Stormwater Drainage Design and Best Management Practices with Applications to Roadways and Climate Change

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A Report from the Pacific Southwest Region University Transportation Center

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16. Abstract
Stormwater runoff is generated from precipitation, snow and ice melt events that flow over impervious surfaces and cannot soak into the ground. It has been long recognized as the major contributor to water quality impairment. This project conducts an analysis of need via an extensive literature review. It shows that there is a critical need to provide a training course that can help better understand stormwater management and provide information for appropriately selecting and implementing Best Management Practices. Based on the results of the literature review, this project proposes to develop a 5-hour in-person training course that is intended for preparing participants to identify and analyze stormwater-associated problems and to select and design Best Management Practices appropriately for stormwater control. The designed course includes five modules, and each module is comprised of the scope statement, lesson topics, and learning objectives. The course covers the basic topics of stormwater, including Concept of Stormwater Management, Common Terms and Definitions used in Stormwater Management, Stormwater Runoff, Stormwater Functions, Stormwater-associated Problems, Storm Drainage System, Best Management Practices, Selection of Best Management Practice, Applications of Best Management Practice, General Principles for Stormwater Design, and Specific Principles for Roadway Drainage. For each topic, step-to-step instruction is provided.

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About the Pacific Southwest Region University Transportation Center

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The Pacific Southwest Region UTC conducts an integrated, multidisciplinary program of research, education and technology transfer aimed at *improving the mobility of people and goods throughout the region.* Our program is organized around four themes: 1) technology to address transportation problems and improve mobility; 2) improving mobility for vulnerable populations; 3) Improving resilience and protecting the environment; and 4) managing mobility in high growth are.

U.S. Department of Transportation (USDOT) Disclaimer

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Abstract

Stormwater runoff is generated from precipitation, snow and ice melt events that flow over impervious surfaces and cannot soak into the ground. It has been long recognized as the major contributor to water quality impairment. This project conducts an analysis of need via an extensive literature review. It shows that there is a critical need to provide a training course that can help better understand stormwater management and provide information for appropriately selecting and implementing Best Management Practices. Based on the results of the literature review, this project proposes to develop a 5-hour in-person training course that is intended for preparing participants to identify and analyze stormwater-associated problems and to select and design Best Management Practices appropriately for stormwater control. The designed course includes five modules, and each module is comprised of the scope statement, lesson topics, and learning objectives. The course covers the basic topics of stormwater, including Concept of Stormwater Management, Common Terms and Definitions used in Stormwater Management, Stormwater Runoff, Stormwater Functions, Stormwater-associated Problems, Storm Drainage System, Best Management Practices, Selection of Best Management Practice, Applications of Best Management Practice, General Principles for Stormwater Design, and Specific Principles for Roadway Drainage. For each topic, step-to-step instruction is provided.

Stormwater Drainage Design and Best Management Practices with Applications to Roadways and Climate Change

Executive Summary

Rapid urbanization continues in the United States at an unprecedented pace (1). Currently, the majority of the country's people lives in suburban and urban areas. According to a 2014 report by the United Nations Department of Economic and Social Affairs, urban populations are expected to account for nearly 70% by 2050 (2). With the advent of urban sprawl, impervious surfaces have also significantly increased. Impervious surfaces prohibit the infiltration of precipitation into the ground, which significantly increases the amount of surface runoff as well as the pollutants carried. The U.S. Environmental Protection Agency classifies urban runoff from impervious surface as a major contributor to water quality impairment (3). Therefore, effective urban stormwater management is important to the successful protection and restoration of water resources.

To better understand the fundamental challenges and needs existing in stormwater management, the project conducts an extensive literature review. Based on the literature review, the following issues are recognized:

1) The urbanization has changed the natural systems and significantly impacted the water quality of ambient water bodies, e.g., rivers, streams, and lakes. There is a critical need to clarify the mechanisms behind stormwater-associated problems and evaluate the relationship between the implementation of BMPs and stormwater control.
2) The performance of many BMPs is uncertain because limited information, e.g., effectiveness, longevity, and benefits, is not available. Regarding this issue, there is a great need to issue more local or national design guidance on BMPs and provide more training on how to properly select and implement BMPs on the ground among the practitioners in the land development community.
3) There is a great need for additional information and technical resources concerning stormwater management.
4) There is a need for the stormwater sector to engage with state programs, through ways like providing stormwater information, technical support, and training, to help identify and meet stormwater needs. The stormwater sector also needs to engage effectively with communities and public officials to improve the public understanding of stormwater. In addition, there is a need for the stormwater sector to provide a platform, e.g., in-person training, to exchange peer-to-peer knowledge and share the experience of stormwater management.

To meet these objectives, the project proposes to develop an in-person training course that is intended to prepare participants to describe and analyze stormwater runoff problems and

select and design appropriate stormwater BMPs, with applications to roadways and climate change. The training course is comprised of the following five modules:

Module 1: the instructor welcomes participants to the course, explains how instruction will take place, and provides an agenda.

Module 2: the instructor introduces the concept of stormwater management and explains the fundamental components of a stormwater management system. Also, this module includes a review of the basic terms and definitions used in stormwater management.

Module 3: the instructor explains how stormwater runoff is generated and how different types of runoff flow is calculated. Then, the instructor explains four stormwater functions that can be used to evaluate the effectiveness and limitation of a BMP. After explaining the four functions, the instructor leads the participants to discuss stormwater-associated problems and complete a group activity, which helps the participants identify stormwater-associated problems. After the group activity, the instructor introduces a storm drainage system. Besides the storm drainage system, BMP is also an integral component of stormwater management. According to the characteristics of BMPs, they can be divided into two groups: Non-structural and structural BMPs. The structural BMPs can be further divided into two groups: Storage types and Infiltration types. The instructor gives several examples for each type of structural BMPs, which helps participants understand the feasibility, benefits, and limitations of each BMP. After showing the examples, the BMP selection process is discussed through a detailed flow chart. Because roadways play a significant role in stormwater runoff, despite that they comprise a small portion of the whole watershed, the module discusses the BMPs implemented for roadways. Also, the instructor leads the participants to discuss how climate change affects BMP selection. The module concludes with a group activity where participants select appropriate BMPs for the stormwater-associated problems identified in the previous activity.

Module 4: the instructor introduces twelve general principles for stormwater design and five principles for roadway drainage design. These principles should always be taken into account when developing or redeveloping a project.

Module 5: the instructor leads a short discussion to review the course goal and content. Participants complete an objectives-based post-test, a course evaluation form, and provide feedback on the course instruction, content, and materials. Additional information will be provided about other training opportunities.

It is expected that this course can improve the understanding of stormwater management and provide a platform for participants with different backgrounds to share the stormwater-associated information and an opportunity to collaborate between groups.

Introduction

The Introduction section describes the motivation of conducting research on stormwater management, especially in the roadway environment. The analysis of need for developing a training course to improve the understanding of stormwater management is provided. The section concludes with a description of the objective of the project.

Motivation

Nationwide, stormwater has been recognized as a major contributor to water quality impairment (1), and it is the only growing source of water pollution in many watersheds (2). After realizing this issue, the U.S. Congress enacted Section 438 of the Energy Independence and Security Act of 2007 (EISA) that imposes requirements on federal agencies to reduce stormwater runoff from federal development and redevelopment projects to protect water resources. Executive Order 13514 assigned the responsibility to the Environmental Protection Agency, in coordination with other Federal agencies as appropriate, to write and issue guidance on the implementation of section 438. One of the factors that exacerbates the adverse effects of stormwater is the increase of impervious surfaces, which prevents precipitation from soaking into the ground. Currently, impervious surfaces have been considered as an important indicator of water quality. To better understand the effects of impervious surfaces, the U.S. Geological Survey's (USGS) 2006 report (3) studied the component makeup of impervious surfaces. It shows that roads, together with building and parking lots, comprise the largest area of impervious cover. The National Academies of Sciences, Engineering, and Medicine's 2006 report (4) highlights that prevention or mitigation of the pollutant discharge from highways has become a primary goal for many jurisdictions, including state Departments of Transportation. The 2014 technical report (5) prepared by the U.S. Department of Transportation, Federal Highway Administration, indicates that transportation-related runoff plays a significant role in water quality impairment, despite the fact that highways may occupy a small percentage of the watershed. Currently, the Nation's awareness of the complex relationships between the transportation infrastructure and environmental quality is increasing, especially the potential for water quality impairment resulting from stormwater runoff over highway surfaces. Therefore, this project proposes to design a training course related to stormwater management.

Analysis of Need

The 2009 National Research Council (NRC) report (1), entitled Urban Stormwater Management in the United States, indicates that training of practitioners to better understand the importance of stormwater volume control and the role of Low Impact Development (LID) is in need, and training of personnel to understand and implement correct Best Management Practices (BMPs) to prevent and mitigate stormwater pollution also needs to be implemented. Lack of training among the members in the land development community is considered as one of the principal causes that hinder the progress in implementing BMPs to mitigate water quality impairment. Since new stormwater technologies are developing rapidly, there is a critical need to implement training programs that can equip stormwater professionals with the latest knowledge and skills.

The report of the Water Environment Federation (WEF) Stormwater Institute (2) highlights that stormwater management is evolving substantially, which drives the need to train a more diverse workforce. Also, the stormwater management professionals need to communicate with communities and public officials, in which, introducing the benefits of stormwater management and training for stormwater BMPs are a good start. Conducting stormwater management training also can provide an opportunity to share the information about stormwater-associated problems and collaborate between groups.

The 2019 National Municipal Separate Storm Sewer System (MS4) Needs Assessment Survey (6), by the WEF's Stormwater Institute, shows that providing workshop/training opportunities on BMPs to stormwater professionals is identified by the respondents as one of the fundamental needs and challenges in the stormwater program.

The 2018 Stormwater Practitioners Guide (7) by the Central Federal Lands Highway Division of the U.S. Department of Transportation, Federal Highway Administration, indicates that there are numerous types of BMPs to mitigate water quality impairment and it is critical to correctly choose and place them for stormwater treatment. Nowadays, the principal challenge we face by stormwater practitioners is how to choose the most cost-effective and practical combination of BMPs to reach the purpose of stormwater control for the area of interest. Implementing inappropriate BMPs leads to adverse impacts. Therefore, stormwater practitioners need to know the feasibility and limitations of different types of BMPs and select appropriate BMPs based on this information, together with additional information such as climate and land use. Also, there is a need for regulatory agencies to know this information because it can help check on the effectiveness and benefits of proposed BMPs.

Through the literature review above, it shows that there is a critical need to provide an in-person training course that can help increase understanding of stormwater management and provide information for selecting and implementing appropriate BMPs and key resources.

Study Objective

The objective of this project is to develop a 5-hour training course that is intended for a target audience, including the Department of Transportation, local traffic management agencies, Metropolitan Planning Organizations, Governmental Administrative, Law Enforcement, and others involved in managing traffic and implementing hazard mitigation and climate adaptation strategies. Particular focus is on the transportation agencies and local governments who are responsible for streets, roadways, and highways. The goal of this course is to prepare participants to describe and analyze stormwater runoff problems and select and design appropriate stormwater BMPs, with applications to roadways and climate change.

Course Design Description

To achieve the purpose of the project, which provides transportation agencies and local governments with a better understanding of stormwater management and supporting stormwater practitioners to evaluate, select, and design appropriate BMPs, a 5-hour in-person training course is developed. This Chapter discusses the training course in detail. In total, this training course covers five modules, which are:

1. Welcome, Introduction, and Administration;
2. Terms & Definitions Used in Stormwater Management;
3. Stormwater Problems and Management;
4. Site Development Principles; and
5. Course Summary and Administration

Each of the modules are introduced and explained thoroughly in the following sections.

Module 1: Welcome, Introduction, and Administration

Scope Statement

This module is the start of the training course. In this module, the instructor welcomes participants to the course, explains how instruction takes place, and provides an agenda. The instructor introduces him- or herself and leads a round of introductions among the participants. The instructor discusses the course purpose, goals, and objectives; describes the course content and states the evaluation strategy; and wraps up any administrative details that remain. Finally, the instructor assesses the participants' existing comprehension of course materials by conducting a pre-test.

Lesson Topics

In this module, the following three topics are covered:

1. Course Evaluation Strategy

Participants are administered two tests--a pre-test during the first module and a post-test at the end of the course. These objective-based tests are written to assess how well participants have mastered the objectives. Participants' post-test scores are compared against their performance on the pre-test to obtain a learning measure and illustrate the benefit of the course. Participants must attain a score of 70 percent or better on the post-test to successfully complete the course.

2. Course Goal

The goal of this course prepares participants to describe and analyze stormwater runoff problems and select and design appropriate stormwater Best Management Practices (BMPs), with applications to roadways and climate change.

3. Course Content Overview and Agenda

This course is a 5-hour in-person training course, which is composed of five distinct modules to address various topics as well as satisfying administrative requirements. These modules include classroom instruction and instructor-facilitated activities on materials presented.

Learning Objectives

For this module, the Terminal Learning Objectives (TLO) enable the participants to state the course goal and objective. The TLO can be broken into three Enabling Learning Objectives (ELO) which enable participants: to state the course agenda; to state the course goal; and to explain how performance is evaluated at the conclusion of the module.

Module 2: Terms & Definitions Used in Stormwater Management

Scope Statement

In this module, the instructor introduces the concept of stormwater management and explains the fundamental components of a stormwater management system. Also, this module includes a review of the basic terms and definitions used in stormwater management.

