranspiration by vegetation. Credit for volume reduction should not be taken for any portions of the bioslope footprint that are above compacted soils. Bioslopes have minimal detention storage because they do not allow ponding and the ecology mix drains rapidly. However, peak discharges are still reduced because of movement across the vegetated surface, percolation through the ecology mix, and infiltration into the subsoil (if subsoil has adequate permeability).

Figure 14.1 Bioslope Example

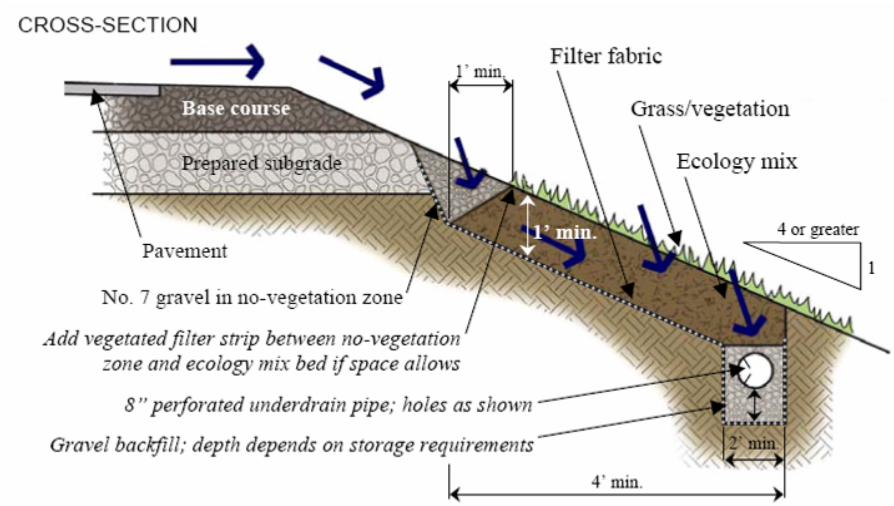


Table 14.10 Bioslope Summary

Location	Median embankment Side slope	
Effectiveness	Water quality High Volume Medium Peak discharge Medium	
Key Design Elements	• Side slope 4:1 to 7:1 preferred; 3:1 max. • Max. 4% longitudinal gradient • Max. slope length is 9 m (30 ft) • Plant with a native grass mix	Bioslope application on embankment

B. Dry Extended Detention Basin. Detention basins are depressed areas that store runoff during wet weather and release it at a controlled rate to reduce the impact of changes in land cover and land use on stormwater runoff. As implied by their name, under normal weather conditions these ponds are typically designed to be dry when it is not raining, or shortly thereafter. Refer to Section 14.16 for detailed design information.

C. Infiltration Trench. An infiltration trench is an excavated trench lined with filter fabric and backfilled with stone. These systems encourage stormwater infiltration into subsurface soils and work well in space-limited applications. Stormwater can enter a trench via sheet flow from open-section roadways or by channelized flow from swales or storm drain outlets. When located adjacent to roadways, the subsurface drainage direction should be to the downhill side (away from pavement subbase), or located lower than the impervious subbase layer. Proper measures should be taken to prevent water infiltrating into the pavement subbase. Infiltration trenches may be used in conjunction with vegetated swales, roadway drainage systems, or both (i.e., a swale over a pipe running between inlets). A common application is to place a flat run of continuously perforated storm sewer in an infiltration trench. The design storm is conveyed through the system the same way it would through a normal storm sewer; however, smaller rain events have time to drain through the perforations and into the gravel bed. Pretreatment of runoff prior to discharging into the infiltration trench is recommended in order to increase the life and effectiveness of the facility. Sediment traps in the storm sewer inlets (inlet invert is 150-300 mm (6-12 in) below pipe invert) and vegetated filters are examples of pretreatment.

Table 14.11 Infiltration Trench Summary

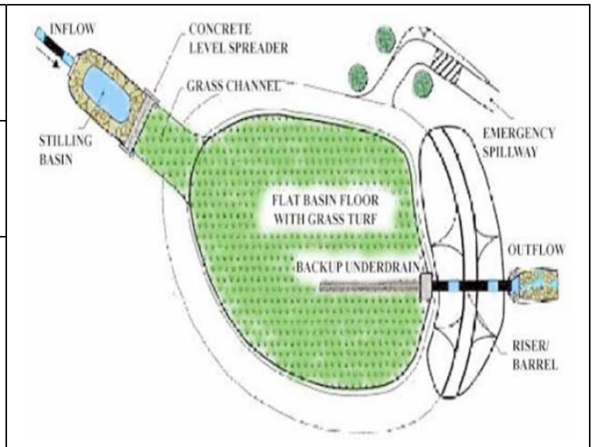
Location	Median Shoulder swales Between curb and sidewalk	
Effectiveness	Water quality Medium Volume Medium Peak discharge Medium	
Key Design Elements	• DA ≤ 2 ha (5 ac) • Min. 600 mm (24 in) between bottom and bedrock/seasonal high GWT • Min. 1.5 m (5 ft) from edge of road • Include underdrain if infiltration rate is < 25 mm/hr (1 in/hr) • Trench invert Elev. < than road subbase Elev.	Curb opening (impervious disconnection) into an infiltration trench. Although not apparent here, a positive overflow device must be provided.

D. Infiltration Basin. Infiltration basins are shallow, impounded areas designed to temporarily store and infiltrate stormwater runoff. Sizes and shapes can vary from a single large basin to multiple, smaller basins throughout a project site. Infiltration basins reduce the volume of stormwater runoff by infiltration and evapotranspiration. Poor soils may be amended by adding sand or gravel to the surface layer to increase the permeability.

Traditional stormwater management basins can be combined with infiltration basin concepts to provide peak flow detention for larger storms and the required volume control. The combined detention/infiltration basin can be utilized at the discharge points of drainage systems or placed in large median areas where positive basin outflow is provided and subbase drainage is not impeded. During the winter months, there will be many occasions when the soil beneath an infiltration basin is frozen and long-duration ponding will occur; therefore, infiltration basins must be placed in areas where this does not create a safety hazard. When runoff containing salt-based deicers is directed to an infiltration basin, soil may become less fertile and less capable of supporting vegetation. Using salt-tolerant plants and incorporating mulch into the soil can help to mitigate this problem. Infiltration basins should not be used to store snow from highways or parking lots because the sand in the snow can clog the basin, and the chlorides and other pollutants can contaminate the groundwater.

Table 14.12 Infiltration Basin Summary

Location	Median Interchange areas Rest stop/park-and-ride lot
Effectiveness	Water quality Medium Volume Low Peak discharge Medium/High
Key Design Elements	• Uncompacted subgrade • Retain increase in 2-yr storm runoff volume • Min. 600 mm (24 in) between bottom and bedrock/seasonal high GWT • 5:1 max. impervious-to-infiltration area



Conceptual Infiltration Basin

E. Infiltration Berm. An infiltration berm is a mound of compacted earth with sloping sides that is usually located along (i.e., parallel to) a contour in a moderately sloping area. Berms create shallow depressions that collect and temporarily store stormwater runoff, allowing it to infiltrate into the ground and recharge groundwater. Berms are ideal in areas where runoff is free to discharge over slopes. The berm can be installed parallel to the road and intercept runoff prior to being discharged into adjacent areas or bodies of water. Berms can be constructed on disturbed slopes and revegetated as part of the construction process. Infiltration berms may also be constructed in combination with a subsurface infiltration trench at the base of the berm to increase the retention capacity.

Table 14.13 Infiltration Berm Summary

Location	Side slope
Effectiveness	Water quality Medium/High Volume Low/Medium Peak discharge Medium
Key Design Elements	• Constructed parallel to contours • Min. 600 mm (24 in) between bottom and bedrock/seasonal high GWT • 600 mm (24 in) max. height • Side slope 4:1 max. • Can be retrofitted on slopes w/o causing significant disturbance

Infiltration berm

F. Summary. See Table 14.14.

Table 14.14 Level 3 BMP Toolbox Summary

Stormwater BMP	Reference	Application
Vegetated swales	Ch 14 [b] Ch 6.4.8 [a]	Shoulder swales, medians, top of cut ditches, storm sewer outlet channels; use check dams to increase volume capacity; plant with salt-tolerant vegetation such as creeping bentgrass and switchgrass
Bioretention	Ch 5 [b]	Divided highway medians; can combine with infiltration trench to increase volume capacity
Bioslopes	Ch 6 [b]	Embankments with engineered soil media; similar to vegetated filter strip except filtering occurs below the surface
Dry extended detention basin	Ch 14 Ch 6.6.3 [a]	Traditional detention basins; use where infiltration is not feasible and wet ponds are undesirable (safety concerns, etc.)
Infiltration trench	Ch 9 [b] Ch 6.4.4 [a]	Design as part of a storm sewer system using perforated pipes: virtually no release of small storm events and normal conveyance of large events; can incorporate with vegetated swales; limited use in karst topography
Infiltration basin	Ch 6.4.2 [a]	Use in conjunction with an extended stormwater detention for peak flow detention; limited use in karst topography; ideal in interchanges
Infiltration berm	Ch 6.4.10 [a]	Locate between roadway and adjacent surface water; place parallel to contours on 4:1 or flatter slopes; can be combined with an infiltration trench; limited use in karst topography

[a] *BMP Manual*, 2006; [b] TRB Evaluation of BMPs for Highway Runoff Control, 2006

14.7 LEVEL 4 TOOLBOX

Information about each of the stormwater BMPs for Level 4 projects is provided in this section. These BMPs should only be considered for Level 4 projects.

A. Constructed Wetland. Constructed wetlands (CWs) are shallow marsh systems planted with emergent vegetation that are designed to treat stormwater runoff. They can provide considerable aesthetic and wildlife benefits, but require a relatively large amount of space and an adequate source of inflow to maintain the permanent water surface. CWs improve runoff quality through settling, filtration, uptake, chemical and biological decomposition, volatilization, and adsorption. They are effective at removing many common stormwater pollutants including suspended solids, heavy metals, total phosphorus, total nitrogen, toxic organics, and petroleum products. Peak rate is primarily controlled through the transient storage above the normal water surface. Although not typically considered a volume-reducing BMP, CWs can achieve some volume reduction through evapotranspiration, especially during small storms. CWs are a good option for retrofitting existing detention basins.

Table 14.15 Constructed Wetland Summary

Location	Median Interchange areas Rest stop/park-and-ride lot
Effectiveness	Water quality High Volume Low Peak discharge High
Key Design Elements	• 2-4 ha (5-10 ac) min. DA needed or sustained base flow • 2:1 length to width ratio • Relatively impermeable soils or engineered liner • Sediment forebay at inlet • Can be combined with wet pond design

Constructed wetland next to highway

B. Wet Pond. Wet ponds, also known as retention basins, are stormwater basins that include a substantial permanent pool for water quality treatment and additional capacity above the permanent pool for temporary runoff storage. Wet ponds are effective for pollutant removal and peak rate mitigation, but do not achieve significant groundwater recharge and volume reduction. Unlike infiltration basins, the permanent pool is a key feature and infiltration is discouraged. Wet ponds should have low permeability soils at the bottom and, where possible, be excavated to close to or below the groundwater table. Interchanges are usually ideal for wet ponds because the basin is surrounded by pavement and receives runoff from all directions. Trees and other types of vegetation should be planted around the perimeter to keep the water in the pond cool and reduce potential thermal impacts. In populated areas, wet ponds may not be desired because of potential mosquito issues. Wet ponds are generally not the preferred BMP when the facility discharges directly into temperature-sensitive water (such as those with temperature TMDLs). Extended detention facilities should (1) be designed with a minimal permanent pool; (2) preserve existing shade trees and plant fast growing trees along the shoreline, but not on the constructed embankment; (3) align ponds in a north-south direction; and (4) avoid excessive riprap and concrete channels that impart heat to runoff. Specific design parameters for wet ponds can be found in Section 14.17.

Table 14.16 Wet Pond Summary

Location	Median Interchange areas Rest stop/park-and-ride lot
Effectiveness	Water quality Medium Volume Low Peak discharge High
Key Design Elements	• 2-4 ha (5-10 ac) min. DA needed • Need a natural high GWT • Average depth 0.9-1.8 m (3-6 ft); 2.4 m (8 ft) max. • Relatively impermeable soils or engineered liner • Sediment forebay at inlet • Vegetation type and location is critical

Wet pond with sediment forebay

C. Permeable Pavement. Permeable pavement consists of a pervious surface course underlain by a uniformly-graded stone bed that provides temporary storage for peak rate control and promotes infiltration. The surface course may consist of porous asphalt, porous concrete, or various porous structural pavers laid on uncompacted soil.

Permeable pavements are best suited for areas that will not be subject to high traffic volumes or high rates of travel speed. Paver blocks are not suitable for high rate travel speeds because of the block design, and the open graded asphalt and concrete in permeable pavements does not wear well in travel lanes. Proper construction is critical for permeable pavement to function properly and, therefore, must be undertaken in such as way as to prevent (1) compaction of underlying soil, (2) contamination of stone subbase with sediment and fines, (3) tracking of sediment onto pavement, and (4) drainage of sediment-laden waters onto pervious surface or into constructed bed.

Table 14.17 Permeable Pavement Summary

Location	Park-and-rides Parking lots Pull offs	Walking paths Sidewalks	
Effectiveness	Water quality Volume Peak discharge	Medium Medium/High Medium/High	
Key Design Elements	• 300-900 mm (12-36 in) typical infiltration bed depth • Uncompacted subgrade • Backup drainage system needed in case pavement area becomes clogged		Porous pavement parking lot

D. Manufactured Products. Certain types of manufactured products, such as water quality inlet inserts, may be used with prior approval from the Bureau of Design, Highway Quality Assurance Division.

E. Summary. See Table 14.18.

Table 14.18 Level 4 BMP Toolbox Summary

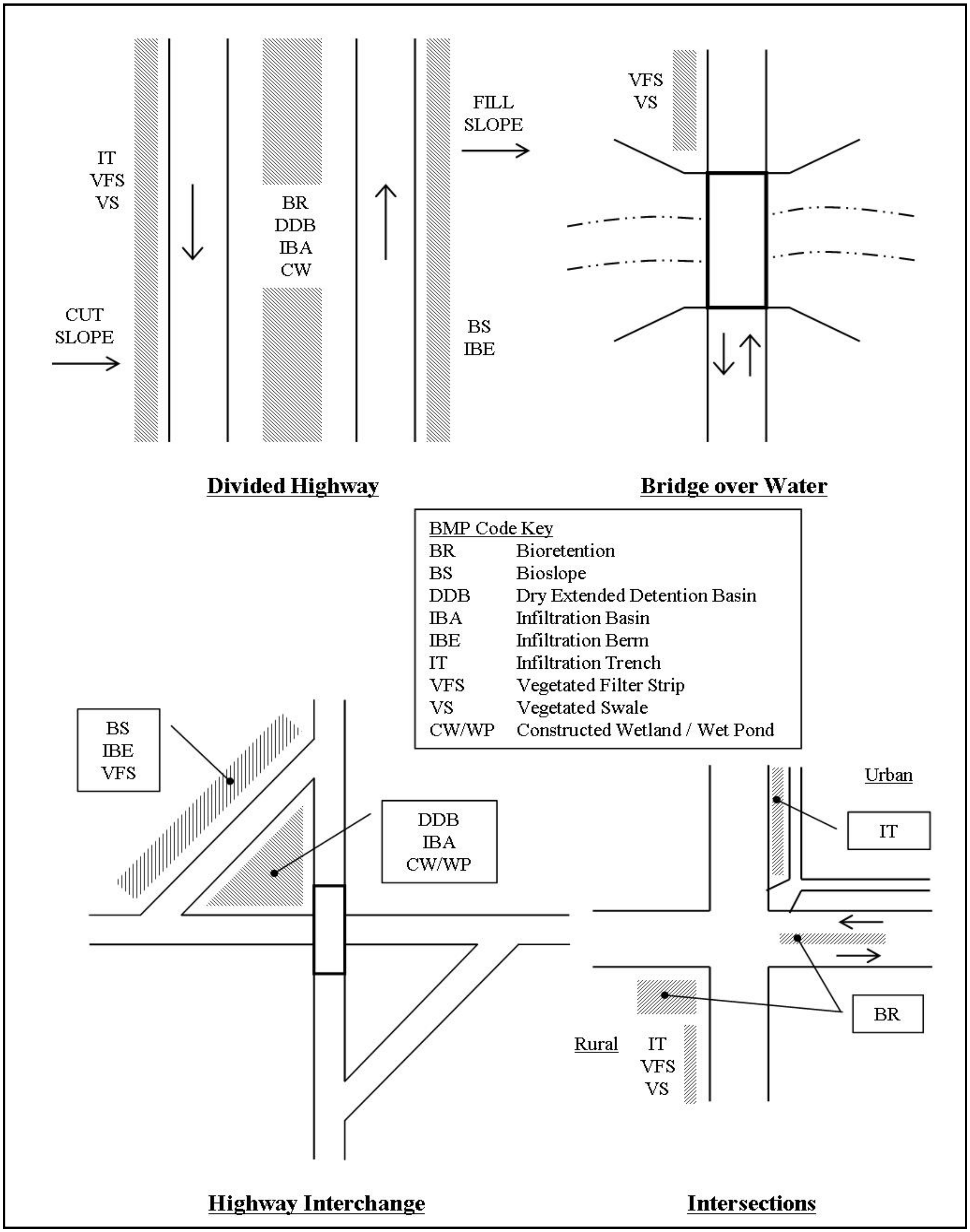
Stormwater BMP	**Reference[1]**	**Application**
Constructed wetlands / Wet ponds	Ch 6.6.1 [a] Ch 6.6.2 [a]	Significant detention of peak flow rates is needed and the contributing drainage area is large; retrofit existing detention basins are construct new in open median or interchange areas
Permeable pavement	Ch 10 [b] Ch 6.4.1 [a]	Limited to park-and-ride sites and parking lots
Manufactured products: subsurface storage, water quality inlets, etc.	Ch 6.6.3 [a] Ch 6.6.4 [a]	Subsurface storage products are designed to temper peak runoff events through infiltration and/or discharge rate reduction. Storm sewer inlet structures or inserts are designed to minimize the discharge of solids, floatables, and oil/grease pollutants. Regular maintenance of these products is necessary and is an important factor in assessing the feasibility of using one of these products.

