Army Low Impact Development Technical User Guide

4 January 2013

Office of the Assistant Chief of Staff for Installation Management

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With Support From:

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EXECUTIVE SUMMARY

The purpose of the Army Low Impact Development Technical User Guide is to assist installation and activity personnel to better understand processes related to planning, designing and constructing appealing and sustainable low impact development (LID) features, known as best management practices (BMPs), to manage stormwater. Low impact development integrated across a project site and especially into installation level planning brings about a decentralized approach to the management of stormwater runoff.

Low Impact Development is a stormwater management strategy designed to maintain site hydrology and mitigate the adverse impacts of stormwater runoff and nonpoint source pollution. Implementation of LID is based on "mimicking" the natural or pre-development hydrology and is recognized as the preferred means to manage stormwater on Army construction projects and is required by Federal legislation, Office Secretary of Defense and Army policy.

It is our hope that the information contained in this Low Impact Development Technical User Guide be used by the many different disciplines involved with the planning, design and execution of Army construction projects including: Garrison Commanders, Director Public Works, Master Planners, Engineers and Designers, Construction Inspectors, Contract Officer Representatives, Stormwater Managers, and Facility Maintenance Personnel to assist them in meeting Army sustainability goals.

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1 INTRODUCTION

The Army Low Impact Development Technical User Guide provides guidance for the planning and design of Low Impact Development (LID) on construction projects in order to comply with stormwater requirements and resource protection goals that effect Army construction.

1.1 LEGISLATION AND POLICY

Army installations have traditionally been required to comply with a number of federal regulatory programs associated with non-point source stormwater discharges. Recent Federal legislation, Executive Order, Secretary of Defense and Secretary of the Army policy require the implementation of LID as a means to manage stormwater.

The Department of Defense (DoD) definition of LID is as follows:

> Low Impact Development (LID) is a stormwater management strategy designed to maintain site hydrology and mitigate the adverse impacts of stormwater runoff and nonpoint source pollution.
>
> LID actively manages stormwater runoff by mimicking a project site's pre-development hydrology using design techniques that infiltrate, store, and evaporate runoff close to its source of origin. LID strategies provide decentralized hydrologic source control for stormwater runoff. (UFC 3-210-10)

1.1.1 EISA Section 438

In December 2007, Congress enacted the Energy Independence and Security Act (EISA) of 2007. EISA Section 438 establishes strict stormwater runoff requirements for federal development and redevelopment projects. The provision reads as follows:

> "*Storm water runoff requirements for federal development projects.* The sponsor of any development or redevelopment project involving a Federal facility with a footprint that exceeds 5,000 square feet shall use site planning, design, construction, and maintenance strategies for the property to maintain or restore, to the maximum extent technically feasible, the pre-development hydrology of the property with regard to the temperature, rate, volume, and duration of flow."

1.1.2 Executive Orders (EO) 13514

Executive Order 13423, Strengthening Federal Environmental Energy and Transportation Management (2007) and Executive Order 13514, Environmental Energy and Economic Performance (2009) both have goals for the reduction of potable water and a zero carbon footprint. EO 13514 enhances previous EOs on water and energy and requires adherence to EISA Section 438. This EO also directed the EPA to develop the *Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act* (EPA, 2009), which provides federal agencies with a foundation for developing policies and procedures to comply with the regulations (see Chapter 4 and Appendix A).

1.1.3 OSD EISA Section 438 Implementation Memorandum

The Office of the Under Secretary of Defense (OSD) memorandum, *DoD Policy on Implementing Section 438 of the Energy Independence and Security Act (EISA)*, January 2010 is the DoD Policy on Implementing Section 438 of EISA. This memorandum states that DoD shall implement EISA Section 438 and the EPA Technical Guidance using LID techniques. The overall design objective for each project is set to maintain predevelopment hydrology and prevent any net increase in storm water runoff. DoD defines "predevelopment hydrology" as the pre-project hydrologic conditions of temperature, rate, volume, and duration of storm water flow from the project site.

1.1.4 Army Sustainable Design and Development Memorandum

The Department of Army memorandum, *Sustainable Design and Development Policy Update*, October 27 2010, establishes the mandatory policy requirements for stormwater facility construction, regardless of funds source. The memorandum requires stormwater management to comply with EISA Section 438 and be consistent with the EPA Technical Guidance by incorporating LID. All master planning, project development and project site planning should follow guidance as detailed in ASHRAE (American Society of Heating, Refrigerating, and Air Conditioning Engineers) Standard 189.1 Section 5, and incorporate LID criteria, maximize use of the existing topography including slope, hydrology, flora and soils, and minimize site clearing and soil grubbing activities to the greatest extent possible.

1.1.5 LEED™ Construction Requirements

LEED is a green building certification system that was developed and is maintained by the U.S. Green Building Council (USGBC). The USGBC and LEED promote sustainable building and development practices through a suite of rating systems that recognize projects that implement strategies for better environmental and health performance.

> The LEED system provides numerous opportunities to use LID within the building footprint, the site plan, and the infrastructure to achieve the desired rating system level. This includes retaining runoff on-site, harvesting stormwater and runoff, and using green design techniques.

The Sustainable Design and Development Policy Update (described above in Section 1.1.4) requires that starting with the FY13 military construction program, all vertical construction will incorporate sustainable design principles into site selection, design and construction. All such construction, to include comprehensive building renovations, will be certified at the LEED-NC/MR SILVER level or higher from the Green Building Certification Institute (GBCI) and will be built following guidance as detailed in ASHRAE Standard 189.1. Integrating LID into the building envelope can help achieve several credits in the Sustainable Sites and Water efficiency categories. A detailed description of each of the credits and how to achieve them is included in Appendix A.

1.2 LOW IMPACT DEVELOPMENT PHILOSOPHY

LID is a rapidly growing concept in stormwater management that began in Prince George's County, Maryland, in the early 1990's. LID was developed to address runoff issues associated with new residential, commercial, and industrial suburban development in Prince George's County, to protect the natural resources of the county (Prince George's County, MD, 1999). LID presents a paradigm shift from treating stormwater as something to be moved quickly from the site to managing stormwater as a valuable resource on a site.

> LID Design for EISA Section 438
>
> LID design is based on "mimicking" the pre-project hydrology of a site by replicating the natural hydrology of the site to manage stormwater runoff. LID design utilizes the existing features on a site to plan for non-structural and structural LID BMPs.

Hydrology is an organizing principle that is integrated into site planning and even installation level planning. Development increases impervious areas and impacts natural hydrology, causing erosion, sedimentation, habitat loss, and water quality degradation. Managing stormwater through the use of integrated small scale LID BMPs provides for infiltration, filtration, evaporation, detention and storage to control stormwater runoff discharge, volume, frequency; maintain water temperatures; and provide pollution prevention opportunities. The primary goal of LID is to mimic a site's pre-development hydrology by managing stormwater runoff close to its source. LID integrated across a project site, and especially into installation level planning, brings about a decentralized and holistic approach to the management of stormwater runoff. Further detail about hydrologic impacts of development and LID can be found in Chapter 2.

1.2.1 LID Fundamentals

The LID approach is based on managing stormwater at the source by the use of planning techniques, known as non-structural LID BMPs, and microscale controls, known as structural LID BMPs, that are distributed throughout the site in order to maintain the pre-project hydrologic function of the site. This is unlike conventional approaches that typically convey and manage runoff in large ponds located at the base of drainage areas. Primary consideration must be given to these key elements:

> LID Principles
>
> - Maintain pre-project hydrologic functions through natural processes.
> - Maintain drainage patterns and watershed timing.
> - Minimize development impacts through non-structural practices.
> - Use distributed BMPs to meet hydrologic goals.

- Maintain pre-project hydrologic functions through preserving the natural landscape. Reduce land clearing and grading activities that impact the hydrology of the site. Direct runoff to natural areas and promote infiltration and recharge to natural features.

- Maintain drainage patterns and watershed timing. Provide a customized site-design that incorporates a holistic approach to ensure hydrologic function on site and within the watershed. Minimize development impacts through non-structural LID practices.

- Use distributed LID BMPs to meet hydrologic goals. Employ a series of small scale controls (micromanagement) on site that work together to alleviate hydrologic impacts.

- Maintain the small-scale controls to ensure efficiency and effectiveness in terms of both water quantity and quality functions, to include pollution prevention. Educate maintenance crew and the public about the functions of LID to ensure proper maintenance and the longevity of controls (UFC 3-210-10, 2010).

Understanding the goal and key elements of LID provides a background for planners, designers, engineers and stormwater managers to begin the site planning process to achieve stormwater management requirements.

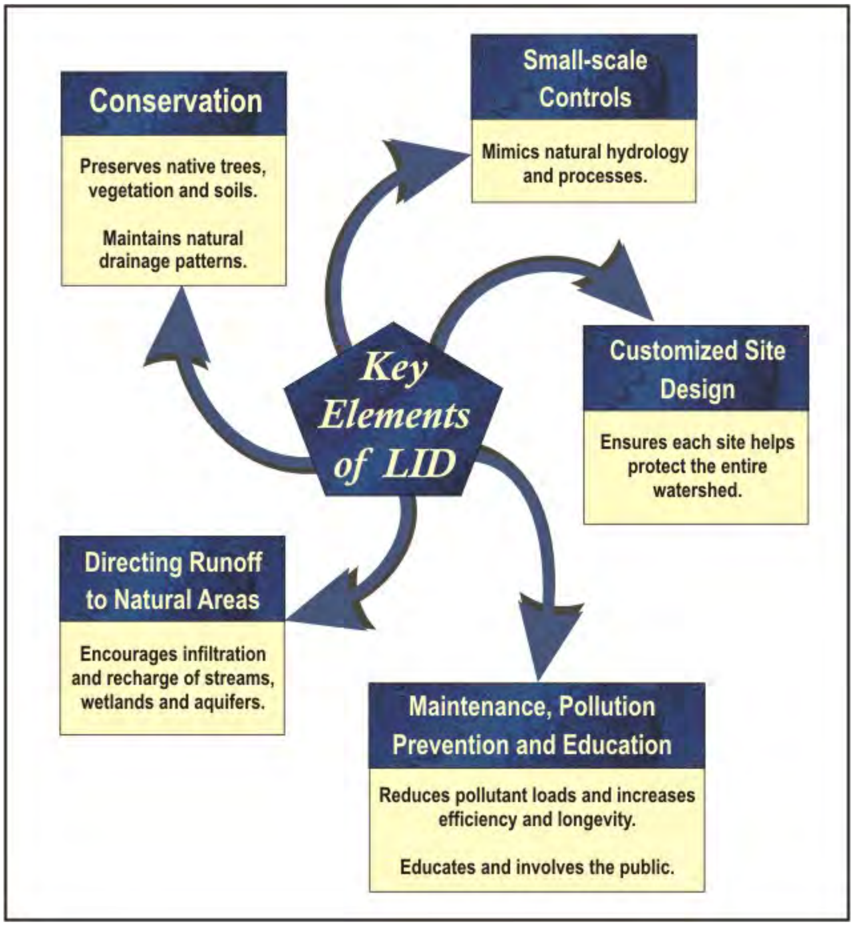

Figure 1-1. Key Elements of LID
(Source: Whole Building Design Guide, 2010)

1.2.2 Benefits of LID

There are a multitude of benefits from integrating LID into a project to include environmental, economic, social, water quality and watershed-scale benefits. Environmental benefits include preserving and protecting the natural ecosystem, protecting habitat, recharging groundwater, and protecting surface waters for both water quantity and water quality. Economic benefits include a reduced infrastructure and utility maintenance costs (streets, curbs, gutters, sidewalks, storm sewer), minimized cost for clearing and grading, and reduced permit fees (i.e., Clean Water Act requirements). Social benefits include reduced risk of flooding, aesthetically pleasing LID features, improved water quality for drinking and recreational water bodies, and increased groundwater recharge that may be used for drinking water. Improved water quality and maintaining the natural hydrology of the site prevents habitat degradation, lowers strain on stormwater infrastructure, preserves quality of drinking water, and lowers risk of floods.

1.3 STORMWATER MANAGEMENT REGULATIONS

> Army installations must comply with an often complex set of federal, state, and local regulations that can have very different goals, objectives, and requirements. LID can be used as a standalone strategy or in conjunction with other stormwater approaches to meet these requirements.

Army installations are subject to federal, state, and local stormwater management regulations for construction projects. The Clean Water Act (CWA) establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters. The National Pollutant Discharge Elimination System (NPDES) Section 402 program focuses on point and non-point sources of stormwater runoff and pollution. The state and local requirements for stormwater management vary throughout the country. Incorporating LID into construction projects and across Army installations may help meet the requirements set forth in the NPDES program.

1.3.1 National Pollutant Discharge Elimination System (NPDES)

As authorized by the Clean Water Act, the NPDES permit program controls water pollution by regulating point sources that discharge pollutants into waters of the United States. Point sources are discrete conveyances such as pipes or man-made ditches. Since nonpoint source runoff enters these conveyance systems, land development activities are covered as point sources. Industrial, municipal, and other facilities (Army facilities) must obtain permits if their discharges go directly to surface waters. The NPDES program is focused on a municipal program, construction program, and an industrial program, all of which present opportunities to include LID strategies and techniques. This program is administered by either the EPA or the State; many States have been authorized by EPA to operate the NPDES stormwater program.

For construction projects, construction site operators engaged in clearing, grading, and excavating activities that disturb one (1) acre or more, including smaller sites in a larger common plan of development or sale, are to obtain coverage under an NPDES permit for their stormwater discharges. Construction site operators are required to develop a Storm Water Pollution Prevention Plan (SWPPP) to include erosion and sediment controls. LID practices, non-structural and structural, can be used to manage stormwater quantity and quality during the construction process.

Municipal stormwater discharges and industrial discharges are also regulated through the NPDES program. Army facilities may require a permit for these activities as determined by

State regulations. LID practices can be employed to help meet the requirements of these stormwater permits by reducing stormwater discharge.

Table B-1 in Appendix B is a list of current state NPDES and regulatory programs.

1.3.2 Additional Regulations, Policies, and Resources

The planning, design, and maintenance of buildings, infrastructure, training areas, and open space is based on numerous policies, Army regulations (AR), Unified Facilities Criteria (UFC), and Public Works Technical Bulletins (PWTB). These documents provide the framework for Army construction, including LID BMPs. Listed below are some of the key documents that will be referenced in this Technical User Guide:

AR 420-1, Facilities Management
PWTB 200-1-62, Low Impact Development for Sustainable Installations
UFC 1-200-01, Design: General Building Requirements
UFC 2-100-01, Installation Master Planning
UFC 3-210-01A, Area Planning, Site Planning, and Design
UFC 3-210-05FA, Landscape Design and Planting Criteria
UFC 3-210-06A, Site Planning and Design
UFC 3-210-10, Low Impact Development
UFC 4-010-01, Design: DoD Minimum Antiterrorism Standards for Buildings
UFC 4-030-01, Sustainable Development

Appendix A includes further LID references.

1.4 ARMY STORMWATER MANAGEMENT USING LID

Incorporation of LID BMPs into the Army's construction program is the methodology used to meet requirements of Section 438 of EISA and DoD and Army policy regarding stormwater management. The Army Guidance, "Army Stormwater Management Using Low Impact Development", provides a framework for planning and implementing LID in Army construction projects.

2 LID BMPS FOR ARMY INSTALLATIONS

2.1 INTRODUCTION

The purpose of this chapter is to provide a background on hydrology and the impacts of development on the hydrologic cycle and what LID non-structural and structural BMPs can be employed to address hydrologic impacts on an Army installation.

The goal of LID and requirements of EISA Section 438 is to maintain the hydrologic function of the watershed by preserving or restoring the hydrologic function of the development project; therefore it is important to understand the natural hydrology of a site and the potential development impacts to the hydrologic cycle. The effects of development on a watershed can be extremely complex and often difficult to predict.

> As hydrology is the organizing principle, or foundation, of LID planning and design, it is important to understand the natural hydrologic cycle and how it is altered by development.
>
> LID requires an understanding of the land use and construction impacts on the hydrologic functionson the site and within the watershed to appropriately apply non-structural and structural LID BMPs.

Conventional approaches to stormwater management have been based on the application of prescriptive approaches that address peak flow rates from specific storm events to maintain watershed hydrologic functions and the use of BMPs to filter urban non-point source pollution. This management scheme does not address many of the other components of the hydrologic cycle that are essential to maintaining or restoring watershed hydrologic functions. LID design requires the designer to understand the hydrologic cycle, the impacts of construction on the elements of this cycle before the planning and design of any project, and how the application of BMPs protect and recreate the hydrologic processes.

2.2 THE HYDROLOGIC CYCLE

The hydrologic cycle is the continuous cycle of water between the atmosphere and the earth's surface and subsurface (Figure 2-1). Water condenses in the air and falls to the earth's surface as precipitation. Precipitation may be stored in lakes and oceans, runoff the ground surface to streams and open waterbodies, be intercepted by vegetation or infiltrate the ground to groundwater. Water returns to the atmosphere by evaporation from waterbodies and ground surfaces or by evapotranspiration from vegetation.

Each component of the hydrologic cycle functions differently across the country, within a watershed, and at the site level. Figure 2-2 depicts the annual precipitation across the country for the year 2010, showing great variability between the coasts, the plains, and the dry southwest regions of the country. Figure 2-3 is an illustration of the amount of runoff that results from the precipitation; runoff is the water from a precipitation event that is not lost to evaporation, interception, infiltration or transpiration. Runoff can occur as overland flow, subsurface flow, and saturated overland flow. When a surface is impervious or the surface storage of depressions in the landscape or the infiltration rate of the soil is exceeded, overland flow begins, also known as Horton overland flow (Figure 2-2). Runoff can also flow through the soils near the surface as subsurface flow. When the subsurface soils are saturated, the runoff can reemerge with the surface runoff and become saturated overland flow. Compare Figure 2-3 and Figure 2-4, and you will notice the variance between precipitation and runoff across the United States. The relationship between precipitation and runoff is not direct as precipitation may infiltrate soils and groundwater, be intercepted by vegetation or fall directly into a surface water. Areas with higher amounts of impervious surfaces and minimal opportunity for infiltration, evaporation and interception generally have greater runoff.

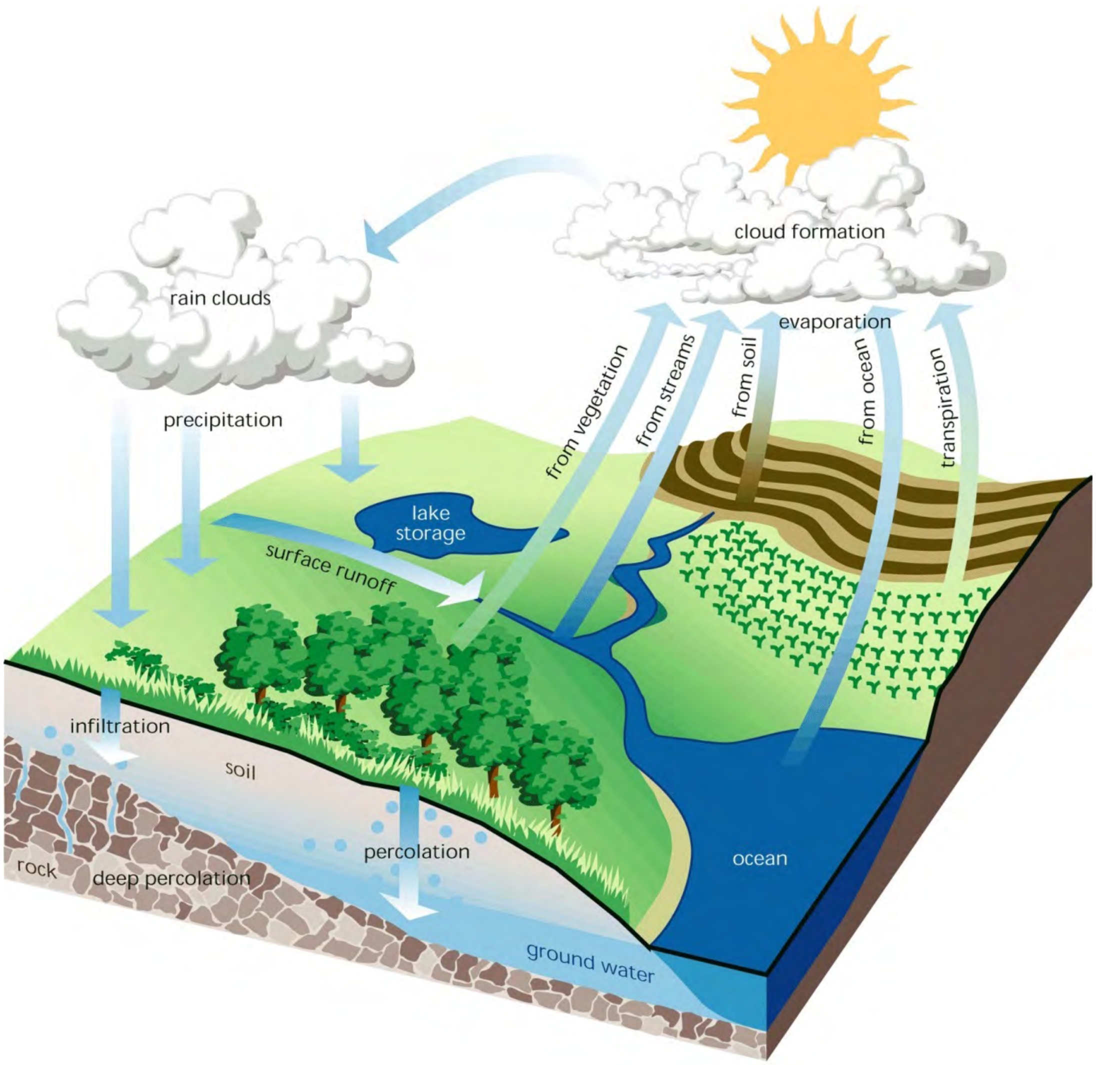

Figure 2-1. The Hydrologic Cycle
(Source: Federal Interagency Stream Restoration Working Group (FISRWG), 1998)

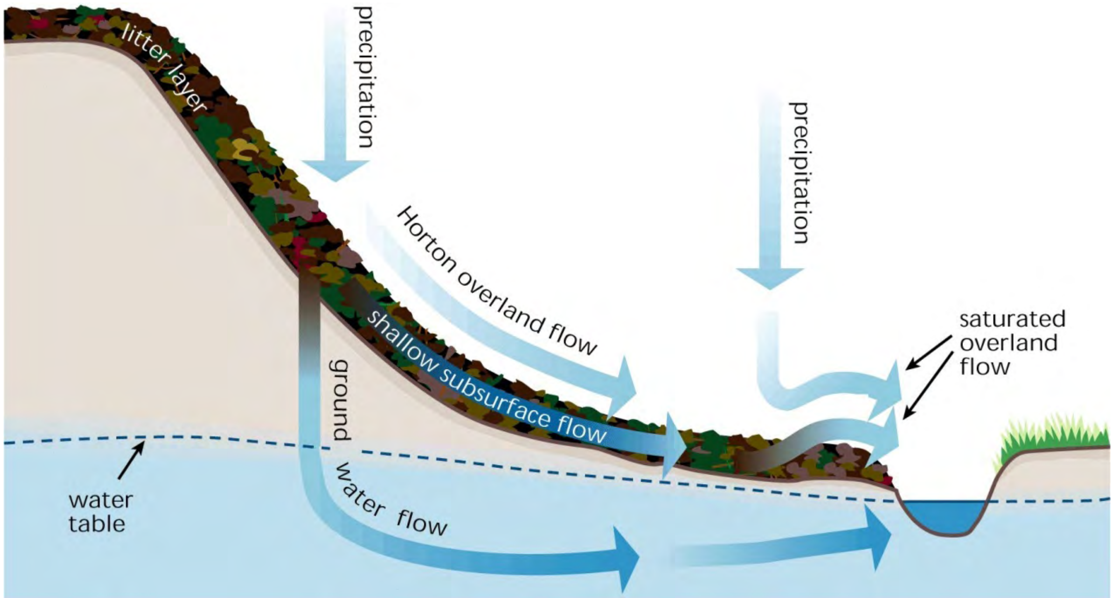

Figure 2-2. Stormwater Flow and Runoff
(Source: FISRWG, 1998)

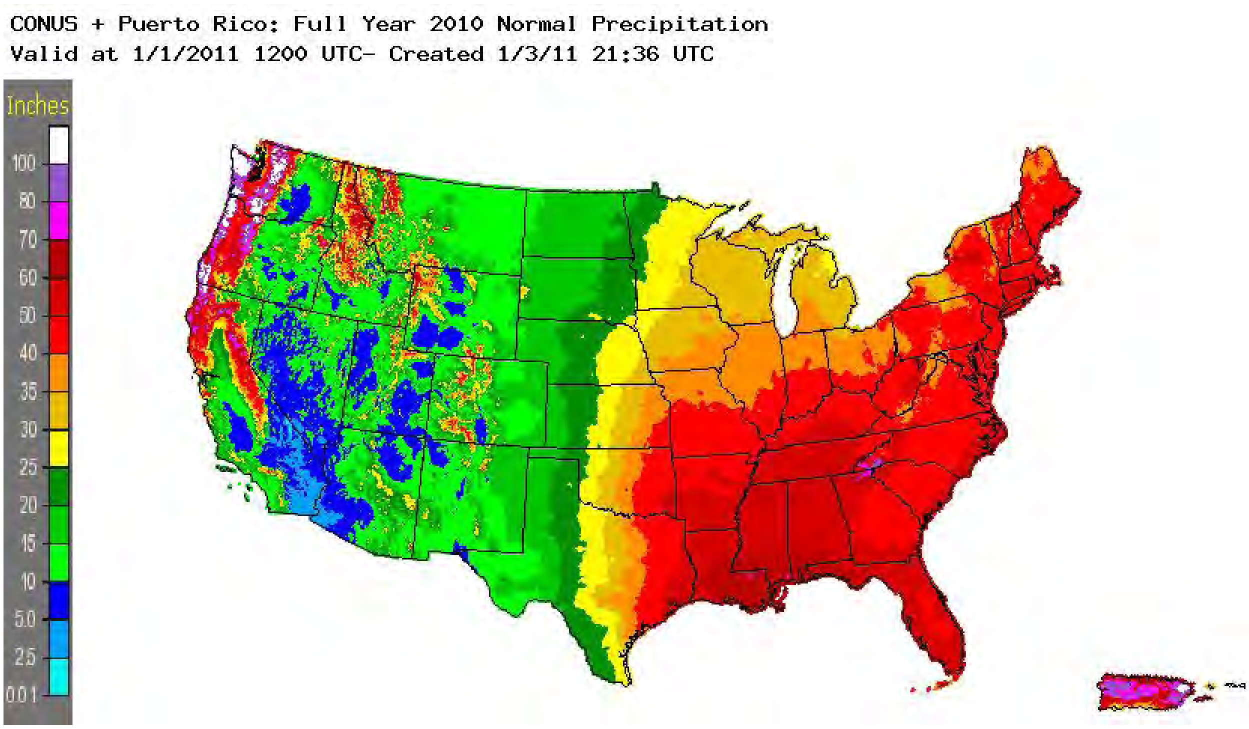

Figure 2-3. Representative Annual Precipitation
(Source: USGS, 2011)

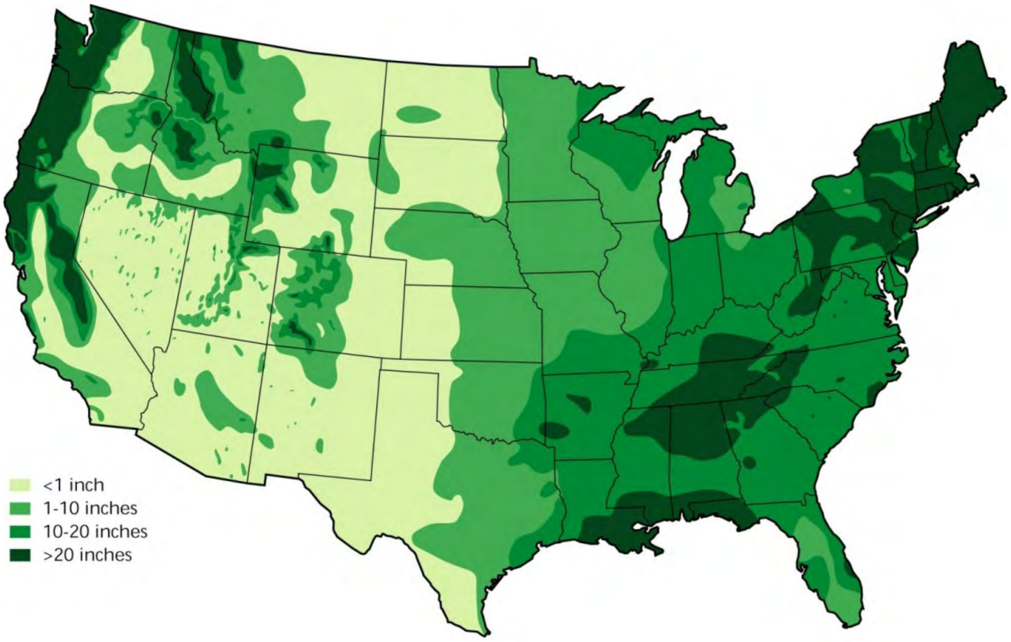

Figure 2-4. Average Annual Runoff in the Contiguous United States
(Source: USGS, 1986)

Precipitation that does not runoff the ground surface to a receiving waterbody, may be intercepted by vegetation or infiltrate soils (Figure 2-5). Water can be intercepted in the canopy of trees and shrubs, throughfall to the understory, or be absorbed by the soils to then be taken up by plant roots or infiltrate to groundwater. The infiltration rate, or capacity, of the soil is dependent on many factors including soil texture, porosity and storage capacity. Soils that are coarse textured, such as sandy soils, have a high porosity, while clays and silty soils have a low porosity. The infiltration rate is also dependent on the vegetative cover and the compaction of the soil. Plant roots help keep soil pores and pathways for infiltration open in soils. Once water enters the soil it can be held and taken up by plant roots or held in the soil through capillary action. If there is not sufficient moisture in the soil then the plants will wilt and likely expire because there is not enough water to meet the transpiration, or uptake, requirements of the plants. When the soil is saturated or when the water holding properties of the soil are exceeded, the water begins to flow downward until it meets a saturated zone of groundwater. It flows through shallow subsurface flow or into an aquifer and then moves, or flows, downgradient towards a water body, spring or seep.

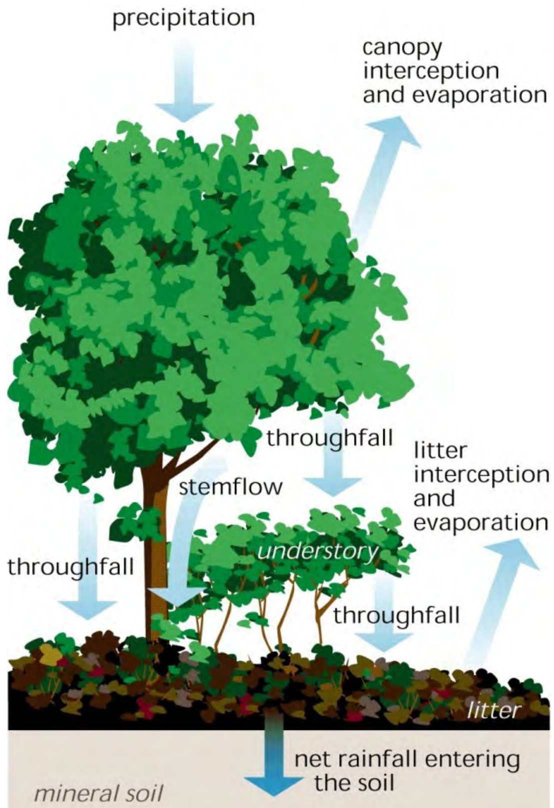

Figure 2-5. Precipitation Pathways in Forested Area
(Source: FISRWG, 1998)

Water returns to the atmosphere through evaporation and evapotranspiration. Evaporation can occur from surface areas, lakes, streams, and surface depressions. Evapotranspiration occurs when water is released from vegetation into the atmosphere, as seen in Figure 2-5.

2.2.1 Impacts to the Hydrologic Cycle from Development

A planner and designer must understand the regional, watershed, and site conditions in order to maintain the hydrologic functions for the project. The understanding of these changes to the hydrologic cycle, or relationships between losses and runoff, is critical when analyzing and design LID sites. When a site is developed and there is an increase in impervious surface, there is a shift in the hydrologic cycle: infiltration and evapotranspiration of precipitation decreases and stormwater runoff increases (Figure 2-6). Rainfall that once was absorbed and infiltrated into the ground now runs off the surface. The addition of impervious surfaces in the form of buildings, roadways, parking lots, and other impermeable surfaces reduces infiltration and increases runoff. These impervious surfaces are often "directly connected" to collection and conveyance systems (gutters, pipes, and channelized ditches) which compounds the problem.

> Land use cover change significantly affects the volume of runoff and the resultant energy of stormwater flows that will adversely affect receiving waters.

For example, the construction of a parking lot in a wooded area may require the removal of trees, grading and compaction of soil, and installation of impervious pavement for the lot. The impacts on the hydrologic cycle from altering pervious surface to impermeable surface includes reduce evapotranspiration, reduced infiltration and increase in runoff. The increased volume of the runoff will leave the site at higher velocities as pavement is smoother and offers less resistance than the forest floor. Peak flows within the area may be increased by the construction of channels and pipes that convey flows off of the site without allowing for infiltration or dissipation. Increased flow with higher velocities will erode stream channels downstream. The stormwater also conveys pollutants, such as oils and grease from roads and parking areas or fertilizers from lawns to the receiving waters.

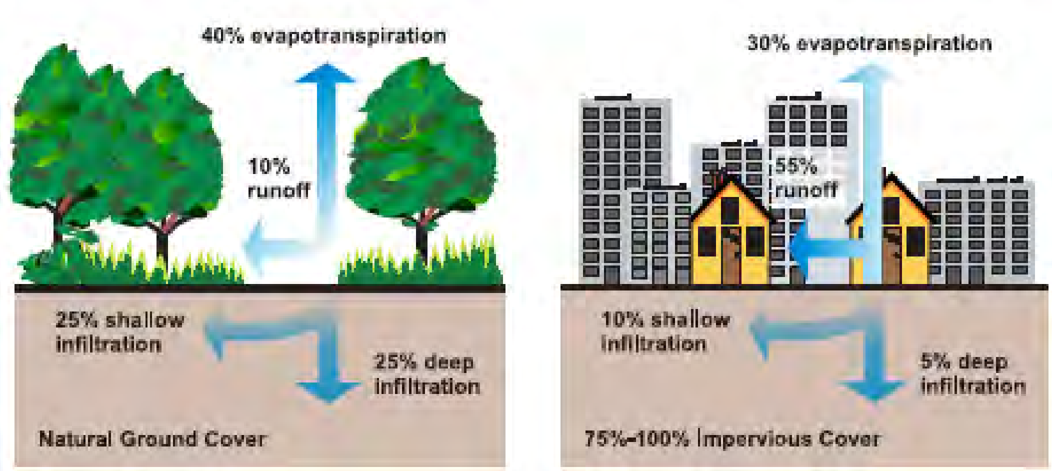

Figure 2-6. Pre-Development and Post-Development Hydrology
(Source: EPA Technical Guidance Manual, 2009)

All of these changes to the natural or pre-developed conditions have significant consequences to the environment. The traditional focus of stormwater management programs has been to remove the stormwater from the site at a high rate for flood risk management purposes. As a result, there are fewer opportunities for evapotranspiration, depressional storage, and infiltration, the volume of runoff. The combination of increased flow rates and volumes also has secondary impacts on the receiving stream system, such as erosion and sedimentation. Finally, the land use and other activities result in accumulation and washoff of pollutants from the surfaces, resulting in water quality degradation. The following sections will describe the impacts of development on the hydrologic cycle and water resources in detail.

2.2.1.1 Changes to Stream Morphology

Stream systems and channel geometry, or morphology, of the stream are the result of various forces acting on the channel over many years. Over time, channels should achieve a state of equilibrium from the forces and develop a "stable" cross section. These forces include flow volumes, durations, velocities, and sediment loads. A change in surrounding land use that alters the hydrology on a site by increasing impervious surface, changing flow patterns, or directing stormwater to a single outfall will increase volume and velocity of the stormwater discharge and increase sediment loads resulting in significant downstream effects (Figure 2-7). The increase in forces puts pressure on the channel to sustain the increased flows at higher velocities with higher sediment loads resulting in a change in channel morphology (physical shape and character of the stream), as described below:

- Stream Widening and Bank Erosion: Increased runoff and higher stream flow velocities strain the existing stream channel to convey the increased amount of flow due to the change in land use. More frequent small and moderate runoff events undercut and scour the lower parts of the streambank, causing the steeper banks to slump and collapse during larger storms. Higher flow velocities further increase streambank erosion rates. A stream can widen many times its original size from the increased bank erosion and scour due to post development runoff. The sediment from the bank can be transported downstream to an estuary, lake, wetlands, or other sensitive environmental area.
- Stream Downcutting: Higher flows will also cause downcutting of the streambed. Downcutting is a result of erosion occurring in the streambed itself, which results in a deeper stream. This causes instability in the stream profile, or elevation along a stream's flow path, which increases velocity and triggers further channel erosion both upstream and downstream.
- Loss of Riparian Tree Canopy: As streambanks are gradually undercut and slump into the channel, the trees that had protected the banks are exposed at the roots. This leaves them more likely to be uprooted during major storms, further weakening bank structure.
- Changes in the Channel Bed Due to Sedimentation: Due to channel erosion and other sources upstream, sediments are deposited in the stream as sandbars and other features, covering the channel bed, or substrate, with shifting deposits of mud, silt, and sand.
- Increase in Floodplain Elevation: The floodplain elevation of a stream typically increases following development in a watershed, due to higher peak flows. This problem is compounded by building and filling in floodplain areas, which can cause flood heights to rise even further. Property and structures that had not previously been subject to flooding may now be at risk.

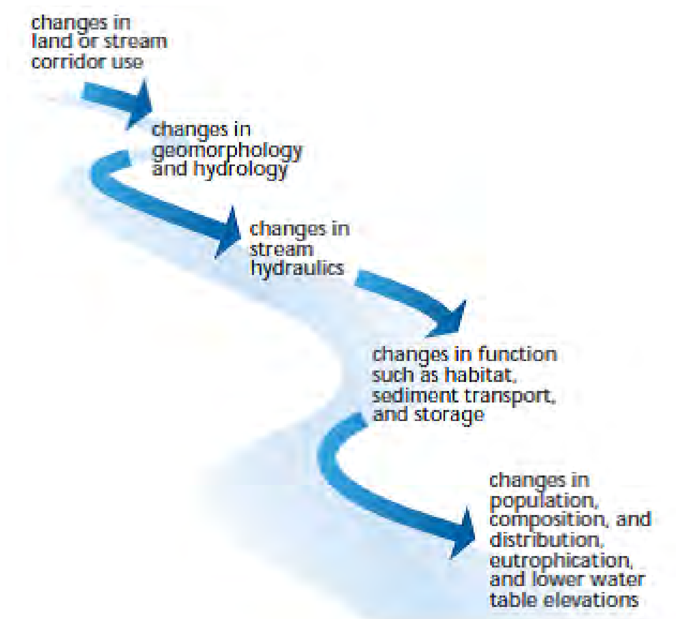

Figure 2-7. Impacts of Development on Stream Channels
(Source: FISRWG, 1998)

2.2.1.2 Impacts to Aquatic Habitat

The habitat value of streams diminishes due to development in a watershed, which impacts the integrity of stream hydrology and morphology. The following impacts on habitat can include:

- Degradation of Habitat Structure: Higher and faster flows can scour channels and wash away entire biological communities. Streambank erosion and the loss of riparian vegetation reduce habitat for many fish species and other aquatic life, while sediment deposits can smother bottom-dwelling organisms and aquatic habitat.

- Loss of Pool-Riffle Structure: Streams draining undeveloped watersheds often contain pools of deeper, more slowly flowing water that alternate with “riffles” or shoals of shallower, faster flowing water. These pools and riffles provide valuable habitat for fish and aquatic insects. As a result of the increased flows and sediment loads from urban watersheds, the pools and riffles are lost to erosion and sediment deposition and replaced with more uniform, and often shallower, streambeds that provide less varied aquatic habitat.

- Reduce Baseflows: Increased impervious cover reduces infiltration of rainfall to recharge groundwater. During drier periods in an undeveloped watershed, streams will have baseflow from groundwater and subsurface flow. With reduced infiltration to the groundwater, baseflows are reduced. This adversely affects in-stream habitats, especially during periods of drought.

- Increased Stream Temperature: Runoff from warm impervious areas, storage in impoundments, loss of riparian vegetation, and shallow channels can all cause an increase in temperature in urban streams. Increased temperatures can reduce dissolved oxygen levels and disrupt the food chain. Certain aquatic species can only survive within a narrow temperature range. Thermal problems are especially critical for many streams which straddle the borderline between coldwater and warmwater stream conditions.

When there is a reduction in various habitats and habitat quality, both the number and the variety, or diversity, of organisms (wetland plants, fish, macroinvertebrates, etc.) are also reduced. Sensitive fish species and other life forms disappear and are replaced by those organisms that are better adapted to the poorer conditions. The diversity and composition of the benthic, or streambed, community have frequently been used to evaluate the quality of urban streams.

2.2.1.3 Water Quality Impacts

Urban stormwater runoff can generate nonpoint source pollution, which is considered the primary cause of water quality impairment. Development and impervious areas concentrate and increase the amount of nonpoint source pollutants, as there is limitied opportunity for filtration and absorption of pollutants as seen in pervious and vegetated areas. As stormwater runoff moves across the land surface, it picks up and carries away both natural and human-made pollutants, depositing them into streams, rivers, lakes, wetlands, coastal waters and marshes, and underground aquifers. Some of the more common water quality impacts are as follows:

- Reduced Oxygen in Streams: As organic matter (leaves, grass clippings, pet waste) is washed off and transported by stormwater, dissolved oxygen levels in receiving waters can be rapidly depleted. The decomposition process of organic matter uses dissolved oxygen (DO) in the water, which is essential to fish and other aquatic life. If the DO deficit is severe enough, fish kills may occur and stream life can weaken and die. In addition, oxygen depletion can affect the release of toxic chemicals and nutrients from sediments deposited in a waterway. Note: there are also a number of non-stormwater discharges of organic matter to surface waters, such as sanitary sewer leakage and septic tank leaching.

- Nutrient Enrichment: Runoff from urban watersheds contains increased nutrients such as nitrogen or phosphorus compounds. Increased nutrient levels are a problem as they promote weed and algae growth in lakes, streams, and estuaries. Algae blooms block sunlight from reaching underwater grasses and deplete oxygen in bottom waters. In addition, nitrification of ammonia (a compound of nitrogen) by microorganisms consumes dissolved oxygen and forms nitrates that can contaminate groundwater supplies. Sources of nutrients in the urban environment include washoff of fertilizers and vegetative litter, animal wastes, sewer overflows and leaks, septic tank seepage, detergents, and the dry and wet fallout of materials in the atmosphere.

- Microbial Contamination: The level of bacteria, viruses, and other microbes found in urban stormwater runoff often exceeds public health standards for water contact recreation such as swimming and wading. Microbes can contaminate shellfish beds, limiting their harvest for both wildlife and human consumption, and increase the costs for treating drinking water. The main sources of these contaminants are sewer overflows, septic tanks, pet waste, and excessive urban wildlife such as pigeons, waterfowl, squirrels, and raccoons.

- Hydrocarbons: Oils, greases, and gasoline contain a wide array of hydrocarbon compounds, some of which have shown to be carcinogenic, tumorigenic, and mutagenic in certain species of fish. In addition, large quantities of oil can impact drinking water supplies and affect recreational use of waters. Oils and other hydrocarbons are washed off roads and parking lots, primarily due to engine leakage from vehicles. Other sources include the improper disposal of motor oil in storm drains and streams, spills at fueling stations, and restaurant grease traps.

- Other Toxic Materials: Besides oils and greases, urban stormwater runoff can contain a wide variety of other toxicants and compounds including heavy metals such as lead, zinc, copper, and cadmium, and organic pollutants such as pesticides, PCBs, and phenols. These contaminants are of concern because they are toxic to aquatic organisms and can bioaccumulate in the food chain. In addition, they also impair drinking water sources and human health. Many of these toxicants accumulate in the sediments of streams and lakes. Sources of these contaminants include industrial and commercial sites, urban surfaces such as rooftops and painted areas, vehicles and other machinery, improperly disposed household chemicals, landfills, hazardous waste sites, and atmospheric deposition.

- Sedimentation: Erosion from construction sites, exposed soils, street runoff, and streambank erosion are the primary sources of sediment in urban runoff. Excessive sediment can be detrimental to aquatic life by interfering with photosynthesis, respiration, growth, and reproduction. Sediment particles transport other pollutants that are attached to their surfaces including nutrients, trace metals, and hydrocarbons. High turbidity due to sediment increases the cost of treating drinking water and reduces the value of surface waters for industrial and recreational use. Sediment also fills ditches and small streams and clogs storm sewers and pipes, causing flooding and property damage. Sedimentation can reduce the capacity of reservoirs and lakes, block navigation channels, fill harbors, and silt estuaries.

- Increased Stream Temperatures: As runoff flows over impervious surfaces such as asphalt and concrete, it increases in temperature before reaching a stream or pond. Water temperatures are also increased due to shallow ponds and impoundments along a watercourse as well as fewer trees along streams to shade the water. Since warm water can hold less dissolved oxygen than cold water, this “thermal pollution” further reduces oxygen levels in depleted urban streams. Temperature changes can severely disrupt certain aquatic species, such as trout and stoneflies, which can survive only within a narrow temperature range, as described above in Section 2.2.1.2.

2.3 INTRODUCTION TO NON-STRUCTURAL AND STRUCTURAL LID BMPS

LID BMPs can be employed to alleviate the pressures of development on a receiving water body by slowing flows, supporting infiltration or small-scale temporary storage of increased stormwater runoff volume, and filtrating stormwater runoff to reduce pollutant loads. LID BMPs include a variety of non-structural and structural techniques that can be used individually or collectively to maximize stormwater management goals, particularly for maintaining pre-development hydrology with regard to temperature, rate, volume and duration of flow. This section provides a toolbox of non-structural and structural LID BMPs for use on Army installations. The applicability, use, design features, and maintenance of the LID BMPs described below are extremely dependent on the climatic conditions, site conditions, land use and installation requirements, such as Anti-Terrorism Force Protection (ATFP) requirements. When developing a plan for a site specific project, each installation will select LID BMPs that are appropriate for the climate and site conditions and meet the regulatory requirements for the project, including EISA Section 438, with consideration of watershed protection goals.

> Structural and Non-Structural LID Practices
>
> - Non-Structural LID practices are planning and site design strategies that minimize development impacts.
> - Structural LID practices are BMPs that are distributed throughout the site to manage the volume and rate of runoff and to address water quality requirements.

2.4 LID NON-STRUCTURAL BMPS

The primary goal of non-structural LID BMPs is to prevent stormwater runoff from the site. Non-structural LID BMPs take broader planning and design approaches, which are less "structural" in their form and focus on conservation and minimizing impacts. Many non-structural LID BMPs apply to an entire site and often to an entire community and can even be applied to the Installation Master Plan. In doing so, LID places an emphasis on non-structural stormwater management measures, seeking to maximize their use prior to utilizing structural LID BMPs. A definition of each of non-structural LID BMPs, their purpose, and potential use on an Army installation are described below.

2.4.1 Minimize Total Disturbed Area

2.4.1.1 Definition

Minimizing the total disturbed area for a construction project is a site planning strategy that is designed to reduce the amount of disturbance to the site from the building footprint and orientation itself, including roads and parking lots, to ground disturbed during construction. This applies to the final site design and the construction phasing of the project.

2.4.1.2 Purpose

This strategy reduces the change in land cover and compaction of existing open space so the amount of change in the hydrologic function of the site is limited. This strategy will preserve as much of the hydrology of the site as possible.

2.4.1.3 Use on Army Installation

Minimizing total disturbed area for a project can be accomplished in residential, commercial, industrial and recreational areas, with limited applications for some training areas, ultra urban, retrofit and highway or road projects (Table 2-1). This practice may have limited utility on small or infill sites. By incorporating this non-structural BMP during site planning, reduced grading and ground disturbance as well as the preservation of existing vegetation can be incorporated into the project, which will result in less impact to the hydrologic function of the site. Areas of high value, such as high infiltration soils or mature vegetation, should be undisturbed to maintain the site hydrology. While minimizing the amount of disturbed area, also consider area where potential structural LID BMPs may be used. ATFP requirements, including standoff distances for parking and roadways and unobstructed views clear of vegetation, must be followed, which may require additional clearing and limit the amount of space that can be left undisturbed.

This planning activity can greatly reduce impacts of construction and to maintain the hydrologic function of the site in terms of both stormwater quantity and quality. There are also aesthetic benefits that may include the preservation of green corridors and natural features around an installation. These benefits come with potentially reduced construction costs by reducing the amount of construction activities that are associated with disturbing land, such as grading, tree clearing and even stockpiles or staging areas. This practice, however, may have increased costs for construction phasing. Costs savings may also be realized by the reduction in maintenance of cleared areas and the reduced need for BMPs to mitigate hydrologic changes. Photo 2-1 shows the reduction of clearing around a building to reduce the disturbed area and protect adjacent woodlands.

Table 2-1. Minimize Total Disturbed Area

Applications		**Stormwater Quantity Functions**	
Residential	Yes	**Volume**	High
Commercial	Yes	**Groundwater Recharge**	High
Ultra Urban	Limited	**Peak Rate**	High
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Limited	**TSS**	High
Highway/Road	Limited	**TP**	High
Recreational	Yes	**NO3**	High
Training Area	Limited	**Temperature**	High
Additional Considerations			
Cost		Low	
Maintenance		Low	
Winter Performance		High	

(Adapted from: South East Michigan Council of Governments (SEMCOG), 2008)

Photo 2-1. Minimal Disturbance to Protect Adjacent Woodlands
(Source: SEMCOG, 2008)

2.4.2 Preserve Natural Flow Pathways and Patterns

2.4.2.1 Definition

Preserving natural flow patterns and pathways during and after construction is a non-structural LID BMP. This is a site planning strategy to maintain existing drainage patterns, areas of sheet flow, areas of the site that have depression storage, existing grades, ditches, and channels as much as possible.

2.4.2.2 Purpose

Maintaining flow patterns is a critical non-structural practice. It is used to maintain watershed timing of runoff, peak runoff discharge rates and runoff volume to these areas so that the increased energy from the runoff does not erode the area to be protected. The length, slope, and surface characteristics of the flowpath should be maintained to the greatest extent possible in order to reduce the peak runoff time during a storm event. The strategy will also help maintain flows to sensitive areas, such as wetlands, soils with high infiltration rates, or upland vegetated areas that are sensitive to changes in hydrology.

2.4.2.3 Use on Army Installations

Protecting natural flow pathways and patterns can be incorporated into most projects and land use areas, with the exception of ultra urban areas that may already have or require stormwater infrastructure (Table 2-2). This site planning strategy can also be applied during installation master planning as it can be used to reduce the need for large scale drainage infrastructure to accommodate concentrated flows and can help preserve the capacity of existing systems by maintaining flow patterns. Land buffers around the larger drainage courses may be required to preserve natural flow patterns as some larger natural streams adjust their pathways horizontally to accommodate flows from urbanization or as a natural process. The preservation of natural flow pathways and patterns also helps protect riparian corridors and habitat areas, provides open space, and can increase the green infrastructure aesthetics of an installation. If protection of natural flow pathways and patterns are not an option or isn't sufficient for stormwater management goals, modify and/or increase these drainage flow paths.

Maintaining natural flow pathways and patterns can lessen the need for increased stormwater infrastructure and large stormwater BMPs, which is a cost savings from conventional stormwater management systems. When natural flow pathways are protected and the hydrology of the surrounding area is not significantly altered by land use changes, maintenance costs should be relatively minimal. Caution must be taken if discharge to these features is increased, which can cause erosion, downcutting, and degradation of the natural flow pathway. Periodic inspections of the pathways should assess erosion, bank stability, sediment and debris accumulation, and vegetative conditions, including the presence of invasive species to ensure the continued function of the flow pathways. Photo 2-2 shows grading to a natural area of shallow concentrated flow. The disturbed area is planted with a tall grass that roughens the surface and absorbs runoff so that the energy and volume of runoff to the natural system is reduced.

Table 2-2. Preserve Natural Flow Pathways and Patterns

Applications		**Stormwater Quantity Functions**	
Residential	Yes	**Volume**	Low/Med
Commercial	Yes	**Groundwater Recharge**	Low
Ultra Urban	No	**Peak Rate**	Med/High
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Yes	**TSS**	Low/Med
Highway/Road	Yes	**TP**	Low/Med
Recreational	Yes	**NO3**	Low
Training Area	Yes	**Temperature**	Low
Additional Considerations			
Cost		Low	
Maintenance		Low/Med	
Winter Performance		Low/Med	

(Adapted from: SEMCOG, 2008)

Photo 2-2. Native Prairie Vegetation in Natural Flow Pathway
(Source: SEMCOG, 2008)

2.4.3 Protect Riparian Buffer Areas

2.4.3.1 Definition

Riparian buffers are vegetated areas, natural or re-established, along water courses that protect the integrity of the habitat and hydrologic functions of that water course.

2.4.3.2 Purpose

The purpose of protecting riparian buffer areas is to protect the habitat functions, hydrologic functions, and physical integrity of the receiving waters. This includes sensitive wetland areas and floodplains. Width and type of vegetation of the riparian buffer varies with climate, region, topography, watershed hydrology, surrounding land uses and several other factors. Riparian buffers protect the receiving waters by dissipating energy and slowing the velocity of runoff, reducing the temperature of runoff and the stream by providing shade, and filtering sediments and nutrient loads from overland runoff.

2.4.3.3 Use on Army Installations

Protection of riparian buffers can be applied during the project planning phase in most land use areas, though may be limited in circumstances where land for development and mission requirements is inadequate (Table 2-3). The optimal width of a riparian buffer varies by region, site conditions, and the condition of the receiving water body for maximum stormwater management and water quality benefits. The development footprint of the project area may extend into a riparian buffer area, which may limit the application of this LID BMP. Several states and counties, however, require the conservation of a buffer for certain water bodies, further protecting the integrity of the natural hydrology of a site and the receiving water body.

In some circumstances, a riparian buffer may need to be revegetated or re-established where it may have degraded due to changes in adjacent land uses. Flows from storm drain systems and channels can be disconnected into the buffer and/or lessened with integration of structural LID BMPs (see Section 2.5), so that the increased energy and thermal loading from the stormwater infrastructure can be dissipated by the vegetation. Photo 2-3 shows a buffer that has been preserved in an agricultural setting. Protecting the riparian buffer area is a low cost BMP that provides significant water quality benefits and preserves the hydrologic function of the site and the receiving water bodies (Table 2-3).

Table 2-3. Protect Riparian Buffer Areas

Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	Low/Med
Commercial	Yes	**Groundwater Recharge**	Low/Med
Ultra Urban	Limited	**Peak Rate**	Low/Med
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Yes	**TSS**	High
Highway/Road	Limited	**TP**	High
Recreational	Yes	**NO3**	Medium
Training Area	Yes	**Temperature**	High
Additional Considerations			
Cost	Low/Med		
Maintenance	Low		
Winter Performance	High		

(Adapted from: SEMCOG, 2008)

Photo 2-3. Riparian Buffer Area
(Source: Iowa Pathways)

2.4.4 Protect Sensitive Areas

2.4.4.1 Definition

Natural areas with high habitat value and function, water supply areas, areas of special geologic concern, culturally significant areas, and natural areas with high stormwater management functions, such as sandy soils, must be identified and protected from pollutants and erosive flows associated with runoff from developed areas. Other areas include, but are not limited to, riparian buffers, wetlands, hydric soils, floodplains, steep slopes, woodlands, and other valuable habitat, such as critical habitat and rare, threatened and endangered species habitat.

2.4.4.2 Purpose

The overarching objective of LID is to accommodate development while protecting the natural resources and function of the site. Avoiding impacts to especially sensitive natural resources minimizes the loss of ecological and hydrologic function on the site. The loss of the ecological and hydrologic functions of many sensitive areas cannot be completely mitigated or replaced because of their complexity.

2.4.4.3 Use on Army Installation

Protection of sensitive areas can be accomplished in most land use areas (Table 2-3). Sensitive areas should be identified and mapped early in the planning process to avoid impacts. Small or infill sites may have limited ability to avoid disturbance of sensitive areas. Federal and local regulations may prohibit disturbance of many of these sensitive areas, such as wetlands, habitat for endangered species, and riparian areas. Design and construction that affects sensitive areas can severely impact project schedules due to regulatory requirements. Protecting sensitive areas is a low cost BMP that provides significant water quality benefits and preserves the hydrologic function of the site and the receiving water bodies (Table 2-3). Photo 2-4 shows pathways and a picnic area designed around an existing wetland and forested area. The design shows that the area can be developed while protecting and taking advantage of the natural features.

Table 2-4. Protect Sensitive Areas

Applications		**Stormwater Quantity Functions**	
Residential	Yes	**Volume**	Low/Med
Commercial	Yes	**Groundwater Recharge**	Low/Med
Ultra Urban	Limited	**Peak Rate**	Low/Med
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Yes	**TSS**	High
Highway/Road	Limited	**TP**	High
Recreational	Yes	**NO3**	Medium
Training Area	Yes	**Temperature**	High
Additional Considerations			
Cost		Low/Med	
Maintenance		Low	
Winter Performance		High	

(Adapted from: SEMCOG, 2008)

Photo 2-4. Protection of Existing Native Woodlands and Wetlands, Kalamazoo, MI
(Source: Fishbeck, Thompson, Carr & Huber, Inc.)

2.4.5 Cluster Development

2.4.5.1 Definition

Cluster development refers to the concentrated development of buildings and residential lots on a portion of a larger site through avoidance of sensitive areas and reducing the lot size or reconfiguring the lot footprint.

2.4.5.2 Purpose

Cluster development is a technique that allows the site planner to avoid sensitive areas, focus development on less permeable soils, and maintain natural drainage patterns.

2.4.5.3 Use on Army Installation

Cluster development is most commonly used for residential development and some commercial areas, with limited application in ultra urban, industrial, recreational areas and training areas (Table 2-5). It is primarily achieved by decreasing lot sizes, which allows residences to be constructed in close proximity to one another, preserving open space for conservation. By clustering development, the total disturbed area and total impervious area will be minimized, sensitive and natural resource areas may be conserved and the natural hydrologic function of the site can be preserved. This will minimize the need for stormwater infrastructure and large conventional stormwater BMPs. Clustering reduces the amount of land that must be cleared and graded during construction, and reduces the amount of open lawn that must be maintained, which is a cost savings. Photo 2-5 shows a cluster development designed to preserve existing woodlands and wetlands.

Table 2-5. Cluster Development

Applications		Stormwater Quantity Functions	
Residential	Yes	Volume	High
Commercial	Yes	Groundwater Recharge	High
Ultra Urban	Limited	Peak Rate	High
Industrial	Limited	**Stormwater Quality Functions**	
Retrofit	No	TSS	High
Highway/Road	No	TP	High
Recreational	Limited	NO3	High
Training Area	No	Temperature	High
Additional Considerations			
Cost		Low	
Maintenance		Low/Med	
Winter Performance		High	

(Adapted from: SEMCOG, 2008)

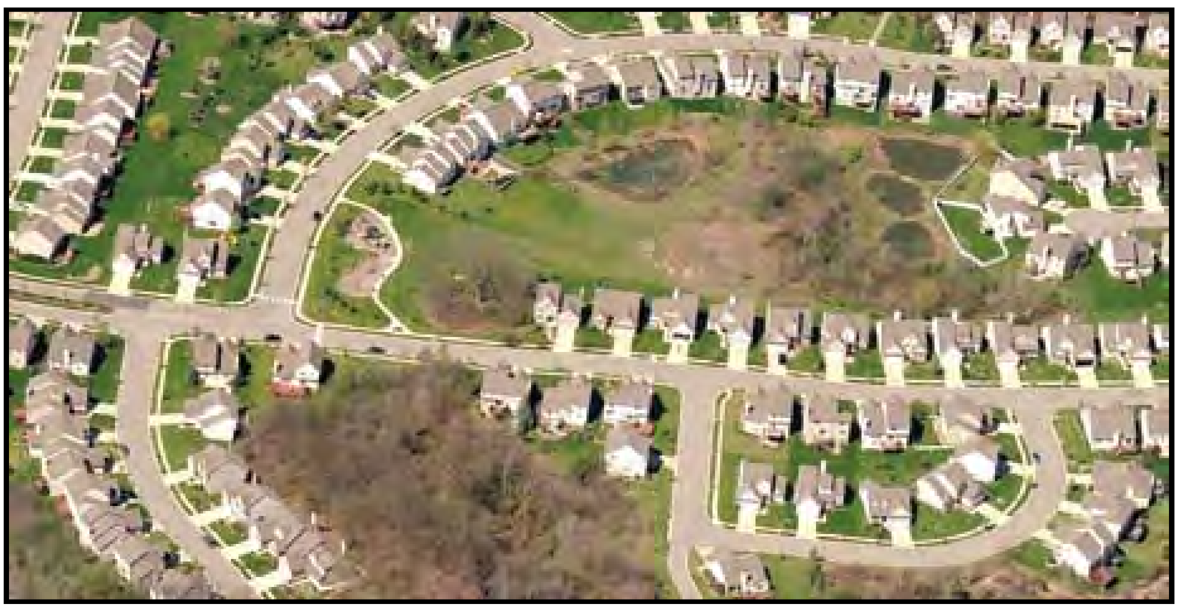

Photo 2-5. Aerial View of Cluster Development in Ann Arbor, MI
(Source: Atwell LLC)

2.4.6 Minimize Soil Compaction

2.4.6.1 Definition

Soil compaction occurs during the land development process when heavy construction vehicles are used in undeveloped areas, soils are cleared or graded, and when materials are stockpiled in staging areas. Soil compaction can also occur from activities such as heavy equipment traffic, high pedestrian use, and even heavy rainfalls. The porous spaces in the soils that hold air and water and allow for water to infiltrate through the soils are consolidated when compacted, resulting in reduced water storage and infiltration, which leads to increased runoff from the soil surface and even reduced plant growth. Minimizing soil compaction is the practice of preventing loss of soil structure and function through avoiding and minimizing ground disturbance during construction and land use activities.

2.4.6.2 Purpose

Minimizing soil compaction will prevent the loss of water storage and infiltration capacity of the soils, an important process of the hydrologic function of a site and a watershed. Water that is not stored or infiltrating the soils will runoff the soil surface, greatly reducing groundwater recharge, pollutant removal opportunities, increasing the volume of discharge to the receiving stream, and space for healthy plant root growth (see Section 2.2.1 for further discussion of impacts).

2.4.6.3 Use on Army Installation

Soil compaction can be minimized at any land development site, with limited applicability where land use requires impervious surfaces such as a road or ultra urban area (Table 2-6). During the site planning process for construction and earth moving activities, the areas of heavy equipment traffic and use, stockpiles and grading should be minimized. Plans should clearly identify "no disturbance areas", where existing soils and vegetation are to be preserved; "minimal disturbance areas", where existing vegetation may be removed and light traffic is permitted, but soils and vegetation are to be restored immediately following construction; and "construction traffic areas", which are to be cleared and graded, and are appropriate sites for construction vehicles and storage areas. Areas for parking personal vehicles and construction vehicles should also be identified to avoid soil compaction. After construction, disturbed soils can be partially restored by aeration and the addition of compost and other soil amendments. Minimizing soil compaction is a low cost BMP that provides significant benefits for stormwater quantity and quality functions. Photo 2-6 shows a construction site where heavy equipment is limited to areas designated for clearing and grading and adjacent areas are left undisturbed.

Table 2-6. Minimize Soil Compaction

Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	Med/High
Commercial	Yes	**Groundwater Recharge**	Med/High
Ultra Urban	Limited	**Peak Rate**	Low/Med
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Limited	**TSS**	Med/High
Highway/Road	Limited	**TP**	Med/High
Recreational	Yes	**NO3**	Low
Training Area	Yes	**Temperature**	Med/High
Additional Considerations			
Cost	Low/Med		
Maintenance	Low		
Winter Performance	Low/Med		

(Adapted from: SEMCOG, 2008)

Photo 2-6. Construction Site Disturbance Showing Grading and Soil Compaction.
(Source: SEMCOG, 2008)

2.4.7 Reduce Impervious Surfaces

2.4.7.1 Definition

Reducing impervious surfaces includes minimizing the area of streets, parking lots, and driveways as well as the surface area of the building roof. Disconnecting large areas of imperviousness or contiguous developed areas with parcels of perviousness is also a consideration when reducing impervious surfaces. Greater amount of impervious surface leads to higher volumes of stormwater runoff, as there is less opportunity for stormwater to infiltrate the ground surface.

2.4.7.2 Purpose

Reducing impervious surfaces decreases stormwater runoff volume and increases opportunities for infiltration and evapotranspiration. Breaking up large areas of imperviousness with pervious areas, also called disconnection, provides an opportunity to reduce runoff velocity, promote settling of suspended pollutants, and reduce runoff volume by promoting storage and infiltration.

2.4.7.3 Use on Army Installations

Reducing impervious surfaces can be applied in most land use areas; streets and parking lots are typically the largest impervious component in most developments (Table 2-7). Road widths should be reduced to the minimum legally required or necessary for anticipated use. Street lengths can be reduced by clustering development. Parking lot sizes can be reduced by application of alternative lot layouts and stall geometries, such as the angled parking and parallel parking shown in Photo 2-7, or shared parking. Not all angled parking can reduce parking lot sizes and may result in fewer parking spaces; the planner and designers should consider various degrees for angled parking to determine what best meets the needs for the project. Use of these techniques can result in reduced material cost, reduced maintenance requirements, and reduced need for stormwater management controls. Impervious cover can be further reduced by using permeable paving materials in driveways, parking stalls, and other low-traffic areas; this structural BMP is further discussed in Section 2.5.4.

Building roofs are another opportunity to reduce impervious surface and disconnect impervious surfaces, by installing green roofs or directing downspouts to pervious areas such as bioretention areas, as shown in Photo 2-8. Existing buildings can be retrofitted to convey runoff from rooftop downspouts to nearby vegetated areas. Setbacks should be observed to prevent infiltrating runoff from flooding basements or undermining foundations. In planning new developments, care should be taken to avoid creating situations that allow rooftop runoff to flow directly to paved areas and then to gutters or storm drains. This can be avoided by grading the site to encourage sheet flow from paved areas to adjacent pervious areas.