Lesson Topics

In this module, the following two topics are covered:

1. Stormwater Management

Stormwater management is the effort to control the quantity and quality of stormwater. The purpose of stormwater management is to collect, treat and (re)use runoff water; to avoid contamination and destruction; and to restore the disturbed urban water cycle. Stormwater management systems are composed of one or more-unit operations, each utilizing one or more-unit processes to control runoff and remove pollutants. The effectiveness of each of these processes is governed by flow, volume, and configuration factors related to regional climatic and precipitation patterns; the variability of stormwater flows, volumes, and pollutant concentrations; the natural setting within which each of these controls is applied; and the integration of processes that occur in stormwater control systems. For example, the following processes can be combined as a stormwater management system to reduce the volume and improve the quality of stormwater runoff:

- Minimization of runoff by reduction of impervious areas and project footprint, protection of native soils to maintain infiltration capacity, and protection of native vegetation to maintain evapotranspiration potential
- Source controls implemented at the point where precipitation reaches the ground to prevent stormwater from contacting pollutants and minimize runoff by promoting infiltration and evapotranspiration

- Control systems distributed throughout the drainage system, close to the sources of runoff, to capture stormwater, remove pollutants, promote further infiltration and evapotranspiration, enable rainwater harvesting, and slowly discharge remaining runoff
- Resource protection such as vegetated setbacks to protect the habitat and assimilative capacity of waterbodies while protecting the surrounding development from flooding and erosion

2. Terms and Definitions

Besides the concept of stormwater management, this module also includes a review of the basic and common terms and definitions used in stormwater management. The following terms and definitions are instructed:

1) **Stormwater**: Water (from precipitation, snow or ice melt), that lands on the ground but does not soak into the ground and becomes surface runoff, which either flows directly into surface waterways or is channeled into storm sewers, which eventually discharges to the ocean.
2) **Runoff**: Stormwater, and associated substances, discharged into streams, lakes, sewers or storm drains.
3) **Watershed**: Land area from which water drains toward a common surface water body in a natural basin.
4) **Detention Basin**: A natural or artificial basin that receives and temporarily holds storm runoff to reduce downstream peak flows for flood control purposes.
5) **Drainage Pipe or Channel**: Part of a stormwater conveyance system that transport stormwater from one place to another.
6) **Manhole**: a junction where two or more drainage pipes confluence and where maintenance access is provided to the drainage system.
7) **Imperviousness**: Portion of a watershed that is covered by surfaces (parking lots, roads, roof tops) that will not absorb rainfall.
8) **Best Management Practices (BMPs)**: Any means, practice or technique to significantly reduce or eliminate stormwater pollution.

Learning Objectives

The TLO of this module is that participants are able to understand what stormwater management is and know the common terms and definitions. The two supporting ELO for the TLO are to enable participants to discuss what stormwater management is and learn and understand common terms and definitions used in stormwater management at the conclusion of this module.

Module 3: Stormwater Problems and Management

Scope Statement

In this module, the instructor explains how stormwater runoff is generated. For stormwater runoff, both channeled and sheet flows should be considered. Therefore, the instructor demonstrates two different equations that are applied to estimate the flow rates for channeled and sheet flows, respectively. Then, the instructor explains four stormwater functions that can be used to evaluate the effectiveness and limitation of a BMP. After explaining the four functions, the instructor leads the participants in a discussion of stormwater-associated problems and complete a group activity, which helps the participants identify stormwater-associated problems. After the group activity, the instructor starts to introduce a storm drainage system. In this part, the instructor leads the participants toward understanding why there is a need to design a storm drainage system; how to design a storm drainage system; and what are the functions, benefits, and adverse effects of a storm drainage system. Besides the storm drainage system, BMP is also an integral component of stormwater management. According to the characteristics of BMPs, they can be divided into two groups: Non-structural and structural BMPs. The structural BMPs can be further divided into two groups: Storage types and Infiltration types. The instructor gives several examples for each type of structural BMPs, which helps participants understand the feasibility, benefits, and limitations of each BMP. After showing the examples, the BMP selection process is discussed through a detailed flow chart. Because roadways play a significant role in stormwater runoff, despite that they comprise a small portion of the whole watershed, the module discusses BMPs for roadways. Also, the instructor leads the participants in discussion of how climate change affects BMP selection. The module concludes with a group activity where participants select appropriate BMPs for the stormwater-associated problems identified in the previous activity.

Lesson Topics

In this module, the following topics are instructed:

1. Stormwater Runoff

Stormwater runoff is generated from rain and snowmelt events that flow over land or impervious surfaces and does not soak into the ground. To design for stormwater runoff, two types of surface runoff, which are Channeled Flow and Sheet Flow, must be considered.

For Channeled Flow, the Manning's equation can be applied to estimate the flow rate as follows:

$$Q = VA = \left(\frac{1.49}{n}\right) AR^{2/3}\sqrt{S} \quad [\text{U.S.}] \tag{1}$$

$$Q = VA = \left(\frac{1.00}{n}\right) AR^{2/3}\sqrt{S} \quad [\text{S.I.}] \tag{2}$$

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where Q represents the flow rate through the channel (ft^3/s), V represents the velocity in the channel (ft/s), A represents the cross-sectional area of the flow (ft^2), n represents the Manning's roughness coefficient, R represents the hydraulic radius (ft), and S represents the channel slope (ft/ft).

There are various shapes of open channels, among which trapezoidal, circular, and rectangular shapes are the most common. Figure 1 shows the calculations of hydraulic radius, R, for these types of channels. Here, T represents the top width, y represents the height, z represents the side slope, b represents the width, and D represents the channel height.

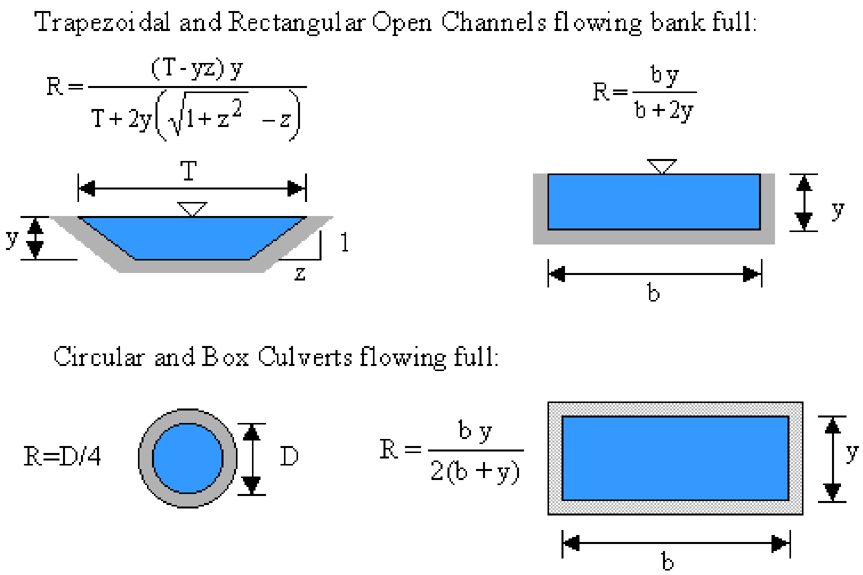

Figure 1. Calculations of hydraulic radius for trapezoidal, circular, and rectangular channel shapes.

Figure 2 shows an example of calculating the flow rate for a pipe using Manning's equation. Channel section geometric properties are expressed in terms of: area, A; wetted perimeter, W.P.; hydraulic radius, R; channel height, D; and hydraulic depth, d. The flow rate (Q) can be derived at a given slope along with a given roughness, Manning's n. The Manning's equation is an empirical equation that applies to uniform flow in open channels and is a function of the channel velocity, flow area, and channel slope.

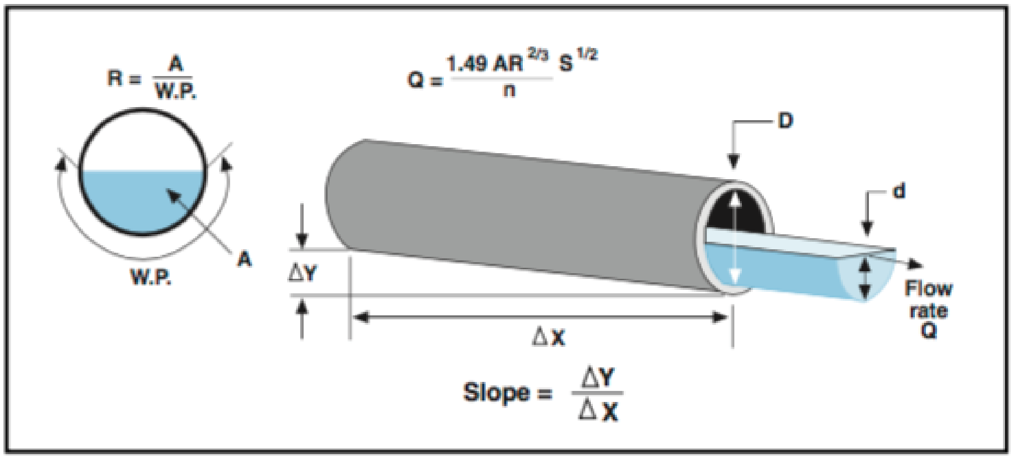

Figure 2. An example of the Manning's equation being applied for a pipe.

For sheet flow, the peak runoff rate can be estimated using the Rational Method as follows:

$$Q = C \cdot I \cdot A \quad (3)$$

where Q represents peak runoff rate (cfs), C represents the dimensionless runoff coefficient used to adjust for abstractions from rainfall, I represents the rainfall intensity for a duration that equals the time of concentration of the basin (in/hr), and A represents the basin area (ac). The Rational Method states that if rainfall occurs over a basin at a constant intensity for a period of time that is sufficient to produce steady-state runoff at the outlet or design point, then the peak outflow rate will be proportional to the product of rainfall intensity and basin area.

After obtaining the runoff flow rates, they can be plotted over time by hydrographs. Hydrographs are charts that display the change of a hydrologic variable over time. Figure 3 shows an example of a stream discharge hydrograph from the US Geological Survey's gaging station on the Tioga River near Mansfield, Pennsylvania (8). The blue line on the hydrograph above shows how the discharge of the Tioga River changed between August 29 and September 5, 2004. A rainfall event in the late afternoon of August 30th produced about 1/4 inch of rain in the area of the gage. However, over one inch of rain fell in less than 15 minutes just a couple miles from the gaging station. Runoff from this precipitation caused the Tioga's discharge to rapidly increase from about 100 cubic feet per second to over 2000 cubic feet per second. Stream Discharge Hydrograph is one of the most frequently created hydrographs. It shows the change in the discharge of a stream over time. Although this example is from a stream, hydrographs can also be made for lakes, water wells, springs and other bodies of water.

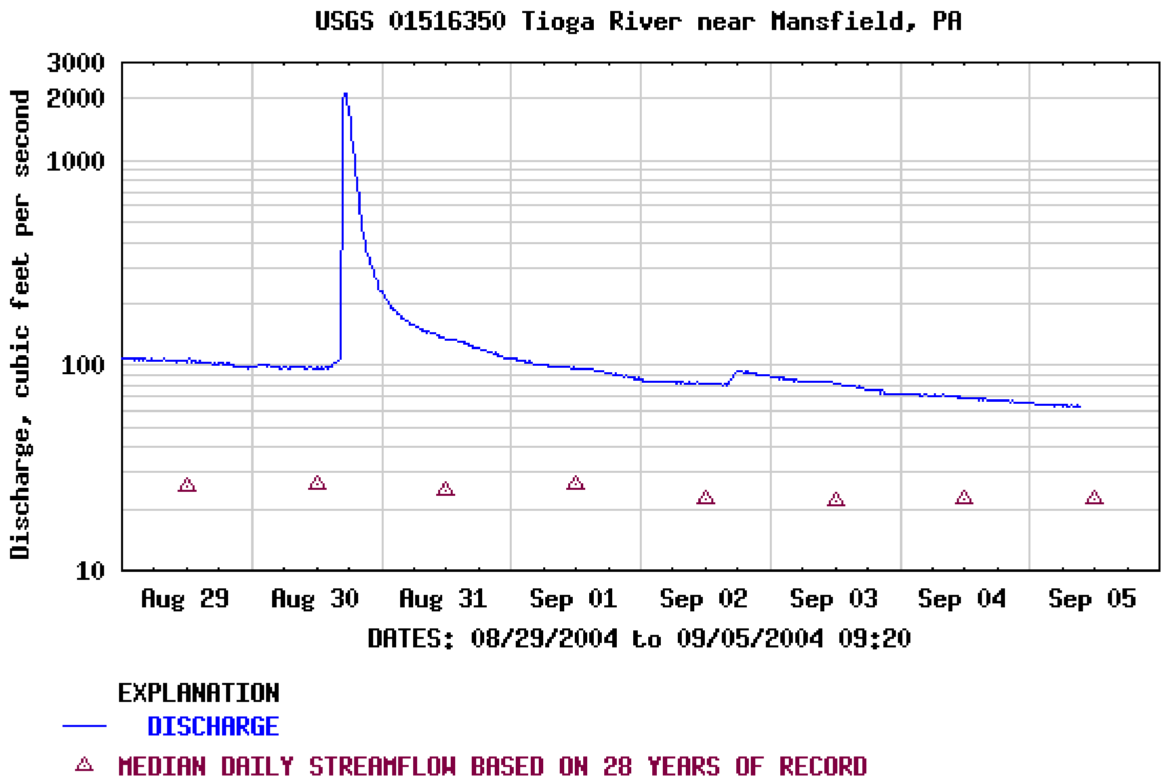

Figure 3. An example of stream discharge hydrograph from the US Geological Survey's gaging station on the Tioga River near Mansfield, Pennsylvania. Source: (8)

2. Stormwater Functions

Stormwater functions handle different types of precipitation. In this module, four stormwater functions which can be used to evaluate the effectiveness and limitation of a BMP are introduced and explained. The four stormwater functions are Volume Reduction, Groundwater Recharge, Peak Rate Control, and Water Quality. Among the four functions, only Peak Rate Control is based on larger storm events, and the other three functions are based on smaller, frequent storm events.

The recommended control guidelines for Volume Reduction is calculated based on the BMP. For example, the volume of Pervious Pavement can be calculated by:

$$Volume = Depth(ft) \times Area(sf) \times Void\ Space \quad (4)$$

where Depth is the depth of the water stored during a storm event, depending on the drainage area and conveyance to the bed.

The recommended control guideline for Recharge (i.e., Infiltration), water on the ground that enters the soil, is calculated based on the BMP. For example, the infiltration volume of Pervious Pavement can be derived from:

$$Infiltration\ Volume = Bed\ \ Bottom\ Area\ \ (sf) \times Infiltration\ Design\ Rate\ \ (in/hr) \times Infiltration\ Period\ \ (hr) \times (1/12) \tag{5}$$

where Infiltration Period is the time when the bed is receiving runoff and capable of infiltrating at the design rate. Not to exceed 72 hours.

Peak Rate Control for large storms, up to the 100-year event, is essential to protect against immediate downstream erosion and flooding. Most designs achieve Peak Rate Control through the use of detention structures. Peak rate control can also be integrated into volume control BMPs in ways that eliminate the need for additional peak rate control detention systems. The recommended control guideline for peak rate control is:

1) Do not increase the peak rate of discharge for the 1-year through 100-year events (at minimum)
2) As necessary, provide additional peak rate control.