[a] *BMP Manual*, 2006; [b] TRB Evaluation of BMPs for Highway Runoff Control, 2006

14.8 AREAS OF APPLICATION

Figure 14.2 depicts four typical types of Department projects and the structural BMPs that would most often be applicable for each type of project. This figure does not preclude the use of a BMP in any of these areas if adequate design documentation is provided.

Figure 14.2 Common Structural BMP Applications



14.9 STORAGE FACILITIES

A. Introduction. The use of storage facilities to provide improved stormwater management has increased dramatically in recent years. Initially these controls were primarily focused on controlling the rate of runoff but in recent years the focus and use of these features has changed from providing solely rate control to addressing both the quality and quantity (rate and volume control) of the stormwater runoff.

B. Quality. Control of stormwater quality using storage facilities offers the following potential benefits:

- Decreased downstream channel erosion and degradation.
- Maintained biologic diversity in receiving watercourses.
- Improved water quality through:
  - Stormwater filtration.
  - Capture, reduction and removal of non-point source pollutants.

C. Quantity. Controlling the quantity of stormwater using storage facilities can provide the following potential benefits:

- Reduction of peak runoff rate caused by development.
- Reduction in the volume of runoff caused by development.
- Mitigation of downstream drainage capacity problems.
- Recharge of groundwater resources which can help maintain baseflow in streams.
- Reduction or elimination of the need for downstream outfall improvements.
- Maintenance of historic low-flow rates by controlled discharge.

D. Objectives. The objectives for managing stormwater quantity using storage facilities are typically based on limiting peak runoff rates to match one or more of the following values:

- Historic rates for specific design conditions (i.e., post-development peak equals pre-development peak for a particular frequency of occurrence).
- Non-hazardous discharge capacity of the downstream drainage system.
- A specified value for allowable discharge set by a regulatory jurisdiction through a watershed wide stormwater management program or Act 167 Stormwater Management Plan (i.e., release rate or management district target resulting in a reduction of the post-development peak flow based on a percentage of the existing or pre-development flow).

The consequence of using only detention storage to mimic pre-development flow rates is especially critical when considering the cumulative impacts of these facilities upon the entire watershed. Under normal conditions a dry detention facility only serves to truncate the peak of the post-development hydrograph, transferring the volume of runoff discharged during the peak of the event to a point that occurs after the end of the normal pre-development flow. This practice essentially extends the peak pre-development flow in a post-development condition for a longer period. The cumulative effect of this practice on a watershed is that the peak runoff from sites throughout the watershed are added to one another making the resultant post-development flow for the entire watershed higher than the pre-development flow.

In certain instances it may not be advantageous to have detention. This can be especially applicable for those areas of the watershed that are close to main tributaries in the lower portions of the watershed which are able to peak and pass their flows prior to the watershed peak arriving in the lower portions of the waterway. Because of the interaction of hydrograph timing between sites in a watershed it is important that the Department's design professionals design facilities to be consistent with applicable watershed management plans that are enacted for a particular location.

For watersheds without an adequate outfall (e.g., unstabilized channel, flood-prone area, etc.), the total volume of runoff is critical and retention storage facilities may be used to store the increase in volume and to control discharge rates.

E. Detention and Retention. Urban stormwater storage facilities are often referred to as either detention or retention facilities. Detention facilities are those facilities that are designed to reduce the peak discharge rate from a particular drainage area by detaining runoff and then releasing it at a controlled rate. The primary function of these facilities is to detain runoff for a short period and then completely drain shortly after a storm has passed. Retention facilities are different from detention facilities in that they are designed to store the runoff for very long period of time or indefinitely until it can be used or returned to the environment through a means other than release downstream. Retention facilities may or may not be designed to contain a permanent pool of water. Because most of the design procedures are the same for detention and retention facilities, the term storage facilities, as used in this chapter, is meant to include both detention and retention facilities. If special procedures or considerations are needed for detention or retention facilities related to the special aspects of their respective designs, these will be specifically cited in this chapter.

Storage facilities may be small in terms of storage capacity and embankment height where serving a single outfall from a watershed of a few acres, or they may be larger providing stormwater management control for larger portions of a watershed. Although the same principles apply to all storage facilities, certain devices are more suited to smaller drainage areas and others function better with larger drainage areas.

F. Underground Storage. Storage of stormwater flows beneath the surface has become an increasingly viable solution for developing sites with large impervious areas. The advantage of underground storage is that the area directly above the storage facility can be used for parking, recreational facilities, etc. The storage volume is typically provided by burying prefabricated storage units, or ordinary storm drain pipes. Application of underground storage on PennDOT projects is not encouraged or recommended. These types of facilities require regular maintenance and their application on highway facilities is not well-documented. Underground storage should only be considered for PCSM Level 3 or Level 4 projects where all other approved measures have been exhausted. In particular, use of these facilities underneath travel lanes and shoulders is highly discouraged.

G. Computer Programs. Routing calculations needed to design storage facilities, although not extremely complex, may be time consuming and repetitive. To assist with these calculations, many computer software programs and spreadsheets have been created to automate the reservoir routing and support the design of storage facilities. Although some models perform one type of computation better than other available models, it is necessary for the Department to concentrate its efforts on the programs in PennDOT's H&H toolbox in order to develop and maintain agency-wide expertise. If a model not included in the forgoing list is used for a specific problem, then the project engineer should ensure that model is appropriate and that approvals are obtained from the Department. Several routing methodologies have been developed to evaluate the capacity and performance of storage facilities, with the storage indication method one of the most common and simplest to use. Regardless of the size, location or function of the facility, all storage facilities should be designed and analyzed using reservoir routing calculations to demonstrate that the storage facilities function as intended. For additional information regarding the Storage-Indication Routing Method, see Chapter 7, *Hydrology*.

14.10 DESIGN CRITERIA

A. General Criteria. Storage may be concentrated in large regional facilities or distributed throughout a watershed in smaller more localized facilities. The primary benefits of a large basin are reduced maintenance costs and consistent application of stormwater management controls for a large portion of the watershed. The negative aspects of the facility are the large amount of land area required and capital necessary to construct such a facility. Conversely, the advantage of smaller facilities is that they require less area to construct and can be placed in locations where large regional basins will not fit. These smaller facilities may be constructed in depressed areas or parking lots, adjacent to road embankments and freeway interchanges, incorporated into parks and recreational areas and contiguous to small lakes, ponds and depressions within urban developments. The benefit of this approach is that small pieces of land area that are not particularly useful for other purposes, because of their size or other limitations, may be incorporated into a project's stormwater management controls.

The utility of any storage facility depends on the amount of storage, its location within the watershed and its operational characteristics. An analysis of such storage facilities should consist of comparing the design flow at a point or several points of interest downstream of the proposed storage site with and without storage. Potential points of interest may include an existing downstream bridge, culvert or storm sewer; a confluence with a downstream tributary; a key drainage feature such as a dam, channel obstruction or stream crossing; or simply a point of concentrated flow at or near the right-of-way.

Complete analysis of storage facilities should include the evaluation of several design storms to properly evaluate the performance of a proposed storage facility. Analysis for a storage facility may include design events ranging between the 2-year and the 100-year design storms (0.50 and 0.01 exceedance probability, respectively). In addition to the design flow, other flows in excess of the design flow that might be expected to pass through the storage facility should be included in the analysis. The design criteria for storage facilities should include:

- Release rate.
- Storage volume.
- Grading and depth requirements.
- Outlet works and location.
- Freeboard above the maximum water surface elevation.
- Time to dewater.
- Provisions for maintenance (such as slope limitations and access ramps).

B. Release Rate. If an approved Act 167 Stormwater Management Plan is available for the watershed in which a project is situated, then all storage facilities and outlet works should be designed to be consistent with the appropriate release rates or management directives identified by the Plan. If an approved Act 167 Stormwater Management Plan is not available for the respective watershed, then the release rate targets outlined in Section 14.2 apply.

C. Storage. In those portions of the Commonwealth that do not have an approved Act 167 Stormwater Management Plan, the minimum performance standard for storage facilities should be based upon the needs of the design. Typically the design event, based upon the roadway classification, is an appropriate condition to start the analysis. However, the design event should then be adjusted based upon the needs of the project. In other words, the design storm cannot be arbitrarily set but must be considered on a case-by-case basis, based upon the projects needs. In certain instances it may be necessary to provide additional storage capacity for other design storms depending on the downstream system's conveyance capacity. If a stormwater storage facility is to be used as sediment basin, or as part of a project's erosion and sediment pollution controls, or if sediment is deposited in the basin during construction causing loss of storage volume, the original design dimensions of the basin should be restored once the drainage area is permanently stabilized and before completion of the project.

D. Grading and Depth. Following is a discussion of the general grading and depth criteria for storage facilities followed by broad criteria related to detention and retention facilities.

1. General. The construction of storage facilities usually requires excavation or placement of earthen embankments to obtain sufficient storage volume. Vegetated embankments should be less than 4.5 m (15 ft) in height, as measured from the downstream toe of the embankment to the top of the berm and should have side slopes no steeper than 1V:3H (3H:1V). Riprap-protected embankments should be no steeper than 1V:2H (2H:1V). Geotechnical slope stability analysis is recommended for all embankments greater than 3 m (10 ft) in height, and is mandatory for embankment slopes steeper than those given above. Procedures for performing slope stability evaluations can be found in most soil engineering textbooks.

Other considerations when setting depths include flood elevation requirements, public safety, land availability, land value, present and future land use, water table fluctuations, soil characteristics, maintenance requirements and freeboard. Aesthetically pleasing features are also important in urbanized areas which can be augmented with landscaping, walking paths, natural areas and other appurtenances. Fencing of basins is addressed in subsequent sections of this chapter.

2. Detention. Areas above the normal high-water elevations of storage facilities should be sloped toward the facilities to allow drainage and prevent standing water from ponding in surface depressions. Typically, careful finish grading above the storage facility is required to avoid creation of upland surface depressions that may retain runoff. This is especially critical in areas which are graded at a slope of less than five percent (5%).

If not specifically designed to retain water in the bottom of the storage facility, the bottom area of storage facilities should be graded toward the outlet to prevent standing water conditions. Although low-flow or pilot channels are discouraged for most applications they may be constructed in special cases where standing water problems are known or anticipated to occur. Typically these channels are aligned across the facility from the inlet to the outlet and function to convey low flows through the facility and prevent standing water conditions. Low flow channels may assist in the complete draining of a facility; however, constructing these channels out of impervious materials may be deleterious to the environment. Therefore, if a low flow channel is deemed necessary to the design it is recommended that such a feature be constructed of pervious materials in a meandering alignment to maximize the flow length within the basin. Check dams may be provided across the channel to slow the water through the facility, and provide limited removal of non-point source pollutants conveyed in the stormwater runoff. This approach allows for the complete emptying of the basin while at the same time providing a measure of water quality treatment of the stormwater runoff conveyed through the basin.

3. Retention. Similar to detention, areas above the normal high-water elevations of retention facilities should be sloped toward the facilities to allow drainage and prevent standing water from ponding in surface depressions. The maximum depth of permanent storage facilities will be determined by site conditions, design constraints and environmental needs. In general, if the facility provides a permanent pool of water, a depth sufficient to discourage the growth of weeds, without creating undue potential for anaerobic bottom conditions, should be considered. A depth of 0.9 m to 1.8 m (3 to 6 ft) is generally reasonable.

Retention facilities can be designed with forebays at the inlet into the storage facilities to prevent the deposition of sediment within the storage facility and preserve the storage capacity of the basin. The typical volume of storage within a forebay is between 10 and 15% of the total permanent pool volume and should be between 1.2 and 1.8 m (4 and 6 ft) deep.

Normally, the volume of water contained within a ponds permanent pool is not available for use as part of the facility's stormwater management controls and must be removed from the available stormwater storage capacity of the basin.

4. Emergency Spillway. Each facility should be designed with an emergency spillway with the outlet works designed to prevent the regular use of the emergency spillway. For large storage facilities, selecting a flood magnitude for sizing the emergency outlet should be consistent with a risk analysis evaluating the potential threat to downstream life and property if the basin embankment were to fail. Whenever possible the emergency spillway should be constructed on undisturbed earth and not placed in fill.

Impoundment depths greater than 4.5 m (15 ft) or volumes greater than 61,675 m^3 (50 ac-ft) are subject to the requirements of PA Code Title 25, Chapter 105, Subchapter B as administered by the Pennsylvania Department of Environmental Protection, Bureau of Waterways Engineering, Division of Dam Safety. Storage facilities of this magnitude should be avoided on Department projects.

E. Outlet Works. Outlet works for storage facilities typically include a principal spillway and an emergency overflow, which must be configured to accomplish the performance objectives of the facility. Outlet works can consist of single stage comprised of a drop inlet, pipe, weir or orifice or may consist of several stages comprised of any combination of the aforementioned control devices set at different elevations. Typically, small orifices less than 75 mm (3 in) in diameter, small pipes less than 450 mm (18 in) in diameter and slotted riser pipes are discouraged from use in permanent stormwater facilities because of the potential for clogging. Perforated metal pipes are acceptable if they are of sufficient gage and are galvanized, coated, or aluminized. To facilitate the construction of these features dimensions should be set at values which are easily defined and measured, such as whole numbers set in increments of 25 mm (1 in) for an orifice or weir and increments of 75 mm (3 in) for pipes less than 900 mm (36 in) in diameter. Pipes larger than 900 mm (36 in) in diameter which are used in the design of storage facilities should be sized in increments of 150 mm (6 in). The Publication 72M, *Standards for Roadway Construction*, RC-70M, may be referenced for standard drawings related to storage facilities and outlet works.

The principal spillway is intended to convey the design storm without allowing flow to enter the emergency outlet. All design storms should be routed through the principal spillway reserving the emergency spillway for extreme events and in case of clogging/malfunction of the principal spillway. Sizing of the outlet works for a storage facility should be based on the results of hydrologic routing calculations.

F. Location. In addition to controlling the peak discharge through the outlet works, storage facilities will change the timing of the hydrograph for the area draining from a storage facility. The construction of storage facilities not only effects the location of the peak with respect to the hydrograph timing but also the length of time in which pre-development flow rates are exceeded in a post-development condition. If not properly planned, the aggregate effects of several storage facilities within the same drainage basin may create more flooding problems than if no stormwater controls were provided. Thus it is very important to determine what effects a particular facility may have on combined hydrographs downstream of the facility. The effects of hydrograph timing upon the watershed are assessed as part of the Act 167 planning process. Therefore, it is vital that if an Act 167 Stormwater Management Plan is approved that all proposed facilities be consistent with the enacted plan. When consistent with an approved *basin wide* stormwater management plan no further downstream analysis is necessary to demonstrate the acceptable performance of a proposed storage facility.

14.11 GENERAL PROCEDURE

A. Data Needs. Three essential types of data are necessary to evaluate the routing of stormwater through a storage facility and assess the effectiveness of a proposed basin. This data includes:

- Inflow hydrographs for all selected design storms.
- Stage-storage curve for proposed storage facility.
- Stage-discharge curve for all outlet control structures based upon the configuration of the outlet control works.

Using this data, a systematic design procedure can be followed to route the inflow hydrograph through the storage facility to establish an outflow hydrograph below the storage area. If the desired outflow results are not achieved, either the basin or the outlet geometry must be altered to yield a new stage-storage and/or a stage-discharge curve to obtain an acceptable outflow hydrograph. As it is usually necessary to control the flow from events of different return intervals (i.e., 2-, 10-, 25-, 50-, 100-year) typically, an iterative approach is needed to achieve the prescribed performance targets, requiring successive routings until the desired outflow hydrographs are achieved (see Example 14.9).

B. Stage-Storage Curve. A stage-storage curve defines the relationship between the depth of water and the available storage volume in a storage facility. Ordinarily these curves plot the storage along the x-axis and the stage against the y-axis. The data for the stage-storage curve is usually developed using a topographic map and one of the following formulas: the average-end area, frustum of a pyramid, or prismoidal formula.

The average-end area formula is most often used on non-geometric areas. The average-end area formula is expressed as:

(Equation 14.1)

$$V_{1,2} = [(A_1 + A_2)/2]d$$

where:
- $V_{1,2}$ = storage volume between Elevations 1 and 2, m^3 (ft^3)
- $A_{1,2}$ = surface area at Elevations 1 and 2 respectively, m^2 (ft^2)
- d = change in elevation between Points 1 and 2, m (ft)

The incremental change in elevation d is typically set at 0.25 m (1 ft) for use with the average-end area formula when designing stormwater storage facilities. Smaller values of d result in more accurate estimation of the available storage.