Table 2-7. Reduce Impervious Surfaces

Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	High
Commercial	Yes	**Groundwater Recharge**	High
Ultra Urban	Limited	**Peak Rate**	High
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Limited	**TSS**	Medium
Highway/Road	Yes	**TP**	Low
Recreational	Yes	**NO3**	Low
Training Area	Limited	**Temperature**	Medium
Additional Considerations			
Cost		Low	
Maintenance		Low	
Winter Performance		High	

(Adapted from: SEMCOG, 2008)

Photo 2-7. Use of Reduced Parking Footprint in On Street Areas
(Source: Institute of Transportation Engineers)

Photo 2-8. Downspout Disconnection to a Vegetated Area
(Source: Prince George's County, MD Department of Environmental Resources)

2.4.8 Site Fingerprinting

2.4.8.1 Definition

Site fingerprinting is a technique used to minimize site disturbance during construction. The smallest possible disturbance area is delineated and flagged to prevent traffic or materials storage on areas designated for conservation.

2.4.8.2 Purpose

Site fingerprinting preserves existing trees and soils, maintaining as much of the existing hydrology and infiltration capacity of the site as possible.

2.4.8.3 Use on Army Installation

Site fingerprinting can be accomplished during construction on most sites with limited application on ultra urban and highway sites (Table 2-8). The size of the construction envelope can be minimized by limiting planned disturbance areas to the developed footprint and necessary equipment access routes. Material stockpiles should be located within the development envelope and soil and vegetation protection areas should be clearly delineated and flagged to prevent inadvertent construction traffic, as seen in Photo 2-10. Existing topography and drainage should be maintained to reduce hydrologic impacts.

Table 2-8. Site Fingerprinting

Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	Low/Med
Commercial	Yes	**Groundwater Recharge**	Low/Med
Ultra Urban	Limited	**Peak Rate**	Low/Med
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Yes	**TSS**	High
Highway/Road	Limited	**TP**	High
Recreational	Yes	**NO3**	Medium
Training Area	Yes	**Temperature**	High
Additional Considerations			
Cost		Low/Med	
Maintenance		Low/Med	
Winter Performance		High	

(Adapted from: SEMCOG, 2008)

Photo 2-9. Protection of Vegetation on a Construction Site
(Source: SEMCOG, 2008)

2.5 STRUCTURAL LID BMPS

LID Structural BMPs

- Small scale controls that mimic natural processes are used to restore and maintain hydrology.
- The sizing and location of practices is often iterative. Matching practices with the appropriate land uses is essential.

Non-structural LID BMPs should be employed to the maximum extent possible so structural LID BMPs can then be implemented to restore or maintain site hydrology where impacted. The planning and selection of BMPs is performed after the amount of disturbance to the site is minimized by maximizing non-structural LID BMPs in site planning. The location and selection of the practice is often iterative in nature. The variability of site factors (e.g. climatic conditions, drainage area, runoff volume and rate, land use, maintenance, force protection requirements, etc.) influence the location, size, and operation of the BMPs. The stormwater management goal or objective for the site must also be considered when selecting a structural LID BMP as some perform multiple functions for water quantity and water quality.

The following sections describe structural LID BMPs and include a definition, purpose and application or use on an Army installation for each BMP. Detailed information on construction, specifications, and maintenance are included in Chapter 5.

2.5.1 Bioretention

2.5.1.1 Definition

Bioretention is a flat-bottomed, shallow landscaped depression or basin used to collect and hold stormwater runoff; allowing pollutants to settle and filter out as the water infiltrates into the ground or to an underdrain, depending on soil conditions. Stormwater runoff enters the basin, where it temporarily ponds within the shallow depression and subsequently filters down through the various layers in the bioretention area: plants, mulch or ground cover, engineered soil media, a gravel base layer with a possible underdrain, or infiltrates into the underlying soils (see Figure 2-8).

Bioretention is designed to treat runoff from small drainage areas, typically ½ acre or less. Bioretention BMPs are classified into three types by size of contributing drainage area: bioretention cells treat approximately ½ acre to five acres, micro-bioretention treats approximately 10,000 square feet up to ½ acre, and rain gardens treat less than 10,000 square feet and typically infiltrate to groundwater. Further details are found in Chapter 5.

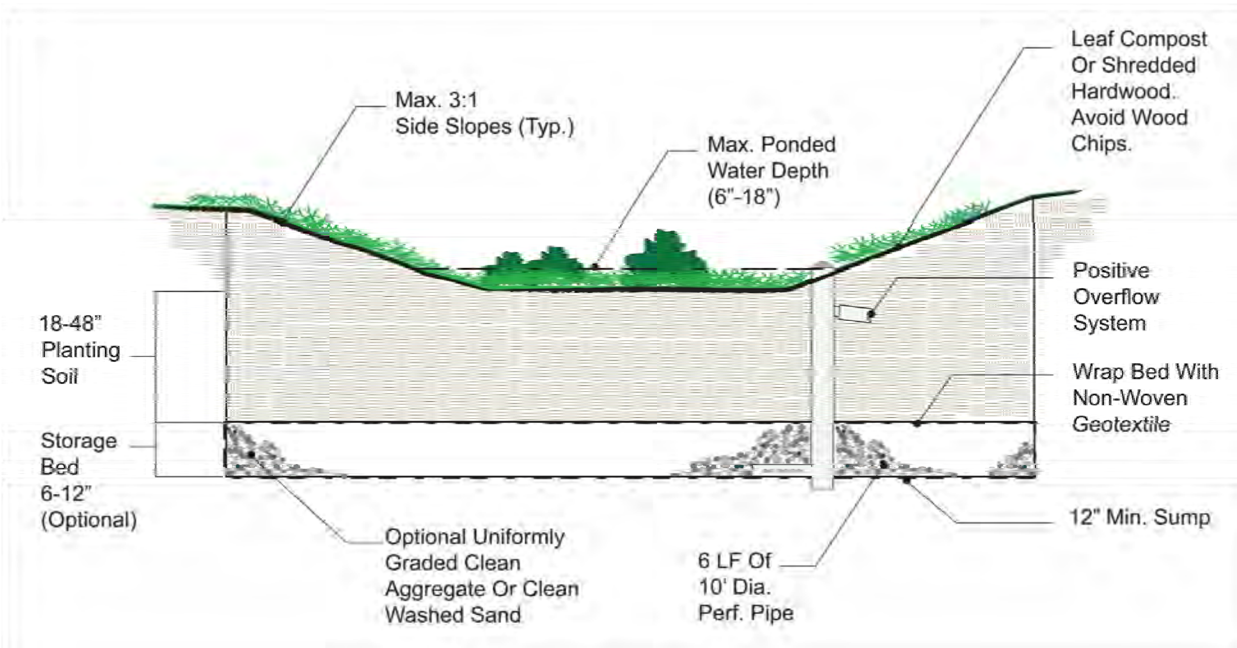

Figure 2-8. Cross-Section of a Bioretention Area

2.5.1.2 Purpose

Bioretention BMPs are multifunctional, as they manage stormwater runoff quantity and quality. Stormwater runoff is conveyed to a bioretention BMPs through curb cuts or sheetflow from an impervious area where small volumes of runoff are absorbed and treated through storage in the soil media and uptake by plants. Larger volumes of runoff are detained in the system and are then drained into an underdrain or are infiltrated into the ground, if the conditions permit. The soil media is designed with a high flow through rate but absorbs and/or adsorbs pollutants and helps reduce the thermal loading of stormwater. They can be designed for infiltration, filtration, or a combination of both. This is highly dependent on the subsurface soil conditions and the drainage infrastructure.

The bioretention BMP components make use of the chemical, biological and physical properties of soil, water, and plants to remove pollutants from stormwater runoff. Bioretention BMPs are used to remove a wide range of pollutants, such as suspended solids, nutrients, heavy metals, hydrocarbons, and bacteria from stormwater runoff.

Photo 2-10. Bioretention in a Parking Lot
(Source: Larry Coffman, 2008)

2.5.1.3 Use on Army Installation

Bioretention BMPs can be applied to almost all Army land uses (Table 2-9), as the size, function and design is flexible to work in a variety of site conditions. The design is directed by the climatic conditions, site soils, geology, and groundwater, land use that it is designed to treat, and the hydrologic requirements. Bioretention can either infiltrate to groundwater or filter to an underdrain, or a combination of both. Sites with high pollutant runoff, such as industrial sites, may require use of an underdrain and a liner to avoid contaminating groundwater. Infiltration may be limited by the soil types requiring an underdrain to quickly drain the collected stormwater runoff.

Bioretention BMPs are commonly located in or adjacent to parking lots, roads, medians and sidewalks or within small pockets in residential neighborhoods, commercial and industrial developments, training areas and institutional areas (Photo 2-10 and Photo 2-11) serving as a means to successfully accomplish disconnection of impervious surfaces, a non-structural LID BMP (see Section 2.4.7). Bioretention can also be used to retrofit existing stormwater BMPs. Bioretention can be used in brownfields or geologic conditions, such as karst topography, where infiltration should not be encouraged and the use of underdrains and liners are necessary to avoid groundwater contamination of areas with known water quality concerns. Where space is limited, a series of smaller bioretention BMPs can be installed.

Table 2-9. Bioretention

Applications		**Stormwater Quantity Functions**	
Residential	Yes	**Volume**	Med/High
Commercial	Yes	**Groundwater Recharge**	Med/High
Ultra Urban	Limited	**Peak Rate**	Medium
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Yes	**TSS**	High
Highway/Road	Yes	**TP**	Medium
Recreational	Yes	**TN**	Medium
Training Area	Yes	**Temperature**	High
Additional Considerations			
Cost		Medium	
Maintenance		Medium	
Winter Performance		Medium	

(Adapted from: SEMCOG, 2008)

Photo 2-11. Bioretention
(Source: USACE Savannah District)

2.5.2 Vegetated Swale

2.5.2.1 Definition

A vegetated swale is a broad, shallow stormwater channel that is often used as a pretreatment device for other BMPs or to reduce the timing of and volume of runoff. Vegetated swales are densely planted with a variety of grasses, shrubs, and/or trees designed to slow, filter, and, in some cases, infiltrate stormwater runoff from adjacent areas. Where slopes are steeper, check dams may be used to improve attenuation and infiltration performance. The maximum drainage area for a vegetated swale is typically 5 acres. There are three types of vegetated swales: grass swale, wet swale and bio-swale. Chapter 5 describes each type of swale in detail.

2.5.2.2 Purpose

Vegetated swales are designed to slow runoff, promote infiltration, and filter pollutants and sediments while conveying runoff from the source to a receiving waterbody or stormwater infrastructure or to infiltrate to groundwater. Vegetated swales are a cost-effective and environmentally friendly method to managing stormwater than the standard curbs and gutter conveyance systems. Often used as a pretreatment system, vegetated swales are typically heavily vegetated with a variety of native, close-growing plants; include soils that are conducive to plant growth. Bio-swales involve placement of soil media, similar to bioretention, to encourage pollutant and nutrient uptake and plant growth. As vegetated swales convey water, opportunity for infiltration may be limited during various storm events so it is recommended to install check dams or discharge to another LID BMP to promote maximum infiltration. Check dams at pipe inlets, driveway crossings, and/or periodically along swales or other pretreatment devices can be installed in order to reduce erosion, and improve its pollutant removal efficiency.

Swales can be modified to increase the infiltration and water quality efficiency of the conveyance system. Aggregates can be added below the surface to help absorb the runoff volume. Figure 2-9 is a schematic of a vegetated swale with an underlying aggregate layer. Other common variations include a vegetated swale with infiltration trench, a grass swale, and linear wetland swales. Common variations are depicted in Photos 2-12, 2-13, and 2-14.

Photo 2-12. Vegetated Swale with Infiltration Trench
(Source: USDA NRCS)

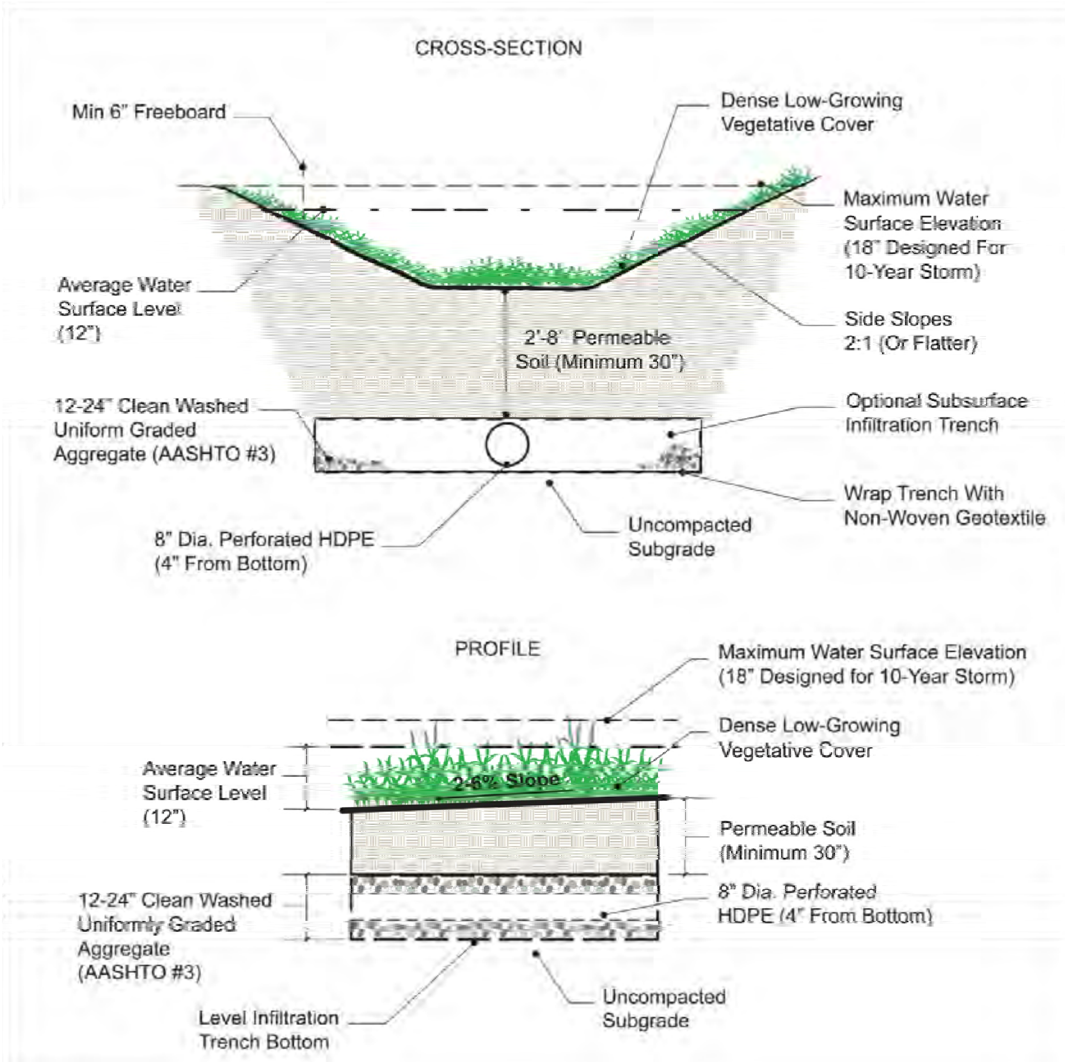

Figure 2-9. Schematic of a Vegetate Swale
(Source: Pennsylvania Stormwater IMP Manual, 2006)

Photo 2-13. Wet Swale
(Source: Hubbell, Roth & Clark, Inc.)

Photo 2-14. Grass Swale
(Source: PA Stormwater IMP Manual, 2006)

2.5.2.3 Use on Army Installation

Vegetated swales are highly versatile and can be well integrated into a variety of landscape settings, including residential, commercial/industrial areas, and training areas (Table 2-10). Swales can be used along road rights-of-ways, for yard drainage, and conveyance between BMPs. Use in ultra-urban settings is possible but limited, and potential retrofit applications depend on space and topographic limitations. On sites with little to no slope, for example, vegetated swales may not move water fast enough. Vegetated swales are a cost-effective and environmentally friendly alternative to traditional curbs and gutters along roads. Care needs to be taken when designing a vegetated swale so that excessive stormwater flows do not exceed the capacity of the vegetated swale and cause erosion or downcuts. Swales must be designed to have an appropriate slope for the setting so that water does not stand in the swale for long periods to avoid attracting mosquitos and other vectors.

Table 2-10. Vegetated Swale

Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	Low/Med
Commercial	Yes	**Groundwater Recharge**	Low/Med
Ultra Urban	Limited	**Peak Rate**	Low/Med
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Limited	**TSS**	Med/High
Highway/Road	Yes	**TP**	Low/High
Recreational	Yes	**TN**	Medium
Training Area	Yes	**Temperature**	Medium
Additional Considerations			
Cost		Low/Med	
Maintenance		Low/Med	
Winter Performance		Medium	

(Adapted from: SEMCOG, 2008)

2.5.3 Vegetated Filter Strip

2.5.3.1 Definition

A vegetated filter strip is a densely vegetated strip of gently sloping area that receives runoff from an adjacent impervious area as sheet flow (Figure 2-10). The vegetated filter strip slows the velocity of runoff and allows for removal of sediments and other pollutants as the runoff flows through the filter strip. The runoff may flow from the vegetated filter strip to another structural LID BMP, a vegetated area, or a receiving waterbody. Vegetated filter strips are most effective in treating runoff from isolated impervious areas such as rooftops, parking lots and smaller impervious areas.

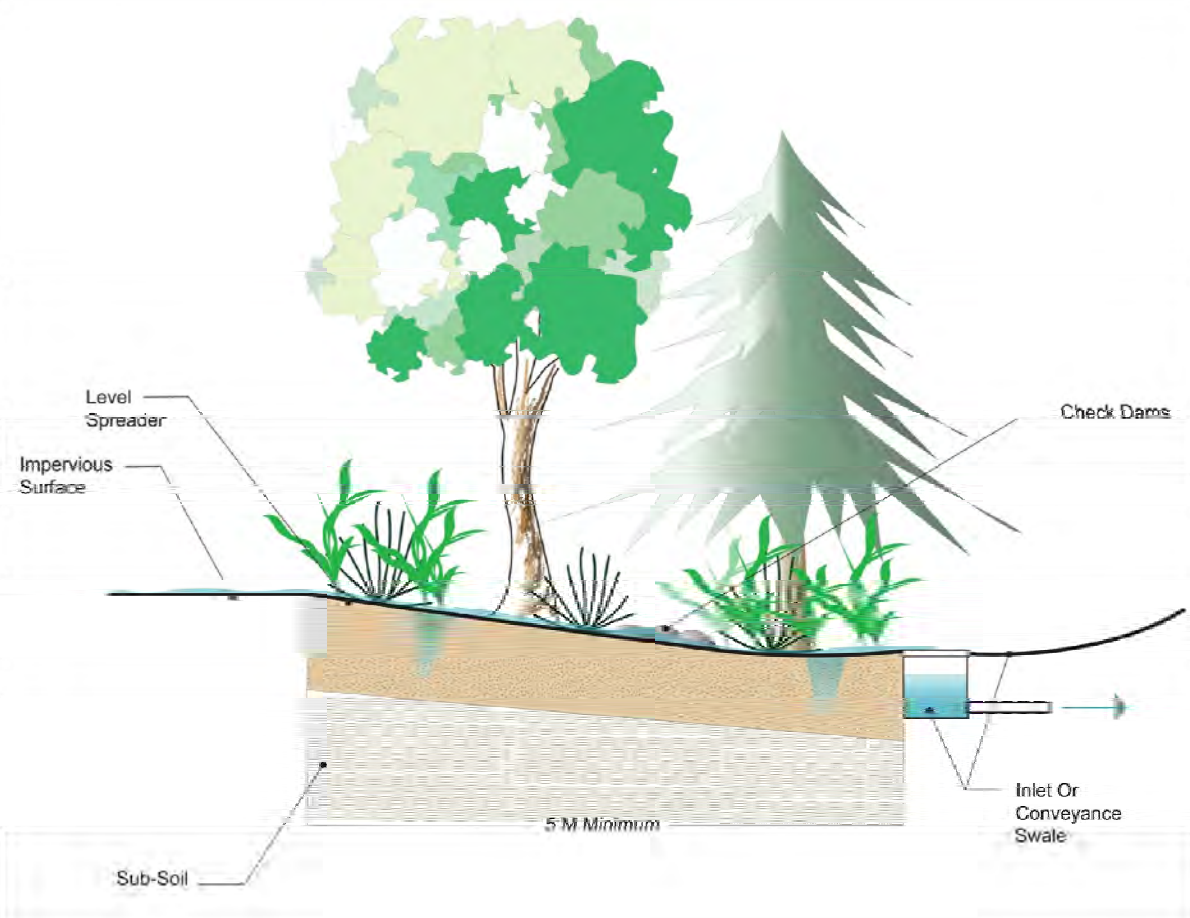

Figure 2-10. Vegetated Filter Strip
(Source: Landmark Design Group)

2.5.3.2 Purpose

Vegetated filter strips are used to minimize flow velocities and filter sediments and associated nutrients, and other pollutants from sheet flow runoff from impervious surfaces. When treating runoff from roofs or curbed impervious areas, a more structural approach, such as a gravel trench, is required. For smaller storms, vegetated filters also provide some runoff volume reduction benefits by infiltration. Usually, a vegetated filter strip is used as a pretreatment component to reduce sediments and particulate pollutant load before runoff reaches the primary stormwater BMP, such as bioretention, vegetated swale, or infiltration trench; the dense vegetation, grasses and/or woody plants, of the filter strip slows runoff to allow for sediments and particulates to settle out. A level spreading device, such as a stone drop, can be placed at the edge of the impervious or pervious surface being treated to prevent sediment deposition at the entry point. Natural spreader materials, such as earthen berms, are generally recommended, though they can be more susceptible to failure. Stormwater runoff flows through the vegetated filter strip to either a BMP, receiving waterbody or vegetated or wooded area, as seen in Figure 2-11. Figure 2-12 illustrates an optional earthen berm that temporarily slows the flow of water to encourage infiltration and can allow discharge through a pipe. When creating a filter strip, existing natural areas, such as forests and meadows, should never be unduly disturbed.

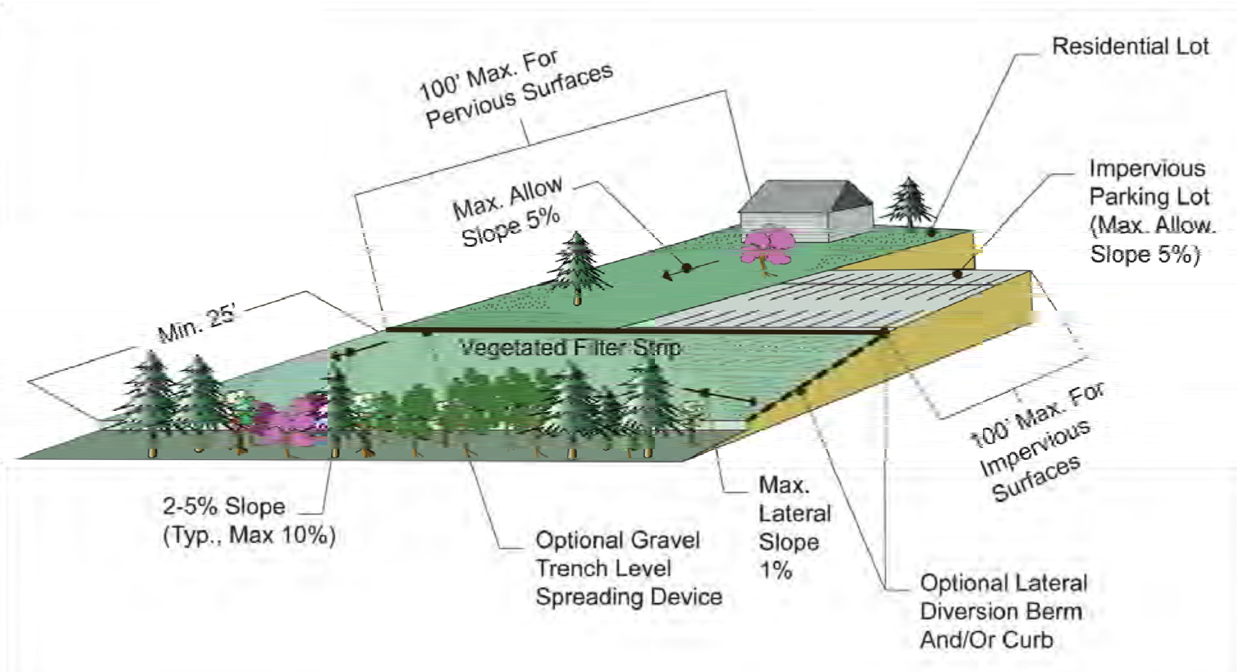

Figure 2-11. Diagram of a Vegetated Filter Strip
(Source: SEMCOG, 2008)

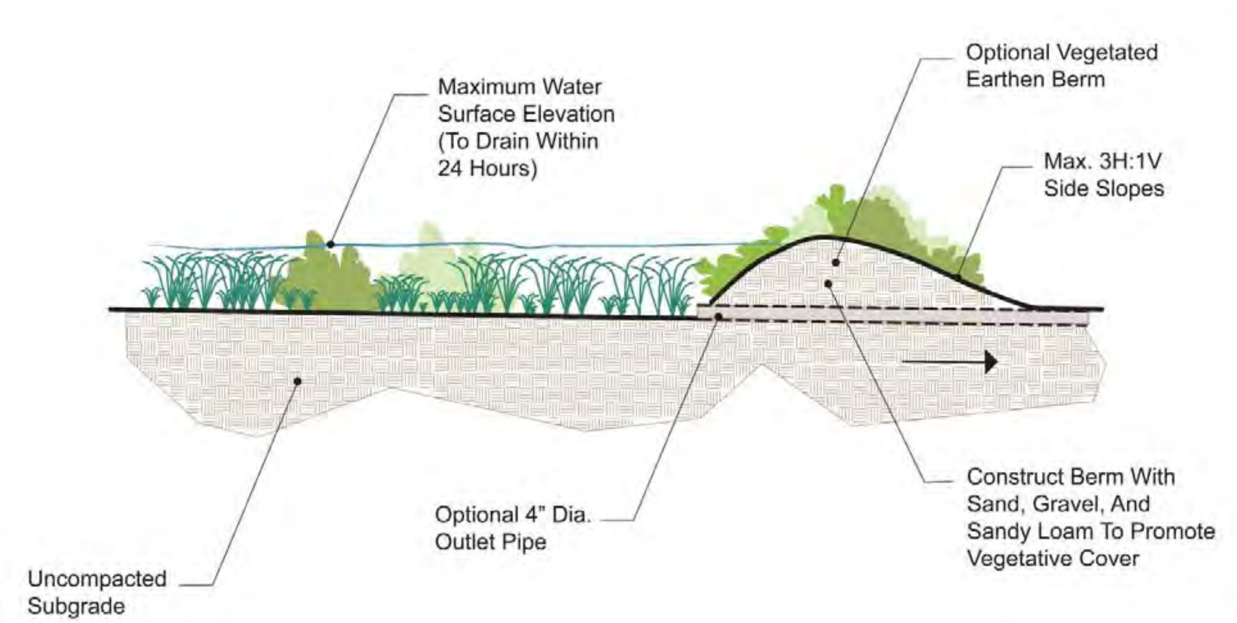

Figure 2-12. Cross-Section of Vegetated Filter Strip with an Optional Earthen Berm
(Source: SEMCOG, 2008)

2.5.3.3 Use on Army Installation

Vegetated filter strips can be applied in many land use types, including residential, commercial, industrial, training areas and road/highway transportation projects, as space and slopes are available (Table 2-11). Frequently, vegetated filter strips are designed where runoff is directed from a parking lot into a stone trench, a grass strip, and a longer naturally vegetative strip. Vegetated filter strips treat runoff from roads, disconnected rooftops, and other impervious surfaces (see Photo 2-15). For ultra-urban areas and some redevelopment areas, they might not be appropriate due to a lack of space. Because vegetated filter strips should be constructed as part of a larger stormwater treatment system, space requirements for additional BMPs should also be considered. Using vegetated filter strips as pretreatment practices to other BMPs is highly recommended. Access for stormwater runoff to sheet flow across the vegetated filter strip from upslope impervious areas is necessary for the proper function and effectiveness of a vegetated swale.

Table 2-11. Vegetated Filter Strip

Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	Low
Commercial	Yes	**Groundwater Recharge**	Low
Ultra Urban	Limited	**Peak Rate**	Low
Industrial	Limited	**Stormwater Quality Functions**	
Retrofit	Yes	**TSS**	Med/High
Highway/Road	Yes	**TP**	Med/High
Recreational	Yes	**NO3**	Med/High
Training Area	Yes	**Temperature**	Med/High
Additional Considerations			
Cost		Low	
Maintenance		Low Varies dependent on type of vegetation	
Winter Performance		High	

(Adapted from: SEMCOG, 2008)

Photo 2-15. Vegetated Filter Strip Along Roadway
(Source: SEMCOG, 2008)

2.5.4 Permeable Pavements

2.5.4.1 Definition

Permeable pavements are similar to conventional pavements but have pores or voids that allow stormwater runoff to filter through the pavement surface into an underlying stone reservoir, where it is temporarily stored then either infiltrated or directed to another BMP or permeable area. Permeable pavements provide high volume control and groundwater recharge benefits, as well as moderate peak rate control. The contributing drainage area is typically limited to the paved area.

2.5.4.2 Purpose

Permeable pavements are alternative paving surfaces that encourage filtration and/or infiltration that reduces the volume and velocity of stormwater runoff. There are various methods of installing pavement that allows stormwater to infiltrate while still providing the structural benefits of pavement. The four main design variations are: 1) porous asphalt, 2) pervious concrete, 3) permeable concrete pavers, and 4) reinforced turf or gravel. All four variations typically consist of a surface pavement layer, an underlying stone aggregate reservoir layer, and a filter layer or fabric installed on the bottom (Figure 2-13).

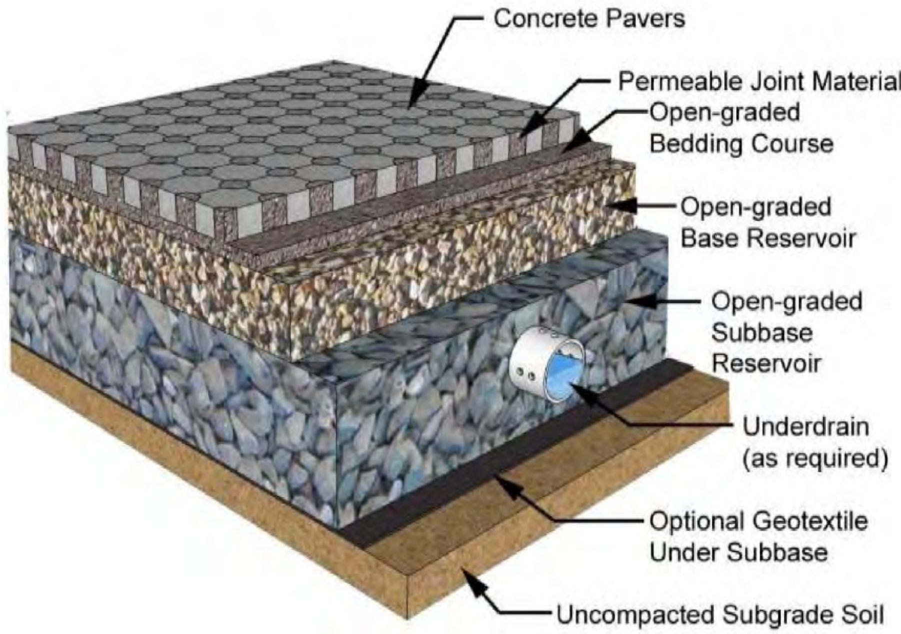

Figure 2-13. Cross Section of Permeable Pavement
(Source: Interlocking Concrete Pavement Institute)

The reservoir layer serves to retain stormwater and support the design traffic loads for the pavement, and its thickness is determined by both a structural and hydrologic design analysis. In low-infiltration soils, some or all of the filtered runoff is collected in an underdrain and returned to the storm drain system. If infiltration rates in the native soils allow, permeable pavement can be designed without an underdrain, to enable full infiltration of runoff. Permeable pavements designed for infiltration should be constructed on uncompacted subgrades; therefore, extensive coordination with the geotechnical engineer is necessary to determine an adequate pavement section for the subsoil conditions. A combination of these methods can be used to infiltrate a portion of the filtered runoff.

While the contributing drainage area is typically limited to the actual pavement surface area, it may also be used to accept runoff from small adjacent impervious areas, such as impermeable driving lanes or rooftops. However, careful sediment control is needed to avoid clogging of the down-gradient permeable pavement.

Photo 2-16. Permeable Pavement Parking Lot with Bioretention
(Source: Hawkins Partners, Inc., 2009)

Photo 2-17. Permeable Pavers
(Source: Leigh Ann Campbell)

Photo 2-18. Permeable Concrete Pavers in Street in Dowagiac, MI
(Source: Pokagon Band of Potawatomi Indians)

Photo 2-19: Porous Asphalt Pathway at Grey Towers National Historic Site, Milford PA
(Source: SEMCOG, 2008)

Photo 2-20. Pervious Pavement Basketball Court
(Source: Philadelphia Water Department)

2.5.4.3 Use on Army Installation

Photos 2-16, 2-17, 2-18, 2-19 and 2-20 depict various applications of the difference variations of permeable pavement. Because permeable pavement does not normally require any additional space to install but instead is used in lieu of traditionally impervious materials, it is applicable for a variety of commercial, institutional, and residential sites, and certain types of roadways and can be used to reduce the effective impervious cover of a development site (Table 2-12). Permeable pavement overlays can be used to slow runoff velocities, reduce runoff volumes and reduce the sediments and pollutants in runoff. The permeable pavement design should include methods to infiltrate, detain, or convey larger storms (e.g., 2-yr, 10-yr) to the storm drain system without the runoff backing up into the surface layers. An underdrain or connection to another BMP can receive runoff from the permeable pavements and can handle periods of excess runoff with larger storms and can be applied to meeting the EISA Section 438 requirements. Permeable pavement should not be hydraulically connected to foundations of structures or road beds. Infiltration from permeable pavement is not recommended in designated hotspots where contamination of groundwater and water supplies is a risk. It is also not recommended to install permeable pavements with underlying expansive soils due to the possibliltiy of heaving the pavements. Permeable pavement is not intended to treat sites with high sediment or trash/debris loads, as sediments and trash can clog the pores prohibiting filtration and resulting in an impervous surface.

Maintenance requirements for permeable pavements may limit their use in certain areas. Porous asphalt and concrete require regular maintenance with a conventional street sweeper to prevent clogging and malfunction. In areas of higher sediment and dust loads a vacuum-type sweeper or high-pressure hosing (for porous asphalt & concrete) may be required for cleaning. Turf pavers can require mowing, fertilization, and irrigation and aeration. In cold weather regions plowing of pavers is possible but it requires use of skids. Areas adjacent to pervious pavement should be fully stabilized with vegetation to prevent sediment-laden runoff from clogging the surface, and sand and salt should not be applied.

Table 2-12. Permeable Pavements

Applications		Stormwater Quantity Functions	
Residential	Yes	Volume	Low
Commercial	Yes	Groundwater Recharge	Low
Ultra Urban	No	Peak Rate	Low
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Yes	TSS	Low
Highway/Road	Yes	TP	Low
Recreational	Yes	NO3	Low
Training Area	Yes	Temperature	Low
Additional Considerations			
Cost		Low	
Maintenance		Low	
Winter Performance		High	

(Adapted from: SEMCOG, 2008)

2.5.5 Rainwater Harvesting

2.5.5.1 Definition

Rainwater harvesting involves the collection and storage of rainwater for future use. Rainwater harvesting applies to collection from rooftops and on a large-scale from other impervious surfaces, such as parking lots. Collected rainwater is stored in tanks, barrels, or cisterns for later use in non-potable applications or irrigation.

2.5.5.2 Purpose

Rainwater harvesting serves multiple functions in managing stomrwater runoff and promoting water conservation. Collecting runoff from roofs and impervious surfaces reduces the peak flows and runoff volumes to the receiving waterbodies, which alleviates erosive forces downstream. Stormwater runoff collected from rooftops is sodium and chlorine free, low in salt content, and high in nitrogen, and relatively clean that can be used for irrigation and for non-potable uses such as flushing toilets and urinals. Harvested water can also be discharged into the stormwater system or for infiltration if discharged to pervious area or a BMP; in these cases, rainwater harvesting serves mainly to reduce runoff volumes and peak flows.

The complexity of the rainwater harvesting system will depend on the objective of the application. A barrel can collect water from a roof, as shown in Photo 2-21, and store the water until ready for use for irrigation, non-potable purposes or released. More complex systems may contain water quality treatment, pumps and other devices for storing the collected water and directing for non-potable uses, as seen in Photo 2-22. The sizing of the systems varies across the country based on the climatic conditions, water demand, surface area, and allowable use of the collected water according to the applicable plumbing code.

Photo 2-21. Rain Barrels for Rainwater Harvesting from Roof
(Source: U.S. Army Fort Bragg)

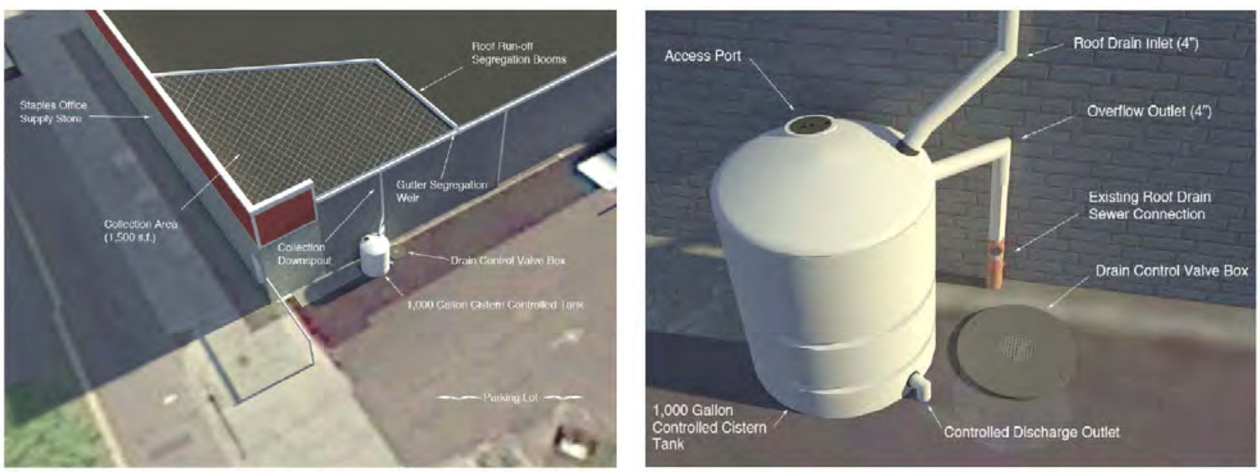

Photo 2-22. Cistern for Rainwater Harvesting

2.5.5.3 Use on Army Installation

Rainwater harvesting systems can be applied to many types of buildings, structures and even parking lots to reduce the volume of runoff from impervious areas (Table 2-13). Rain barrels or cisterns can easily be retrofit to existing buildings or parking garages. Rainwater harvesting systems can vary in size depending on available space, climatic conditions (i.e., average rainfall), and site requirements for stormwater runoff management or non-potable water and irrigation needs. This structural LID BMP is particularly beneficial in ultra urban areas where space is limited for other types of LID BMPs and in areas of low infiltration where use of other LID BMPs may be limited. Rainwater harvesting system design can be as simple as a rain barrel with a spigot (Photo 2-21) or as complex as a large tank with water quality treatment, a pumping system, and real time controls to direct the release of the runoff (Photo 2-22). Plumbing codes often dictate the level of treatment and if the water can be used for potable or non-potable uses. Common uses of the harvested rainwater include flushing of toilets and urinals inside buildings, landscape irrigation, exterior washing (e.g. car washes, building facades, sidewalks, street sweepers, fire trucks, etc.), and fire suppression (sprinkler) systems. Cisterns and rain barrels also have value for promoting environmental stewardship and education.

Table 2-13. Rainwater Harvesting

Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	High
Commercial	Yes	**Groundwater Recharge**	Low
Ultra Urban	Yes	**Peak Rate**	Low
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Yes	**TSS**	High
Highway/Road	No	**TP**	Medium
Recreational	Yes	**NO3**	Medium
Training Areas	Yes	**Temperature**	High
Additional Considerations			
Cost **- Rain barrel** **- Cistern** **- Manufactured product**		 - Low - Medium - Varies	
Maintenance		Medium	
Winter Performance		Medium	

(Adapted from: SEMCOG, 2008)

2.5.6 Green Roofs

2.5.6.1 Definition

Green roofs (also known as living roofs and eco roofs) consist of a layer of vegetation installed on top of a conventional flat or slightly sloped roof that absorb rainwater in the soil media to be uptaken and transpired by vegetation or discharged to another BMP or stormwater system. Green roofs include waterproofing material, root permeable filter fabric, growing media, and specially selected plants. Types of green roofs include intensive and extensive, ranging from deep, heavier growing media to shallower, lighter growing media.

2.5.6.2 Purpose

Green roofs capture and temporarily store stormwater as it hits the top of a building, reducing the amount of runoff from the building roof. Stormwater is held in the soil media and uptaken and transpired by plants to reduce the amount of runoff or slowly released to the stormwater system when stormwater exceeds the green roof storage capacity, reducing peak runoff rates. Depending on the objective of the green roof and the building structure, either an intensive green roof or extensive green roof may be installed. Intensive systems that have a deep growing media (typically greater than 4 inches), are limited to flat roofs, require a high degree of maintenance, and are often ‘park-like’ in appearance (Photo 2-23 and 2-24). Extensive systems, on the other hand, have a shallow substrate layer, are limited to herbs, grasses, mosses, and drought tolerant succulents such as sedum, have a higher mitigation of stormwater runoff, and are much lighter and less expensive than intensive vegetated roofs. Figure 2-14 is a cross section of a single layer extensive roof system.

Photo 2-23. Green Roof at the Pentagon Remote Delivery Facility
(Source: CAPT Robin Brake, 2008)

Photo 2-24. Green Roof at the California Academy of Sciences
(Source: Inhabitat)

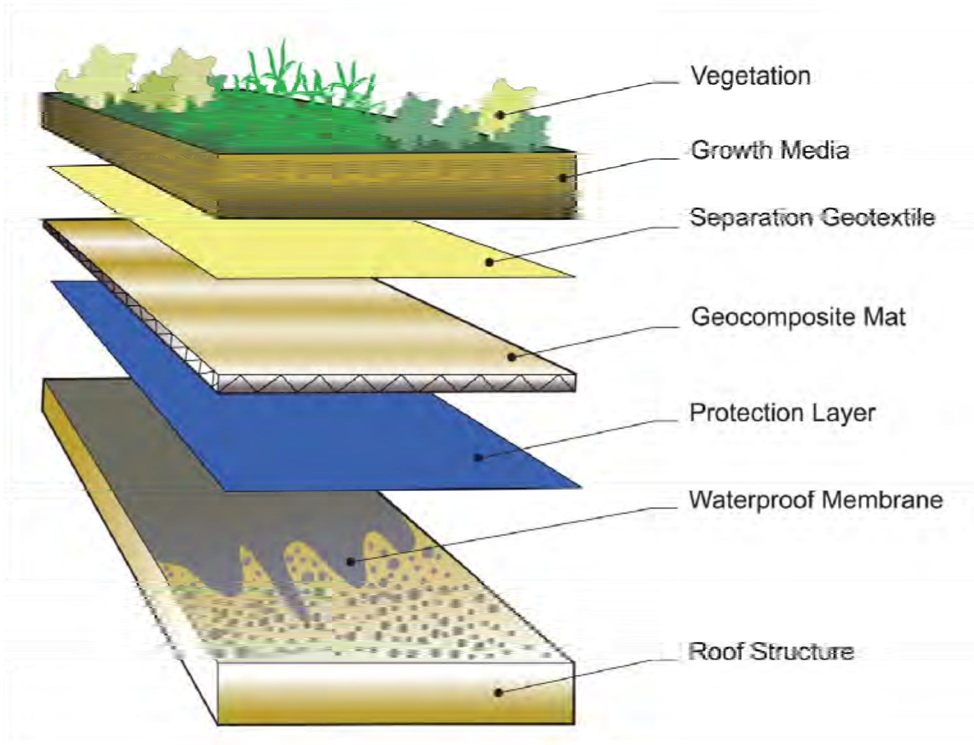

Figure 2-14. Cross Section of an Extensive Green Roof
(Source: SEMCOG, 2008)

2.5.6.3 Use on Army Installation

Green roofs are ideal for use on commercial, industrial, institutional, municipal and multi-family residential buildings, and are particularly well suited for use on ultra-urban development and redevelopment sites (Table 2-14). Roofs need to be flat or with minimal slope and buildings should be able to withstand the weight of the green roof media and vegetation. While extensive vegetative roofs are the most common due to their lower costs and maintenance requirements and their higher mitigation of stormwater runoff, intensive roofs can be utilized for gardening or therapeutic reasons. All green roofs should be sized to capture a portion of stormwater to reduce the overall stormwater runoff volume from the site. The required size will depend on several factors, including the growing media's porosity and hydraulic conductivity and the underlying drainage material. Irrigation and inspections are required during the vegetated roof's establishment period and in times of drought. Once plants are established, it is crucial to maintain the roof once or twice a year for extensive roofs. For intensive green roofs, a higher level of maintenance and service will be required throughout the year.

When designing a green roof, designers must not only consider the stormwater capacity of the green roof, but also the structural capacity of the roof and the building. For example, a conventional rooftop typically must be designed to support an additional 15 to 30 pounds per square foot (psf) for an extensive green roof. The roof's pitch, roof type, roof access, building codes, and construction costs are also common site constraints that must be considered. For green roof retrofits, key factors to consider include the age, area, structural capacity, and accessibility of the existing roof, as well as the building owner's capability to maintain it. Designers and reviewers should fully understand manufacturer specifications for each system component prior to installing. Further details are found in Chapter 5.

Table 2-14. Green Roofs

Applications		Stormwater Quantity Functions	
Residential	Limited	**Volume**	Med/High
Commercial	Yes	**Groundwater Recharge**	Low
Ultra Urban	Yes	**Peak Rate**	Medium
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Yes	**TSS**	Medium
Highway/Road	N/A	**TP**	Medium
Recreational	Yes	**TN**	Medium
Training Area	Limited	**Temperature**	High
Additional Considerations			
Cost	High		
Maintenance	Medium		
Winter Performance	Medium		

(Adapted from: SEMCOG, 2008)

2.5.7 Infiltration Practices

2.5.7.1 Definition

Infiltration practices are natural or constructed land areas located in permeable soils that capture, store, and infiltrate the volume of stormwater runoff into the surrounding soil. They are applicable to most drainage basins ranging in size from less than an acre to greater than 5 to 10 acres. There are several types of infiltration practices to meet the site conditions and needs for a project area.

2.5.7.2 Purpose

Infiltration practices serve to capture and temporarily store stormwater before allowing it to infiltrate into the underlying soil through the bottom and sides of the trench or subsurface area, and then either be partitioned into groundwater recharge. They are designed to rapidly treat and infiltrate the water so that the facility is ready to receive runoff from the next storm event or through the process of transpiration. By doing so, it serves to mitigate potential flooding events by decreasing peak runoff flow rates and the volume of stormwater runoff, reducing stormwater pollutants, and increasing groundwater recharge.

Variations of infiltration practices include the following:

- **Dry wells** (also known as seepage pits, French drains, and Dutch drains) are structural subsurface chambers or excavated pits backfilled with a coarse stone aggregate that are typically designed to handle stormwater runoff from smaller drainage areas less than one acre in size (Figure 2-15).

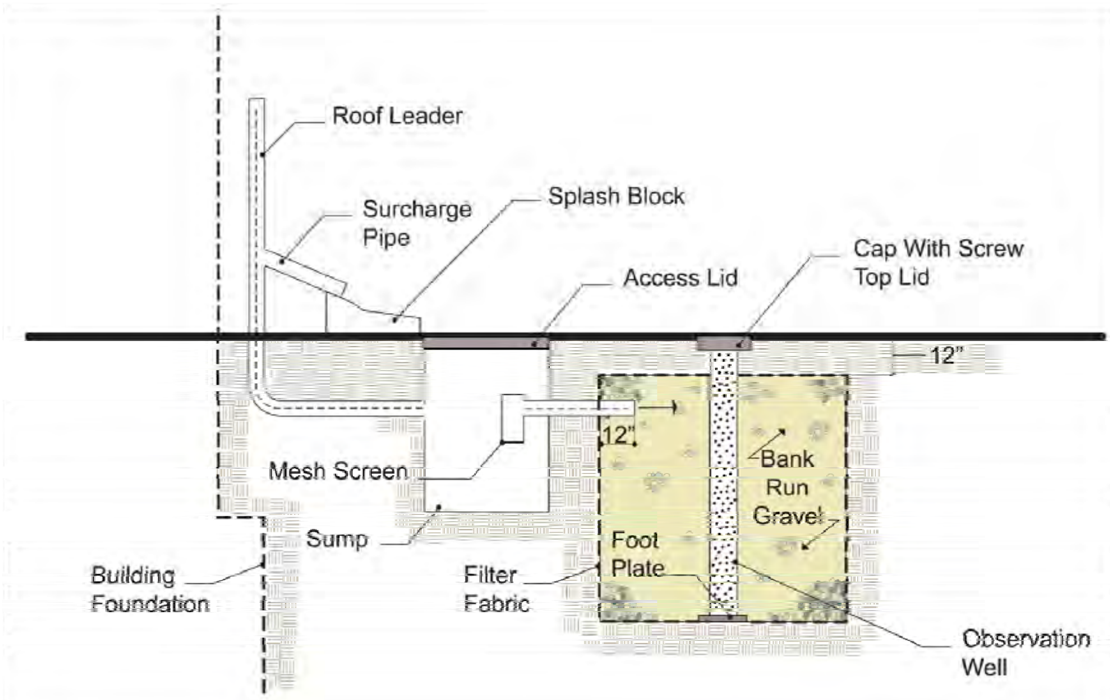

Figure 2-15. Dry Well Schematic
(Source: SEMCOG, 2008)

- **Infiltration basins** are either natural or constructed shallow surface impoundments that often include a flat, densely vegetated floor situated over naturally permeable soils, with typical permeable soil depths ranging from 2 to 12 feet (Photo 2-25). They serve to temporarily capture, store, and infiltrate runoff over a period of days, and are best suited for larger drainage areas with land slopes of less than 20 percent.

Photo 2-25. Infiltration Basin
(Source: SEMCOG, 2008)

- An **infiltration berm** is a mound of compacted earth with sloping sides that helps manage stormwater and prevent erosion by using the existing topography on the site. Berms may function independently in grassy areas or may be incorporated into the design of other stormwater BMPs, such as bioretention and constructed wetlands. Berms may also serve various stormwater drainage functions, including creating a barrier to flow, retaining flow for volume control, and directing flows.

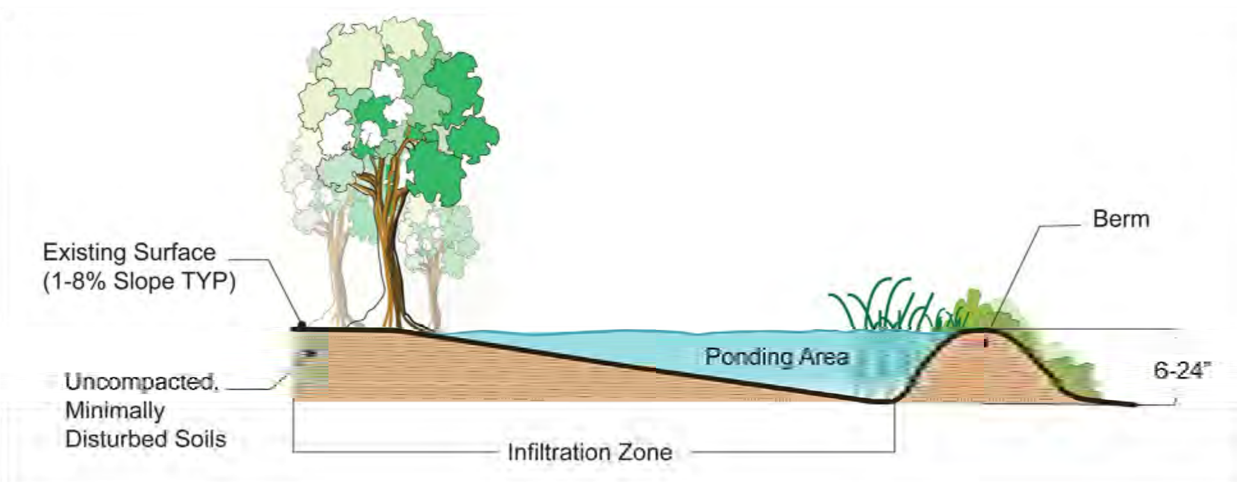

Figure 2-16. Infiltration Berm
(Source: SEMCOG, 2008)

- **Infiltration trenches** are linear, narrow excavations typically filled with stone and lined with geotextile (Photo 2-26), that are designed to create an underground reservoir for stormwater runoff in drainage areas less than five acres in size.

Photo 2-26. Infiltration Trench
(Source: Tony Parker, Classic Landscapes, 2007)

- **Subsurface infiltration beds** generally consist of a rock storage or alternative bed below ground surfaces, typically under parking lots, lawns, and playfields, for temporary storage and infiltration of stormwater runoff. Photo 2-27 shows the installation of a subsurface infiltration bed.

Photo 2-27. Installation of a Subsurface infiltration Bed
(Source: Cardno JFNew)

2.5.7.3 Use on Army Installation

While all of the varying infiltration practices achieve the same goal of capturing, storing, and infiltrating stormwater runoff into the surrounding soil, they are can be applied in a variety of situations at varying scales (Table 2-15). In order for any infiltration practice to function properly, the underlying soils must be well-suited for infiltration and the water table or bedrock must be located well below the base. The infiltration practice should be protected from sediment loads and erosive velocities by using pretreatment BMPs. Care should be taken when locating infiltration areas near buildings or areas where seepage or overflows could affect infrastructure are important.

Table 2-15. Best Uses for Infiltration Practices

PRACTICE	BEST USE
Dry well	Treatment of small impervious areas such as driveways or rooftop downspouts as an alternative to infiltration trenches. May be appropriate on steeper slopes where trenches or other facilities cannot be installed.
Infiltration basin	Best used in situations where source-area controls will not be enough to accomplish established peak runoff or water-quality goals (e.g., urban areas).
Infiltration berm	Easily incorporated into the landscape and often used in conjunction with recreational features, such as trails or walkways.
Infiltration trench	Treatment of rooftop runoff and runoff from small impervious surfaces with light sediment loads and minimal oil and grease buildup.
Subsurface infiltration bed	Areas where space is limited; secondary treatment for runoff from impervious surfaces, such as parking lots that have pretreatment structures in place.

Infiltration practices can be applied to most land uses on an Army installation (Table 2-16). There are limitations in areas where there is a risk of groundwater contamination from hotspots, or AT/FP requirements may restrict the placement of size of the BMP. For infiltration basins, it is important that vehicles are not driven in the basin to avoid compaction, which reduces the permeability of the soil.

Table 2-16. Infiltration Practices

	Applications							
	Residential	Commercial	Ultra Urban	Industrial	Retrofit	Highway/Road	Recreational	Training Area
Dry Well	Yes	Yes	Yes	Limited	Yes	No	Yes	Yes
Infiltration Basin	Yes	Yes	Limited	Yes	Limited	Limited	Yes	Yes
Infiltration Berm	Yes	Yes	Limited	Yes	Yes	Yes	Yes	Yes
Infiltration Trench	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Subsurface Infiltration Bed	Yes	Yes	Yes	Yes	Yes	Limited	Yes	Yes

	Stormwater Quantity Functions		
	Volume	Groundwater Recharge	Peak Rate
Dry Well	Medium	High	Medium
Infiltration Basin	High	High	High
Infiltration Berm	Low/Medium	Low/Medium	Medium
Infiltration Trench	Medium	High	Low/Medium
Subsurface Infiltration Bed	High	High	High

	Stormwater Quality Functions			
	TSS	TP	NO3	Temperature
Dry Well	High	High/Medium	Medium/Low	High
Infiltration Basin	High	Medium/High	Medium	High
Infiltration Berm	Medium/High	Medium	TN-Medium	Medium
Infiltration Trench	High	High/Medium	Medium/Low	High
Subsurface Infiltration Bed	High	Medium/High	Low	High

(Adapted from: SEMCOG, 2008)

2.5.8 Level Spreaders

2.5.8.1 Definition

A level spreader is an erosion control measure that is designed to mitigate the impact of high-velocity stormwater surface runoff, and can also serve to increase infiltration and reduce water pollution. While there are numerous variations, they can essentially be categorized into two types: inflow and outflow level spreaders. The applicable drainage area for a single level spreader should not exceed 5 acres.

2.5.8.2 Purpose

Level spreading devices help to reduce the erosive nature of stormwater runoff by uniformly diffusing both high and low flows over a wide area. They can also serve to promote infiltration and improve water quality by evenly distributing flows over a stabilized vegetated surface. Typically, it is constructed at a zero percent grade across the slope consisting of a permanent linear structure in order to disperse concentrated flow widely over a vegetated buffer, filter strip, bioretention cell, or wetland (Figure 2-17). While level spreaders themselves do not remove pollutants, by dispersing runoff to a buffer or bioretention cell, pollutants can be effectively removed.

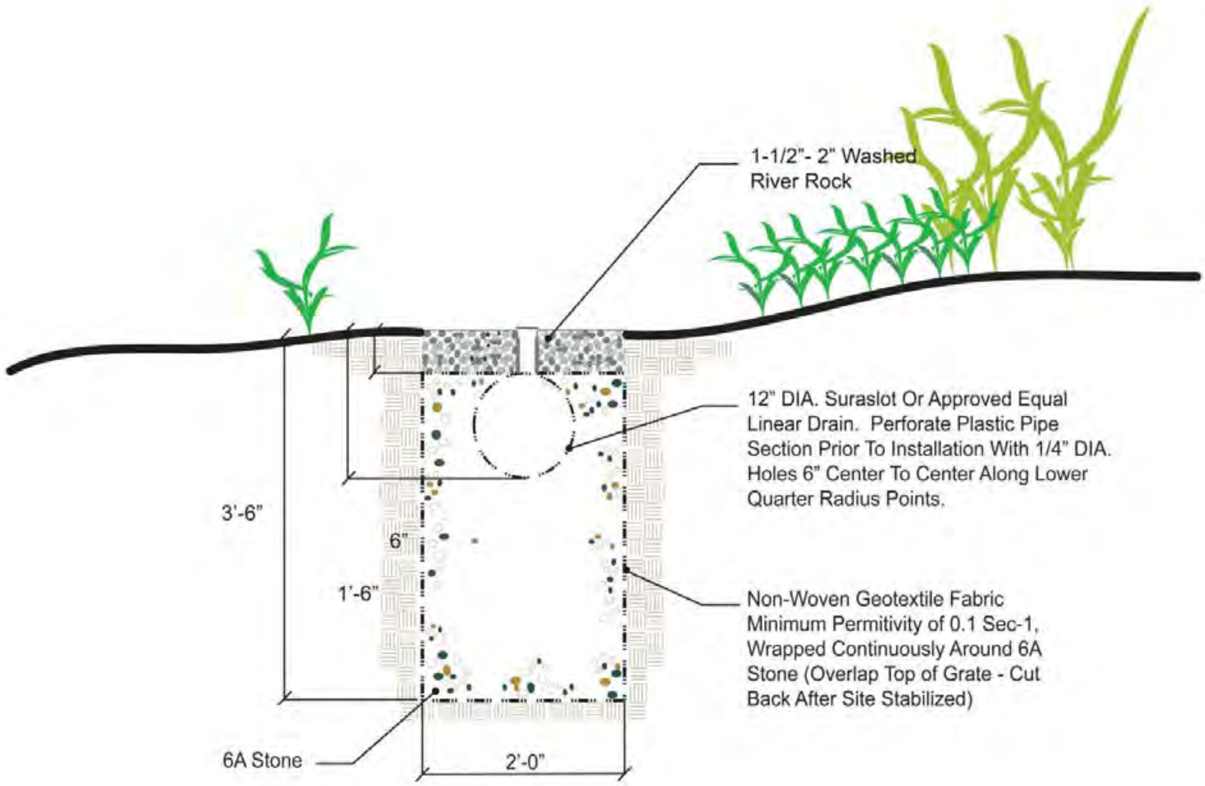

Figure 2-17. Schematic of a Typical Level Spreader
(Source: InSite Design Studio)

There are two main categories of level spreaders. Inflow level spreaders (e.g., concrete sills, curbs, earthen berms) help to evenly distribute flow into another structural practice, such as filter strips or a vegetated swale (Figure 2-18). Outflow level spreaders (e.g., perforated pipe in a shallow aggregate trench) help to reduce the erosive potential of low to moderate flows while also enhancing natural infiltration opportunities (Figure 2-19). For outflow level spreaders, the total amount of runoff volume reduced is dependent on the length of the level spreader, the soil type and density of receiving vegetation, as well as the downhill length and slope and the design runoff.

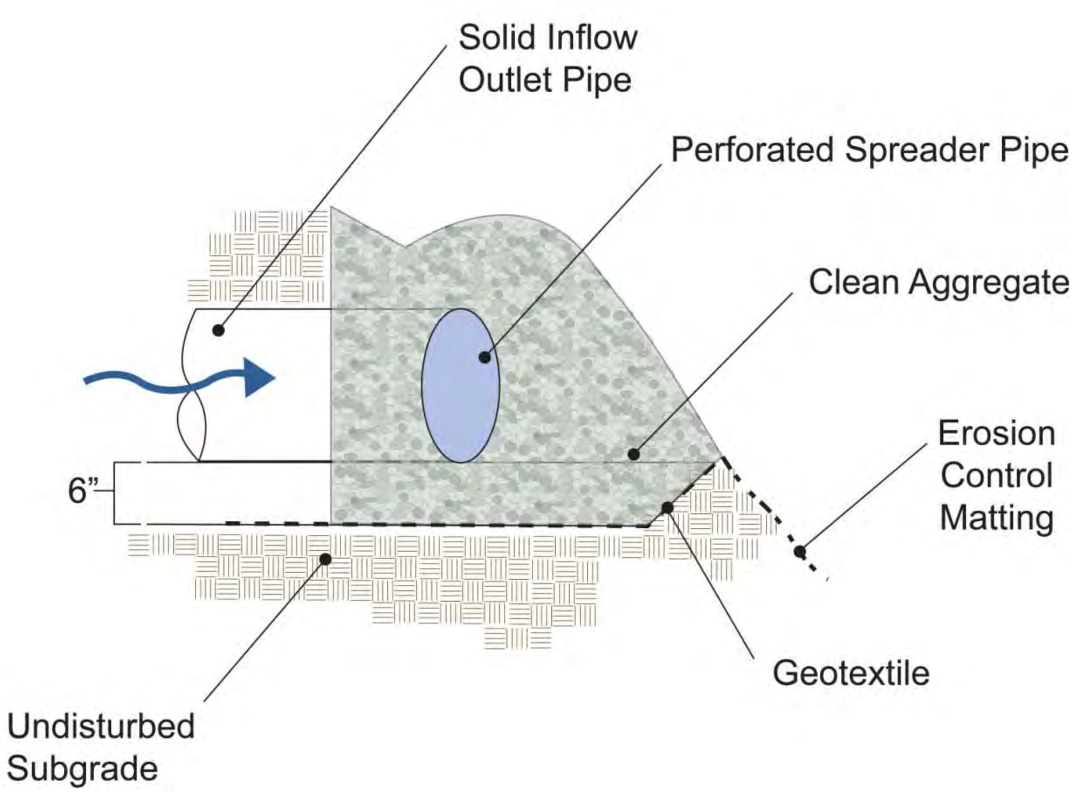

Figure 2-18. Level Spreader with an Inflow Pipe
(Source: SEMCOG, 2008)

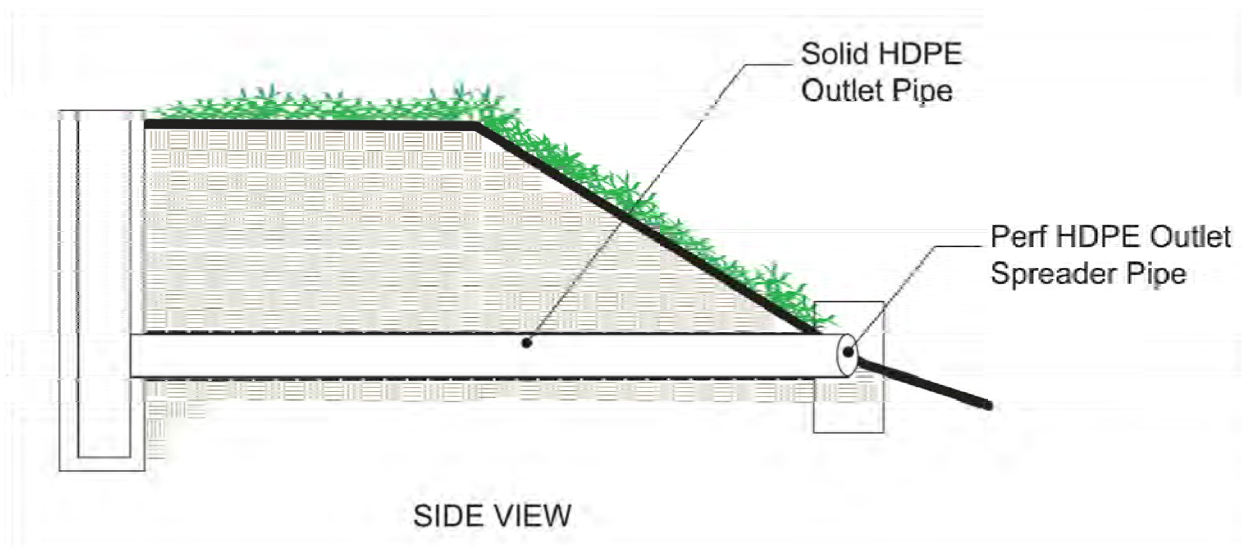

Figure 2-19. Level Spreader with a Perforated Outflow Pipe
(Source: SEMCOG, 2008)

Both inflow and outflow level spreader systems typically consist of pre-treatment (forebay), principal treatment (e.g., level spreader with grassed buffer), and an emergency spillway (reinforced grassy swale downslope of spreader) device. The forebay helps to remove some of the sediment and debris that normally accumulate behind these systems, while also dissipating the energy, thus reducing the velocity prior to entering the level spreader. If the flow from a drainage area exceeds the capacity of a level spreader, another BMP such as a detention basin may be used before the level spreader to attenuate the flow to an appropriate rate. Level spreaders are not applicable where slopes exceed 5 for wooded areas or 10 for thick ground cover/grass, nor are they applicable where highly erodible soils are present or when there is little/no vegetation.

2.5.8.3 Use on Army Installation

A level spreader can be used in a variety of applications, from residential and commercial (to manage stormwater from disconnected rooftops, driveways, sidewalks, and parking lots) to highway/road projects (Table 2-17). Level spreaders are often used in conjunction with other LID BMPs or conventional stormwater BMPs. The primary requirement is that there must be adequate area with an acceptable slope to receive the outflow. Because of this, level spreaders are generally not applicable in ultra-urban settings. Photo 2-28 shows a level spreader at the edge of a wetland area that disperses stormwater from the paved paths across the one side of the wetland.