Perform hydrologic modeling to provide the basis for establishing more stringent release rate controls on sub-districts within the watershed. As volume reduction BMPs are incorporated into stormwater management on a watershed basis, release rate values will require re-evaluation. The use of the control guidelines will reduce or perhaps even eliminate the increase in peak rate and runoff volume for some storms.

The recommended control guideline for total water quality control is to achieve an 85 percent reduction in post-development particulate associated pollutant load (as represented by Total Suspended Solids), an 85 percent reduction in post-development total phosphorus loads, and a 50 percent reduction in post-development solute loads (as represented by NO3-N), all based on post-development land use.

3. Stormwater-Associated Problems

Stormwater is the water originates from precipitation, including snow and ice melt. In rural areas, stormwater can soak into the soil, and replenish the groundwater. However, in urban areas, the impervious surfaces prevent stormwater from soaking into the ground and form the runoff. In general, the uncontrolled stormwater results in two major issues. One is related to the volume and flow rate of runoff, e.g., flooding, and the other one is related to the pollutants the runoff carries. The cumulative impacts of uncontrolled stormwater include, but are not limited to, the following:

1) Flooding;
2) Stream Erosion;
3) Increased Turbidity;
4) Habitat Destruction;
5) Waterway Blockage;
6) Sewage Overflow;
7) Infrastructure Damage;
8) Water Quality Impairment; and

9) Human Health Problems due to Contaminated Stormwater

After introducing the stormwater-associated problems, the instructor leads the participants to complete a group activity, which helps the participants better understand and identify stormwater-associated problems. Participants should use the "Stormwater-Associated Problem Identification" matrix, located in Appendix A, to guide their identification and analyses of local, relevant stormwater-associated problems. After completing the matrix, participants answer the following questions:

1) What types of stormwater-associated problems are of greatest concern in your local area?
2) What is the severity of those problems?
3) What are your top three concerns?

4. Stormwater Management – Storm Drainage System

The storm drainage system is a key component of stormwater management. In rural areas, stormwater can be filtered and replenishes aquifers or flows into streams and rivers when it is absorbed into soil. In urban areas, however, impervious surfaces, e.g., roof, parking lots, roadways, prevent precipitation from naturally soaking into the ground. Instead, the storm drainage system is applied to collect, convey, and discharge stormwater to an adequate receiving body without causing adverse on- or off-site impacts. The reasons why there is a need to design a storm drainage system is due to:

1) Surface runoff has to be reduced to prevent flooding, especially in urbanized areas where natural infiltration is reduced.
2) Sediments and Pollutants (e.g., nutrients from agriculture) must be removed.

After explaining the necessity of designing storm drainage, the instructor leads the participants to discuss how to design a storm drainage system. The design of a storm drainage system for highways are introduced as an example. The primary elements of the process includes Data Collection, Agency Coordination, Preliminary Concept Development, Concept Refinement (Hydrologic and Hydraulic Design), and Final Design Documentation (9).

Also, the instructor leads the participants in discussion of the function, benefits, and adverse effects of a storm drainage system, which is briefly described in the following.

The storm drainage system is functional able to:

1) Remove stormwater from streets and permit the transportation arteries to function during bad weather;
2) Control the rate and velocity of runoff along gutters and other surfaces that reduces hazard;
3) Convey runoff to natural or manmade major driveways; and

4) Offer opportunities for multiple uses such as recreation, parks, and wildlife preserves from major open drainage ways and detention facilities.

The benefits of storm drainage systems include preventing erosion, reducing flooding, eliminating standing water, and developing better horticulture. However, it will increase stream pollution since it drains untreated stormwater directly into rivers or streams.

5. Stormwater Management – Best Management Practice (BMP)

Besides the storm drainage systems, BMP is also an integral component of stormwater management. As shown in Figure 4, stormwater BMPs can be classified as Structural BMPs and Non-Structural BMPs. Structural BMPs take on an active role and the measures taken are to actively "mitigate" stormwater destruction and Non-Structural BMPs take on a passive role and the measures are taken to "prevent" stormwater destruction. This course focuses on Structural BMPs, which, in further, are divided into two categories: Storage and Infiltration, as shown in Figure 4.

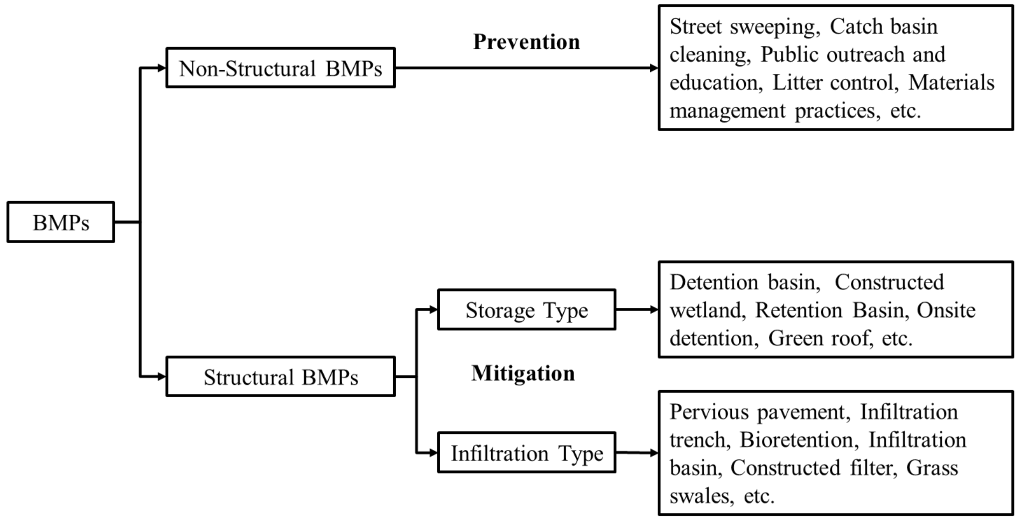

Figure 4. Types of Best Management Practices (BMPs).

In this module, the instructor introduces and analyzes the following five storage-type BMPs: Detention Basin, Constructed Wetland, Retention Basin, Onsite Detention, and Green Roofs. For infiltration types, the instructor introduces and analyzes the following ten BMPs: Pervious Pavements, Infiltration Basin, Subsurface Infiltration Bed, Infiltration Trench, Rain Garden, Dry Well, Constructed Filter, Grass Swales, Vegetated Filter Strips, and Infiltration Berm. When introducing each type of BMP, the instructor provides basic information, ratings for the four stormwater functions discussed above, and suggestions for potential applications, which are presented in the following sections.

BMP 1: Dry Extended Detention Basins

As opposed to the "non-extended" version, the dry "extended" detention basin is able to maximize water quality benefits. An example of a dry extended detention basin is provided below in Figure 5. Extended detention basins are an effective means of removing particulate pollutants from urban stormwater runoff. A dry extended detention basin is an earthen structure constructed either by the impoundment of a natural depression or excavation of existing soil, that provides temporary storage of runoff and functions hydraulically to attenuate stormwater runoff peaks. The dry detention basin has represented the primary BMP measure until now, and has served to control the peak rate of runoff, although some water quality benefit accrues by the settlement of the larger particulate fraction of suspended solids. In general, an extended detention basin has two stages. The bottom stage is expected to be inundated frequently. The top stage remains dry except during large storms.

Figure 5. An example of a dry extended detention basin. Source: (10)

For the stormwater functions, the dry extended detention basin's rating of Peak Rate Control is high. When plotting flow rates over time, the hydrographs are based on a 24-hour rainfall event and are calculated and routed for each design storm. The dry extended detention basin has a low rating for both the Volume Reduction and Water Quality. Water quality mitigation is partially achieved by retaining the runoff volume from the water quality design storm for a minimum prescribed period. Sediment forebays are incorporated into the design to improve sediment removal. The storage volume of the forebay may be included in the calculated storage of the water quality design volume. In this case, the rating for Recharge is not available.

With respect to the applications, the dry extended detention basin has the potential to be implemented in residential, commercial, ultra-urban, industrial, and Highway/Road environment. It also can be retrofitted.

BMP 2: Wet Retention Basins

Wet 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. Figure 6 shows an example of a wet retention basin. A high removal rate of sediment, Biochemical Oxygen Demand (BOD), organic nutrients, and trace metals can be achieved if stormwater is retained in the wet pond long enough. During wet weather, the incoming runoff displaces the old stormwater from the permanent pool from which significant amounts of pollutants have been removed. The new runoff is retained until it is displaced by subsequent storms. The permanent pool, therefore, captures and treats the small and frequently occurring stormwater runoff that generally contains high levels of pollutant loading. The storage volume above the permanent pool is used to control the runoff peaks caused by the specified design storm events.

Figure 6. An example of a wet retention basin. Source: (10)

For the stormwater functions, the wet retention basin has a high rating for Peak Rate Control because it is primarily controlled in wet ponds through the transient storage above the normal water surface. The wet retention basin has a low rating for both Volume Reduction and Recharge. Typically, the wet retention basin is not considered as a volume-reducing BMP. However, wet ponds can achieve some volume reduction through infiltration and evapotranspiration, especially during small storms. According to the Stormwater BMP

Database, wet ponds have an average annual volume reduction of 7 percent (11). With respect to Water Quality, the wet retention basin has a rating of Medium. Wet ponds improve runoff quality through settling, filtration, uptake, chemical and biological decomposition, volatilization, and adsorption. Wet ponds are relatively effective at removing many common stormwater pollutants, including suspended solids, heavy metals, total phosphorus, total nitrogen, and pathogens. It has been suggested that this type of BMP does not provide significant nutrient removal in the long term unless vegetation is harvested because captured nutrients are released back into the water by decaying plant material. Even if this is true, nutrients are usually released gradually and during the non-growing season when downstream susceptibility is generally low.

With respect to applications, the wet retention basin has the potential to be implemented in residential, commercial, ultra-urban, industrial, and Highway/Road environment. It also has the potential for retrofit.

BMP 3: Constructed Wetlands

Constructed Wetlands are shallow marsh systems planted with emergent vegetation that are designed to treat stormwater runoff (10). Figure 7 shows an example of a constructed wetland. The constructed wetlands are one of the best BMPs for pollutant removal and can also mitigate peak rates and even reduce runoff volume to a certain degree. It also can provide considerable aesthetic and wildlife benefits.

For the stormwater functions, the constructed wetland has a low rating for Volume Reduction and Recharge. Typically, the constructed wetland is not considered as a volume-reducing BMP, but it can achieve some volume reduction through evapotranspiration, especially during small storms. An evapotranspiration study could be done to account for potential volume reduction credit. The constructed wetland has a high rating for both Peak Rate Control and Water Quality. Peak rate is primarily controlled in constructed wetlands through the transient storage above the normal water surface. The runoff quality can be improved by the constructed wetlands through settling, filtration, uptake, chemical and biological decomposition, volatilization, and adsorption. Constructed wetlands are effective at removing many common stormwater pollutants, including suspended solids, heavy metals, total phosphorus, total nitrogen, toxic organics, and petroleum products. The pollutant removal effectiveness varies by season and may be affected by the age of the wetland. It has been suggested that Constructed wetlands do not remove nutrients in the long term unless vegetation is harvested because captured nutrients are released back into the water by decaying plant material. Even if this is true, nutrients are generally released gradually and during the non-growing season when downstream susceptibility is generally low.

With respect to applications, the constructed wetland has the potential to be implemented in residential, commercial, industrial, and Highway/Road environments and also can be retrofitted. But the constructed wetland’s application in the ultra-urban environment is limited due to the fact that it uses a relatively large amount of space and requires an adequate source of inflow to maintain the permanent water surface.

Figure 7. An example of a constructed wetland. Source: (12)

BMP 4: Onsite Detention (OSD)

Onsite detention (OSD) is applied to collect and store stormwater runoff during a storm event, then release it at controlled rates to the downstream drainage system, thereby attenuating peak discharge rates form the site and ensuring the receiving system is not overloaded. Figure 8 shows an example of OSD. Commonly, OSD is used as a pretreatment before other stormwater BMPs. The required size of storage and rate of discharge vary depending on the location, size, and subsequent impact of the development.

For the stormwater functions, the ratings for Volume Reduction, Recharge, and Peak Rate Control are not available. The rating for Water Quality is medium.

With respect to applications, the OSD has the potential to be implemented in residential, commercial, ultra-urban, and industrial environments and also can be retrofitted. However, its application to Highway/Road is limited.

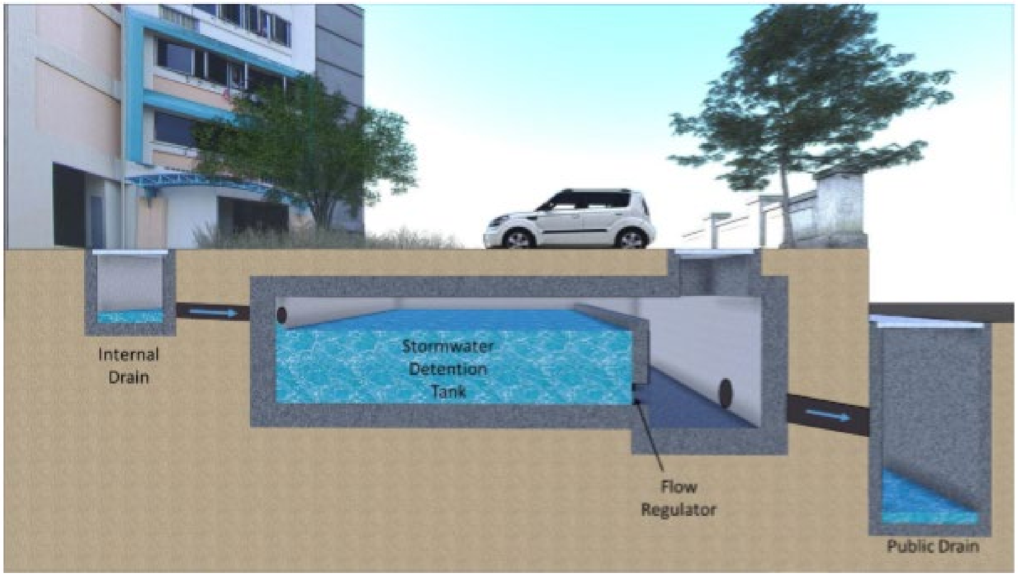

Figure 8. An example of onsite detention (OSD). Source: (13)

BMP 5: Green Roofs

A Green roof is a roof of a building that is covered with vegetation and a growing medium. An example of a green roof is shown in Figure 9. Extensive vegetated roof covers are usually six inches or less in depth and are typically intended to achieve a specific environmental benefit, such as rainfall runoff mitigation. For this reason, they are most commonly not irrigated. While some installations are open to public access, most extensive vegetated roof covers are for public viewing only. In order to make them practical for installation on conventional roof structures, lightweight materials are used in the preparation of most engineered media. Developments in the last 40 years that have made these systems viable include: 1) recognition of the value of vegetated covers in restoring near open-space hydrologic performance on impervious surfaces, 2) advances in waterproofing materials and methods, and 3) development of a reliable temperate climate plant list that can thrive under the extreme growing conditions on a roof.