The frustum of a pyramid is expressed as:

(Equation 14.2)

$$V = d/3\ [A_1 + (A_1A_2)^{0.5} + A_2]$$

where:
- V = volume of frustum of a pyramid, m^3 (ft^3)
- d = change in elevation between Points 1 and 2, m (ft)
- $A_{1,2}$ = surface area at Elevations 1 and 2 respectively, m^2 (ft^2)

The prismoidal formula for trapezoidal basins is expressed as:

(Equation 14.3)

$$V = LWD + (L + W)\,ZD^2 + 4/3\,Z^2\,D^3$$

where:
- V = volume of trapezoidal basin, m^3 (ft^3)
- L = length of basin bottom, m (ft)
- W = width of basin bottom, m (ft)
- D = depth of basin, m (ft)
- Z = side slope factor, ratio of horizontal to vertical

C. Stage-Discharge Curve. A stage-discharge curve defines the relationship between the depth of water and the discharge or outflow from a storage facility based upon the configuration of the basin's outlet control features. Normally the discharge is plotted on the x-axis with the stage plotted on the y-axis. A typical storage facility has two spillways, a principal spillway and an emergency spillway, and the stage-discharge curve should be developed using the cumulative discharge from both spillways. The stage-discharge curve is affected by the size and configuration of the outlet pipe culvert, weir, orifice or other outlet control device which is typically located in the principal spillway or outlet. To accurately model the outflow hydrograph from a storage facility, tailwater influences and structure losses must also be considered when developing discharge curves. As with the stage-storage curve, computation of smaller incremental changes in head will result in a more accurate stage-discharge relationship.

D. Procedure. A general procedure for using the above data in the design of storage facilities is presented below.

Step 1 Compute inflow hydrograph for runoff from various return periods being assessed design storms using the procedures outlined in Chapter 7, *Hydrology*. Both pre- and post-development hydrographs are required for all of the design storms of interest.

Step 2 Perform preliminary calculations to evaluate detention storage requirements for the hydrographs from Step 1.

Step 3 Determine the physical dimensions of the storage facility necessary to hold the estimated volume from Step 2. Extra storage volume will be needed to account for freeboard. The maximum storage requirement calculated from Step 2 should be used to set the preliminary size of the storage facilities.

Step 4 Size and configure the outlet structure to control the rate and flow from the storage facility in order to achieve the facility's stormwater management objectives. For initial computations assume the peak stage will occur at the estimated volume from Step 2 for the event analyzed with the largest return period (least probability of occurrence).

Step 5 Perform routing calculations using inflow hydrographs from Step 1 to check the preliminary design using the storage routing equations. If any of the routed post-development peak rates of discharge exceed the pre-development peak discharges, or exceed those release rates prescribed by the watershed's stormwater management plan, or if the peak stage varies significantly from the estimated peak stage from Step 4, then revise the estimated volume and return to Step 3.

Step 6 Design an emergency overflow for the storage facility with the capacity to safely convey the largest inflow that is capable of entering the basin, safely through the basin, in the event the principal spillway malfunctions. Often times large events are not capable of entering a storage facility because of conveyance limitations associated with other aspects of the drainage system, for example when storm drainage systems are designed for a return interval less than the 100-year event.

Step 7 Evaluate the downstream effects of detention outflow in a manner consistent with the methodology discussed in the Design Criteria section of this chapter to ensure that the routed hydrograph does not cause downstream degradation problems.

Step 8 Evaluate the outlet velocity of stormwater runoff conveyed through the outlet control structure and discharged to the environment to ascertain if channel/bank stabilization immediately downstream of the storage facility is necessary to control excessive velocities which can cause erosion problems.

The design of storage facilities is an iterative process which can involve a significant number of reservoir routing calculations to obtain the desired results.

14.12 OUTLET HYDRAULICS

A. Outlets. Sharp-crested weir flow equations for no end contractions, two end contractions and submerged discharge conditions are presented below, followed by equations for broad-crested weirs, V-notch weirs, weirs and orifices. If culverts are used as outlets works, procedures presented in Chapter 9, *Culverts* should be used to develop stage-discharge data. When analyzing release rates, the tailwater influence of the principal spillway culvert on the outlet control structure (orifice and/or weirs) must be considered to determine the effective head on each opening. Although the configuration of outlets may take on many different geometric shapes and forms, slotted riser pipes should not be used for the outlet of permanent stormwater facilities because of their propensity to clog. Perforated metal risers may be used provided the metal is of sufficient gage and is galvanized, coated, or aluminized.

B. Sharp-Crested Weirs. A sharp crested weir is a vertical device placed across a flow area, which controls the rate of flow, through an opening or over the top of a device, based upon the amount of head above the invert of the flow area through the weir. Sharp crested weirs differ from broad crested weirs in that they the cause flow lines exiting the weir to bend or curve downward. A sharp-crested weir with no end contractions is illustrated in Figure 14.3. The discharge equation for this configuration is :

(Equation 14.4)

Metric:

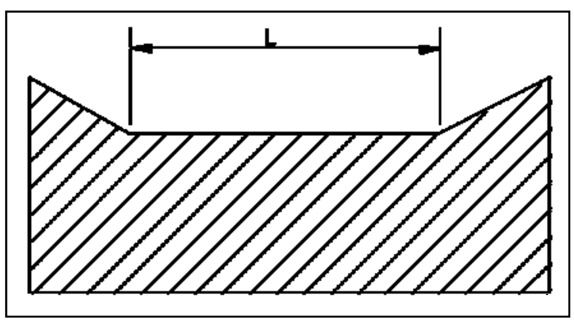
$$Q = [1.805 + 0.221(H/H_c)]\ LH^{1.5}$$

U.S. Customary:

$$Q = [3.22 + 0.44(H/H_c)]\ LH^{1.5}$$

where:
- Q = discharge, m^3/s (cfs)
- H = head above weir crest excluding velocity head, m (ft)
- H_c = height of weir crest above channel bottom, m (ft)
- L = horizontal weir length, m (ft)

Figure 14.3 Sharp-Crested Weir (No End Contractions)



A sharp-crested weir with two end contractions is illustrated in Figures 14.4 and 14.5. The discharge equation for this configuration is:

(Equation 14.5)

Metric:

$$Q = [1.805 + 0.221(H/H_c)]\ (L - 0.2H)\ H^{1.5}$$

U.S. Customary:

$$Q = [3.22 + 0.44(H/H_c)]\ (L - 0.2H)\ H^{1.5}$$

where: variables are the same as Equation 14.4.

Figure 14.4 Sharp-Crested Weir (Two End Contractions)

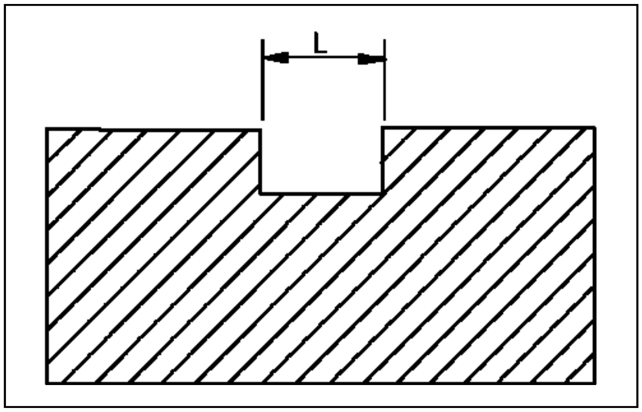
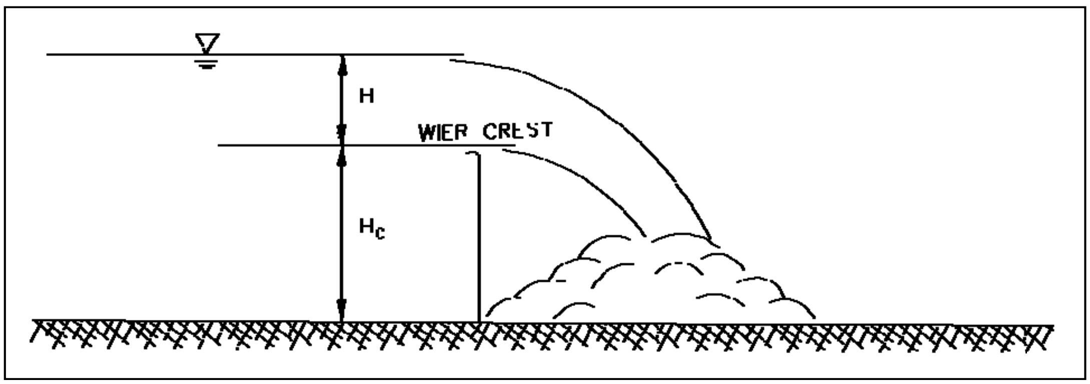


Figure 14.5 Sharp-Crested Weir and Head



A sharp-crested weir will be affected by submergence when the tailwater rises above the weir-crest elevation. The result will be that the discharge over the weir will be reduced by the rising tailwater. The discharge equation for a sharp-crested submerged weir is:

(Equation 14.6)

$$Q_S = Q_f(1 - (H_2/H_1)^{1.5})^{0.385}$$

where:
- Q_s = submergence flow, m^3/s (cfs)
- Q_f = free flow, m^3/s (cfs)
- H_1 = upstream head above crest, m (ft)
- H_2 = downstream head above crest, m (ft)

C. Broad-Crested Weirs. Broad crested weirs function similar to sharp crested weirs in that the flow over the weir is a function of the amount of head above the invert of the weir opening. Broad crested weirs differ from sharp crested weirs in that the flow exiting the weir leaves the weir in a horizontal direction and does not bend downward like with a sharp crested weir. The equation generally used for a broad-crested weir is:

(Equation 14.7)

$$Q = CLH^{1.5}$$

where:
- Q = discharge, m^3/s (cfs)
- C = broad-crested weir coefficient
- L = broad-crested weir length, m (ft)
- H = head above weir crest, m (ft)

If the upstream edge of a broad-crested weir is rounded to prevent contraction and if the slope of the crest is as great as the loss of head due to friction, flow will pass through critical depth at the weir crest; this gives the maximum C value of 1.704 ($C_{U.S.\ Customary}$ = 3.087). For sharp corners on the broad-crested weir, a minimum C value of 1.435

($C_{U.S.\ Customary}$ = 2.6) should be used. Additional information on C values as a function of weir crest breadth and head is given in Table 14.6.

Table 14.19 (a) Broad-Crested Weir Coefficient C-Values as a Function of Weir Crest Breadth and Head (m)

Measured Head, *H*[1] (m)	**Breadth of the Crest of Weir (m)**										
	0.15	0.23	0.30	0.46	0.61	0.76	0.91	1.22	1.52	3.05	4.57
0.06	1.55	1.52	1.49	1.45	1.40	1.37	1.35	1.31	1.29	1.37	1.48
0.12	1.61	1.55	1.50	1.46	1.44	1.44	1.42	1.40	1.38	1.41	1.49
0.18	1.70	1.60	1.52	1.46	1.44	1.44	1.48	1.49	1.49	1.49	1.49
0.24	1.82	1.68	1.57	1.48	1.44	1.44	1.47	1.48	1.48	1.49	1.46
0.30	1.83	1.73	1.65	1.52	1.47	1.46	1.46	1.47	1.48	1.48	1.45
0.37	1.83	1.77	1.70	1.58	1.49	1.46	1.46	1.47	1.47	1.49	1.46
0.43	1.83	1.80	1.77	1.61	1.53	1.48	1.46	1.46	1.46	1.47	1.46
0.49	1.83	1.82	1.81	1.69	1.60	1.52	1.48	1.47	1.46	1.46	1.45
0.55	1.83	1.83	1.83	1.69	1.59	1.51	1.48	1.47	1.46	1.46	1.45
0.61	1.83	1.83	1.82	1.67	1.57	1.52	1.52	1.48	1.46	1.46	1.45
0.76	1.83	1.83	1.83	1.81	1.69	1.60	1.55	1.50	1.47	1.46	1.45
0.91	1.83	1.83	1.83	1.83	1.77	1.68	1.61	1.51	1.47	1.46	1.45
1.07	1.83	1.83	1.83	1.83	1.83	1.76	1.64	1.52	1.48	1.46	1.45
1.22	1.83	1.83	1.83	1.83	1.83	1.83	1.69	1.54	1.49	1.46	1.45
1.37	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.59	1.51	1.46	1.45
1.52	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.69	1.54	1.46	1.45
1.68	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.59	1.46	1.45

Table 14.19(b) Broad-Crested Weir Coefficient C-Values as a Function of Weir Crest Breadth and Head (ft)

Measured Head, *H*[1] (ft)	**Breadth of the Crest of Weir (ft)**										
	0.50	0.75	1.00	1.50	2.00	2.50	3.00	4.00	5.00	10.00	15.00
0.2	2.80	2.75	2.69	2.62	2.54	2.48	2.44	2.38	2.34	2.49	2.68
0.4	2.92	2.80	2.72	2.64	2.61	2.60	2.58	2.54	2.50	2.56	2.70
0.6	3.08	2.89	2.75	2.64	2.61	2.60	2.68	2.69	2.70	2.70	2.70
0.8	3.30	3.04	2.85	2.68	2.60	2.60	2.67	2.68	2.68	2.69	2.64
1.0	3.32	3.14	2.98	2.75	2.66	2.64	2.65	2.67	2.68	2.68	2.63
1.2	3.32	3.20	3.08	2.86	2.70	2.65	2.64	2.67	2.66	2.69	2.64
1.4	3.32	3.26	3.20	2.92	2.77	2.68	2.64	2.65	2.65	2.67	2.64
1.6	3.32	3.29	3.28	3.07	2.89	2.75	2.68	2.66	2.65	2.64	2.63
1.8	3.32	3.32	3.31	3.07	2.88	2.74	2.68	2.66	2.65	2.64	2.63
2.0	3.32	3.31	3.30	3.03	2.85	2.76	2.72	2.68	2.65	2.64	2.63
2.5	3.32	3.32	3.31	3.28	3.07	2.89	2.81	2.72	2.67	2.64	2.63
3.0	3.32	3.32	3.32	3.32	3.20	3.05	2.92	2.73	2.66	2.64	2.63
3.5	3.32	3.32	3.32	3.32	3.32	3.19	2.97	2.76	2.68	2.64	2.63
4.0	3.32	3.32	3.32	3.32	3.32	3.32	3.07	2.79	2.70	2.64	2.63
4.5	3.32	3.32	3.32	3.32	3.32	3.32	3.32	2.88	2.74	2.64	2.63
5.0	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.07	2.79	2.64	2.63
5.5	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32	2.88	2.64	2.63

[1]Measured at least 2.5*H* upstream of the weir.
Source: Reference (Brater and King, 1976)

D. V-Notch Weirs. The discharge through a V-notch or triangular weir can be calculated from the following equation:

(Equation 14.8)

Metric:	**U.S. Customary:**
$Q = 1.38 \tan(\theta/2)H^{2.5}$	$Q = 2.5 \tan(\theta/2)H^{2.5}$

where:
Q = discharge, m^3/s (cfs)
θ = angle of V-notch, degrees
H = head on apex of notch, m (ft)

E. Orifices. An orifice is a vertical or horizontal opening through which water may pass. Orifices may be configured in any variety of shapes and sizes, and are not limited to circular shapes only. In certain instances flow through pipes may be calculated using the orifice equation. Pipes smaller than 300 mm (12 in) may be analyzed as a submerged orifice if *H/D* is greater than 1.5. Pipes with an H/D ratio of less than 1.5 may be flowing only partially full and may be acting under outlet control. Thus, the discharge through the pipe may be less than that determined using the orifice equation. For sharp-edged entrance conditions the discharge through the orifice can be calculated from:

(Equation 14.9)

$$Q = CA(2gH)^{0.5}$$

where:
Q = discharge, m^3/s (cfs)
A = cross-section area of orifice/pipe, m^2 (ft^2)
g = acceleration due to gravity, 9.81 m/s^2 (32.2 ft/s^2)
H = head on pipe, from the center of pipe to the water surface, m (ft) *
C = discharge coefficient

* *Where the tailwater is higher than the center of the opening, the head is calculated as the difference in water surface elevations*

The discharge coefficient used in the orifice discharge equation will vary based upon the shape and configuration of the outlet according to the values provided in Table 14.20.