Table 2-17. Level Spreaders

Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	Low
Commercial	Yes	**Groundwater Recharge**	Low
Ultra Urban	No	**Peak Rate**	Low
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Yes	**TSS**	Low
Highway/Road	Yes	**TP**	Low
Recreational	Yes	**NO3**	Low
Training Area	Yes	**Temperature**	Low
Additional Considerations			
Cost		Low	
Maintenance		Low	
Winter Performance		High	

(Adapted from: SEMCOG, 2008)

Photo 2-28. Level Spreader at the Edge of a Wetland Area
(Source: Lee R. Skabelund, Kansas State University, 2006)

2.5.9 Constructed Filter

2.5.9.1 Definition

Constructed filters are precast or cast in place structures or excavated areas containing a layer of sand, compost, organic material, peat, or other media that filter and treat stormwater runoff. The maximum drainage area is typically less than one half acre.

2.5.9.2 Purpose

These are typically shallow and small-scale facilities that are used to provide water quality treatment and reduce velocities of stormwater runoff for small impervious drainage areas such as parking lots, walks, and roofs. Constructed filter systems typically contain a high flow rate media that requires some type of pretreatment to reduce the potential for clogging. Pre-cast systems often contain pretreatment chambers to prevent large amounts of debris, sediment, or oil and grease from entering the constructed filter. They are often designed with bypass systems for large storm events which could overload or erode the media.

2.5.9.3 Use on Army Installation

Constructed sand filters can be used at infill sites or areas where there is a limited amount of space to treat the runoff from impervious areas (Table 2-18). The media in these systems is highly sensitive to clogging and usually requires a significant amount of maintenance. Filters that use peat and sand or surface sand filters, require frequent inspection to make sure vegetation does not grow in the media and reduce the filtration capacity. These facilities do not significantly reduce the amount of runoff volume from a site unless there is a sandy soil below the filter where it can infiltrate to groundwater. Photo 2-29 shows a two chambered sand filter. The part of the sand filter with the grate (on the left) allows water to enter a chamber where debris, heavy sediments, and oils and grease are filtered out. The chamber with the cover (on the right) includes the sand filter media. Photo 2-30 is a picture of a surface sand filter. Note the grass area around the filter and the stone on the surface to reduce the amount of sediment and debris entering the system and reduce the velocity of the flows. The flows enter the system through the outfalls at the side and rear of the facility and leave the facility through the grate inlet at the front. The system contains an underdrain that discharges to the stormwater system.

Table 2-18. Constructed Filter

Applications		Stormwater Quantity Functions	
Residential	Limited	**Volume**	Low/High
Commercial	Yes	**Groundwater Recharge**	Low/High
Ultra Urban	Yes	**Peak Rate**	Low/High
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Yes	**TSS**	High
Highway/Road	Yes	**TP**	Medium
Recreational	Yes	**TN**	Medium
Training Area	Yes	**Temperature**	Low
Additional Considerations			
Cost	Med/High		
Maintenance	High		
Winter Performance	Medium		

(Adapted from: SEMCOG, 2008)

Photo 2-29. Two Chambered Sand Filter
(Source: Wayne County, MI Department of Public Works)

Photo 2-30. Surface Sand Filter
(Source: City of Portland, OR)

2.5.10 Soil Restoration

2.5.10.1 Definition

Soil restoration is a practice used to deeply till compacted soils and restore their porosity by amending them with compost or other acceptable organic material.

2.5.10.2 Purpose

Soil restoration can be used to increase the water retention capacity, soil porosity and soil structure, reduce erosion, and immobilize/degrade pollutants (depending on soil media makeup), and ultimately reestablish the long term capacity of the soil for infiltration (see Section 3.3.1.2 for further information about soils). Soil restoration is suitable for any pervious area where soils have been or will be compacted by the grading and construction process. This practice is particularly well suited when existing soils have low infiltration rates and when the pervious area will be used to filter runoff (downspout disconnections and grass channels). The area or strip of amended soils should be hydraulically connected to the stormwater conveyance system.

Soil restoration is not recommended where existing soils have high infiltration rates: where the water table or bedrock are located within 1.5 feet of the soil surface; on slopes of 10 percent or greater or where the downhill slope runs towards a building foundation; where existing soils are seasonally wet or saturated; where existing tree roots would be harmed; or where the contributing impervious surface area exceeds the surface area of the amended soils. Soil restoration can be applied to the entire pervious area of a development or be applied only to select areas of the site to enhance the performance of runoff reduction. Figure 2-20 illustrates the profile of healthy soil. The top layer, or "O Horizon", provides organic matter from dead leaves and decomposing as nutrients for the plants and to retain surface moisture. The A horizon is the topsoil layer that contains organic material, organisms, and the root zones of plants. This is the most biologically productive area of the soil and provides pathways for air and water. The B zone is the mineral zone where sands, silts, clays and rocks occur. The C zone is primarily composed of weathered rocks and minerals. Photo 2-31 shows a compacted soil where the root zones of the turf, or sod cannot penetrate the upper soil horizons.

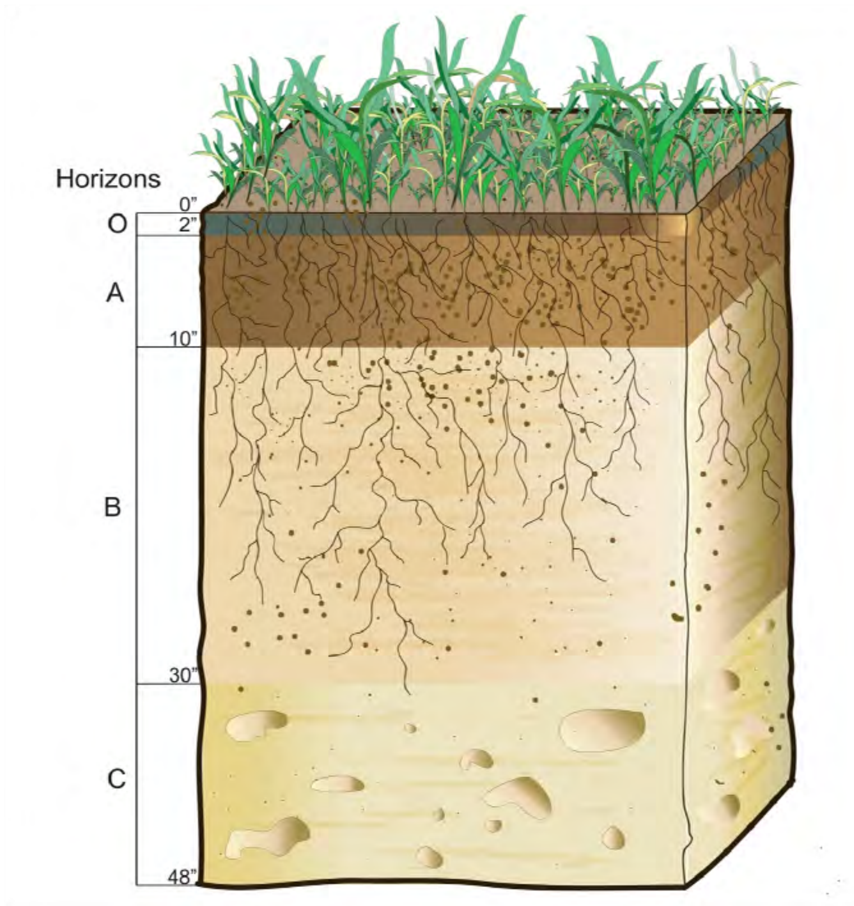

Figure 2-20. Profile of a Healthy Soil
(Source: USDA NRCS)

Photo 2-31. Compacted Soils
(Source: Low Impact Development Center, Inc.)

2.5.10.3 Use on Army Installation

Soil restoration can occur anywhere to alleviate soil compaction, and is applicable to multiple land uses (Table 2-19). Soil restoration can be used to reduce runoff from compacted lawns and to enhance the runoff reduction performance of other BMPs such as downspout disconnections, grass channels, filter strips, detention basins, or a reforested area. Soil restoration is particularly important in training areas, where vehicular movement and heavy traffic have compacted soils, reducing infiltration and in some cases creating an impervious surface. Prior to any modifications, a soil test is required to ascertain the soil properties at the proposed amendment areas to determine potential drainage problems and what, if any, soil amendments are needed. Areas should be marked so that heavy vehicles do not compact the soils.

Table 2-19. Soil Restoration

Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	Medium
Commercial	Yes	**Groundwater Recharge**	Low
Ultra Urban	Yes	**Peak Rate**	Medium
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Yes	**TSS**	High
Highway/Road	Limited	**TP**	High
Recreational	Yes	**NO3**	Medium
Training Area	Yes	**Temperature**	Medium
Additional Considerations			
Cost		Medium	
Maintenance		Low	
Winter Performance		High	

(Adapted from: SEMCOG, 2008)

2.5.11 Reforestation and Afforestation

2.5.11.1 Definition

Reforestation refers to the reestablishment of forested cover in areas where development has removed forest. Afforestation is the establishment of forests on grasslands or other areas that were previously unforested.

2.5.11.2 Purpose

Reforestation and afforestation can be effective tools for reducing the quantity of stormwater runoff. In addition to intercepting and absorbing stormwater runoff, trees help filter pollutants and can greatly improve slope stability. Site reforestation involves planting trees on existing turf or barren ground at a development site with the goal of establishing a mature forest canopy that will intercept rainfall and maximize infiltration. The method used for reforestation must achieve 75 percent forest canopy cover within ten years. Reforestation areas are planted with a variety of understory trees and shrubs and overstory trees in order to encourage biodiversity. Photo 2-32 is a recently planted reforestation area with tubes around the whip stock to prevent animals from feeding on the bark and to prevent sun scorch.

Photo 2-32. Recently Planted Reforestation Area
(Source: USDA)

2.5.11.3 Use on Army Installation

Reforestation and aforestation can be applied to cleared sites, in developments or parks, along roadsides, or in parking lots (Table 2-20). There may be opportunities in training areas for reforestation in areas where training no longer occurs or if there are changes in training activities. There are several reforestation programs that Army installations participate in, making this LID BMP especially effective at managing both stormwater and natural resources. Establishing a forested buffer along stream corridors can filter pollutants and reduce flood hazards. Reforestation areas can be used to improve air quality and reduce urban heat island effects.

Table 2-20. Reforestation and Afforestaton

Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	Low/Med/High
Commercial	Yes	**Groundwater Recharge**	Low/Med/High
Ultra Urban	Limited	**Peak Rate**	Low/Med
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Yes	**TSS**	High
Highway/Road	Limited	**TP**	High
Recreational	Yes	**TN**	Med/High
Training Area	Yes	**Temperature**	Medium
Additional Considerations			
Cost		Low/Medium	
Maintenance		Low	
Winter Performance		Medium	

(Adapted from: SEMCOG, 2008)

2.5.12 Riparian Buffer Restoration

2.5.12.1 Definition

Riparian buffer restoration refers to natural or constructed low-maintenance ecosystems adjacent to surface waterbodies. The riparian vegetation slows and dissipates stormwater runoff entering the receiving waterbody by absorbing the energy and volume of the stormwater runoff (Photo . The riparian vegetation also acts as a filter to remove pollutants from both overland stormwater flow and shallow groundwater flow.

2.5.12.2 Purpose

Riparian buffers provide water quality, habitat, and erosion control benefits, by slowing the velocity of the stormwater runoff and absorbing some of the ruoff volume. The specific restoration strategy, however, is dependent upon the overarching goal (e.g., a riparian buffer restored for water quality benefits can differ from one restored for habitat purposes). Photo 2-33 is an illustration of a stream buffer with dense vegetation that slows and filters runoff from the adjacent field.

Photo 2-33. Riparian Buffer in Agricultural Setting
(Source: USDA)

For water quality and erosion control, a riparian buffer is most effective when used as part of a sound land management system that includes nutrient management and runoff, sediment, and erosion control practices. Riparian buffer zones require considerations for water quality as well as existing vegetation should be evaluated to determine a restoration strategy and identify desirable, undesirable, and sensitive species, and care should be taken to evaluate the soil which will greatly influence the plant selection. Depending on existing site conditions, the soils, topography, or hydrology may first need to be restored. Where steep slopes or highly erodible soils are present, the buffer may need to be expanded to ensure soil stability. Photo 2-34 shows a steep and eroded bank adjacent to a stream without a buffer. Photo 2-35 shows the restored buffer and stream bank.

Photo 2-34. Eroded Streambank
(Source: FISRWG, 1998)

Photo 2-35. Restored Buffer and Streambank
(Source: FISRWG, 1998)

2.5.12.3 Use on Army Installation

Army installations may have significant stream networks and waterways that are subject to impacts from training activities and development. Table 2-21 indicates that restoration of riparian buffers can be applied in all settings; on some installations the local or state government may require a riparian buffer of a certain width. Maintaining an adequate buffer from trails, temporary access roads, and grading is imperative to protect the integrity of the stream. Buffers are also valuable habitat corridors.

Table 2-21. Riparian Buffer Restoration

Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	Low/Med
Commercial	Yes	**Groundwater Recharge**	Low/Med
Ultra Urban	Yes	**Peak Rate**	Low/Med
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Yes	**TSS**	Med/High
Highway/Road	Limited	**TP**	Med/High
Recreational	Yes	**NO3**	Med/High
Training Areas	Yes	**Temperature**	Med/High
Additional Considerations			
Cost		Low/Medium	
Maintenance		Low	
Winter Performance		High	

(Adapted from: SEMCOG, 2008)

2.6 LID BMP SELECTION

Site conditions, including climate, and stormwater management requirements highly influence the selection of LID BMPs for the project. Table 2-22 lists a selection of structural and non-structural LID BMPs and their effectiveness in each climate. Table 2-23 lists a selection of non-structural and structural LID BMPs and the hydrologic objective they meet; volume control is the most important objective for compliance with EISA Section 438. Hydrologic modeling and simulation tools for the selection and sizing of LID BMPs are presented in Chapter 4. Further details about the most common structural LID BMPs are presented in Chapter 5.

Table 2-22. Climatic Considerations for LID BMP Selection

LID BMP	TROPICAL (MEGATHERMAL)	DRY (ARID AND SEMIARID)	TEMPERATE (MESOTHERMAL)	CONTINENTAL (MICROTHERMAL)	POLAR
Reduce Impervious Surface	●	◉	◉	◉	○
Site Fingerprinting	●	●	●	●	◉
Bioretention	●	◉	●	◉	○
Vegetated Swales	●	◉	●	◉	○
Vegetated Filter Strips	●	◉	●	◉	○
Permeable Pavements	●	◉	◉	○	○
Rainwater Harvesting	●	○	●	●	○
Soil Restoration	●	◉	◉	◉	○
Reforestation	●	○	◉	◉	○

KEY	
●	High Effectiveness (Recommended)
◉	Medium Effectiveness (Recommended with Reservation)
○	Low Effectiveness (Not Recommended)

Table 2-23. LID Structural Practices & Hydrologic Objective Effectiveness

LID PRACTICE / DEVICE	PEAK FLOW CONTROL	VOLUME REDUCTION	WATER QUALITY IMPROVEMENT	WATER CONSERVATION
Reduce Impervious Surfaces	●	●	●	
Bioretention	●	●	●	
Vegetated Swales	●	●	●	
Permeable Pavement	●	●	●	
Rainwater Harvesting	●	●		●
Green Roof	●		●	
Infiltration Trench	●	●	●	
Constructed Filter	●		●	
Reforestation	●	●		

(Adapted from: WBDG Design Guide: Low Impact Technologies)

2.7 TREATMENT TRAINS

LID BMPs can provide excellent stormwater runoff volume reduction, peak flow reduction, and pollutant removal for small storm events. Treatment of larger events, however, may require the use of supplemental stormwater treatment structures designed to detain larger runoff volumes. Both large and small events can be effectively handled by creating a treatment train that uses a series of LID BMPs and conventional BMPs as needed.

Non-structural and structural LID BMPs are the first elements in the treatment train, where they can provide capture and treatment of runoff from even the smallest rain events. They are constructed with overflows, which allow runoff from larger events to flow to secondary BMPs. These secondary BMPs are typically larger, and are focused on large-scale detention and retention. Examples of such secondary practices would be extended detention ponds and infiltration basins or storage vaults. These practices are generally constructed with a focus on peak flow reduction and flood control for the 10- to 100- year 24-hour peak storm events.

The requirements for the use of conventional end-of-pipe needs to be determined by a detailed hydrologic and hydraulic analysis because of the complexity of the storage, discharge, and conveyance relationships that occurs when multiple BMPs are placed in a series.

A treatment train consisting of multiple LID BMPs can also be used to maximize stormwater runoff volume reduction and water quality performance. This is particularly useful in conjunction with non-structural practices. For example, a roof downspout is disconnected, allowing runoff to flow over a permeable area. Any excess runoff that is not infiltrated by this permeable area can then be collected in a vegetated swale and conveyed to a bioretention cell. Photo 2-36 illustrates the use of a level spreader in combination with a vegetated swale. Figure 2-21 shows the use of permeable pavement in a parking lot that can discharge to a vegetated swale as well. Each element of this treatment train provides water quality improvement, volume reduction, and reduces runoff velocity. BMPs also have different effectiveness for treating pollutant loads and can be used in combinations. For example, compost amended soils may have a high affinity for removing soluble metals from roofs and bioretention cells with additional detention storage may reduce nitrogen loads from roofs.

Appendix C includes a discussion of Green Streets, which is an initiative that encourages use of LID BMPs and treatment trains in several cities. Case studies of Green Streets are also included in Appendix C.

Photo 2-36. Treatment Train - Level Spreader and Vegetated Swale

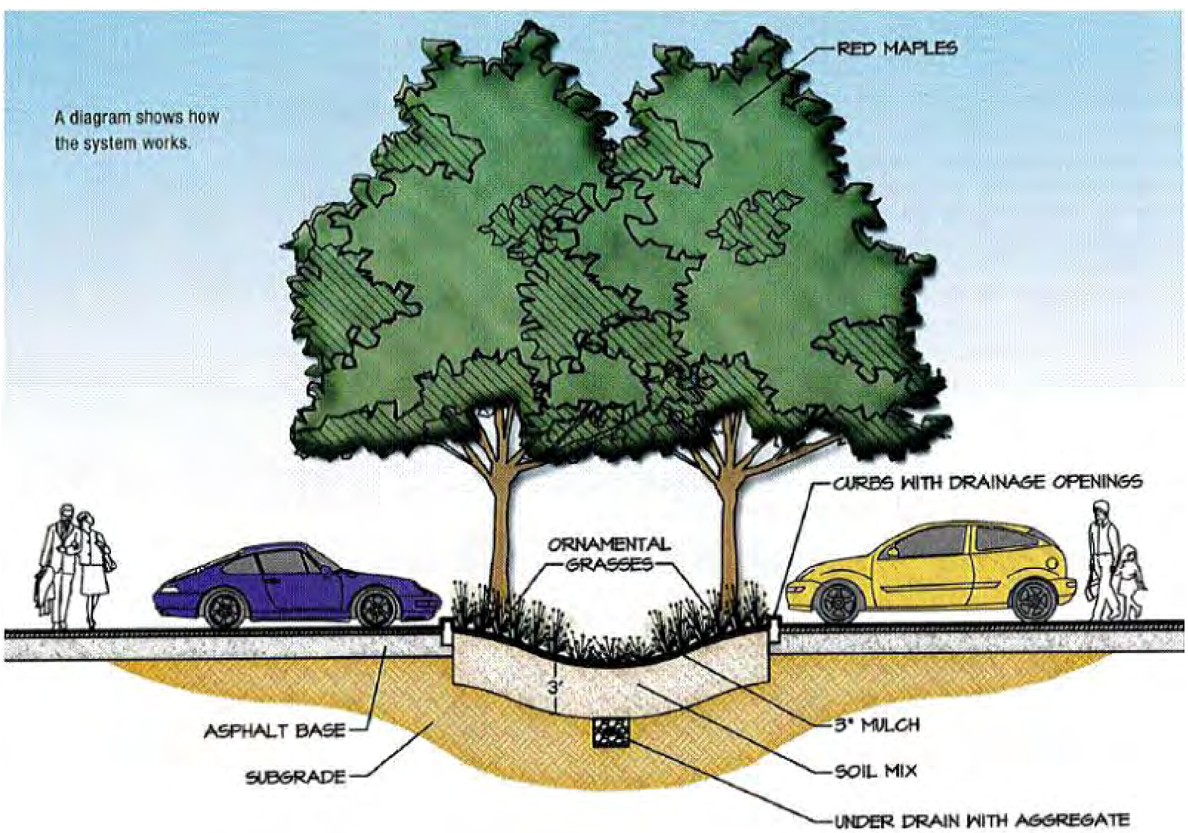

Figure 2-20. Treatment Train - Permeable Pavers and Vegetated Swale

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3 IMPLEMENTING LID ON AN ARMY INSTALLATION

3.1 INTRODUCTION

Implementation of LID on an Army installation can be achieved at various levels, from master planning, Installation Design Guides and through planning charrettes and site planning and design for specific projects. This chapter will take the user through LID implementation from the master planning level down to the site specific final design of a LID BMP. For the purposes of meeting the stormwater requirements and EISA Section 438, the site planning sections will guide planners, designers, engineers and stormwater managers through the steps of planning their site to effectively choose LID BMPs that meet the stormwater volume requirements. The master planning and site planning processes require a basic understanding of Army Land Uses and activities and a fundamental knowledge of Army planning and site design Uniform Facilities Criteria (UFC's), Public Works Technical Bulletins (PWTB's), Directives, and Regulations, which are referenced throughout this chapter and listed in Section 1.3.3.

3.2 LID AND INSTALLATION MASTER PLANNING

Army master planning is a continuous analysis of present and future development needs of an installation in a sustainable and energy efficient manner. Through the master planning process, a vision is established for the installation with goals and objectives, which is an opportunity to imbed LID into the future development and management of the installation. Figure 3-1 and Figure 3-2 illustrate the master planning process, from the vision plan for the installation through the Installation Design Guide (IDG), short-term and long-term development planning and project site requirements; from installation scale planning to site planning. While strategizing the layout of land uses and connectivity of resources with functional relationships, water resources and stormwater infrastructure should also be considered. The identification and understanding of the existing natural features, installation land uses, and infrastructure, and the potential hydrologic response of planned development and opportunities to restore hydrologic functions are critical in creating a sustainable installation. This concept can be carried through in the IDG and Area Development Plans (ADP).

An IDG provides design standards and guidelines for the visual aesthetics of an installation, to include both the built and natural environment, to create a comprehensive and sustainable installation character. The IDG includes standards and general guidelines for the design issues of site planning; architectural character, colors and materials; vehicular and pedestrian circulation; and landscape elements. LID should be incorporated into the standards and guidelines for site planning for all land uses, especially for buildings, roads, parking lots and landscape elements. These LID standards and guidelines will carry through to short-term and long-term project requirements and ADPs.

The ADP process uses urban design principles to integrate incompatible land uses and functional requirements within the existing manmade and natural environment. Army land uses can have certain requirements depending on their purpose and security, such as training areas, communications facilities, and other military operations. Integrating the land uses within a functional area for an ADP can present challenges not only with the requirements but also the site constraints. As many of the land uses can require impervious area, the hydrologic functions of the area need to be considered in the ADP. This is a great opportunity to identify constraints and opportunities for preserving the hydrologic function of the watershed and area by using both non-structural and structural LID BMPs. Identifying these opportunities and including LID in the requirements for project specific plans will help minimize the hydrologic impacts and ensure compliance with EISA Section 438. The remainder of the chapter will take the user through the details of site planning with LID.

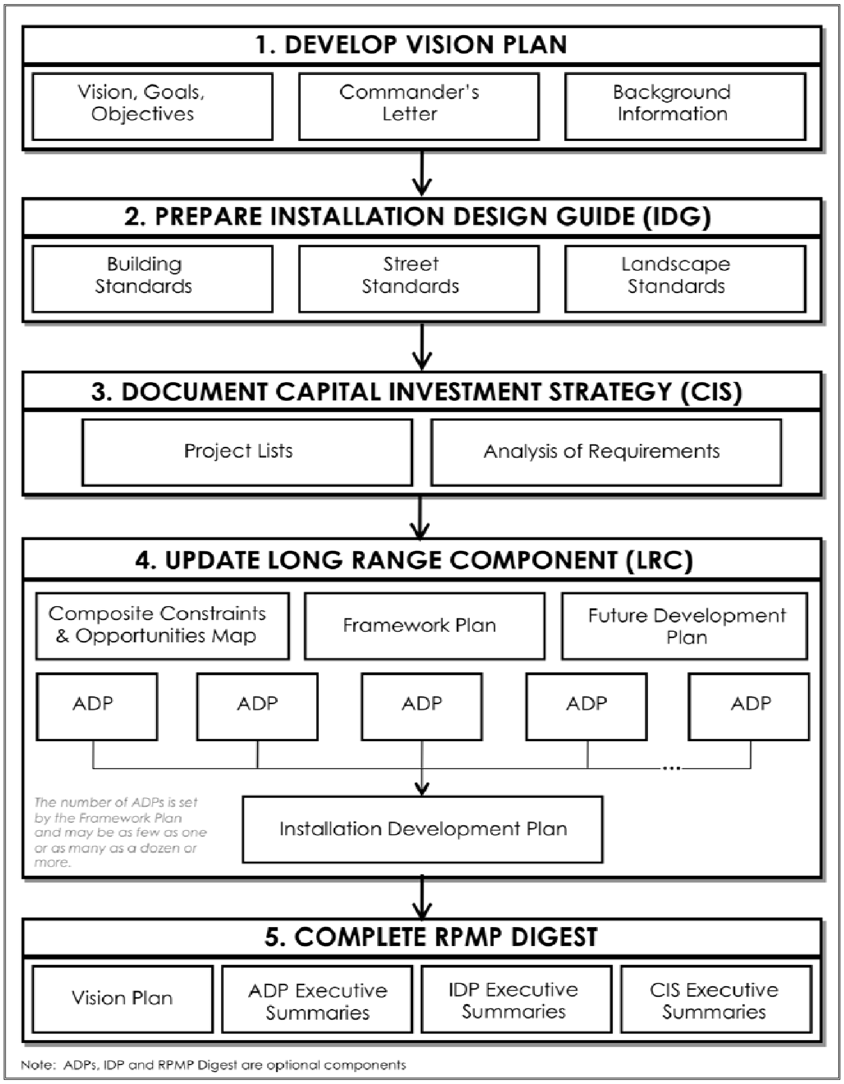


Figure 3-1. Overview of Installation Master Planning Process
(Adapted from: AR 210-20, 2005)

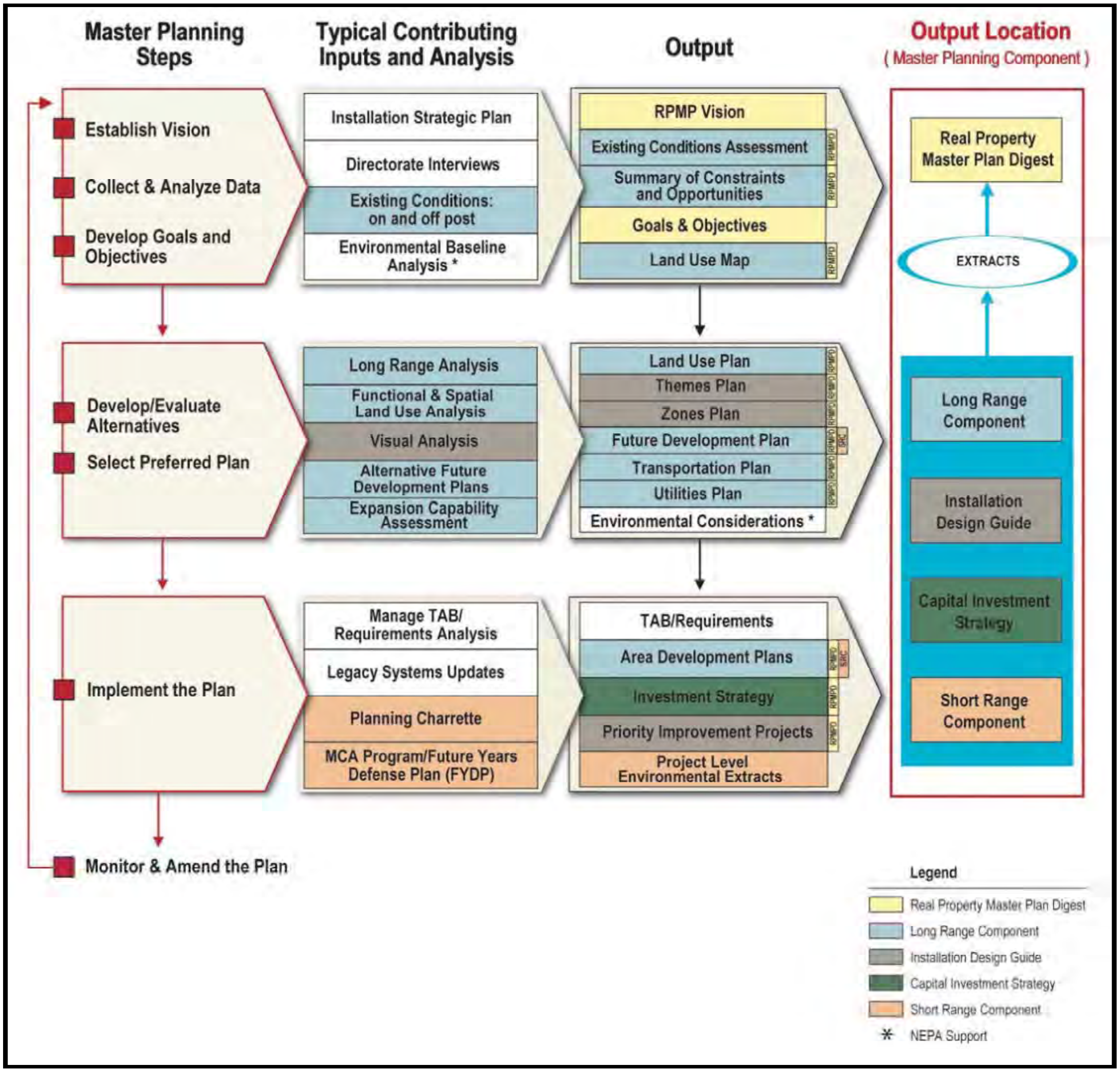


Figure 3-2. Real Property Master Planning
(Source: RPMPTM, 2008)

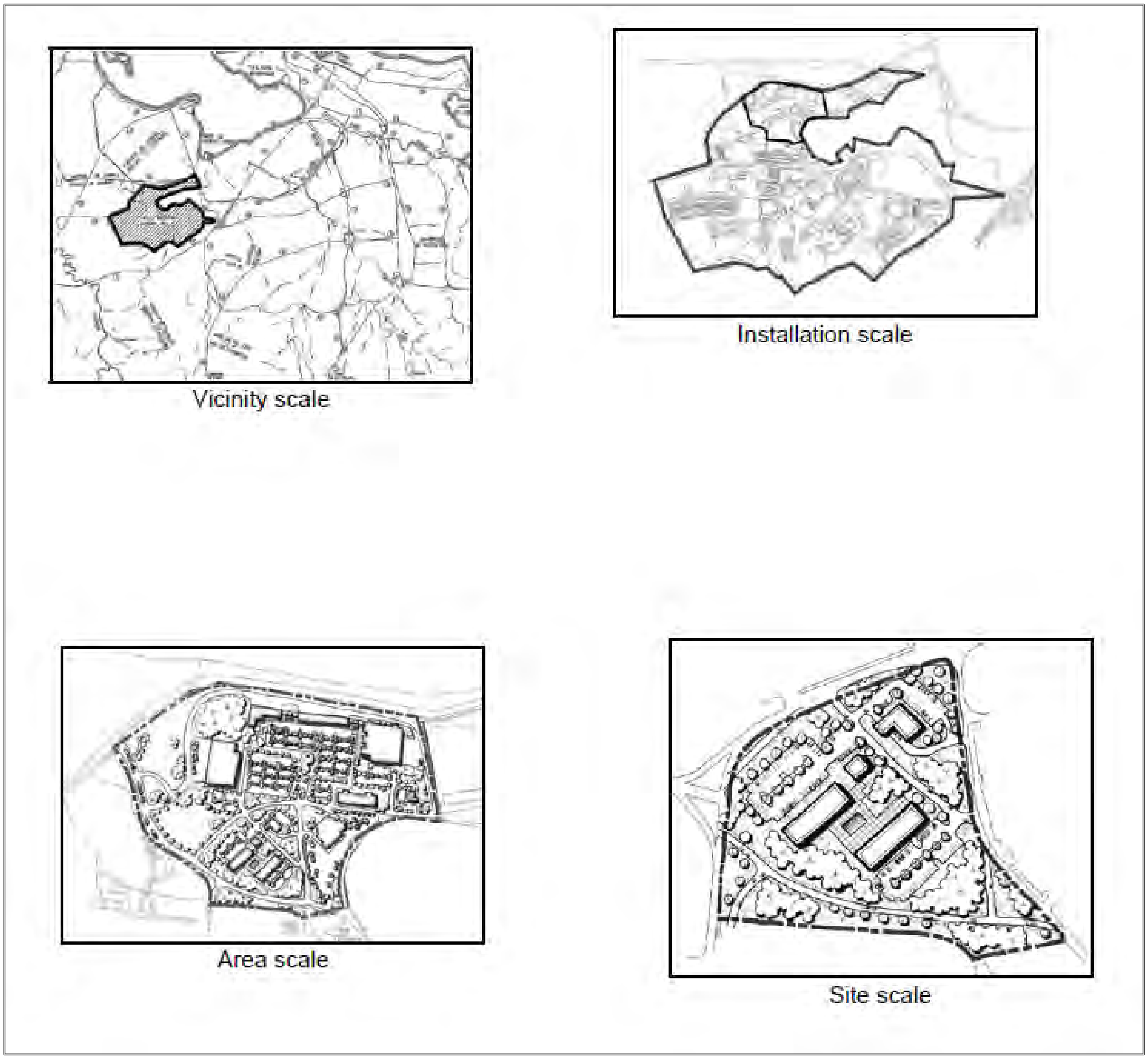


Figure 3-3. Scales of Master Planning
(UFC 3-210-01A, 2004)

3.2.1 Army Land Uses

For the purpose of integrating LID in the planning process and selecting LID BMPs for specific sites, Army land uses can be grouped into five categories based on similarity in land cover type (e.g. parking, open space, buildings), intensity of use, and hydrologic characteristics. This grouping allows planners and site designers to develop consistent and predictable non-structural and structural LID BMP implementation strategies for the installation. The land use categories are adapted from UFC 2-200-02AN (2005) as follows:

1. **Industrial**: Industrial sites are often highly impervious areas, such as roofs, parking, and storage areas that are densely developed with a variety of activities that potentially produce pollutants and high volumes of runoff. These may include areas for manufacturing, supply

and storage, maintenance activities, motor pools, and handling and storage of hazardous materials. Pollutants from industrial activities, such as vehicle washing and repair, are industrial activities and must be treated under separate permits and strategies. Specific land uses include:

- Operations
- Supply/Storage
- Maintenance
- Manufacturing and Production
- Research, Development, and Testing
- Utilities
- Airfield Hangers and Maintenance Areas

2. **Professional/Institutional/Community**: These land uses contain large impervious areas including rooftops and sizable areas for parking, roads, and pedestrian circulation. These facilities include both commercial services such as the Post Exchange and commissary and community services of a non-commercial nature such as the library, chapel, and craft workshops. They also include medical and dental facilities, such as hospitals, clinics, and supporting laboratory facilities. Specific land uses are:

    - Administration
    - Commercial Services
    - Community Facilities
    - Medical and Dental

3. **Residential**: Residential land uses include both troop and family housing areas. Troop areas consist of living quarters for enlisted personnel, non-commissioned officers, and commissioned officers, as well as supporting service, administrative, storage, and supply facilities related to housing. These can be detached houses with large yards, multi-family or barracks with large buildings, parking, and assembly areas, or townhouse type developments. There may be large open spaces between buildings, for assembly areas and for lower density developments. Residential also includes roadways and trails. Specific land uses are:

    - Troop Housing
    - Family Housing

4. **Ranges and Training**: Ranges and Training facilities include classroom buildings and other indoor facilities, as well as outdoor maneuver and range areas. They can have large open spaces as well as building and parking structures. These may include large impervious areas for parking and storage, cleared areas for operations, temporary and permanent roads and trails ranging from dirt to asphalt or concrete surfaces, permanent and temporary buildings and structures. A detailed description of the planning and design of ranges and training areas has been previously published (PWTB 200-1-62, 2008). Specific land uses include:

- Assembly Areas
- Bivouac Areas
- Driver Training Sites
- Drop Zones
- Maneuver Corridors
- Urban Operations (MOUT)
- Multi-Purpose Range Complex
- Parking Areas
- Secondary Roads
- Small Arms Ranges
- Tank Trails

5. **Open Space and Water**: Open space and water areas generally have much less impervious surfaces and may be used for passive and active recreation, reserved areas designated to separate incompatible uses or protect fragile ecosystems, and as a safety measure around operational or training uses. Parking and access roads may be included Specific uses include:

    - Reserved Land/Buffer
    - Recreation
    - Water Areas

The relationship between these land uses on an Army installation is important to the function and circulation for installation activities. It is also important to understand how the siting of these land uses interact with the natural environment and hydrology, both on the installation and within the watershed. Developing these relationships allow for holistic planning for LID that preserves the natural hydrology and environment while achieving the installation mission. Integrating LID BMPs on some of these land uses may be limited due to the types of activities, for example, infiltration practices may be limited on industrial land uses to avoid groundwater contamination, however, a bioretention cell with an underdrain may perform better. The following sections will describe the site planning process in seven steps for the implementation of LID BMPs to meet the requirements of EISA Section 438.

3.3 SITE PLANNING AND SITE DESIGN WITH LID

Site planning for LID involves a shift in the traditional approach for managing stormwater. When planning for a built environment, preventing increased stormwater runoff and maintaining the pre-development hydrology of the site is required by EISA Section 438. Any unavoidable increase in stormwater should be viewed as a resource that can be managed on-site with an opportunity to infiltrate the soils and/or be treated for pollutants by working with the natural site conditions, such as topography and soils. Using non-structural and structural LID BMPs through treatment trains, or in combination with conventional stormwater infrastructure when necessary, will minimize the impacts of the project on the hydrologic function of the site. Maintenance of the LID BMPs needs to be included in the parameters of the site, to ensure sustainability of the site hydrology.

3.3.1 MILCON Execution and LID

Site specific planning under the Military Construction (MILCON) process requires implementation of LID BMPs to comply with EISA Section 438. UFC 3-210-01A (Area Planning, Site Planning, and Design) and UFC 3-210-06A (Site Planning and Design) provide guidance on the site planning and design process and the "Army Standard Operating Procedure: Integrating Low Impact Development into MILCON Process" provides guidance on integrating LID into the early stages of project development and programming. Figure 3-4 illustrates the site planning and design process.

The site planning process begins with planning charrettes and the development of DD Form 1391 or DA Form 4283 where project requirements, site location and costs for the project are determined and carried through to the approval process. The DD Form 1391 is a planning document used to develop project scope and associated costs to complete the project as identified in the "Primary" and "Supporting Facilities" and "Project Description" sections of the 1391. The project 1391 is completed during the Planning Charrette process and is managed by the USACE. Tab J of the 1391 should be used to identify LID related criteria including the square footage of impermeable surface being added to the project site; and a description of LID features planned for incorporation within the project and used to manage the increased runoff from the additional impermeable surface. During this early stage of project planning, LID should be identified as a project requirement, as identified in the Master Plan, IDG and/or ADP.

The Project Definition Report (PDR) is a validation of the scope of work in the DD Form 1391. The PDR is developed and completed during the project Design Charrette process and contains the data for the parametric design (15%). Paragraph 2.1.6 (Site Development/Civil) of the PDR describes site development features that will be used to address LID implementation for the project. A project parametric design (Code 3) consists of a Project Definition Report (PDR) and a completed ENG Form 3086 detailed cost estimate based on the scope of work in the PDR. Identifying LID requirements in the early phases of planning ensures that LID will be carried through to be included in the cost estimate and design process. Figure 3-5 identifies seven steps for optimal LID BMP selection to ensure compliance with EISA Section 438 that should be followed during the planning process from DD Form 1391 developmen through the PDR, Parametric Design and ENG Form 3086.

For a local DPW funded project using Sustainment, Restoration and Modernization program funds (O&M), the process of identifying LID requirements should be determined the same way as outlined in the Project Definition Report (PDR), paragraph 2.1.6. It is imperative that sufficiently detailed LID requirements be identified in the PDR because the 3086 cost estimate is developed to determine the project cost.

For Design-Build projects, it is important to have the installation IDG, ADP and Master Plan updated to identify installation LID policy and preferred LID BMPs for meeting EISA Section 438 requirements. The installation DPW will indicate their preference for certain LID BMPs for a project as they work with the USACE project team who will get the Design-Build project awarded. The USACE project team will identify LID features and submit a concept plan (35% design) or fully developed LID BMP design to be submitted with the RFP. The installation IDG, ADP and Master Plan can be referred to in the request for proposal that will include either the LID BMP concept plan of full LID BMP design to contract with the Architect-Engineer firm. It is imperative that the project manager at the USACE review the AE designs to verify compliance with EISA Section 438. It is important for the project manager to provide construction oversight to ensure the LID BMPs are built correctly.

For Design-Bid-Build projects, the project design to include the full LID BMP designs are included in the bid package developed by the USACE project team. The USACE project team will design the site and LID BMPs to meet the EISA Section 438 requirements. It is important for the project manager to provide construction oversight to ensure the LID BMPs are built correctly.

The following sections will describe the seven steps in Figure 3-5 for integrating LID in site planning and design, which are to be followed concurrently with the site planning and design process for the development project.

LID Site Planning Goals

- Plan first,
- Prevent. Then mitigate,
- Manage stormwater as a resource – not a waste,
- Mimic the natural water cycle,
- Replicate pre-development hydrology where possible,
- Integrate natural systems,
- Disconnect. Decentralize. Distribute,
- Maximize the multiple benefits of LID,
- Use LID everywhere, and
- Make maintenance a site parameter.

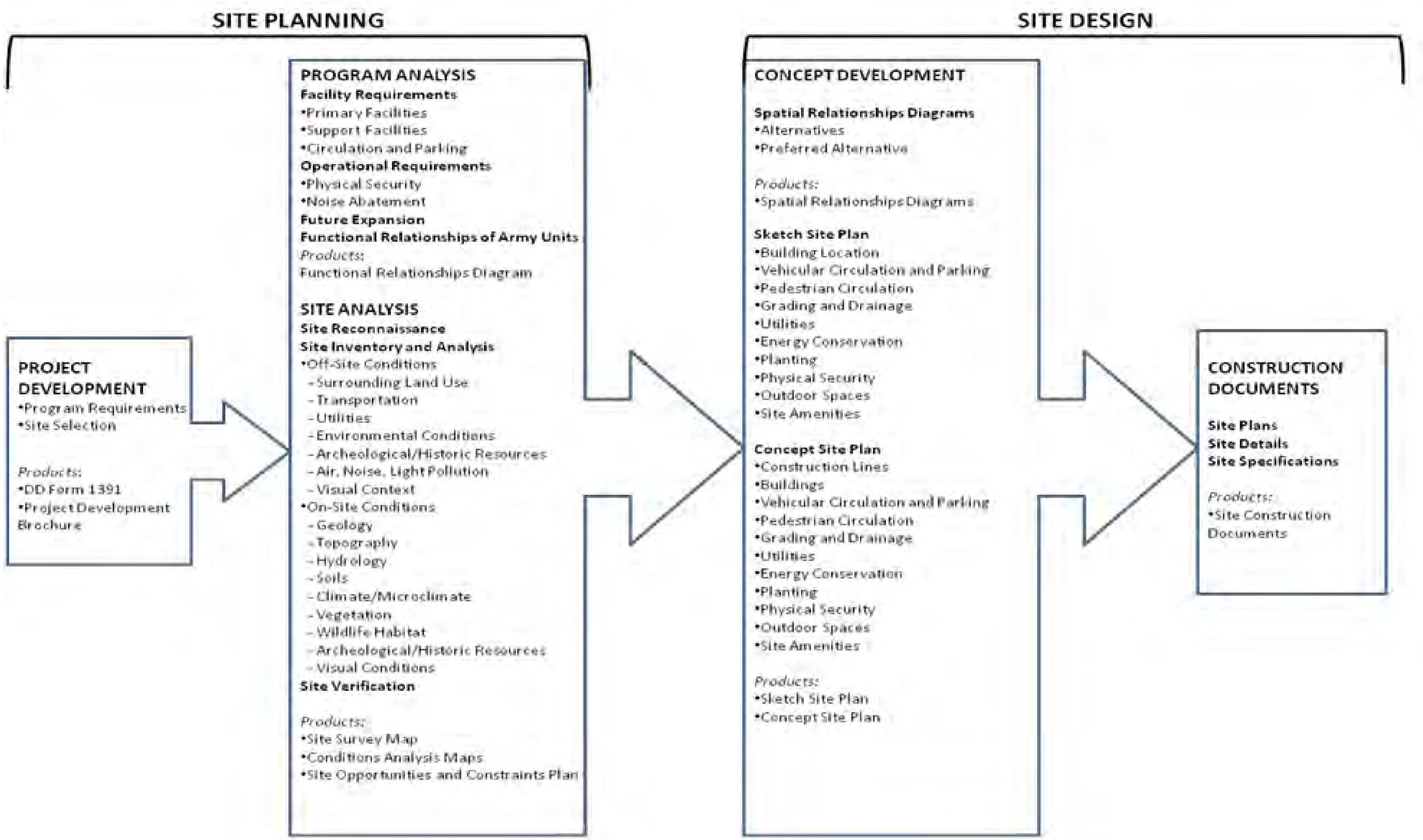


Figure 3-4. Site Planning and Design Process
(Source: UFC 3-210-06A, 2004)

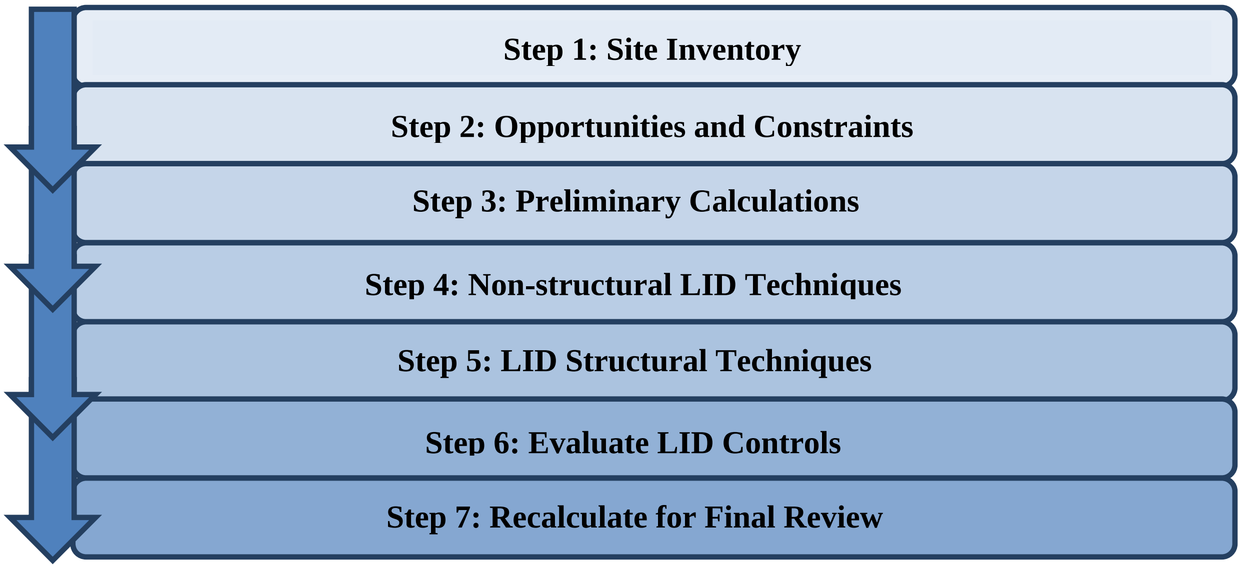


Figure 3-5. Steps for Site Planning and Design for LID

3.3.2 LID Site Planning and Design Step 1: Site Inventory

The first step to planning a site is to take a detailed inventory of what currently exists on the site and the site conditions. Incorporating LID into site design begins with a thorough assessment of the site and its natural systems which may pose challenges and/or opportunities for stormwater management and site development. Substantial guidance on the assessment of natural systems and infrastructure has been developed in UFC 3-210-01a and UFC 3-210-06a and supporting documents regarding collecting data on the natural environment, built environment, and the socio-cultural environment for site planning; in this Army LID Technical User Guide, the focus will be on collecting data with the goal of integrating LID into site planning and design.

<u>Environmental and Man-Made Features to Consider in LID Design</u>

- Geological Conditions
- Soils
- Hydrology
- Topography
- Natural Resources
- Land Use/Land Cover
- Facilities Infrastructure

Site conditions that influence LID BMP selection and design include geology, soils, hydrology, topography, natural resources, land use/land cover and facilities infrastructure. The site inventory should include data collection on these features, as described in the following sub-sections adapted from UFC 3-210-01a and UFC 3-210-06a, and spatial data to develop the opportunities and constraints maps in Step 2 of the LID Site Planning process. While conducting the site inventory for project planning and LID Site Planning, keep in mind that the goal is to maintain pre-development hydrology by avoiding, minimizing and/or mitigating project impacts to the hydrologic function of the site. Key environmental and man-made systems including human environment features and their importance to LID design are described below.

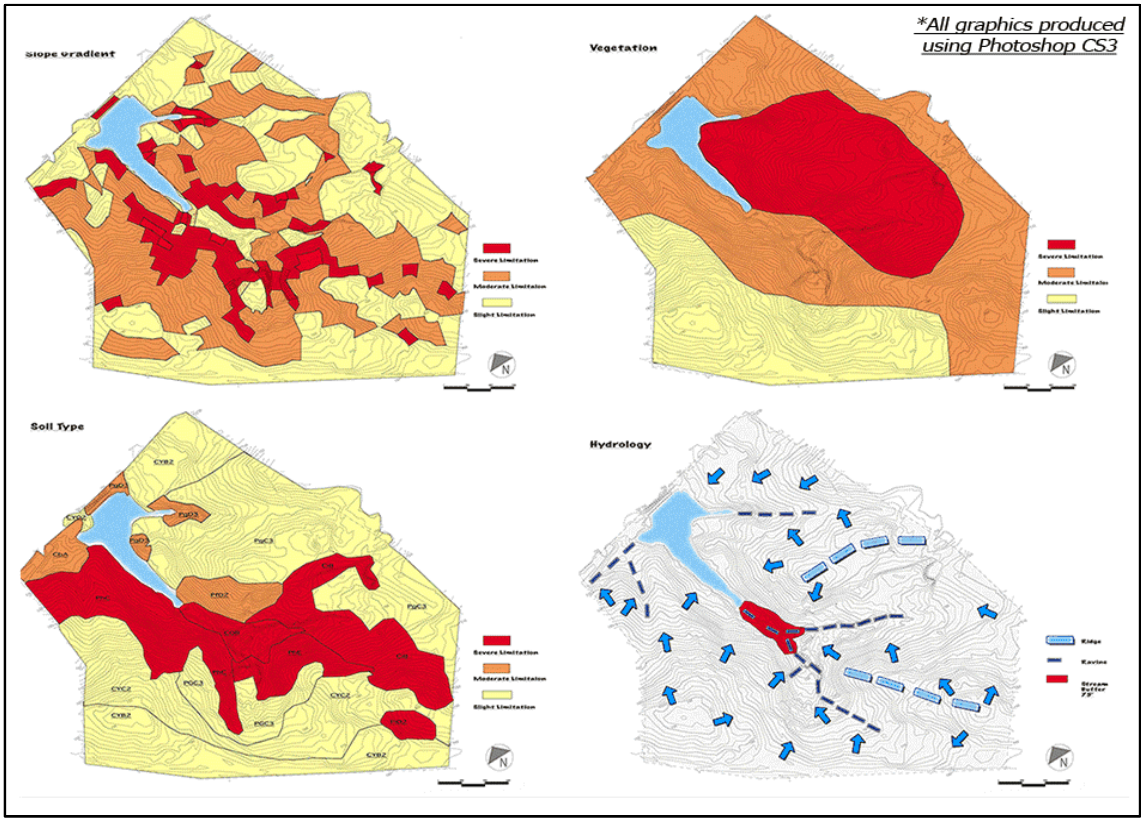


Figure 3-6. Watershed Inventory of Natural Resources
(Source: Birtice A. Garner IV, The University of Georgia)

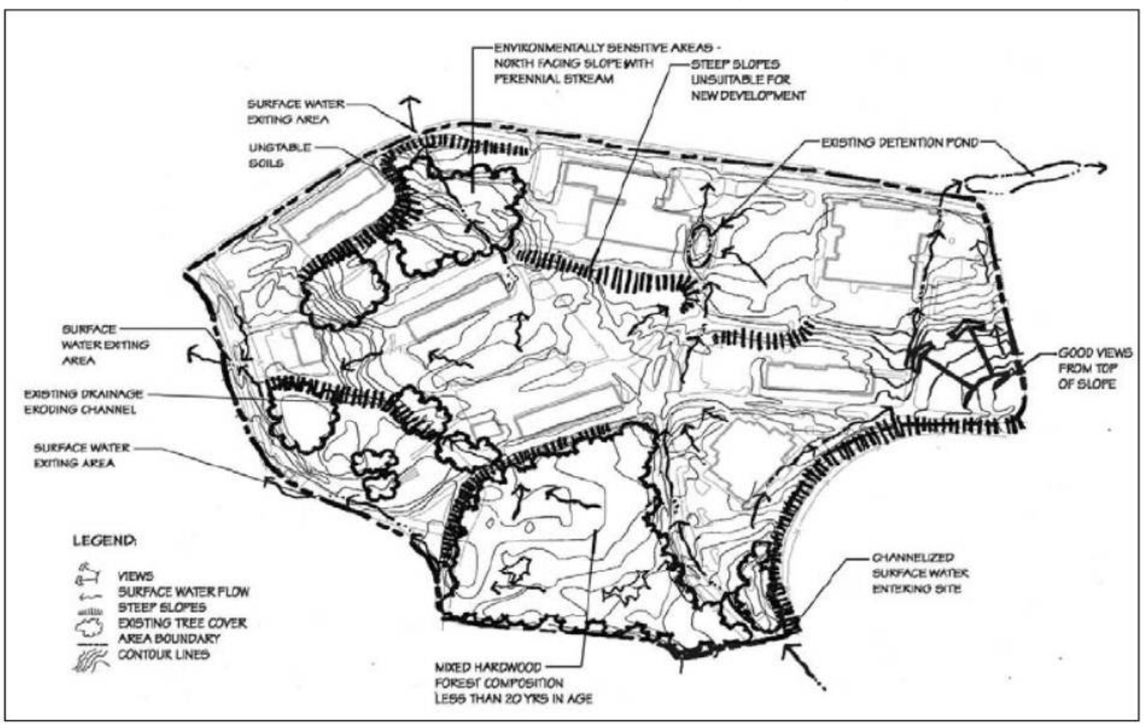


Figure 3-7. Site Inventory
(Source: UFC 3-210-01A, 2004)

3.3.2.1 Geologic Conditions

The geologic conditions of the site that should be inventoried include underlying geologic formations, depth to bedrock, substrate drainage, and areas that are sensitive to erosion from groundwater, such as limestome or Karst topography. This data can be collected from the U.S. Geologic Service (USGS) or from state resource agencies. If the project is in an area of concern (e.g. limiting formations, limestone or karst topography) field investigations, borings, and geologic assessments should be conducted. Understanding the geologic conditions of the site is important for LID site planning, as it may restrict the use of on-site infiltration – shallow bedrock will limit infiltration and karst topography or high water tables may allow for polluted runoff to enter the groundwater before sufficient filtration can occur.

3.3.2.2 Soils

The soils on the site are a key element in LID planning, as the characteristics of the soil will influence the selection and design of LID BMPs. Soils have varying infiltration capacity and permeability, which influences the amount of runoff from the site; as such soils are divided into four hydrologic soil groups (NRCS, 2007):

- **Hydrologic Soil Group A**: Soils in this group have low runoff potential when thoroughly wet. Water is transmitted freely through the soil. Group A soils typically have less than 10 percent clay and more than 90 percent sand or gravel and have gravel or sand textures. Some soils having loamy sand, sandy loam, loam or silt loam textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments. They consist chiefly of deep, well to excessively drained sands or gravels and have a high rate of water transmission (greater than 0.30 in./hr.).

- **Hydrologic Soil Group B**: Soils in this group have moderately low runoff potential and moderate infiltration rates when thoroughly wet. Water transmission through the soil is unimpeded with a moderate rate of water transmission (0.15 to 0.30 in/hr). Group B soils typically have between 10 percent and 20 percent clay and 50 percent to 90 percent sand and have loamy sand or sandy loam textures. Some soils having loam, silt loam, silt, or sandy clay loam textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments. Group B soils consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately course textures.

- **Hydrologic Soil Group C**: Soils in this group have moderately high runoff potential when thoroughly wet. Water transmission through the soil is somewhat restricted with a layer that impedes downward movement of water; the rate of water transmission is moderate (0.05-0.15 in/hr). Group C soils typically have between 20 percent and 40 percent clay and less than 50 percent sand and have loam, silt loam, sandy clay loam, clay loam, and silty clay loam textures. Some soils having clay, silty clay, or sandy clay textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments.

- **Hydrologic Soil Group D**: Soils in this group have high runoff potential when thoroughly wet due to very low infiltration rates; these soils have a very low rate of water transmission (0.00 to 0.05 in/hr). Water movement through the soil is restricted or very restricted. Group D soils typically have greater than 40 percent clay, less than 50 percent sand, and have clayey textures. In some areas, they also have high shrink-swell potential. All soils with a depth to a water impermeable layer less than 50 centimeters [20 inches] and all soils with a water table within 60 centimeters [24 inches] of the surface are in this group, although some may have a dual classification, as described in the next section, if they can be adequately drained.

During the site inventory, soils can be identified using soil surveys, which can be found on the internet at the NRCS Soil Data Mart website: *http://soildatamart.nrcs.usda.gov/* or the Web Soil Survey website: *http://websoilsurvey.nrcs.usda.gov/*. These resources provide detailed information about the soils on site, including spatial data, drainage class, ability to transmit water (hydraulic conductivity), approximate depth to groundwater, and general properties and qualities. For the purposes of LID site planning, the hydraulic conductivity and the hydrologic soil group are key characteristics, as they dictate the runoff potential of the soils on site. This needs to be considered when selecting LID BMPs that will infiltrate the natural soils, or if they will require soil amendments, addition of soil media, or an underdrain where water cannot infiltrate. Depth to groundwater must also be considered to avoid polluting groundwater from limited filtration. Once a concept plan is developed, additional borings at proposed LID BMP locations may be required to determine the infiltration rates for the design of the LID BMP.

Some of the limitations include soils with low permeability, high shrink-swell soils, or soils susceptible to frost heaving, soils susceptible to wind erosion, soils with high organic material, soils with high water tables or confining (compacted) layers, soils with high erosion potential, or soils that are unstable for grading as steeper slopes. Soils with high infiltration rates should be protected from construction activities and development because they have the ability to infiltrate larger volumes of water after development.

3.3.2.3 Hydrology

Hydrology on the site includes surface waters, such as streams and wetlands, and groundwater as well as precipitation data. It is important to understand where the site is positioned in the watershed, to consider upstream effects and potential downstream impacts from the project. In order to meet EISA Section 438, the pre-development hydrology of the site must be maintained, so understanding the existing hydrology and functions of the site is critical. The capacity and the function of the drainage infrastructure surrounding the site is also an important factor.

An inventory of the hydrology of the site should include:

- Precipitation data
- Location and functions of surface waters, including streams and wetlands
    - Drainage area – subbasins and larger watershed information
    - Flow direction
    - Interaction with groundwater
    - Surface area
    - Classification (i.e, perennial, intermittent or ephemeral stream)
    - Waterbody impairments (i.e., TMDL)
- Groundwater supplies and depth
- Floodplain areas and flooding concerns
- Drainage basin and watershed characteristics and mapping

Much of this information can be found in the installation Master Plan, the Integrated Natural Resources Management Plan, and other installation documents provided by the installation DPW. Other sources of information include National Oceanic and Atmospheric Administration precipitation data (www.noaa.gov), the US Fish and Wildlife Service National Wetlands Inventory (http://www.fws.gov/wetlands/), Federal Emergency Management Agency floodplain maps, and state and local agencies.

Planning for LID BMP selection and placement, requires an understanding of the hydrology and functions on the site and within the watershed. The LID BMPs should work with the existing hydrology, so the natural hydrology of the site is maintained and continues to function without adversely impacting existing water resources and downstream resources.

3.3.2.4 Topography

Topography on the site, and the surrounding area, strongly influences the direction of runoff across the site. Topographic data will show slopes, potential drainageways, low points and depressions where water may flow or be stored. This data may be available at the installation DPW or the installation spatial data office. If topography is not readily available on the installation, contour lines and digital elevation models (DEM) are available from USGS and state and local agencies. For detailed topography, a survey may be conducted on the site.

Understanding the topography of the site will help with the location of LID BMPs. It is best to use the existing topography and minimize grading when possible, to maintain the natural flow paths down slopes and drainageways. Placement of a LID BMP at the bottom of a slope or along a drainageway works with the natural landscape and will minimize ground disturbance and stormwater infrastructure requirements. LID BMPs such as vegetated swales, bioretention and level spreaders can and should be designed to take advantage of the existing slopes, depressions and flat open space.

3.3.2.5 Natural Resources

Natural resources on the site and in the surrounding area can play a significant role in planning for LID. An inventory of the vegetative communities and habitat areas will identify any sensitive ecological areas that may need protection. Sensitive areas could include wetlands, old growth forests, rare, threatened and endangered species habitat, riparian zones, and habitat corridors. The vegetative cover and soils on the site will influences the movement of water across the site, as vegetation can slow the runoff and aid in infiltration into the soils; this information is necessary to determine the curve number for hydrologic simulation as discussed in Chapter 4. Natural resources data can be found in the Installation Natural Resources Management Plan or by conducting a survey of flora and fauna. State and local resource agencies can also supply information regarding rare species and sensitive habitats.

Natural areas can provide buffers to streams and wetlands, dissipate stormwater runoff sheetflow, and provide pollutant removal benefits from runoff. Protecting these natural areas coincides with several non-structural LID BMP, and can provide great ecological and hydrologic benefits at minimum costs.

3.3.2.6 Land Use/Land Cover

Existing land use and land cover on and surrounding the project site play a significant role in the movement of stormwater across the area. *Land use* refers to the activity, economic purpose, intended use, and/or management strategy placed on the land cover type(s) by human agents or land managers. *Land cover* refers to the characteristics and surface cover of Earth's surface, as represented by vegetation, water, bare earth, impervious surfaces, and other physical features of the land. Areas of forested lands and open areas will slow the movement of water and allow for infiltration, while areas of impervious surface restrict infiltration and typically convey water to stormwater infrastructure. A change in land use on the site from pervious to impervious surface will significantly impact the hydrology of the site and the surrounding area, by reducing the opportunity for infiltration and altering the natural flow paths and velocity of stormwater. Understanding the relationship between the existing and proposed changes to land use and the hydrology of the area will allow for effective planning and implementation of LID BMPs to preserve the pre-development hydrology of the site. The cumulative impacts of land uses and changes to land use upstream of the site should also be considered to plan for changes in hydrology on a comprehensive level. Land use and land cover data may be found at the installation DPW and/or GIS office or from a state agency. Future land use and land cover changes can be determined from the Installation Master Plan.

Preserving open space and vegetated areas, minimizing grading, and maintaining existing natural drainageways and flowpaths are appropriate non-structural LID BMPs to include during the planning phases. Incorporating structural LID BMPs will work with most land uses, as there are great opportunities for LID BMPs in parking lots.

3.3.2.7 Facilities Infrastructure

Mapping of the existing facilities infrastructure, to include stormwater infrastructure, utility lines, roads, and other man-made features, are necessary to determine opportunities for LID BMPs. This map is available at the installation DPW office and/or GIS office.

There may be opportunities to retrofit stormwater infrastructure with a LID BMP or to reduce a planned conventional stormwater system by incorporating LID BMPs. Understanding the existing and proposed networks of roads and pipes, allow for an opportunity to take a comprehensive look at where incorporation of LID BMPs can create a more natural hydrologic regime on site and in the surrounding area.

3.3.3 Site Planning and Design Step 2: Opportunities and Constraints

Using all of the data collected in the Site Inventory step, maps of geology, soils, hydrology, topography, land use/land cover, and facility infrastructure can be overlayed to identify areas of opportunities and constraints for planning a development project with non-structural and structural LID BMPs (Figure 3-8). This analysis can and should extend outside of the site to include watershed and installation scale factors or influences. This data analysis process must consider and incorporate the potential for change in the hydrologic function during future development activities.

The opportunities and constraints map should consider the all of the existing physical conditions on the site, both natural and man-made, within the context of the development program. Identifying the opportunities and constraints provide the foundation for making decisions on the site layout and the location of non-structural and structural LID BMP practices. When planning the development project and integrating LID, restricting development on areas with mature vegetation and soils with high infiltration rates, and maintaining drainage patterns to those areas is an example of a non-structural LID BMP that could reduce the amount and size of structural LID BMPs and any necessary stormwater infrastructure. The opportunities and constraints map will provide a guide for the configuration of the development project and illustrate opportunities for the integration of LID. Opportunities for LID include, for example, preserving riparian buffers, using the existing topography to locate swales or bioretention, allowing for infiltration where soils permit and risk of groundwater pollution is low and retrofits to existing stormwater infrastructure and impervious surfaces. Constraints for LID include steep or unstable slopes, risks of contamination to groundwater by using infiltration associated with a shallow water table, impermeable soils that would limit infiltration, risks of flooding would influence LID BMP selection, and some ATFP requirements.

Figure 3-8 shows an opportunity and constraints map that addresses the physical features of the site. It includes recommended buffers, potential areas for development, and flow patterns that should be preserved. LID focuses on maintaining existing flow patterns and volumes, as well as buffers to protect the hydrologic function of the resource.