Vegetated roof covers that are ten inches, or deeper, are referred to as ‘intensive’ vegetated roof covers. These are more familiar in the United States and include many urban landscaped plazas. Intensive assemblies can also provide substantial environmental benefits, but are intended primarily to achieve aesthetic and architectural objectives. These types of systems are considered “roof gardens” and are not to be confused with the simple “extensive” design. Benefits beyond the stormwater considerations include temperature moderation and roof longevity.

Figure 9. An example of Green Roof. Source: (14)

The performance of vegetated roof covers as stormwater BMP cannot be represented by a simple algebraic expression. Conventional methods are used to estimate surface runoff from various types of surfaces. In the analysis of vegetated roof covers, the water that is discharged from the roof is not surface runoff, but rather underflow, (i.e., percolated water). The rate and quantity of water released during a particular design storm can be predicted based on knowledge of key physical properties, including:

- Maximum media water retention – i.e., max quantity of water held against gravity under drained conditions;
- Filed capacity;
- Plant cover type;
- Saturated hydraulic conductivity; and
- Non-capillary porosity

For the stormwater functions, green roofs have a low rating for Peak Rate Control. Vegetated roof covers can exert an influence on runoff peak rates derived from roofs. A general rule is to consider the first portion of the rainfall fills the volume reduction capacity. The rating for Volume Reduction is medium/high and that for Water Quality is medium. Once the plant cover is established, nutrient additions should be suspended. Experience indicates that the efficiency of vegetated covers in reducing pollutants and nutrient releases from roofs will increase with time. The vegetated cover should reach its optimum performance after about five years.

With respect to applications, the green roofs have the potential to be implemented in residential, commercial, ultra-urban, and industrial environments and also can be retrofitted. However, it cannot be applied to Highway/Road.

BMP 6: Pervious Pavements

A pervious pavement bed consists of a pervious surface course underlain by a stone bed of uniformly graded and clean-washed coarse aggregate, 1-1/2 to 2-1/2 inches in size, with a void space of at least 40%. The pervious pavement may consist of pervious asphalt, pervious concrete, or pervious pavement units. Figure 10 shows an example of a pervious paver parking lot. Stormwater drains through the surface, is temporarily held in the voids of the stone bed, and then slowly drains into the underlying, uncompacted soil mantle. The stone bed can be designed with an overflow control structure so that during large storm events peak rates are controlled, and at no time does the water level rise to the pavement level. A layer of geotextile filter fabric separates the aggregate from the underlying soil, preventing the migration of fines into the bed. The bed bottom should be level and uncompacted. If a new fill is required, it should consist of additional stone and not compacted soil.

Figure 10. A pervious paver parking lot. Source: (15)

For the stormwater functions, all the ratings for Volume Reduction, Recharge, and Peak Rate Control and Water Quality are medium. As presented in the second lesson topic of this module, Stormwater Functions, the volume and infiltration volume can be calculated by Equations (4) and (5).

Regarding applications, the pervious pavements have the potential to be implemented in commercial, ultra-urban, and industrial environments and also can be retrofitted. However, the applications for residential and Highway/Road environment are limited. Pervious pavement is well suited for parking lots, walking paths, sidewalks, playgrounds, plazas, tennis courts, and other similar uses. Pervious pavement can be used in driveways if the homeowner is aware of the stormwater functions of the pavement. Pervious pavement roadways have seen wider applications in Europe and Japan than in the U.S., although at least one U.S. system has been constructed (10).

BMP 7: Infiltration Basin

Infiltration basins are shallow, impounded areas designed to temporarily store and infiltrate stormwater runoff. Figure 11 demonstrates the schematic of an infiltration basin. The size and shape of infiltration basins can vary from a single large one to multiple, smaller ones throughout a site. Ideally, the basin should avoid disturbance of existing vegetation. If disturbance is unavoidable, replanting and landscaping may be necessary and should integrate the existing landscape as subtly as possible and compaction of the soil must be prevented. Infiltration basins use the existing soil mantle to reduce the volume of stormwater runoff by infiltration and evapotranspiration. The quality of the runoff is also improved by the natural cleansing processes of the existing soil mantle and also by the vegetation planted in the basins. The key to promoting infiltration is to provide enough surface area for the volume of runoff to be absorbed. An engineered overflow structure should be provided for the larger storms.

For the stormwater functions, the ratings for Volume Reduction and Recharge are high. The rating for Peak Rate Control is medium/high, and the rating for Water Quality is medium. When calculating the Volume Reduction, the volume can be derived from:

$$Volume = Depth(ft) \times Area(sf) \tag{6}$$

Here, Depth is the depth of the water stored during a storm event, depending on the drainage area and conveyance to the bed. The infiltration volume can be calculated by Equation (5), and the Infiltration Period is equal to 2 hours or the time of concentration, whichever is larger.

Regarding applications, infiltration basins have the potential to be implemented for residential, commercial, and industrial environments and also can be retrofitted. However, the applications for ultra-urban and Highway/Road environment are limited due to the space constraints. Infiltration Basins can be incorporated into the new development. Ideally, existing vegetation can be preserved and utilized as the infiltration area. Runoff from adjacent buildings and impervious surfaces can be directed into this area, which will “water” the vegetation, thereby increasing evapotranspiration in addition to encouraging infiltration. Existing grassed areas can be converted to infiltration basins. If the soil and infiltration capacity is determined to be sufficient, the area can be enclosed through the creation of a berm and runoff can be directed to it without excavation. Otherwise, excavation can be performed.

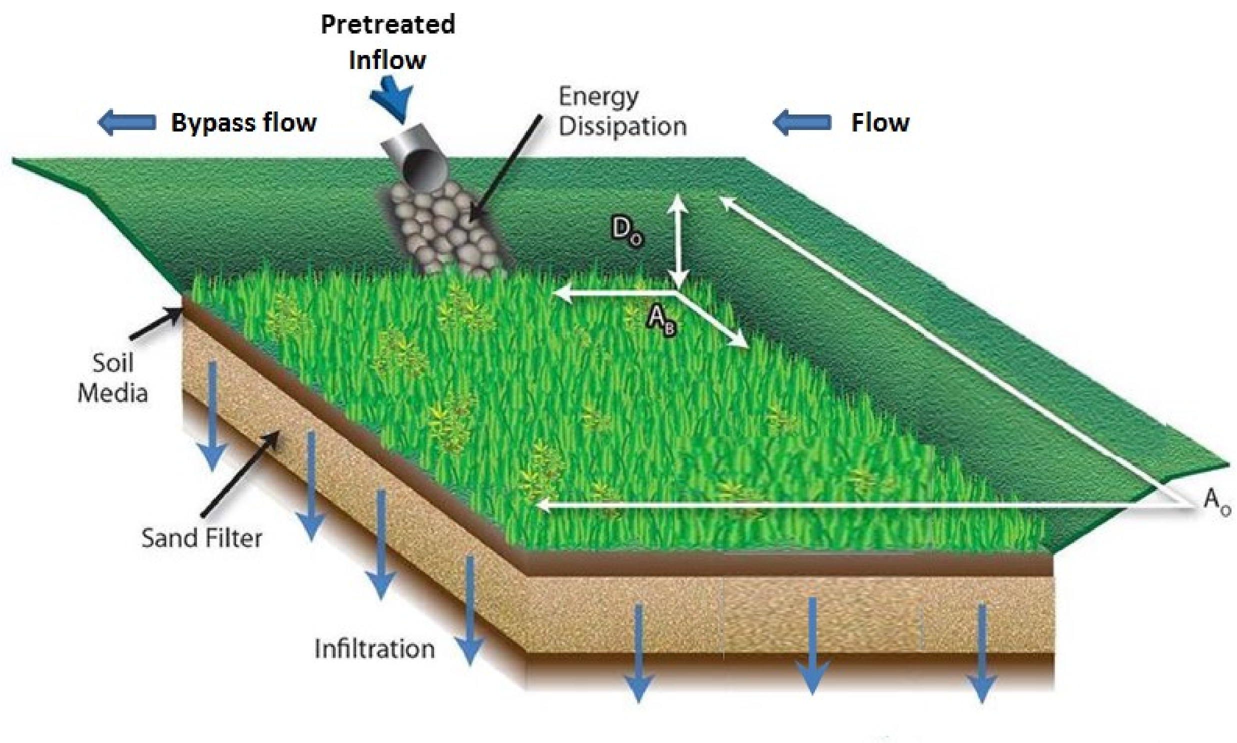

Figure 11. Infiltration basin schematic. Source: (16)

BMP 8: Subsurface Infiltration Bed

A subsurface infiltration bed generally consists of a vegetated, highly pervious soil media underlain by a uniformly graded aggregate (or alternative) bed for temporary storage and infiltration of stormwater runoff. Figure 12 shows the schematic of a subsurface infiltration bed. Subsurface infiltration beds are ideally suited for expansive, generally flat open spaces, such as lawns, meadows, and playfields, which are located downhill from nearby impervious areas. Subsurface infiltration beds can be stepped or terraced down sloping terrain provided that the base of the bed remains level. Stormwater runoff from nearby impervious areas (including rooftops, parking lots, roads, walkways, etc.) can be conveyed to the subsurface storage media, where it is then distributed via a network of perforated piping.

The storage media for subsurface infiltration beds typically consists of clean-washed, uniformly graded aggregate. However, other storage media alternatives are available. These alternatives are generally variations on plastic cells that can more than double the storage capacity of aggregate beds, at a substantially increased cost. Storage media alternatives are ideally suited for sites where potential infiltration area is limited.

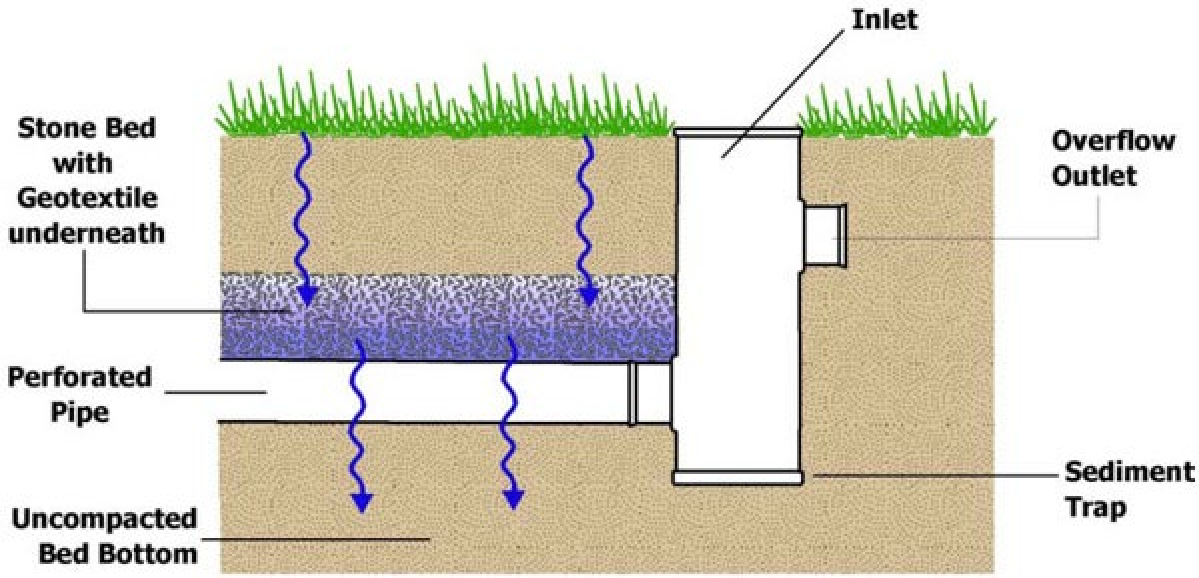

Figure 12. Subsurface infiltration bed schematic. Source: (10)

If designed, constructed, and maintained as per the guidelines, subsurface infiltration features can stand alone as significant stormwater runoff volume, rate, and quality control practices. These systems can also maintain aquifer recharge, while preserving or creating valuable open space and recreation areas. They have the added benefit of functioning year-round, given that the infiltration surface is typically below the frost line.

For the stormwater functions, the ratings for Volume Reduction, Recharge, and Water Quality are high. The rating for Peak Rate Control is medium/high. When calculating the Volume Reduction, the volume can be derived from Equation (4). In the equation, Depth is the depth of water stored during a storm event, depending on the drainage area and conveyance to the bed. Also, the infiltration volume can be derived from Equation (5). Here, the Infiltration Period is equal to 2 hours or the time of concentration, whichever is larger.

Regarding applications, the subsurface infiltration bed has the potential to be implemented for residential, commercial, ultra-urban, and industrial environments and also can be retrofitted. However, the application for Highway/Road environment is limited. For example, runoff from nearby roofs may be directly conveyed to subsurface beds via roof leader connections to perforated piping, and cleanout(s) with a sediment sump is recommended between the building and infiltration bed; catch basins, inlets, and area drains may be connected to subsurface infiltration beds, however, sediment and debris removal should be provided and storm structures should, therefore, include sediment trap areas below the inverts of discharge pipes to trap solids and debris. Also, the subsurface infiltration bed is very well suited below playfields and other recreational areas with special consideration given to the engineered soil mix. It is also appropriate in either existing or proposed open space areas because it is essentially hidden stormwater management features, making them ideal for open space locations.

BMP 9: Infiltration Trenches

An infiltration trench is a linear stormwater BMP consisting of a continuously perforated pipe at a minimum slope in a stone-filled trench. Usually, an infiltration trench is part of a conveyance system and is designed so that large storm events are conveyed through the pipe with some runoff volume reduction. Figure 13 shows a photo of an infiltration trench beside the road in Lino Lakes, MN. During small storm events, volume reduction may be significant and there may be little or no discharge. All infiltration trenches are designed with a positive overflow. An infiltration trench differs from an infiltration bed in that it may be constructed without heavy equipment entering the trench.