Table 14.20 Orifice Discharge Coefficients

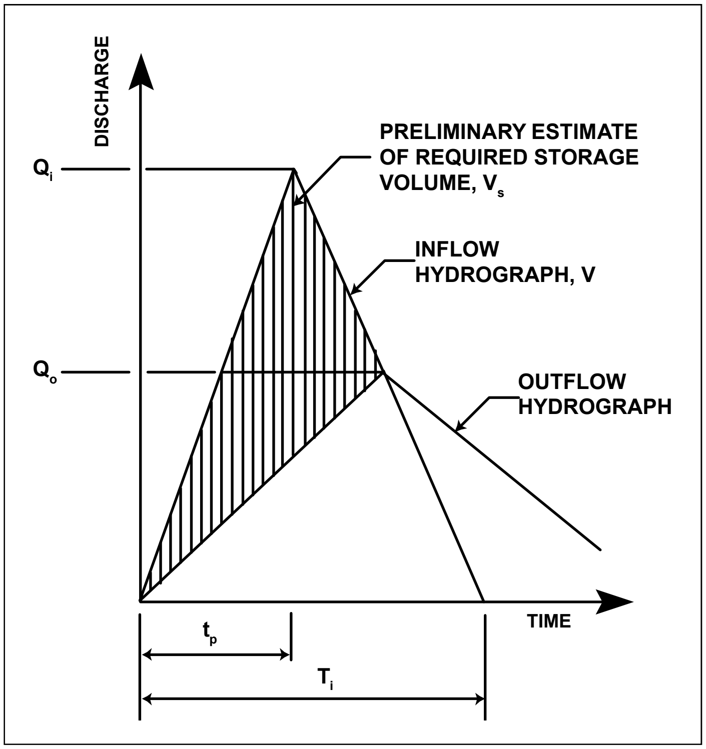
Description	**Discharge Coefficient**
Sharp-edged	0.62
Round edged	0.98
Short tube (fluid separates from walls)	0.61
Sharp tube (no separation)	0.82
Sharp tube with rounded entrance	0.97
Projecting entrance tube, (projection<½D)	0.54
Projecting entrance tube, (projection>½D)	0.72
Nozzle, Smooth and well tapered	0.98

Source: P.E. Reference Manual (Lindeburg, 2003)

14.13 PRELIMINARY DETENTION CALCULATIONS

A. Storage Volume. A preliminary estimate of the storage volume required for peak-flow attenuation may be obtained from a simplified design procedure that replaces the actual inflow and outflow hydrographs with the standard triangular shapes shown in Figure 14.6. Irrespective of the preliminary storage volume calculations the Department's design professionals are obligated to prove the size of storage facilities are adequate, by routing post-development flows through the basin, and demonstrating the applicable performance standards are achieved.

Figure 14.6 Triangular Shaped Hydrographs (For Preliminary Estimate of Required Storage Volume)



The required storage volume may be estimated from the area above the outflow hydrograph and inside the inflow hydrograph, expressed as:

(Equation 14.10)

$$V_S = 0.5T_i(Q_i - Q_o)$$

where:
- V_S = storage volume estimate, m^3 (ft^3)
- Q_i = peak inflow rate, m^3/s (cfs)
- Q_o = peak outflow rate, m^3/s (cfs)
- T_i = duration of basin inflow, s

B. Alternative Method. An alternative preliminary estimate of the storage volume required for a specified peak-flow reduction can be obtained by the following regression equation procedure:

1. Determine input data, including the allowable peak outflow rate, Q_o, the peak flow rate of the inflow hydrograph, Q_i, the time base of the inflow hydrograph, t_b, and the time to peak of the inflow hydrograph, t_p.

2. Calculate a preliminary estimate of the ratio V_S/V_r using the input data from Step 1 and the following equation:

(Equation 14.11)

$$V_S/V_r = [1.291(1 - Q_o/Q_i)^{0.753}]/[(t_b/t_p)^{0.411}]$$

where:
- V_S = volume of storage, m^3 (ft^3)
- V_r = volume of runoff, m^3 (ft^3)
- Q_o = outflow peak flow, m^3/s (cfs)
- Q_i = inflow peak flow, m^3/s (cfs)
- t_b = time base of the inflow hydrograph, hour (Determined as the time from the beginning of rise to a point on the recession limb where the flow is 5% of the peak)
- t_p = time to peak of the inflow hydrograph, hour

3. Multiply the volume of runoff by the ratio of the volume of storage to volume of runoff calculated in Step 2 to determine the estimated basin storage volume.

C. Peak-Flow Reduction. A preliminary estimate of the potential peak-flow reduction for a selected storage volume can be obtained by the following procedure:

1. Determine the following:

- Volume of runoff, V_r
- Peak-flow rate of the inflow hydrograph, Q_i
- Time base of the inflow hydrograph, t_b
- Time to peak of the inflow hydrograph, t_p
- Storage volume, V_S

2. Calculate a preliminary estimate of the potential peak-flow reduction for the selected storage volume using the following equation:

(Equation 14.12)

$$Q_o/Q_i = 1 - 0.712(V_S/V_r)^{1.328}(t_b/t_p)^{0.546}$$

3. Multiply the peak-flow rate of the inflow hydrograph, Q_i, times the potential peak-flow reduction calculated from Step 2 to obtain the estimated peak outflow rate, Q_o, for the selected storage volume (see Section 14.10.C of the example).

D. Preliminary Storage Dimensions.

- Plot the control structure location on a contour map.
- Select a desired depth of ponding for the design storm based upon site constraints, risk analysis, and jurisdictional regulations.
- Divide the estimated storage volume needed by the desired depth to obtain the surface area required of the reservoir.
- Based on site conditions and contours, estimate the geometric shape(s) required to provide the estimated basin surface area.

14.14 ROUTING PROCEDURE

The following procedure is used to perform routing through a storage facility (Puls Method of storage routing):

Step 1 Develop an inflow hydrograph, stage-storage curve and stage-discharge curve for the proposed storage facility. An example stage-storage curve is shown in Figure 14.8 and a stage-discharge curve is shown in Figure 14.9.

Step 2 Select a routing time period, Δt, to provide at least five points on the rising limb of the inflow hydrograph ($t < T_c/5$).

Step 3 Use the storage and discharge data from Step 1 to develop storage characteristics curves that correlate values of $S \pm (O/2)\Delta t$ to stage for a given basin configuration and outlet control structure design. An example tabulation of storage characteristics curve data is shown in Figure 14.7.

Step 4 Determine the value of $S_{i+1} + (O_{i+1}/2)\Delta t$ from the following equation:

(Equation 14.13)

$$S_{i+1} + (O_{i+1}/2)\Delta t = [S_i - (O_i/2)\Delta t] + [(I_i + I_{i+1})/2]\Delta t$$

where:

	S_{i+1}	=	storage volume at end of time interval, m^3 (ft^3)
	O_{i+1}	=	outflow rate at end of time interval, m^3/s (cfs)
	Δt	=	routing time period, s
	S_i	=	storage volume at beginning of time interval, m^3 (ft^3)
	O_i	=	outflow rate at beginning of time interval, m^3/s (cfs)
	I_i	=	inflow rate at beginning of time interval, m^3/s (cfs)
	I_{i+1}	=	inflow rate at beginning of next time interval, m^3/s (cfs)

Other consistent units are equally appropriate.

Step 5 Between interval 1 and 2, both I_i and I_{i+1} are known. At the start of the storm the inflow into the basin is just beginning to occur and the stage is the bottom of the basin. Therefore, at the start of the initial time interval the outflow from the basin and storage within the basin are both 0 and the resulting value of $S_i - (O_i/2)\Delta t$ is also 0. Combining the appropriate values, the right side of Equation 14.13 reduces to $(I_i+I_{i+1})\Delta t/2$, at the beginning of the event. Since, $S_i - (O_i/2)\Delta t = 0$, the left side of the equation equals $(I_i+I_{i+1})\Delta t/2$, the stage may be determined from Figure 14.7 using the $S+(O/2)\Delta t$ curve. This represents the stage at the end of the time interval. The storage and discharge at the end of the interval may then be read off of Figure 14.7, respectively. The data used to create the respective curves is provided in Table 14.21.

Step 6 The stage, discharge and storage values calculated in the previous step are then used to calculate the unknown values for the next time interval. This process is repeated using the new value for I_i, I_{i+1}, O_i, and S_i to calculate a value for the left hand side of Equation 14.13. Figure 14.9 and the $S+(O/2)\Delta t$ curve is used to determine the stage at the end of the interval between periods 2 and 3. Figure 14.7 can be used to determine the discharge and storage at the end of the respective time interval.

Step 7 Step 5 and 6 may be repeated using the known values from the previous steps to determine the stage storage and discharge of the current step until the entire hydrograph is routed through the storage facility.

14.15 ROUTING EXAMPLE PROBLEM

A. Example. This example demonstrates the application of the routing methodology presented in this chapter for the design of a typical detention storage facility. Example inflow hydrographs and associated peak discharges for both pre- and post-development conditions can be developed using hydrologic methods from Chapter 7, *Hydrology*.

Table 14.21(a) Stage-Discharge-Storage Data (Metric)

Stage (m)	**Discharge, O (m^3/s)**	**Storage, S (m^3)**	**S+OΔt/2 (m^3)**
0.00	0	0	0
0.27	0.3	320	372
0.46	0.6	520	618
0.57	0.9	690	837
0.65	1.1	850	1049
0.77	1.4	1000	1239
0.87	1.7	1150	1447
0.97	2.0	1295	1644
1.07	2.3	1445	1842
1.17	2.6	1580	2012
1.25	2.9	1725	2214
1.38	3.4	2010	2593
1.47	3.7	2160	2800
1.54	4.0	2310	2989
1.61	4.2	2441	3187
1.69	4.6	2590	3378
1.77	4.9	2740	3569
1.81	5.1	2885	3784
1.95	5.7	3195	4172
2.07	6.2	3490	4574
2.13	6.5	3640	4770
2.25	7.0	3960	5189

Note: Δt = *6 min (360 sec)*

Table 14.21(b) Stage-Discharge-Storage Data (U.S. Customary)

Stage (ft)	**Discharge, O (cfs)**	**Storage, S (ac-ft)**	**S+OΔt/2 (ac-ft)**
0.0	0	0.00	0.00
0.9	11	0.26	0.30
1.4	21	0.42	0.51
1.8	30	0.56	0.68
2.2	40	0.69	0.86
2.5	49	0.81	1.01
2.9	61	0.93	1.18
3.2	71	1.05	1.34
3.5	81	1.17	1.51
3.7	88	1.28	1.65
4.0	99	1.40	1.81
4.5	118	1.63	2.12
4.8	130	1.75	2.29
5.0	139	1.87	2.44
5.3	151	1.98	2.61
5.5	160	2.10	2.76
5.7	169	2.22	2.92
6.0	182	2.34	3.09
6.4	201	2.58	3.41
6.8	220	2.83	3.74
7.0	230	2.95	3.90
7.4	250	3.21	4.24

Note: Δt *= 6 min (360 sec)*

Figure 14.7(a) Example Storage Characteristics Curve (Metric)

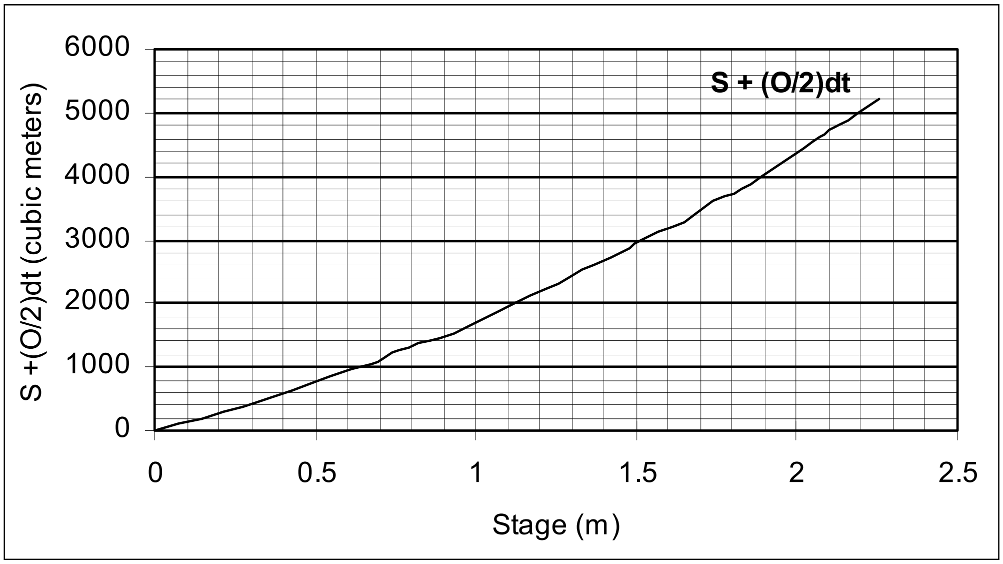


Figure 14.7(b) Example Storage Characteristics Curve (U.S. Customary)

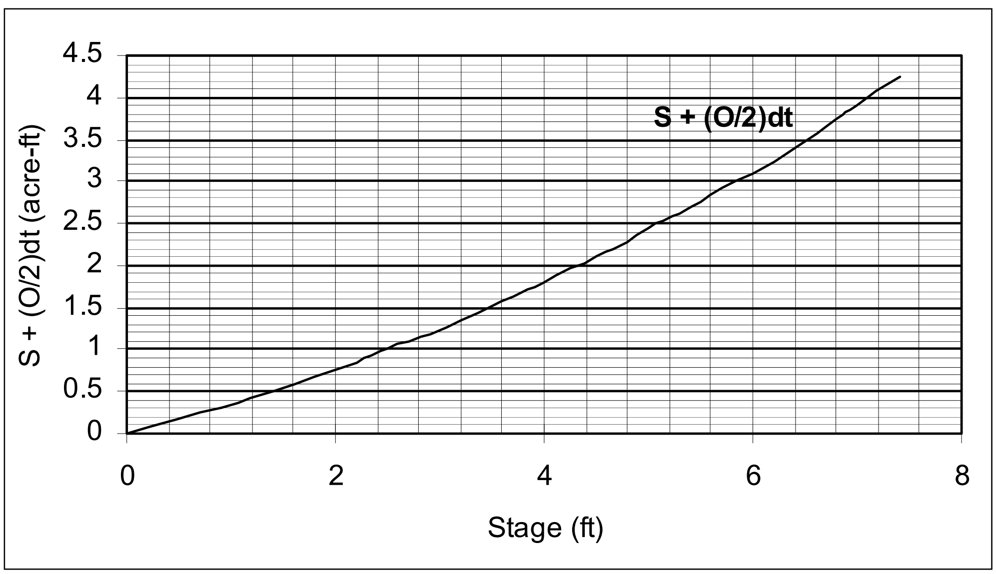


Figure 14.8(a) Example Stage-Storage Curve (Metric)

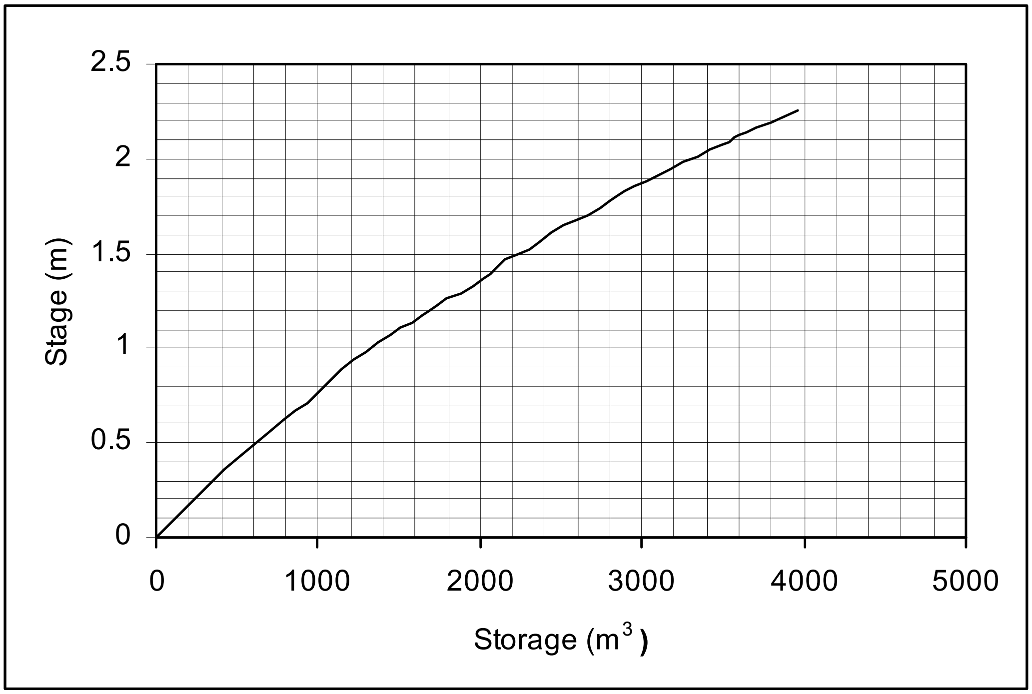


Figure 14.8(b) Example Stage-Storage Curve (U.S. Customary)