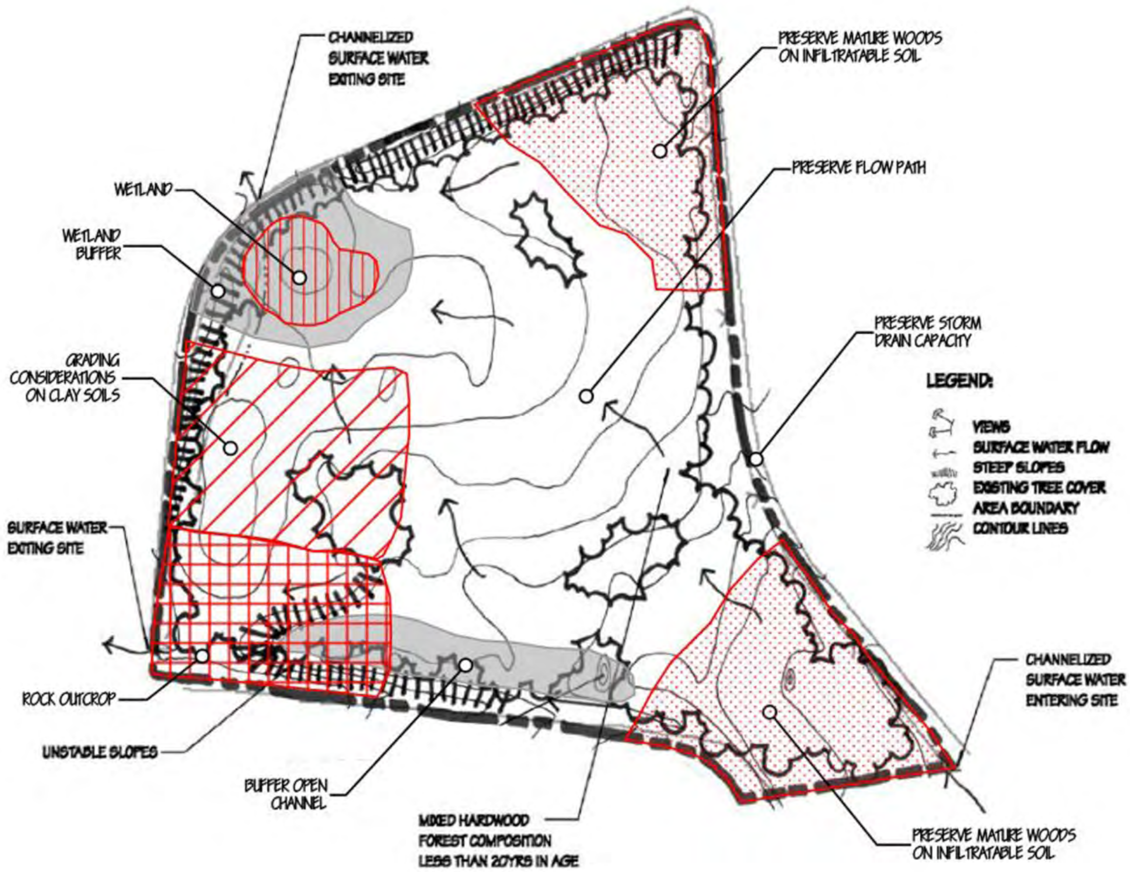


Figure 3-8. Site LID Opportunities and Constraints
(Source: UFC 3-210-01A, 2004)

3.3.4 Site Planning and Design Step 3: Preliminary Calculations

The requirements of the development project with regards to building space, parking, and other associated needs are identified during the planning charrette and DD-1391 development for the project and will direct the configuration of the site and provide an estimate of ground disturbance. As the focus of EISA Section 438 is to maintain pre-development runoff volume, runoff rate, and the temperature of runoff, the existing hydrologic conditions and the post-development hydrologic conditions must be calculated to demonstrate the difference in stormwater runoff pre- and post-development. A volume of stormwater runoff will be calculated from the hydrologic analysis using one of two options that will be the required volume of runoff to be managed on site using LID BMPs. The project engineer or a hydrologist can perform these preliminary calculations and follow them through the project as LID BMPs are incorporated.

The two options for estimating the required volume of runoff that needs to be retained on-site using LID BMPs to comply with EISA Section 438 are described in detail in Chapter 4, along with a hydrologic simulation tool to assist in the calculations. One option is to retain the runoff from the 95th percentile rainfall event. The second is to conduct a detailed hydrologic analysis of the site to compare the pre-and post-development hydrologic conditions. Both methods require some assessment of the post-development runoff characteristics in order to determine the appropriate mix and type of LID BMPs to meet the requirements. Other federal and state regulatory requirements and infrastructure capacity requirements must also be satisfied. This may require the use of more than one method of analysis to determine the hydrologic, hydraulic, and water quality management approach for the project.

Once the initial volume requirements or pre-development conditions for the base are determined, a concept plan that includes LID strategies and techniques can be developed.

3.3.5 Site Planning and Design Step 4: Non-Structural LID BMPs

At this point in the site planning and design process, the project requirements and site conditions are known and site design can begin. Using the opportunities and constraints maps with the project requirements and the stormwater runoff volume requirements, conceptual designs can be created using non-structual LID BMPs. The method of developing non-structural site planning and design strategies is an iterative process with an objective to develop a plan with the least impact on the hydrologic function.

The opportunities and constraints map identifies sensitive environmental areas and illustrates areas to preserve. The development footprint should occur outside of stream and wetland buffers, areas with steep slopes, soils with high infiltration rates, and mature vegetation. The width and conditions of the buffers are dependent on many local and regional environmental factors, including but not limited to habitat type, soil erosion factors, and receiving waters conditions. Flow patterns and flow lengths should be maintained wherever possible. Opportunities to connect or enhance buffers and corridors should also be identified. The development area can be then be distinguished. Figure 3-9 illustrates how to use the site conditions, such as the topography, to orient development to preserve drainageways, which helps mimic the pre-development hydrology; the road and buildings are aligned parallel to the contours so that grading is reduced and stormwater runoff flows can be disconnected or sheet flow into vegetated areas. Figure 3-10 shows opportunities for non-structural LID BMPs that work with the site conditions and the development requirements for the site: riparian and wetland buffers are preserved as are existing flowpaths and mature woods with infiltratable soils. Figure 3-11 illustrates clustered development to maximize the use of space while minimizing impacts to the natural hydrology.

Planning and site design requirements, including ATFP, ASHRAE, LEED, Installation Design Guides, and Technical Manuals must also be met and incorporated into the design.

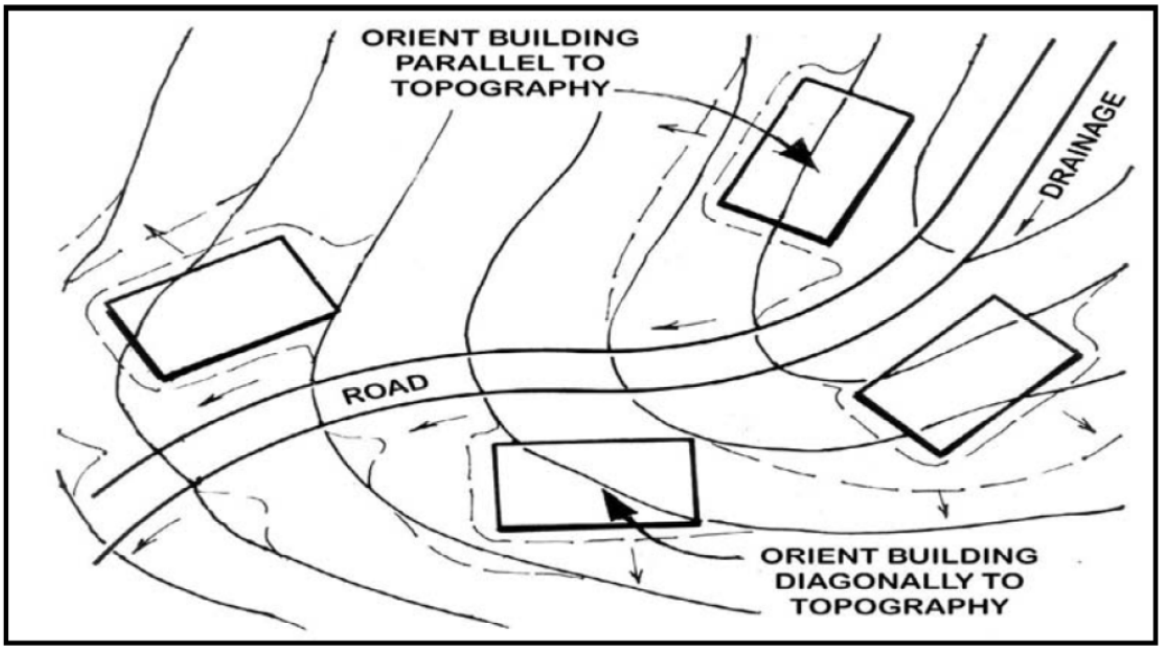


Figure 3-9. Site Concept Plan Using Existing Natural Conditions
(Source: UFC 3-210-01A, 2004)

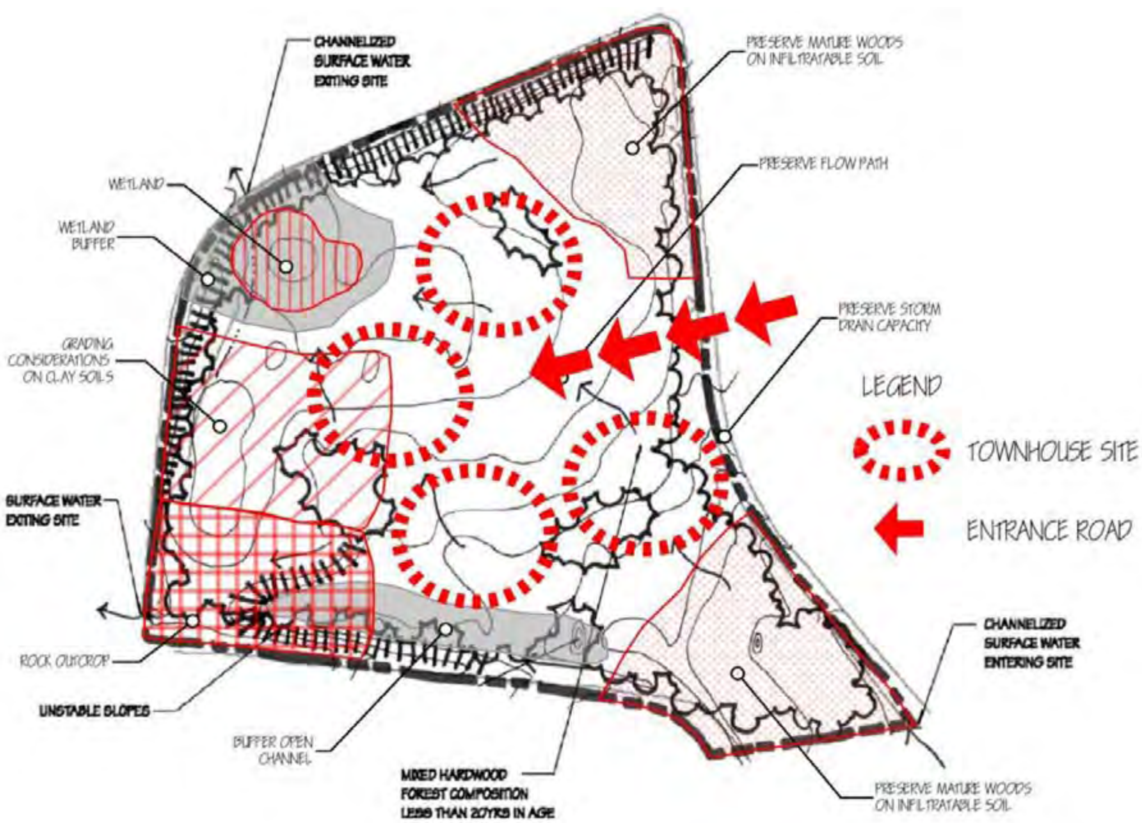


Figure 3-10. Concept Design with Non-Structural LID BMPs
(Source: UFC 3-210-01A, 2004)

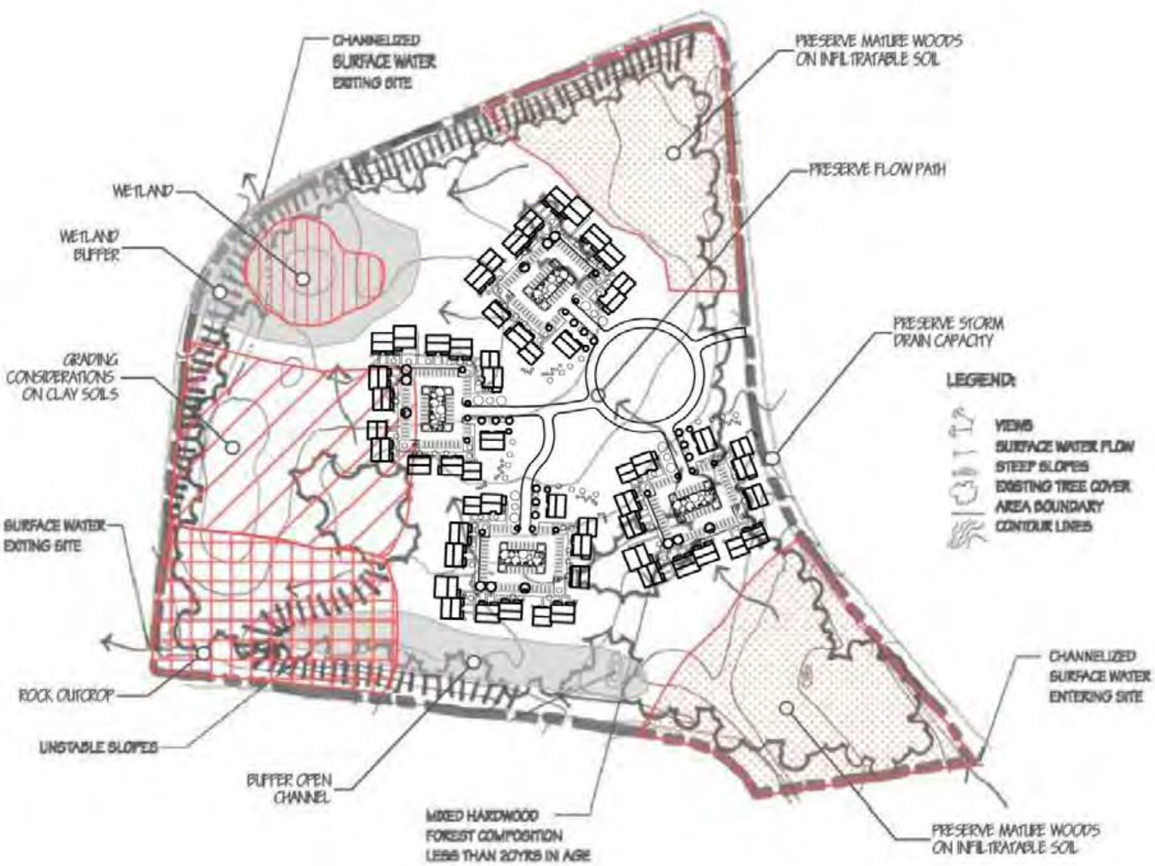


Figure 3-11. Detailed Site Design Using Non-Structural LID BMPs
(Source: UFC 3-210-01A, 2004)

3.3.6 Site Planning and Design Step 5: Structural LID BMPs

Non-structural LID BMPs can go far to maintain pre-development hydrology, though may likely not alleviate all hydrologic impacts alone. Applying structural LID BMPs on-site with the non-structural LID BMPs can provide cumulative benefits to meet the requirements of EISA Section 438. An overview of structural LID BMPs is found in Chapter 2 and design and construction specifications for the most common structural LID BMPs is found in Chapter 5. Structural LID BMPs may be combined with other LID BMPs or can tie into a conventional stormwater system.

Figure 3-12 shows a conventional stormwater management system that collects runoff into a pipe and carries it directly to a stormwater pond to store before discharging the water off-site. Figure 3-13 illustrates how non-structural and structural LID BMPs can reduce the need for portions of the conventional stormwater system by incorporating BMPs without altering the configuration of the development. Permeable pavers are used in the parking lot, bioretention is used in the parking lot island, and a bioswale is located where a drainageway may already exist. However, due to limiting factors such as a high groundwater table or soils with low infiltration an underdrain may need to be installed to collect water from the LID BMP and discharge to the stormwater system, as seen by the pipes in Figure 3-13. The use of the non-structural LID BMPs, reforestation and riparian buffer, eliminates the need for a portion of the stormwater system, the pond and pipes. The level spreader slows the flow of runoff to the natural stream as do the bioretention and permeable pavers that discharge to the pipe; this prevents erosive forces on the stream channel and maintains the natural hydrology and aquatic habitat.

Photo 3-1 and Photo 3-2 show how a typical street within military housing can include structural LID BMPs such as permeable paving and the addition of a vegetated "bump-out" along the road, which can also include a bioretention cell or rain garden. This example shows how a street could use LID BMPs such as reduced road widths to reduce pervious surface and permeable pavements to reduce the runoff volume without impacting the land use or density of development.

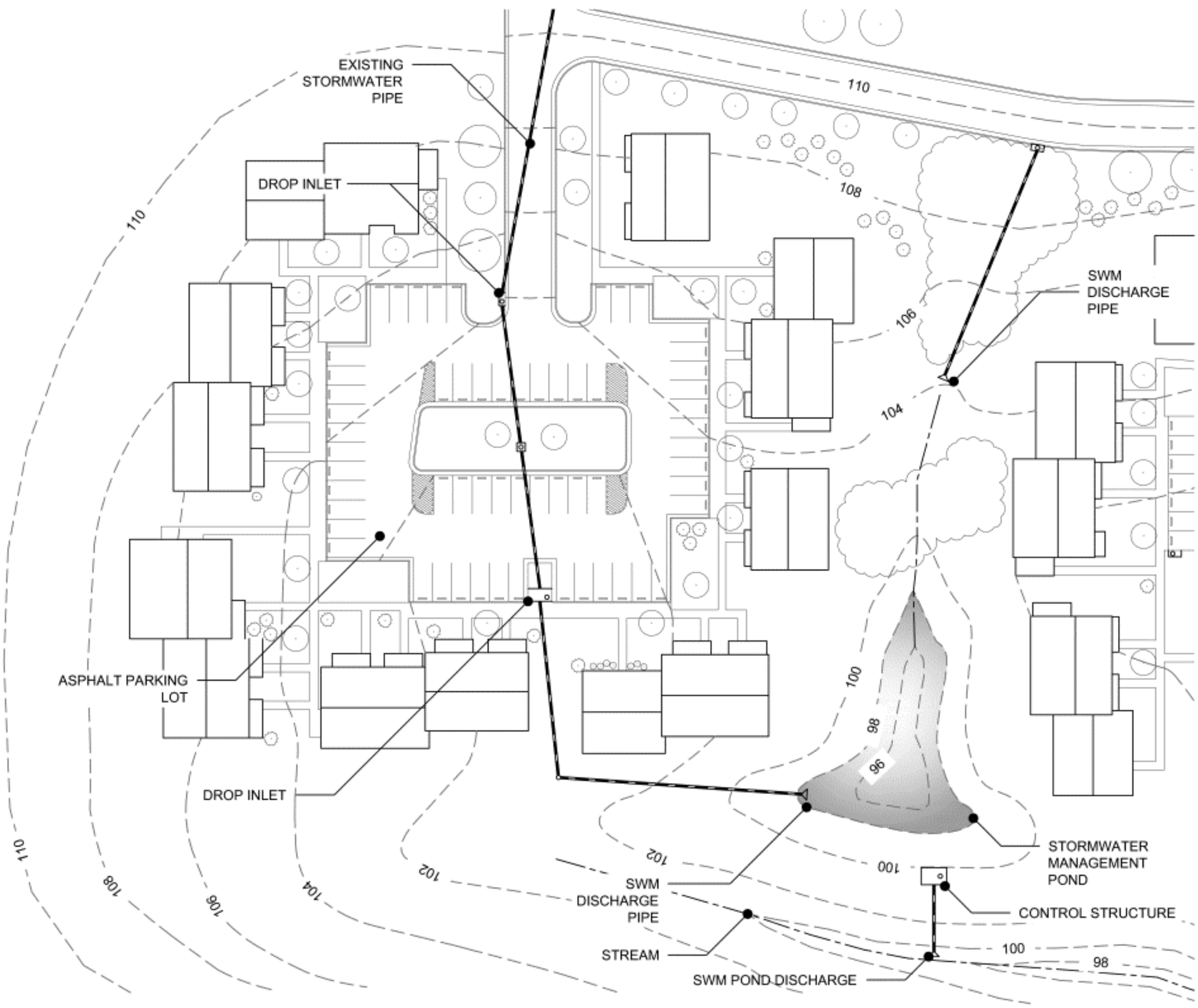


Figure 3-12. Conventional Stormwater Management
(Source: Low Impact Development Center, Inc.)

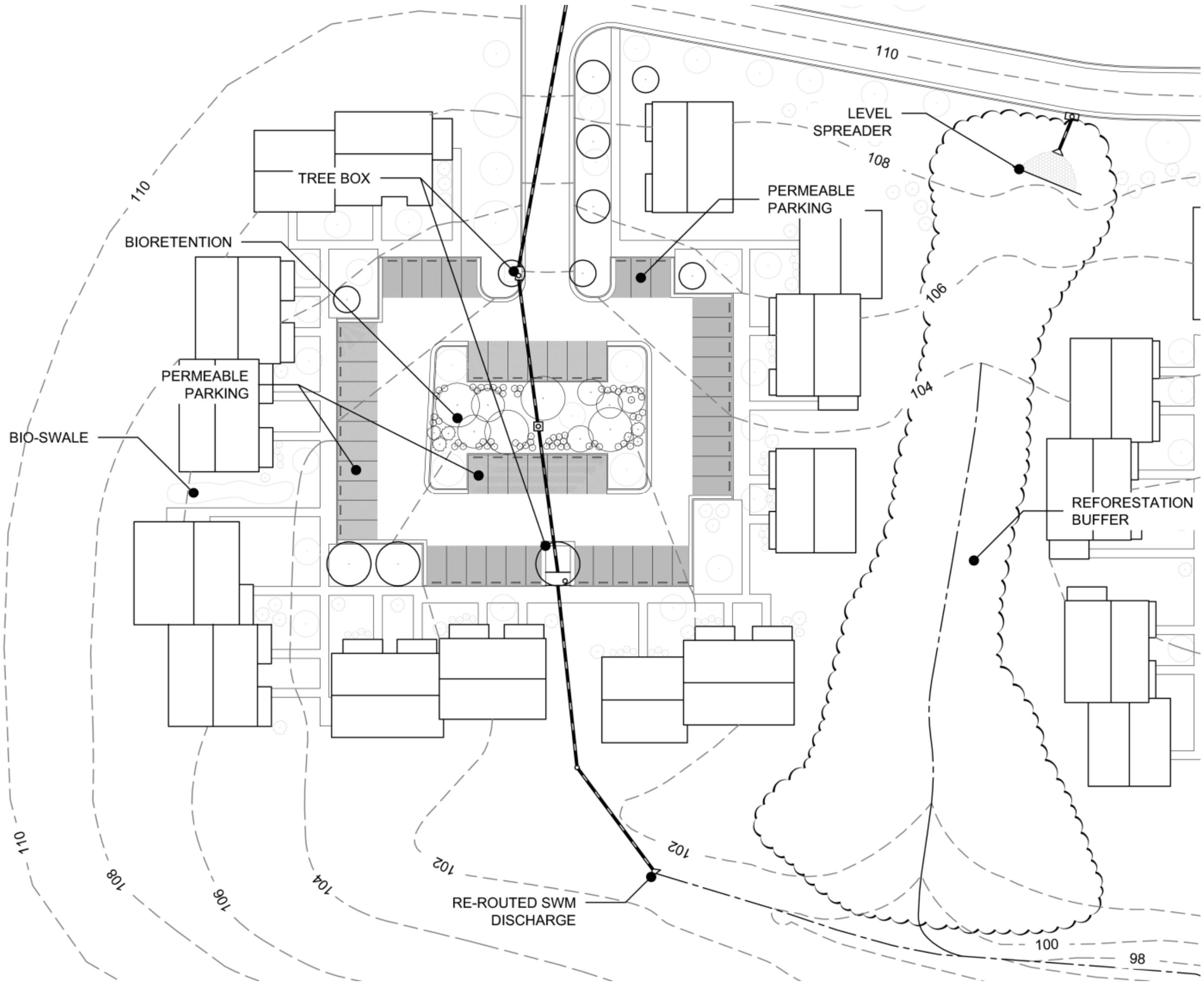


Figure 3-13. Stormwater Mnanagement with LID BMPs
(Source: Low Impact Development Center, Inc.)

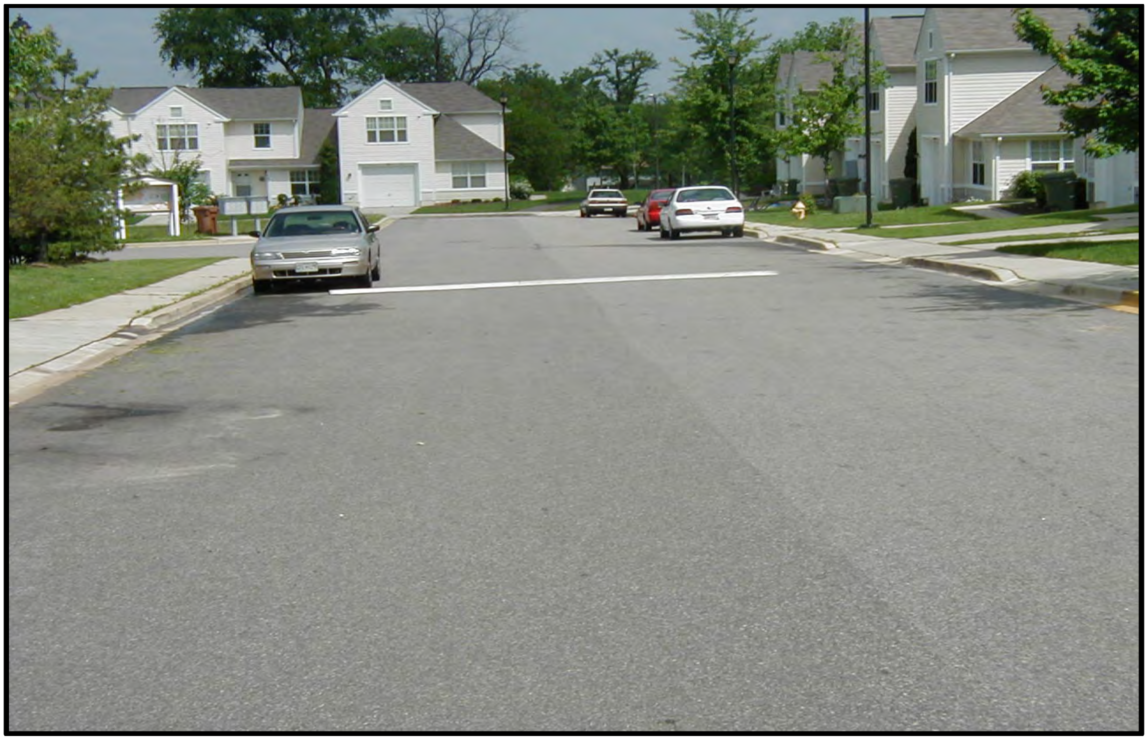


Photo 3-1. Typical Street for Military Housing
(Source: UFC 3-210-10, 2004)

Photo 3-2. Street wtih Structural LID BMPs for Military Housing
(Source: UFC 3-210-10, 2004)

3.3.7 Site Planning and Design Step 6: Evaluate LID BMPs

Once the combination of non-structural and structural LID BMPs is selected and the conceptual designs are complete, the site plan must be reevaluated to determine the effectiveness of meeting the EISA Section 438 volume requirements and any other federal and state requirements. This can be accomplished through repeating the hydrologic analysis from Step 3 for the option that was selected and using the simulation provided in Chapter 4. The results of the hydrologic analysis may indicate that additional LID BMPs are necessary or larger structural LID BMPs. In some instances the volume of stormwater may be too large for the LID BMPs to manage or there may be some other limiting factors on the site. In those instances, additional end-of-pipe, or offsite stormwater controls may be required. Once the site plan team is confident that the type, arrangement and size of LID facilities is appropriate for the land use and can meet the requirements final calculations, construction documents, and be developed.

3.3.8 Site Planning and Design Step 7: Recalculate for Final Review

Once the design for the development to include non-structural and structural LID BMPs is complete, a final review to indicate compliance with EISA Section 438 is conducted. The site design process is iterative in nature and will require repeating Steps 4 through 6 using different configurations and LID BMPs to effectively maintain or mimic pre-development hydrology. The site design must also manage stormwater to meet all state and federal requirements. The final review will include documentation of the site planning and design process to illustrate compliance with EISA Section 438. If it is found that it is technically not feasible to meet the requirements of EISA Section 438, the limiting factors and basis for this conclusion must be documented.

A final site hydrologic and hydraulic report is prepared for regulatory requirements, construction review, and to document compliance with EISA Section 438, ASHRAE 189, and LEED. Final construction details, standards, and specifications are then prepared for construction and project documentation. Details for design, construction and maintenance specifications for structural LID BMPs are found in Chapter 5. It is important to note that the design specifications are clear to ensure structural LID BMPs are constructed properly to ensure function and success.

4 HYDROLOGIC MODELING AND SIMULATION

4.1 INTRODUCTION

This chapter is intended to discuss simple, reliable hydrologic methods and models to quickly estimate volume control requirements, and to allow screening, selection, and approximate sizing of LID BMPs to achieve stormwater volume reduction goals to meet EISA Section 438. The methods and models presented have been used in numerous studies and are generally accepted by regulating authorities.

The purpose of water quantity and water quality modeling is to establish a means for the designer to visualize how water flows through a site, how much runoff is generated in a given sub-catchment, and determine how much water can be captured by a given BMP. This chapter will discuss background information about the design calculations set forth by the EPA Technical Guidance Manual, various hydrologic models to use for each design option and go through case studies applying hydrologic modeling and simulation.

For the purposes of the hydrologic analysis, the site design process is divided into three stages:

1) hydrologic analysis, in which the 95th percentile rainfall event is established, and the corresponding runoff volume for the developed and predevelopment condition are calculated;
2) site design, in which LID site design strategies are implemented to minimize increases in runoff volume resulting from development; and
3) application of BMPs to capture unavoidable runoff.

Standard hydrologic modeling and simulation reference tables are located in Appendix D, for reference to parameters described in this chapter.

4.2 DESIGN CALCULATIONS

The EPA Technical Guidance Manual for complying with EISA Section 438, *Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act* (2009), provides a four step process to implement EISA Section 438 (Figure 4-1). Step 1 is to determine the applicability of the project of being over 5,000 square feet. Step 2 is to establish the design objective and analytical options; two (2) options are provided to meet the performance objective of preserving or restoring the hydrology of the site. Both options require the design, construction, and maintenance of stormwater management practices that manage rainfall on-site and prevent the off-site discharge of stormwater to the METF. Option 1 requires the management of all rainfall less than or equal to the 95th percentile rainfall event Option 1 is a statistical determination of estimating the design retention volume between pre-development and post development conditions. Option 2 requires a detailed hydrologic analysis that uses site-specific and local conditions to demonstrate compliance. Option 2 encompasses continuous modeling techniques which call for a comparison of runoff volume between pre-development and post development conditions over a period of time (multiple storm events) using a period of record rainfall. Step 3 is a description of the representative design considerations and options for management of on-site stormwater; applying LID is the recommended design option to manage the required volume of stormwater determined in step 2. Step 4 is to finalize the site design and the cost estimate.

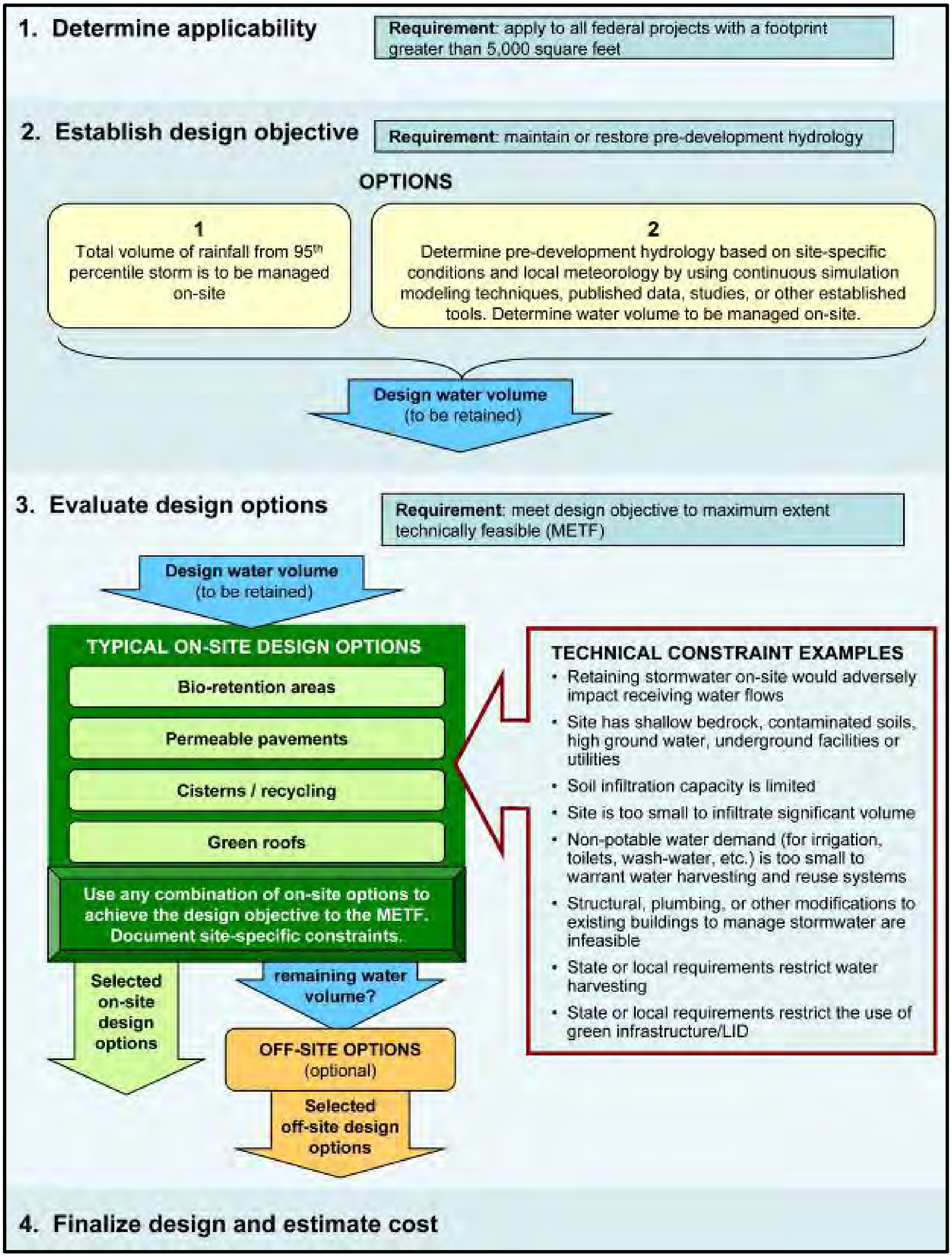


Figure 4-1. Implementation of EISA Section 438
(Source: EPA Technical Guidance Manual, 2009)

4.2.1 Option 1

Option 1 specifies the use of the 95th percentile rainfall event as the basis for the design storm calculation, Table 4-1; the difference in pre and post project volume of rainfall from 95th percentile storm is to be managed on-site. The 95th percentile rainfall event represents a daily rainfall volume, which on average will equal or exceed 95 percent of all daily rainfalls over a given period; at least 20-30 years. In more technical terms, the 95th percentile rainfall event is defined as the measured precipitation depth accumulated over a 24-hour period for the period of record that ranks as the 95th percentile rainfall depth based on the range of all daily event occurrences during this period. The 24-hour period is typically defined as 12:00:00 am to 11:59:59 pm. In general, at least a 20-30 year period of rainfall record is recommended for such an analysis. This raw data is readily available and collected by most airports across the country. Small rainfall events that are on tenth of an inch or less are excluded from the percentile analysis because this rainfall generally does not result in any measureable runoff due to absorption, interception, and evaporation by permeable, impermeable, and vegetated surfaces. Many stormwater modelers and hydrologists typically exclude rainfall events that are one tenth of an inch or less from calculations of rainfall events of any storm from their modeling analyses of rainfall event frequencies. The retention volumes for Option 1 are derived by taking the difference between estimating the pre- and post development runoff volumes for the 95% rainfall. However, this approach does not consider the effect of having series of multiple 24-hour rainfalls. This can be significant, particularly in climates with a greater average number of rainfall days per year, because the LID practices may take days or even weeks to dissipate the captured rainfall. Locations where it is not uncommon to have clusters of several days of rainfall either a dissipation time of more than 24 hours should be used with Option 1 or a continuous simulation as suggested for Option 2 of the EPA Technical Guidance Manual can be used.

Table 4-1. 95th Percentile Storm Events for Select U.S. Cities

City	95th Percentile Event Rainfall Total (in)	City	95th Percentile Event Rainfall Total (in)
Atlanta, GA	1.8	Kansas City, MO	1.7
Baltimore, MD	1.6	Knoxville, TN	1.5
Boston, MA	1.5	Louisville, KY	1.5
Buffalo, NY	1.1	Minneapolis, MN	1.4
Burlington, VT	1.1	New York, NY	1.7
Charleston, WV	1.2	Salt Lake City, UT	0.8
Coeur D'Alene, ID	0.7	Phoenix, AZ	1.0
Cincinnati, OH	1.5	Portland, OR	1.0
Columbus, OH	1.3	Seattle, WA	1.6
Concord, NH	1.3	Washington, DC	1.7
Denver, CO	1.1		

(Source: Hirschman and Kosco, 2008)

4.2.2 Option 2

Option 2 of the EPA Technical Guidance Manual is a hydrologic analysis of pre-development site conditions to establish the base runoff characteristics. The designer compares the runoff characteristics resulting from the proposed development with those of the base runoff conditions. LID practices are incorporated and sized into the site plan such that the character of the post development runoff volume matches that of the base runoff conditions. The dissipation rate is an essential parameter for simulating the performance and determining the appropriate retention volume of LID practices. The relationship of the dissipation rate to the retention volume for LID practices is similar to the relationship between discharge rate and detention volume. However, the important difference between dissipation and discharge, other than how they occur, is that dissipation is much slower and is considered in terms of volume per day verses discharges, which are volume per second or per hour. The result is that a LID practice will take several days or even weeks to dissipate the retained water from a single rainfall. Therefore it is not unusual for another rainfall to occur before all the water from the previous rainfall has been dissipated.

The following is a discussion of possible modeling and simulation tools and methods that can be used to evaluate pre and post development site conditions, Table 4-1. The following sections discuss models of varying scales and capabilities to help guide planners, designers, surveyors, and construction engineers in selecting the proper tools for evaluating a particular site. The models are separated by those that would be most applicable for Option 1: Retain the difference between the pre and post project 95th Percentile Rainfall Volume, and those most applicable for Option 2: Site-Specific Continuous Hydrologic Simulation and Analysis. In addition, not all of these models have been used in the case studies due to time and financial limitations.

Table 4-2. Possible Modeling and Simulation Tools and Methods

MODEL/METHOD	EISA OPTION	FEATURES
Rational Method	1	Computes peak water depths and volumes
SCS CN Method	1	Computes peak water depths and volumes
NRCS WinTR-55 (Model)	1	Computes temporally varying water runoff and volume
EPA SWMM (Model)	1	Computers temporally varying water and constituent runoff and volume
RVSM (Model)	2	Computes long-term runoff based on a 50 year period of record of precipitation
HSPF (Model)	2	Computes long-term temporally varying water and constituent runoff and volume

4.3 STANDARD HYDROLOGIC MODELING AND SIMULATION TOOLS FOR OPTION 1

4.3.1 Rational Method

4.3.1.1 Introduction

The rational method is the most widely used method for the analysis of runoff response from small catchments. It has particular application to urban storm drainage, where it is used to calculate peak runoff rates for the design of storm sewers and small drainage structures (Ponce, 1989). The popularity of the rational method is attributed to its simplicity, although reasonable care is necessary in order to use the method correctly.

The rational method takes into account the following hydrologic characteristics or processes: 1) rainfall intensity; 2) rainfall duration; 3) rainfall frequency; 4) catchment area; 5) hydrologic abstractions; 6) runoff concentration; and 7) runoff diffusion.

In general, the rational method provides only a peak discharge, although in the absence of runoff diffusion it is possible to obtain an isosceles triangle shaped runoff hydrograph which can be used to compute runoff volume, Figure 4-2.

From Figure 4-2, t_r is rainfall duration, t_c is concentration time, Q_e is equilibrium flow (maximum flow possible for a specified rainfall intensity), I_e is effective rainfall intensity (Total rainfall minus all hydrologic abstractions).

The peak discharge is the product of: 1) runoff coefficient; 2) rainfall intensity; and 3) catchment area, with all the processes being lumped into these three parameters, Equation 4.1. Rainfall intensity contains information on rainfall duration and frequency. In turn, rainfall duration is related to concentration time, i.e., to the runoff concentration properties of the catchment. The runoff coefficient accounts for both hydrologic abstractions and runoff diffusion and may also be used to account for frequency. In this way, all the major hydrologic processes responsible for runoff response are embodied in the rational formula.

$$Q_p = CIA \tag{4.1}$$

Where, flow rate (Q_p) is cubic feet per second, rainfall intensity (I) is in inches per hour, catchment area (A) is in acres, and the runoff coefficient (C) is dimensionless.

The rational method does not take into account the following characteristics or processes: 1) spatial or temporal variations in either total or effective rainfall, 2) concentration time much greater than rainfall duration, and 3) a significant portion of runoff occurring in the form of streamflow. In addition, the rational method does not explicitly account for the catchment's antecedent moisture condition, although the latter may be implicitly accounted for by varying the runoff coefficient.

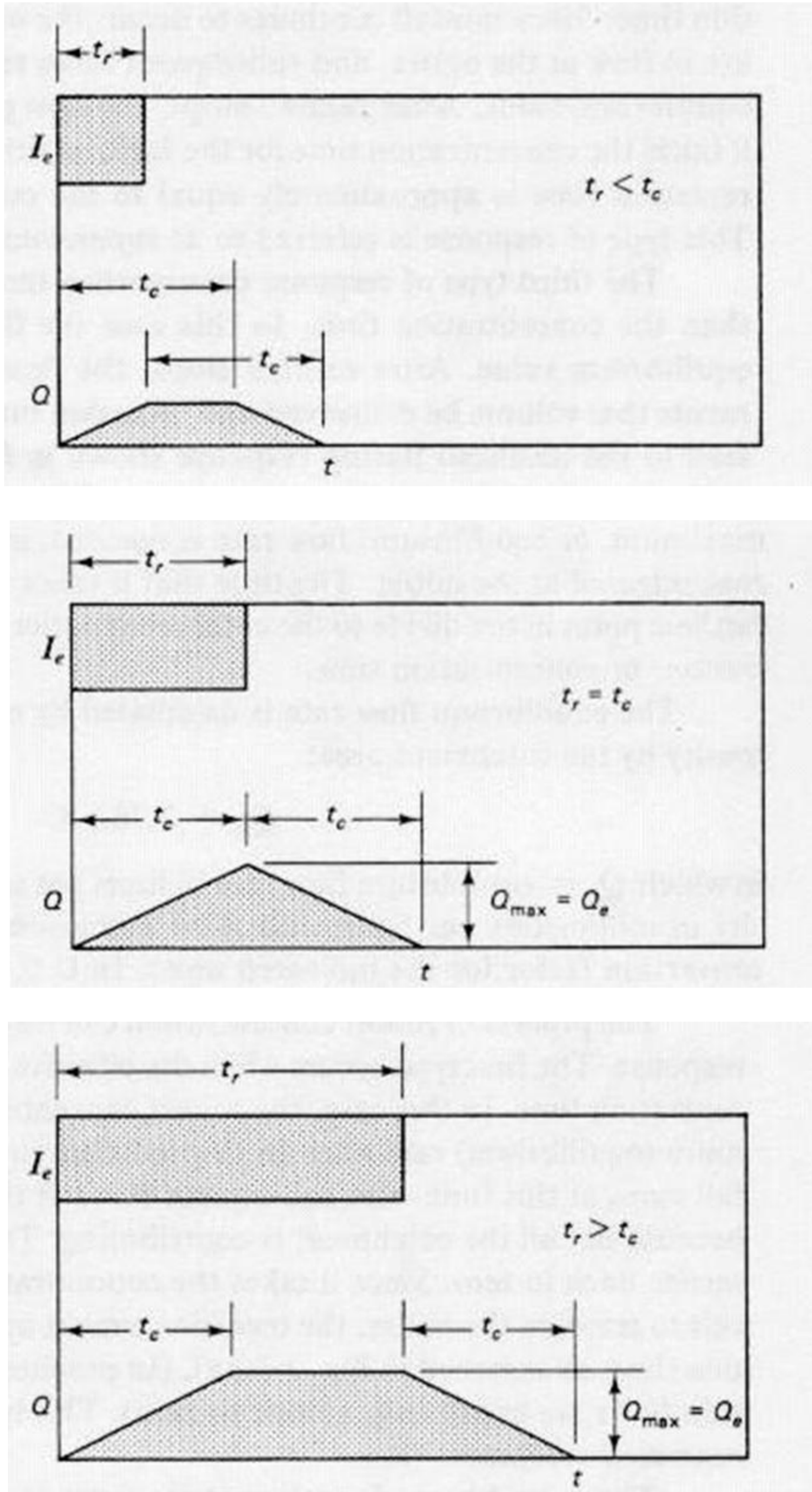


Figure 4-2. Rational Method Hydrographs
(Source: Ponce, 1989)

4.3.1.2 Methodology

The first requirement of the rational method is that the catchment be small. There is no consensus regarding the upper limit of a small catchment, however values ranging from 0.65 to 12.5 km^2 (0.2 to 4.5 mi^2) have been quoted in the literature. The current trend is to use 1.3 to 2.5 km^2 (0.5 to 0.9 mi^2) as the upper limit for the applicability of the rational method. Once the drainage boundary has been determined, the drainage area survey should also include: 1) land use and land use changes; 2) percentage of imperviousness; 3) characteristics of soil and vegetative cover that may affect the runoff coefficient; and 4) general magnitude of ground slopes and catchment gradient necessary to determine time of concentration.

Design values of runoff coefficients are usually a function of rainfall intensity and therefore of rainfall frequency. Higher values of runoff coefficient are applicable for higher values of rainfall intensity and return period, Appendix D, Tables D.1 to D.3.

With runoff coefficient, rainfall intensity, and catchment area determined, the peak discharge is calculated using Equation 4.1. The apparent simplicity of the procedure is misleading due to the range of possible runoff coefficients for each surface condition. Therefore the chosen C value is usually based on additional field information or designer's experience. The effect of frequency and/or antecedent moisture condition needs to be evaluated carefully.

4.3.2 SCS Runoff Curve Method

4.3.2.1 Introduction

The runoff curve number method is a procedure for hydrologic abstraction developed by the USDA Natural Resource Conservation Service (NRCS). In this method, runoff depth (i.e., effective rainfall depth) is a function of total rainfall depth and an abstractive parameter referred to as runoff curve number, curve number, or CN. The curve number varies in the range of 1 to 100, being a function of the following runoff producing catchment properties: 1) hydrologic soil type; 2) land use and treatment; 3) ground surface condition; and 4) antecedent moisture condition (Ponce, 1989).

The runoff curve number method was developed based on 24-h rainfall-runoff data. It limits itself to the calculation of runoff depth and does not explicitly take into account temporal variations of rainfall intensity. In the runoff curve number method, actual runoff is referred to as Q, and the potential runoff (total rainfall) is represented by P, with P being greater than or equal to Q. The actual retention after runoff begins is P minus Q. The potential retention (or potential maximum retention) is S, with S being greater than or equal to P minus Q.

The method is based on an assumption of proportionality between retention and runoff:

$$\frac{P - Q}{S} = \frac{Q}{P} \tag{4.2}$$

Where,

Q = Total runoff depth (inches)
P = Total rainfall depth (inches)
S = Maximum retention depth (inches)

This assumption states that the ratio of actual retention to potential retention is equal to the ratio of actual runoff to potential runoff. For practical applications, Equation 4.2 is improved by reducing the potential runoff by an amount equal to the initial abstraction. The initial abstraction consists mainly of interception, infiltration, and surface storage, all of which occur before runoff begins.

$$\frac{P - I_a - Q}{S} = \frac{Q}{P - I_a} \tag{4.3}$$

Where, I_a is equal to initial abstraction. In the original development of the SCS Curve Number Method, the Intial Abstraction ration (I_a /S) was assigned a value of 0.20.

Solving for Q and setting I_a = 0.2S, results in the following runoff relationship:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \tag{4.4}$$

Which is subject to the restriction that P is greater than or equal to 0.2S.

Since potential maximum retention varies widely, it is more appropriate to express it in terms of a runoff curve number, an integer varying in the range of 1 to 100, in the following form:

$$S = \frac{1000}{CN} - 10 \tag{4.5}$$

In which CN is dimensionless and S, 1000, and 10 are given in inches.

4.3.2.2 Estimation of Runoff Curve Number (CN)

For ungaged watersheds, estimates of CN are given in tables supplied by federal agencies and local city and county departments. Tables of runoff curve numbers for various hydrologic soil-cove complexes are widely available. The hydrologic soil-cover complex describes a specific combination of hydrologic soil group, land use and treatment, hydrologic surface condition, and antecedent moisture condition. All these have a direct bearing on the amount of runoff produced by a catchment. The hydrologic soil group describes the type of soil. The land use and treatment describes the type and condition of vegetative cover. The hydrologic condition refers to the ability of the catchment surface to enhance or impede direct runoff. The antecedent moisture condition accounts for the recent history of rainfall and consequently it is a measure of the amount of moisture stored by the catchment.

For hydrologic soil groups all the soils are classified into four hydrologic soil groups of distinct runoff producing properties. These groups are labeled A, B, C, or D. Group A consists of soils of low runoff potential having high infiltration rates even when wetted thoroughly. They are primarily deep, very well drained sands and gravels with a characteristically high rate of water transmission. Group B consists of soils with moderate infiltration rates when wetted thoroughly, primarily moderately deep to deep, moderately drained to well drainged, with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission. Group C consists of soils with slow infiltration rate when wetted thoroughly, primarily soils having a layer that impedes downward movement of water or soils of moderately fine to fine texture. These soils have a slow rate of water transmission. Group D consists of soils of high runoff potential, having very slow infiltration rates when wetted thoroughly. They are primarily clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay layer near the surface, and shallow soils overlying impervious material. These soils have a very slow rate of water transmission.

The effect of the surface condition of a watershed is evaluated by means of land use and treatment classes. Land use pertains to the watershed cover, including every kind of vegetation, litter and mulch, fallow (bare soil), as well as non-agricultural uses such as water surfaces (lakes, swamps, etc.), impervious surfaces (roads, roofs, etc.), and urban areas. Land treatment applies mainly to agricultural land uses however non-agricultural best management practices could be evaluated as well. The runoff curve number method distinguishes between cultivated lands, grasslands, and woods and forests.

The runoff curve number method has three levels of antecedent moisture, depending on the total rainfall in the 5 day period preceding a storm, Appendix D, Table D.4. The dry antecedent condition (AMC I) has the lowest runoff potential. The average antecedent moisture condition (AMC II) has an average runoff potential. The wet antecedent moisture condition (AMC III) has the highest runoff potential with the catchment practically saturated from previous storms.

Tables depicting average curve number values for various soils and land use and treatment conditions can be found in Appendix D, Tables D.5 to D.7.

Since this method will be demonstrated in the case studies to follow, the steps outlined below should be used in determining the required volume of water to manage.

- Determine project boundary
- Determine hydrologic soil group for the project area by reviewing the USDA soils database
- Determine existing condition landuse areas
- Estimate the runoff curve number for each existing condition landuse

- Compute the area weighted average runoff curve number for the existing condition landuse
- Determine the post project condition landuse areas
- Estimate the runoff curve number for each post project condition landuse
- Compute the area weighted average runoff curve number for the post project conditions
- Based on a 30 to 50 year period of daily rainfall, compute the 95th percentile storm depth
- Compute the existing condition runoff depth using the SCS curve number equation (Eq. 4.4)
- Compute the post project condition runoff depth using the SCS curve number equation
- Compute the volume of water to be managed by multiplying the difference in existing and post project condition runoff depth by the total catchment area

Once the volume of water to be managed has been computed then one can evaluate various LID practices to see which one or combinations will allow one to manage the required volume on site.

4.3.3 NRCS WinTR-55

4.3.3.1 Introduction

WinTR–55 is a single-event rainfall-runoff, small watershed hydrologic model. The model generates hydrographs from both urban and agricultural areas and at selected points along the stream system. Hydrographs are routed downstream through channels and/or reservoirs.
Multiple sub-areas can be modeled within the watershed (USDA, 2009).

4.3.3.2 TR-55 Methodology

The WinTR-55 method is a collection of simplified procedures developed by the NRCS to calculate peak discharges, flood hydrographs, and stormwater detention storage volumes in small and midsize urban watersheds. It consists of two main procedures: 1) a graphical method, and 2) a tabular method. The graphical method is used to calculate peak discharges, whereas the tabular method calculates flood hydrographs by using simplified routing procedures. These methods were developed based on information obtained from the SCS TR-20 hydrologic computer model. They are designed to be used in cases where their applicability can be clearly demonstrated, in lieu of more elaborate techniques. Whereas TR-55 does not specify watershed size, the graphical method is limited to catchments with concentration times in the range of 0.1 to 10.0 hours. Likewise, the tabular method is limited to catchments with concentration times of 0.1 to 2.0 hours.

Rainfall in TR-55 is described in terms of total rainfall depth and one of four standard 24 hour temporal rainfall distributions: type I, type IA, type II, and type III, Figure 4-2.

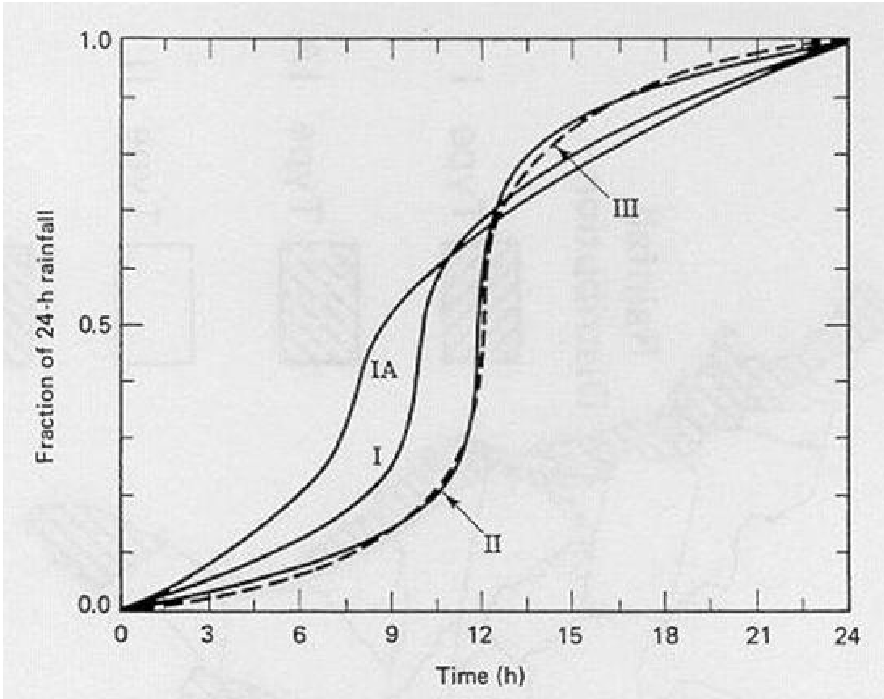


Figure 4-3. SCS 24-Hour Rainfall Distribution
(Source: Ponce, 1989)

Type I applies to California (south of the San Francisco Bay area) and Alaska; type IA applies to the Pacific Northwest and Northern California; type III applies to the Gulf Coast states; and type II applies everywhere else within the contiguous United States, Figure 4-3.

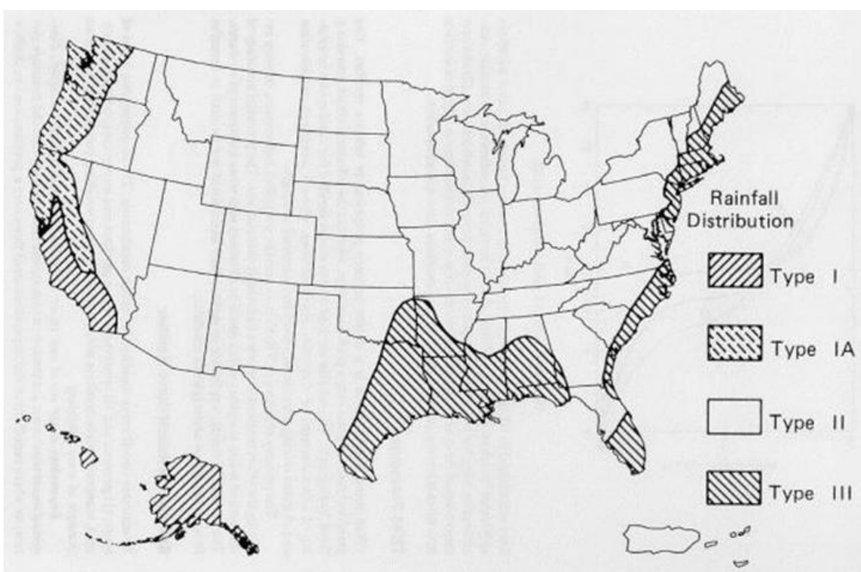


Figure 4-4. Approximate Geographical Boundaries for SCS Rainfall Distribution
(Source: Ponce, 1989)

The duration of these rainfall distributions is 24 hours. This constant duration was selected because most rainfall data is reported on a 24 hour basis. TR-55 uses the runoff curve number method to abstract total rainfall depth and calculate runoff depth. In addition, TR-55 includes procedures to determine concentration time for the following types of surface flow: 1) overland flow; 2) shallow concentrated flow; and 3) streamflow. Shallow concentrated flow is a type of surface flow of characteristics in between those of overland flow and streamflow (i.e. rill flow and gully flow).

4.3.3.3 Model Overview

A watershed consists of sub-areas (land areas) and reaches (major flow paths in the watershed). For each sub-area, a hydrograph is generated based on land and climate characteristics. Reaches are designated as either channel reaches, through which hydrographs are routed based on physical stream characteristics, or as storage reaches, through which hydrographs are routed based on reservoir storage and outlet characteristics. Sub-area and reach hydrographs are combined as needed to represent the accumulation of flow as water moves from the upland areas down through the watershed reach network. The watershed outlet represents the location at which all runoff from the watershed is accumulated.

In modeling LID practices with Win-TR-55, the infiltration and evapotranspiration are implicitly accounted for through the weighted curve number. As LID practices are introduced into the landscape then the user must be able to quantify the reduction in infiltration and evapotranspiration volume due to the project and how much infiltration capacity needs to be introduced into the project area with the LID practice in order to mitigate this loss in volume. There are a number of capabilities and limitations associated with this model, Table 4-3.

Table 4-3. Win TR-55 Capabilities and Limitations

Variable	Limits
Minimum Area	Minimum area is 0.01 acre. Carefully examine results from sub-areas less than 1 acre.
Maximum Area	25 square miles (6,500 ha)
Number of subwatersheds	1 to 10
Time of concentration for any sub-area	0.1 hour <= Tc <= 10 hours
Number of reaches	0 to 10
Types of reaches	Channel or structure
Reach routing	Muskingum-Cunge
Structure routing	Storage-Indication
Structure types	Pipe or weir
Structure trial sizes	1 to 3
Rainfall depth	Default or user-defined 0 to 50 inches (0 to 1,270 mm)
Rainfall distributions	NRCS Type I, IA, II, III, NM60, NM65, NM70, NM75, or user-defined
Rainfall duration	24-hour
Dimensionless unit hydrograph	Standard peak rate factor 484, or user-defined
Antecedent runoff condition	2 (average)

(Source: USDA, 2009)

In order to use WinTR-55, there is a minimum data requirement that needs to be met.

These data include:

- Project Identification Data
    - User
    - State
    - County
    - Project
    - Subtitle
- Dimensionless Unit Hydrograph
- Storm Data Source
- Rainfall Distribution Identifier
- Sub-area Entry and Summary
    - Sub-area Name
    - Sub-area Description
    - Sub-area Flows to Reach/Outlet
    - Area (ac. or sq. mi.)
    - Weighted curve number (CN)
    - Time of concentration (Tc)

Once the input data has been inserted and the model has been run, the File Display window, also referred to as the Report Viewer, displays various WinTR–55 reports, Table 4.3. This window opens after a WinTR–55 run. If there are any errors in the WinTR–55 run, this window opens with the Error File displayed. The user should carefully examine the error messages, and/or modify the input data to correct the errors.

In addition to the reports, there are hydrograph plotting options for sub-areas and reaches, Figure 4-5.

Table 4-4. Win TR-55 Reports

Report Name	Description
Current data description	Lists the current user input data
Storm data	Lists the rainfall depth by rainfall return period information. Also shows Storm Data source, Rainfall Distribution, and the Dimensionless Unit Hydrograph.
Watershed Peak Table	Not available until an error-free WinTR-55 run is executed. Upon completion of an error-free WinTR-55 run, this option will give a listing of peak discharges, by reach, for each storm evaluated.
Hydrograph Peak/Peak Time Table	Not available until an error-free WinTR-55 run is executed. Upon completion of an error-free WinTR-55 run, this option gives a listing of peak discharge and time by sub-area or reach identifier, for each storm evaluated.
Structure Output Table	Not available until an error-free WinTR-55 run is executed. Upon completion of an error-free WinTR-55 run, this option gives a listing of peak flow (PF), storage volume (SV), and maximum stage (STG) for structures included in the WinTR-55 run. If there are no structures in the run, this table option is grayed out.
Sub-Area Summary Table	A listing by sub-area of drainage area, time of concentration, runoff curve number, receiving reach, and sub-area description.
Reach Summary Table	Identifies, by reach, the receiving reach, reach length, and routing method used.
Sub-Area Time of Concentration Details	A listing, by sub-area, of flow length, slope, Manning's n value, end area, wetted perimeter, velocity and travel time of concentration flow path segments along with the total time of concentration.
Sub-Area Land Use and Curve Number Details	A listing, by sub-area, of land use, hydrologic soil group, and area for each particular land use in a sub-area. Also lists the total area and weighted curve number for each sub-area.
Reach Channel Rating Details	Identifies, by reach, the reach length, Manning's n value used for that reach, friction slope, bottom width, and side slope. Also includes the computed channel rating for each reach. Channel ratings are in the WinTR-55 input data format: Stage-Flow-End Area. Rating tables also include top width and friction slope.
Structure Description	Provides a summary of the entered structure data by reach. If there are no structures in the run, this table option is grayed out.
Structure Rating Tables	Provides a summary of the computed structure ratings: stage, storage, and flow. If there are no structures in the run, this table option is grayed out.

(Source: USDA, 2009)

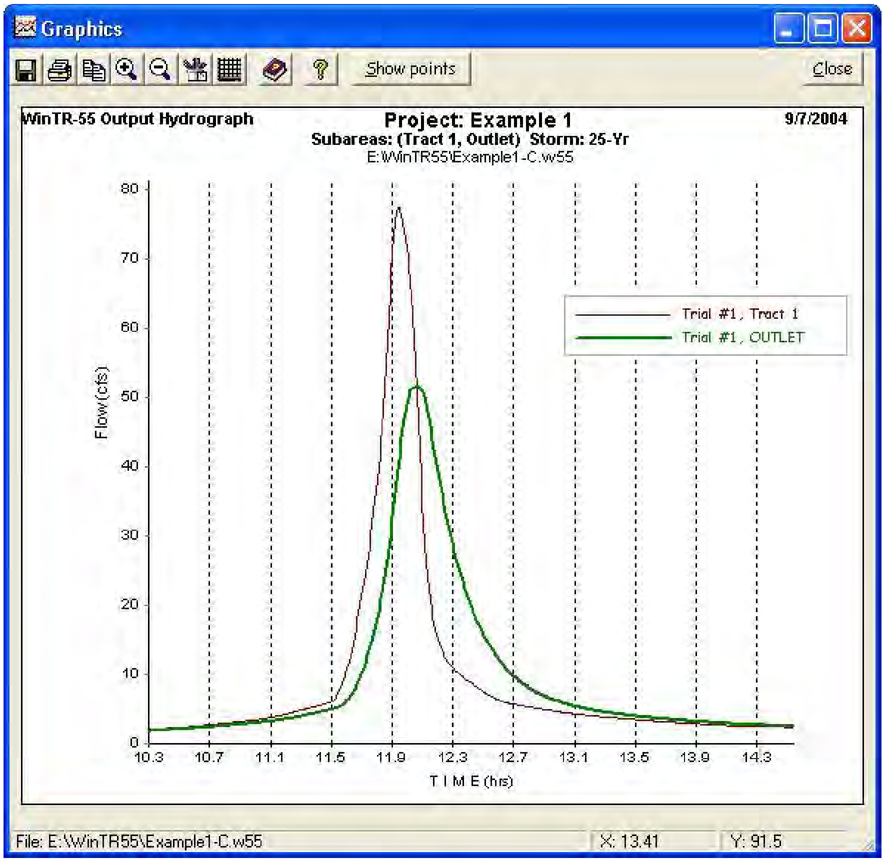


Figure 4-5. Example Win TR-55 Hydrograph Plot
(Source: USDA, 2009)

4.3.4 EPA SWMM

4.3.4.1 Introduction

The EPA Storm Water Management Model (SWMM) is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas (Rossman, 2010). The runoff component of SWMM operates on a collection of subcatchment areas that receive precipitation and generate runoff and pollutant loads. The routing portion of SWMM transports this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM tracks the quantity and quality of runoff generated within each subcatchment, and the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period comprised of multiple time steps.

SWMM was first developed in 1971, and has since undergone several major upgrades since then. It continues to be widely used throughout the world for planning, analysis and design related to stormwater runoff, combined sewers, sanitary sewers, and other drainage systems in urban areas, with many applications in non-urban areas as well. The current edition, Version 5, is a complete re-write of the previous release. Running under Windows, SWMM 5 provides an integrated environment for editing study area input data, running hydrologic, hydraulic and water quality simulations, and viewing the results in a variety of formats. These include color-coded drainage area and conveyance system maps, time series graphs and tables, profile plots, and statistical frequency analyses.

4.3.4.2 Capabilities

SWMM accounts for various hydrologic processes that produce runoff from urban areas. These include:

- time-varying rainfall
- evaporation of standing surface water
- snow accumulation and melting
- rainfall interception from depression storage
- infiltration of rainfall into unsaturated soil layers
- percolation of infiltrated water into groundwater layers
- interflow between groundwater and the drainage system
- nonlinear reservoir routing of overland flow
- runoff reduction via Low Impact Development (LID) controls.

Spatial variability in all of these processes is achieved by dividing a study area into a collection of smaller, homogeneous subcatchment areas, each containing its own fraction of pervious and impervious sub-areas. Overland flow can be routed between sub-areas, between subcatchments, or between entry points of a drainage system.