Figure 13. Photo of an infiltration trench in Lino Lakes, MN. Source: (17)

For the stormwater functions, the ratings for Volume Reduction and Peak Rate Control are medium, and the ratings for Recharge and Water Quality are high. When calculating the Volume Reduction, the volume can be derived from Equation (4). In the equation, Depth is the depth of water stored during a storm event, depending on the drainage area and conveyance to the bed. Also, the infiltration volume can be derived from Equation (5). Here, the Infiltration Period is the time when the bed is receiving runoff and capable of infiltration, not to exceed 72 hours. If the conveyance pipe is within the Storage Volume area, the volume of the pipe may also be included. All infiltration trenches should be designed to infiltrate or empty within 72 hours.

Regarding applications, the infiltration trench has the potential to be implemented for residential, commercial, ultra-urban, industrial, and Highway/Road environments and also can be retrofitted. For example, roof leaders may be connected to infiltration trenches. Roof runoff generally has lower sediment levels and often is ideally suited for discharge through an infiltration trench. A cleanout with a sediment sump should be provided between the building and infiltration trench. Catch basins, inlets and area drains may be connected to infiltration trenches, however, sediment and debris removal should be addressed. Structures should include a sediment trap area below the invert of the pipe for solids and debris. In areas of high traffic or areas where excessive sediment, litter, and other similar materials may be generated, a water quality insert or other pretreatment device is needed. Besides, an infiltration trench may be preceded by or used in combination with a vegetative filter, grassed swale, or other vegetative element used to reduce sediment levels from areas such as high traffic roadways. The design should ensure the proper functioning of the vegetative system.

BMP 10: Rain Garden / 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 techniques are used to accomplish water quality improvement and water quantity reduction. Figure 14 shows a sketch of a street scape bioretention system.

Bioretention can be integrated into a site with a high degree of flexibility and can balance nicely with other structural management systems, including porous asphalt parking lots, infiltration trenches, as well as non-structural stormwater BMPs.

Properly designed bioretention techniques mimic natural ecosystems through species diversity, density and distribution of vegetation, and the use of native species, resulting in a system that is resistant to insects, disease, pollution, and climatic stresses. The functions of bioretention include:

- Reduce runoff volume;
- Filter pollutants, through both soil particles (which trap pollutants) and plant material (which take up pollutants);
- Recharge groundwater by infiltration;
- Reduce stormwater temperature impacts;
- Enhance evapotranspiration;
- Enhance aesthetics; and
- Provide habitat.

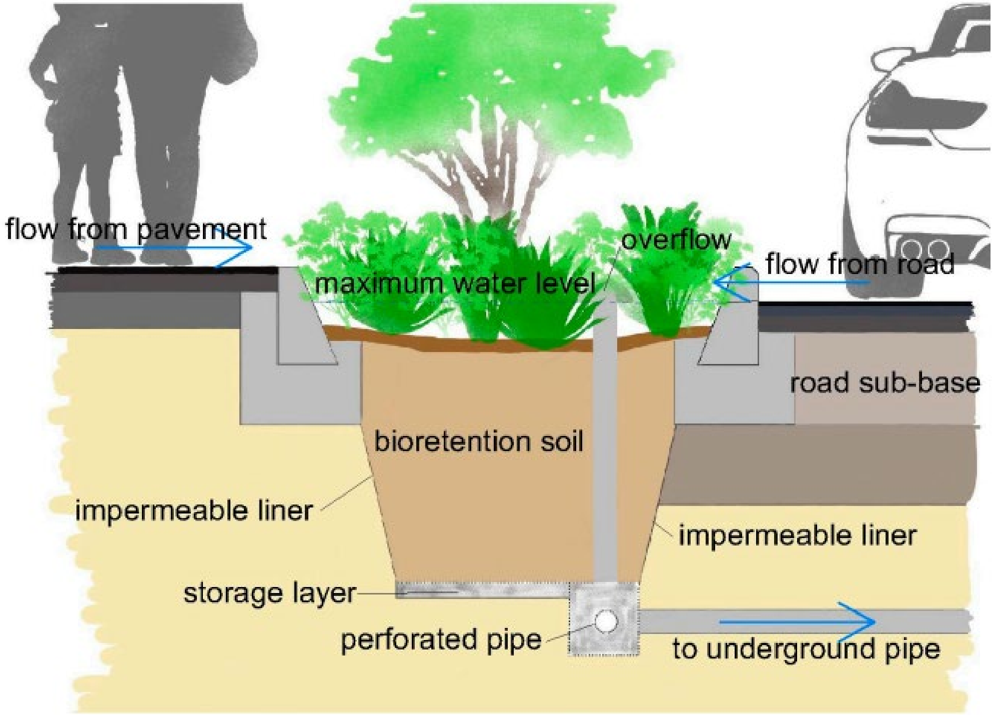

Figure 14. Sketch of a street scape bioretention system. Source: (18)

For the stormwater functions, the rating for Volume Reduction is high; the ratings for Recharge and Water Quality are medium/high; the rating for Peak Rate Control is low/medium. The surface storage volume of a bioretention can be calculated from:

$$Surface\ Storage\ Volume = Bed\ \ Area\ \ (ft^2) \times Average\ Design\ Water\ Depth \tag{7}$$

The Volume and infiltration volume can be derived from the Equations (8) and (9), respectively.

$$Volume = Bed\ \ Bottom\ \ Area\ \ (ft^2) \times Soil\ Mix\ Bed\ Depth \times Void\ \ Space \tag{8}$$

$$\begin{aligned} Infiltration\ \ Volume = Bed\ \ Bottom\ \ Area\ \ (ft^2) \times Infiltration\ \ Design\ Rate\ \ (in/hr) \\ \times Infiltration\ \ Period(hr) \times (1/12) \end{aligned} \tag{9}$$

The storage volume of a bioretention area is defined as the total of Surface Storage Volume and the smaller of Volume or Infiltration Volume above. The surface storage volume should account for at least 50% of the total storage. Inter-media void volumes may vary considerably based on design variations.

Regarding applications, the bioretention has the potential to be implemented under residential, commercial, ultra-urban, industrial, and Highway/Road environment and also can be retrofitted. For example, bioretention areas can be used in the following scenes:

- Residential on-lots
- Tree and shrub pits

- Roads and highways
- Parking lots
- Parking lots island bioretention
- Commercial / Industrial / Institutional
- Curbless (curb cuts) parking lot perimeter bioretention
- Curbed parking lot perimeter bioretention
- Roof leader connection from an adjacent building

BMP 11: Dry Wells / Seepage Pit

A dry well, or seepage pit, is a subsurface storage facility that temporarily stores and infiltrates stormwater runoff from the roofs of structures. In general, the dry well is deeper than its width at the surface as shown in Figure 15. Most dry wells are 30 to 70 ft deep and 3 ft wide at the surface (19). Roof leaders connect directly into the dry well, which may be either an excavated pit filled with uniformly graded aggregate wrapped in geotextile or a prefabricated storage chamber or pipe segment. By capturing runoff at the source, dry wells can dramatically reduce the increased volume of stormwater generated by the roofs of structures. Though roofs are generally not a significant source of runoff pollution, they are still one of the most important sources of new or increased runoff volume from developed areas. Dry wells discharge the stored runoff via infiltration into the surrounding soils. In the event that the dry well is overwhelmed in an intense storm event, an overflow mechanism (surcharge pipe, connection to larger infiltration area, etc.) will ensure that additional runoff is safely conveyed downstream.

For the stormwater functions, the ratings for Volume Reduction, Peak Rate Control and Water Quality are medium; the rating for Recharge is high. The following equation can be used to determine approximate storage volume of a dry well:

$$Dry\ Well\ Volume = Dry\ Well\ Area\ (ft^2) \times Dry\ Well\ Water\ Depth\ (ft) \times 40\%\ (if\ stone\text{-}filled) \quad (10)$$

Regarding applications, the dry wells have the potential to be implemented for residential, commercial, and ultra-urban environments and also can be retrofitted. However, dry wells are not available for Highway/Road and their application for industrial environments is limited.

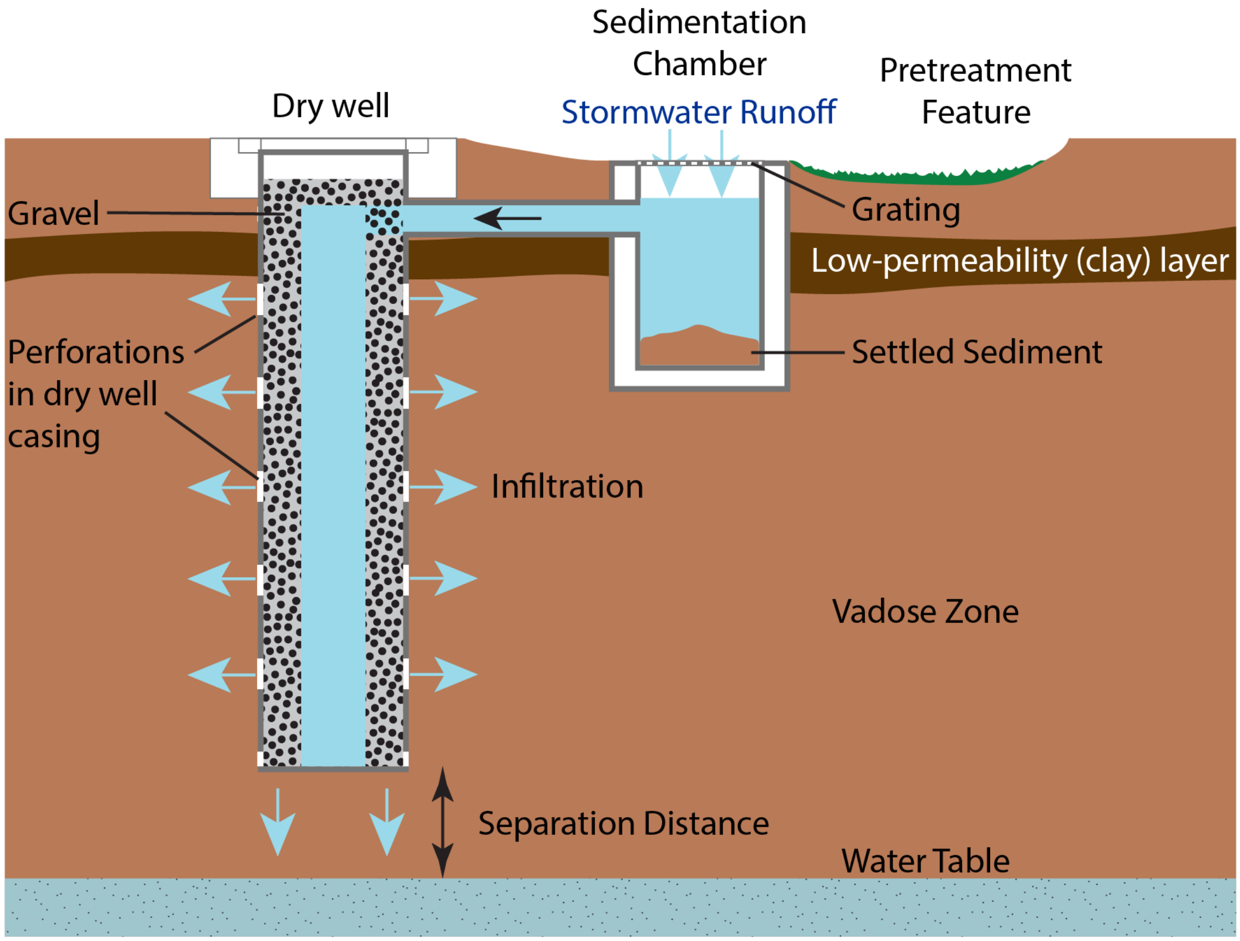

Figure 15. A dry well with two stages of pretreatment: grassy swale and sedimentation well. Image Credit: Edwards, E and Mandler B. Source: (19)

BMP 12: Constructed Filter

A stormwater filter is a structure or excavation filled with material and designed to filter stormwater runoff to improve water quality. An example of a constructed filter is shown in Figure 16. The filter media may be comprised of materials such as sand, peat, compost, granular activated carbon (GAC), perlite, or other material. Additional filtration media will be acceptable for use as long as data is available to verify the media is capable of meeting performance goals. In some applications, the stormwater runoff flows through open air, "pretreatment" chamber to allow the large particles and debris to settle out (sedimentation). Surface vegetation is another good option for pretreatment. The runoff then passes through the filter media where additional pollutants are filtered out, and is collected in an under-drain and returned to the conveyance system, receiving waters or infiltrated into the soil mantle.

Figure 16. An example of a constructed filter. Source: (10)

For the stormwater functions, the ratings for Volume Reduction, Recharge, and Peak Rate Control are low-high; the rating for Water Quality is high. If a filter is designed to include infiltration, the Volume Reduction is a function of the area of the filter and infiltration rate. There is minimal volume reduction for filters that are not designed to infiltrate. The different types of Volume can be calculated from the following equations:

$$Volume = Infiltration\ Volume^{*} + \ Filter\ Volume \tag{11}$$

$$Infiltration\ Volume = Bottom\ Area\ (ft^2) \times Infiltration\ Rate\ (in/hr) \times Drawdown\ Time^{**}(h) \tag{12}$$

$$\text{Filter Volume=Area of Filter (ft}^2\text{)}\times\text{Depth (ft)}\times 20\%^{***} \tag{13}$$

* Infiltration Volume is for filters with infiltration only, **Drawdown Time does not to exceed 72 hours, and ***20% is used for sand, amended soil, compost, and peat unless more specific data is available.

Regarding applications, the constructed filter has the potential to be implemented for commercial, ultra-urban, and industrial environments and also can be retrofitted. However, its application for residential environment is limited. Filters are applicable in urbanized areas having high pollutant loads and are especially applicable where there is limited area for construction of other BMPs. Filters may be used as a pretreatment BMP before other BMPs such as wet ponds or infiltration systems. Filters may be used in Hot Spot areas for water quality treatment, and spill containment capabilities may be incorporated into a filter. Examples of typical areas that benefit from the use include:

- Parking lots
- Roadways and highways

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- Light industrial sites
- Marina areas
- Transportation facilities
- Fast food and shopping areas
- Waste transfer stations
- Urban streetscapes

BMP 13: Grass Swales

Grass (vegetated) swales are broad, shallow channels designed to slow runoff, promote infiltration, and filter pollutants and sediments in the process of conveying runoff. Figure 17 shows a grass swale with concrete check dams. Vegetated swales provide an environmentally superior alternative to conventional curb and gutter conveyance systems, while providing partially treated (pretreatment) and partially distributed stormwater flows to subsequent BMPs. Swales are often heavily vegetated with a dense and diverse selection of native, close-growing, water-resistant plants with high pollutant removal potential. The various pollutant removal mechanisms of a swale include: sedimentary filtering by the swale vegetation (both on side slopes and bottom), filtering through a subsoil matrix, and/or infiltration into the underlying soils with a full array of infiltration-oriented pollutant removal mechanisms.