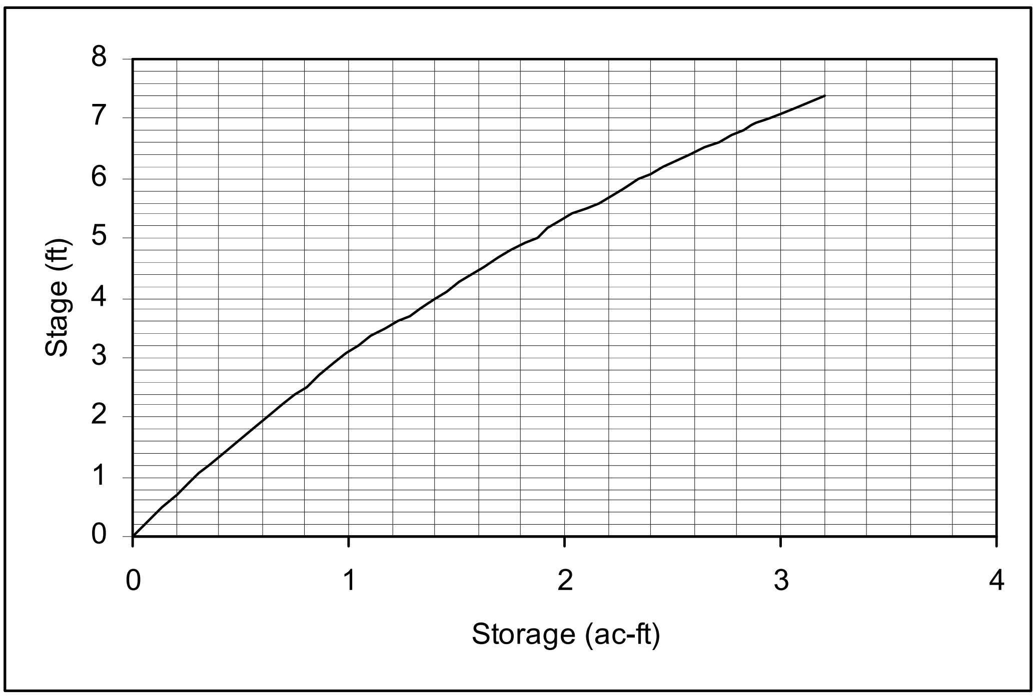


Figure 14.9(a) Stage-Discharge Curve (Metric)

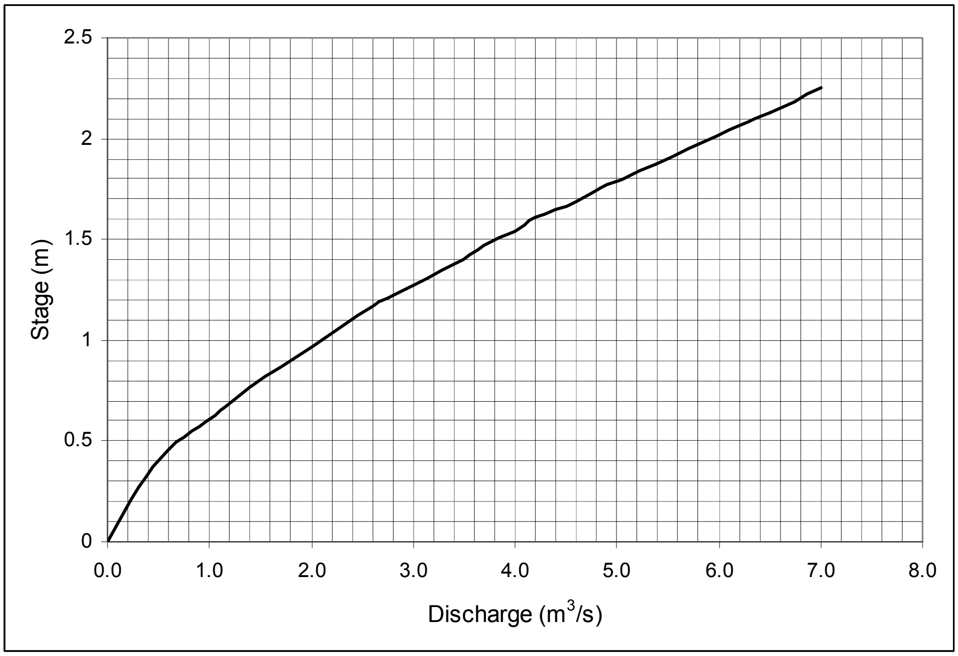
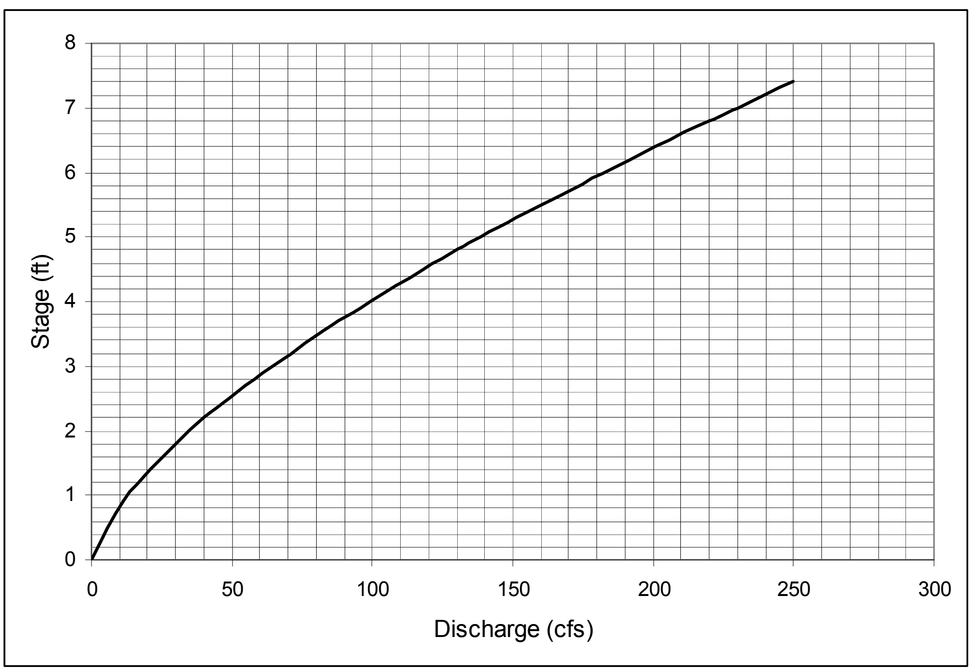


Figure 14.9(b) Stage-Discharge Curve (U.S. Customary)



B. Design Discharge and Hydrographs. Storage facilities are ordinarily designed to control runoff from a range of design storms to ensure that the facility can accommodate runoff from several events of varying sizes without creating problems associated with uncontrolled stormwater runoff. However, for this example, only peak discharges for the 10-year design storm event are presented for demonstration purposes. The respective hydrographs for the pre- and post-development conditions are as follows:

- Pre-development 10-year peak Q = 5.66 m^3/s (200 cfs)

- Post-development 10-year peak Q = 7.08 m^3/s (250 cfs).

Therefore, the allowable design discharge is 5.66 m^3/s (200 cfs) for the 10-year storm. This maximum allowable discharge limit is established so that the post-development peak discharge does not exceed the pre-development peak discharge.

Example runoff hydrographs are shown in Table 14.22. The inflow duration for the post-development hydrograph is approximately 1.25 hours.

Table 14.22(a) Example Runoff Hydrographs (Metric)

Time (h)	**Pre-Development Runoff (m^3/s)**	**Post-Development Runoff Without Storage (m^3/s)**
0.0	0	0
0.1	0.68	1.42
0.2	2.29	5.04
0.3	4.81	7.08*
0.4	5.66	4.67
0.5	4.25	2.55
0.6	2.69	1.42
0.7	1.73	0.82
0.8	1.13	0.45
0.9	0.79	0.25
1.0	0.51	0.14
1.1	0.42	0.08
1.2	0.37	0.03

*Note: The peak discharge without stormwater management controls is higher than the allowable discharge of 5.66 m^3/s for the 10-year design storm.

Table 14.22(b) Example Runoff Hydrographs (U.S. Customary)

Time (h)	Pre-Development Runoff (cfs)	Post-Development Runoff Without Storage (cfs)
0.0	0	0
0.1	24	50
0.2	81	178
0.3	170	250*
0.4	200	165
0.5	150	90
0.6	95	50
0.7	61	29
0.8	40	16
0.9	28	9
1.0	18	5
1.1	15	3
1.2	13	1

*Note: The peak discharge without stormwater management controls is higher than the allowable discharge of 200 cfs for the 10-year design storms.

C. Preliminary Volume Calculations. A preliminary estimate of the required storage volume is obtained using the simplified method outlined in Figure 14.8. For runoff from the 10-year storm, the required storage volume, V_S, is computed using Equation 14.10:

$$V_S = 0.5T_i\,(I - O)$$

$$V_S = [0.5(1.25)(3600)(7.08 - 5.60)] = 3195 \text{ m}^3 \text{ (2.58 ac-ft)}$$

The stage-storage data for the proposed storage facility is provided in Table 14.21 and a graphical presentation of the storage curve is provided in Figure 14.8.

D. Design and Routing Calculations. A stage-storage and stage-discharge relationship for a proposed storage facility is shown in Figures 14.8 and 14.9, respectively. The proposed basin is capable of providing adequate peak-flow attenuation a 10-year design storm. The storage-discharge relationship was developed for the proposed facility by providing, at a minimum, the estimated storage volume for 10-year design storm at a stage where the peak discharge occurs. Discharge values were computed by solving the broad-crested weir equation using the head, H, acting upon the weir and a discharge coefficient of 1.7 ($C_{\text{U.S. Customary}}$ = 3.1), assuming a constant weir length of 1.2 m (4 ft) and no tailwater submergence.

Storage routing was conducted for runoff from the 10-year design storm to confirm the preliminary storage volume estimate and to establish a design water surface elevation. Routing results using the Storage Characteristics Curve given previously in Figure 14.7 and the Stage-Discharge-Storage data given in Table 14.21 using 0.1-hour incremental time steps are shown in Figure 14.22 for runoff from the 10-year design storm. The preliminary design provides adequate peak discharge attenuation for the 10-year design storm.

For the routing calculations, Equation 14.13 was used:

$$S_{i+1} + (O_{i+1}/2)\Delta t = [S_i - (O_i/2)\Delta t] + [(I_i + I_{i+1})/2]\Delta t$$

Because the routed peak discharge is lower than the maximum allowable peak discharge, the storage and outlet design are acceptable. If the discharge was significantly lower than permitted, the weir length could be increased or the storage decreased to avoid the design of a facility that is larger than needed. However, if either the stage-discharge or stage-storage relationship is altered, routing calculations must be repeated to verify that the design meets the prescribed stormwater control guidelines.

Although not shown for this example, runoff from the project specific design storm should be routed through the storage facility to establish freeboard and to evaluate emergency overflow capacity and stability requirements. In addition, the example problem presents hydraulic details only. Final design should consider site constraints (e.g., depth of water, side slope stability, maintenance, grading) to prevent standing water and provide for public safety.

Table 14.23(a) Storage Routing for the 10-Year Storm (Metric)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Time (h)	**I Inflow (m^3/s)**	**$[(I_1 + I_2)]\Delta t/2$ (m^3)**	**Stage (m)**	**S Storage (m^3)**	**$S_i - (O_i/2)\Delta t$ (m^3)**	**$S_{i+1} + (O_{i+1}/2)\Delta t$ (m^3)**	**O Outflow (m^3/s)**
0.0	0.00	254.86	0.00	0.00	0.00	254.86	0.00
0.1	1.42	1162.17	0.19	218.13	181.43	1343.61	0.20
0.2	5.04	2181.61	0.82	1065.71	787.87	2969.51	1.54
0.3	7.08	2115.34	1.51	2272.48	1575.56	3690.92	3.87
0.4	4.67	1299.79	1.78	2801.43	1912.04	3211.84	4.94
0.5	2.55	713.61	1.61	2441.14	1668.68	2382.30	4.29
0.6	1.42	402.68	1.28	1838.25	1294.29	1696.98	3.02
0.7	0.82	229.37	0.99	1324.74	952.55	1181.93	2.07
0.8	0.45	127.43	0.73	947.32	712.75	840.18	1.30
0.9	0.25	71.36	0.55	688.89	536.79	608.16	0.85
1.0	0.14	40.78	0.42	506.41	404.72	445.50	0.56
1.1	0.08	20.39	0.32	377.02	308.58	328.97	0.38
1.2	0.03	5.10	0.24	281.54	234.16	239.26	0.26
1.3	0.00	0.00	0.17	204.79	170.34	170.34	0.19

Table 14.23(b) Storage Routing for the 10-Year Storm (U.S. Customary)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Time (hour)	**I Inflow (cfs)**	**$[(I_i + I_{i+1})]\Delta t/2$ (ft^3)**	**Stage (ft)**	**S Storage (ft^3)**	**$S_i - (O_i/2)\Delta t$ (ft^3)**	**$S_{i+1} + (O_{i+1}/2)\Delta t$ (ft^3)**	**O Outflow (cfs)**
0.0	0	9,000	0	0	0	9,000	0
0.1	50	41,040	0.61	7703	6,407	47,447	7
0.2	178	77,040	2.68	37,634	27,822	104,862	55
0.3	250	74,700	4.95	80,249	55,638	130,338	137
0.4	165	45,900	5.83	98,928	67,520	113,420	174
0.5	90	25,200	5.30	86,205	58,926	84,126	152
0.6	50	14,220	4.20	64,915	45,705	59,925	107
0.7	29	8,100	3.26	46,781	33,637	41,737	73
0.8	16	4,500	2.40	33,453	25,169	29,669	46
0.9	9	2,520	1.80	24,327	18,956	21,476	30
1.0	5	1,440	1.37	17,883	14,292	15,732	20
1.1	3	720	1.04	13,314	10,897	11,617	13
1.2	1	180	0.79	9,942	8,269	8,449	9
1.3	0	0	0.55	7,232	6,015	6,015	7

Calculation Procedure:

1. At the start of the storm $I_i = 0$, $H_i = 0$, $S_i = 0$ and $O_i = 0$. Thus, 0 is entered into column 4, column 5 and column 8.
2. Calculate $[(I_i + I_{i+1})]\Delta t/2$, and record in column 3.
3. Calculate $S_i - (O_i/2)\Delta t$ and record in column 6.
4. Sum column 3 and column 6 and record in column 7.

5. The outflow and storage at time increment i+1 is determined by finding the stage using the $S + (O_i/2)\Delta t$ and stage relationship. Record the stage in column 4 for time increment i+1.
6. Use the stage at time increment i+1 to determine the storage and discharge at time increment i+1 from the stage-storage and stage-discharge relationship. Record these values in column 5 and column 8 for time increment i+1.
7. Advance to next time increment and repeat steps 2 through 7.

Figure 14.10(a) Runoff Hydrographs (Metric)

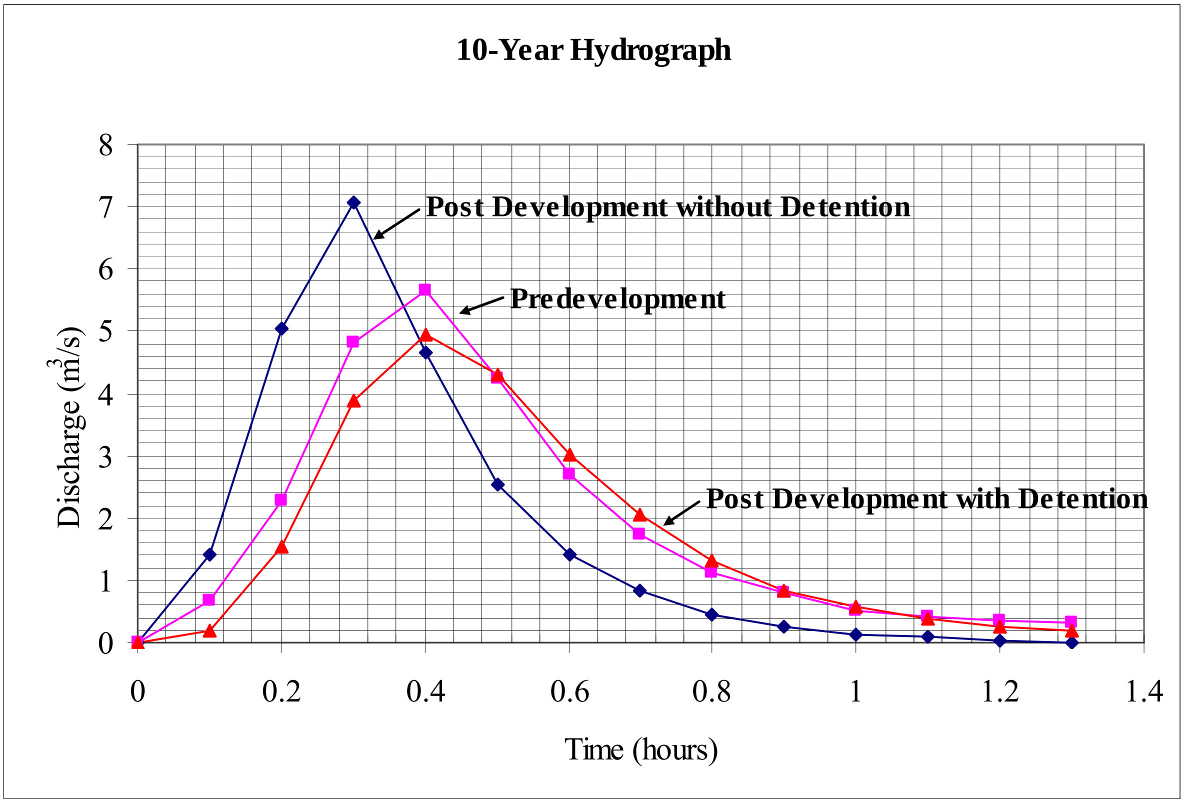
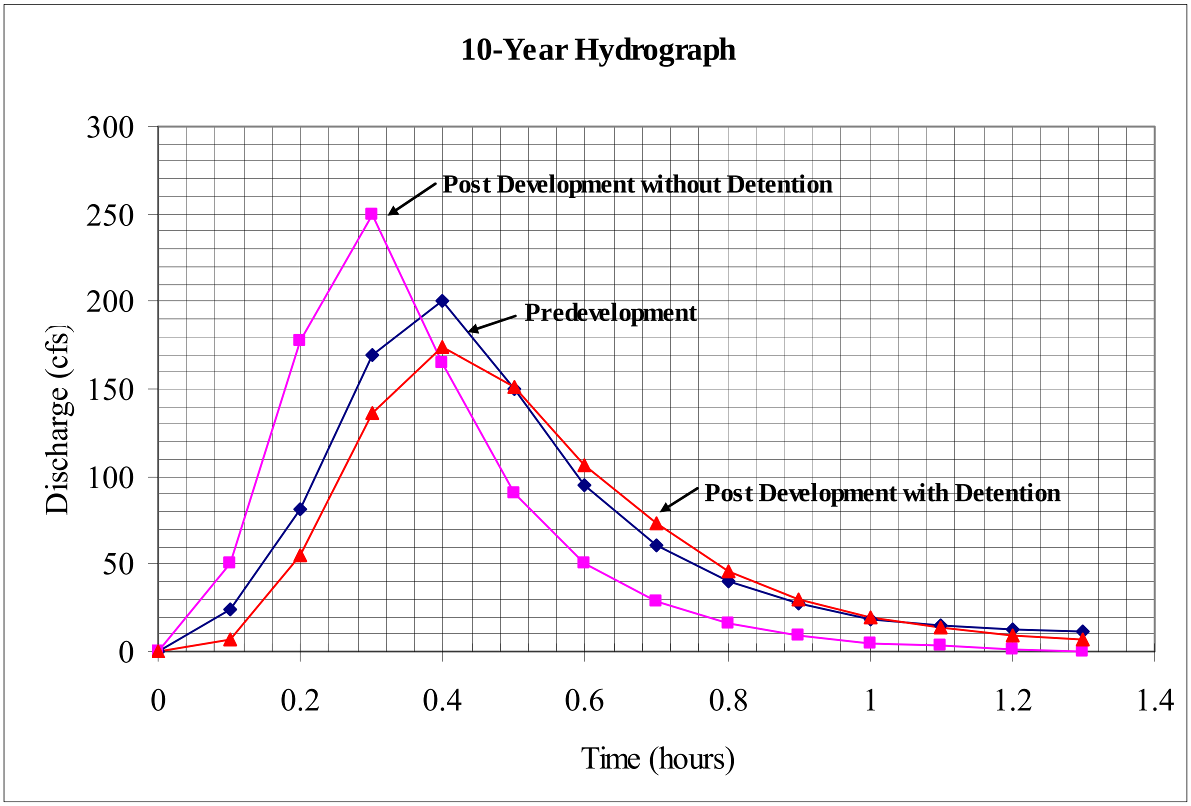