SWMM also contains a flexible set of hydraulic modeling capabilities used to route runoff and external inflows through the drainage system network of pipes, channels, storage/treatment units and diversion structures. These include the ability to:

- handle drainage networks of unlimited size
- use a wide variety of standard closed and open conduit shapes as well as natural channels
- model special elements such as storage/treatment units, flow dividers, pumps, weirs, and orifices
- apply external flows and water quality inputs from surface runoff, groundwater interflow, rainfall-dependent infiltration/inflow, dry weather sanitary flow, and user-defined inflows
- utilize either kinematic wave or full dynamic wave flow routing methods
- model various flow regimes, such as backwater, surcharging, reverse flow, and surface ponding
- apply user-defined dynamic control rules to simulate the operation of pumps, orifice openings, and weir crest levels

In addition to modeling the generation and transport of runoff flows, SWMM can also estimate the production of pollutant loads associated with this runoff. The following processes can be modeled for any number of user-defined water quality constituents:

- dry-weather pollutant buildup over different land uses
- pollutant washoff from specific land uses during storm events
- direct contribution of rainfall deposition
- reduction in dry-weather buildup due to street cleaning
- reduction in washoff load due to BMPs
- entry of dry weather sanitary flows and user-specified external inflows at any point in the drainage system
- routing of water quality constituents through the drainage system
- reduction in constituent concentration through treatment in storage units or by natural processes in pipes and channels

In modeling LID practices with EPA SWMM, the infiltration and evapotranspiration are explicitly accounted for through the computation of infiltration and evapotranspiration. As LID practices are introduced into the landscape then the user will be able to better quantify the reduction in infiltration and evapotranspiration volume due to the project given the more explicit formulations and thus will be able to better determine infiltration capacity that needs to be accounted for with the LID practice in order to mitigate this loss in volume.

4.4 STANDARD HYDROLOGIC MODELING AND SIMULATION TOOLS FOR OPTION 2

4.4.1 The Retention Volume Simulation Model (RVSM)

4.4.1.1 Introduction

The RVSM simulates the pre-development conditions by modifying the runoff equation from the Curve Number Method found inTR-55 Runoff Equation (TR-55, equation 4.7) (Lemoine, 2011). Although the Curve Number Method is used in flow-based hydrology modeling, it is the closest method to being a volume-based model, because the method directly estimates a runoff volume. The method estimate runoff based on soil type and ground cover. Since the volume of rainwater retain, and not dissipated, in the soil and in depression storage of the previous day has the same effect as though it were part of the rainfall for the next day, the Runoff Equation from TR-55 can be modified to make it a continuous simulation. This modification involves adding to the rainfall volume of the current day, the rainfall retained in the soil and on the surface through depression storage from previous day less the estimate dissipation volume, Figure 4-6.

$P_a =$	$P + R_n$		**(4.6)**
$R_n =$	$Pa - Qn - Q_d$		**(4.7)**
$Q_d \approx$	I_a	*(Model Assumption)*	**(4,8)**
$I_a =$	$0.2S$	*(eq. 2-2, TR-55)*	**(4,9)**
$S =$	$(1000/CN) - 10$	*(eq. 2-4, TR-55)*	**(4.10)**
$Q_n =$	$(P_a - 0.2S)^2 / (P_a + 0.8S)$	*(eq. 2-3, TR-55)*	**(4.11)**

P = *24-Hour Precipitation*

P_a = *Precipitation adjusted for retained moisture*

R_n = *Retained moisture*

Q_d = *Dissipation volume from infiltration, evapo-transpiration, and/or reuse*

I_a = *Initial abstraction*

S = *Potential maximum retention after runoff begins*

Qn = *Pre-Development Runoff*

NOTE: All volumes are unit volumes of inches over the catchment area.)

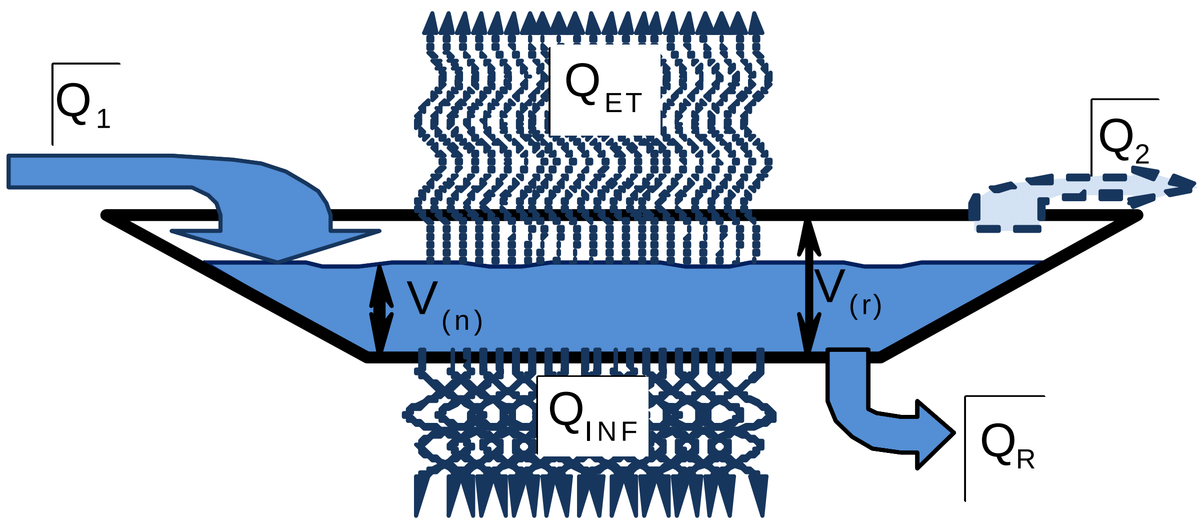


Figure 4-6. RVSM Water Balance

(Source: Lemoine, 2011)

The principle of continuity of volumes is used by the RVSM in simulating the performance of post-construction LID practices. Based on the continuity principle the retained volume is equal to the inflow volume minus the outflow volumes. The TR-55 Runoff Equation is used to calculate the inflow volume. The outflow volumes consist of; the infiltration volume, the evapo-transpiration volume, the reuse volume, and an overflow discharge volume when the LID retention capacity is exceeded. The RVSM groups the infiltration, evapo-transpiration, and reused volume into one variable called the dissipation rates.

The RVSM has four input variables: the pre-development curve number CN_n, the post-development curve number CN_d, the LID retention capacity V_r, and the dissipation rate Q_D.

Using those variables, the RVSM determines the number of occurrences when the discharge volume exceeded the 2-year runoff volume, and the number of occurrences when there is an overflow discharge of the LID practice based on the given retention capacity and dissipation rate. The goal is for the post-development discharge volume to "mimicking" the pre-development runoff volume. This goal is achieved by changing either the retention capacity or dissipation rate of the LID practice until the number of post-development discharge occurrences matches the pre-development occurrences. It is generally acknowledged that accelerated erosion occurs when the flow rate and frequency exceed the runoff from a 2-year rainfall. Therefore, the pre-development, 2-year runoff volume is used as the threshold for evaluating whether the post development discharge volume matches (mimics) the pre-development runoff volume.

4.4.1.2 RVSM for Reuse Applications

This same model can be used to evaluate the performance of reuse application. The model's dissipation rate is the reuse rate. The reuse performance is measured by counting the number of days that there was sufficient retention volume to meet the demand for the retained water. The average availability is expressed as a percentage, calculated by dividing the number of days of available retention volume by the total number of days in the data set. This percentage provides an indication of whether and how much a supplemental source of water will be needed and how much. Various scenarios can be evaluated and this information used in a cost-benefit analysis to determine the optimum size retention tank.

The RVSM is created using a spreadsheet; however, a spreadsheet template has been created that can be used at any locality simply by inserting the 24-hour rainfall data and rainfall frequency data specific to that region. Once the appropriate local data has been input into the spreadsheet template, site specific evaluations and scenarios can be performed to estimate the required retention capacity and dissipation rate for LID practices. Alternatively the RVSM can be used to generate tables, charts and equations for use in designing LID practices anywhere within the local region.

4.4.2 EPA HSPF

4.4.2.1 Introduction

HSPF simulates for extended periods of time the hydrologic, and associated water quality, processes on pervious and impervious land surfaces and in streams and well-mixed impoundments. The model uses continuous rainfall and other meteorologic records to compute streamflow hydrographs and pollutographs (Bicknell et al, 2005). HSPF simulates interception soil moisture, surface runoff, interflow, base flow, snowpack depth and water content, snowmelt, evapotranspiration, ground-water recharge, dissolved oxygen, biochemical oxygen demand (BOD), temperature, pesticides, conservatives, fecal coliforms, sediment detachment and transport, sediment routing by particle size, channel routing, reservoir routing, constituent routing, pH, ammonia, nitrite-nitrate, organic nitrogen, orthophosphate, organic phosphorus, phytoplankton, and zooplankton. The program can simulate one or many pervious or impervious unit areas discharging to one or many river reaches or reservoirs. Frequency-duration analysis can be done for any time series. Any time step from 1 minute to 1 day that divides equally into 1 day can be used. Any period from a few minutes to hundreds of years may be simulated. HSPF is generally used to assess the effects of land-use change, reservoir operations, point or nonpoint source treatment alternatives, flow diversions, etc. Programs, available separately, support data preprocessing and postprocessing for statistical and graphical analysis of data saved to the Watershed Data Management (WDM) file.

4.4.2.2 Conceptual Model Design

To design a comprehensive simulation system, one must have a consistent means of representing the prototype; in our case, the real world. We view it as a set of constituents which move through a fixed environment and interact with each other. Water is one constituent; others are sediment, chemicals, etc. The motions and interactions are called processes.

The mathematical prototype is a continuum of constituents and processes. Simulation of such a system on a computer requires representation in a discrete fashion. In general, we do this by subdividing the prototype into "elements" which consist of "nodes" and "zones."

A node corresponds to a point in space. Therefore, a particular value of a spatially variable function can be associated with it, for example, channel flow rate and/or flow cross sectional area. A zone corresponds to a finite portion of the real world. It is usually associated with the integral of a spatially variable quantity, for example, storage in a channel reach. The relationship between zonal and nodal values is similar to that between the definite integral of a function and its values at the limits of integration.

An element is a collection of nodes and/or zones. We simulate the response of the land phase of the hydrological cycle using elements called "segments." A segment is a portion of the land assumed to have areally uniform properties. A segment of land with a pervious surface is called a "Pervious Land-segment" (PLS) and an impervious surface is called an “Impervious Land-segment” (ILS). A PLS or ILS has no nodes. In regards to stream or reservoir routing, we model a computational reach as a one dimensional element consisting of a single zone situated between two nodes. We simulate the flow rate and depth at the nodes; the zone is associated with storage.

4.4.2.3 Pervious Land Segments

A land segment is a subdivision of the simulated watershed. The boundaries are established according to the user's needs, but generally, a segment is defined as an area with similar hydrologic characteristics. For modeling purposes, water, sediment, and water quality constituents leaving the watershed move laterally to a downslope segment or to a reach/reservoir. A segment of land which has the capacity to allow enough infiltration to influence the water budget is considered pervious. In HSPF, PERLND (Pervious Land Segment) is the module that simulates the water quality and quantity processes which occur on a pervious land segment.

The primary module sections in PERLND simulate snow accumulation and melt, the water budget, sediment produced by land surface erosion, and water quality constituents by various methods. Other sections perform the auxiliary functions of correcting air temperature for use in snowmelt and soil temperature calculations, producing soil temperatures for estimating the outflow temperatures and influencing reaction rates in the agri-chemical sections, and determining outflow temperatures which influence the solubility of oxygen and carbon dioxide.

In modeling LID practices with HSPF, the PERLND segmentation is the primary module where the infiltration and evapotranspiration are explicitly accounted for through the computation of infiltration and evapotranspiration. As LID practices are introduced into the landscape then the user will be able to better quantify the reduction in infiltration and evapotranspiration volume due to the project given the more explicit formulations found within HSPF and thus will be able to better determine infiltration capacity that needs to be accounted for with the LID practice in order to mitigate this loss in volume.

4.4.2.4 Impervious Land Segments

In an impervious land segment, little or no infiltration occurs however, land surface processes do occur. Snow may accumulate and melt, and water may be stored or may evaporate. Various water quality constituents accumulate and are removed. Water, solids, and various pollutants flow from the segments by moving laterally to a downslope segment or to a reach/reservoir.

The HSPF IMPLND (Impervious Land Segment) module simulates a number of processes with many of them similar to the corresponding sections in the PERLND module. In fact, since sections snow and air temperature components perform functions that can be applied to pervious or impervious segments, they are shared by both modules.

4.4.2.5 Streams and Reservoirs

This module simulates the processes which occur in a single reach of open or closed channel or a completely mixed lake. For convenience, such a processing unit is referred to as a RCHRES. In keeping with the assumption of complete mixing, the RCHRES consists of a single zone situated between two nodes, which are the extremities of the RCHRES.

Flow through a RCHRES is assumed to be unidirectional. Water and other constituents which arrive from other RCHRES's and local sources enter the RCHRES through a single gate. Outflows may leave the RCHRES through one of several gates or exits. A RCHRES can have up to five outflow exits. Precipitation, evaporation, and other fluxes also influence the processes which occur in the RCHRES, but do not pass through the exits.

4.5 STORMWATER MANAGEMENT TECHNOLOGIES CASE STUDIES

4.5.1 Introduction

The purpose of this section is to demonstrate the application of the SCS Curve Number method for estimating the volume of water that needs to be managed for installations from different climatic zones and for different project design purposes using the Army LID Planning Tool. The SCS CN method was chosen due to its wide spread acceptance by watershed modelers and its flexibility in describing landscape parameters and features when modeling small catchments.

During the planning process, a general project boundary is typically determined. Using this project boundary or limit of disturbance, when available, to the engineer will evaluate the natural features that direct flow either to the area of interest or away from the area of interest. Once that has been done then man-made features, such as roads, drainage ditches, etc., need to be considered since they do alter the natural flow paths. After these features have been identified then the designer will need to delineate the catchment boundary, where the project will impact hydrology or increase runoff, using their best engineering judgement. In some cases, it may not be clear exactly how far out a boundary needs to go since the actual construction area may be small and the natural and man-made features may be sufficiently far away. In these cases, one needs to keep in mind that we are looking at the difference in existing and post project runoff conditions rather than absolute runoff depths so again some engineering judgement may need to be made in regards to how far out to set the catchment boundary. The consequences of setting the boundary too far away from the project site could cause the model to not be able to discern pre and post project differences accurately and thus cause the designer to either under design or over design the LID practices. In the case of over designing, this would cause an unnecessary increase in project cost. In the case of under designing, some local flooding may occur at the 95th percentile storm that otherwise should not occur.

Finally, this section demonstrates how different LID practices can be used in the design such that the water can be retained on site rather than allowed to runoff. The case studies presented here are hypothetical and are only meant to demonstrate estimating the EISA Section 438 volume requirement and applying LID BMPs to meet EISA.

4.5.2 Data Needs

The following sites were used in evaluating various LID Best Management Plans (BMPs): 1) Fort Drum; 2) Fort Hood; 3) Fort Benning; and 4) Fort Meade. The goal was to use sites that represented varying climatic regions in order to show the robustness of the LID BMPs to be used across the whole Department of Defense (DoD). In performing the LID analysis is was necessary to gather the following data:

- Land use/Land cover: The terms land use and land cover are often used interchangeably, but each term has its own unique meaning. *Land cover* refers to the characteristics and surface cover of Earth’s surface, as represented by vegetation, water, bare earth, impervious surfaces, and other physical features of the land. Identification of land cover establishes the baseline information for activities like thematic mapping and change detection analysis. *Land use* refers to the activity, economic purpose, intended use, and/or management strategy placed on the land cover type(s) by human agents or land managers. Changes in intent or management practice likewise constitute land use change. When used together the phrase Land Use/Land Cover generally refers to the categorization or classification of human activities and natural elements on the landscape within a specific time frame based on established scientific and statistical methods of analysis of appropriate source materials.

- Digital Elevation Map (DEM): A DEM is a digital representation of ground surface topography or terrain. It is also widely known as a digital terrain model (DTM). A DEM can be represented as a raster (a grid of squares) or as a triangular irregular network. For the LID analysis a minimum of 2-foot contour intervals (1-foot intervals are better) is necessary.

- Soil Texture Map: Soil texture is a soil property used to describe the relative proportion of different grain sizes of mineral particles in a soil. Particles are grouped according to their size into what are called soil separates. At a minimum, the soil texture should be classified as sand, silt, or clay. A more detailed discussion of soil texture and possible soil amendments can be found in Chapter 3. Once the soil texture has been determined, then the hydrologic soil group (A, B, C, or D) can be ascertained and the appropriate infilatration rate (A=14.343 inches/day, B=9.743 inches/day, C=4.430 inches/day, and D=0.769 inches/day) will be determined by the planning spreadsheet.

- Facilities Map: The facilities map should show basic man-made features associated with the selected installation (e.g., buildings, roads, parking lots, sewer/storm pipe systems, etc.)

- Precipitation: Precipitation is the quantity of water falling to earth at a specific place within a specified period of time. Precipitation can be in the form of rainfall or snow. For the LID analysis, 50 continuous years of 24-hour precipitation data is recommended.

For the case studies, the SCS Curve Number method was used in the hydrologic design of selected LID practices. In performing the hydrologic analysis, the following steps must be done:

- Evaluate existing soils (analysis) and surface features across project site.

- Determine the area (sq-ft / acres) of existing and planned: building foot print, parking, sidewalks, etc.

- Determine the area (sq-ft / acres) of existing vegetation features and the planned changes to the landscape.

- Compute changes in runoff volume from existing to planned site conditions.

- Evaluate LID practices appropriate for managing the change in runoff volume.

4.5.3 Fort Drum Case Study

4.5.3.1 Background

Fort Drum, New York is located in Western New York State, approximately 80 miles north of Syracuse, NY (Figure 4-7). Fort Drum gets 39 inches of rain per year. On average, there are 160 sunny days. The July high is around 80^{o}F and the January low is 10^{o}F.

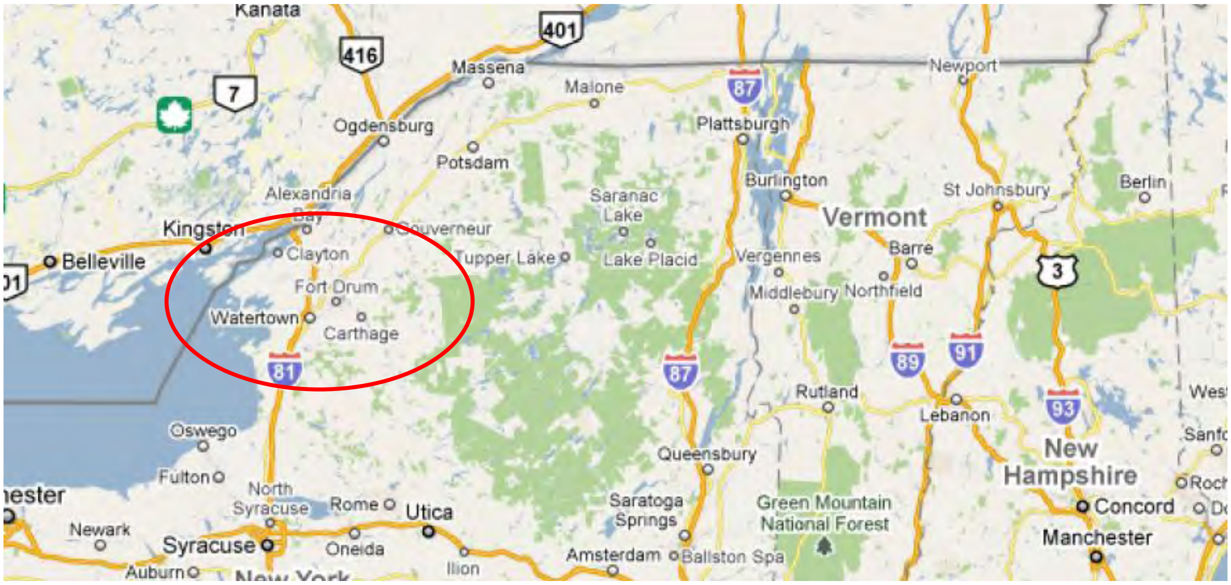


Figure 4-7. Fort Drum, NY Location Map

Fort Drum has been used as a military training site since 1908, however the Army's presence in the North Country may be traced back to the early 1800's. Today, Fort Drum consists of 107,265 acres. Its mission includes commanding active component units assigned to the installation, providing administrative and logistical support to tenant units, supporting tenant units, supporting active and reserve units from all services in training at Fort Drum, and planning and support for the mobilization and training of almost 80,000 troops annually. The Fort Drum installation can be seen in Figure 4-8.

Figure 4-8. Fort Drum, NY Installation Area

4.5.3.2 Pre-Project Conditions

For this case study, an existing housing site was selected for enlargement.

From a review of the USDA soils database, the predominant hydrologic soil group for the project site is Hydrologic Soil Group B. The existing land use consisted of Trees/Shrubs, Grassland, Lawns, and Existing Houses, Figure 4-9. By inputting the percent site area of each land use to the spreadsheet tool, the estimated SCS curve number, CN, for each land use type is populated. Then the area weighted average pre-project CN is computed to be **61.6** (Figure 4-10).

Figure 4-9. Fort Drum, NY Project Site - Existing Landuse Conditions

4.5.3.3 Post-Project Conditions

The post project land use, Figure 4-11, consisted of Lawn, Existing Houses, New Houses, Club House, Parking Lots, and Roads. By inputting the percent site area of each land use to the spreadsheet tool, the estimated SCS curve number, CN, for each land use type is populated. Then the area weighted average pre-project CN is computed to be **74.9** (Figure 4-10).

U.S. ARMY

SIMPLIFIED RUNOFF CURVE NUMBER METHOD

PRELIMINARY SELECTION AND SIZING OF LID PRACTICES

FOR COMPLIANCE WITH THE RUNOFF VOLUME CONTROL REQUIREMENT, EISA 438, EPA OPTION I

ERDC

DATE: 14-Jun-11 INSTALLATION: Fort Drum, NY

PLANNER: Bill Sproul

PROJECT NAME: New Housing Development

PROJECT LOCATION: Fort Drum

PROJECT AREA (acres): 28.5 95% RAINFALL 0.94 SELECT THE SITE'S GEN. SOIL TYPE: Sandy-Loam HSG = B

PRE-PROJECT LAND COVER	% of SITE	CN		POST-PROJECT LAND COVER	% of SITE	CN
WOODED (Fair)	60.7%	60		WOODED (Fair)		
MEADOW				MEADOW		
BRUSH & WEEDS (Fair)	18.7%	56		BRUSH & WEEDS (Fair)		
LAWN	18.8%	69		LAWN	77.8%	69
ROADS & DRIVES (W*/C&G)				ROADS & DRIVES (W*/C&G)	5.7%	89
ROADS & DRIVES (W/C&G)				ROADS & DRIVES (W/C&G)		
PARKING, DRIVEWAYS & SIDEWALKS				PARKING, DRIVEWAYS & SIDEWALKS	4.4%	98
BUILDING ROOF	1.8%	98		BUILDING ROOF	12.1%	98
			SELECTION OF OTHER LAND COVER TYPES			
TOTAL %	100.0%			TOTAL %	100.0%	
WEIGHTED AVERAGE CNn =		61.6		WEIGHTED AVERAGE CNd =		74.9

PRE-PROJECT: RUNOFF VOLUME (95% RAIN) = 0.037 ACRE-FEET; 1628 CUBIC FEET; 12180 GALLONS

POST-PROJECT: RUNOFF VOLUME (95% RAIN) = 0.048 ACRE-FEET; 2095 CUBIC FEET; 15672 GALLONS

MINIMUM RUNOFF RETENTION VOLUME TO COMPLY WITH EISA 438 VOLUME CONTROL REQUIREMENT

0.011 ACRE-FEET 467 CUBIC FEET 3,492 GALLONS

Figure 4-10. Fort Drum Runoff Computations

Figure 4-11. Fort Drum, NY Project Site - Post-Project Landuse Conditions

4.5.3.4 Calculate EISA Volume Requirement

The next step in the hydrologic design is to compute the 95th percentile storm. Based on an evaluation of a 50 year period of record of daily precipitation at Fort Drum, Figure 4-12, the 95th percentile storm was computed to be **0.94 inches**.

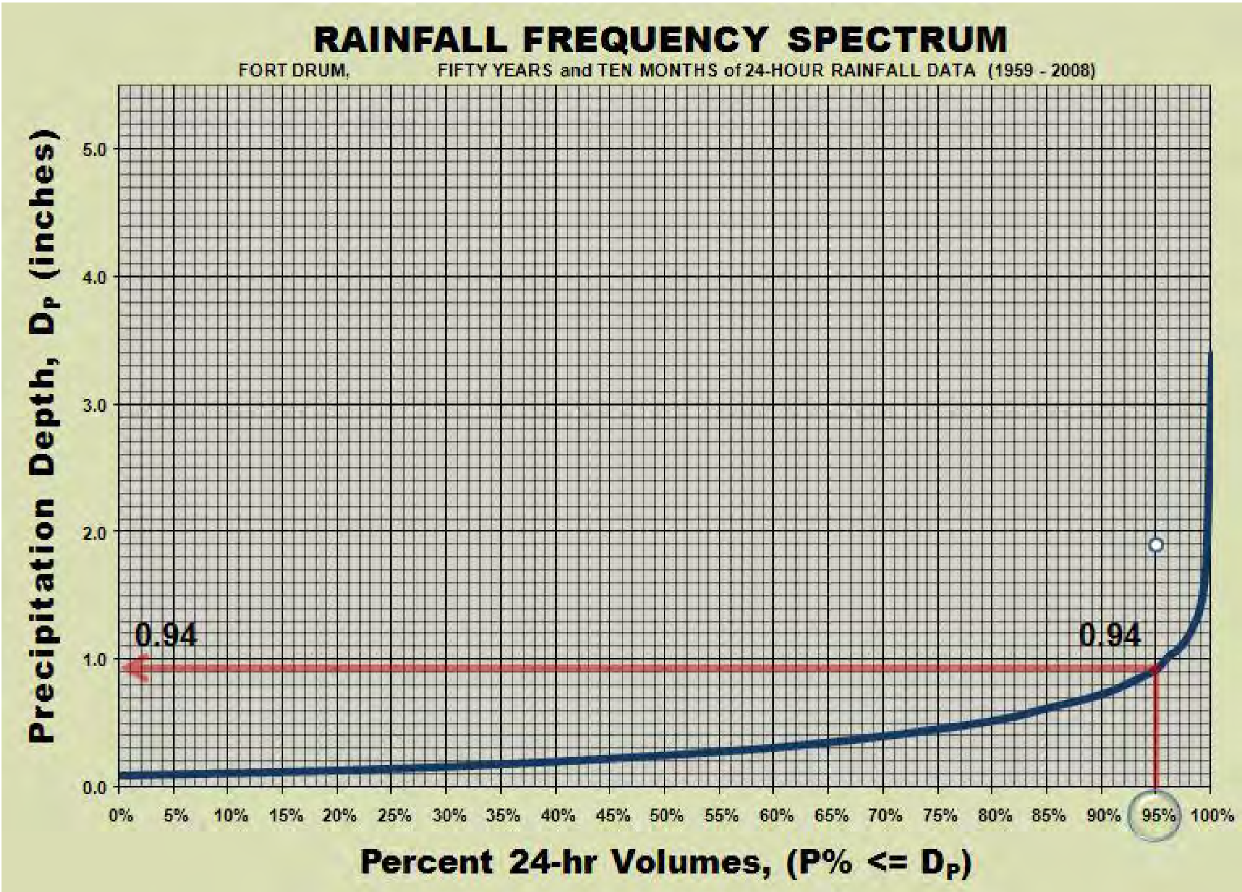


Figure 4-12. Fort Drum, NY - 95th Percentile Storm Depth (Inches)

Input Parameters:
Site Area (A) = 28.5 acres
95^{th} Storm (P) = 0.94 inches
Existing CN = 61.6
Post CN = 74.9

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad S = \frac{1000}{CN} - 10$$

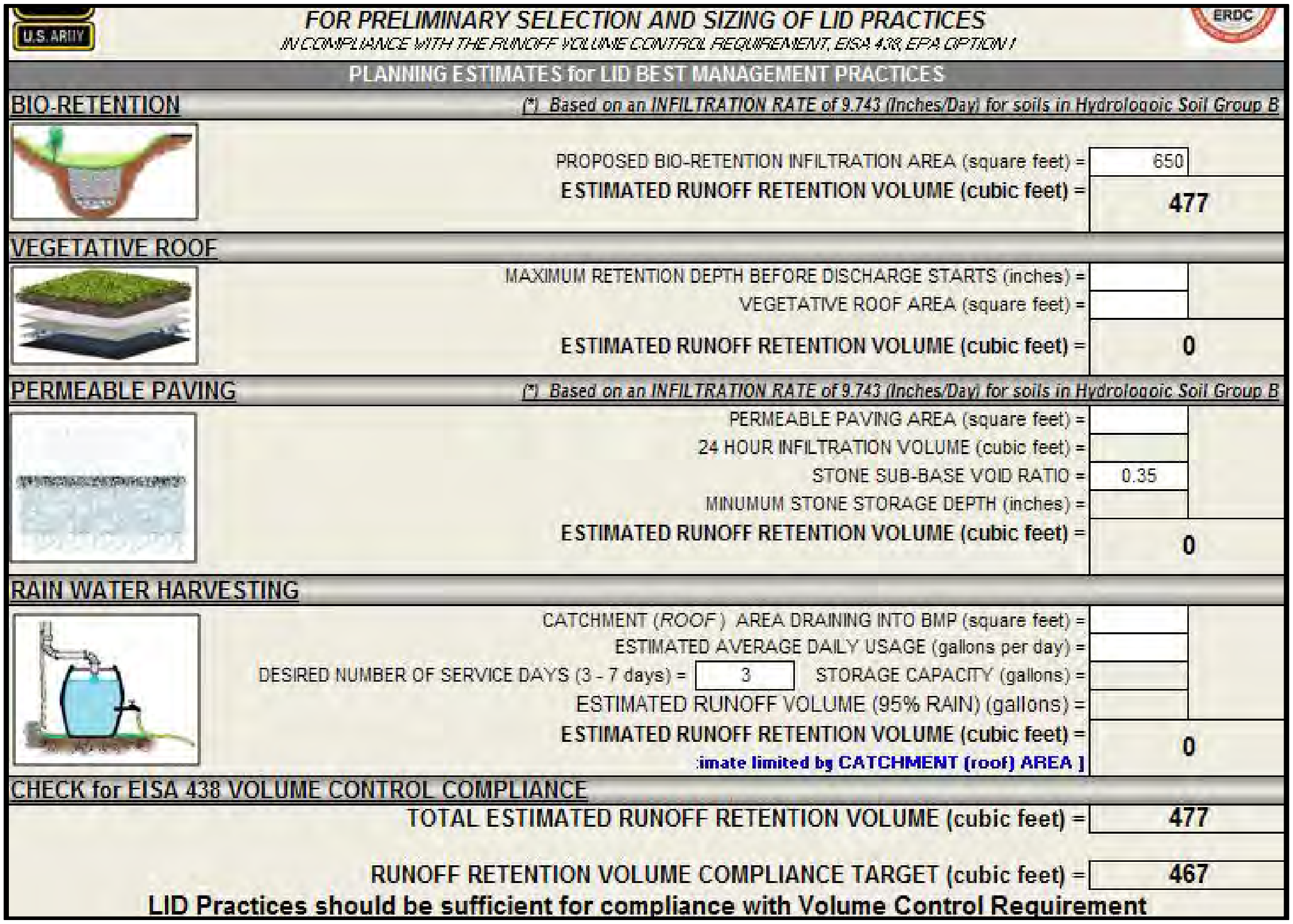
Output:
Existing Q = 0.016 inches
Post Q = 0.02 inches

At this point one is able to compute the peak runoff depths for both the existing and post project conditions using the SCS CN method. The peak runoff depths were computed to be 0.016 inches and 0.02 inches, respectively using the 95^{th} percentile storm.

Once one computes the existing and post runoff depths then they are able to compute the amount of water that needs to be managed on the project site by multiplying the change in runoff depth by the site area, 28.5 acres. From this analysis, the Fort Drum project needs to manage **467 ft^3** of runoff, as computed in Figure 4-10.

4.5.3.5 Select LID BMPs to Manage EISA Volume

The LID practice that was evaluated for this project was a bioswale, Figure 4-13. For this analysis, a Group B soil allows for 9.743 inches/day of water removed from the project site using this LID practice. Since this LID feature is an infiltration practice, it was determined that a bioswale area of 650 ft^2 (0.02 acres) was needed assuming a 24-hour dissipation time.



FOR PRELIMINARY SELECTION AND SIZING OF LID PRACTICES

IN COMPLIANCE WITH THE RUNOFF VOLUME CONTROL REQUIREMENT, EISA 438, EPA OPTION I

PLANNING ESTIMATES for LID BEST MANAGEMENT PRACTICES

BIO-RETENTION — (*) Based on an INFILTRATION RATE of 9.743 (Inches/Day) for soils in Hydrologic Soil Group B

PROPOSED BIO-RETENTION INFILTRATION AREA (square feet) = 650

ESTIMATED RUNOFF RETENTION VOLUME (cubic feet) = 477

VEGETATIVE ROOF

MAXIMUM RETENTION DEPTH BEFORE DISCHARGE STARTS (inches) =

VEGETATIVE ROOF AREA (square feet) =

ESTIMATED RUNOFF RETENTION VOLUME (cubic feet) = 0

PERMEABLE PAVING — (*) Based on an INFILTRATION RATE of 9.743 (Inches/Day) for soils in Hydrologic Soil Group B

PERMEABLE PAVING AREA (square feet) =

24 HOUR INFILTRATION VOLUME (cubic feet) =

STONE SUB-BASE VOID RATIO = 0.35

MINUMUM STONE STORAGE DEPTH (inches) =

ESTIMATED RUNOFF RETENTION VOLUME (cubic feet) = 0

RAIN WATER HARVESTING

CATCHMENT (ROOF) AREA DRAINING INTO BMP (square feet) =

ESTIMATED AVERAGE DAILY USAGE (gallons per day) =

DESIRED NUMBER OF SERVICE DAYS (3 - 7 days) = 3 STORAGE CAPACITY (gallons) =

ESTIMATED RUNOFF VOLUME (95% RAIN) (gallons) =

ESTIMATED RUNOFF RETENTION VOLUME (cubic feet) = 0

:imate limited by CATCHMENT (roof) AREA]

CHECK for EISA 438 VOLUME CONTROL COMPLIANCE

TOTAL ESTIMATED RUNOFF RETENTION VOLUME (cubic feet) = 477

RUNOFF RETENTION VOLUME COMPLIANCE TARGET (cubic feet) = 467

LID Practices should be sufficient for compliance with Volume Control Requirement

Figure 4-13. Fort Drum LID BMP Computations

Since the Total Runoff Volume Retained (477 ft^3) exceeds the EISA Volume Requirement (467 ft^3), this project is expected to comply with EISA Section 438 using the selected LID BMPs.

4.5.4 Fort Hood Case Study

4.5.4.1 Background

Fort Hood is a United States military post located outside of Killeen, Texas (Figure 4-14). Fort Hood gets 32 inches of rain per year. The number of days with any measurable precipitation is 64. On average, there are 226 sunny days per year in Fort Hood. The July high is around 96^{o}F and the January low is 34^{o}F.

Figure 4-14. Fort Hood, TX Vicinity Map

The post is named after Confederate General John Bell Hood. It is located halfway between Austin and Waco, about 60 miles (97 km) from each, within the U.S. state of Texas. Its origin was the need for wide-open space to test and train with World War II tank destroyers. Today, Fort Hood has nearly 65,000 soldiers and family members and serves as a home for the following units: Headquarters III Corps; First Army Division West; the 1st Cavalry Division; 13th Sustainment Command (formerly 13th Corps Support Command); 89th Military Police Brigade; 504th Battlefield Surveillance Brigade; 21st Cavalry Brigade (Air Combat); Combat Aviation Brigade, 4th Infantry Division; and the 31st Air Defense Artillery Brigade. Fort Hood also includes Carl R. Darnall Army Medical Center and the Medical and Dental Activities as tenant units.

The Fort Hood installation can be seen in Figure 4-15.

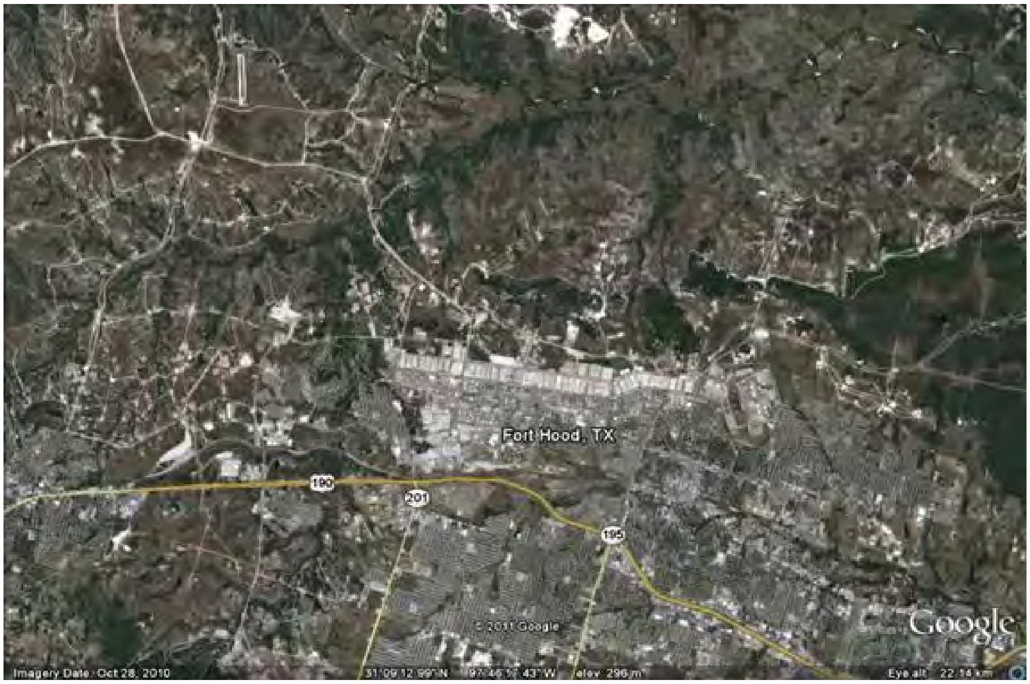


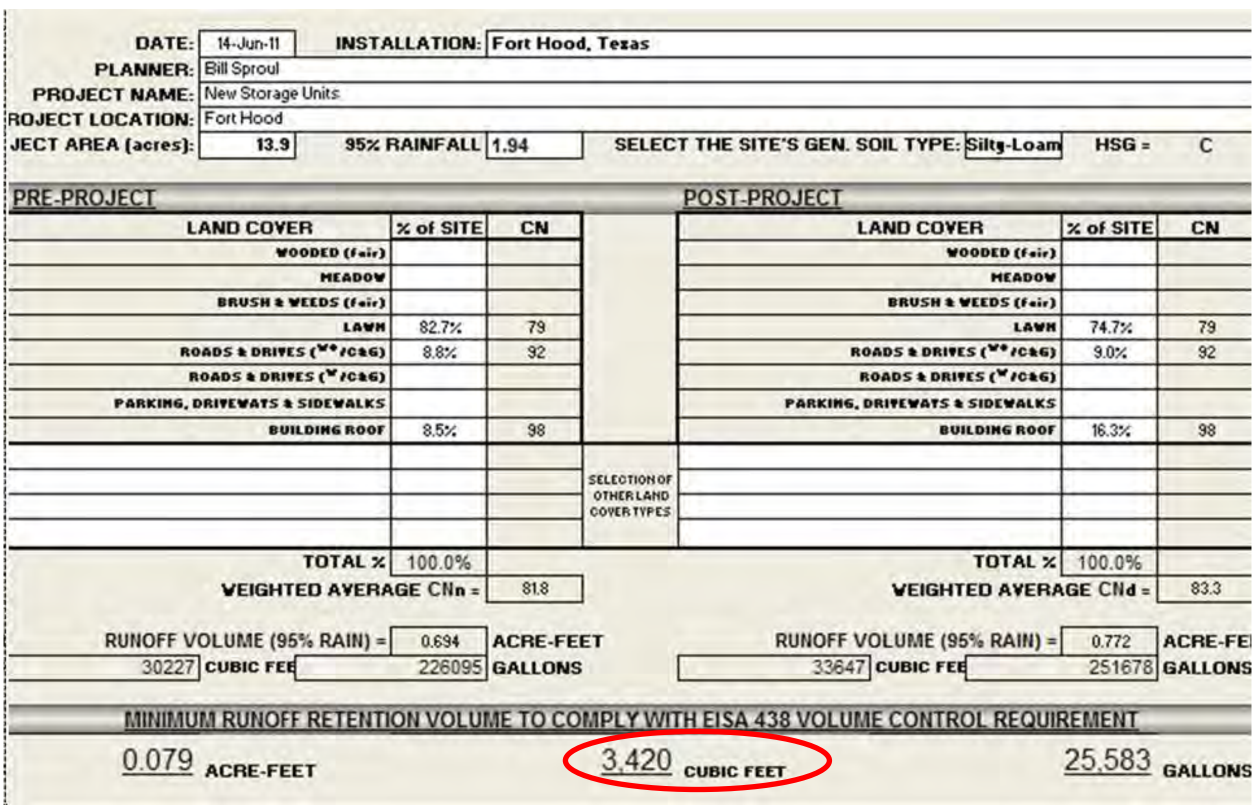
Figure 4-15. Fort Hood, TX Installation Area

4.5.4.2 Pre-Project Conditions

For this demonstration project, four new buildings were added to the project site.

From a review of the USDA soils database, the predominant hydrologic soil group for the project site is Hydrologic Soil Group C. The existing land use consisted of Lawn, and Existing Buildings, Figure 4-16. By inputting the percent site area of each land use to the spreadsheet tool, the estimated SCS curve number, CN, for each land use type is populated. Then the area weighted average pre-project CN is computed to be **81.8** (Figure 4-17).

Figure 4-16. Fort Hood, TX Project Site - Existing Landuse Conditions



DATE: 14-Jun-11 INSTALLATION: Fort Hood, Texas
PLANNER: Bill Sproul
PROJECT NAME: New Storage Units
ROJECT LOCATION: Fort Hood
JECT AREA (acres): 13.9 95% RAINFALL 1.94 SELECT THE SITE'S GEN. SOIL TYPE: Silty-Loam HSG = C

PRE-PROJECT

LAND COVER	% of SITE	CN
WOODED (fair)		
MEADOW		
BRUSH & WEEDS (fair)		
LAWN	82.7%	79
ROADS & DRIVES (W*/C&G)	8.8%	92
ROADS & DRIVES (W/C&G)		
PARKING, DRIVEWAYS & SIDEWALKS		
BUILDING ROOF	8.5%	98
TOTAL %	100.0%	
WEIGHTED AVERAGE CNn =		81.8

RUNOFF VOLUME (95% RAIN) = 0.694 ACRE-FEET
30227 CUBIC FEE 226095 GALLONS

SELECTION OF OTHER LAND COVER TYPES

POST-PROJECT

LAND COVER	% of SITE	CN
WOODED (fair)		
MEADOW		
BRUSH & WEEDS (fair)		
LAWN	74.7%	79
ROADS & DRIVES (W*/C&G)	9.0%	92
ROADS & DRIVES (W/C&G)		
PARKING, DRIVEWAYS & SIDEWALKS		
BUILDING ROOF	16.3%	98
TOTAL %	100.0%	
WEIGHTED AVERAGE CNd =		83.3

RUNOFF VOLUME (95% RAIN) = 0.772 ACRE-FEI
33647 CUBIC FEE 251678 GALLONS

MINIMUM RUNOFF RETENTION VOLUME TO COMPLY WITH EISA 438 VOLUME CONTROL REQUIREMENT

0.079 ACRE-FEET 3,420 CUBIC FEET 25,583 GALLONS

Figure 4-17. Fort Hood Runoff Computations

4.5.4.3 Post-Project Conditions

The post project land use, Figure 4-18, consisted of Lawn, Existing Buildings, and New Buildings. By inputting the percent site area of each land use to the spreadsheet tool, the estimated SCS curve number, CN, for each land use type is populated. Then the area weighted average pre-project CN is computed to be **83.3** (Figure 4-17).

Figure 4-18. Fort Hood, TX Project Site - Post-Project Landuse Conditions

4.5.4.4 Calculate EISA Volume Requirement

The next step in the hydrologic design is to compute the 95th percentile storm. Based on an evaluation of a 50 year period of record of daily precipitation at Fort Hood, Figure 4-19, the 95th percentile storm was computed to be **1.94 inches**.

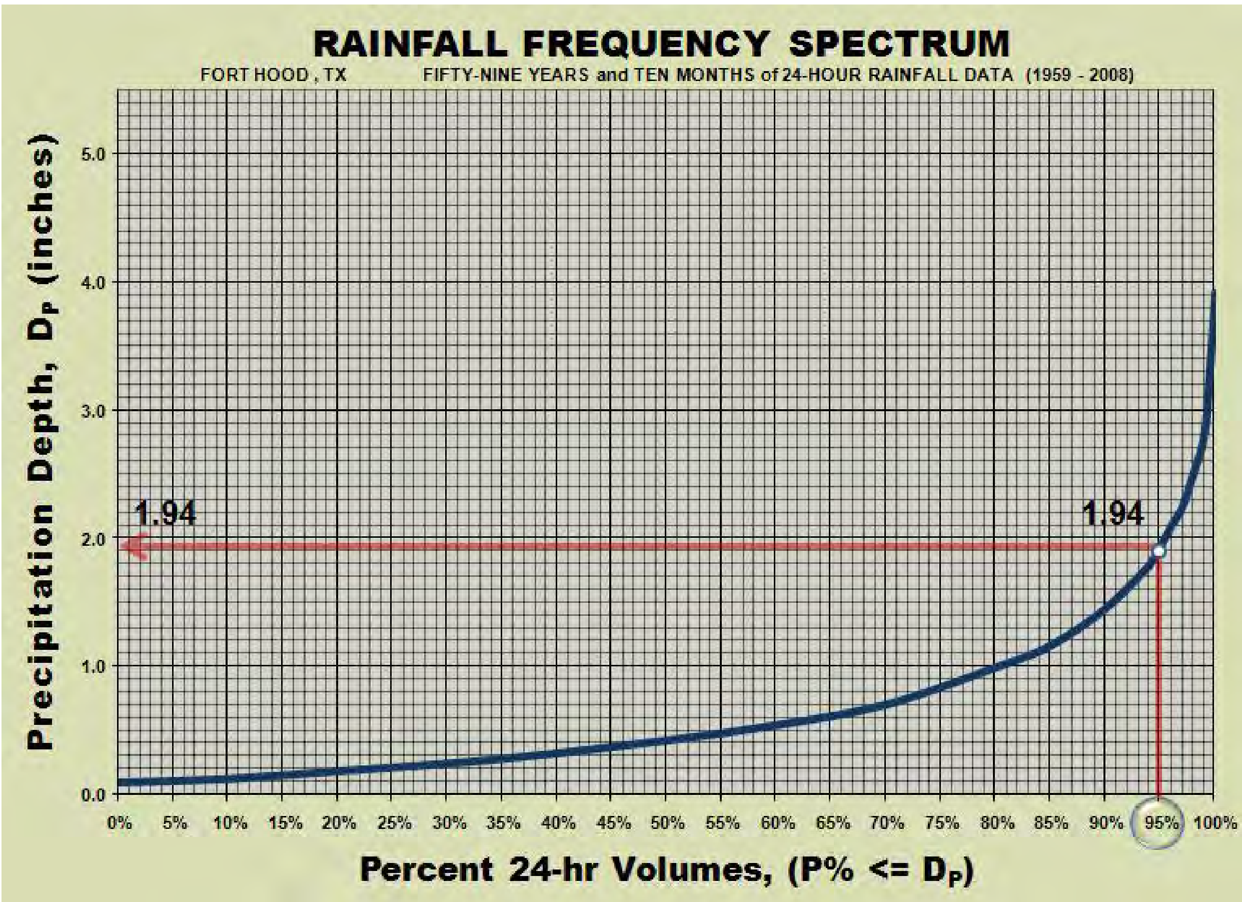


Figure 4-19. Fort Hood, TX - 95th Percentile Storm Depth (Inches)

At this point one is able to compute the peak runoff depths for both the existing and post project conditions using the SCS CN method. The peak runoff depths were computed to be 0.60 inches and 0.67 inches respectively using the 95th percentile storm.

Once one computes the existing and post runoff depths then they are able to compute the amount of water that needs to be managed on the project site by multiplying the change in runoff depth by the site area, 13.9 acres. From this analysis, the Fort Hood project needs to manage **3,420 ft^3** of runoff, as shown in Figure 4-17.

<u>Input Parameters:</u>
Site Area (A) = 13.9 acres
95th Storm (P) = 1.94 inches
Existing CN = 81.8
Post CN = 83.3

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \qquad S = \frac{1000}{CN} - 10$$

<u>Output:</u>
Existing Q = 0.60 inches
Post Q = 0.67 inches

4.5.4.5 Select LID BMPs to Manage EISA Volume

The LID practice that was evaluated for this project was a series of rain gardens, Figure 4-20. For this analysis, a Group C soil allows for 4.43 inches/day of water removed from the project site using this LID practice. Since this LID feature is an infiltration practice, it was determined that a rain garden area of 16,500 ft^2 (0.38 acres) was needed assuming a 24-hour dissipation time.

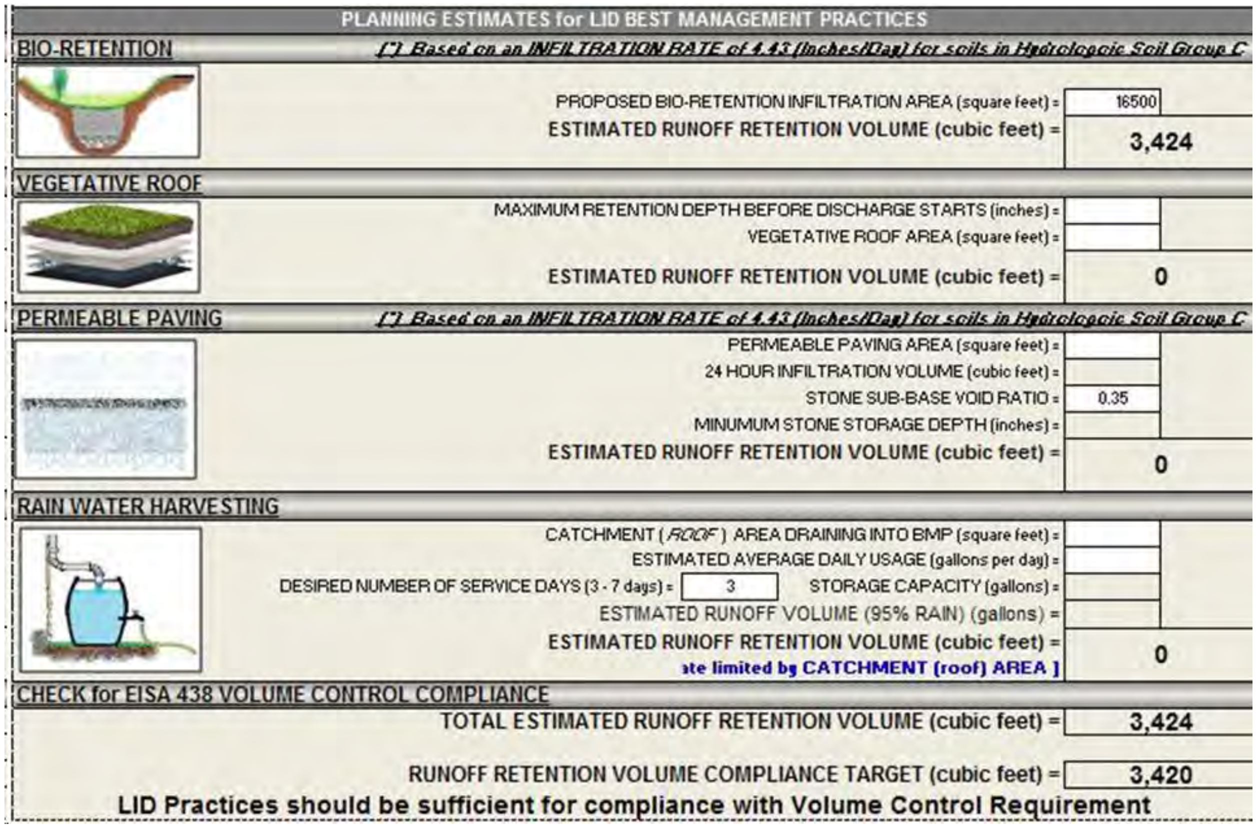


Figure 4-20. Fort Hood LID BMP Computations

Since the Total Runoff Volume Retained (3,424 ft^3) exceeds the EISA Volume Requirement (3,420 ft^3), this project is expected to comply with EISA Section 438 using the selected LID BMPs.

4.5.5 Fort Benning Case Study

4.5.5.1 Background

Fort Benning is a United States military post located outside of Columbus, GA (Figure 4-21). Columbus, GA, gets 49 inches of rain per year. The number of days with any measurable precipitation is 109. On average, there are 212 sunny days per year in Columbus, GA. The July high is around 92^{o}F and the January low is 36^{o}F.

Figure 4-21. Fort Benning, GA Vicinity Map

Fort Benning was established is 1918 and is named for Major General Henry L. Benning. It is south of Columbus, Georgia on U.S. highway 27. It has an active duty population of 34,834. This includes both reserve components. Fort Benning covers 73,533 hectares (181,626 acres) of land with 93% in west central Georgia and the remaining 7% in east central Alabama. Major portions of land lie in 3 counties: Muscogee and Chattahoochee Counties Georgia and Russell County in Alabama. There are about 124 hectares of open water, including ponds, streams, and rivers. The Chattahoochee River divides Fort Benning between Georgia and Alabama.

The Fort Benning installation can be seen in Figure 4-22.

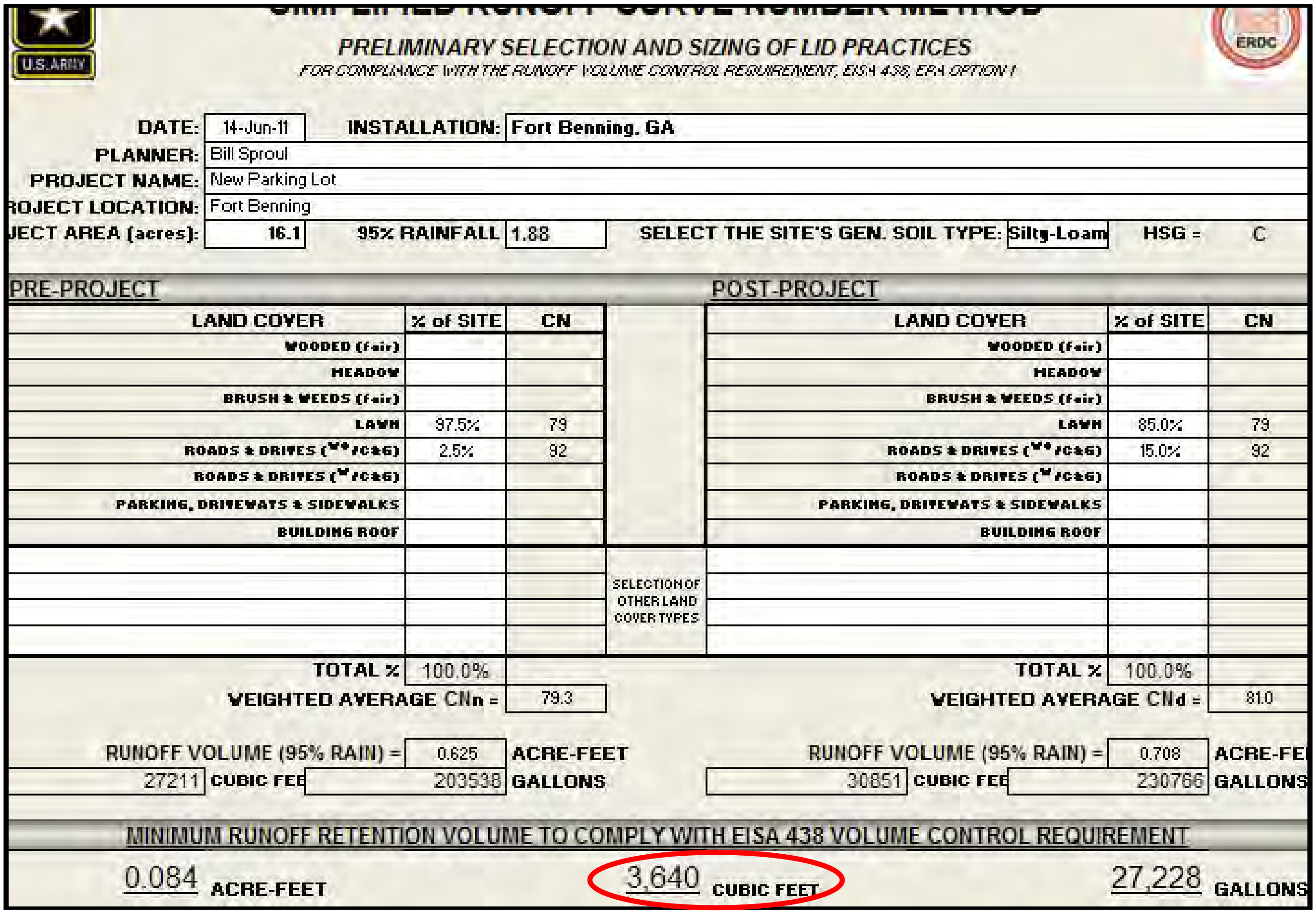
Figure 4-22. Fort Benning, GA Installation Area

4.5.5.2 Pre-Project Conditions

For this demonstration project, a new impervious parking lot was added to the project site.

From a review of the USDA soils database, the predominant hydrologic soil group for the project site is Hydrologic Soil Group C. The existing land use consisted of Grassland and Road, Figure 4-23. By inputting the percent site area of each land use to the spreadsheet tool, the estimated SCS curve number, CN, for each land use type is populated. Then the area weighted average pre-project CN is computed to be **79.3** (Figure 4-24).

Figure 4-23. Fort Benning, GA Project Site - Existing Landuse Conditions


SIMPLIFIED RUNOFF CURVE NUMBER METHOD

PRELIMINARY SELECTION AND SIZING OF LID PRACTICES

FOR COMPLIANCE WITH THE RUNOFF VOLUME CONTROL REQUIREMENT, EISA 438, EPA OPTION I

DATE: 14-Jun-11 INSTALLATION: Fort Benning, GA

PLANNER: Bill Sproul

PROJECT NAME: New Parking Lot

PROJECT LOCATION: Fort Benning

PROJECT AREA (acres): 16.1 95% RAINFALL 1.88 SELECT THE SITE'S GEN. SOIL TYPE: Silty-Loam HSG = C

PRE-PROJECT LAND COVER	% of SITE	CN	POST-PROJECT LAND COVER	% of SITE	CN
WOODED (fair)			WOODED (fair)		
MEADOW			MEADOW		
BRUSH & WEEDS (fair)			BRUSH & WEEDS (fair)		
LAWN	97.5%	79	LAWN	85.0%	79
ROADS & DRIVES (W+/C&G)	2.5%	92	ROADS & DRIVES (W+/C&G)	15.0%	92
ROADS & DRIVES (W/C&G)			ROADS & DRIVES (W/C&G)		
PARKING, DRIVEWAYS & SIDEWALKS			PARKING, DRIVEWAYS & SIDEWALKS		
BUILDING ROOF			BUILDING ROOF		
SELECTION OF OTHER LAND COVER TYPES					
TOTAL %	100.0%		TOTAL %	100.0%	
WEIGHTED AVERAGE CNn =		79.3	WEIGHTED AVERAGE CNd =		81.0

	PRE-PROJECT	POST-PROJECT
RUNOFF VOLUME (95% RAIN) =	0.625 ACRE-FEET	0.708 ACRE-FEET
	27211 CUBIC FEET	30851 CUBIC FEET
	203538 GALLONS	230766 GALLONS

MINIMUM RUNOFF RETENTION VOLUME TO COMPLY WITH EISA 438 VOLUME CONTROL REQUIREMENT

0.084 ACRE-FEET 3,640 CUBIC FEET 27,228 GALLONS

Figure 4-24. Fort Benning Runoff Computations

4.5.5.3 Post-Project Conditions

The post project land use (Figure 4-25), consisted of Grassland, Road, and New Parking Lot. By inputting the percent site area of each land use to the spreadsheet tool, the estimated SCS curve number, CN, for each land use type is populated. Then the area weighted average pre-project CN is computed to be **81.0** (Figure 4-24).

Figure 4-25. Fort Benning, GA Project Site - Post-project Landuse Conditions

4.5.5.4 Calculate EISA Volume Requirement

The next step in the hydrologic design is to compute the 95th percentile storm. Based on an evaluation of a 50 year period of record of daily precipitation at Fort Benning (Figure 4-26), the 95th percentile storm was computed to be **1.88 inches**.

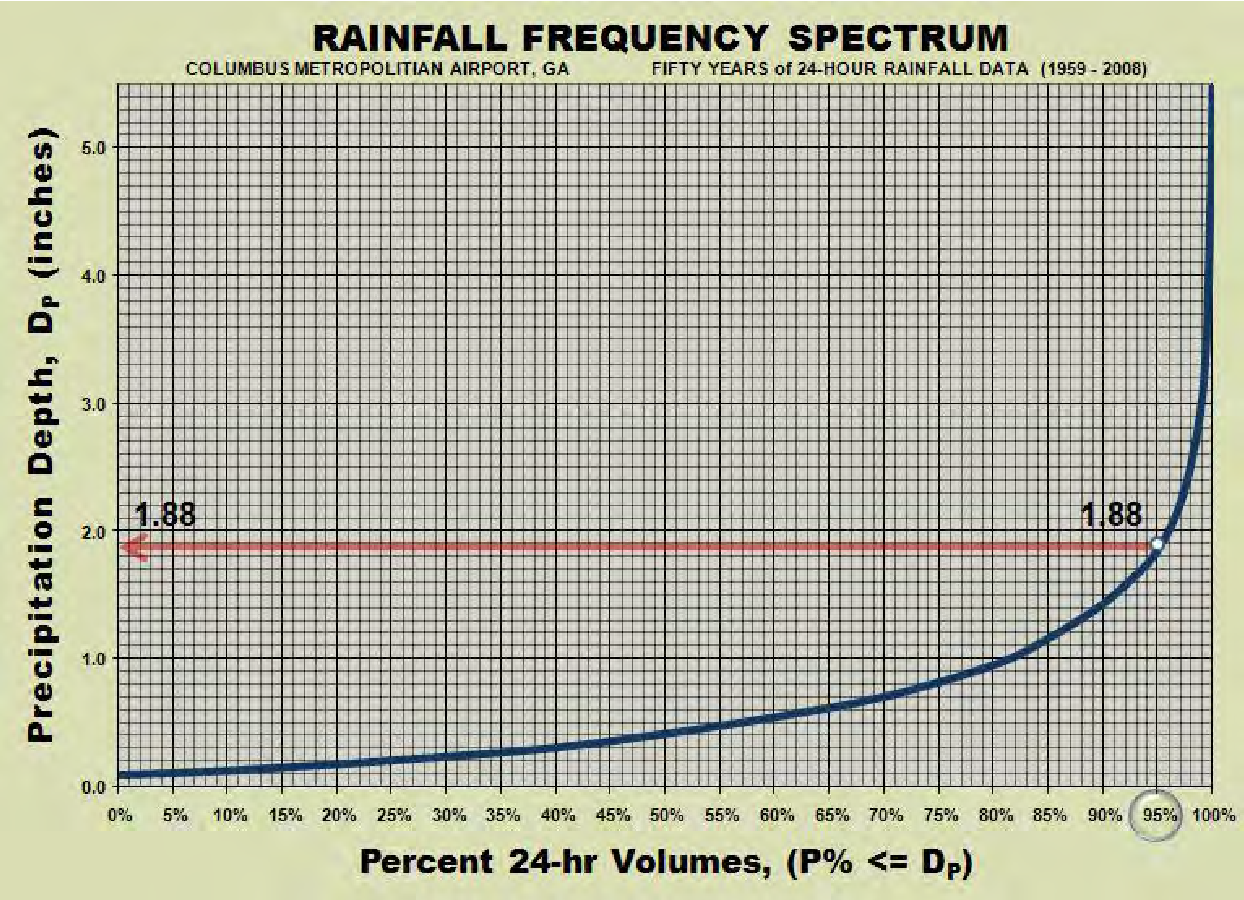


Figure 4-26. Fort Benning, GA - 95th Percentile Storm Depth (Inches)

At this point one is able to compute the peak runoff depths for both the existing and post project conditions using the SCS CN method. The peak runoff depths were computed to be 0.46 inches and 0.53 inches respectively using the 95th percentile storm.

Once one computes the existing and post project runoff depths, then they are able to compute the amount of water that needs to be managed on the project site by multiplying the change in runoff depth by the site area, 16.1 acres. From this analysis, the Fort Benning project needs to manage **3,640 ft^3** of runoff.

Input Parameters:
Site Area (A) = 16.1 acres
95th Storm (P) = 1.88 inches
Existing CN = 79.3
Post CN = 81.0

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad S = \frac{1000}{CN} - 10$$

Output:
Existing Q = 0.46 inches
Post Q = 0.53 inches

4.5.5.5 Select LID BMPs to Manage EISA Volume

The LID practice that was evaluated for this project was a bioswale, Figure 4-27. For this analysis, a Group C soil allows for 4.43 inches/day of water removed from the project site using this LID practice. Since this LID feature is an infiltration practice, it was determined that a bioswale of 17,200 ft2 (0.4 acres) was needed assuming a 24-hour dissipation time.