Figure 17. A grass swale with concrete check dams. Credit: LimnoTech. Source: (20)

A vegetated swale typically consists of a band of dense vegetation, underlain by at least 24 inches of permeable soil. Swales constructed with an underlying 12 to 24-inch aggregate layer provide significant volume reduction and reduce the stormwater conveyance rate. The permeable soil media should have a minimum infiltration rate of 0.5 inches per hour and contain a high level of organic material to enhance pollutant removal. A nonwoven geotextile should completely wrap the aggregate trench.

For the stormwater functions, the ratings for Volume Reduction and Recharge are low/medium; the ratings for Peak Rate Control and Water Quality are medium/high. If check dams are installed perpendicular to the flow in the grass swale, the volume retained behind each check-dam can be approximated from:

$$Storage\ Volume = 0.5 \times L \times D \times (WT + WB) / 2 \tag{14}$$

where L represents the length of the swale impoundment area per check dam, D represents the depth of the check dam, WT represents the top width of the check dam, and WB represents the bottom width of the check dam.

Regarding applications, the grass swales have the potential to be implemented for residential, commercial, industrial, and Highway/Road environments and also can be retrofitted. However, the application for the ultra-urban environment is limited. Following are some application examples of the grass swale:

- Parking
- Commercial and light industrial facilities
- Roads and highways
- Residential developments
- Pretreatment for volume-based BMPs
- Alternatives to curb/gutter and storm sewer

BMP 14: Vegetated Filter Strips

Vegetated filter strips, as shown in Figure 18, are gently sloping, densely vegetated areas that filter, slow, and infiltrate sheet flowing stormwater. Filter strips are best utilized to treat runoff from roads and highways, roof downspouts, small parking lots, and pervious surfaces. In highly impervious areas, they are generally not recommended as “stand alone” features, but as pretreatment systems for other BMPs, such as infiltration trenches or bioretention areas. Filter strips are primarily designed to reduced Total Suspended Solids (TSS) levels, however pollutant levels of hydrocarbons, heavy metals, and nutrients may also be reduced. Pollutant removal mechanisms include sedimentation, filtration, absorption, infiltration, biological uptake, and microbial activity. Depending on the hydrologic soil group, vegetative cover type, slope, and length, a filter strip can allow for a modest reduction in runoff volume through infiltration.

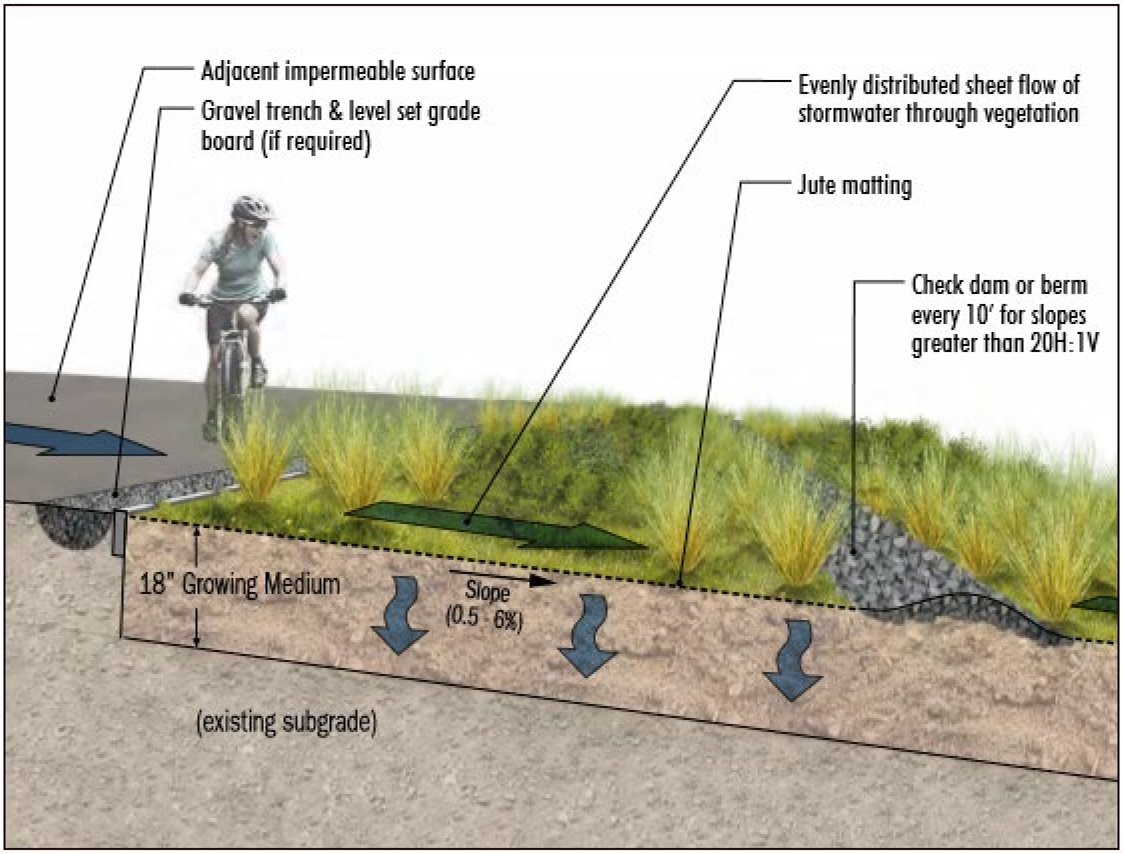

Figure 18. An example of vegetated filter strip. Source: (21)

The vegetation for filter strips may be comprised of turf grasses, meadow grasses, shrubs, indigenous areas of woods and native vegetation, including trees. The use of a variety of trees, shrubs, and native vegetation can add aesthetic value as well as water quality benefits; the use of turf grasses will increase the required length of the filter strip, as compared to other vegetation options; the use of indigenous vegetated areas that have surface features that disperse runoff is encouraged, as the use of these areas will also reduce overall site disturbance and soil compaction. Runoff must be distributed so that erosive conditions cannot develop. The vegetation in filter strips must be dense and healthy. Indigenous wooded areas should have a healthy layer of leaf mulch or duff. Indigenous areas that have surface features that concentrate flow are not acceptable.

For the stormwater functions, the ratings for Volume Reduction and Recharge are low/medium; the rating for Peak Rate Control is low; and the rating for Water Quality is high. To determine the volume reduction over the length of a filter strip, the following equation is recommended:

$$Filter\ Strip\ Volume\ \mathrm{Re}duction = Filter\ Strip\ Area \times Infiltration\ Rate \times Storm\ Duration \qquad (15)$$

When a berm is positioned at the toe of the slope, the total volume reduction shall be defined as the amount calculated above plus the following:

$$\begin{aligned}Berm\ Storage\ Volume &= (Cross\text{-}sectional\ Area\ Behind\ Berm \times Length\ of\ Berm) \\ &+ (Surface\ Area\ Behind\ Berm \times Infiltration\ Rate \times 12\ hours)\end{aligned} \quad (16)$$

The inundated area behind the berm should be designed to drain within 24 hours. An outlet pipe or overflow weir may be needed to provide adequate drain down. In that case, the infiltration volume behind the berm should be adjusted based on the invert of the overflow mechanism.

Regarding applications, the vegetated filter strips have the potential to be implemented for residential, commercial, and Highway/Road environments and also can be retrofitted. However, the applications for the ultra-urban and industrial environments are limited. Following are some application examples of the vegetated filter:

- Residential development lawn and housing areas
- Roads and highways
- Parking lots
- Pretreatment for other structural BMPs (Infiltration trench, Bioretention, etc.)
- Commercial and light industrial facilities
- As part of a Riparian Buffer

BMP 15: Infiltration Berm

Infiltration berms are linear landscape features located along (i.e. parallel to) existing site contours in a moderately sloping area. Figure 18 shows an infiltration berm schematic. Infiltration berms can be described as built-up earthen embankments with sloping sides, which function to divert, retain and promote infiltration, slow down, or divert stormwater flows. Berms are also utilized for reasons independent of stormwater management, such as to add interest to a flat landscape, create noise or wind barrier, separate land uses, screen undesirable views or to enhance or emphasize landscape designs. Berms are often used in conjunction with recreational features, such as pathways through woodlands. Therefore, when used for stormwater management, berms and other retentive grading techniques can serve multifunctional purposes and are easily incorporated into the landscape.

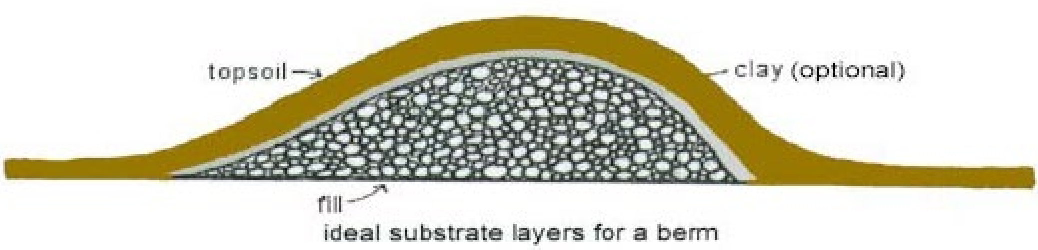

Figure 18. An infiltration berm schematic. Source: (10)

Infiltration berms create shallow depressions that collect and temporarily store stormwater runoff, allowing it to infiltrate into the ground and recharge the groundwater. Infiltration berms may be constructed in series along a gradually sloping area. For example:

1) Infiltration berms can be constructed on disturbed slopes and revegetated as part of the construction process. Infiltration berms should not be installed on slopes where soils having low shear strength (or identified as "slip prone" or "landslide prone", etc.).
2) Infiltration berms can be installed along the contours within an existing woodland area to slow and infiltrate runoff from a development site.
3) Infiltration berms may be constructed in combination with a subsurface infiltration trench at the base of the berm.

For the stormwater functions, the rating for Volume Reduction is low/medium; the rating for Recharge is low; the rating for Peak Rate Control is medium; and the rating for Water Quality is medium/high. For infiltration berms, storage volume is defined as the ponding area created behind the berm, beneath the discharge invert (i.e., crest of the berm). Storage volume can be calculated differently depending on the variations utilized in the design. Surface Storage Volume is defined as the volume of water stored on the surface at the ponding depth, which can be calculated from:

$$Surface\ Storage\ Volume = Cross\text{-}sectional\ Area\ of\ Ponded\ Water \times Berm\ Length \tag{17}$$

Regarding applications, the infiltration berms have the potential to be implemented for residential, commercial, industrial and Highway/Road environments and also can be retrofitted. However, the application for the ultra-urban environment is limited. Following are some application examples of the infiltration berms:

- Meadow/Woodland infiltration berms
- Slope protection
- Flow pathway creation
- Constructed wetland berms

6. BMP Selection

Structural stormwater BMP is an integral component of stormwater management. They are designed and implemented to address the following three criteria that are critical to manage stormwater runoff:

1. Reduce or delay the volume of stormwater that enters the sewer system
2. Reduce the maximum flow rate by decreasing the stormwater volume and increasing the duration of discharge
3. Improve water quality through filtering, biological or chemical processes.

To achieve the objectives of collecting, detaining, and treating stormwater runoff, BMPs can be implemented as a stand-alone practice or in series, referred to as 'treatment trains', that combine multiple BMPs. In general, combining BMPs as a treatment train rather than using a single method of treatment can improve the levels and reliability of pollutant removal, as well as runoff reduction, and groundwater recharge (22).

So far, a large number of BMPs have been designed and implemented to mitigate stormwater problems. Some of them are best used to reduce runoff volume, while others focus on water quality improvement; some BMPs are easy to implement, while others may need more extensive design and engineering. Also, there are many solutions, rather than a single answer, to the question of which BMP or BMPs should be selected for a project. Therefore, selecting appropriate BMPs for a developing or redeveloping site can be a perplexing and arduous process. It is critical to correctly choose and place BMPs for stormwater treatment because inappropriate BMPs will lead to adverse impacts. To ensure that the selected BMPs can achieve the objectives of stormwater control, the following factors need to be considered (8,23):

1) Land use factors
2) Physical/site feasibility
3) Downstream resources,
4) Maintenance factors
5) Climatic factors
6) Pollutants of concern
7) Costs

Typically, BMP selection is applied after the site characterization, project objectives and treatment goals have been defined and after the preliminary conceptual site layout and integrated stormwater design considerations have been developed (7). Figure 19 shows the components and steps of the selection process.

As shown in Figure 19, the selection process is conducted in two steps: 1) BMP Screening and 2) BMP Evaluation. The BMP Screening step evaluates individual BMPs and, in turn, identify the most appropriate BMPs for the project. In this step, the factors including effectiveness of pollutants of concern, site suitability and physical constraints, maintenance needs and constraints, and costs are scored and rated to help identify appropriate BMPs. Then, these identified BMPs are used to develop treatment train alternatives. The BMP Evaluation step evaluates alternatives further and, in more detail, concerning conceptual design layouts for the individual components of the treatment train. As Figure 19 shows, the project team and regulatory agencies have two opportunities, one time in each step, to join the discussion of documented decisions.

Currently, most BMPs have been evaluated for effectiveness at treating certain pollutants of concern. According to the recorded BMP effectiveness information, the BMPs that have a treatment mechanism effective for target pollutant removal are considered as preferred BMPs for treating these pollutants. If preferred BMPs for the target pollutants are feasible and appropriate for the site, the second step, BMP Evaluation, can be bypassed because these BMPs have been determined to be suitable for treating the target pollutants, as illustrated in Figure 19. However, the stormwater engineer still needs to design the system and ensure that the BMP is feasible and meets design standards.