Figure 14.10(b) Runoff Hydrographs (U.S. Customary)



E. Downstream Effects. An estimation of the potential downstream effects (i.e., increased peak-flow rate and recession time) of storage facilities may be obtained by comparing the recession limbs of the pre-development and routed post-development hydrographs. A comparison of the hydrographs used in this example is provided in Figure 14.10 for the 10-year design storm.

It is important to be aware that as a watershed is developed it typically becomes more impervious with less water being infiltrated into the ground and greater volumes of water released into waterways and conveyed downstream. Detention basins simply hold the water and release it over a longer period of time, thus reducing the peak rate of runoff. Although the post-development peak rate of runoff is kept from exceeding the pre-development peak rate of runoff with a detention basin, the volume of runoff is usually increased and the length of time the peak is held is typically extended. This increase in volume of water being released may contribute to bed and bank degradation in the receiving channel.

14.16 DRY POND (DETENTION BASIN)

A. Introduction. Detention basins are depressed areas that store runoff during wet weather and release it at a controlled rate to reduce the impact of changes in land cover and land use on stormwater runoff. As implied by their name, under normal weather conditions these ponds are typically designed to be dry when it is not raining, or shortly thereafter. They are very popular because of their comparatively low cost, few design limitations, ability to serve large and small watersheds, and depending on their size, their ability to be incorporated into other uses (e.g., recreational areas).

With few design constraints these facilities are not restricted to a maximum drainage area limit. To ensure the greatest probability of success and construction of a functional dry pond, the following should be considered when locating and designing a dry detention basin.

1. Site Selection.

a. Locate the pond to maximize flow to the facility (i.e., at the low point in the topography in close proximity to an existing waterway or drainage course).

b. Fit the pond into the existing terrain. Design the pond as if it were a natural part of the landscape while being cognizant that intricate grading plans may be difficult and costly to construct. Generally, simpler geometric configurations are preferred over more complex configurations and should be selected as long as the project's water quality objectives can be achieved.

c. Pond awareness. Situate the pond in a location where it does not become a hazard or in areas without known problems. Without special considerations or features incorporated into the design, dry detention basins should not be located near or within recreation facilities. Dry detention basins can be potentially dangerous during storm events with water depths rapidly increasing in short spans of time.

2. Pond Grading. Grade dry ponds into the proposed site according to the following design criteria:

- 1% (.01ft/ft) Minimum longitudinal slope of basin bottom (flow from inlet to outlet).
- 3 m (10 ft) Minimum pond embankment top width.
- 4.5 m (15 ft) Maximum pond embankment height without potentially requiring a dam permit.
- 1V:3H (3H:1V) Maximum outer side slopes.
- 1V:2H (2H:1V) Maximum inside side slopes.
- 1V:4H (4H:1V) Maximum steepness for mowable side slopes.

3. Pond Shape. Dry ponds are most effective when they contain an irregular curvilinear pattern. Shapes such as squares, rectangles, and pointed triangles are easy to construct, but often do not appear natural and are less aesthetically pleasing than the aforementioned geometric shapes. As best as possible, the pond shape should blend into the existing environment. The shape of the pond can affect the pollutant-removal efficiency. Typically, the length-to-width ratio should be at least 2L:1W.

4. Maintenance Access. An access road with a minimum width of 3 m (10 ft) should be provided so that maintenance personnel can easily access the pond to facilitate the removal of debris and sediment and rehabilitate the BMP as needed.

5. Fencing/Safety. Safety considerations to reduce the chance of drowning include fencing the basin, reducing the maximum ponding depth, and including ledges or mild slopes. Fencing around dry ponds should only be considered when inside side slopes do not meet the criteria mentioned above and the pond is considered a hazard. Clear zone requirements and/or guide rail are necessary regardless if fences are present or not. When fences are proposed, they should be located outside of the clear zone for traffic safety reasons.

6. Emergency Spillway. All basins should be equipped with an emergency spillway. The emergency spillway provides relief in the event the principal spillway becomes blocked or fails. Flows larger than the design event are usually conveyed by the emergency spillway. Spillway side slopes should be no steeper than 1V:3H (3H:1V) with a minimum bottom width of 3 m (10 ft). All spillways should be designed to prevent erosive exit velocities by stabilizing the spillway with suitable vegetated or rock lining. In certain instances the top of the outlet control structure may be used as an emergency spillway. For a case where the top of the principal spillway is used as an emergency spillway, a secondary emergency spillway should be considered in the event the principal spillway outlet fails. Freeboard above the design depth of the spillway, to the top of the basin embankment, should be no less than 150 mm (0.5 ft).

7. Principal Spillway. As the primary outlet of the pond, the principal spillway system includes the riser assembly (outlet structure), the outfall pipe, outfall scour protection, weirs, orifices, maintenance drains, trash racks or any other components necessary for proper stormwater release. Outlets for dry ponds can be designed in a wide variety of configurations, but most outlets use riser structures constructed from concrete. Corrugated metal risers are acceptable for long-term operations if they are of sufficient gage and are galvanized, coated, or aluminized. These risers can be designed to control different storms using a single or combination of openings set at different elevations on the riser.

a. Riser Assembly (outlet structure). Risers are designed to satisfy the post-construction stormwater management objectives for a project using orifices, weirs, or a combination of these elements set at different elevations on the riser. For example, a small orifice is used to control the water quality volume or provide extended detention and a series of larger orifices or weirs set at different elevations may be used to control the larger events where rate controls are required. Larger flows may be controlled by allowing stormwater to flow through the top of the riser, using the entire riser diameter to convey the stormwater out of the facility. In some cases, an antivortex design may be necessary. The outlet structure should be designed to convey the appropriate design flow and dewater the basin completely within 48 hours after the end of each event. The design flow is not set arbitrarily for all a facilities, but is developed based on the project needs. Typically, the design process is initiated using a design storm based upon the roadway classification and then adjustment are made to select the appropriate event based upon the project's needs. As part of the design process for the riser assembly, a check should be made to assess the impact of the extended dewatering upon two successive 24-hour events and appropriate provisions be made to prevent overtopping of the facility if necessary.

b. Outfall Pipe. An outfall pipe functions to convey flow from the riser assembly to the outfall located downstream of the basin. Outfall pipes should convey the maximum outflow from the basin for the design event. The pipe should be reinforced concrete pipe or corrugated plastic pipe at the size and length dictated by design and necessary to provide the needed conveyance capacity. All pipes should be watertight and properly installed in accordance with Publication 408, *Specifications*. The minimum pipe diameter is 450 mm (18 in). If the principal spillway is to be used as an emergency spillway, the outfall pipe should be sized to convey the peak inflow that is capable of entering the basin.

c. Outfall Scour Protection. To prevent scour at the pond outfall, outlet protection should be provided and sized using the maximum discharge from the basin.

d. Weirs and Orifices. Any combination of weirs and orifices may be used to control the discharge of stormwater to meet the applicable performance standards. Orifice diameters should be no smaller than 75 mm (3 in) for clean out and maintenance purposes. Weirs and orifices should be designed such that the size and shape of the outlet are not compromised during the life of the outlet structure. To facilitate the construction of these features, the dimensions of weirs and orifices should be set at values which are easily defined and measured, such as whole numbers set in increments of 25 mm (1 in).

e. Trash Racks. Trash racks should be provided as necessary to protect orifices from clogging. Although trash racks are required for the lowest orifice, they may also be provided for other orifices if debris is a potential problem. Trash racks should be provided for the large opening in the top of the riser structure when a grate is not attached to provide for safety and prevent the deposition of debris in the outlet control structure, especially if the top of the structure is used to convey the larger events through the basin. Publication 72M, *Roadway Construction Standards*, RC-70M, may be referenced for standard drawings concerning trash racks, storage facilities and outlet works.

B. Design Objective.

1. Quality. A detention basin may be designed to improve its water quality features. This may be accomplished by constructing a series of BMPs within the basin and by designing the basin's outlet controls to manage the extended detention or retention of runoff. Incorporating pocket wetlands, shallow marshes or wet bottoms into the bottom of dry detention basins can provide an opportunity to meet the water quality objectives.

2. Quantity. The minimum performance standard with respect to quantity is that the pond should be designed to reduce the post-construction peak flow for the design storm event to levels that satisfy the PCSM targets, or if applicable, the release rate or district management objectives set forth in an approved watershed-wide Act 167 Stormwater Management Plan. To control these storms, the basin's storage should be at approximately equal to the area between the pre- and post-construction hydrographs. After a storage volume has been determined for each event, the design storm should be routed through the facility to ensure that the peak flows from the post-construction watershed do not exceed the permissible rates.

3. Quantity and Quality Combined. Combining the two design objectives (quality and quantity) will yield a dual-purpose detention basin. Several design variations may be considered to enhance the capabilities of the facility. One consideration is shaping the basin to improve its pollutant-removal capabilities by extending the flow length within the basin. Inlet, outlet and side slopes should be stabilized with vegetation to prevent erosion, or in those areas subject to high velocities and shear stress, riprap or other stabilization measures. The basin floor should be stabilized with dense vegetation to prevent erosion and promote biological uptake of stormwater and certain non-point source pollutant. Impervious low flow channels or pilot channels through the basin are strongly discouraged except in the cases where severe ponding is an issue. A marsh or wetland can be established on the pond floor to increase biological uptake, and a sediment forebay (a small sediment trap at the inlet of the basin with a very flat bottom where sediment is easily deposited) can be used to trap the sediment before it enters the basin (see Figure 14.12). A check dam is typically placed downstream of the forebay area to separate the forebay from the remainder of the basin. Check dam sizing is based upon forebay size and depth with a spillway typically provided to facilitate the conveyance of water from the forebay into the main chamber of the basin.

Figure 14.11 Concrete Riser Example

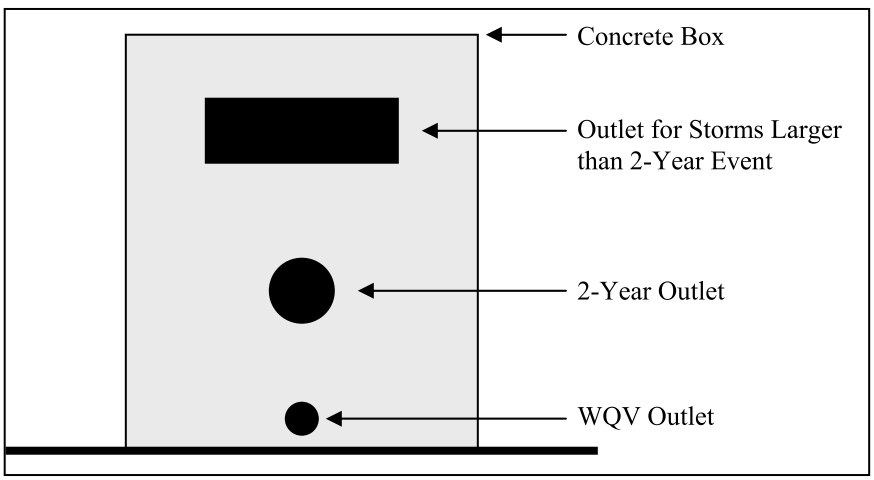
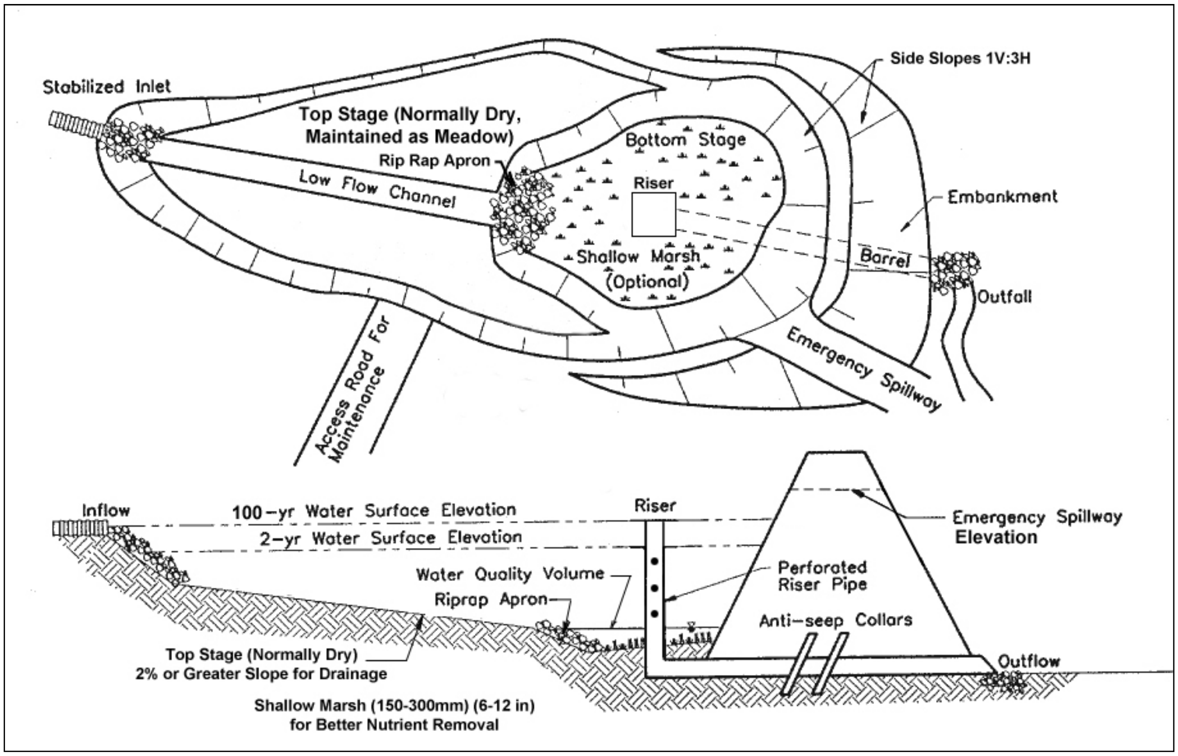


Figure 14.12 Example of Dry Pond Configuration



Reference: Schueler, 1987

14.17 WET POND

A. Introduction. A wet pond is very similar to a dry detention basin in that it detains stormwater, but it is different in that it maintains a permanent pool during dry weather. The benefit of a wet pond is that it may be used for both water quantity and water quality control, and because of the permanent pool, they may also be more aesthetically pleasing. Wet ponds are usually more expensive than dry detention basins to construct and maintain and are typically designed to serve large watersheds, in excess of 4-6 ha (10-15 ac). To ensure the greatest probability of success and a design that is fully functional, which is accepted by the public, the following standards should be adhered to in the wet pond design.