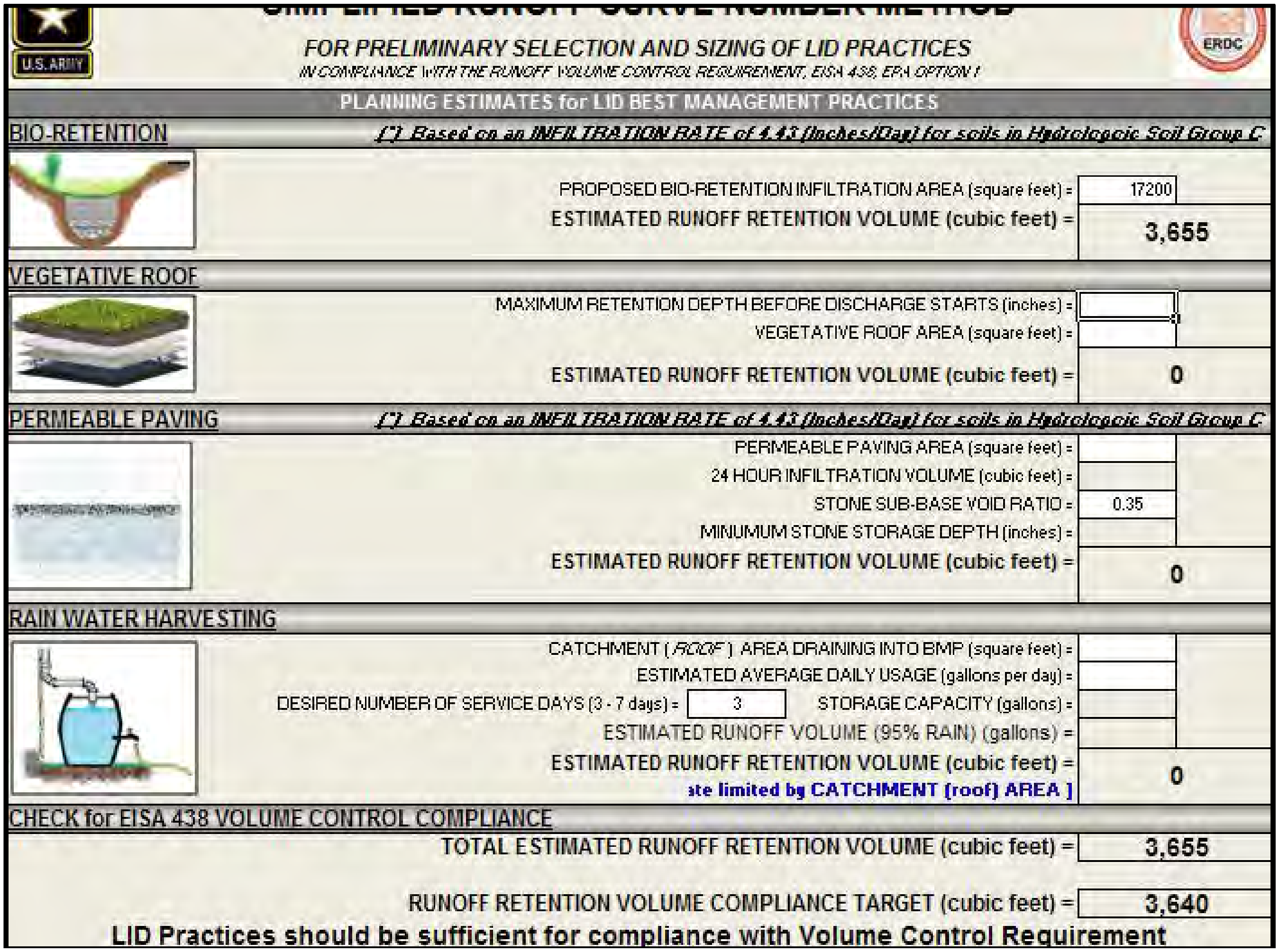


Figure 4-27. Fort Benning, GA LID BMP Computations

Since the Total Runoff Volume Retained (3,655 ft^3) exceeds the EISA Volume Requirement (3,640 ft^3), this project is expected to comply with EISA Section 438 using the selected LID BMPs.

4.5.6 Fort Meade Case Study #1: AWG Headquarters Complex

4.5.6.1 Background

Fort Meade is a United States military post located outside of Baltimore, MD (Figure 4-28). Fort Meade, MD, gets 44 inches of rain per year. The number of days with any measurable precipitation is 109. On average, there are 215 sunny days per year in Fort Meade, MD. The July high is around 88°F and the January low is 24°F.

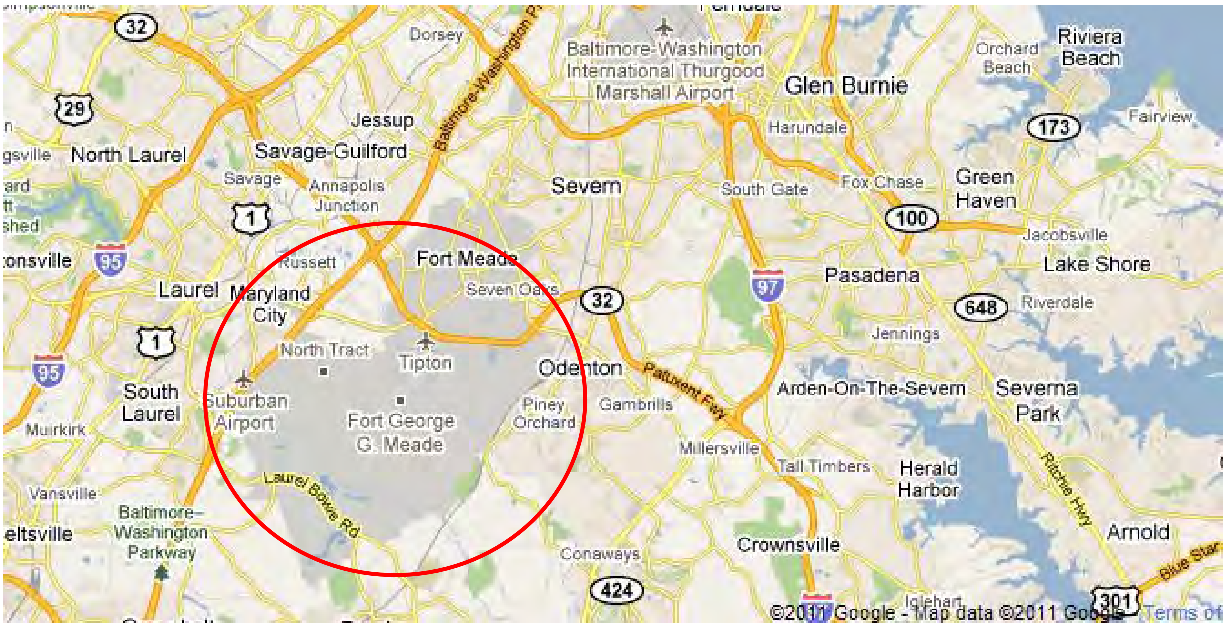


Figure 4-28. Fort Meade, MD Vicinity Map

Fort Meade became an active Army installation in 1917. Authorized by an Act of Congress in May 1917, it was one of 16 cantonments built for troops drafted for the war with the Central Powers in Europe. In August 1990, Fort Meade began processing Army Reserve and National Guard units from several states for the presidential call-up in support of Operation Desert Shield. In addition to processing reserve and guard units, Fort Meade sent two of its own active duty units, the 85th Medical Battalion and the 519th Military Police Battalion, to Saudi Arabia. In all, approximately 2,700 personnel from 42 units deployed from Fort Meade during Operation Desert Shield/Desert Storm.

The Fort Meade installation can be seen in Figure 4-29.

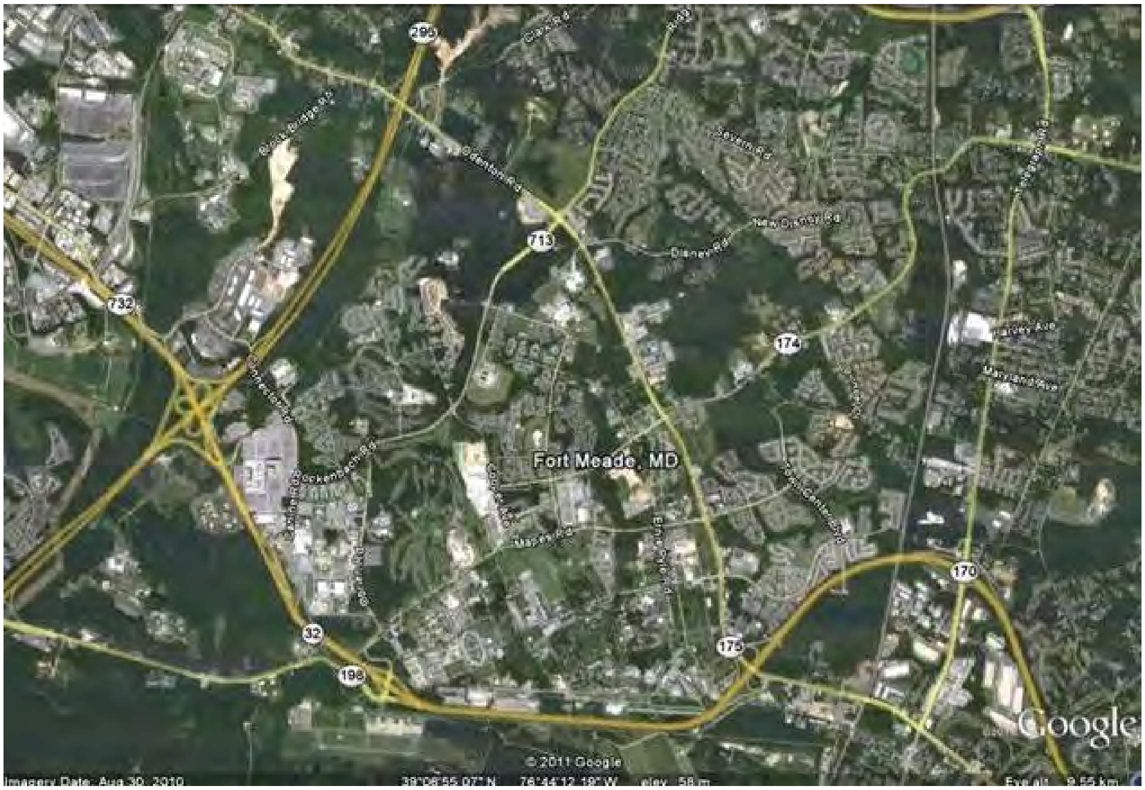


Figure 4-29. Fort Meade, MD Installation Area

4.5.6.2 Pre-Project Conditions

This project includes a proposed Headquarters Building, Visitor Control Center, and associated roads and parking.

The existing 9.30 acre site, as shown in Figure 4-30 is predominantly meadow, with a small pocket of mature woods. There are a few abandoned buildings and associated pavement to be demolished as part of this project. There are no wetlands or streams within the site limits. Groundwater is not an issue; soil borings show the water table to be at least 15 feet below the ground surface. Based on a review of the USDA soils database, the predominant hydrologic soil group for the project site is Hydrologic Soil Group B, “Sandy Loam”.

By inputting the percent site area of each land use (Meadow, Woods, Building Roof, Parking/Driveways/Sidewalk) to the spreadsheet tool, the estimated SCS curve number, CN, for each land use type is populated. Then the area weighted average pre-project CN is computed to be **62** (Figure 4-32).

Figure 4-30. Pre-Project Landuse Conditions

4.5.6.3 Post-Project Conditions

The proposed includes a 47,000 square foot Headquarters Building, a 2,900 square foot Visitor Control Center (VCC), and supporting facilities including parking, a loading dock, a maintenance drive, and a front drop off circle.

The post-project land use, Figure 4-31, consists of Grass, Building Roof, and Parking/Driveways/Sidewalks. By inputting the percent of site area of each land use to the spreadsheet tool, the estimated SCS curve number, CN, for each land use type is populated. Then the area weighted average post-project CN is computed to be **80** (Figure 4-32).

Figure 4-31. Post-Project Landuse Conditions

LOW IMPACT DEVELOPMENT

SIMPLIFIED RUNOFF CURVE NUMBER METHOD

PRELIMINARY SELECTION AND SIZING OF STRUCTURAL LID PRACTICES

FOR COMPLIANCE WITH THE RUNOFF VOLUME CONTROL REQUIREMENT, EISA 438, MODIFIED EPA OPTION 2

V 9.2 — PLANNING ESTIMATES for PRE & POST RUNOFF VOLUMES — Page 1 of 3

DATE:	5-Oct-2012	ARMY INSTALLATION:	FORT MEADE
PLANNER:	EEM		
PROJECT NAME:	AWG HEADQUARTERS COMPLEX		
PROJECT LOCATION:	ROCK AVE.		
PROJECT AREA (acres):	9.3	95% RAINFALL	1.6
SELECT THE SITE'S OVERALL SOIL TYPE:	Sandy-Loam	HSG =	B

PRE-PROJECT LAND COVER	% of SITE	CN		POST-PROJECT LAND COVER	% of SITE	CN
WOODED (fair)	9.4%	60		WOODED (fair)		
MEADOW	82.0%	58		MEADOW		
BRUSH & WEEDS (fair)				BRUSH & WEEDS (fair)		
LAWN				LAWN	61.0%	69
ROADS & DRIVES (w/C&G)				ROADS & DRIVES (w/C&G)		
ROADS & DRIVES (w/C&G)				ROADS & DRIVES (w/C&G)		
PARKING, DRIVEWAYS & SIDEWALKS	4.6%	98		PARKING, DRIVEWAYS & SIDEWALKS	27.0%	98
BUILDING ROOF	4.0%	98		BUILDING ROOF	12.0%	98
			SELECTION OF OTHER LAND COVER TYPES			
TOTAL %	1			TOTAL %	1	
WEIGHTED AVERAGE CNn =		62		WEIGHTED AVERAGE CNd =		80

Figure 4-32. Pre-Project and Post-Project Curve Numbers

4.5.6.4 Calculate EISA Volume Requirement

At this point one is able to calculate the EISA Volume Requirement for the project, using the inputs of Pre-Project CN, Post-Project CN, Site Area, and 95th percentile storm depth. For this example, instead of calculating the 95th percentile rainfall depth as in previous examples, the 95th percentile depth for Baltimore, MD, given in Table 4-1 of this guide (also in Table 1 of EPA's *Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act*) is used, **1.6 inches**.

The spreadsheet tool uses the SCS CN Method to compute the peak runoff volumes for both pre- and post-project conditions. The peak runoff volumes are computed to be 645 ft^3 and 11,672 ft^3, respectively. The difference between these volumes is the EISA Volume Requirement, which is the amount of runoff that needs to be retained on site using LID BMPs.

From this analysis, the Fort Meade project needs to manage **11,027 ft^3** of runoff, as shown in Figure 4-33.

<u>Input Parameters:</u>
Site Area (A) = 9.3 acres
95th Storm (P) = 1.6 inches
Existing CN = 62
Post CN = 80

<u>Output:</u>

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

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

Q = Runoff Volume (ft^3)
Pre-Project Q = 645 ft^3
Post-Project Q = 11,672 ft^3
Difference in Q = 11,027 ft^3

SIMPLIFIED RUNOFF CURVE NUMBER METHOD

PRELIMINARY SELECTION AND SIZING OF STRUCTURAL LID PRACTICES

FOR COMPLIANCE WITH THE RUNOFF VOLUME CONTROL REQUIREMENT, EISA 438, MODIFIED EPA OPTION 2

V 9.2 — **PLANNING ESTIMATES for PRE & POST RUNOFF VOLUMES** — Page 1 of 3

DATE:	5-Oct-2012	ARMY INSTALLATION:	FORT MEADE
PLANNER:	EEM		
PROJECT NAME:	AWG HEADQUARTERS COMPLEX		
PROJECT LOCATION:	ROCK AVE.		
PROJECT AREA (acres):	9.3	95% RAINFALL	1.6
SELECT THE SITE'S OVERALL SOIL TYPE:	Sandy-Loam	HSG =	B

PRE-PROJECT LAND COVER	% of SITE	CN		POST-PROJECT LAND COVER	% of SITE	CN
WOODED (fair)	9.4%	60		WOODED (fair)		
MEADOW	82.0%	58		MEADOW		
BRUSH & WEEDS (fair)				BRUSH & WEEDS (fair)		
LAWN				LAWN	61.0%	69
ROADS & DRIVES (WO/C&G)				ROADS & DRIVES (WO/C&G)		
ROADS & DRIVES (W/C&G)				ROADS & DRIVES (W/C&G)		
PARKING, DRIVEWAYS & SIDEWALKS	4.6%	98		PARKING, DRIVEWAYS & SIDEWALKS	27.0%	98
BUILDING ROOF	4.0%	98		BUILDING ROOF	12.0%	98
			SELECTION OF OTHER LAND COVER TYPES			
TOTAL %	1			TOTAL %	1	
WEIGHTED AVERAGE CNn =		62		WEIGHTED AVERAGE CNd =		80
RUNOFF VOLUME (95% RAIN) =	0.01	ACRE-FEET		RUNOFF VOLUME (95% RAIN) =	0.267949603	ACRE-FEET
645 CUBIC FEET	4828	GALLONS		11672 CUBIC FEET	87306	GALLONS

MINIMUM RUNOFF RETENTION VOLUME TO COMPLY WITH EISA 438 VOLUME CONTROL REQUIREMENT

0.25 ACRE-FEET	11027 CUBIC FEET	82478 GALLONS

Figure 4-33. Runoff Computations

4.5.6.5 Select LID BMPs to Manage EISA Volume

The LID practices chosen for this project to retain runoff is bioretention areas, concrete permeable pavers, and infiltration trenches (dry well). Figure 4-34 shows these proposed practices. Inputing the proposed surface area of each LID BMP in the spreadsheet, the volume of runoff retained is calculated, as shown in Figure 4-35. Summing these retention volumes (15947 ft^3 + 214 ft^3 + 1773 ft^3 + 1640 ft^3) gives a Total Volume Retained for the site, **19,574 ft^3**.

Since the Total Runoff Volume Retained (19,574 ft^3) exceeds the EISA Volume Requirement (11,027 ft^3), this project fulfills EISA Section 438 with the selected LID BMPs.

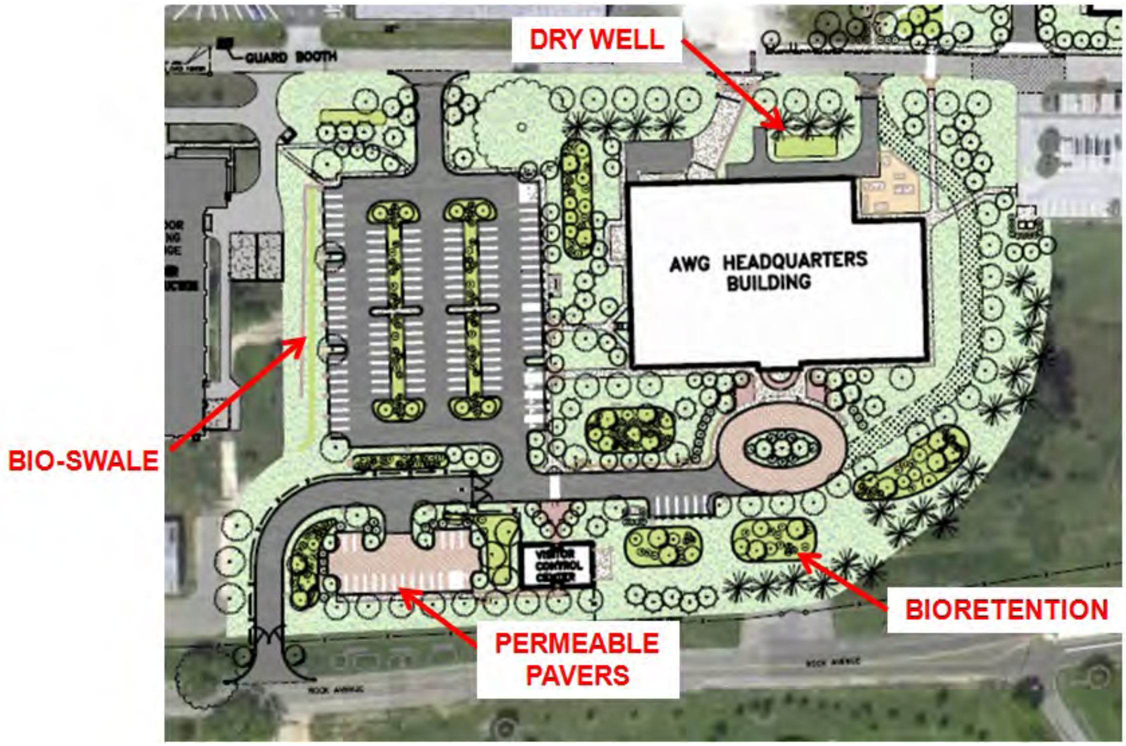
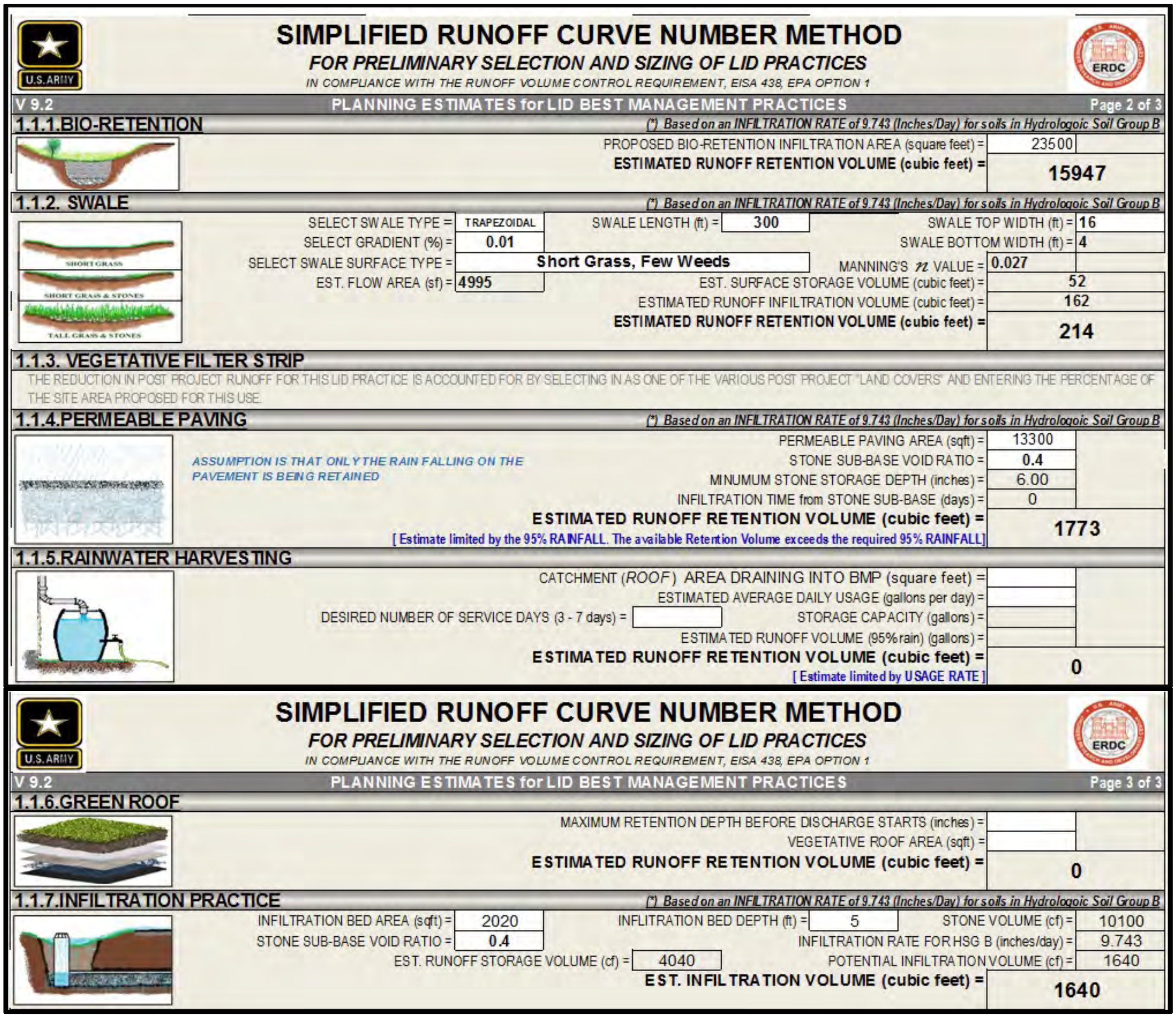


Figure 4-34. Proposed LID BMPs Implemented



SIMPLIFIED RUNOFF CURVE NUMBER METHOD

FOR PRELIMINARY SELECTION AND SIZING OF LID PRACTICES

IN COMPLIANCE WITH THE RUNOFF VOLUME CONTROL REQUIREMENT, EISA 438, EPA OPTION 1

V 9.2 — PLANNING ESTIMATES for LID BEST MANAGEMENT PRACTICES — Page 2 of 3

1.1.1.BIO-RETENTION — (*) Based on an INFILTRATION RATE of 9.743 (Inches/Day) for soils in Hydrologoic Soil Group B

PROPOSED BIO-RETENTION INFILTRATION AREA (square feet) = 23500

ESTIMATED RUNOFF RETENTION VOLUME (cubic feet) = 15947

1.1.2. SWALE — (*) Based on an INFILTRATION RATE of 9.743 (Inches/Day) for soils in Hydrologoic Soil Group B

SHORT GRASS / SHORT GRASS & STONES / TALL GRASS & STONES

SELECT SWALE TYPE = TRAPEZOIDAL; SWALE LENGTH (ft) = 300; SWALE TOP WIDTH (ft) = 16

SELECT GRADIENT (%) = 0.01; SWALE BOTTOM WIDTH (ft) = 4

SELECT SWALE SURFACE TYPE = Short Grass, Few Weeds; MANNING'S n VALUE = 0.027

EST. FLOW AREA (sf) = 4995; EST. SURFACE STORAGE VOLUME (cubic feet) = 52

ESTIMATED RUNOFF INFILTRATION VOLUME (cubic feet) = 162

ESTIMATED RUNOFF RETENTION VOLUME (cubic feet) = 214

1.1.3. VEGETATIVE FILTER STRIP

THE REDUCTION IN POST PROJECT RUNOFF FOR THIS LID PRACTICE IS ACCOUNTED FOR BY SELECTING IN AS ONE OF THE VARIOUS POST PROJECT "LAND COVERS" AND ENTERING THE PERCENTAGE OF THE SITE AREA PROPOSED FOR THIS USE.

1.1.4.PERMEABLE PAVING — (*) Based on an INFILTRATION RATE of 9.743 (Inches/Day) for soils in Hydrologoic Soil Group B

ASSUMPTION IS THAT ONLY THE RAIN FALLING ON THE PAVEMENT IS BEING RETAINED

PERMEABLE PAVING AREA (sqft) = 13300

STONE SUB-BASE VOID RATIO = 0.4

MINUMUM STONE STORAGE DEPTH (inches) = 6.00

INFILTRATION TIME from STONE SUB-BASE (days) = 0

ESTIMATED RUNOFF RETENTION VOLUME (cubic feet) = 1773

[Estimate limited by the 95% RAINFALL. The available Retention Volume exceeds the required 95% RAINFALL]

1.1.5.RAINWATER HARVESTING

CATCHMENT (*ROOF*) AREA DRAINING INTO BMP (square feet) =

ESTIMATED AVERAGE DAILY USAGE (gallons per day) =

DESIRED NUMBER OF SERVICE DAYS (3 - 7 days) = ; STORAGE CAPACITY (gallons) =

ESTIMATED RUNOFF VOLUME (95%rain) (gallons) =

ESTIMATED RUNOFF RETENTION VOLUME (cubic feet) = 0

[Estimate limited by USAGE RATE]

SIMPLIFIED RUNOFF CURVE NUMBER METHOD

FOR PRELIMINARY SELECTION AND SIZING OF LID PRACTICES

IN COMPLIANCE WITH THE RUNOFF VOLUME CONTROL REQUIREMENT, EISA 438, EPA OPTION 1

V 9.2 — PLANNING ESTIMATES for LID BEST MANAGEMENT PRACTICES — Page 3 of 3

1.1.6.GREEN ROOF

MAXIMUM RETENTION DEPTH BEFORE DISCHARGE STARTS (inches) =

VEGETATIVE ROOF AREA (sqft) =

ESTIMATED RUNOFF RETENTION VOLUME (cubic feet) = 0

1.1.7.INFILTRATION PRACTICE — (*) Based on an INFILTRATION RATE of 9.743 (Inches/Day) for soils in Hydrologoic Soil Group B

INFILTRATION BED AREA (sqft) = 2020; INFILTRATION BED DEPTH (ft) = 5; STONE VOLUME (cf) = 10100

STONE SUB-BASE VOID RATIO = 0.4; INFILTRATION RATE FOR HSG B (inches/day) = 9.743

EST. RUNOFF STORAGE VOLUME (cf) = 4040; POTENTIAL INFILTRATION VOLUME (cf) = 1640

EST. INFILTRATION VOLUME (cubic feet) = 1640

Figure 4-35. LID BMP Computations

4.5.7 Fort Meade Case Study #2: Vehicle Maintenance Facility

4.5.7.1 Background

Please see Section 4.5.6.1 for Fort Meade background information. It is referenced instead of copied here to minimize redundancy.

4.5.7.2 Pre-Project Conditions

This re-development project includes a proposed Vehicle Maintenace Facility and associated pavement for vehicle and supply storage.

The existing 3.0 acre site, as shown in Figure 4-36 is developed and mostly impervious, with an existing building and associated pavement. These will be demolished as part of this prior to constructing the Vehicle Maintenance Facility. The site area is surrounded by mature woods. The site drains to the northwest to an ephemeral stream. Groundwater is not an issue; soil borings show the water table to be at least 15 feet below the grouned surface. Based on a review of the USDA soils database, the predominant hydrologic soil group for the project site is Hydrologic Soil Group A, “Sandy”.

By inputting the percent site area of each land use (Building Roof, Parking/Driveway/Sidewalk, Grass) to the spreadsheet tool, the estimated SCS curve number, CN, for each land use type is populated. Then the area weighted average pre-project CN is computed to be **87** (Figure 4-38).

Figure 4-36. Pre-Project Landuse Conditions

4.5.7.3 Post-Project Conditions

The proposed includes a 14,000 square foot Vehicle Maintenace building with surrounding pavement for vehicle and supply storage. There is no POV parking requirement for this project; the existing parking lot south of the site will be used.

The post-project land use, Figure 4-37, consists of Grass, Building Roof, and Parking/Driveway/Sidewalks. By inputting the percent of site area of each land use to the spreadsheet tool, the estimated SCS curve number, CN, for each land use type is populated. Then the area weighted average post-project CN is computed to be **90** (Figure 4-38).

Figure 4-37. Post-Project Landuse Conditions

SIMPLIFIED RUNOFF CURVE NUMBER METHOD

PRELIMINARY SELECTION AND SIZING OF STRUCTURAL LID PRACTICES

FOR COMPLIANCE WITH THE RUNOFF VOLUME CONTROL REQUIREMENT, EISA 438, MODIFIED EPA OPTION 2

V 9.2 — PLANNING ESTIMATES for PRE & POST RUNOFF VOLUMES — Page 1 of 3

DATE:	5-Oct-2012
ARMY INSTALLATION:	FORT MEADE
PLANNER:	EEM
PROJECT NAME:	VEHICLE MAINTENANCE FACILITYY (VMF)
PROJECT LOCATION:	MORRISON STREET
PROJECT AREA (acres):	3.0
95% RAINFALL	1.6
SELECT THE SITE'S OVERALL SOIL TYPE:	Sandy
HSG =	A

PRE-PROJECT LAND COVER	% of SITE	CN		POST-PROJECT LAND COVER	% of SITE	CN
WOODED (fair)				WOODED (fair)		
MEADOW				MEADOW		
BRUSH & WEEDS (fair)				BRUSH & WEEDS (fair)		
LAWN	23.0%	49		LAWN	16.0%	49
ROADS & DRIVES (WO/C&G)				ROADS & DRIVES (WO/C&G)		
ROADS & DRIVES (W/C&G)				ROADS & DRIVES (W/C&G)		
PARKING, DRIVEWAYS & SIDEWALKS	59.0%	98		PARKING, DRIVEWAYS & SIDEWALKS	74.0%	98
BUILDING ROOF	18.0%	98		BUILDING ROOF	10.0%	98
			SELECTION OF OTHER LAND COVER TYPES			
TOTAL %	1			TOTAL %	1	
WEIGHTED AVERAGE CNn =		87		WEIGHTED AVERAGE CNd =		90

Figure 4-38. Pre-Project and Post-Project Curve Numbers

4.5.7.4 Calculate EISA Volume Requirement

At this point one is able to calculate the EISA Volume Requirement for the project, using the inputs of Pre-Project CN, Post-Project CN, Site Area, and 95th percentile storm depth. For this example, instead of calculating the 95th percentile rainfall depth as in previous examples, the 95th percentile depth for Baltimore, MD, given in Table 4-1 of this guide (also in Table 1 of EPA's *Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act*) is used, **1.6 inches**.

The spreadsheet tool uses the SCS CN Method to compute the peak runoff volumes for both pre- and post-project conditions. The peak runoff volumes are computed to be 6,457 ft^3 and 8,407 ft^3, respectively. The difference between these volumes is the EISA Volume Requirement, which is the amount of runoff that needs to be retained on site using LID BMPs.

From this analysis, the Fort Meade project needs to manage **1,950 ft^3** of water, as shown in Figure 4-39.

<u>Input Parameters:</u>
Site Area (A) = 3.0 acres
95th Storm (P) = 1.6 inches
Existing CN = 87
Post CN = 90

<u>Output:</u>

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

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

Q = Runoff Volume (ft^3)
Pre-Project Q = 6,457 ft^3
Post-Project Q = 8,407 ft^3
Difference in Q = 1,950 ft^3

SIMPLIFIED RUNOFF CURVE NUMBER METHOD

PRELIMINARY SELECTION AND SIZING OF STRUCTURAL LID PRACTICES

FOR COMPLIANCE WITH THE RUNOFF VOLUME CONTROL REQUIREMENT, EISA 438, MODIFIED EPA OPTION 2

V 9.2 — PLANNING ESTIMATES for PRE & POST RUNOFF VOLUMES — Page 1 of 3

DATE:	5-Oct-2012	ARMY INSTALLATION:	FORT MEADE
PLANNER:	EEM		
PROJECT NAME:	VEHICLE MAINTENANCE FACILITYY (VMF)		
PROJECT LOCATION:	MORRISON STREET		
PROJECT AREA (acres):	3.0	95% RAINFALL	1.6
SELECT THE SITE'S OVERALL SOIL TYPE:	Sandy	HSG =	A

PRE-PROJECT LAND COVER	% of SITE	CN		POST-PROJECT LAND COVER	% of SITE	CN
WOODED (fair)				WOODED (fair)		
MEADOW				MEADOW		
BRUSH & WEEDS (fair)				BRUSH & WEEDS (fair)		
LAWN	23.0%	49		LAWN	16.0%	49
ROADS & DRIVES (^{WC}/C&G)				ROADS & DRIVES (^{WC}/C&G)		
ROADS & DRIVES (^{W}/C&G)				ROADS & DRIVES (^{W}/C&G)		
PARKING, DRIVEWAYS & SIDEWALKS	59.0%	98		PARKING, DRIVEWAYS & SIDEWALKS	74.0%	98
BUILDING ROOF	18.0%	98		BUILDING ROOF	10.0%	98
			SELECTION OF OTHER LAND COVER TYPES			
TOTAL %	1			TOTAL %	1	
WEIGHTED AVERAGE CNn =		87		WEIGHTED AVERAGE CNd =		90
RUNOFF VOLUME (95% RAIN) =	0.15	ACRE-FEET		RUNOFF VOLUME (95% RAIN) =	0.192990864	ACRE-FEET
6457 CUBIC FEET	48297	GALLONS		8407 CUBIC FEET	62882	GALLONS

MINIMUM RUNOFF RETENTION VOLUME TO COMPLY WITH EISA 438 VOLUME CONTROL REQUIREMENT

0.04 ACRE-FEET	1950 CUBIC FEET	14585 GALLONS

Figure 4-39. Runoff Computations

4.5.7.5 Select LID BMPs to Manage EISA Volume

The LID practices chosen for this project to retain runoff is bioretention areas, bio-swale, grass swale, and landscape infiltration. Figure 4-40 shows these proposed practices. Inputing the proposed surface area of each LID BMP in the spreadsheet, the volume of runoff retained is calculated, as shown in Figure 4-41. Summing these retention volumes (2719 ft^3 + 85 ft^3 + 741 ft^3) gives a Total Volume Retained for the site, **3545 ft^3**.

Since the Total Runoff Volume Retained (3545 ft^3) exceeds the EISA Volume Requirement (1950 ft^3), this project fulfills EISA Section 438 with the selected LID BMPs.

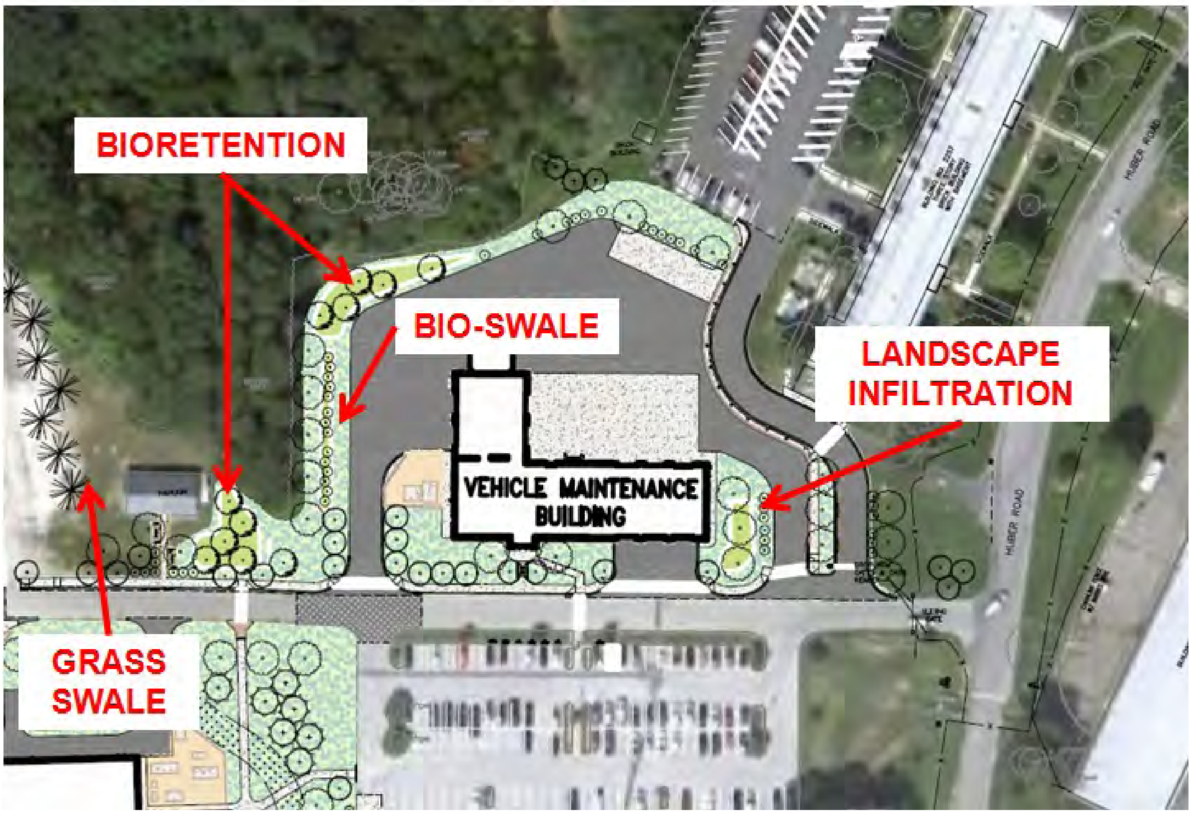


Figure 4-40. Proposed LID BMPs Implemented

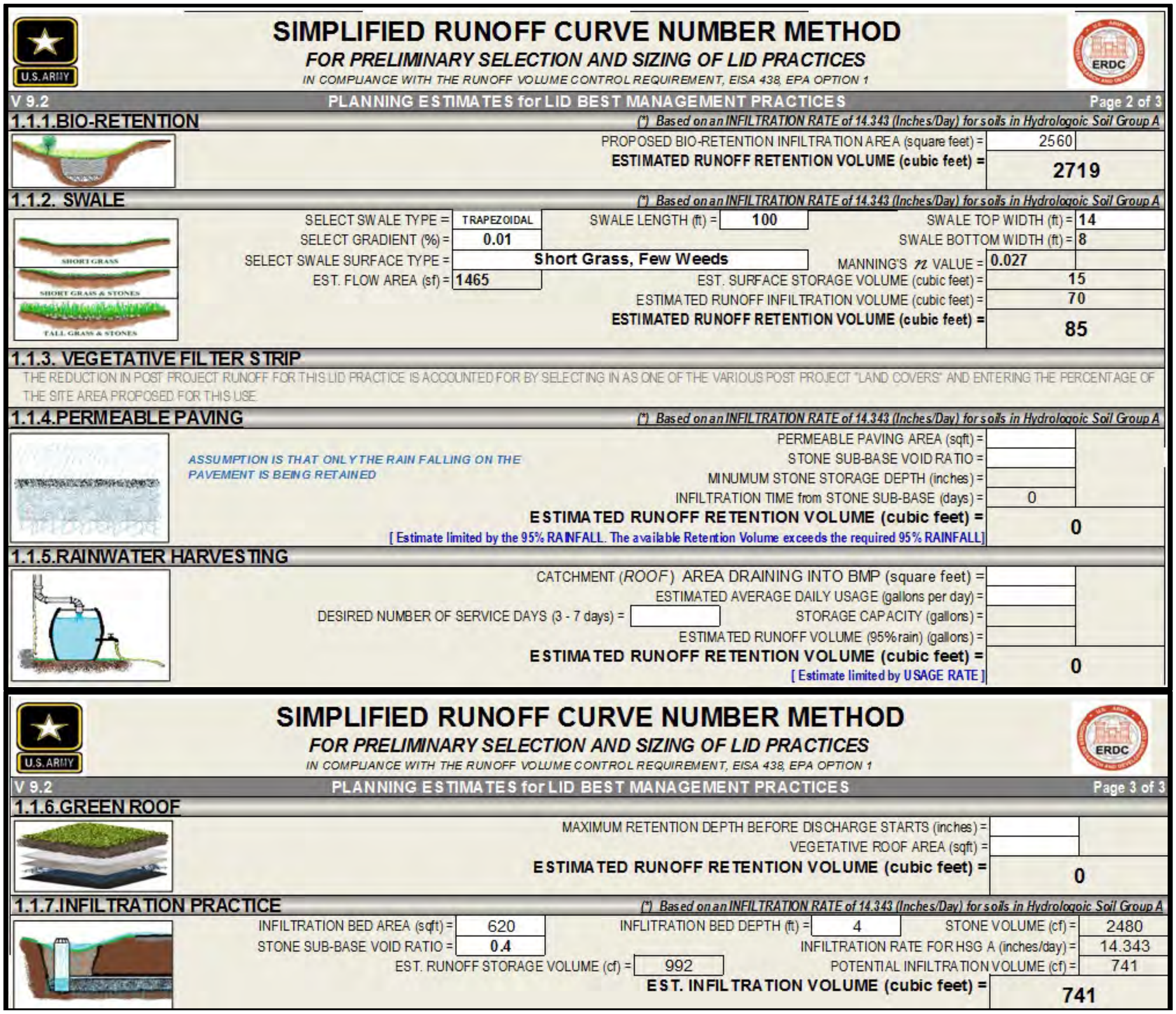


Figure 4-41. LID BMP Computations

Hydrologic modeling and simulation to meet the requirements of EISA Section 438 can be complemented by models and simulations that meet other regulatory requirements. As mentioned throughout the LID Technical User Guide, LID can be used to meet other regulatory requirements, such as state and local jurisdictions. Appendix E illustrates how LID and complementary modeling can be used to maximize compliance with regulations.

4.5.8 Fort Meade Case Study #3: DPW Building

4.5.8.1 Background

Please see Section 4.5.6.1 for Fort Meade background information. It is referenced instead of copied here to minimize redundancy.

4.5.8.2 Pre-Project Conditions

This re-development project includes a proposed Department of Public Works (DPW) Building with associated parking for POV and organizational vehicles and outdoor storage area.

The existing 3.30-acre site, as shown in Figure 4-42 is developed and mostly impervious, with a few grass islands that break up the pavement. An intermittent stream surrounded by woods divides the site in half. The site drains towards the stream which leaves the site through a culvert under 1st St. Groundwater is highly variable; a few feet below the ground in some places. Based on a review of the USDA soils database, the predominant hydrologic soil group for the project site is Hydrologic Soil Group C, “Silty Loam”.

By inputting the percent site area of each land use (Parking/Driveway/Sidewalk, Lawn, Woods) to the spreadsheet tool, the estimated SCS curve number, CN, for each land use type is populated. Then the area weighted average pre-project CN is computed to be **91** (Figure 4-44).

Figure 4-42. Pre-Project Landuse Conditions

4.5.8.3 Post-Project Conditions

The proposed includes a 15,000 square foot DPW Building with associated pavement for parking and outdoor storage.

The post-project land use, Figure 4-43, consists of Lawn, Building Roof, Woods, and Parking/Driveway/Sidewalks. By inputting the percent of site area of each land use to the spreadsheet tool, the estimated the SCS curve number, CN, for each land use type is populated. Then the area weighted average post-project CN is computed to be **89** (Figure 4-44).

Note that the post-project CN (89) is less than the pre-project CN (91). This makes sense because the project reduced the total impervious area of the site from pre-project conditions.

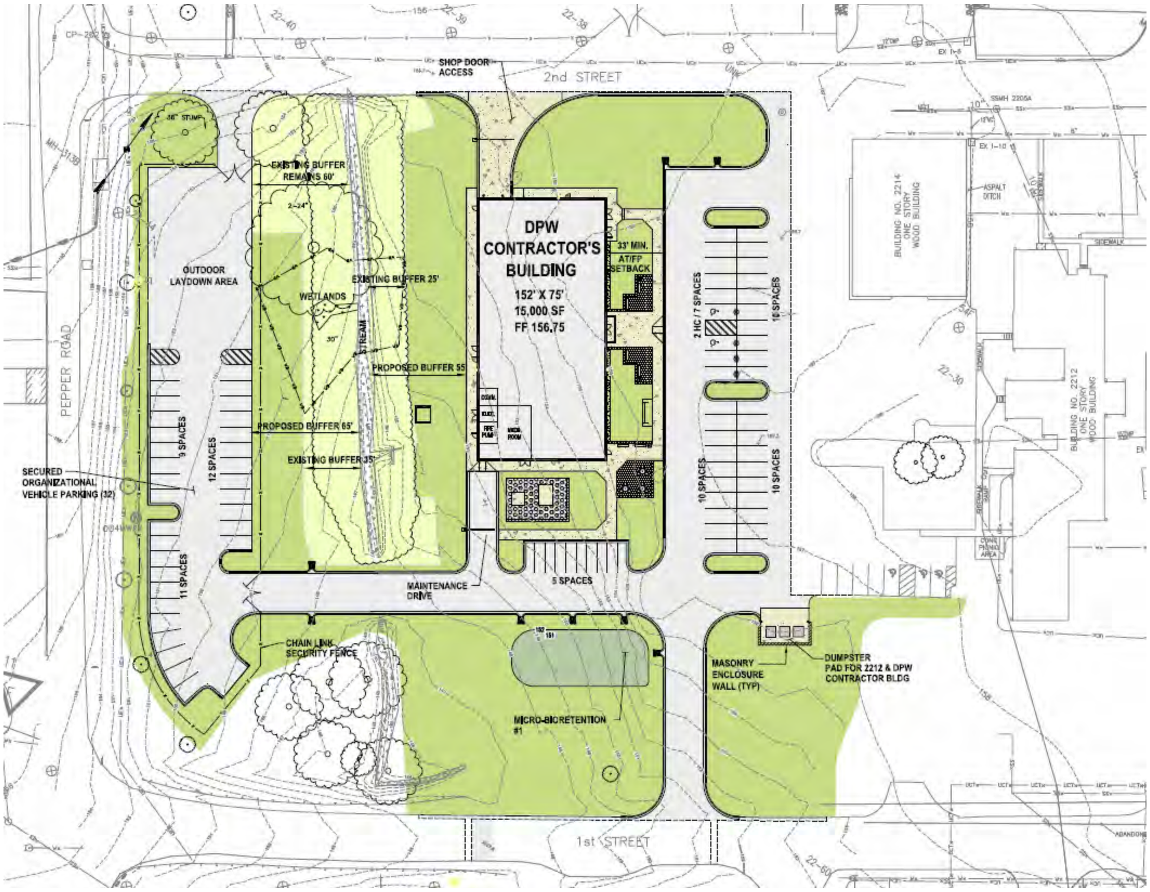


Figure 4-43. Post-Project Landuse Conditions

SIMPLIFIED RUNOFF CURVE NUMBER METHOD

PRELIMINARY SELECTION AND SIZING OF STRUCTURAL LID PRACTICES

FOR COMPLIANCE WITH THE RUNOFF VOLUME CONTROL REQUIREMENT, EISA 438, MODIFIED EPA OPTION 2

V 9.2 — PLANNING ESTIMATES for PRE & POST RUNOFF VOLUMES — Page 1 of 3

DATE:	5-Oct-2012	ARMY INSTALLATION:	FORT MEADE				
PLANNER:	EEM						
PROJECT NAME:	DPW CONTRACTOR'S BUILDING						
PROJECT LOCATION:	CHISHOLM AVE						
PROJECT AREA (acres):	3.3	95% RAINFALL	1.6	SELECT THE SITE'S OVERALL SOIL TYPE:	Silty-Loam	HSG =	C

PRE-PROJECT LAND COVER	% of SITE	CN		POST-PROJECT LAND COVER	% of SITE	CN
WOODED (fair)	10.0%	73		WOODED (fair)	10.0%	73
MEADOW				MEADOW		
BRUSH & WEEDS (fair)				BRUSH & WEEDS (fair)		
LAWN	23.0%	79		LAWN	35.0%	79
ROADS & DRIVES (WO/C&G)				ROADS & DRIVES (WO/C&G)		
ROADS & DRIVES (W/C&G)				ROADS & DRIVES (W/C&G)		
PARKING, DRIVEWAYS & SIDEWALKS	67.0%	98		PARKING, DRIVEWAYS & SIDEWALKS	47.0%	98
BUILDING ROOF				BUILDING ROOF	8.0%	98
			SELECTION OF OTHER LAND COVER TYPES			
TOTAL %	1			TOTAL %	1	
WEIGHTED AVERAGE CNn =		91		WEIGHTED AVERAGE CNd =		89

Figure 4-44. Pre-Project and Post-Project Curve Numbers

4.5.8.4 Calculate EISA Volume Requirement

At this point one is able to calculate the EISA Volume Requirement for the project, using the inputs of Pre-Project CN, Post-Project CN, Site Area, and 95th percentile storm depth. For this example, instead of calculating the 95th percentile rainfall depth as in previous examples, the 95th percentile depth for Baltimore, MD, given in Table 4-1 of this guide (also in Table 1 of EPA's *Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act*) is used, **1.6 inches**.

The spreadsheet tool uses the SCS CN Method to compute the peak runoff volumes for both pre- and post-project conditions. The peak runoff volumes are computed to be 9,946 ft^3 and 8,372 ft^3, respectively. The difference between these volumes is the EISA Volume Requirement, which is the amount of runoff that needs to be retained on site using LID BMPs.

Since the post-project CN is less than pre-project CN, the post-project runoff volume is also reduced from the pre-project volume, resulting in a negative value as the EISA Volume Requirement, **-1,574 ft^3**, as shown in Figure 4-45.

<u>Input Parameters:</u>
Site Area (A) = 3.3 acres
95th Storm (P) = 1.6 inches
Existing CN = 91
Post CN = 89

<u>Output:</u>

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

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

Q = Runoff Volume (ft^3)
Pre-Project Q = 9,946 ft^3
Post-Project Q = 8,372 ft^3
Difference in Q = -1,574 ft^3

Since DoD defines the "pre-development" condition as "pre-project" (UFC 3-210-10), this redevelopment project results in an improved hydrologic condition (decrease in runoff volume), and no additional retention is need to comply with EISA.

SIMPLIFIED RUNOFF CURVE NUMBER METHOD

PRELIMINARY SELECTION AND SIZING OF STRUCTURAL LID PRACTICES

FOR COMPLIANCE WITH THE RUNOFF VOLUME CONTROL REQUIREMENT, EISA 438, MODIFIED EPA OPTION 2

V 9.2 — **PLANNING ESTIMATES for PRE & POST RUNOFF VOLUMES** — Page 1 of 3

DATE:	5-Oct-2012	ARMY INSTALLATION:	FORT MEADE
PLANNER:	EEM		
PROJECT NAME:	DPW CONTRACTOR'S BUILDING		
PROJECT LOCATION:	CHISHOLM AVE		
PROJECT AREA (acres):	3.3	95% RAINFALL	1.6
SELECT THE SITE'S OVERALL SOIL TYPE:	Silty-Loam	HSG =	C

PRE-PROJECT LAND COVER	% of SITE	CN	POST-PROJECT LAND COVER	% of SITE	CN
WOODED (fair)	10.0%	73	WOODED (fair)	10.0%	73
MEADOW			MEADOW		
BRUSH & WEEDS (fair)			BRUSH & WEEDS (fair)		
LAWN	23.0%	79	LAWN	35.0%	79
ROADS & DRIVES (WO/C&G)			ROADS & DRIVES (WO/C&G)		
ROADS & DRIVES (W/C&G)			ROADS & DRIVES (W/C&G)		
PARKING, DRIVEWAYS & SIDEWALKS	67.0%	98	PARKING, DRIVEWAYS & SIDEWALKS	47.0%	98
BUILDING ROOF			BUILDING ROOF	8.0%	98
SELECTION OF OTHER LAND COVER TYPES					
TOTAL %	1		TOTAL %	1	
WEIGHTED AVERAGE CNn =		91	WEIGHTED AVERAGE CNd =		89
RUNOFF VOLUME (95% RAIN) =	0.23	ACRE-FEET	RUNOFF VOLUME (95% RAIN) =	0.1921921	ACRE-FEET
9946 CUBIC FEET	74396	GALLONS	8372 CUBIC FEET	62622	GALLONS

MINIMUM RUNOFF RETENTION VOLUME TO COMPLY WITH EISA 438 VOLUME CONTROL REQUIREMENT

-0.04 ACRE-FEET	-1574 CUBIC FEET	-11774 GALLONS

Figure 4-45. Runoff Computations

4.5.8.5 Select LID BMPs to Manage EISA Volume

Although EISA Section 438 is satisified, the project still had to comply with State of Maryland stormwater management requirements. The project used the following LID BMPs to fulfill State requirements:

Non-Structural LID BMPs: Protect Sensitive Areas, Reduce Impervious Surfaces, Riparian Buffer Restoration, and Reforestation.

Structural LID BMPs: Bioretention, Grass Swale, Vegetated Filter Strip.

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5 DESIGN AND CONSTRUCTION CONSIDERATIONS FOR COMMON STRUCTURAL LID BMPS

5.1 INTRODUCTION

This chapter provides technical guidance on design and construction specifications for commonly used structural LID BMPs, as introduced in Chapter 2. Detailed descriptions, planning considerations, design considerations, components and materials, construction considerations and maintenance requirements are outlined for:

- Bioretention
- Vegetated Swales
- Vegetated Filter Strips
- Permeable Pavements
- Rainwater Harvesting
- Green Roofs

This chapter is intended to be used primarily by professionals engaged in master planning, designing, constructing, and maintaining stormwater projects at military facilities. Others who can benefit from the information in this chapter include: Department of Public Works (DPW), public officials, engineers, architects, landscape architects, and site design planners responsible for land use planning and decision making in watershed management.

The technical contents of this chapter are based on, and derived from, materials almost entirely in the public domain, published by federal or state agencies or public educational institutions. It must be noted that this chapter provides general technical guidance on LID BMP design and construction specifications. Since every site is unique - locally, geographically, and regionally, the soil type and topographic characteristics may differ even from site to site at the same installation. As such, the chapter is developed primarily to educate Army installation personnel (especially those responsible for policy making and engaged in stormwater management) in areas such as: (1) Role and significance of LID in addressing watershed stormwater management, and (2) Providing technically-sound knowledge and background information on design, construction and maintenance for their use in making intelligent policy and management decisions in planning, budgeting, project management, field implementation, and the monitoring of LID practices and procedures.

Therefore, the materials presented in this chapter are not intended to substitute formal project design and construction drawings which must be prepared and obtained from licensed industry professionals. It is recommended that the following guidance should be used while developing formal design and construction drawings and specifications for LID projects.

- Use the information presented in this chapter primarily for planning and initial design and construction purposes.

- Adapt the information provided in the chapter to specific conditions at your site.

- Prior to construction of any practice described in this chapter, all permits must be obtained, including approval of erosion and sediment control plans and stormwater management plans from local permitting authority.

- It is extremely important to obtain professional services and have a licensed surveyor site stake to locate underground utilities. If in doubt, the identification and location of underground utilities must be performed early on during planning and design processes to avoid "work stop orders" and added costs later encountered during construction.

- Consult the local USDA NRCS Extension Service Office on your project development, especially regarding site-specific soil types and establishing and maintaining vegetation. Use boring logs and geotech report information as available.

- Final "Design and Construction Drawings" must be prepared by licensed engineering professionals in accordance with existing land use conditions and current site surveys.

5.2 BIORETENTION

5.2.1 Description

Bioretention is a stormwater infiltration and/or filtration practice used to reduce site stormwater runoff volume and pollutant loading. Bioretention systems are flexible in design and can be used to help fulfill the landscape requirements of a site. Bioretention systems are commonly located in or adjacent to parking lots or within small pockets in residential neighborhoods or commercial developments and have wide applicability.

Bioretention systems are flat-bottomed, shallow landscaped depressions used to collect and hold stormwater runoff, allowing pollutants to settle and filter out as the water infiltrates into the ground or to an underdrain. Stormwater runoff from the contributing drainage area (e.g., parking lot) enters as sheet or concentrated flow into the bioretention system, where it temporarily ponds within the shallow depression and subsequently filters down through the various layers in the bioretention area: plants, mulch or ground cover, engineered soil media, a gravel base layer with a possible underdrain, until it infiltrates into the underlying soils. Runoff from larger storms is generally diverted through or around the bioretention system to the storm drain system via a yard inlet or overland relief via a spillway. Bioretention systems often provide complete on-site infiltration for small storm events (the "first flush"). Bioretention systems can be sized to infiltrate large storms in areas where soils are sandy, highly permeable, and drain well or bypass to an approved discharge point. Bioretention systems reduce peak runoff rates and increase stormwater infiltration for volume reduction when designed to a larger capacity.

The bioretention system components make use of the chemical, biological and physical properties of soil, water, and plants to remove pollutants from stormwater runoff. Processes that take place within the soil-plant media of a bioretention system include sedimentation, adsorption, evapo-transpiration, physical filtration, infiltration, decomposition, phyto-remediation, bioremediation, storage, and pollutant uptake by plants. Bioretention systems remove a wide range of pollutants, such as suspended solids, nutrients, heavy metals, hydrocarbons, and bacteria from stormwater runoff. Bioretention systems encourage biologic, microbial and physical processes to occur and to self-perpetuate. This self-perpetuation represents a significant difference between bioretention and other stormwater treatment strategies. The components are intended to blend over time with soil, water, plant and root growth to produce organic decomposition and the development of a macro and microorganism community for removal of runoff pollutants. This microbial community in turn helps develop a natural soil horizon and structure that lengthens the bioretention systems' life span and reduces the need for maintenance.

5.2.2 Types of Bioretention

There are three main types of bioretention systems based on their scale and size of constructed area: bioretention, micro-bioretention, or rain gardens.

5.2.2.1 Bioretention Cell

Bioretention cells are systems that generally treat larger areas such as parking lots, commercial rooftops and areas in commercial, institutional or industrial settings (Photo 5-1). When constructed in residential areas, they may be distributed throughout the subdivision, but mostly they are located in common areas or within the drainage easements to treat a combination of roadway or parking lot runoff.

Contributing drainage areas to a bioretention cell should not exceed 5 acres. Pretreatment is often required to avoid sediment and debris clogging the filter bed. Forms of pretreatment include a forebay, stone diaphragm or vegetative filter strip.

Photo 5-1. Bioretention Cell
(Source: Low Impact Development Center, Inc., XXXX)

5.2.2.2 Micro-Bioretention Cell

Micro-bioretention cells are structurally and functionally the same as the bioretention cells described above. The only difference between the two is merely the size, wherein micro-bioretention cells are smaller than traditional bioretention cells. Since these practices are smaller, they do not require the same pretreatment techniques as traditional bioretention cells. Micro-bioretention cells have contributing drainage areas between approximately 10,000 square feet and 1/2 acre. Pretreatment is not usually required, except where concentrated flows, such as roof drain outfalls, are entering the filter bed.

5.2.2.3 Rain Gardens

Rain gardens have contributing drainage areas less than 10,000 square feet. Contrary to the common use of bioretention cells and micro-bioretention cells in commercial, industrial, and institutional applications, rain gardens are essentially small, distributed practices designed to treat runoff from small areas. Rain gardens are typically used to treat runoff from individual rooftops, driveways, and other on-lot features mostly in single family detached residential developments, as shown in Photo 5-2. Because of their small size and location, rain gardens often do not require an underdrain system or overflow inlet.

Table 5-1. Bioretention Types

Bioretention Type	Contributing Drainage Area	Infiltration or Underdrain?
Bioretention	1/2 to 5 acres	Could have one or both
Micro-Bioretention	10,000 sf to 1/2 acre	Could have one or both
Rain Garden	Less than 10,000 sf	Infiltration, no underdrain

Photo 5-2. Rain Garden

5.2.3 Planning Considerations

Bioretention systems are suitable for many types and sizes of new construction and redevelopment projects, including single-family residential as well as commercial, industrial, and institutional settings.

5.2.3.1 Applications

Bioretention systems can be used to filter the runoff from both residential and nonresidential developments. They are most effective when they receive runoff as close to its source as possible. They can vary in size and can receive and treat runoff from a variety of drainage areas within a land development site. They can be installed in lawns, median strips, parking lot islands, unused lot areas, and certain easements. They are intended to receive and filter storm runoff from both pervious and impervious areas.

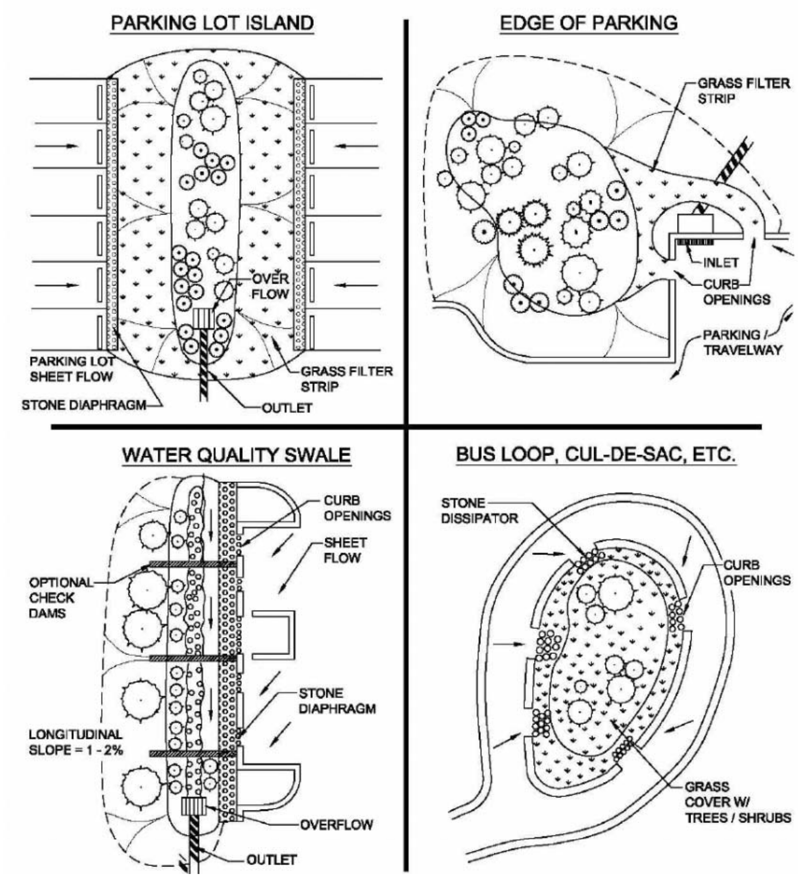

Figure 5-1. Typical Bioretention Applications

Typical residential, commercial and industrial applications for bioretention systems are shown in Figure 5-1, and are described below:

- Parking lots, parking lot edge, road medians, roundabouts, interchanges, cul-de-sacs, public right-of-way, commercial setbacks, courtyards, individual residential lots, etc. are the prime areas where bioretention can be successfully applied to enhance stormwater quality and aesthetics.

- Commercial/Industrial: Bioretention can be designed to treat runoff commercial parking lots, roads, rooftops, pervious areas, and/or pervious areas such as managed lawns.

- Institutional (*e.g.,* schools, government buildings, and parks): Bioretention features can be incorporated into bus loops, parking lot islands, roof downspout areas and access road shoulders, etc.

- Residential: Bioretention applications are most appropriate for residential settings. In this regard, they should be designed as distributed practices within areas designated as open space and covered by drainage easements. For example, roof or driveway runoff can be directed to rain gardens located at the front, side, or rear of a home. In residential applications, bioretention features increase property values and enhance aesthetics.

- Retrofitting: Numerous options are available to retrofit an existing stormwater system or impervious area with bioretention applications in urban landscape.

5.2.3.2 Constraints

One of the most advantageous qualities of bioretention systems is that they can be installed independent of soil conditions (sandy, clayey, or in between) because stormwater infiltration and filtration is made artificially possible using engineered soil percolation media where soil conditions are not favorable. Nevertheless, there are several site constraints that must be considered in the designing and construction of bioretention facilities and practices.

<u>Drainage Area</u>
Ideally, the bioretention systems are used on small drainage areas, *i.e.,* less than 5 acres.

<u>Site Location and Topography</u>
The practice is best applied in areas with relatively gradual slopes, of the order of less than 5 percent but greater than 1 percent. Bioretention should not be constructed in areas where mature trees would have to be removed or within a floodplain.

<u>Available Hydraulic Head</u>
Hydraulic head is the difference in elevation between the runoff inflow point and the outflow point at the underdrain outlet where it meets the storm sewer system or overflows to downstream swale or a stream. The bioretention system is fundamentally and functionally constrained by the invert of the existing outlet to which the practice discharges (i.e., the bottom elevation needed to tie the underdrain from the bioretention system into the storm drain/sewer system or the downstream open channel). In general, a minimum of 4 to 5 feet of elevation above this invert is needed to create a hydraulic head needed to overcome friction losses through the proposed filter and gravel bed. For the bioretention facility to function properly and adequately, it must be capable of emptying the percolating runoff at a considerably faster rate than that of the infiltration rate of soil media above.

<u>Groundwater Table</u>
In order to avoid possible groundwater contamination, a minimum separation distance of 2 feet is required between the bottom of the excavated bioretention section and the seasonally high groundwater table.

<u>Soils</u>
As stated above, the soil conditions do not constrain the use of bioretention, although they do determine whether an underdrain or impermeable liner is needed. Clay soils, with low infiltration rates, often necessitate an underdrain pipe, which may not be required in loamy sand soils where infiltration is higher. If the site has karst (limestone) topography and is susceptible to sinkholes, the geotechnical engineer may require an impermeable liner to prevent any infiltration into the underlying soils that could cause instability or groundwater contamination.

Hotspot Land Uses

Hotspot land uses (gas stations, auto repair shops, motor pools, etc.) generate high concentrations of petroleum-base hydrocarbons and chemical contaminant loads. These areas should not be treated using infiltration bioretention systems but instead with bioretention systems that drain to an underdrain that is directed to the stormwater infrastructure. In addition to an underdrain, an impermeable bottom liner must be employed where bioretention is to receive and treat hotspot runoff to prevent aquifer contamination.

Root Barrier

The use of a vegetation root barrier should be considered when there are susceptible services or utilities nearby, such as water or sewer lines that are likely to be at risk from root penetration. The root barrier should be placed adjacent to the utilities which require protection.