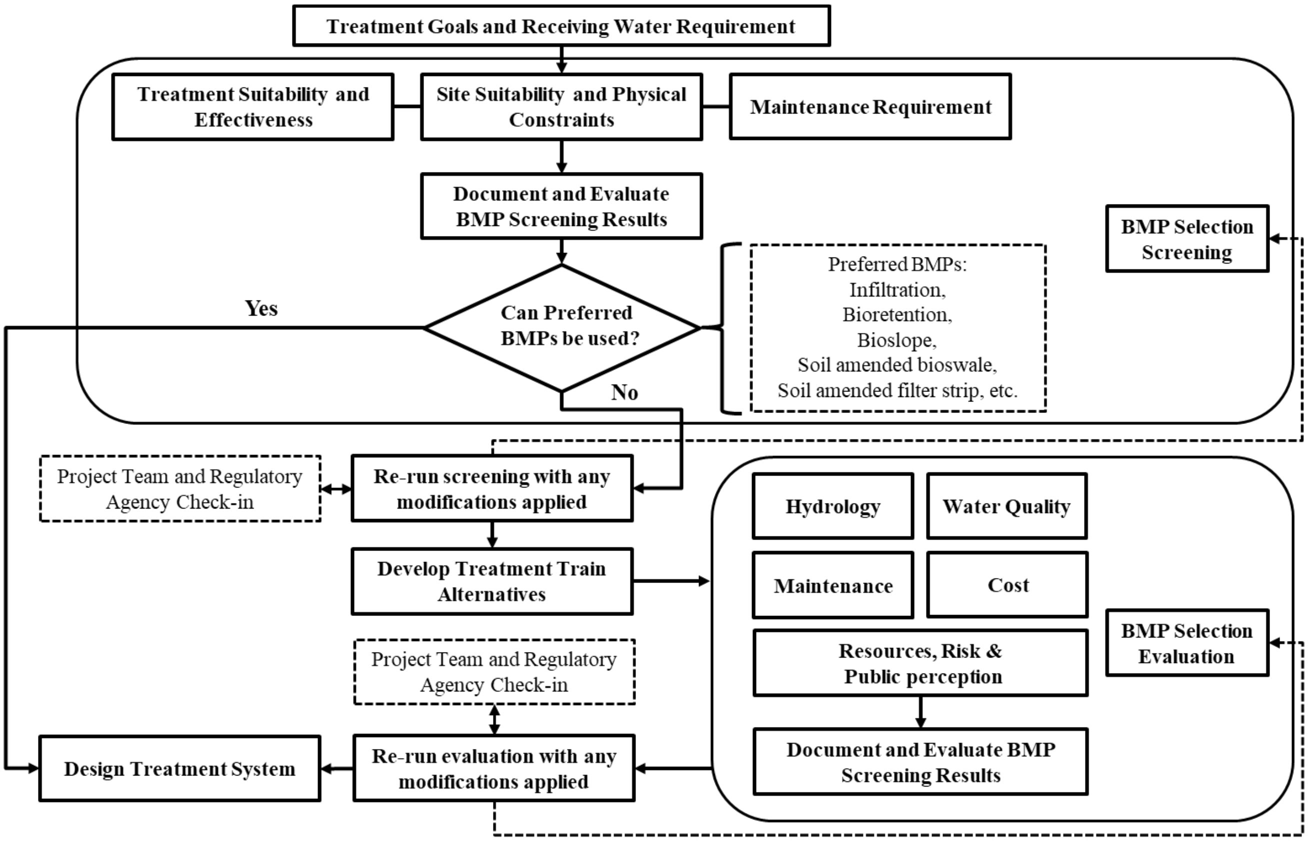

Figure 19. The process of Best Management Practice (BMP) selection. Source: (7)

7. BMP Applications

After the detailed explanation of the BMP selection process, the instructor introduces two topics about BMP applications to improve the participants' understanding of BMP implementation. The first topic is about the challenges and considerations for BMPs implemented in the roadway environment, and the second topic is about the impacts of climate change on BMPs. The two topics will be discussed in the following sections.

1). BMPs Implemented in the Roadway Environment

Roadways, which serve as the primary mode for moving goods and people, carry stormwater runoff pollutants from the adjacent land and vehicles including heavy metals from tires, brakes, and engine wear, etc. Despite that roadways only occupy a small portion of the overall watershed, they play a significant role in stormwater runoff since water takes the path of least resistance (5). Also, the U.S. Environmental Protection Agency has identified the stormwater runoff from transportation systems as one of its focus points to improve water quality under the Clean Water Act (23). For this reason, this project conducts a study on BMPs implemented for roadways.

Roadways are different from other land uses due to their specific characteristics. For example, roadways are typically characterized by the elongated linear nature, a high degree of imperviousness, and the tendency to cross multiple watersheds, and jurisdictions (24). Therefore, stormwater runoff from roadways discharges to many distributed points and need to be managed at a great number of locations along the length of the roadway. Also, various impervious surfaces, such as buildings, walkways, etc., that are directly adjacent to roadways can produce runoff that drains onto or into the roadway right-of-way. These flows need to be taken into account. Besides, stormwater runoff from roadways contains specific transportation-related pollutants that make it significantly different from the runoff from other land uses. The difference in stormwater characteristics can impact the BMP selection. Due to these specific situations of roadways, implementing BMPs faces many constraints, such as limited flexibility in geometric design, safety consideration, and space constraints due to long-reinforced design standards. Many BMPs commonly applied in other land uses are not suitable or require careful application in this space-constraint environment. The 2019 report of National Academies of Sciences, Engineering, and Medicine suggests considering stormwater infiltration, where the reasons include, but are not limited to (25):

1) Infiltration of stormwater may need to be considered or implemented to comply with applicable regulations, e.g., National Pollutant Discharge Elimination System (NPDES) permits or Total Maximum Daily Loads (TMDLs).
2) Pollutant removal performance of BMPs can be improved when volume reduction is increased.
3) Infiltration can be more cost-effective than other BMPs under favorable conditions.
4) Multiple benefits exist when implementing stormwater infiltration such as ground augmentation and reduction of the hydraulic load to stream; infiltrated water that enters receiving water tends to be cleaner and mimics natural flow regimes compared with direct surface runoff.

To enable the participants to better design and select BMPs for their operations in a complex roadway environment, the instructor introduces a consistent, centralized, and scientifically defensible database on BMP design and related performance. The database, named International Stormwater BMP Database (http://www.bmpdatabase.org/), is a project that initiated under a cooperative agreement between the American Society of Civil Engineers (ASCE) and the U.S. Environmental Protection Agency (USEPA) (26). Now, the project is led by the Water Research Foundation (WRF) and supported by a coalition of partners, including the Federal Highway Administration (FHWA), American Public Works Association (APWA), and The Environmental and Water Resources Institute (EWRI) of ASCE. The Database is a publicly accessible repository for BMP studies, performance analysis results, tools for use in BMP performance studies, monitoring guidance and other study-related publications. The key purpose of the Database is to serve as an important resource for stormwater practitioners to provide consistent and scientifically sound information to improve the design, selection and performance of BMPs.

The latest 2019 International Stormwater BMP Database shows that there are 771 BMP studies included in the database as of 2019, of which more than 20% (175 studies) were implemented for Roads/Highways in the U.S. Table 1 and Figure 20 provide a summary for the studies contained in the database that relate to Roads/Highways environment. Table 1 shows that there are 15 types of BMPs related to Roads/Highways, implemented in 9 states of the U.S. based on the records of the International Stormwater BMP Database. Among the 15 types of BMPs, the five most common BMPs are Bioretention, Manufactured Device, Biofilter (Grass Strip), Media Filter, and Biofilter (Grass Swale). Figure 20 shows that the state of California has the maximum number of BMP studies related to Roads/Highways, which account for 30%. The state of Washington accounts for 27%, the state of Texas accounts for 14%, and the state of North Carolina accounts for 13%. Each of the rest of the states accounts for less than 10%, respectively. The results summarized in Table 1 and Figure 20 do not necessarily forecast what BMPs will be implemented in future projects, however, it provides an indication of the BMPs that have been successfully applied for Roads/Highways, results of performance analysis and guidance for these BMPs.

Table 1. BMP studies related to Roads/Highways in the International BMP Database as of 2019.

BMP Category		State								
	Total	CA	DE	MN	NC	OR	SC	TX	WA	WI
Biofilter (Grass Strip)	**31**	29			2					
Bioretention	**34**	2	1		6				25	
Biofilter (Grass Swale)	**12**	5			5			1	1	
Composite (Treatment Train)	**8**				4			3	1	
Control	**7**			3				2		2
Detention Basin	**8**	5						3		
Infiltration Basin	**2**	2								
Manufactured Device	**34**	3	4			2	6	2	15	2
Media Filter	**13**	6						7		
Maintenance Practice	**2**									2
Permeable Friction Course	**6**				3			3		
Porous Pavement	**7**			6	1					
Retention Pond	**7**	1						3	3	
Wetland Basin	**2**								2	
Wetland Channel	**2**				2					
Total	**175**	**53**	**5**	**9**	**23**	**2**	**6**	**24**	**47**	**6**

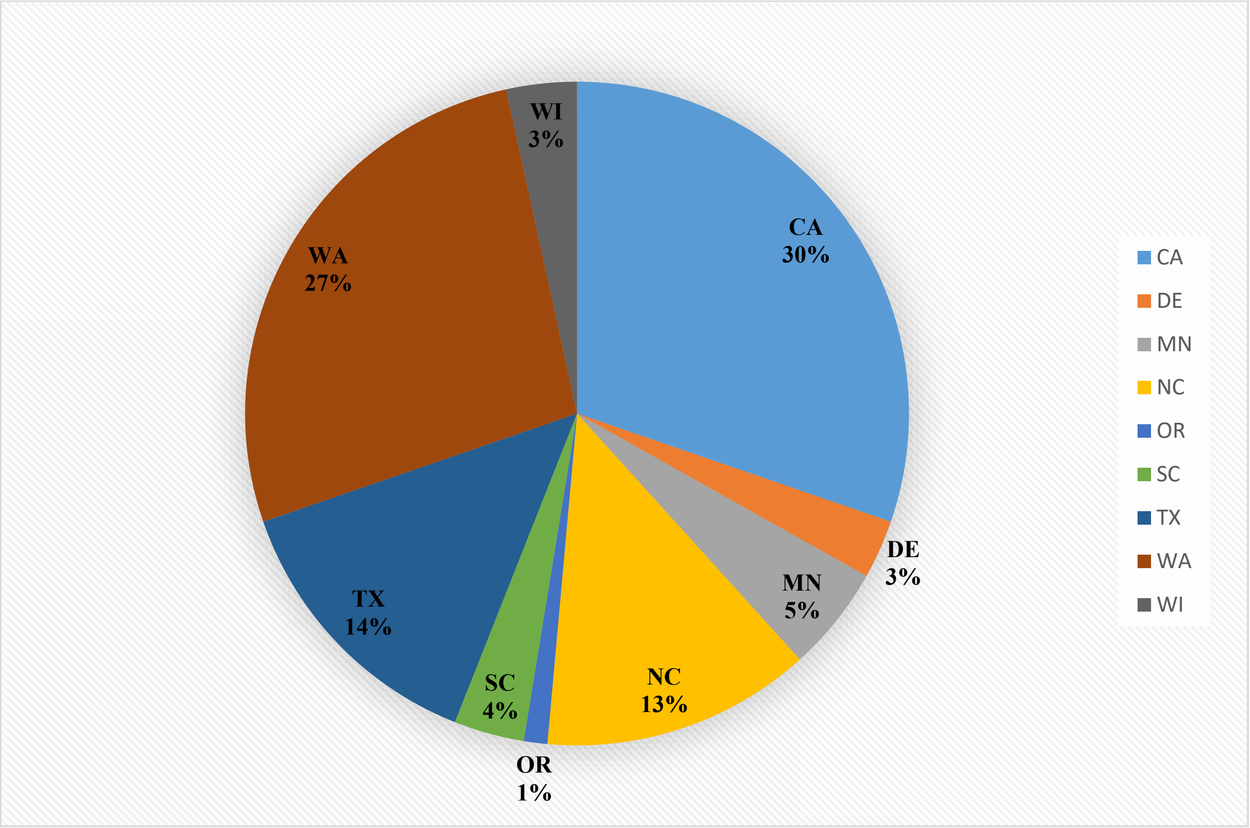

Figure 20. Distribution of BMP studies related to Roads/Highways in the International BMP database as of 2019.

2). Impacts of Climate Change on BMPs

Local weather and climate play a significant role in stormwater management (27). Stormwater Infrastructure is typically designed to convey, capture, or improve the runoff associated with a design storm. The design of stormwater infrastructure may vary due to local regulations, but generally, it depends on the estimates of local weather and climate, e.g., amount, timing, precipitation intensity or depth associated with a fixed return period (28). In 2018, the Water Environment Federation's (WEF) Stormwater Institute (SWI) conducted a national survey of MS4 permittees to better understand the fundamental challenges and needs. The conclusion of the survey results indicate an unexpected finding that the respondents point out there is a lack of priority concerning climate change, e.g., extreme events and episodic flood events (6). Climate stressors, such as changing precipitation patterns and extreme events, are impacting water resources. However, recent studies show that, generally, the current approach of stormwater infrastructure is designed based upon an assumption of climatological consistency (28). In the face of climate change, these stormwater infrastructures are becoming increasingly inadequate to control runoff volume and improve water quality. Therefore, there is a critical need to take action on incorporating climate change into stormwater management planning.

Water resources and stormwater management are affected in different ways as the climate continues to change. In turn, climate change also affects the selection of BMPs, which is an essential part of stormwater management. The results in (28) show that the magnitude and direction of precipitation depths and intensities vary from one climate model to the next. And, climate change is anticipated to result in changes to the statistical properties of both precipitation depths and precipitation intensity. Due to the fact that BMPs are designed under the assumption that the probability distribution of rainfall events is static, climate change also affects the selection of BMPs when the probability distribution changes.

To estimate future loads on a system from climate change, the Intensity-Duration-Frequency (IDF) curves are applied. The IDF curve is a mathematical function that describes the relationship between rainfall intensity, rainfall duration, and return period. IDF analysis is used to capture the essential characteristics of point rainfall for shorter durations and can summarize regional rainfall information. Therefore, IDF is commonly used in municipal stormwater management practices. Following are the steps to create IDF curves:

1) The intensity duration frequency analysis starts by gathering time series records of different durations.
2) After time series data is gathered, annual extremes are extracted from the record for each duration.
3) The annual extreme data is then fit to a probability distribution in order to estimate rainfall quantities. The fit of the probability distribution is necessary in order to standardize the character of rainfall across stations with widely varying lengths of record. For example, the following Gumbel extreme value distribution can be applied to fit the annual extremes of rainfall data:

$$x_T = \mu_z + K_T \sigma_z \tag{18}$$

where X_T represents the magnitude of the T-year event, μ_z represents the mean of the annual maximum series, σ_z represents the standard deviation of the annual maximum series, K_T represents the frequency factor which is equal to $\frac{-\sqrt{6}}{\pi}\left[0.5772+\ln\left(\ln\left(\frac{T}{T+1}\right)\right)\right]$, and T represents the return period.