1. Site Selection

a. Locate the pond to maximize flow to the facility (i.e., the low point in the topography that is in close proximity to an existing waterway or drainage course). Ordinarily wet ponds are located below a spring or adjacent to a waterway so that a regular source of water is available to flow through the pond and prevent the water from stagnating.

b. Existing soils should be either of Hydrologic Soil Group C or D or an impervious liner is needed to create and retain the permanent pool.

c. Fit the pond into the original terrain. Design the pond as if it were a natural part of the landscape while being cognizant that intricate grading plans may be difficult and costly to construct. Generally simpler geometric configurations are preferred over more complex configurations and should be selected as long as the projects water quality objectives can be achieved.

d. Pond awareness. Locate the pond in an area such that it does not become a hazard.

2. Pond Grading. Grade wet ponds into the proposed site according to the following design criteria:

- 3.0 m (10 ft) Minimum pond embankment top width.
- 4.5 mm (15 ft) Maximum pond embankment height without potentially requiring a dam permit.
- 1.5 - 3.0 m (5 - 10 ft) Normal pond depth should be between.
- 1V:3H (3H:1V) Maximum outer side slopes.
- 1V:2H (2H:1V) Maximum inside side slopes.
- 1V:4H (4H:1V) Maximum steepness for mowable side slopes.

3. Pond Shape. The shape of the pond can significantly affect the pollutant-removal efficiency of a wet pond and a minimum length-to-width ratio of 2L:1W should be provided. Figure 14.13 shows several pond configurations that may be used to increase the length-to-width ratio of the pond. Although many shapes of ponds are possible care should be taken to avoid designing a pond which cannot be physically constructed. Normally, the further a pond diverges from regular geometric shapes the more difficult and costly the feature becomes to construct.

4. Safety/Vegetation Ledge. All ponds that maintain a permanent wet pool require a 3 m (10 ft) minimum safety bench (ledge). The safety bench (ledge) should be 300 mm (1 ft) below the normal pool elevation of the pond for establishment of vegetation. An additional safety bench/ledge should be provided 300 mm (1 ft) above the normal pool elevation. This bench should be a minimum of 3 m (10 ft) wide and should have a reverse cross slope.

5. Maintenance Access. Provide an access road with a minimum width of 3 m (10 ft). Provide access such that maintenance personal can access various sections of the wet pond (i.e., spillway, outlet structure, and safety/vegetation ledge). All wet ponds should be designed with a drain pipe which can be opened to drain the pond to facilitate maintenance of the pond and cleaning of the permanent pool. The drain should be capable of draining the entire pond within 24 hours.

6. Fencing. Fencing around wet ponds should be considered when inside side slopes do not meet the criteria mentioned above, safety benches are not constructed within the pond, and the facility is considered a potential hazard. Clear zone requirements and/or guide rail will be necessary regardless if fences are present or not to prevent access to the basin by pedestrians and others. When fences are proposed, they should be located outside of the clear zone for traffic safety considerations.

7. Emergency Spillway. All ponds should be equipped with an emergency spillway. The emergency spillway provides relief in the event the principal spillway becomes blocked or fails. Flows larger than the design event are usually conveyed by the emergency spillway. Spillway side slopes should be no steeper than 1V:3H (3H:1V) with a minimum bottom width of 3 m (10 ft). All spillways should be designed to prevent erosive exit velocities by stabilizing the spillway with suitable vegetated or rock linings. In certain instances the top of the outlet control structure may be used as an emergency spillway. For a case where the top of the principal spillway is used as an emergency spillway, a secondary emergency spillway should be considered for installation in the event the principal spillway outlet fails. Freeboard above the design depth of the spillway, to the top of the basin embankment, should be no less than 150 mm (0.5 ft).

8. Outlet. A principal spillway is the primary outlet of the pond. The principal spillway system includes the riser assembly (outlet structure), the outfall pipe, outfall scour protection, weirs, orifices, maintenance drains, trash racks or any other component necessary for proper stormwater release. Similar to dry detention basins, outlets for wet ponds can be designed in a wide variety of configurations, but most outlets use riser structures constructed from concrete. Although corrugated metal risers are acceptable for short-term operations, because of there susceptibility to damage and corrosion concrete structures are preferred. The primary components of a principal spillway system include:

a. Riser Assembly. Risers should be designed to satisfy the post-construction stormwater management objectives for a project using orifices, weirs, or a combination of these elements set at different elevations on the riser. For example, a small orifice is used to control the water quality volume or provide extended detention and a series of larger orifices or weirs set at different elevations may be used to control the larger events, where rate controls are required. Larger flows may be controlled by allowing stormwater to flow through the top of the riser, using the entire riser diameter to convey the stormwater out of the facility. In some cases, an antivortex design may be necessary. If the smallest orifice is easily clogged from floating debris, or if heated pond water causes problems downstream during the summer, the outlet can be modified so that it will release water from below the surface of the pond. The outlet structure should be designed to dewater the volume of water above the permanent pool completely within 48 hours after the end of each stormwater event. As part of the design process for the riser assembly a check should be made to assess the impact of the extended dewatering upon two successive 24-hour events and appropriate provisions be made to prevent overtopping of the facility if necessary.

b. Outfall Pipe. An outfall pipe functions to convey flow from the riser assembly to the outfall located downstream of the pond. Outfall pipes should be designed to convey the maximum outflow from the pond. The pipe should be reinforced concrete pipe or corrugated plastic pipe at the size and length dictated by design and necessary to provide the needed conveyance capacity. All pipes should be watertight and properly installed in accordance with Publication 408, *Specifications*. The minimum pipe diameter should be no less than 450 mm (18 in). If the principal spillway is to be used as an emergency spillway the outfall pipe should be sized to convey the peak inflow to the pond.

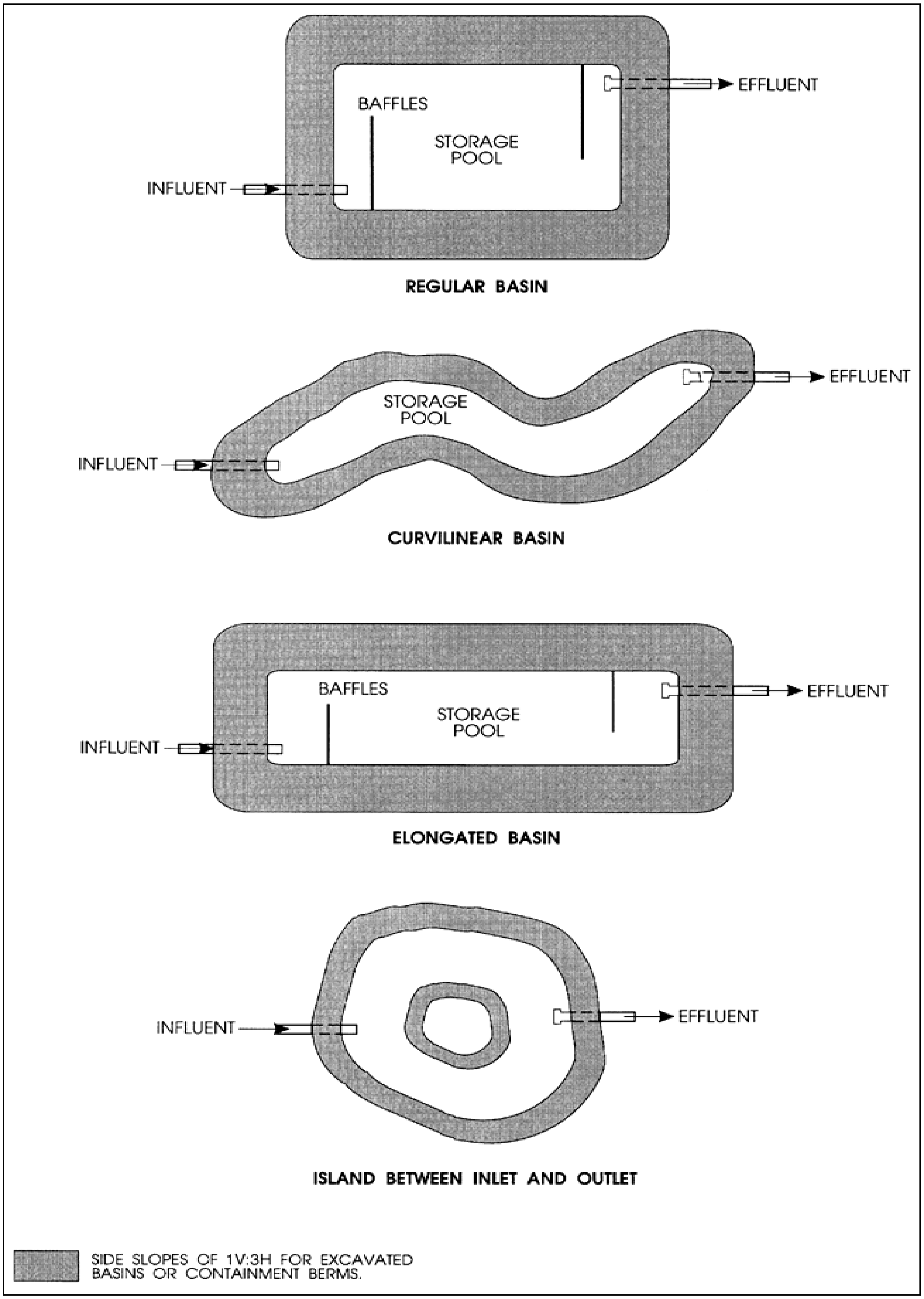
c. Outfall Scour Protection. Scour protection should be provided to prevent scour at the pond outfall, using rock or other means of energy dissipation based upon the maximum rate of discharge through the principal spillway.

d. Weirs and Orifices. The minimum orifice diameter should be no smaller than 75mm (3 in) for clean out and maintenance purposes to prevent the outlet from clogging. Weirs should be designed such that the integrity of the riser structure is not compromised during the life of the outlet structure. To facilitate the construction of these features the dimensions should be set at values which are easily defined and measured, such as whole numbers set in increments of 25 mm (1 in).

e. Trash Racks. Trash racks should be provided as necessary to protect orifices from clogging. Although trash racks are required for the lowest orifice they may also be provided for other orifices if debris is anticipated to be a potential problem. Trash racks should be provided for the large opening in the top of the riser structure to provide for safety and prevent the deposition of debris within outlet control structure, especially if a grate is not provided on the top of the structure and the top of the structure is used to convey the larger events through the pond. The Standards for Roadway Construction, RC 70M, may be referenced for standard drawings concerning trash racks, storage facilities and outlet works.

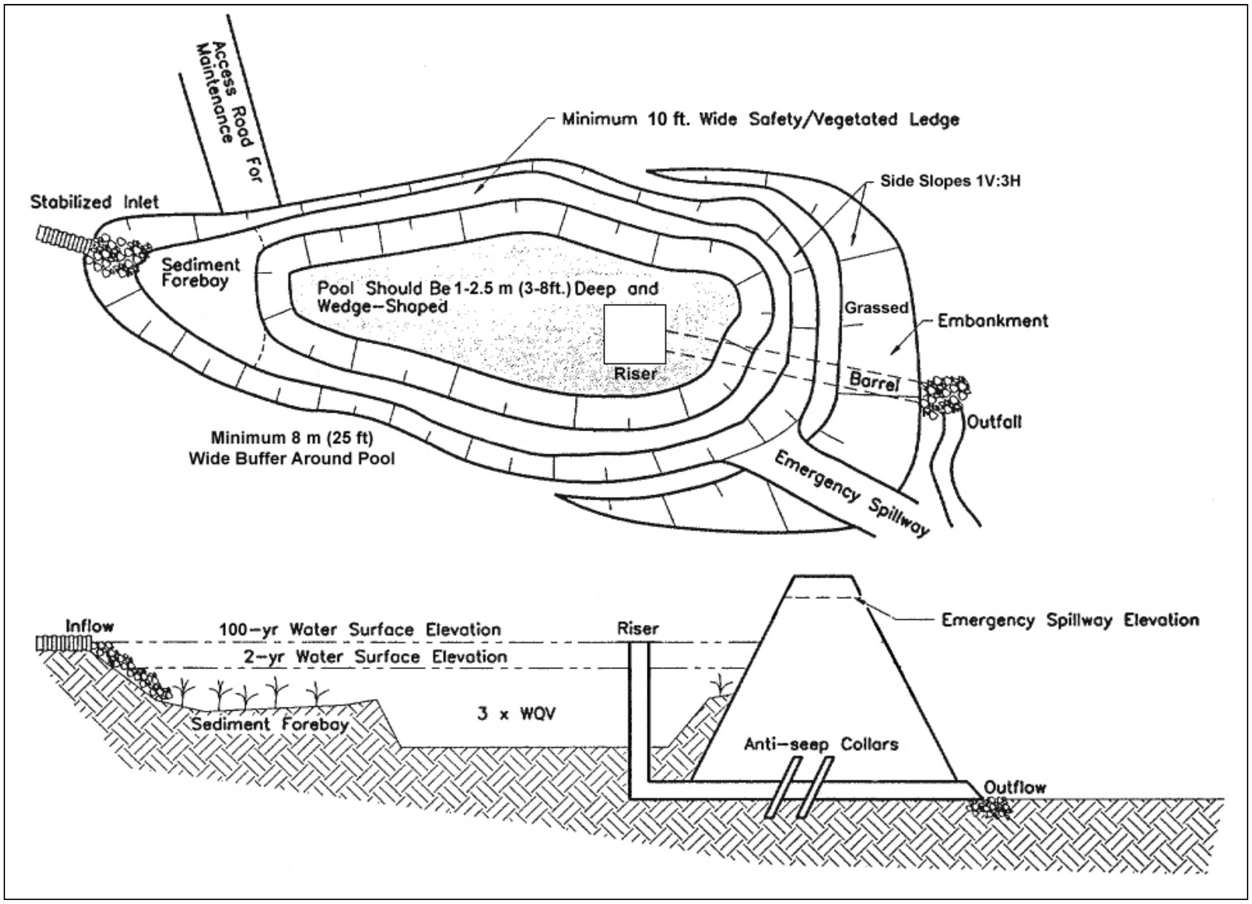
f. Anti-Seep Collars. Provide anti-seep collars along the principal spillway outlet pipe to prevent seepage around the outfall pipe.

Figure 14.13 Example of Methods of Increasing the Length-to-Width Ratio of a Storage Facility



Reference: Schueler, 1987

Figure 14.14 Wet Pond



Reference: Schueler, 1987

B. Design Objectives.

1. Quality. For quality management, the permanent pool should be at least 3 times the WQV for the watershed. The theory behind the function of a wet pond is that incoming runoff displaces old stormwater from the pond, with the new runoff retained until it is displaced by more runoff from the next storm. A permanent pool of 3 times the WQV provides adequate retention time for the removal of non-point source pollutants and maintenance of a healthy aquatic environment. Watershed size, soil conditions and groundwater elevation must be evaluated to ensure the capability of the site to support a permanent wet pond. To enhance pollutant removal, several other BMPs should be added into the flow path of the stormwater before it enters the wet pond to provide pretreatment of the stormwater. At a minimum, all wet ponds should include a sediment forebay at the entrance to the pond, which is separated from the main storage chamber of the pond by an earthen berm or gabion wall to remove sediment before it enters the permanent pool of the pond. The forebay should be sized to accommodate approximately 10 to 15% of the permanent pool volume. Typically, the forebay should be between 1.2 to 1.8 m (4 to 6 ft) deep and fitted with a spillway to convey flow from the forebay into the main chamber of the pond.

Pond depth is essential to maintaining water quality. Ponds that are shallower than the specified limit can allow insect breeding and wind re-suspension of settled particles while those that are deeper may result in thermal stratification and anaerobic conditions in deep water areas. Wet ponds are most effective and are more readily accepted when they contain a curvilinear shape and blend into the existing topography (see Figure 14.13). Other shapes and configurations may be suitable.

2. Quantity. For quantity, the wet pond system should be designed similarly to the dry pond. The pond should be designed to reduce the peak flow for the design event and be able to pass the design flow through the basin without the regular use of the emergency spillway. When performing stormwater management computations to support the design of the pond, the volume of the permanent pool should not be considered part of the available storage volume as this will inflate the available storage volume and result in erroneous stage storage and outflow data.

14.18 PROTECTIVE TREATMENT

Protective treatment may be required to prevent entry to facilities that present a hazard to children and, to a lesser extent, the public in general. Fences may be required for storage areas where one or more of the following conditions exist:

- Occurrence of rapid-stage increases and the configuration of facility geometrics which make escape difficult, especially near areas where small children frequently visit such as playgrounds.
- Existence of storage depths that either exceed 0.9 m (3 ft) for more than 24 hours or are permanently wet and have side slopes steeper than 1V:4H (4H:1V).
- Presence of a low-flow watercourse or ditch traversing a storage area with a depth greater than 1.5 m (5 ft) or a flow velocity greater than 1.5 m/s (5 ft/s).
- Existence of side slopes equal to or steeper than 1V:1.5H (1.5H:1V).

Guards or grates may be appropriate for other conditions but, in all circumstances, heavy debris should be kept from entering the detention area. In some cases, it may be advisable to fence the watercourse or ditch rather than the entire storage area.

Fencing should be considered for all retention areas with design depths in excess of 0.9 m (3 ft) for 24 hours, unless the area is within a fenced, limited-access facility.

14.19 MAINTENANCE

Regular BMP maintenance is an essential part of preserving the stormwater management functions of a facility. Poorly maintained BMPs often function less efficiently and may cause more problems than they were intended to resolve. Therefore, it is important to consider maintenance issues when selecting a BMP. Typically, it is best to select the least maintenance intensive BMP that will allow the stormwater management objectives to be achieved. Prior to selecting a BMP and completing the design, it is recommended that the Department's maintenance staff be contacted for suggestions on how to minimize future maintenance issues for proposed stormwater BMPs. It is important to have consistent communication with the maintenance staff to ensure that appropriate BMPs (from a future maintenance standpoint) are being implemented.