Tail Water

The hydraulic design of the underdrain and overflow systems, as well as any stormwater quantity control outlets, must consider any significant tail water effects of downstream waterways, conveyance systems, or other stormwater management facilities. This includes instances where the lowest invert in the outlet or overflow structure is below the flooding or tide elevation in a downstream waterway or storm sewer system.

5.2.4 Design Criteria & Specifications

The major design goal for a bioretention is to maximize volume reduction and removal of stormwater suspended solids and other pollutants/contaminants. The basic design parameters of a bioretention systems is its storage volume, the thickness, character, and permeability or infiltration rate of its planting soil bed, and either the hydraulic capacity of its underdrain or the permeability of its subsoil (whichever is applicable). The system must have sufficient storage volume, if possible, above the surface of the soil bed to contain the design storm runoff volume without overflow. The thickness and character of the soil bed itself must provide adequate pollutant removal, while the soil bed permeability must be sufficient to drain the stored runoff. In addition, depending upon the type of bioretention system (i.e., infiltration or non-infiltration), either the capacity of the underdrain or the infiltration rate of the existing subsoil must also be sufficient to allow the system to drain preferably within 48 hours. Details of these and other design parameters and system components are presented in the following sections.

5.2.4.1 General

An important design factor to consider when designing a bioretention system is the size and scale of the practice at which it will be applied, as well as the existing site (i.e., soil texture) conditions where the bioretention facility will be constructed. The location and scale will determine the physical characteristics of the facility and whether it will require pretreatment measures. The soil characteristics of the site will further determine if the system can achieve full or partial on-site infiltration or if it will require an underdrain system connected to a conventional storm drain system.

Since the geology and soil conditions vary with the site location, bioretention design specifications will vary accordingly. The source of contributing drainage area and the resulting pollutant loading and its characteristics generated from within the drainage area will be another important factor in the design of a bioretention system. If the source is a high traffic area that generates large pollutant loads, such as a parking lot, the depth of filter bed or soil bed media will have to be greater than if the contributing drainage area is a residential lot producing relatively low pollutant loads.

5.2.4.2 Infiltration versus Underdrain

Bioretention systems can be designed to fully infiltrate the required volume, or can have an underdrain to convey treated stormwater to a storm drain system, or a combination of the two.

Non-Infiltration with Underdrain

Bioretention systems accept runoff from the contributing area (such as parking lot), filter runoff to remove and treat pollutants in the soil media, and then temporarily store runoff in a gravel storage layer. If the system includes an underdrain, the treated runoff is returned to the traditional storm drain system or daylights to the surface downstream. The underdrain consists of a perforated pipe buried within the gravel layer. A bioretention facility with an underdrain system is commonly referred to as an off-line bioretention practice. Typical details of an offline practice, with limited infiltration capability, are shown in Figure 5-2.

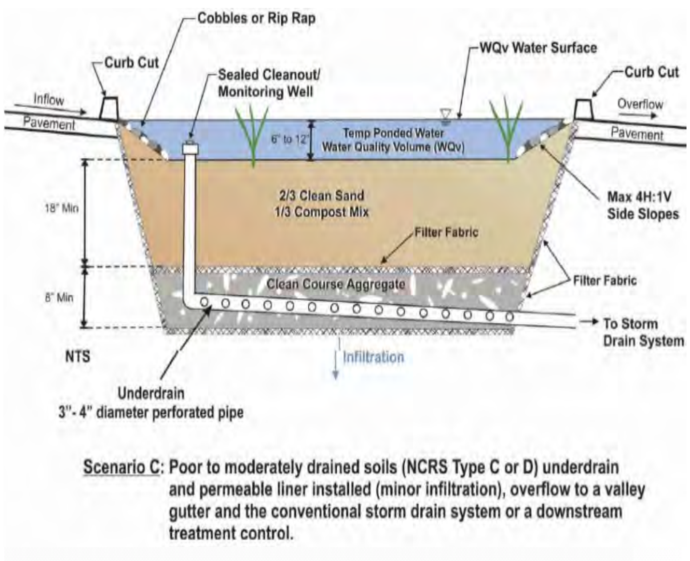

Figure 5-2. Design Components of an "Offline" Bioretention with Limited Infiltration

Infiltration without Underdrain

A bioretention system without an underdrain will allow the treated runoff to infiltrate directly into the native soils underneath. Infiltration (also called “online”) bioretention systems require permeable, sandy loam or loamy sand underlying soils (USDA Hydrologic Soil Group A or B) to function properly; these soils have infiltration rates in excess of 1 to 2 inch per hour. Typical details of an online practice are shown in Figure 5-3. Infiltration bioretention systems are designed for sites where soils are highly permeable, groundwater table is low, and there is no risk for groundwater contamination.

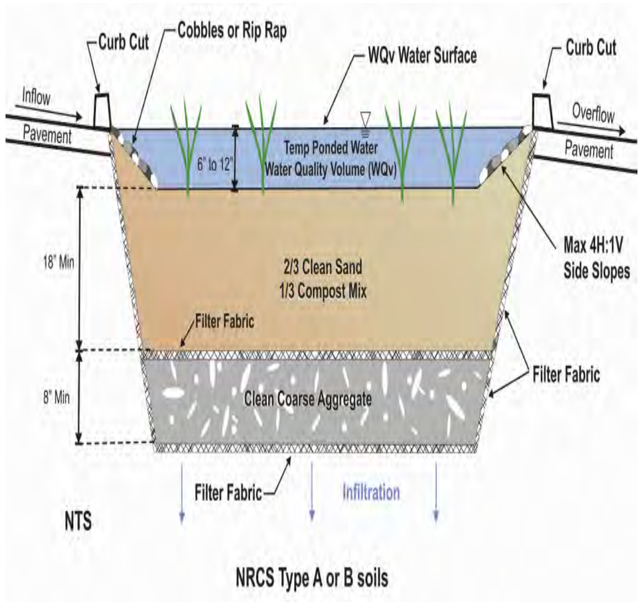

Figure 5-3. Design Componenets of an "Online" Infiltration Bioretention

<u>Combination Infiltration and Underdrain</u>
A combination of offline and online systems can be used where the underdrain is installed near the top of the gravel storage layer with a few inches of gravel over the top of the pipe, leaving a gravel "sump" that temporarily stores water for infiltration (Figure 5-4). This type of system will infiltrate runoff until the gravel layer fills up to the underdrain elevation, and then the underdrain will convey runoff to the storm drain system before it saturates the soil media layer.

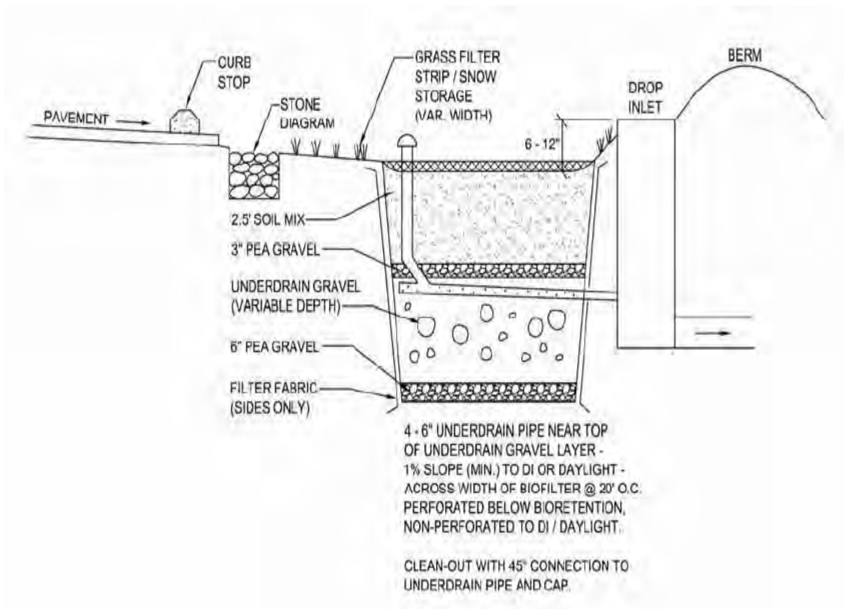

Figure 5-4. Combination Infiltration and Underdrain Bioretention System

5.2.4.3 Storage Volume, Depth, and Duration

Bioretention systems shall be designed to manage the volume of stormwater runoff required by EISA Section 438 through the EPA Technical Guidance Manual for the project site. Techniques to compute the stormwater runoff volume to be managed are discussed in Chapter 4, Hydrologic Modeling and Simulation; these techniques should be used as a guideline to determine the maximum water depth for managing the required runoff volume for the design storm. For more detailed information about sizing criteria, see the local permitting authority's stormwater design manual.

5.2.4.4 Contributing Drainage Area

Generally, the bioretention systems are constructed on sites that are disconnected by impervious area and consist of small contributing areas (i.e., two acres or less for impervious and less than 5 acres where the contributing drainage area is pervious). The cell size is designed to treat the first flush of runoff generated from approximately 1 inch of rainfall. The bioretention filter bed surface area may range between 3 percent to 12 percent of the contributing area depending on the imperviousness and desired bioretention type (bioretention cell, micro-bioretention cell, or rain garden).

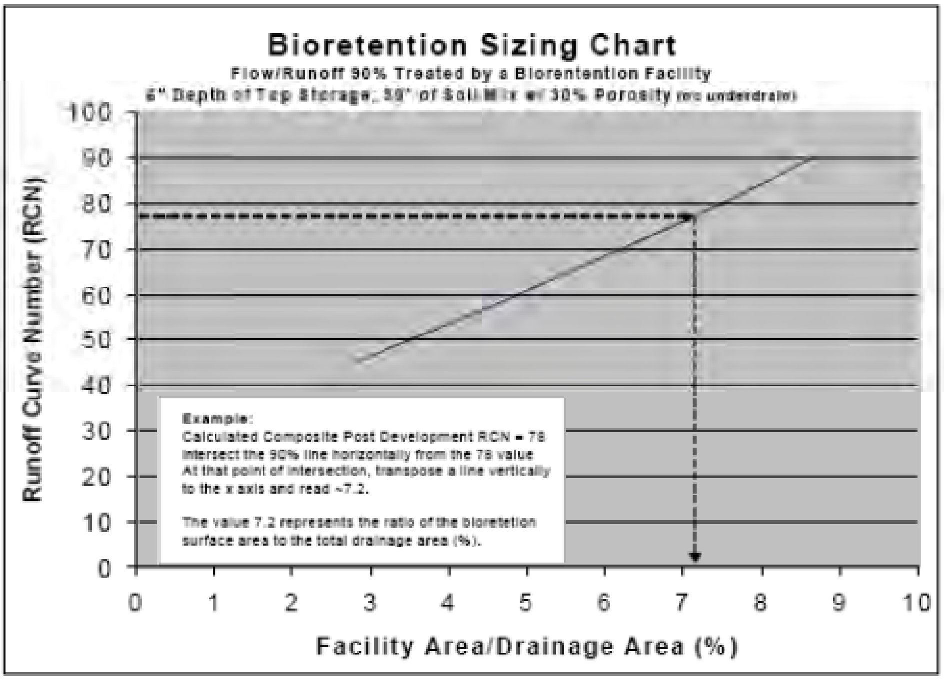

Figure 5-5. Bioretention Sizing Chart

Prince George's County, Maryland has developed a simplified criteria for sizing bioretention surface area (Figure 5-5) based on design drainage area and the post development curve number (that can be estimated using methods presented in Chapter 4, Hydrologic Modeling and Simulation). The graph presented in Figure 5-5 is applicable only for "online" infiltration-specific applications, and assumes surface ponding depth of 6 inches and soil storage capacity of 2.5 feet depth with 30 percent soil porosity.

5.2.4.5 Components of a Typical Bioretention

Bioretention is flexible in design and can be designed either as an infiltration or non-infiltration practice. The key elements of a bioretention are:

- Inflow Entrance
- Pretreatment
- Surface Ponding
- Mulch Layer
- Vegetation
- Soil Media
- Pea Gravel Choking Layer
- Gravel Storage Layer
- Underdrain
- Filter Fabric
- Liner
- Overflow or Drop Inlet

The system components of a bioretention are illustrated in Figure 5-6, and briefly described below.

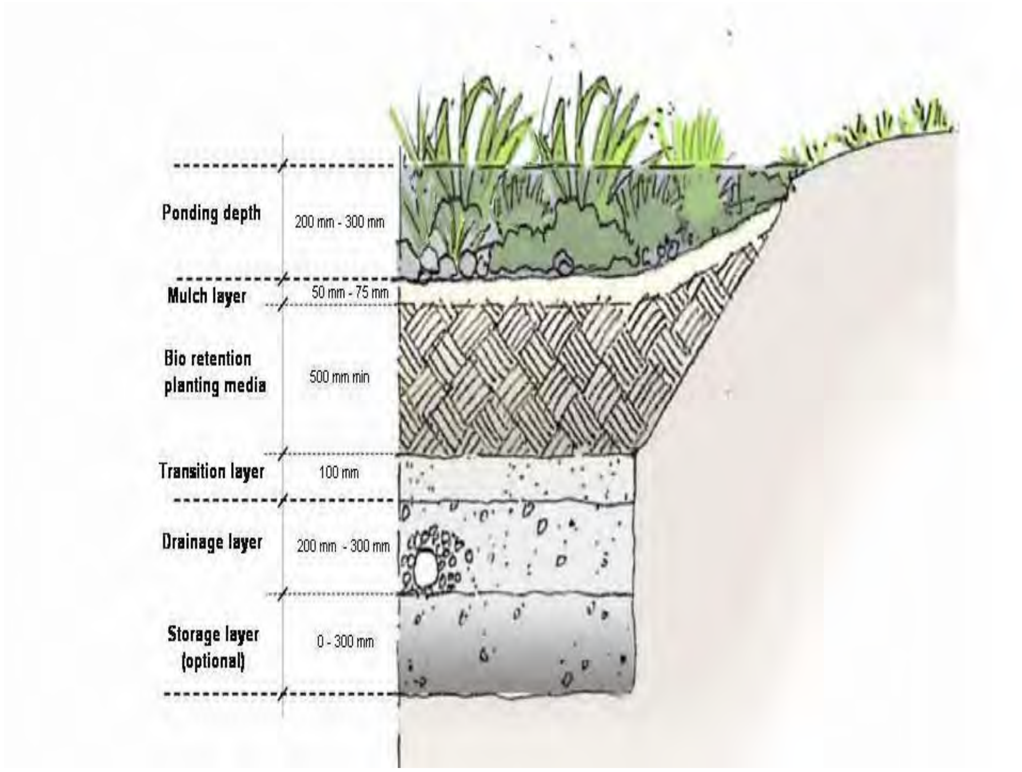

Figure 5-6. Typical Components of a Bioretention System

Inflow Entrance

The inflow entrance of a bioretention system is an important component as this is where the stormwater runoff will enter the system. The best method of capturing and treating runoff is to allow the water from contributing drainage area to sheet flow into the bioretention over grassed areas. This is not always possible, especially where site constraints or space limitations impede such an approach. A remedy to this problem is to provide flow entrances that can reduce the velocity of the water, such as riprap channels. In the case of parking lot landscape islands, curb cuts protected with energy dissipaters (such as landscape or surge stone or riprap) can be used. The curb cuts for the inflow entrance can be designed as a weir or flume, to regulate and allow defined flow volume directly from a contributing area into the bioretention. The design engineer will determine how many curb cuts are necessary (i.e., one curb cut every 20 linear feet of curb). Photos 5-3 and 5-4 show examples of curb cut inflow entrances with riprap and stone channels.

It is important to note that entrances of this type may become obstructed with sediment and trash that settles out at lower velocities. The accumulated sediment and debris should be removed from the inflow entrance area regularly.

Photo 5-3. Inflow Entrance - Curb Cut with Riprap

Photo 5-4. Inflow Entrance – Stone Channel

Pretreatment

To prevent premature clogging and possible failure of bioretention cells, incorporation of a pretreatment system is strongly recommended, and often required by the local stormwater management permitting authority. Pretreatment is a fundamental component of any bioretention in order to reduce incoming velocities and capture suspended sediment particles before runoff enters the bioretention facility. Pretreatment also extends the life of the bioretention. Sediments deposited in the pretreatment device must be periodically removed to maintain the system performance and functionality.

Several pretreatement options are listed below:

- Forebay, an excavated depression that collects runoff prior to the bioretention cell
- Grass filter strip between impervious area and bioretention cell
- Pea gravel diaphragm
- Riprap channel
- Level spreader

The most commonly used form of pretreatment is achieved through the use of a simple grass strip, which filters out most of the suspended sediment in the first 10 to 15 feet of the strip. Which pretreatment method to use depends on on the scale of the bioretention practice and whether it receives sheet flow, shallow concentrated flow or deep concentrated flows. For example, grass filter strips are appropriate for sheet flow whereas a gravel or stone diaphragm is recommended both for sheet flow and concentrated flow.

Surface Ponding Area

The surface storage ponding area is the area above the mulch layer that provides temporary storage for stormwater runoff and an environment for the settlement of suspended sediment and fine particles before infiltration, filtration, evaporation, and uptake processes can occur within the bioretention system. Ponding time provides water quality benefits by allowing larger debris and sediment to settle out from the runoff. The bioretention area should have a design depth of approximately one foot above the mulch layer, but may vary between 6-18 inches. Ponding time should not exceed 48 hours.

A convenient way to determine design ponding depth is simply to multiply the desired ponding time with infiltration rate of the planting soil. Conversely, the design ponding time (in hours) can be determined simply dividing ponding depth (in inches) by soil infiltrate rate (inches/hour).

Vegetation

Vegetation is an important component of a bioretention system. Plants uptake water and release it into the atmosphere through evapotranspiration and also uptake pollutants and nutrients; this contributes to the management of the stormwater runoff volume and quality. Plant roots enhance the infiltration capacity of the soil, creating pathways for percolation and infiltration of runoff through the soil. The plants species selected for bioretention planting should be native and designed to survive stresses such as frequent periods of inundation, ponding fluctuations and drought.

Root growth provides a media that fosters bacteriologic growth, which in turn develops a healthy soil structure. A variable plant community structure is preferred to avoid monoculture susceptibility to insect and disease infestation and to create a microclimate, which ameliorates urban environmental stresses including heat and drying winds. Bioretention systems in parking lot islands are particularly susceptible to extended dry conditions because of urban heat effects. A layered planting scheme will help discourage weeds as well as creating suitable microclimates. There are many potential side benefits to the use of planting systems other than water quality and quantity treatment. Planting systems, if designed properly, can improve the property value of the site, provide shade and wind breaks, improve aesthetics, support wildlife, and absorb noise.

Native plants are preferable. Planting soil, mulch and plants selected will be appropriate for the local climatic conditions. The use of wetland plants is not recommended for bioretention planting, as these plants are not well suited to free draining soils or dry conditions. Plant materials should conform to the American Standard Nursery Stock as well as meet local requirements.

Organic Layer or Mulch

The mulch layer plays a vitally important role in the overall bioretention design and has several functions:

- Protects the soil bed from erosion
- Retains soil moisture to the benefit of plants
- Provides a medium for biological growth and decomposition
- Prevents evaporation, thus protects the soil surface from excessive drying
- Enhances plant survival
- Suppresses weed groth
- Provides runoff pretreatment by filtering sediment and fines before they enter the soil media

The mulch layer may consist of either a standard landscape shredded hardwood or hardwood chips (Figure 5-5). Other mulch materials include: organic materials such as compost, bark mulch, leaves, as well as small river gravel, pumice, or other inert materials. The mulch should be uniformly applied at approximately 3 to 4 inches in depth and replenished as necessary. If aged mulch is used, select the shredded type over the chip variety to minimize floatation and washouts. Mulch should be free of weed seeds, soil, roots, or any other substance not consisting of either branch wood or bark. Stone or gravel are not recommended in parking lot applications, since they increase soil temperature and have little or no water holding capacity.

As an alternative, if a dense herbaceous cover or 70 to 80 percent of tree canopy is established, a mulch layer is no longer necessary. While mulching provides an important function in the bioretention process, the establishment of an herbaceous layer or groundcover may be preferred over mulching for several reasons. First, the mulch material has the ability to float up-and-out during heavy rain events. Second, the herbaceous layer provides more opportunities to capture and hold water through interception and evapotranspiration. Finally, providing thick, lush groundcover increases the aesthetic appeal and adds to the landscape character. A combination of groundcover and mulch is an equally preferable option.

Photo 5-5. Mulch Layer in Bioretention

<u>Planting Soil Media</u>
The planting soil media (also called soil media, filter media, planting growth media, soil mix, etc.) is the crucial component, and may be considered the "heart", of the bioretention providing several important functions, including:

- Provides media for infiltration and runoff volume reduction
- Support plant growth
- Provides home for soil microbial activity
- Provides environment for removal of pollutants
- Acts as a storage reservoir for moisture for plants

The planting soil is the region that provides water and nutrients for the plants to sustain growth. The upper soil zones are designed to enhance biological activity and encourage root growth. The macro-fauna breaks up organic matter into smaller parts, preparing it for the next stage of decomposition. In addition, as these microbes move through the soil, they provide aeration and redistribute soil components. This change in soil texture also allows more infiltration. The microbes (i.e., bacteria and fungi) break down complex organic compounds and transform nutrients into forms usable to plants. Symbiotic microbes living within plant roots enhance nutrient uptake and water retention. Clay particles also can adsorb heavy metals, nutrients, hydrocarbons, and other pollutants. The soil particles can also absorb some additional pollutants through chemical processes, and the pore space (porosity) within soil particles can temporarily store a portion of runoff volume and dampen downstream peak flow from increased time of concentration.

The soil media composition will vary depending on design goals, available media (native soil or manufactured), targeted pollutants and the type of vegetation selected for the design bioretention practice. The soil media composition usually consists of sand and organic materials. The soil media should have a small amount of fines (silt and clay) to support plant growth and remove and treat pollutants and heavy metals. The soil media also must be permeable enough to allow water to pass at rates greater than 2 inches per hour. This balance is best achieved by using sandy loam or loamy sand soil, provided additional leaf compost or similar organic matter is added to increase soil pore space and, thus, the permeability. Leaf compost is essentially composed of aged leaf mulch and provides added organic matter to improve the health of the soil and ensure adequate soil structure. The soil must be a uniform mix, free of stones, stumps, roots, or other similar objects larger than two inches. No other materials or substances should be mixed or dumped within the bioretention that may be harmful to plant growth, or prove a hindrance to the planting or maintenance operations. The planting soil must be free of plant or seed material of non-native, invasive species, or noxious weeds.

Use of the native soil if it belongs to the USDA Hydrologic Soil Group A category (sandy loam) is acceptable to save costs and resources. The approach should simply consist of excavating the bioretention site to the design depth, save the excavated soil, and mix into it a 4 to 6 inch of well-aged organic matter, such as composted leaf mulch, double shredded mulch or pine fines, and planted with vegetation.

If soil conditions necessitate the use of manufactured media, make sure its characteristics conform to or exceed sandy loam soil characteristics in terms of structure, permeability, water holding capacity, the capability to support plant growth as well as water quality treatment characteristics such as the capability to remove suspended sediment and pollutants carried by runoff.

Soil bed depth will vary from site to site and depend on the type and function of bioretention.
The types of vegetation expected to grow in the bioretention cell also affect the depth of media selected. Grasses do not need more than 15 to 18 inches to survive, while certain small trees require a minimum of 4 to 5 feet soil depth. Most bioretention shrubs can survive and even flourish with a minimum of 24 inches, whereas bulbs may only need 12 inches to 18 inches. Most stormwater permitting authorities required a minimum 24 inches of soil media.

<u>Pea Gravel Choking Layer</u>
A pea gravel (No. 7, 8, or 89 stone) layer serves as a transition layer between the soil media and the underdrain gravel storage layer. This layer prevents fines from the soil media layer from migrating into open-graded gravel storage layer below.

<u>Sand Layer</u>
Sometimes the local permitting authority prefers a sand layer to serve as a transition between the planting soil bed and the gravel/underdrain layer in lieu of pea gravel. It must have a minimum

thickness of 9 to 12 inches and consist of pure washed sand or that of clean medium aggregate concrete sand. To ensure proper system operation, the sand layer must have a permeability rate at least twice as fast as the design permeability rate of the planting soil bed. The infiltration rate of sand is greater than 4 inches per hour compared with 1 to 2 inches per hour design permeability of soil media above.

Gravel “Sump” Storage Layer

The gravel layer is the bedding material and conveyance medium for the underdrain pipes. Thickness of the gravel layer will depend on the size of the perforated drain pipe and should be no less than 12 inches and consist of of clean, double washed No. 57 stone or equivalent. The design rule for gravel layer is that it must have sufficient thickness to provide a minimum of 3 inches or more of gravel above the underdrain pipe.

Depending on the placement of the underdrain, the gravel layer can provide some or no infiltration to the underlying soils. If the bioretention system does not require an underdrain, the gravel provides temporary storage for runoff before it infiltrates into the underlying soils. If some infiltration is desired, the underdrain can be placed within the gravel layer so there is additional gravel below the underdrain invert. The depth of the storage layer will depend on the target treatment and storage volume needed to meet EISA Section 438 and other stormwater volume and water quality or channel protection criteria, and should be a minimum of 12 inches deep. If no infiltration is desired, the underdrain should be placed at the bottom of the gravel layer. The bottom of the gravel layer must be at least 2 feet above the seasonally high water table to prevent the potential for groundwater contamination.

Underdrain

An underdrain is a perforated pipe (typically 4 to 6 inch diameter) installed within the gravel storage layer that conveys filtered runoff to the storm drain system (or daylights to a suitable, non-erosive outfall on the downstream slope). Bioretention systems may or may not incorporate an underdrain in their design depending on treatment goals and site conditions.

The role of an underdrain in the bioretention facility is to ensure proper drainage for the vegetation and to keep the soil at an adequate aerobic state, allowing plants to thrive and flourish. Underdrains are configured in many different ways and typically include a gravel/stone "blanket" encompassing a horizontal, perforated discharge pipe (Figure 5-7). The underdrain piping must connect to a downstream storm sewer manhole, catch basin, channel, swale, or ground surface at a location that is not subject to blockage by debris or sediment and is readily accessible for inspection and maintenance.

Underdrains are sometimes not necessary for in-situ soils with high infiltration rates (e.g. greater than 1 to 2 inches per hour) and where seasonally high water table depths are known to be greater than 2 feet below the proposed invert of the bioretention facility.

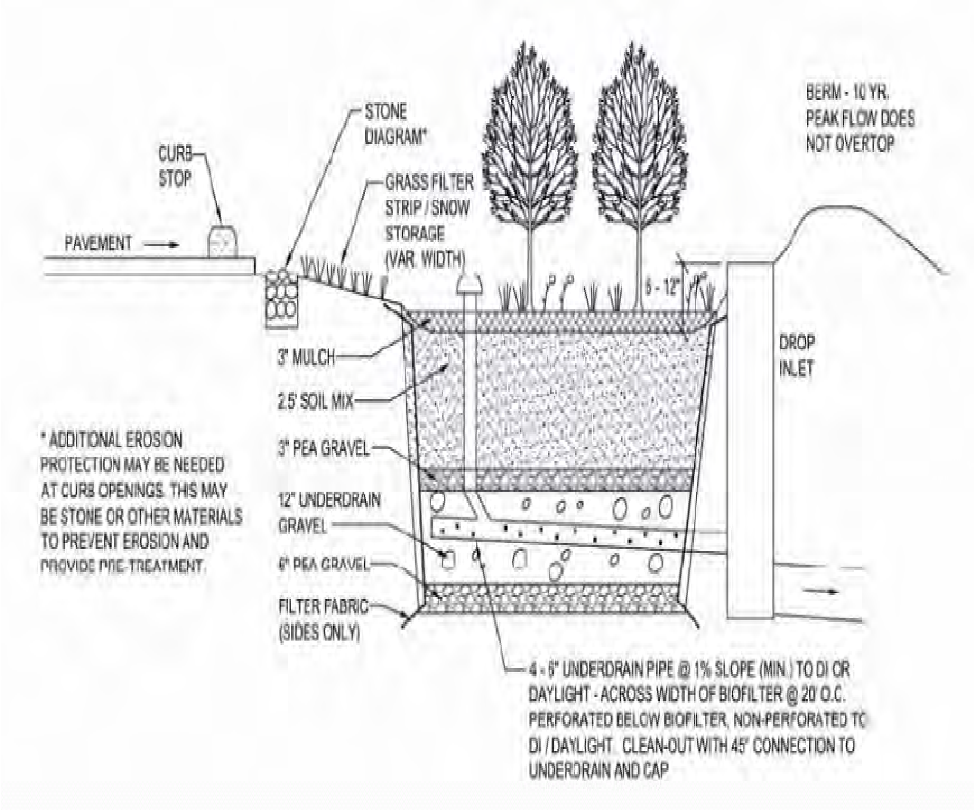

Figure 5-7. Use of Underdrain for Bioretention with Little or No Infiltration

Filter Fabric – Geotextile

The filter fabric is used to control silt and sediment migration and to control the direction of flow. There is a debate whether to use a permeable filter fabric between the gravel layer and the overlying soil growth media – this is on the premise that filter fabric does not adequately prevent the migration of finer soil as intended for bioretention applications. Preferably, in lieu of permeable fabric, pure sand and/or choking stone may be used as a separation layer between the underdrain gravel and the soil above.

Filter fabric should be placed along the sidewalls of the bioretention facility to help direct the water flow downward and to reduce lateral flows.

Liner – Impermeable Layer

In applications where bioretention is used for areas that require groundwater protection (karst topography, hotspot land uses, or source water protection), an appropriate impervious liner should be specified, provided, and installed. Clay liner should be of an appropriate impervious material, whereas synthetic liners, such as HDPE or PVC of appropriate thickness (at least 30 millimeters) can also be used. Any underdrain system shall be placed above the liner with a provision to cap the underdrain discharge pipe to confine drainage if needed. Care during placement of the liner is necessary to avoid puncture. To avoid compaction, soil medium placed over the liner should be placed by hand shovel rather than construction equipment.

Overflow/Outlet

As in the case of any impoundment, overflow of storm events that exceed the storage capacity of the facility should be addressed appropriately. An evaluation of overflow risks should always be performed when designing a stormwater facility.

In a residential setting where a rain garden is used, overflow may not present a problem if the system is located within a grassy area that provides a safe, non-erosive surface for any overflow conditions that may arise. Even in these cases, downstream conveyance must also be considered and designed appropriately.

For bioretention cells and micro-bioretention cells, it is important to design an overflow system to safely convey heavier, less frequent storms either through or around the bioretention facility. In commercial and industrial settings, a spillway or overflow yard inlet is often installed within the bioretention cell, as shown in Photo 5-6. The top of the outlet or overflow box is set at the desired maximum ponding depth. The overflow can outfall to the storm drain system or may "daylight" to a suitable, non-erosive outfall such as a swale or downslope area.

Photo 5-6. An Overflow within Bioretention

One common approach is to create an alternate flow path at the inflow point into the structure such that when the maximum ponding depth is reached, the incoming flow is bypassed or diverted past the bioretention facility to the storm drain system. In this case, the higher flows do not enter the bioretention area, and low flows are able to enter as the ponding water filtrates through the soil media.

Observation Well/Cleanout

An observation/cleanout standpipe should be installed in every bioretention facility that has a depth greater than 2 feet and/or an underdrain system. The standpipe will indicate how quickly the bioretention facility dewaters following a storm, provides a maintenance cleanout port, and it will be connected to the underdrain system to facilitate cleanout. It should be located in the center of the structure and be capped flush with the ground elevation of the facility. The top of the well should be capped with a screw, or flange type cover.

5.2.5 Materials

Table 5-2 provides a summary of the typical material requirements for the bioretention components described in previous pages. Designers should follow their local stormwater management requirements when specifying materials.

Table 5-2. Typical Bioretention Material Specifications

Material	Specification	Notes
Surface Ponding	6 to 12 inches	Not to exceed 18 inches
Plantings	Natives trees, shrubs, or grasses: Plant 1 tree per 250 sq. ft. Plant shrubs that are a minimum of 30 inch high at 10-ft on-center. Plant ground cover plugs at 12 to 18 inch on-center. Plant container grown plants at 18 to 24 inch on-center; depending on the initial plant height and how large it will grow	Plants are site-specific. Establish plant material as specified in the local landscaping plan and recommended plant list. In general, plant species must be native and spacing must be sufficient to ensure the plant material achieve 80% cover in the proposed planting areas within a 3-year period. If seed mix is used, they should be free of weed and from an approved supplier' should be appropriate for stormwater basin applications.
Mulch Surface Layer	Shredded hardwood mulch 3 to 4 inch thick	Spread layer on the surface of soil filter bed. Alternative is native groundcover, such as seedums, in which case topsoil would replace mulch layer
Soil Filter Media	2 to 4 feet, to consist of: Sand = 85% to 88% Soil Fines = 8% to 12% Organic Matter = 3% to 5% ASTM C33	Use soil filter media 10% extra than computed value to account for settling or compaction. pH to range from 5.5 to 7.0. USDA soil types loamy sand or sandy loam with infiltration rate of 1 to 2 inches/ hour Soil media layer thickness depends on vegetation type: shrubs and trees require thicker layer than grasses and flowers
Pea Gravel Choking Layer	Minimum 4 inches No. 7, No. 8, or No. 9 washed stone	Transition between soil media and underdrain gravel.
Underdrain Gravel/ Storage Layer	Minimum 12 inches No. 57 or No. 6, double washed stone (3/8 to 3/4 inch) AASHTO M-43	Can exceed 12 inches for additional storage

Material	Specification	Notes
Underdrain Pipe, Cleanouts, and Observation Wells	4 to 6 inch rigid schedule 40 PVC or equivalent. 3/8 inch perforations at 6 inches on center on underdrain (non-perforated on cleanout) Minimum 3 inches gravel over pipe Wrap pipe with 1/4 inch galvanized hardware cloth Space 20 feet on-center.	Lay the perforated pipe under the length of the bioretention cell; and install non-perforated pipe as needed to connect with storm drain or daylight to ground surface Install T's and Y's as needed, depending on the underdrain configuration. Extend cleanout pipes to the surface with vented caps. Not required for Rain Garden application.
Stone Diaphragm or Curtain Drain	River washed cobbles 2 to 5 inch	Depends on inlet flow velocity; engineer will design
Sand (if required)	AASHTO M6 or ASTM C-33	Clean, concrete sand, free of deleterious materials, grain size range 0.02 to 0.04 inch
Geotextile	ASTM D751 (puncture strength 125 lb), ASTM D 1117 (Mullen burst 400 PSI), and ASTM D 1682 (Tensile strength – 300 lb) PE Type 1 Non-woven	Fabric should have 0.08 inch thick, and maintain 120gal/ft^2 flow rate
Overflow Conveyance	Overflow yard inlet or Spillway	Not required for Rain Garden application

5.2.6 Construction Considerations

5.2.6.1 General

The construction phase of a bioretention is critical and must be phased to avoid soil media compaction or inflow of sediment laden runoff from disturbed areas during construction. All contributing drainage areas must be stabilized before the bioretention section is constructed. In this case, stabilization means having all pervious areas either fully landscaped (with mulch installed) or having well established grass or other stabilizing ground cover. If this is not possible, sediment laden runoff should be diverted around the bioretention and treated with erosion and sediment control practices. If sediment from disturbed areas is introduced to the bioretention cell during construction, the Contractor must remove the section and reconstruct it with new materials.

5.2.6.2 Excavation

The bioretention facility should be excavated to the dimensions, side slopes, and elevations indicated on the design plans. The method of excavation should minimize the compaction of the soils on the bottom of the bioretention facility. Excavators and backhoes, operating on the ground adjacent to the bioretention facility, should be used to excavate the facility if possible. Low ground-contact pressure equipment may also be used for excavation. Use of equipment with narrow tracks or narrow tires, rubber tires with large lugs, or high pressure tires will cause excessive compaction resulting in reduced infiltration rates and storage volumes, which should be avoided. Compaction of the base and the side walls of the bioretention area should be minimized. Excavation should not occur during wet or saturated conditions.

The bottom of the bioretention area should be tilled at least to an additional depth of 12 inch to promote infiltration for basins that allow for limited or full infiltration.

5.2.6.3 Soil Media Placement

The bioretention area should be prepared for soil media placement by scarifying the invert area of the bioretention facility in lifts of 12 to 18 inches. The preparation of the area should include light to minimal compaction to allow for adequate filtration; minimal compaction effort can be applied to the soil by tamping with a bucket from a dozer or backhoe. Excessive compaction will result in reduced infiltration rates, which reduces storage volumes and contributes to design failure.

The soil media should be placed and graded using excavators and/or backhoes operating on the ground adjacent to the bioretention facility or spread by hand, in order to avoid compaction and maintain the porosity of the media. If equipment must operate within the filter area itself, it must be light equipment that will not compact the soil to any appreciable degree (e.g., small loader with wide tracks or marsh tracks). No heavy equipment and/or equipment with narrow tracks, narrow tires, rubber tires, or high pressure tires should be used within the immediate filter area during or after the placement of the soil mix. The media should be overfilled above the proposed surface elevation, as needed, to allow for natural settling. After the final lift is placed, the soil media should be raked (to level it), saturated and allowed to settle for at least one week prior to installation of plant materials.

5.2.6.4 Watering

Once plant materials are planted, the bioretention area must be watered frequently to ensure establishment of the plants. Watering the plants is critical during establishment, especially during dry periods. Regular and frequent watering will reduce plant loss and provide the new plant materials with a chance to establish root growth.

5.2.6.5 Construction Sequence

The following is a typical construction sequence to properly install a bioretention facility. These steps may be modified to reflect different bioretention applications or site conditions:

1. The owner and the contractor should have a pre-construction conference and check the boundaries of the contributing drainage area and the actual inlet elevations to ensure they conform to original design. The designer should clearly communicate, in writing, any project changes determined during the preconstruction meeting to the installer and the plan review/inspection authority.

2. Construction of the bioretention area may only begin after the entire contributing drainage area has been stabilized with vegetation. It may be necessary to block certain curbs or other inlets while the bioretention area is being constructed.

3. Temporary erosion and sediment controls are needed during construction of the bioretention area to divert stormwater away from the bioretention area until it is completed. Special protection measures, such as erosion control fabrics, may be needed

to protect vulnerable side slopes from erosion during the construction process. Construction runoff should be directed away from the proposed bioretention location using erosion and seiment control protection. Proposed bioretention areas may only be used as sediment traps during construction if at least two feet of soil are removed and replaced.

4. Excavate bioretention area to proposed invert depth and manually scarify the existing soil surfaces. Do not compact in-situ soils. It may be necessary to scarify the bottom soils to a depth of 6 to 12 inches to promote greater infiltration.

5. Place geotextile fabric on the sides of the bioretention area as per manufacturer specifications. If a stone storage layer will be used, place the appropriate depth of gravel on the bottom, install the perforated underdrain pipe, and place gravel to a minimum of 3 inches above the underdrain pipe.

6. Place choker stone/pea gravel as a transition between gravel layer and the soil media.

7. Place soil media in 12-inch lifts until the desired top elevation of the bioretention area is achieved. Wait a few days to check for settlement, and add additional media, as needed, to achieve the design elevation.

8. Prepare planting holes for any trees and shrubs, install the vegetation, and water accordingly. Install any temporary irrigation.

9. Place the surface cover in both cells (mulch, river stone or groundcover), depending on the design. If coir or jute matting will be used in lieu of mulch, the matting will need to be installed prior to planting, and holes or slits will have to be cut in the matting to install the plants.

10. Seed and plant vegetation as indicated on the plans and specifications.

11. Place mulch and hand grade to final elevations.

12. Water vegetation regularly during first year to ensure successful establishment.

5.2.7 Maintenance

5.2.7.1 General

Maintenance for bioretention systems is similar to the routine maintenance for any landscaped area. Routine repair and maintenance tasks specific for bioretention systems are presented in Table 5-3. Repair and maintenance inside the cell should not be conducted if its soil surface is wet or saturated to prevent compaction. Perform maintenance tasks when the soil is dry.

All bioretention system components expected to receive and/or trap debris and sediment must be inspected for clogging and excessive debris build up and sediment accumulation at least once after each storm event exceeding one inch rain. Besides the surface ponding area above the facility, such components may include trash racks, low flow channels, outlet structures, riprap or gabion aprons, and cleanouts.

Sediment removal should take place when the basin is thoroughly dry. Disposal of debris, trash, sediment, and other waste material should be done at suitable disposal/recycling sites and in compliance with all applicable local, state, and federal waste regulations.

5.2.7.2 Vegetative Maintenance

Mowing and/or trimming of vegetation must be performed on a regular schedule based on specific site conditions. Grass outside of the bioretention system should be mowed at least once a month during the growing season. Vegetation within the bioretention system must be carefully maintained so as not to compact the soil, and by using hand-held tools, such as a hand held line trimmer. Vegetated areas must be inspected at least annually for erosion and scour. Vegetated areas should also be inspected at least annually for unwanted growth, which should be removed with minimum disruption to the planting soil bed and remaining vegetation.

When establishing or restoring vegetation, biweekly inspections of vegetation health should be performed during the first growing season or until the vegetation is established. Once established, inspections of vegetation health, density, and diversity should be performed at least twice annually during both the growing and non-growing seasons. All use of fertilizers, mechanical treatments, pesticides and other means to assure optimum vegetation health should not compromise the intended purpose of the bioretention system. All vegetation deficiencies should be addressed without the use of fertilizers and pesticides whenever possible.

5.2.7.3 Watering Requirements

Water is needed once a week during the first 2 months of planting, and then as needed during the entire growing period (April – October). Watering the vegetation on an “as needed basis” helps ensure a healthy condition and pleasing appearance. During dry periods the underdrain may cause the planting soil to dry out, resulting in plant stress.

5.2.7.4 Removal of Debris and Dead Plants

Experience has shown that up to 10 percent of the plants may die off in the first year. The construction contracts should include a care and replacement warranty to ensure that vegetation is properly established and survives during the first growing season following construction. The typical thresholds below which replacement is required are 85 to 90 percent survival of plants and 100 percent survival for trees.

5.2.7.5 Inspection

It is highly recommended that a spring maintenance inspection and cleanup plan be in place and conducted for each bioretention area. The following is a list of some of key maintenance problems to look for and take care of them accordingly.

- Check to see if 75 to 90 percent cover of mulch and vegetation has been achieved in the soil bed

- Check the bioretention bed for evidence of mulch floatation, excessive ponding, dead plants or concentrated flows

- Check for accumulated sediment and trash at filter strips, curb cuts, gravel diaphragms, pavement edges that may prevent flow from entering the bed, and check for other signs of stormwater bypassing.

- Check for clogged or slow-draining soil media or a crust formed on the top of soil bed layer

The most common non-routine maintenance problem involves standing water inside the basin. If water remains on the surface for more than 72 hours after a storm, it is an alarm that the soil bed and/or the underdrain perforated pipe is not functioning properly and may have become clogged. This is a serious problem and a precursor to practice failure and, thus, be addressed promptly. Open the underdrain observation well or cleanout and pour in water to verify that the underdrains are functioning and not clogged or otherwise in need of repair. The purpose of this check is to see if there is standing water all the way down through the soil. If there is standing water on top, but not in the underdrain, then there is a clogged soil layer. If the underdrain and stand pipe indicates standing water, then the underdrain must be clogged and will need to be snaked.

5.2.8 Benefits

The use of bioretention not only has the potential for quantity control and water quality, it also improves aesthetics and can increase property value.

- Can be very effective for removing fine sediment, trace metals, nutrients, bacteria, and organic
- Layout of bioretention facilities can be very flexible, and selection of plant species can provide a wide variety of landscape designs
- Can be applied in many different climates and geologic environments, with some minor design modifications
- Ideally suited for many highly impervious areas, such as parking lots, commercial roofs, and within public right of way
- Reduces the size and cost of downstream stormwater control facility and/or storm drain systems by runoff reductions *via* infiltration and evapotranspiration in upland areas.
- Reduces downstream flooding and protects streambank integrity by dampening flow peaks.
- Can be applied as stormwater retrofit, by modifying existing landscaped areas

Table 5-3. Suggested Maintenance Activities for Bioretention

	Task	Frequency	Maintenance Notes
1	Mowing of grass filter strips and bioretention turf cover	As needed	At least three times a year
2	Spot weeding, erosion repair, sediment, trash and debris removal, and mulch raking	Twice each year	
3	Replant vegetation to maintain desired planting density, remove invasive plants, stabilize the contributing area to prevent concentrated flow and erosion	As needed	Vegetative cover should be maintained at 75 to 90%. When vegetation falls below 50%, replant area in accordance with original specifications.
4	Spring inspection and clean up	Annually	
5	Remove sediment in pre-treatment cells and inflow/outflow points	Annually	
6	Pruning of Plants	1 to 2 times/yr	Nutrients cause vegetation to flourish and thus need pruning
7	Mulching	Biannually	Use hard wood to suppress weeds and retain moisture
8	Watering	As needed	Initially more frequently
9	Inspect inflow/overflow	After each storm	Check for clogging, rubbish, and debris

5.3 VEGETATED SWALES

5.3.1 Description

Vegetative swales are stormwater runoff conveyance systems that provide surface flow as an alternative to underground storm sewer systems. Vegetated swales are shallow in depth and configured as linear channels, with parabolic or trapezoidal cross sections (Photo 5-7 and Photo 5-8). Vegetated swales are densely planted with a variety of trees, shrubs, grasses, and other herbaceous plants. They can infiltrate entire stormwater runoff from low flows or carry runoff from heavy rains to storm drains or directly to surface waters.

Vegetative swales provide reduction in peak flow by increasing time of concentration and reducing runoff volume through infiltration and evapotranspiration. Vegetated swales provide improved water quality through settling, filtering, infiltration and plant uptake of pollutants from stormwater runoff. Swales can also provide pre-treatment for other stormwater treatment practices.

Vegetated swales are a preferable alternative to both curb and gutter and storm drains as a stormwater conveyance system, where development density, topography and soils permit. Contrary to a concrete or riprap lined drainage channel or ditch, vegetated swales are aesthetically pleasing and can be landscaped similar to bioretention. Vegetated swales are generally less expensive to construct and maintain than concrete/riprap lined channels.

Photo 5-7. Vegetated Swale Adjacent to Impervious Parking Lot

Photo 5-8. Vegetated Swale in a Commercial Setting

5.3.2 Types of Vegetated Swales

There are three types of grass swales: grass swale, wet swale, and bio-swale. Brief descriptions of each are provided below.

5.3.2.1 Grass Swale

Grass swale (also known as grass channel) is quite similar to a conventional drainage ditch, with the major differences being flatter side slopes and longitudinal slopes, and a slower design velocity for water quality treatment of small storm events (Figure 5-9). Grass swales are the least expensive option because they are constructed in native soils without the use of manufactured soil media. A common application of a grass swale is as a pretreatment to other structural stormwater treatment practices, such as bioretention (as described in Section 5.1).

The length of the swale is generally equivalent to the contributing impervious area. The runoff enters the grass swale as lateral sheet flow and the total contributing drainage area cumulatively increases along the length of the swale. The treatment component of the swale can extend to a greater length for additional storage.

Grass swales can provide a modest amount of runoff filtering and volume attenuation within the stormwater conveyance system. The performance of grass swales will vary depending on the underlying soil permeability. Grass swales, however, are not capable of providing the same stormwater functions as bio-swales as they lack the storage volume associated with the bio-swale's cross section (engineered soil media and gravel layers). Their runoff reduction performance can be boosted when compost amendments are added to the bottom of the swale. Grass swales can also be used to treat runoff from the managed turf areas of turf-intensive land uses, such as sports fields and golf courses, and drainage areas with combined impervious and turf cover (e.g., roads and yards).

Photo 5-9. Grass Swale

5.3.2.2 Wet Swale

Wet swales are similar to grass swales but intersect the groundwater table, and behave almost like a linear wetland cell. This design variation incorporates a shallow permanent pool and wetland vegetation to provide stormwater treatment.

These linear wetland cells often intercept shallow groundwater to maintain a wetland plant community. The saturated soil and wetland vegetation provide an ideal environment for gravitational settling, biological uptake, and microbial activity. The cells are formed within the channel to create saturated soil or shallow standing water conditions (typically less than 6 inches deep).

5.3.2.3 Bio-Swale

A bio-swale is a linear adaptation of a bioretention system that lines the edge of a contributing impervious area such as a roadway or parking lot (Figure 5-10). The cross section of a bio-swale is similar in design to traditional bioretention areas (see Section 5.1, *Bioretention*). The design incorporates a manufactured/engineered soil media and gravel layer under the channel. The gravel layer may or may not have an underdrain system (perforated pipe along the length of the swale).

The bio-swale is a soil bio-filtering system that filters and temporarily stores the stormwater runoff. If the underlying soils are very permeable, runoff infiltrates and the system functions exactly like a bioretention system without an underdrain. If the bio-swale has an underdrain, the runoff treated by the soil media flows into the underdrain, which conveys treated runoff back to the storm drain system further downstream (or daylights to surface flow), functioning like an off-line bioretention. The underdrain system consists of a perforated pipe within a gravel layer on the bottom of the swale beneath the filter media.

Photo 5-10. Typical Bio-Swale

5.3.3 Planning Considerations

5.3.3.1 Applications

The linear nature of vegetative swales makes them well-suited to treat roadway, low- and medium-density residential roadway runoff, or commercial applications where there is real estate to grade a swale. Typical applications of vegetative swales include the following:

- Within a roadway right-of-way, along roads and highways
- At roof downspout discharge points
- Along edges of paved areas (roads, parking lots), parking lot islands, intermediary common areas, open spaces, or adjacent to buildings.
- Within residential developments and commercial properties
- Pre-treatment for other LID practices
- Alternative to conventional curb/gutter and storm sewer

5.3.3.2 Constraints

Vegetated swales have some limitations, including:

- Individual grass swales cannot treat a very large drainage area
- Wet swales may become a nuisance due to mosquito breeding
- A thick vegetative cover must be maintained for proper function
- Vegetated swales are not recommended when residential density exceeds more than 4 dwelling units per acre, due to a lack of available land and the frequency of driveway crossings along the channel
- Runoff from hotspot land uses, such as gas stations and auto repair shops, should not be treated with infiltrating dry swales – an impermeable liner should be used when hotspot runoff is filtered

5.3.4 Design Criteria and Specifications

Vegetated swales can be designed to be simple, such as a grass swale, or more complex, such as the bio-swales, but all types require space and the appropriate topography or grading to convey water. The key to designing a vegetated swale is to ensure the conveyance of stormwater runoff from the impervious surface to either a receiving waterbody, a stormwater system, or to infiltrate to groundwater while slowing the velocity of the runoff and increasing the time of concentration. Design criteria and specifications are discussed below and presented in Table 5-4 for all three types of vegetated swales.

5.3.4.1 Available Space

Vegetative swale footprints can fit into relatively narrow corridors between utilities, roads, parking areas, or other site constraints. Dry swales should be approximately 3 to 10 percent of the size of the contributing drainage area, depending on the amount of impervious cover.

5.3.4.2 Site Topography

Vegetative swales should have longitudinal slopes of less than 4 percent, but preferably less than 2 percent. The gradual slope helps to reduce the velocity of flow in the channel.

5.3.4.3 Contributing Drainage Area

The maximum contributing drainage area to a bio-swale should be 5 acres, but preferably not more than two acres. When bio-swales or vegetated swales treat larger drainage areas, the velocity of flow through the surface channel often becomes too great to treat runoff or prevent erosion in the channel. Similarly, the longitudinal flow of runoff through the soil, stone, and underdrain may cause hydraulic overloading at the downstream sections of the swale. An alternative is to provide a series of inlets or diversions that convey the treated water to an outlet location.

5.3.4.4 Soils

Soil conditions do not constrain the use of vegetated swales, although they normally determine whether an underdrain is needed. Low-permeability soils with an infiltration rate of less than 1/2 inch per hour, such as those classified in Hydrologic Soil Groups (HSG) C and D, will require an underdrain.

5.3.4.5 Depth to Water Table

Restrictions on the depth to groundwater depend on the type of swale used. The bottom of a grass swale or bio-swale should be at least 2 feet above the seasonally high groundwater table, to ensure that groundwater does not intersect the swale bottom, since this could lead to groundwater contamination or practice failure. In a wet swale it is permissive to intersect the groundwater table since treatment is enhanced by the saturated conditions.

5.3.4.6 Hydraulic Capacity and Swale Size

Vegetated swales are usually sized to temporarily store and infiltrate the “first flush” (one inch) storm event. In addition to treating runoff for water quality, grass swales need to convey larger storms safely. Typical designs allow the runoff from the 2-year storm (i.e., the storm that occurs, on average, once every two years) to flow through the swale without causing erosion. Swales should also have the capacity to pass larger storms (typically a 10-year storm) safely**.** This means the swale should contain the 10-year design flow within its banks, so the swale's surface dimensions are more often determined by the need to pass the 10-year storm events, which can be a constraint in the siting of vegetated swales within existing rights-of-way (e.g., constrained by sidewalks or roads). The maximum ponding time is 48 hours, though 24 hours is more desirable. Studies have shown that the maximum amount of swale filtering occurs for water depths below 6 inches.

A major difference between vegetated swales and other stormwater treatment practices is the method used to size the practice. Most stormwater treatment practices are sized by volume of runoff. That is, the practice captures and treats a defined water quality volume, or the volume of water. The grass swale, on the other hand, is based on flow rate (i.e., a peak flow from the water quality storm; this varies from region to region but a typical value is the one inch storm), grass swales should be designed to ensure that runoff takes an average of ten minutes to flow from the top to the bottom of the channel. Bio-swales use a combination of this sizing method but also incorporate storage in the soil media and gravel layers.

5.3.4.7 Available Hydraulic Head

A minimum amount of hydraulic head is needed for effective bio-swales, measured as the elevation difference in elevation between the inflow point and the downstream underdrain invert. Bio-swales typically require 3 to 5 feet of hydraulic head since they have both a filter bed and an underdrain layer.

5.3.4.8 Vegetation

The dense vegetation helps reduce flow velocities, protect the swale from erosion, and acts as a filter to treat stormwater runoff. During construction, it is important to stabilize the channel of the swale before the turf has been established, either with a temporary grass cover, or the use of natural or synthetic erosion control products.

5.3.4.9 Channel Geometry

Although there are different design variations of the vegetated swales *(*e.g., grass, wet, and bio-swale), several design considerations are common to all. For example, the cross-sectional geometry of all three options is similar. Channels should generally have a trapezoidal or parabolic cross section with relatively flat side slopes (generally 3:1 or flatter). Designing the channel with flat side slopes also maximizes the wetted perimeter. The wetted perimeter is the length along the edge of the channel cross section where runoff flowing through the channel is in contact with the vegetated sides and bottom of the swale. Increasing the wetted perimeter slows runoff velocities and provides more contact with vegetation to encourage filtering and infiltration. Another advantage of flat side slopes is that runoff entering the grassed swale from the side receives some pretreatment along the side slope. The flat channel for each type of vegetated swale should be between two and eight feet wide. The minimum width ensures filtration for water quality treatment, and the maximum width prevents braiding, the formation of small channels within the swale bottom.

Table 5-4 summarizes design guidance for vegetated swales.

Table 5-4. Vegetated Swale Design Guidance

Design Criteria	Grass Swale	Wet Swale	Bio-Swale
Bottom Width	4 to 8 feet	4 to 8 feet	4 to 8 feet
Side Slope	3H:1V or flatter	3H:1V or flatter	3H:1V or flatter
Longitudinal Slope	2 to 4%	2 to 4%	2 to 4%
Water Quality Treatment	Sized for 1 inch (first flush)	Sized for 1 inch (first flush)	Sized for 1 inch (first flush)
Maximum Contributing Drainage Area	5 acres	5 acres	5 acres
Flow Capacity: 2-year storm	Convey at non-erosive velocity	Convey at non-erosive velocity	Convey at non-erosive velocity
Flow Capacity: 10-year storm	Convey within banks at minimum 6 inches freeboard	Convey within banks at minimum 6 inches freeboard	Convey within banks at minimum 6 inches freeboard
Vegetation	Grass	Wetlands plants	Native vegetation that can handle ponding or drought
Depth from Channel Bottom to Water Table	Minimum 2 feet	Water table intersects channel	Minimum 2 feet
Gravel Layer/Underdrain	No	No	Yes
Engineered Filter Media	No	No	Yes

5.3.5 Components of a Vegetated Swale

The design components of vegetated swales vary between the grass swale, wet swale and bio-swale. The key elements of a vegetated swale are:

- Pretreatment
- Conveyance and Overflow
- Landscaping and Planting Plan
- Soil Media (for bio-swale sonly)
- Underdrain and Gravel Storage Layer (for bio-swales only)

5.3.5.1 Pretreatment

No matter which swale type is chosen, pre-treatment is recommended to allow for removal of sediments from the stormwater runoff. Pre-treatment could be in the form of a small forebay upstream of the channel to trap incoming sediments. A pea gravel diaphragm (a small trench filled with river run gravel) can also be used to pretreat runoff that enters the sides of the channel. In addition, a grass filter strip (minimum 10 feet wide) along the length of the contributing impervious drainage area, such as parking lot, could be used.

5.3.5.2 Conveyance and Overflow

The bottom width and slope of a vegetative swale should be designed such that the velocity of flow from a 1-inch rainfall will not exceed 3 feet per second. Gravel check dams may be used to achieve the needed runoff reduction volume and flow velocity. Check dams should be spaced based on channel slope and ponding requirements. Use non-erosive material such as wood, gabions, riprap, or concrete. All check dams should be underlain with filter fabric, and include weep holes. Wood used for check dams should consist of pressure-treated logs or timbers, or water-resistant tree species such as cedar, hemlock, swamp oak or locust.

5.3.5.3 Landscaping and Planting Plan

Designers should choose grasses, herbaceous plants, or trees that can withstand both wet and dry periods and relatively high velocity flows for planting within the channel. Salt tolerant grass species should be chosen for vegetative swales located along roads. Taller and denser grasses are preferable, although the species is less important than good stabilization and dense vegetative cover. Grass species should have the following characteristics: a deep root system to resist scouring, high stem density with well-branched top growth, water-tolerance, resistance to being flattened by runoff, and an ability to recover growth following inundation. Photo 5-11 illustrates the thick vegetation of a dry swale. To find a list of plant species suitable for your area, consult the local USDA NRCS office.

Photo 5-11. Dry Swale

5.3.5.4 Soil Media (for bio-swales only)

Bio-swales require replacement of native soils with an engineered soil media. The soil media provides adequate drainage, supports plant growth, and facilitates pollutant removal within the swale. The soil media for bio-swales is identical to that used for bioretention systems. The soil media should be obtained from an approved vendor to create a consistent, homogeneous fill media.

5.3.5.5 Underdrain and Gravel Storage Layer (for bio-swales only)

Where the underlying soil infiltration rates meet applicable requirements, bio-swale design would not need an underdrain. In case of impermeable soils (infiltration rates less than 0.50 inches per hour), a gravel storage layer will surround a perforated underdrain pipe to ensure proper drainage after storms. The underdrain should be encased within a gravel bed. The depth of the gravel storage layer will depend on the target treatment and storage volumes needed to meet water quality, channel protection, and/or flood protection criteria. Typical construction details of a bio-swale with an underdrain and gravel storage layer are given in Figure 5-8.

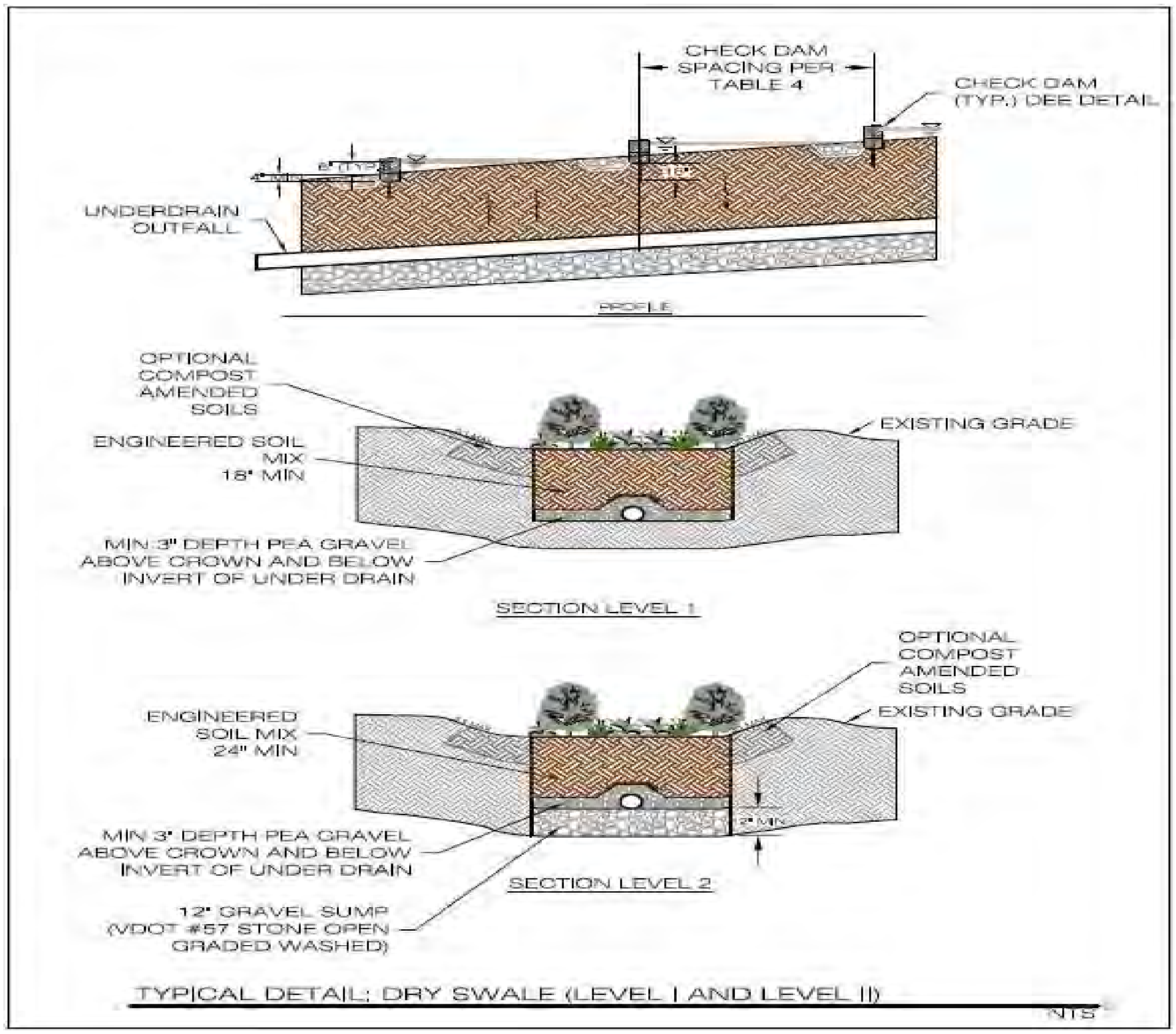

Figure 5-8. Typical Design Details of a Bio-Swale

5.3.6 Materials

Bio-swales are the only swale type that involves manufactured materials. See the materials specifications in Table 5-2 in Section 5.2.5 for bioretention materials. Designers should follow their local stormwater management requirements when specifying materials.

5.3.7 Construction Considerations

5.3.7.1 General

Construction of the vegetated swale should begin when the up-gradient site has been sufficiently stabilized and state-approved temporary erosion and sediment control measures are in place. Use light equipment and avoid excessive compaction and/or land disturbance during construction of the vegetated swale. Excavating equipment should operate from the sides of the swale and never on the bottom. If excavation leads to substantial compaction of the subgrade, excavate 18 inches and replace with a blend of topsoil and sand to promote infiltration and biological growth. Vegetative swales should be fully protected by silt fence or construction fencing, particularly if they will provide an infiltration function (i.e., have no underdrains) during construction within the immediate area.

Vegetative swales should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment. However, this is seldom practical given that swales are a key part of the drainage system at most sites. In these cases, temporary erosion and sediment controls such as dikes, silt fences and other similar measures should be integrated into the swale design throughout the construction sequence. Specifically, barriers should be installed at key check dam locations, erosion control fabric should be used to protect the channel, and excavation should be no deeper than 2 feet above the proposed invert of the bottom of the planned underdrain. Vegetative swales without an underdrain that provide for infiltration must be fully protected by silt fence or construction fencing to prevent compaction by heavy equipment during construction within the immediate area.

5.3.7.2 Construction Sequence

The following is a typical construction sequence to properly install a vegetated swale, although the steps may be modified to adapt to different site conditions.

1. Installation may only begin after the entire contributing drainage area has been stabilized.

2. Excavators or backhoes should work from the sides to excavate the vegetative swale area to the appropriate design depth and dimensions. Excavating equipment should have scoops with adequate reach so they do not have to sit inside the footprint of the project area.

3. The bottom of the swale should be ripped, roto-tilled or otherwise scarified to promote greater infiltration.

4. Rough grade the swale. For bio-swale, continue to Step 5. For grass and wet swale, skip to Step 7.

5. Place filter fabric on the excavated sides of the vegetated swale with a minimum overlap as specificed by manufacturer. Place the stone needed for storage layer. Lay the perforated underdrain pipe. Add the remaining stone jacket, ensuring a minimum 3 inches of gravel above the top of the underdrain, and then add pea gravel choker layer.

6. Place the engineered soil media in 12-inch lifts until the desired top elevation of the swale is achieved. Wait a few days to check for settlement, and add additional media as needed.

7. Install check dams, driveway culverts and internal pre-treatment features, as specified in the plan.

8. Fine grade the swale.

9. Prepare planting holes for specified trees and shrubs, install erosion control fabric where needed, spread seed or lay sod, and install any temporary irrigation.

10. Plant landscaping materials as shown in the landscaping plan, and water them weekly during the first 2 months. The construction contract should include a care and replacement warranty to ensure that vegetation is properly established and survives during the first growing season following construction.

5.3.7.3 Final Inspection

A final construction inspection should be conducted and a punch list developed for facility acceptance. Items to inspect are as follows:

- Check elevations such as the invert of the underdrain, inverts for the inflow and outflow points, and the ponding depth provided between the surface of the filter bed and the overflow structure.

- Check the filter media to confirm that it meets specifications and is installed to the correct depth.

- Ensure that caps are placed on the upstream (but not the downstream) ends of the underdrains.

- Make sure the desired coverage of turf or erosion control fabric has been achieved following construction, both on the filter beds and their contributing side-slopes.

- Inspect check dams and pre-treatment structures to make sure they are properly installed and working effectively.

- Check that outfall protection/energy dissipation measures at concentrated inflow and outflow points are stable.

The real test of a vegetative swale occurs after its first big storm. The post-storm inspection should focus on whether the desired sheet flow, shallow concentrated flows or fully concentrated flows assumed in the plan actually occur in the field. Also, inspectors should check that the swale drains completely within the minimum 6-hour drawdown period. Minor adjustments are normally needed as a result of this post-storm inspection (e.g., spot reseeding, gully repair, added armoring at inlets or outfalls, and check dam realignment).

5.3.8 Maintenance

Once established, vegetated swales have minimal maintenance needs outside of the spring cleanup, regular mowing, and pruning and management of trees and shrubs. Additional effort may be needed to repair check dams, stabilize inlet points, and remove deposited sediment from pre-treatment cells.