The IDF data derived with the above methods is typically fitted to a continuous function in order to make the process of IDF data interpolation more efficient. For example, 10-year intensity for a duration of 45 minutes is not readily available in the published IDF data. Therefore, IDF data is fitted to the following three-parameter function:

$$i = \frac{A}{(t_d + B)^C} \tag{19}$$

where i represents the rainfall intensity (mm/hr), t_d represents the rainfall duration (min), and *A, B, C* are coefficients. After selecting a reasonable value of parameter *B*, the method of least squares is used to estimate values of *A* and *C*. The calculation is repeated for a number of different values of *B* in order to achieve the closest possible fit of the data. After IDF data is fitted to the above function, plots of rainfall intensity vs. duration (for each return period) are produced.

To help the participants better understand the impacts of climate changes on BMP selection, this module demonstrates a case study that analyzes the climate change and stormwater infrastructure in the mid-Atlantic region based on the performance of the detention basin under several different climate change model scenarios (28). In this study, 24-h design storms consistent with the future climate precipitation data is applied to drive a rainfall-runoff model simulating a watershed/detention basin system. Following are the results of the study:

1) The performance of a detention basin design based on present climate is inadequate under future climate conditions, in terms of current infrastructure to carry future flood loads, and in terms of potential strategies for design of infrastructure, in the face of a nonstationary climate.
2) The large number of elevated metrics simulated indicates that it is more likely than not that detention ponds and possibly other stormwater infrastructure do not perform as intended as precipitation changes under future climate.
3) Several design approaches to face of climate change include: do nothing, design toward a fixed endpoint, and progressive adaptation. A cost-benefit analysis might identify strategies that are superior to others.
4) More detail on Methodology used: Log-Pearson Type III frequency analysis is employed to estimate the 2- and 10-year precipitation depths for durations of 3, 6, 12, 24, and 48 h. Numerical optimization is used to fit intensity-duration-frequency curves through the above estimated precipitation data for four different regional climate models + general circulation model pairs. Symmetric 24-h design storms are generated for each model pair and return period. Derived precipitation depths and storm distributions are used to drive a rainfall-runoff model to examine uncontrolled changes in peak discharge and changes in detention basin performance both in terms of controlled peak discharge and maximum pond storage.

The case study above demonstrates the significant impacts of climate changes on BMP selection. Table 2 shows the objectives and corresponding performance of some stormwater controls. It shows that stormwater management goals are not exclusive of each other but rather complementary, building on each other. For instance, satisfying requirements for recharge and evapotranspiration also may partially or fully achieve those for water quality and channel protection. Also, for the objectives of flood control, the basis of the BMP performance standard depends on the design storm. If the design storm considers the climate change, then the capacity of the BMP for flood control, together with other control objectives, is improved.

Table 2. Performance of stormwater controls

Stormwater Management Control Objective	Basis of Performance Standard	Basins	Swales and Strips	Filters	Infiltrators	Gross Pollutant Traps and Mechanical Operations
Recharge and Evapotranspiration	Recharge Rate, Evapotranspiration Rate	S	S		X	
Water Quality Control						
• Capture and Release	Capture Volume, Drawdown Time	X		X	X	
• Flow-through	Capture Volume, Design Hydrograph		X	X		X
Channel Protection	Shear Stress	X	S	S	X	
Overbank Flood Control	Design Storm, Peak Attenuation	X			S	
Extreme Flood Control	Design Storm, Peak Attenuation	X			S	

X=primary function; S=secondary function. Stormwater controls. Source: (29)

The module concludes with a group activity where participants evaluate and select appropriate BMPs for the stormwater-associated problems identified in the previous activity. In the group activity, the participants should return to their Activity 1 groups, await instructions, and prepare to complete the "Evaluating and Selecting Appropriate BMPs" matrix, provided in the Activity 2 Group Handout (located in Appendix B), to guide their BMP selection process. The questions listed below can help participants complete the activity:

1) What are the main stormwater-associated problems in your local area?
   - Here, the participants list three stormwater-associated problems that have been identified in the previous activity.
2) What BMPs have been implemented in your local area?
   - List one or more BMPs that have been applied to mitigate the negative effects of Stormwater.
3) What are the main factors affecting your BMP selection?
   - The following factors are likely to affect the BMP selection: <1> Geophysical factors, e.g., climate, hydrology, land, soils, and topography <2> Law and social factors <3> Technical and economic factors
4) What new BMPs are appropriate for the stormwater-associated problems in your local area?
   - According to the information provided in this module, select one single or a combination of BMPs that are appropriate for stormwater control.
5) Who is the primary entity responsible for the implementation of the new BMPs?

- The following parties likely to be responsible for the BMP implementation: <1> Federal government <2> State government <3> Local government <4> Land owner <5> Private organization

6) What is the level of effort required for the new BMPs?
    - <1> Continuous <2> Periodic <3> One-time
7) To what degree is the public likely to accept the new proposed BMPs?
    - <1> Poor <2> Fair <3> Good <4> Excellent
8) What is the appropriate timeline for the implementation of new BMPs?
    - <1> Immediately <2> Short term <3> Long term

Learning Objectives

The TLO of this module is that participants are able to identify and analyze the problems caused by stormwater runoff and implement appropriate BMPs to control them. Following are the six supporting ELO, for the TLO, which enable the participants to:

1) Understand stormwater runoff and demonstrate how to estimate flow rates for channeled and sheet flow and plot them over time.
2) Explain stormwater functions.
3) Discuss stormwater-associated problems.
4) Explain why and how to design the storm drainage system and discuss its functions, benefits, and adverse effects.
5) Understand different types of stormwater BMPs by reviewing corresponding examples and explain the BMP selection process.
6) Discuss applications to roadways and climate change.

Module 4: Site Development Principles

Scope Statement

In this module, the instructor introduces twelve general principles for stormwater design and five principles for roadway drainage design. These principles should always be followed when developing or redeveloping a project. The instructor also demonstrates some principles by examples that can help the participants have a better understanding.

Lesson Topics

In this module, the following two topics are covered:

1. Twelve General Principles for Stormwater Design

Urban runoff can cause significant impacts on hydrologic and water quality. However, if a developed area behaves hydrologically as it did before the site was developed (i.e., the amount of stormwater leaving the site should not increase after development), there would be no cause and effect of development and no correlation between imperviousness and stream health (22). The developer should seek to use the site's natural features, protect sensitive areas and limit imperviousness. Following are the twelve general principles that need to be taken into account when conducting stormwater management:

1) Each parcel of land is connected and part of a much larger watershed.
2) Stormwater is an important resource that should be used to replenish our rivers, streams, and lakes.
3) It is generally more efficient and cost-effective to prevent problems rather than attempt to correct them after the fact.
4) The final design of a stormwater management system should attempt to mimic and use the natural drainage features of the site. This is usually the most cost-effective and lower maintenance option.
5) Post-development runoff characteristics (volume, rate, timing and pollutant load) for a given site should closely resemble pre-development conditions.
6) The final site design should maximize onsite storage, infiltration and evaporation of stormwater. Remember, stormwater is a resource. Consideration should also be given to neighborhood or regional storage. Two examples of this principle are on-site infiltration trench and on-site sand filter, of which both are designed to address pollutant load in runoff and encourage groundwater recharge on site.
7) Avoid discharging stormwater directly to a surface water body such as a stream. To do this, try to incorporate BMPs that slow down or reduce the stormwater pollutant load before it is discharged. For example, a vegetated or grassy island is designed to allow the infiltration of parking lot runoff, and a constructed wetland is designed to slow down stormwater runoff and reduce the pollutant load.
8) Stormwater management systems (particularly methods that use vegetation as a key component) should be designed, constructed and stabilized before the facilities that discharge to them are built.

9) Begin at the "end of the pipe," the receiving stream. That is, understand where the stormwater from the site will discharge and how it will impact downstream areas before the design of the stormwater system.
10) Design and construct, to the extent possible, the stormwater management system along natural site contours.
11) Vegetated buffer strips (riparian corridors) should be retained or created along banks of streams or lakes.
12) Regular inspection and maintenance is a key component of a stormwater management system.

2. Five Principles for Roadway Drainage

As discussed above, development or redevelopment implemented in the roadway environment includes a variety of diverse conditions and constraints that should be evaluated and considered. For example, hazardous waste must be considered when designing for roadways due to oil spills from vehicles. Therefore, from the twelve general principles, stem five principles for roadway drainage design:

1) Roadway runoff should not be discharged directly to infiltration systems without first reducing sediment loads.
2) Vegetative BMPs such as grassed swales and filter strips can be highly effective in reducing pollutant loads from roadways but must be properly designed in terms of slope, flow velocity, flow length, and vegetative cover.
3) The potential for spills must be considered.
4) Consideration should be given to the types of vegetation used in vegetative BMPs, as high chloride levels may adversely affect some vegetation as well as the soil microbial community.
5) New discharges should provide mitigation for temperature impacts prior to discharge to the receiving water.

Besides the considerations mentioned above, two additional factors need to be taken into account when designing for roadways. First are the possible drainage scenarios of structures near roadways. Structures will tend to divert their runoff towards a roadway so stormwater drains must be able to handle the loads of all these combined properties. The second factor is the steep slopes. The loading on storm drains from runoff during heavy precipitation events must be accounted for.

Learning Objectives

The TLO of this module is that participants are able to describe and properly use the principles of stormwater design and roadway drainage design. The two supporting ELO for the TLO are to enable participants to discuss general principles of stormwater design with BMP examples and to discuss principles for roadway drainage design.

Module 5: Course Summary and Administration

Scope Statement

In this module, the instructor leads a short discussion to review the course goal and content. Participants complete an objectives-based post-test. Participants must score at least 70 percent to receive a Certificate of Completion. Participants also complete a course evaluation form and provide feedback on the course instruction, content, and materials. Additional information is to be provided about other FEMA training opportunities.

Lesson Topics

In this module, the following three topics are covered:

1. Course Summary

This course has prepared participants to describe and analyze stormwater runoff problems and select and design appropriate stormwater Best Management Practices (BMPs), with applications to roadways and climate change.

2. Additional Resources

The instructor introduces additional resources related to stormwater management to the participants. For example, National Disaster Preparedness Training Center (NDPTC) offers a flooding-related training course, named AWR-362 Flooding Hazards: Science & Preparedness, that may be of aid should agencies desire to learn more about stormwater. The course is free to attend.

3. Course Evaluation

The instructor distributes a Course Evaluation Form to participants and asks them to provide constructive feedback on the course material and instruction. Participants have 15 minutes to complete the form.

4. Post-test

This course concludes with a post-test, which allows the instructor to evaluate participant knowledge on the topics addressed in the course. The post-test provides participants with an opportunity to demonstrate mastery of the TLO and is similar in design and content to the pre-test that participants completed at the beginning of the course. Participants' pre-test and post-test scores are compared to measure the benefit of the course and identify the knowledge and skills participants gained during their attendance.

Unlike the pre-test, every question should be answered. Participants must not leave any answers blank on the answer sheet. Participants have 20 minutes to complete the post-test and should work independently to complete the answers.

Learning Objectives

In this module, the TLO is to enable participants to successfully complete the post-test and all final administrative tasks for the course. The TLO can be broken into three ELO, which are enabling participants to identify additional resources and training opportunities, to provide an evaluation of the course materials and instruction, and to complete a post-test.

Conclusion

Uncontrolled stormwater runoff can lead to adverse effects on the environment, and in turn, on humans. Therefore, an effective stormwater management program is important for the protection and restoration of water resources.

The objective of the project is to develop a 5-hour in-person training course. The goal of the course is to prepare the participants to identify and analyze stormwater runoff problems and select and design appropriate stormwater. The course is comprised of the following five modules:

1. Welcome, Introduction, and Administration
2. Terms & Definitions Used in Stormwater Management
3. Stormwater Problems and Management
4. Site Development Principles
5. Course Summary and Administration

The first module briefly introduces the course such as course goals, course content, course agenda and evaluation strategy. The module also indicates the administrative details about the course.

The second module introduces and explains the concept of stormwater management. This module also demonstrates some common terms and definitions used in stormwater management.

The third module is the core of the course. This module starts with how stormwater runoff is generated. Next, the calculations of different types of runoff flows are introduced. Then, the instructor leads the participants in a discussion of stormwater-associated problems and to complete a group activity, which helps the participants identify stormwater-associated problems. After introducing the stormwater-associated problems, the instructor gives several examples for each type of structural BMPs, which helps participants understand the feasibility, benefits, and limitations of each BMP. After mastering the basic information of different types of BMPs, the BMP selection process is showed and explained through a flow chart. Lastly, two topics about BMP applications, BMPs for roadways and impacts of climate change on BMPs, are discussed to help participants better understand BMPs.

The fourth module focuses on the general principles for stormwater design and specific ones for roadway drainage design.

The fifth module is the last module of the course. It focuses on reviewing the course and evaluating the participants through a post-test.

According to the concept of non-structural BMP, this training course itself is a type of BMP. It is expected that this course can improve the understanding of stormwater management in a national scope; this course can equip the participants, especially transportation agencies, with the fundamental knowledge and skills of stormwater management; this course can serve as a start of the communication between stormwater management professionals and public officials; and this course can provide a platform for participants with different background to share the stormwater-associated information and an opportunity to collaborate between groups.

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Data Management Plan

No data were collected for this study, as this is a course delivery, rather than a research project.

Appendix A

Activity 1 Group Handout: Stormwater-Associated Problem Identification

Stormwater-Associated Problems	Impact Degree (High/Medium/Low)	Description of Impact
Stormwater Flooding	Ex. High	Ex. Stormwater flooding creates road closures
Stream Bank Erosion		
Increased Turbidity		
Habitat Destruction		
Waterway Blockage due to Excessive Sediment Deposition		
Sewage Overflow		
Infrastructure Damage		
Increased Loads of Pollutants into Streams, Rivers or Other Water Bodies		
Human Health Problems due to Stormwater Contamination		

Appendix B

Activity 2 Group Handout: Evaluating and Selecting Appropriate BMPs

Category	Problem 1	Problem 2	Problem 3
Stormwater-Associated Problems	Ex. Street Flooding		
Existing BMPs	Ex. Onsite Detention		
Factors Affecting BMP Selection	Ex. Technical and Economic		
Proposed BMPs	Ex. Green Roof		
Implementation Party	Ex. Land Owner		
Level of Effort Required	Ex. Periodic		
Acceptance	Ex. Good		
Urgency	Ex. Short Term		