All BMPs should be developed with a list of maintenance practices and a schedule of maintenance activities to be performed which provide for the long-term viability of the BMP. The maintenance schedule should provide for both short-term maintenance needs and long term rehabilitation items that may be necessary in the future and which are more extensive than the routine maintenance performed throughout the year. The District maintenance unit should be provided with this list and schedule of BMP maintenance activities, as they will be responsible for the routine maintenance of the BMP. Regardless of their location all BMPs should be designed to provide for access to the facility so that routine maintenance may be easily performed. Often times BMPs are placed in close proximity to other significant environmental resources, such as rivers, lakes, wetlands, or wooded areas; therefore, it is essential that BMPs be located in a way that they do not infringe upon these areas and that suitable points of access are provided such that routine maintenance operations at the facility can be accomplished without encroaching upon other known environmental resources.

Regardless of the BMP selected, basic minimum maintenance efforts should normally include the following activities:

- Regular inspection.
- Routine mowing.
- Removal of accumulated debris and sediment.
- Re-stabilization of pervious areas where vegetation has been destroyed.

- Resolution of any known causes of accumulated debris and sediment.
- Removal of invasive plant species.
- Resolution of maintenance items which inhibit the BMP from functioning as intended.
- Cleaning of outlet control structures, storm pipes, and outfalls.
- Restoration of rock filters, level spreaders, earthen berms and energy dissipation devices.

Although it is the objective to have the BMPs blend in to the environment, often times these features may be encroached upon or destroyed by activities of others who are not aware of their function or significance. To protect BMPs from unintentional abuse it may be necessary to provide signs indicating the limits and purpose of the BMP as well as restricted activities around the BMP.

14.20 FREQUENTLY ASKED QUESTIONS

A. What is the difference between stormwater management that may discharge to Special Protection waters, or EV wetlands, and all other waters? In Special Protection watersheds, or EV wetlands, there can be no measurable change in the rate or volume of runoff from site. For all other waters, there can be no loss in the existing or designated use from a change in the post-construction runoff. The process of analyzing and using non-discharge alternatives, and antidegradation best available control technologies (ABACT), must be documented in HQ and EV watersheds, or EV wetlands. The PA DEP NPDES construction permit includes an Antidegradation Analysis Module so that the applicant can provide information that demonstrates non-degrading discharges.

B. Are wetlands and streams treated the same in terms of PCSM requirements? For the most part, yes, since they are both considered surface waters. However, a project can also indirectly impact a wetland without even discharging stormwater to it by cutting off the wetland's hydrologic input. The source of hydrology for adjacent, downstream wetlands should be evaluated to ensure that the project does not have adverse impacts. In addition, wetlands that exhibit characteristics listed in PA Code 105.17.1 are classified as EV.

C. Do maintenance projects require an NPDES construction permit? A maintenance project may require a permit depending on the types and extents of construction activities that are associated with it. PA Code Title 25 Chapter 102 defines Roadway Maintenance Activities. Projects disturbing 10.1 ha (25 ac) or more of earth as a result of maintenance activities require an Erosion and Sediment Control Permit. Projects disturbing 0.4 ha (1.0 ac) or more of earth as a result of non-maintenance activities require an NPDES construction permit.

D. A project has between 0.4 hectares (1.0 acre) and 2.0 hectares (5.0 acres) of disturbance, but all of the runoff leaves the site via sheet flow. Does the project require an NPDES construction permit? No, only when there is a point-source (end of pipe, channel, etc.) discharge with between one and five acres of disturbance is a permit required. However, an E&S plan must be developed and submitted to the applicable county conservation district.

E. Is a PCSM analysis required when the project does not require an NPDES construction permit and it is not located in an approved Act 167 plan watershed? No, there is no law, per se, that requires PCSM in the absence of an NPDES permit and Act 167 plan. However, PennDOT's MS4 permit outlines BMPs to be used for maintenance facilities and practices. Even if a PCSM plan is not required, the low-impact design concepts and non-structural BMPs described in this policy should be evaluated on a project-by-project basis.

F. Is it acceptable to leave parts of the NPDES permit application blank, or can questions be addressed by simply writing "not applicable?" No. Any application for NPDES Permits for Stormwater Discharges Associated with Construction Activities, regardless of the type of project or applicant, requires that all sections and parts of the application be completed.

G. Chapter 8 of *BMP Manual* provides for water quality calculations – when do these calculations have to be completed for PennDOT projects? PCSM plans for Level 3 and 4 projects require a water quality analysis, even if the targets for rate and volume have been met. Infiltration generally satisfies PA DEP's reduction requirements for two of the three representative pollutants: total suspended solids (TSS) and total phosphorus (TP). However, infiltration does not necessarily remove solute from runoff before it enters groundwater flow. PA DEP uses a representative solute, nitrate, as an indicator for solute removal. The designer must use Flow Chart D and the associated worksheets in Chapter 8 of the *BMP Manual* to document consistency with the pollutant removal guidelines. Since Level 1 and 2 projects should have minimal increases in rate and runoff, and no change in the types or sources of pollutants; therefore, these calculations are not required for Level 1 and 2 projects. Worksheet 10 from Chapter 8 of the *BMP Manual* should be completed for Level 3 and 4 projects.

H. What information should the PCSM section of an NPDES permit application submission contain? The PCSM plan should contain all of the information listed in the NPDES permit application checklist (note that General and Individual permits have different checklists), which is attached to the permit application form. Worksheets 1-5, which are attached to the application package, must be completed for all NPDES permit applications, regardless of the PCSM Level. Worksheet 7 from Chapter 8 of the *BMP Manual* must be completed for Level 2 projects, and Worksheet 10 must be completed for all Level 3 and Level 4 projects. Also note that the seal of a qualified licensed professional (Engineer, Land Surveyor, Professional Geologist or Landscape Architect) is required on PCSM plans for engineered structural BMP calculations and specifications.

I. The Summary Data Table in the NPDES permit application requires calculations demonstrating the net change in peak discharge rate and volume of runoff. Is it necessary to complete this table for all projects that require an NPDES permit, and what design event should be indicated in the table? Yes, the table must be completed for every NPDES permit, and the data in the table should be completed for the 2-year 24-hour rainfall event.

J. Do peak discharge rates and runoff volumes have to be mitigated at each source of disturbance and before runoff goes beyond PennDOT's right-of-way? No. Peak rate control must be demonstrated at each point at which discharge from the project reaches the receiving surface water. Areas in between the point where discharge leaves PennDOT's right-of-way and the receiving surface water must be analyzed for erosion potential and flooding impacts. Volume control must be demonstrated within the respective watershed, and analogous when comparing the pre and post drainage areas.

K. What information should be contained in the thermal impact analysis section of the NPDES permit? Although documentation must be provided with every PCSM plan, thermal impacts are primarily an issue when a project significantly increases impervious area and the resulting runoff is directly connected (i.e., ditch, storm sewer, etc.) to a cold water, headwater stream, or when the activity results in the removal of vegetation within the floodway/stream corridor. The strategies developed by PA DEP and PennDOT in Section 14.1.C are examples of BMPs that can help reduce thermal impacts. The general idea is to break any direct connection between the impervious area and the surface water, and reduce impervious areas, where practicable. In most cases, a narrative discussing the BMPs located between the impervious surface and surface water will be sufficient.

14.21 DEFINITIONS

Additional Impervious Surfaces - Refers to the difference between post-development and pre-development impervious surfaces.

Best Management Practices (BMPs) - Schedules of activities, prohibitions of practices, maintenance procedures and other management practices to prevent or reduce pollution to surface waters of this Commonwealth. The function of many stormwater BMPs is to prevent or minimize increases in runoff rate and volume caused by changes in the landscape.

Combined Sewer Systems (CSSs) - A single pipe sewer system designed, permitted, and constructed to convey both sewage and stormwater during periods of excess precipitation (runoff).

Degradation - For HQ and EV watersheds, degradation is an adverse effect that results in a negative change in the existing water quality of the receiving surface water. For non-HQ/EV watersheds, it is a negative change in the existing or designated in-steam water use or the level of water quality necessary to protect the use.

Disturbed Area - Unstabilized land area where an earth disturbance activity is occurring or has occurred. Note that any area that is resistant to erosion, sliding, or other movement is considered stable. For example, placing stone on a geotextile liner over a stable landscape does not constitute a disturbed area. Repair or reconstruction of an existing paved area should not be included in disturbed area calculations.

Earth Disturbance Activity - A construction or other human activity which disturbs the surface of the land, including, but not limited to, clearing and grubbing, grading, excavations, embankments, land development, agricultural plowing or tilling, timber harvesting activities, road maintenance activities (on unpaved areas), mineral extraction, and the moving, depositing, stockpiling, or storing of soil, rock or earth materials.

Evapotranspiration (ET) - The sum of evaporation and plant transpiration of water. Evapotranspiration accounts for a significant portion of the rainfall that is lost (not returned to streams via surface runoff) in Pennsylvania watersheds. The amount of water that is lost by evapotranspiration is influenced mostly by the types of vegetation and land use in a watershed. Because water transpired through leaves comes from the roots, plants with deep reaching roots can more constantly transpire water. Thus, herbaceous plants transpire less than woody plants because herbaceous plants usually lack a deep taproot. Also, woody plants keep their structure over long winters while herbaceous plants must grow up from seed in the spring in seasonal climates, and will contribute almost nothing to evapotranspiration in the spring.

Impaired Stream - A stream that does not meet the water quality criteria for its designated or existing use.

Infiltration - The process by which surface water penetrates through the ground surface into the soil. The soil texture and structure, vegetation types and cover, water content of the soil, soil temperature, and rainfall intensity all play a role in controlling infiltration rate and capacity. For example, coarse-grained sandy soils have large spaces between each grain and allow water to infiltrate quickly. Vegetation creates more porous soils by both protecting the soil from pounding rainfall, which can close natural gaps between soil particles, and loosening soil through root action. This is why forested areas have the highest infiltration rates of any vegetative types.

Long Term Control Plan - A plan developed by municipalities and/or municipal authorities designed to mitigate the impact of combined sewer system discharges and meet water quality standards.

Municipal Separate Storm Sewer System (MS4) - Certain small municipal separate storm sewer systems in urbanized areas, as defined in 40 CFR Part 122, that discharge stormwater into surface waters of the Commonwealth (including intermittently flowing streams and drainage channels) are required to have the discharges authorized by an NPDES stormwater permit. The MS4 classification includes a conveyance or system of conveyances (including roads with drainage systems, streets, catch basins, curbs, gutters, ditches, man-made channels or storm drains) primarily used for collecting and conveying stormwater runoff.

Net Change - Refers to the change from pre-development to post-development conditions.

Non-discharge Alternative - For activities requiring coverage under an NPDES Permit for Stormwater Discharges Associated with Construction Activities, means no "net change" in existing stormwater runoff conditions (volume, rate, and quality) per watershed. Non-discharge alternative does <u>not</u> mean that there can be no discharge from the site.

Pre-development - Refers to runoff condition that exists onsite immediately before the planned project occurs. Pre-development is not intended to be interpreted as the period before any human-induced land disturbance activity has occurred.

Post Construction Stormwater Management (PCSM) - The term "post-construction" is used to differentiate PCSM from discharges during construction. Erosion and sediment (E&S) pollution control plans are required for most construction projects to show that runoff from disturbed areas during construction is properly managed. PCSM deals with runoff from the project <u>after</u> the earth disturbance is completed and the site has been stabilized.

Surface Waters - Perennial and intermittent streams, rivers, lakes, reservoirs, ponds, wetlands, springs, natural seeps and estuaries.

Thermal Impact - Per Chapter 93, Title 25 of the PA Code, thermal degradation is a two degree (or more) change during a one-hour period in mean water temperature of the receiving surface water. The water quality criteria do not preclude the allowance of a reasonable mixing zone if there is no significant effect on the ambient temperature of the stream outside the mixing zone.

Total Maximum Daily Load (TMDL) - The amount of pollutant loading that a waterbody can assimilate and meet water quality standards. The TMDL process is a planning tool to develop pollution reduction goals that will improve impaired waters to meet water quality standards.

14.22 CHAPTER 14 NOMENCLATURE

Symbol	Definition	Units
A	Cross-sectional area or surface area	m^2 or ft^2
$A_{1,2}$	Surface area at Elevations 1 and 2 respectively for a stage-storage curve	m^2 or ft^2
C	Weir coefficient	dimensionless
C	Discharge coefficient	dimensionless
d	Change in water surface elevation	m or ft
d	Depth of infiltration basin	m or ft
D	Depth of basin	m or ft
D	Pipe diameter	m or ft (cm or in)
f	Infiltration rate	mm/hr or in/hr
g	Acceleration due to gravity	m/s^2 or ft/s^2
H	Head on a structure	m or ft
H	Head above weir crest	m or ft
H_1	Upstream head above crest	m or ft
H_2	Downstream head above crest	m or ft
H_c	Height of weir crest above channel bottom	m or ft
I_i, I_{i+1}	Inflow rate at beginning, end of time interval	m^3/s or cfs
L	Length	m or ft
L	Horizontal weir length	m or ft
O_i, O_{i+1}	Outflow rate at beginning, end of time interval	m^3/s or cfs
Q	Discharge, flow	m^3/s or cfs
Q_f	Free flow	m^3/s or cfs
Q_i	Peak inflow rate	m^3/s or cfs
Q_o	Peak outflow rate	m^3/s or cfs
Q_s	Submergence flow	m^3/s or cfs
S_a	Surface area	m^2 or ft^2
S_i, S_{i+1}	Storage volume at beginning, end of time interval	m^3 or ft^3
T_i	Duration of basin inflow	seconds
T_s	Storage time or detention time	hours
t_b	Time base of the inflow hydrograph	hours
t_p	Time to peak of the inflow hydrograph	hours
V	Volume of basin	m^3 or ft^3
Vol_s	Storage volume of infiltration basin	m^3 or ft^3
V_r	Void ratio	dimensionless
V_S	Storage volume	m^3 or ft^3
V_1, V_2	Storage volume between Elevations 1 and 2 for a stage-storage curve	m^3 or ft^3
W	Width	m or ft
Z	Side slope factor, ratio of horizontal to vertical	dimensionless
θ	Angle of V-notch weir	degrees
Δt	Routing time period for basin routing	seconds

14.23 REFERENCES

Atlanta Regional Commission (2001). *Georgia Stormwater Management Manual.*

Brater, E. F. and H. W. King (1976). *Handbook of Hydraulics*, 6th edition. McGraw Hill Book Company, New York, NY, 1976.

Dane County Conservation District. *Predicting the Impact of Urban Development on Stream Temperature Using a Thermal Urban Runoff Model (TURM).* Dane County Conservation District, Wisconsin.

Donaldson, B.M. (2004). *Highway Runoff in Areas of Karst Topography.* Virginia Transportation Research Council, Charlottesville, Virginia.

Fennessey, Lawrence, A.J., Ph.D., P.E. (2003). *Defining Natural Land Areas Critical for Stormwater Control in Karst Regions.* Proceedings of the 2003 Pennsylvania Stormwater Management Symposium.

FHWA (2003). *Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring.* Federal Highway Administration, U.S. Department of Transportation.

FHWA (1996a). *Retention, Detention, and Overland Flow for Pollutant Removal from Highway Stormwater Runoff. Volume I: Research Report.* Publication No. FHWA-RD-96-095, Office of Environment and Planning, Federal Highway Administration, Washington, DC, 1996.

FHWA (1996b). *Retention, Detention, and Overland Flow for Pollutant Removal from Highway Stormwater Runoff. Volume II: Design Guidelines*, Publication No. FHWA-RD-96-095, Office of Environment and Planning, Federal Highway Administration, Washington, DC, 1996.

FHWA (1996c). *Evaluation and Management of Highway Runoff Water Quality*, Publication No. FHWA-PD-96-032, Office of Environment and Planning, Federal Highway Administration, Washington, DC, 1996.

LID Center (2006). Low *Impact Development Design Manual for Highway Runoff Control.* Transportation Research Board, Washington, DC.

Lindeburg, M.R. *Civil Engineering Reference Manual for the PE exam, 9th edition.* Belmont Publications, Inc, Belmont CA, 2003.

New Jersey Department of Environmental Protection (2004). *New Jersey Stormwater Best Management Practices Manual.* New Jersey Department of Environmental Protection, Trenton, NJ.

Pennsylvania Association of Conservation Districts (1998). *Pennsylvania Handbook of Best Management Practices for Developing Area*s.

Pennsylvania Department of Environmental Protection (2006). *Pennsylvania Stormwater Best Management Practice Manual,* December 2006.

Schueler, T.R. (1987). *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs.* Metropolitan Washington Council of Governments, Washington, DC, 1987.

Transportation Research Board (2006). *Evaluation of Best Management Practices for Highway Runoff Control.* NCHRP Report 565, Transportation Research Board, Washington, DC.

Virginia DCR (1999). *Virginia Stormwater Management Handbook.* Volumes 1 and 2, First Edition, Division of Soil and Water Conservation, Virginia Department of Conservation and Recreation.

Washington State DOT (2006). *Highway Runoff Manual.* Washington State Department of Transportation.