In a bio-swale, the surface of the filter bed can become clogged with fine sediment over time, but this can be alleviated through core aeration or deep tilling of the filter bed. Additional effort may be needed to repair check dams, stabilize inlet points, and remove deposited sediment from pre-treatment cells. Maintenance activities are similar to that of bioretention; refer to Section 5.1.7 for bioretention maintenance.

Table 5-5 is a schedule of inspection and maintenance activities recommended for vegetated swales.

Table 5-5. Suggested Maintenance Activities for Vegetated Swales

	Task	Frequency	Maintenance Notes
1	Re-mulch /re-plant void areas	As needed	
2	Replace diseased trees, shrubs, vegetation	As needed	
3	Clean Overflow	Monthly	Clear leaves and debris
4	Inspect soil and repair eroded areas	Monthly	
5	Remove litter and debris from swale	Monthly	
6	Inspect for sediment buildup, vegetative condtions, etc.	Annually	
7	Inspect all trees and shrubs to evaluate helath	Biannually	

5.3.9 Benefits

Vegetative swales provide reduction in peak flow by increasing time of concentration and runoff volume reduction by infiltration and evapotranspiration. Vegetated swales also provide improved water quality via filtering polluted runoff. They are more aesthetically pleasing than concrete/riprap lined drainage ditch. Vegetated swales are generally less expensive to construct and maintain than lined channels. Vegetated swales protect local and regional water quality by reducing sediment and nutrients; and increase community character and aesthetics. Some benefits are summarized below.

- Can be used in residential and commercial settings
- Inexpensive
- Combines water quality treatment with runoff conveyance
- Reduces runoff velocities
- Low maintenance

5.4 VEGETATED FILTER STRIP

5.4.1 Description

A vegetated filter strip is a densely vegetated strip of land designed to receive stormwater runoff from an impervious area, such as a road or parking lot. These systems function by slowing stormwater runoff and filtering out sediment and other pollutants as the stormwater runoff passes through the filter strip or infiltrates to groundwater. Stormwater runoff is absorbed by the soils and is taken up by plants and transpired or may infiltrate into the ground if the soil is well drained. A properly designed and operating filter strip reduces overland flow velocity and provides water quality treatment by reducing the amount of sediment, organic matter, nutrients, and metals carried in stormwater runoff.

The main purpose of a VFS is to reduce the velocity of the stormwater runoff through the surface roughness of the vegetation and to encourage filtration, sediment deposition, infiltration, absorption, and plant uptake of nutrients from the stormwater runoff. Usually, a vegetated filter strip is used as a pretreatment component in conjunction with a primary stormwater BMP (such as bioretention, vegetated swale, etc.) for slowing runoff velocity and reducing sediment and particulate pollutant load that could otherwise reach the primary BMP and impact its effectiveness.

Vegetated filter strips have historically been used and proven effective on agricultural lands, usually downslope along field crops (Grimser, 2006). In urban settings, vegetated filter strips are most effective in treating runoff from isolated impervious areas such as rooftops, parking lots, and small impervious areas. Sheet flow access from upslope paved areas to the filter strip is a mandatory requirement for its proper function and effectiveness. One challenge associated with filter strips, therefore, is that it is difficult to maintain sheet flow over longer flow paths, so the practice may be "short circuited" by concentrated flows, receiving little or no treatment.

5.4.2 Planning Considerations

5.4.2.1 Applications

The vegetated filter strips are suitable for many types of development projects in residential, commercial and industrial settings. They are usually recommended for use as a pretreatment component for other stormwater BMPs as they slow runoff velocities and can direct stormwater runoff to another BMP, though they do not provide adequate pollutant removal benefits while acting as a standalone practice. As stated above, vegetated filter strips are generally not recommended as “stand alone” features, but as pretreatment systems for other BMPs, such as infiltration trenches, vegetated swales, or bioretention areas. They are generally a poor stormwater retrofit option because they consume a relatively large amount of space and cannot treat large drainage areas (PA DEP, 2006).

Vegetated filter strips rely on their relatively flat cross slope, mild downslope, and dense vegetation to slow and remove stormwater runoff pollutants. These design features ensure that runoff remains as sheet flow while passing through the strip. The Virginia Departement of Conservation and Recreation (2011) recommends that vegetated filter strip systems are effective only where the runoff enters the filter strip, from above the contributing drainage area, as sheet flow and remains in sheet flow condition while flowing through the strip. This requirement limits flow length over impervious surfaces not to exceed 75 feet (Claytor and Schueler, 1996).

The proper planning and construction of a filter strip should consider factors such as: soil characteristics (texture, soil type, hydrologic soil group, infiltration rate, and permeability); the slope, shape, length, and size of the contributing area; and the designed quantity of pollutant removal from runoff (sediment, nutrient, organic matter, metals and hydrocarbons, etc.). The type of vegetation applicable to local climatic conditions, and time of the year to properly establish that vegetation (by seed or sod) are also important considerations. Although, the type of vegetation used can be very broad, the best performance is associated with native plant species having deep, fibrous roots and dense ground patterns such as turf-forming grasses.

5.4.2.2 Constraints

Vegetated filter strips require runoff to enter as sheet flow to work effectively, therefore, they should not receive large volumes of runoff since such flows tend to concentrate and form channels. Channels within a filter strip allow runoff to short-circuit the BMP, rendering it ineffective.

Vegetated filter strips have several other limitations related to their performance and space consumption such as:

- VFSs are not intended to treat concentrated flow and are only effective when runoff flows as sheet flow
- Not recommended for soils with high clay content because VFSs require some infiltration for proper treatment
- Very poor soils that cannot sustain a grass cover are also a limiting factor
- Filter strips require a large amount of space, making them often infeasible in urban environments where land space is limited
- Vegetated filter strips should not receive “hot spot” runoff for potential aquifer contamination, because the practice encourages infiltration
- Sheet flow is the mandatory requirement for proper functioning of the BMP which is difficult to achieve and maintain, especially for longer flow reaches

5.4.3 Design Criteria & Specifications

Vegetated filter strips require minimal design as they essentially a grassed landscape with a gentle to flat slope. Thus, the design and construction criteria are not much different than seeding/sodding a residential lawn. However, some design features are critical to ensure that a vegetated filter strip properly slows stormwater runoff and provides intended water quality treatment. These features include its slope, length, width, and type of surface cover. To be effective, vegetated filter strips require the stormwater runoff to sheet flow across the entire strip.

Key vegetated filter strip design elements are described in several state Stormwater BMP Manuals, such as New Jersey BMP Manual (2003), PA DEP (2006), Virginia DCR (2011), etc., and are also discussed on the USEPA Website: EPA Menu of Stormwater BMPs (http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm) under "Management Measures for Vegetated Treatment Systems. These elements are briefly described in the following sections.

5.4.3.1 General

The basic design parameters for a vegetative filter strip are its longitudinal slope and length (i.e., parallel to flow) and the type of vegetative cover. The vegetation in the filter strip will slow the stormwater runoff; the degree to which the vegetation slows the runoff is associated with the roughness of the vegetation. Different types of vegetation have different roughness coefficients called the Manning's roughness coefficient, n, which refers to the resistance of the bed of a channel to the flow of water. The vegetation is selected to have a certain roughness for slowing runoff velocity which, in combination with vegetated filter strip slope, is used to determine the required filter strip length parallel to flow through the strip. In addition, since runoff from upslope contributing drainage area must enter as sheet flow into the vegetated filter strip, the peak runoff rate originating from the contributing drainage area (such as from a parking lot) must be sufficiently low and uniformly distributed to ensure sheet flow conditions over the entire area. The sheet-flow length limitation, in turn, limits the size of the contributing drainage area to the filter strip and, consequently the peak runoff rate. Details of these and other design parameters are presented in the following sections. The components of a typical vegetated filter strip are shown in Figure 5-9.

5.4.3.2 *Contributing Drainage Area and Runoff Characteristics*

Typically, vegetated filter strips are used to treat very small drainage areas. The limiting design factor, however, is not the drainage area but the sheet flow requirement for the runoff to travel over the impervious area, which limits the length of flow not to exceed 75 feet over the paved area (CWP, 1996). As noted above, the maximum sheet flow travel length over an impervious, paved surface is 75 feet (CWP, 1996). Therefore, the maximum contributing drainage area to a VFS will be limited to an area 75 feet long measured perpendicular to the upslope edge of the filter strip. If the width of the drainage is equal to the width of the vegetated filter strip, then the contributing drainage area is essentially equal to length multiplied by width.

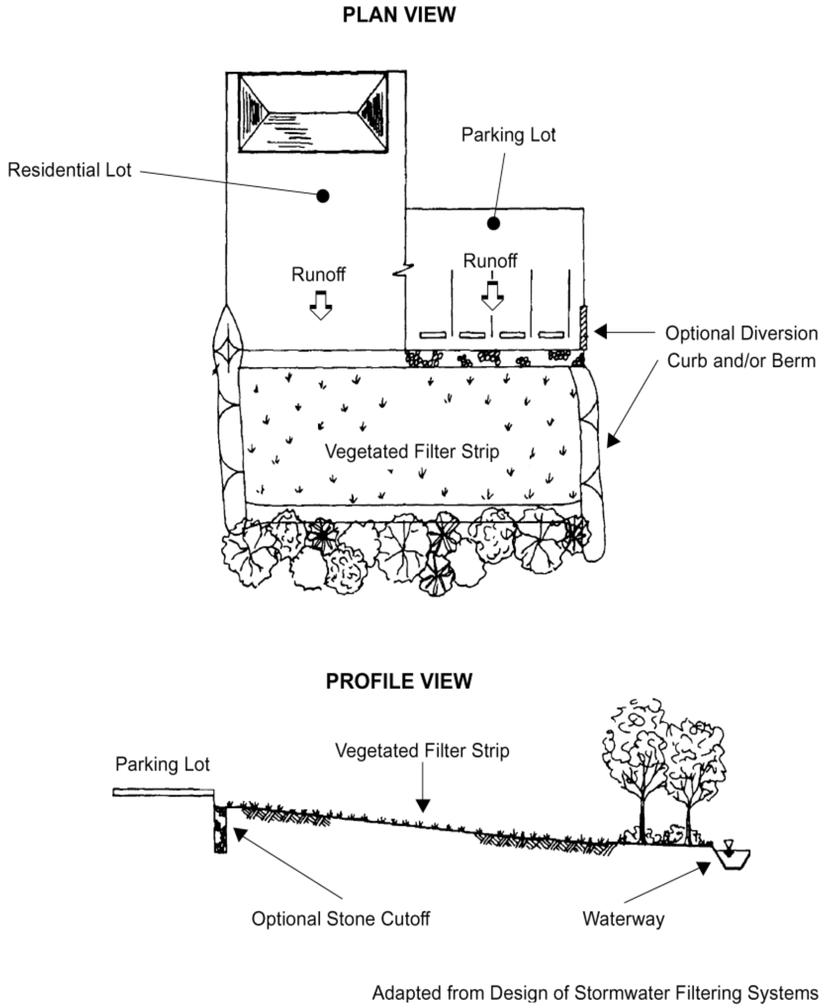

Figure 5-9. Vegetated Filter Strip Components
(Source: CWP, 1996)

5.4.3.3 *Vegetation Cover and Manning's Roughness Coefficient, n*

Vegetation for filter strips may be comprised of turf grasses, meadow grasses, shrubs, and native vegetation. Native vegetation helps to minimize erosion by stabilizing the soil with deep root structure common in native plants. A vegetated filter strip should be densely vegetated with a mix of erosion resistant species that have fibrous root system to effectively bind the soils. The selection of plants should be based on their compatibility with local climatic conditions, soils, topography; and their ability to tolerate urban thermal stress, variable soil moisture conditions, drought, and ponding conditions.

Table 5-6 below presents Manning's roughness coefficient, n, values for various surface covers. These Manning's "n" values, in combination with respective slopes may be used to determine maximum filter strip lengths for VFS systems (New Jersey BMP Manual, 2003).

Table 5-6. Manning's Roughness Coefficients (n)

Vegetation Cover in Filter Strip	Manning's N
Dense Grass	0.25
Sod	0.35
Meadow or Woods with Dense Vegetation	0.35
Natural Woods with Dense Vegetation	0.40

(Source: New Jersey BMP Manual, 2003)

5.4.3.4 Filter Strip Slope

The vegetated filter strips should, in general, be designed for slopes, parallel to flow length, between 2 and 6 percent. The maximum slope should not be more than 8 percent, whereas the minimum should be not less than 2 percent to promote positive drainage. Steeper slopes will increase flow velocity and lead to concentration of runoff and likelihood of erosion and gullying. In addition, as the slope increases, the treatment effectiveness decreases. Slopes flatter than 2 percent may be appropriate in some geographic regions, but are discouraged in residential areas due to the tendency for surface ponding that creates potential nuisance conditions. The recommended cross slope for a vegetated filter strip is 1 percent or flatter.

The maximum filter strip slopes for various vegetation covers and soil types for a vegetated filter strip are shown in Table 5-7. Except for coarse sandy soils, the recommended slopes for other soils types and hydrologic soil groups (HSG) are mostly in the range of 8 percent. County soil surveys can help determine the soil type and HSG within a vegetated filter strip, although site soil testing may be necessary for accurate design.

Table 5-7. Maimum Vegetated Filter Strip Slopes for Various Soil Types

Soil Type	HSG	Maximum Slope, %	Maximum Slope, %
		Dense Grass, Sod, and Bermuda Grass	Woods with Dense Underbrush
Sand	A	7	5
Sandy Loam	A	8	7
Loam, Silt Loam	B	8	8
Sandy Clay Loam	C	8	8
Clay Loam, Silty Clay, Clay	D	8	8

(Source: New Jersey Stormwater BMP Manual, 2003)

5.4.3.5 *Filter Strip Length*

In vegetated filter strip systems, the limiting design factor is the length of the flow both over the contributing drainage area, as well as, through the vegetated filter strip itself; sheetflow needs to be maintained across the contributing drainage area and the vegetated filter strip (PA DEP, 2006). Vegetated filter strip length (the dimension parallel to flow path) is a function of slope, vegetation type, soil type, and the desired amount of pretreatment. Figure 5-10 provides vegetated filter strip lengths as a function of various vegetation types (Manning's roughness, n, Table 5-6) and slopes, Table 5-7. It should be noted that that linear interpolation may be used for Manning's n values not specifically plotted in the figure. As shown in the figure, the minimum filter strip length is 20 feet regardless of slope or Manning's n value**.**

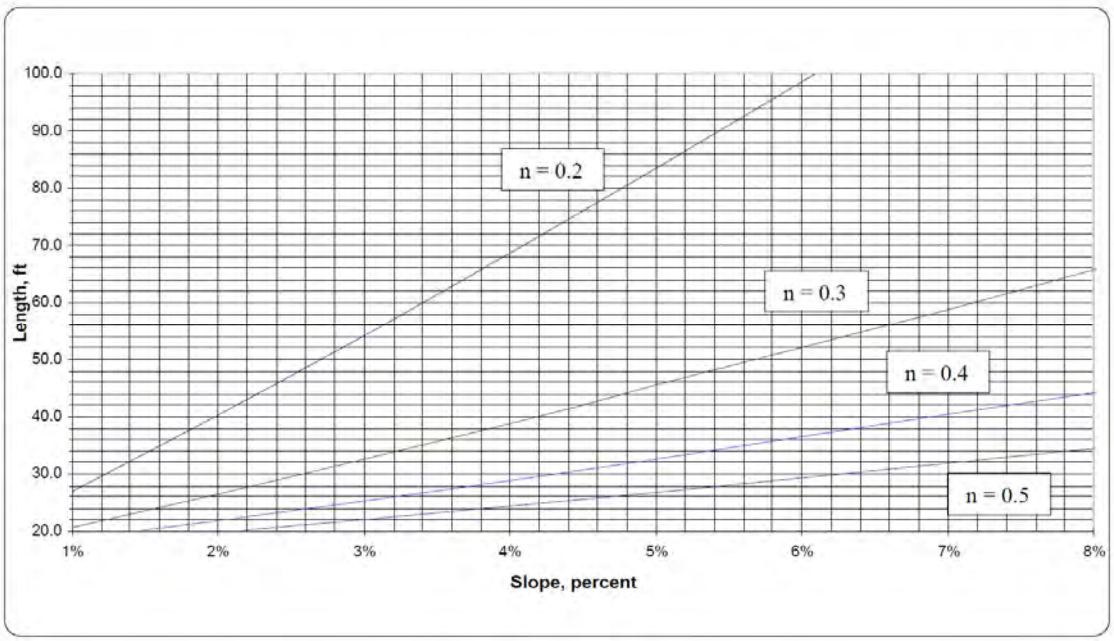

Figure 5-10. Vegetated Filter Strip Length Determination

(Source: New Jersey BMP Manual, 2003)

It is also important to note that the lengths shown in Figure 5-10 are applicable only for filter strips with coarse soils, such as sands. For filter strip areas with less coarse soils, such as silt and clays, the length shown in the Figure 5-10 must be multiplied by the factors shown in Table 5-8.

Table 5-8. Filter Strip Length Correction Factors

Soil Type	HSG	Correction Factor
Sand	A	1.0
Sandy Loam	A	1.1
Loam, Silt Loam	B	1.3
Sandy Clay Loam	C	1.5
Clay Loam, Silty Clay, Clay	D	1.8

(Source: New Jersey BMP Manual, 2003)

5.4.3.6 Filter Strip Width and Travel (Contact) Time

The vegetated filter strip should be designed to provide a 20-minute travel time (contact time) for runoff passing through the filter strip. The Iowa SUDAS (2000) recommends that this 20-minute level of contact time with vegetation would provide approximately 85 percent removal of total suspended solids.

The width of the VFS, perpendicular to flow length, should be sized according to Manning's equation to limit the flow depth to one half inch or less. As a general rule, the width should be equal to the width of the contributing drainage area above. When this is not possible, a pea gravel diaphragm or a level spreader should be provided to reduce the flow width to that of the filter strip. CWP (1996) and Virginia DCR (2011) guidelines suggest a minimum vegetated filter strip width of 25 feet at 1 percent or flatter cross slope.

5.4.3.7 Pea Gravel or Gravel Trench

A pea gravel diaphragm should be installed along the entire up-gradient edge of the strip. The pea gravel diaphragm serves two purposes. First, it acts as a pretreatment device, settling out sediment particles before they reach the practice. Second, it acts as a level spreader or energy dissipater for maintaining sheet flow as runoff flows over the filter strip. The pea gravel diaphragm is created by excavating a 2-foot wide and 1-foot deep trench that runs on the same contour as the top of the filter strip. A layer of geotextile filter fabric should be placed between gravel and underlying soil trench. When placed directly adjacent to an impervious surface (parking lot), a drop (between the paved edge and the trench) of 2-3 inches is recommended.

5.4.3.8 Permeable Berm

Filter strip effectiveness may be enhanced through the addition of a pervious berm at the toe of the slope for providing a temporary ponded area. The filter strip should be designed with a permeable berm of sand and pea gravel at toe of the vegetated filter strip. The runoff volume ponded behind the berm should be equal to the water quality volume. The water quality volume is the amount of runoff that will be treated for pollutant removal inside the filter strip. Typical water quality volume is the runoff from a 1-inch storm or ½-inch of runoff over the entire contributing drainage area to the filter strip. The permeable berm should have the following design characteristics:

- A wide and shallow trench, 6-12 inches deep, should be excavated at the upstream toe of the berm
- Media for the berm should consist of 40 percent excavated soils, 40 percent coarse sand, and, and 20 percent pea gravel
- The berm, 6 to 12 inches high, should be located down gradient of the excavated trench and should have gentle side slopes to promote easy mowing
- Stone may be used to armor the top of the berm to handle runoff overtopping

A permeable berm is not needed when a VFS is used as a pretreatment to another stormwater practice.

5.4.4 Materials

Vegetation selected for filter strips should have dense growth to provide good, uniform soil cover, and a fibrous root system for stability. In addition, the type of vegetation selected should be adapted to local soil and climatic conditions, and have good regrowth characteristics following dormancy and mowing. Common materials used in filter strips are outlined in Table 5-9.

Table 5-9. Vegetated Filter Strip Material Specifications

Material	Specification
Gravel Diaphragm	Pea gravel ASTM D 448, size #6 or #8 (1/8-nch to 3/8-inch dia); DOT stone #57: Diaphragm should be 2 feet wide, 1 feet deep, and at least 3 inches below the edge of pavement
Permeable Berm	Not required when VFS is used as a pretreatment practice; otherwise use 40% topsoil, 40% sand, and 20% gravel
Geotextile	Non-woven, ASTM D4491
Compost	Compost shall be derived from plant material

(Source: Virginia DCR, 2011)

5.4.5 Construction Considerations

In general, the same considerations apply for the installation of a filter strip as for the establishment of lawns and other landscaped areas. Land grading and other soil surface preparation is necessary to ensure establishing vegetation and that the runoff will enter the strip in the form of sheet flow.

Begin vegetated filter strip construction only when the up-gradient site has been sufficiently stabilized and "state-approved" temporary erosion and sediment control measures are in place.

Construction should be initiated, if possible, at a time of the year when successful establishment without irrigation is most likely. However, irrigation may be needed in periods of little or no rain.

5.4.5.1 Construction Sequence

The following procedures should be followed during construction.

1. Rough grade the site using light equipment to avoid compaction.

2. If existing topsoil is stripped during grading, it should be stockpiled for later use.

3. Prepare a firm seedbed by plowing and cultivating to a depth of 6-12 inches.

4. Plant the seed shallow (1/4-inch) with a seed drill or by broadcast. Make sure the seed is on a firm seedbed to obtain good seed-to-soil contact.

5. Before seeding, apply soil amendments that would ordinarily be used for turf grasses including fertilizer, lime, compost or gypsum per soil tests.

6. Use native vegetation as recommended by your local USDA NRCS Extension Office.

7. Must use wheat straw or blanket mulch over seeded area to ensure germination and early plant establishment.

8. Irrigate after seeding. During periods of dry weather, germination of seed and plant establishment may require subsequent irrigations.

5.4.6 Maintenance

Vegetated filter strips require regular maintenance. Inspections are critical during the first few years to ensure that the VFS becomes adequately established. Once a VFS is established and is functioning, as intended, periodic maintenance such as watering, fertilizing and spot repair may still be necessary. Overseeing and replanting should be limited to those species which have exhibited the ability to thrive.

Maintenance for grassed filter strips may consist of the following simple steps and as summarized in Table 5-10.

Table 5-10. Suggested Maintenance Activities for Vegetated Filter Strips

Activity	Frequency
Inspect pea gravel diaphragm for clogging and remove build-up sediment	Annually
Inspect vegetation for rills and gullies and correct	Annually
Seed or sod bare areas	Annually
Ensure that grass has established. If not, replace with an alternate species	Annually
Mow during growing season	As needed
Remove weeds and invasive species	As needed

5.4.7 Benefits

Vegetated filter strips are agricultural BMPs and their effectiveness in urban settings, especially as a pretreatment practice, has not been widely investigated and established (Yu et al., 1992). However, some significant benefits and limitations of vegetated filter strip systems include:

- Water quality treatment via filtering of suspended sediments and NPS pollutant control
- Provides pretreatment control to capture coarse sediments before they reach main stormwater BMP such as a bioretention or vegetated swale
- Can be used to treat runoff along residential streets, stream corridors, and parking lots
- Provides an aesthetically pleasing appearance

5.5 PERMEABLE PAVEMENTS

Pervious or permeable pavements consist of a permeable surface course underlain by a uniformly graded stone-bed laid on uncompacted soil. The surface course consists of porous asphalt, porous concrete, or various porous pavers. Stormwater drains through the permeable surface course to the stone bed, where it is temporarily stored to provide peak flow reduction and promote infiltration to the underlying soils. A layer of geotextile filter fabric separates the aggregate from the underlying soil, preventing the migration of fines into the bed. The application of permeable pavement allows stormwater runoff to infiltrate the surface more evenly, resulting in a reduction of runoff and minimizes concentrated flows. Permeable pavements and pavers provide water quantity and quality benefits by promoting infiltration, while still providing a stable load-bearing surface without increasing the project impervious area.

5.5.1 Types of Permeable Pavement

There are several types of permeable pavements and pavers. For the purposes of the Army LID Technical User Guide, the four main categories of permeable pavements and pavers will be discussed: porous asphalt, pervious concrete, permeable concrete pavers, reinforced turf.

5.5.1.1 Porous Asphalt

Porous asphalt is similar to conventional asphalt in structure and form, except that the fines (sand and finer material) from parent asphalt mix have been removed. The same mixing and application is used for porous or pervious asphalt as the impervious asphalty; only the formula for the asphalt is different.

Porous asphalt is appropriate for only pedestrian-use areas and for very low-volume, low-speed vehicular areas such as overflow parking areas, residential driveways, alleys, and parking stalls. Photo 5-12 shows porous asphalt use on a playground and basketball court.

Photo 5-12. Porous Asphalt in Playground

5.5.1.2 Pervious Concrete

Pervious concrete can be used in place of conventional concrete in most situations. Smaller amounts of fines, larger pea gravel, and a lower water-to-cement ratio are used to achieve a pebbled, open surface that is roller compacted. In northern and mid-Atlantic climates, such as Pennsylvania, pervious concrete should always be underlain by a stone subbase designed for stormwater management and should never be placed directly onto a soil subbase. Pervious concrete has a coarser appearance than its conventional counterpart, as seen in Photo 5-13. Care must be taken during placement to avoid working the surface and creating an impervious layer.

Photo 5-13. Standard and Porous Concrete

5.5.1.3 Permeable Concrete Pavers

Permeable pavers consist of interlocking units (often concrete or brick) that have pervious pea gravel, vegetation or mulch in the spaces between the units to form a grid system. The pervious spaces between the pavers allow for filtration of stormwater through layers of open-graded aggregated and infiltration into the underlying soils. Permeable pavers provide pervious surfaces throughout the otherwise impervious surface and also enhance the aesthetic appeal of the area. They are most often used for driveways, small parking areas, entryways, walkways, plazas, patios or terraces to achieve a more aesthetically pleasing appearance. Photo 5-14 illustrates the use of two colors of permeable pavers to outline parking spots within a larger parking lot.

Photo 5-14. Permeable Pavers at Multnomah Art Center
(Source: Portland Philadelphia Stormwater Manual)

5.5.1.4 Reinforced Turf

Reinforced turf and gravel are highly permeable as they have voids where, once installed, grass, flowers, or vegetation are planted inside and allowed to grow through the paver. The pavers themselves can be made from plastic, concrete, or gravel, and can be used in high traffic areas (Photo 5-15).

Reinforced turf consists of interlocking structural units that contain voids or areas for turf grass growth and are suitable for traffic loads and parking. The reinforce turf is underlain by a stone and/or sand layer to filter pollutants and temporarily store runoff. There are also products available that provide a fully permeable surface through the use of high strength plastic geogrids (often made from recycled materials) filled with gravel or grass. After heavy rains, the grids act as mini holding-ponds, and allow water to gradually absorb into the soil below.

Reinforced turf applications work well for fire access roads, overflow parking, and occasional use parking. Reinforced turf application allows for the reduction of the required standard pavement width for paths and driveways that must occasionally provide for emergency vehicle access.

The reinforced turf grides provide a support structure for heavy vehicles, and prevent erosion. While both plastic and concrete units perform well for stormwater management and traffic needs, plastic units tend to provide better turf establishment and longevity, largely because the plastic will not absorb water and diminish soil moisture conditions. A number of products (e.g., Grasspave, Geoblock, GravelPave, Grassy Pave, Geoweb) are available and the designer is encouraged to evaluate and select a product suitable to the design in question.

Photo 5-15. Examples of Reinforced Turf

5.5.2 Planning Considerations

Permeable pavements can be used as a substitute for impervious pavements in most land use areas to reduce stormwater runoff. However, as there are many opportunities to employ permeable pavers, there are also many constraints. Permeable pavements work well in parking lots and some roads but the may be limited in supported the weight of heavy vehicles or heavy traffic. There are also human safety concerns, such as use in handicap parking areas, where pavers can be a hazard if the surface is uneven.

5.5.2.1 Applications

There are several opportunities to incorporate permeable pavements into many types of land uses. Such applications include:

- Ultra urban, commercial, industrial, retrofit, highway/roadway(limited use), and residential streets and driveways
- Public play grounds, tennis courts, parking lots, plazas, and similar uses
- Areas adjacent to tree islands in parking lots (Photo 5-16)
- Service drives and emergency vehicle access lanes and fire lanes
- Pedestrian sidewalks (Photo 5-17 and Photo 5-18)

Photo 5-16. Permeable Pavers in Parking Lots Adjacent Tree Island

Photo 5-17. Porous Asphalt Along Pedestrian Walkways

Photo 5-18. Pervious Concrete Along Roads and Streets

5.5.2.2 Constraints

Permeable pavements are not suitable in areas where the underlying soils do not drain well. Permeable pavements should be laid on uncompacted, level soil. Compacting the subgrade will prevent runoff from being able to infiltrate. If new fill is required, it should consist of additional stone and not compacted soil.

Permeable pavements/pavers are not recommended where:

- Excessive sediment could be deposited on the surface
- Steep erosion prone areas that are likely to deliver sediment and clog pavement
- Underlying soils are composed of fill material, which can become unstable when saturated
- Maintenance is unlikely to be performed at appropriate intervals
- Porous asphalt is not recommended for slopes exceeding 5%

- Pervious concrete is not recommended on slopes exceeding 6%

- Porous asphalt not ideal for high traffic/high speed areas because it has lower load-bearing capacity than conventional asphalt.

- Areas where requirements under the Americans with Disabilities Act apply, such as handicap parking spaces

- Permeable pavement should not be used on stormwater "hotspot land use" (such as gas stations) applications with high pollutant loads because the rain falling directly on the paved surface cannot be pretreated prior to filtering through the pavement section and infiltrating into the subgrade.

5.5.3 Design Criteria & Specifications

Permeable pavements can be used in place of conventional pavements, though additional factors must be considered in the placement and design as there are some structural differences. Design considerations include the permeability of underlying soils, risk of contaminating groundwater in hotspots, and the type of permeable pavement to be used.

5.5.3.1 Site Investigation

The overall site should be evaluated for potential pervious pavement/infiltration areas early in the design process. Pervious pavement and infiltration beds should not be placed on areas of recent fill or compacted fill. Any grading that requires fill should be done using the gravel subbase material.

5.5.4 Components of Permeable Pavement Section

A permeable pavement section consists of a pervious surface course (porous asphalt, pervious concrete, permeable concrete pavers or reinforced turf) underlain by layers uniformly graded and clean-washed coarse aggregate with a void space of at least 40 percent. The depth of the bed is a function of stormwater storage requirements, frost depth considerations, site grading, and anticipated loading. 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 or subdrain so that during large storm events peak rates are controlled, and at no time does the water level rise to the surface course. A layer of geotextile filter fabric separates the aggregate from the underlying soil, preventing the migration of fines into the bed. Figure 5-11 shows an example of a permeable concrete paver section without an underdrain.

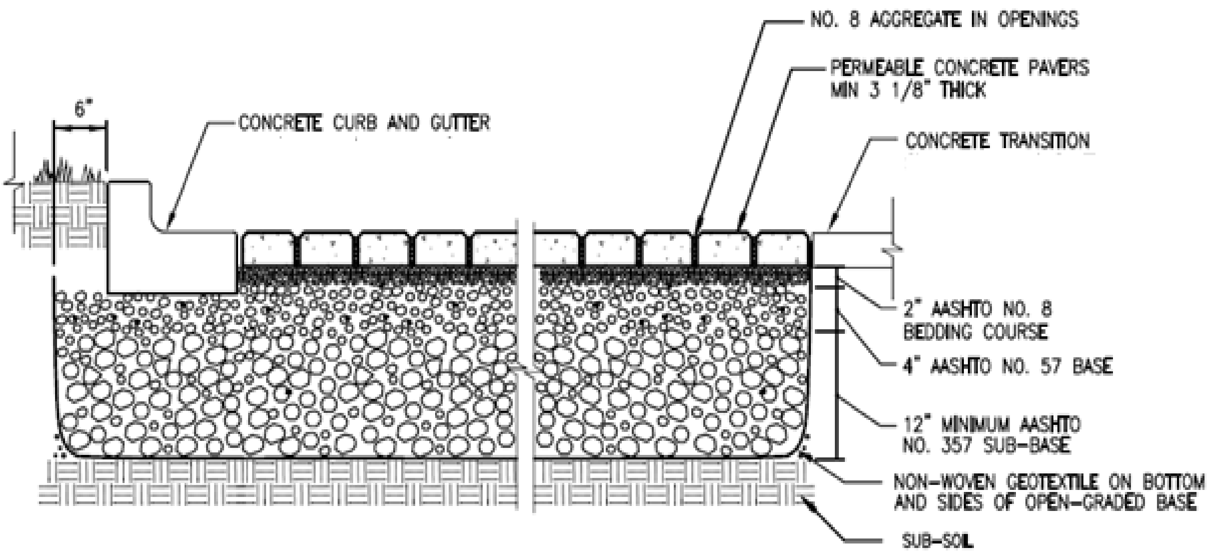

Figure 5-11. Cross Section of Permeable Concrete Paver
(Source: USACE, 2011)

5.5.4.1 Drainage/Overflow

All systems should be designed with an overflow system. Water within the subsurface stone bed should never rise to the level of the pavement surface.

While infiltration beds are typically sized to handle the increased volume from a storm, they should also be able to convey and mitigate the peak of the less-frequent, more intense storms (such as the 10 or 100-year). The subsurface bed and overflow may be designed and evaluated in the same manner as a detention basin to demonstrate the mitigation of peak flow rates. In this manner, the need for a detention basin may be eliminated or reduced in size. Control in the beds is usually provided in the form of an outlet control structure. A modified inlet box with an internal weir and low-flow orifice is a common type of control structure. The specific design of these structures may vary, depending on factors such as rate and storage requirements, but it always should include positive overflow from the system.

All pervious pavement installations should have a backup method for water to enter the stone storage bed in the event that the pavement fails or is altered. In uncurbed lots, this backup drainage may consist of an unpaved stone edge or curtain drain connected directly to the bed. In curbed lots, inlets with water quality devices may be required at low spots. Backup drainage elements will ensure the functionality of the infiltration system, if the pervious pavement is compromised.

In areas with poorly draining soils, infiltration beds below pervious pavement may be designed to slowly discharge to adjacent wetlands or bioretention areas. Only in extreme cases (i.e., industrial sites with contaminated soils or karst topography) will the aggregate bed need to be lined to prevent infiltration.

5.5.5 Materials

Table 5-11 provides a summary of the typical material requirements for the permeable pavement components described in previous pages. Designers should follow their local stormwater management requirements when specifying materials.

Table 5-11. Typical Permeable Pavement Material Specifications

Material	Specification	Notes
PERMEABLE PAVER		
Interlocking Concrete Paver	Min. 3-1/4 in. thick meeting ASTM C 396 or CSA A231.2	20% or more surface area open
Pea Gravel Bedding Course	2-inch layer 1/8 to 3/8 – inch aggregate (AASHTO No. 8 stone)	
Open Graded Base Course	4-inch layer AASHTO No. 57 stone	
Subbase Course	AASHTO No. 2 stone	40% voids Thickness varies, minimum 6 inches
Non-woven Geotextile	ASTM-D4632 ASTM-D3786 ASTM-D4491 ASTM D-4355 Nonwoven polypropylene fibers	
REINFORCED TURF		
Plastic Geogrid	Minimum 1-3/4 inch thick	
Subbase Course	AASHTO No. 2 stone	Minimum 30% voids Thickness varies, minimum 6 inches
POROUS ASPHALT AND PERVIOUS CONCRETE		
Cement	Portland Cement Type I or II conforming to ASTM C 150 Portland Cement Type IP or IS conforming to ASTM C 595	Cement content shall not be less than 600 lbs/cy for pavement subjected to vehicle loads
Air Entraining Agent	ASTM C 260	
Admixture	Type D Water Reducing – ASTM D 494	
Mixing Water	Potable	
Aggregate/Cement Ratio	4:1 to 4.5:1	
Water/Cement Ratio	0.34 to 0.40	
Asphalt and Concrete Mix Design	Consult pavement designer	Pavement shall have load capacity cable of supporting applicable traffic and vehicle loads

Material	Specification	Notes
Asphalt and Concrete	Minimum 15 percent air voids in the completed top lift. Concrete strength 2400 to 2500 psi after 28 days curing period.	
ALL PERMEABLE PAVEMENT TYPES		
Subgrade (Existing Subsoil)	Subgrade shall not be compacted	
Aggregate Layers	Aggregates shall be washed and free of fines	
Underdrain	Minimum 6-inch perforated pipe PVC Schedule 40 HDPE to meet AASHTO M252, Type S or AASHTO M294, Type S.	

5.5.6 Construction Considerations

5.5.6.1 General

Due to the nature of construction sites, permeable pavement and other infiltration measures should be installed toward the end of the construction period, when the surrounding areas are stabilized. If this is not possible, sediment laden runoff during construction shall be diverted around the permeable pavement. Sediment on the pervious surface or in the constructed gravel bed can clog the pores and lead to system malfunction.

During construction, the excavated bed may serve as a temporary sediment basin or trap. This will reduce overall site disturbance. The bed should be excavated to within one foot of the final bed bottom elevation for use as a sediment trap or basin. Following construction and site stabilization, sediment should be removed and final grades established.

5.5.6.2 Construction Sequence

Installation techniques vary for the type of permeable material chosen, but the sequence is in general similar. The installation and construction of permeable pavement should be done in accordance with designer of record specifications and standards. However the following construction sequence should be followed.

1. Bed bottoms should be level. Sloping bed bottoms will lead to areas of ponding and reduced distribution.

2. Excavate the project area to the depth of the entire pavement section.

3. Cover the uncompacted subsoil with geotextile fabric to reduct migration of fines into the gravel reservoir. Place geotextile in accordance with manufacturer’s specifications.

4. Install clean, washed gravel subbase (and perforated underdrain if required). Place gravel in lifts and lightly compact according to specifications.

5. Install gravel base course (to transition bedding course to subbase).

6. Install the bedding course (pea gravel or sand depending on permeable pavement type).

7. Lay the surface course (set in place concrete pavers or open grid units, plastic geogrid, or cast in place asphalt/concrete).

8. If using permeable concrete pavers fill the voids between pavers with pea gravel. For reinforced turf, fill spaces or voids with planting soil, sand or gravel. Follow manufacturer's specifications.

9. Seed, fertilize, and mulch the entire surface for grass applications.

10. Water immediately and then every couple of days until the grass is established.

5.5.7 Maintenance

5.5.7.1 General

The primary goal of permeable pavement maintenance is to prevent the pavement surface and/or the underlying infiltration-bed from being clogged with fine sediments. To keep the system clean throughout the year and its lifespan, the pavement surface should be swept with a street sweeper and vacuumed once every two years with a commercial vacuum unit. Use of conventional pavement washing and/or compressed systems is not recommended.

Planted areas adjacent to pervious pavement should be well maintained to prevent soil washout onto the pavement surface. If any washout does occur it should be cleaned off the pavement immediately to prevent future clogging of the pores. Furthermore, if any bare spots or eroded areas are observed within the planted areas, they should be replanted or reseeded to stabilize the area. All trash and other litter that is observed during routine inspections should be removed. Soil particles that become ground from repeatedly traffic use leads to clogging. Therefore, trucks or other heavy vehicles should be prevented from tracking and spilling sediment onto the permeable pavement.

Maintenance agreements should clearly specify how to conduct maintenance activities. See Table 5-12 for suggested maintenance activities and frequency.

5.5.7.2 Winter Maintenance

Winter maintenance for a permeable pavement parking lot may be necessary but is usually less intensive than that required for a standard impervious surface. By its very nature, a permeable pavement system with subsurface aggregate has superior snow melting characteristics compared to standard pavements. The underlying stone bed tends to absorb and retain heat so that freezing rain and snow melt faster on pervious surfaces. However, snow will accumulate during heavier snowstorms. Snow plow blades should be set slightly higher than usual by approximately one inch. Salt is acceptable for use as a deicer on the pervious surface; though nontoxic, organic deicers, applied either as blended, magnesium chloride-based liquid products or as pre-treated salt, are preferable. Sand should never be used.

5.5.7.3 Repairs

Potholes in porous asphalt and pervious concrete are unlikely; though settling might occur if a soft spot in the subgrade is not removed during construction. Small damaged area can be patched by any suitable means. Under no circumstances should the pavement surface ever be seal coated.

Table 5-12. Suggested Maintenace Activities for Permeable Pavement

	Task	Frequency	Maintenance Notes
1	Sweep and Vacuum Pavement	2 to 3 times / yr	Commercial sweeper/vacuum unit
2	Clean Inlets, Drainage Pipe, Stone Edge Drains, etc.	2 times /yr	Remove sediment and debris
3	Water Reinforced Turf and Grass-filled Open Grid Pavement	Regularly	
4	Clean Up Soil Deposited on Pavement	Immediately	
5	Maintain Planted Areas adjacent to Permable Pavement	Regularly	Prevent mulch and soil washout onto pavement surface
6	Snow Removal	As Needed	Raise plow blade 1 inch higher Do not use sand

5.5.8 Benefits

There are numerous advantages to permeable pavement systems, including:

- Reduces drainage infrastructure costs
- Reduces stormwater runoff by infiltration
- Contributes to good water quality
- Volume and Peak flow reduction
- Landscaping for aesthetics
- Promote stormwater infiltration and groundwater recharge
- Improved water quality through pollutant reduction by processes such as filtration/infiltration
- Minimizes “urban heat island” effects

5.6 RAINWATER HARVESTING

5.6.1 Description

Rainwater harvesting is the process of collecting water from roof surfaces and impervious surfaces, such as parking lots, during rain events and storing it in tanks, barrels, or cisterns for non-potable use. Potential uses include indoor non-potable applications (*i.e.*, toilet flushing, laundry) and outdoor applications such as landscape irrigation.

Rainwater harvesting follows ecologically sound principles as it promotes water conservation, reduces peak flows and runoff volumes, and provides irrigation water for landscaping during dry periods. Runoff collected from rooftops is sodium and chlorine free, low in salt content, and high in nitrogen, and relatively clean that can be used for irrigation and for flushing toilets and urinals. Capturing and using rainwater runoff also reduces site discharge and erosion, and the potential for stormwater pollutants.

5.6.2 Types of Rainwater Harvesting Systems

Rain barrels and cisterns are the most common water storage tanks for capturing and storing rooftop rainwater or runoff from other impervious surfaces.

5.6.2.1 Rain Barrels

Rain barrels are 50-150 gallon covered plastic tanks with a hole at the top for downspout discharge, an overflow outlet, and a valve and hose adapter at the bottom. They are used almost exclusively on residential properties. Since rain barrels rely on gravity flow, they should be placed near, and slightly higher than, the point of use (whether a garden, flower bed, or lawn.) A hose is attached to a faucet at the bottom of the barrel and water is distributed by gravity pressure. The overflow outlet should be routed to a dry well, bioretention area, or rain garden. It is important for property owners to use the water in rain barrels on a regular basis, or else they fill up and no additional roof runoff can be stored. It is recommended that each house have at least two rain barrels; a one inch storm produces over 500 gallons of water on a 1000 square foot roof.

For residential applications, a typical rain barrel design will include a hole at the top to allow for flow from a downspout, a sealed lid, an overflow pipe (to divert excess water once the barrel is full), and a spigot at or near the bottom of the barrel (Photo 5-19). A screen is often included to control mosquitoes and other insects. The water can then be used for lawn and garden watering or other uses such as supplemental domestic water supply. Rain barrels can be connected in a series to provide larger volumes of storage

Some commercially available rain barrels are manufactured with upper and lower ports linking the primary barrel to a second barrel (and potentially others) linked together in series. Screening at any orifice or entry point to the tank discourages vectors such as mosquitoes. A food grade plastic barrel used for bulk liquid storage in restaurants and grocery stores can be fitted with a bulkhead fitting and spigot for garden watering. However those that are not opaque must be screened from sunlight. Standard tanks must be installed above ground.

Photo 5-19. Residential Rain Barrel

5.6.2.2 Cisterns

Surface tanks and cisterns may be larger than rain barrels but serve the same function. They can be integrated into sites where a significant water need exists or rain harvesting and reuse is desired. They may drain by gravity or be pumped. Unlike rain barrels, cisterns and tanks typically need design professional assistance for more complex water collection and delivery system design. Also, they typically need to be installed to local code by a certified and bonded plumbing or construction contractor.

Cistern capacities range from 250 to over 30,000 gallons (Virginia Department of Conservation and Recreation Stormwater Design Specification No. 6, 2011). Multiple tanks can be placed adjacent to each other and connected with pipes to balance water levels and increase overall storage as needed.

Cisterns are partially or fully buried tanks with a secure cover and a discharge pump; they provide considerably more storage than barrels as well as pressurized distribution. Cisterns can collect water from multiple downspouts or even multiple roofs, and then distribute this water wherever it needs to go through an electric pump. Property owners may use one large tank or multiple tanks in series. Either way, the overflow for the systems should be a drywell or other infiltration mechanism, so that if the cistern is full, excess roof runoff is infiltrated, and not discharged to the stormwater system. Some cisterns are designed to continuously discharge water at a very slow rate into the infiltration mechanism, so that the tank slowly empties after a storm event.

5.6.3 Planning Considerations

Rainwater harvesting and reuse is a direct way to reduce stormwater runoff volume. The harvesting barrels, tanks or cisterns should be sized for the climate and ranges of rainfall events, and relate to the amount of impervious area, reuse applications and consideration of the downstream effects. There are opportunities to collect rainwater in all land use situation with minimal constraints. Rain barrels and cisterns can be retro-fitted to existing buildings or integrated into new building design. Rainwater harvesting systems can range from a simple 55-gallon rain barrel to a complex multimillion-gallon cistern with electronic pumps and controls. It is important to evaluate existing site conditions of the project to ensure compliance with state and local requirements during the planning phase. Identify opportunities and areas where water can be reused for irrigation, released to an infiltration area, or meet indoor use needs. Estimate the rate at which water can be reused.

5.6.3.1 Applications

Rainwater harvesting systems can be as simple as a rain barrel for garden irrigation at the end of a downspout, or as complex as a domestic potable water supply system or a multiple end-use system at a larger scale. The rainwater harvesting systems may be above or below ground, and they may drain by gravity or be pumped. Stored water may be slowly released to a pervious, grass area, used for landscape irrigation, or used indoors for non-potable purposes such as toilet flushing.

Rain barrel design and construction is simple where the rain barrels are available commercially in almost “ready to install” configurations. The only consideration is that there must be enough room near the downspout for the installation of rain barrels. Also, a rain barrel will need a flat, stable surface to sit upon. On the contrary, cisterns are large and require careful planning in terms of site topography, water table, and soil conditions. However, they do not need to be located adjacent to the building since piping and pumps will convey the rainwater.

Underground utilities, high water tables or shallow bedrock may limit the sites available for tank planned for underground installation. Locate utilities, and investigate groundwater and geological restrictions during the planning phase. Buoyant forces can act on an empty underground and cause it to float out of ground. Careful consideration should be given to manufacturer’s installation guides and instructions in order to correctly site and protect tanks against negative impacts of soils with a high water table.

General planning considerations include:

- Existing topography will influence storage locations, site layout, rainwater harvesting design and layout, and types of rainwater harvesting features.

- Capture as much runoff as possible without depriving adjacent or downstream vegetation of water, and without violating downstream water rights (applicable in the western United States). If all runoff cannot be permanently captured, then slow the flow of the remaining volume to increase percolation and on-site infiltration.

- Design for overflow from large rainfall events with erosion controls and overflow conveyance to useful and safe discharge locations.

- Above-ground tanks maintain head pressure to allow some gravity flow. Below-ground tanks take less space above-ground but usually require pumps. The higher on the site above-ground tanks are located, the more gravity-feed pressure will be available. Water can be distributed by gravity flow or by a booster pump via hoses, irrigation systems, channels, or perforated pipes.

- For all tanks, install a tank overflow and route it to a logical location in the landscape where it will be put to beneficial use. The overflow capacity must be equal to or greater than the inflow capacity.

- Screen inflow from roof to tank to keep debris out. Screen tank outflow before it enters the irrigation system to prevent clogging.

- Select roofing surface based on planned uses of tank water (metal or tile roofing provides high quality runoff water).

- Evaluate the potential to use tank water in site cooling towers or for wash water uses; design location and piping accordingly.

- Carefully plan roof slopes to direct water to specific downspouts based on tank capacity.

5.6.3.2 Constraints

The stormwater volume/peak discharge rate benefits of cisterns and rain barrels depend on the amount of storage available at the beginning of each storm. One rain barrel may provide a useful amount of water for garden irrigation, but it will have little effect on overall runoff volumes, especially if the entire tank is not drained in between storms. Greater effectiveness can be achieved by having more storage volume and by designing the system with a continuous discharge to an infiltration mechanism, so that there is always available volume for retention.

When selecting a location for cistern installation, note that roofs constructed with tar, gravel, treated cedar shakes, or old asbestos shingle roofs may produce too much contamination for rainwater harvesting. Similarly, rainwater should not be harvested if it is conveyed via gutters with lead soldering or lead-based paints. Roofs exposed to air borne particles originating from cement kilns, gravel quarries, crop dusting, or concentrated automobile emissions will create runoff that could adversely affect the rainwater quality.

One concern that must be considered is mosquitoes. In some situations, poorly designed rainwater systems can create habitat suitable for mosquito breeding and reproduction. Designers should provide screens on above- and below-ground tanks to prevent mosquitoes and other vector insects from entering the tanks and vicinity if water is intended for landscaping use.

The water collected is for non-potable uses only and its use for potable (drinking) purpose is not cost-effective.

Storage tank and cisterns may have permit requirements.

5.6.4 Design Criteria & Specification

5.6.4.1 Sizing Criteria

For the purposes of meeting the requirements of EISA Section 438, rainwater harvesting systems should be sized with respect to the stormwater runoff volumes required to be managed onsite (refer to Chapter 4), and also considering the possible use of other BMPs. As a general rule of thumb, one square foot rooftop area will yield approximately 0.62 gallons of water per one inch of rainfall can be collected during a rain event. The volume of water that can be collected from a given rain event can be calculated as:

$$V_{collect} = 0.62 * A_{roof} * Rainfall$$

Where:

$V_{collect}$ = Volume of rainwater collected, gallons
A_{roof} = Roof surface area, ft^2
Rainfall = Design rainfall, inch (such as 95^{th} percentile or 2-year, 24 hour)

The basic rule for sizing any rainwater harvesting system is that the volume of water that can be captured and stored (the supply) must equal or exceed the volume of water used (the demand). Storage capacity needs to be sufficient to store water collected during heavy rain events to last through dry periods. Some residences might be constrained by the size of the collection surfaces and/or the volume of storage capacity that can be installed due to space or costs. The following section describe ways to determine the amount of rainfall, the estimated demand, and how much storage capacity is needed to provide enough rainwater to meet the demand. A much more in-depth analysis of how to calculate potential harvested rainwater is available through the American Rainwater Catchment Systems Associated website (http://www.arcsa.org) in their guidelines publication.

Cisterns can vary in size and may consist of several thousand gallons of storage capacity. It is important to gauge what size and storage capacity is right for the site and facility. Low storage capacities will limit rainwater harvesting so that the system may not be able to provide water in a low rainfall period, and increased storage capacities add to construction and operating costs. A factor that will assist in determining the size of the cistern is the volume of water available for capture. An analysis of precipitation records should be performed to determine the amount, frequency, and seasonal variation of rainfall for the area. Including several years of data is recommended in order to account for dry and wet years. The anticipated daily or monthly demand for the harvested rainwater should also be determined. This will first require determining what the end use of the collected water will be, and then predicting the amount needed. Toilet and urinal flushing impart a consistent daily demand on a water system while outdoor irrigation may be somewhat more episodic. The total surface area of the roof is another factor in determining cistern size.

5.6.4.2 Components of Rainwater Harvesting

Cistern tanks should have three openings where pipes will be placed: an inlet, outlet/outflow (or faucet), and overflow. Overflows should be directed away from structures and toward pervious areas to allow for infiltration.

Generally all rainwater tank/cistern designs should include the components below. More information on some of the components is provided in this section.

- A solid secure cover
- A leaf / mosquito screen at cistern entrance
- A coarse inlet filter with clean-out valve
- An overflow pipe
- A manhole, sump, and drain to facilitate cleaning
- An extraction system that does not contaminate the water (e.g. a tap or pump)
- A soak-away to prevent spilled water from forming puddles near the tank

Additional features might include:

- A device to indicate the amount of water in the tank
- A sediment trap, tipping bucket, or other "foul flush" mechanism
- A lock on the tap

Screen

A screen keeps leaves and other debris from entering and clogging the rain barrel/cistern. A screen also prevents mosquitoes from breeding in the storage element. A screen is typically placed at the end of the roof leader, before flow enters the rain barrel or cistern. A leaf strainer may also be placed where the gutter connects to the roof leader.

Storage Element
The storage element is the barrel, cistern, or tank itself (Photo 5-20). Rain barrels are typically made of plastic. Underground cisterns may be poured concrete or prefabricated plastic tanks similar to septic tanks. Proprietary products that store water in a variety of structures are also available. Tanks larger than rain barrels may be used above or below ground.

The selection of tank is based on three main criteria: size, location, and material.

All systems consist of the same basic components: a collection surface (roof top – only roof surfaces are addressed in this practice), a conveyance system, pre-tank treatment, water storage, and distribution.

Photo 5-20. Rainwater Harvesting Storage Element

Slow Release Mechanism or Pump
For the storage element to serve its stormwater control function, it must be partially or completely drained between most wet weather events. Rain barrels are typically drained in one of two ways: manually by means of a spigot similar to ordinary outside water faucets; and, the continual, slow release using a soaker hose to a garden or infiltration area. Larger surface tanks may drain by gravity or may be pumped. Subsurface systems and systems where stormwater is reused for needs other than irrigation (toilet flushing, car wash) are typically pumped.

Overflow Mechanism
The storage capacity of rain barrels, cisterns, and other tanks may be exceeded in large storms. In rain barrels, a flexible hose is provided at an elevation near the top of the barrel. The diameter of the hose is at least equal in size to the roof leader to allow runoff to flow unimpeded during large events. The overflow from cisterns and larger tanks can occur through a weir, pipe, or other mechanism.

A design consideration involving the overflow pipe is to connect it to the inlet of a second cistern tank (Figure 5-12 and Photo 5-21). This would be appropriate for areas with heavy rainfall or large facilities with a high demand for non-potable water.

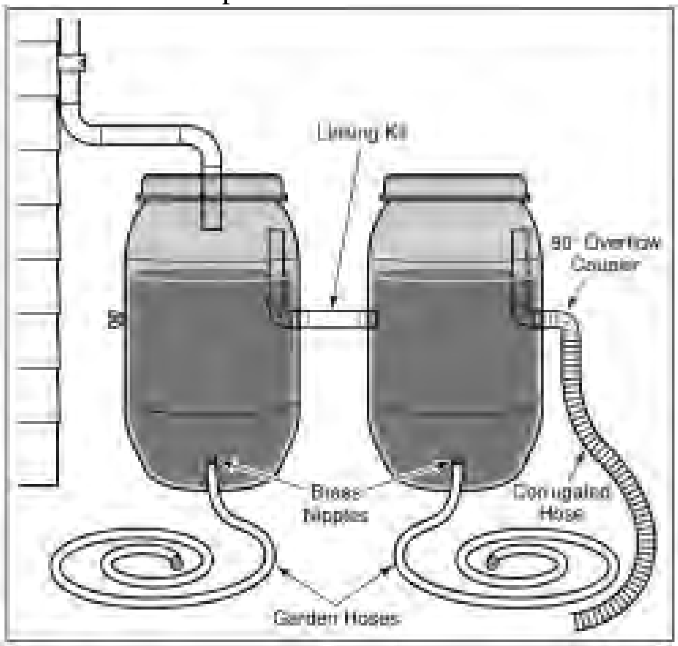

Figure 5-12. Linked Rainwater Harvesting Cisterns

Photo 5-21. Linked Rainwater Harvesting Cisterns

First Flush Diverter

A diverter at the cistern inlet can redirect the "first flush" of runoff which is more likely to have particulates, leaves, and air-deposited contaminants washed off the roof. Direct the first flush to an infiltration trench, bioretention area, or grassed swale sized to infiltrate the required volume.

Make-Up Water

When make-up water is required to be provided to the cistern from the municipal system, steps must be taken to prevent cross-contamination. Pipes connected to the outflow (or any part of the harvesting system) should never connect to potable water piping. The make-up supply to the cistern is the point of greatest risk for cross-contamination of the potable supply. A backflow prevention assembly on the potable water supply line, an air gap, or both must be provided to prevent collected rainwater from entering the potable supply. Dedicated piping should be color-coded and labeled as harvested rainwater, not for consumption. Faucets supplied with non-potable rainwater should also contain signage identifying the water source as non-potable and not for consumption. The designated dual piping system is also part of the cross-contamination prevention measures. Specific requirements can be obtained by local water system authorities.

Vent

All tanks (aboveground and belowground) must have a vent to expel air as rainwater enters the tank and draw air in as rainwater is pumped out of the tank. If the tank overflow does not have a water trap, air can be displaced through the overflow as rainwater enters the tank. In these cases, the vent only needs to be as big in diameter as the water supply line leaving the tank. If air cannot leave the tank through the overflow, the vent diameter should be 1.5 times the diameter of the inlet pipe.

5.6.4.3 Design Considerations

Cistern design should be conducted by a licensed professional engineer experienced in rainwater harvesting design. Licensed plumbers are required by law to install any plumbing systems. Only licensed contractors should install any rainwater harvesting system, but special rainwater harvesting installers are not required.

The following list includes basic guidelines that should be followed when designing and installing rain barrels and cisterns.

- Only rooftop rainwater should be collected.
- The roof materials should be selected carefully.
- Systems must be equipped with overflow pipes that direct water to another tank, stormwater pipes, pervious, grass surface.
- Storage tanks should be accessible for maintenance and cleaning. Underground systems should have a standard size manhole or equivalent opening to allow access for cleaning,

inspection, and maintenance. This access point should be secured/locked to prevent unwanted access.

- Storage tank openings must be covered and screened.
- Gutters and roof drains should be designed in accordance with local code.
- Above ground storage tanks should be UV resistant or otherwise protected from direct sunlight to inhibit algae growth and should be screened to prevent mosquito breeding and reproduction.
- Underground storage tanks must be designed to support the overlying soil burden and any other anticipated loads (e.g., vehicles, pedestrian traffic, etc.).
- All rainwater harvesting systems should be sealed using a water-safe, non-toxic substance.
- For gravity-fed systems, a minimum of 6 inches of dead storage should be provided for sedimentation.
- Tanks should be sized to adequately capture runoff based on local precipitation patterns, roof area, and anticipated demand.
- Water should be drained between rainfall events (for irrigation) to maximize effectiveness.
- Rain barrels are most effective when they are designed to help meet demands for non-potable water, such as irrigation.

Tank size is always dependent on the roof area and the anticipated use of the water. However, size decisions may also be based on availability of space on the site, stormwater or LEED requirements, and the availability of a back-up water supply. Tank size selection will affect possible tank locations and location and size will then help in the selection of tank materials. American Rainwater Catchment System Association has published guidelines for rainwater harvesting systems, and the Association has developed national standards for the rainwater harvesting industry which are available on their web site (www.arcsa.org). Currently Rainwater Catchment Design and Installation Standards are being developed by a joint effort of ARCSA and the American Society of Plumbing Engineers (ASPE). The purpose of these standards is to assist engineers, designers, plumbers, builders, developers, local government, and end users in successfully implementing rainwater catchment systems.

Residential Design

Residential rainwater harvesting systems in residential settings primarily collect rainwater from the rooftops and downspouts. They can be designed for reuse for non-potable needs such as toilet flushing, laundry washing, and landscape irrigation. These non-potable uses account for 78 percent of total household water use, with outdoor use alone accounting for 59 percent of household use (VA Rainwater Harvesting Manual, 2009) Because outdoor use is more than half of residential use, bringing harvested rainwater indoors for potable or non-potable uses is often not cost-effective, particularly in retrofit situations.

Commercial, Industrial, Institutional

Rainwater harvesting systems in commercial, industrial and institutional settings can vary from rooftop collection to collection from large impervious surfaces in underground cisterns. Collected rainwater can serve non-potable needs in these settings. For example, 87 percent of water use in an office building is for restrooms alone (Huston, et al., 2004). Huston (2004) reported that 34 percent of all water use in the United States for landscape irrigation.

Roof Considerations

Roof materials should be non-porous and smooth. Copper roofs and roofs with lead components (for example, flashing or solder) should not be used in any application with a potential for human ingestion (for example, vegetable gardens). Aluminum and rubber membrane are recommended roof materials for rainwater harvesting. Green roofs should be used with caution in rainwater harvesting and rainwater harvested from green roofs with soil bases should only be used for irrigation.

Roof Drains

While rain barrels and cisterns can be integrated with any roof drain system, siphonic roof drains (Photo 5-22) present a number of advantages. When siphonic roof drains are used, the downpipes can be located near the cistern. When conventional roof drains are used instead of siphonic, pipes often have to be brought longer distances (often either around or under the building).

Photo 5-22: Roof Drain

5.6.5 Materials

5.6.5.1 Roofs

Metal roofs, with the exception of copper and lead components, are recommended for rainwater harvesting. Because of a low runoff coefficient and many of the products used to treat wood, wood shingles are not recommended for rainwater harvesting as well. Membrane roofs create an ideal surface for rainwater harvesting. These roofs have a high runoff coefficient and have not been shown to add harmful contaminants to the harvested water.

5.6.5.2 Material Specifications

Cisterns can be constructed of nearly any impervious, water retaining material. However, it is generally advisable to select a material that is rated for potable water use by the National Sanitation Foundation to prevent the introduction of any additional contaminants into the harvested rainwater. Commercially available systems are typically constructed of high density plastics. They can also be made of metal or concrete and can be cast-in-place. Outdoor tanks should be constructed of opaque materials or otherwise shaded or buried to prevent damage from sunlight. They should also contain adequate screening at each opening to prevent insects from entering the tank.

Other materials utilized for the construction of cisterns can include redwood, polyethylene, fiberglass, metal, concrete, plaster (on walls), ferro-cement and impervious rock such as slate and granite.

The basic specifications for rain water harvesting systems are presented in Table 5-13. Designers should consult with experienced irrigation installers on the choice of recommended manufacturers of fabricated tanks and other system components.

Table 5-13. Rain Water Harvesting System Material Specifications

Material	Specification
Gutters and Downspout	• Materials commonly used for gutters and downspouts include polyvinylchloride (PVC), pipe, vinyl, aluminum and galvanized steel. Lead should not be used as gutter and downspout solder, since rainwater can dissolve the lead and contaminate the water supply. • The length of gutters and downspouts is determined by the size and layout of the catchment and the location of the storage tanks. • Be sure to include needed bends and tees
Pre-Treatment	• Provide pretreatment by installing screens to remove debris for all collected rainwater
Storage Tanks	• Materials used to construct storage tanks should be structurally sound • Tanks should be constructed in areas of the site where native soils can support the load associated with design stored water • Tanks should be water tight and sealed using a water-safe, non-toxic substance • Tanks should be opaque to prevent the growth of algae • Underground tanks should be installed below local frost line • Rain barrels commonly plastic, wood or steel • Cisterns commonly fiberglass, concrete, plastic, brick or other materials

(Source: Virginia DCR Stormwater Design Specification No. 6, 2011)

Table 5-14 compares the advantages and disadvantages of different cistern materials.

Table 5-14. Advantages and Disadvantages of Various Cistern Materials

Tank Material	Advantages	Disadvantages
Fiberglass	Commercially available; durable; light weight; integral fitting; no leaks	Must be installed on smooth, solid, level footing; expensive in small sizes
Polyethylene	Commercially available; alterable; affordable; available in wide range of sizes; can install above or below ground; little maintenance; broad application	Can be UV-degradable; must be painted or tinted for above ground installations
Modular Storage	Can modify to topography; can alter foot-print and create various shapes to fit site; relatively inexpensive	Longevity may be less than other materials; higher risk of puncturing of water tight membrane during construction
Plastic	Commercially available; inexpensive	Low storage capacity (20-50 gals.; limited application
Galvanized steel	Commercially available, available in range of sizes; film develops inside to prevent corrosion	Possible external corrosion and rust; must be lined for potable use; can only install above ground; soil pH may limit underground applications
Steel	Commercially available	Small storage capacity; prone to corrosion and rust can lead to leaching of metals; water and soil pH my also limit applications
Ferro Concrete	Durable and immoveable; suitable for above or below ground installations; neutralizes acid rain	Potential to crack and leak
Cast in Place Concrete	Durable; immoveable; suitable for above or below ground installations; neutralizes acid rain	Potential to crack and leak; permanent; will need to provide adequate platform and design for placement in clay soils
Stone or concrete block	Durable and immoveable; keeps water cool in summer months	Difficult to maintain, expensive to build

(Source: Cabell Brand, 2009)

5.6.6 Construction Considerations

5.6.6.1 General

Prefabricated rainwater harvesting cisterns or rain barrels can be purchased and installed professionally. The interior of tanks should be accessible for periodic inspection and maintenance. Position outlet pipes several inches above the bottom of the tank to allow sediment to settle in the bottom. All tanks need an overflow pipe of equal or greater capacity than the fill pipe. Overflow pipes should be able to operate passively (i.e. not dependent on a pump). Water in aboveground tanks can be delivered by gravity flow alone to low-pressure uses nearby. Below-ground tanks save land area, but require substantially more construction. A booster pump can be added to hook tanks into an irrigation system. Tank water should be filtered as it enters irrigation lines to keep debris from plugging the irrigation system. The tank should be installed somewhat angled upward to protect settled sediment and inlet installed above tank bottom to provide for sediment sedimentation. The tank should have an overflow of at least the same diameter as the inlet pipe to prevent backup in gutters and downspouts. This overflow should be directed to a pervious area such as nearby landscape grass area.

5.6.6.2 Construction Sequence

Commercially available aboveground and belowground tanks should always be installed in compliance with manufacturers' recommendations. Depending on the type and purpose of the system, the installation can be involved. Cisterns must be installed by licensed professional contractor. When constructing underground cisterns, local utility companies should be contacted in order to locate any underground pipes or cables that may be in the installation site.

It is advisable to have a single contractor install the rainwater harvesting system, outdoor irrigation system and secondary runoff reduction practices. The contractor should be familiar with rainwater harvesting system sizing, installation, and placement. A licensed plumber is required to install the rainwater harvesting system components to the plumbing system.

A standard construction sequence for proper rainwater harvesting system installation is provided below. This can be modified to reflect different rainwater harvesting system applications or expected site conditions.

1. Check with local jurisdiction if a permit is required to install a rain barrel and/or cistern for non-potable water use.

2. Excavate the hole to the required dimensions (for underground) or prepare platform for above ground system. Ensure smooth stable surface for cistern or rain barrel.

3. Install the pre-fabricated cistern or rain barrel as per manufacturer's specifications.

4. Seal the inside of the cistern.

5. Install the pump (if needed) and piping to end-uses (indoor re-use, outdoor irrigation, or tank dewatering release)

6. Install the lid, screens and hatches.

7. Route all downspouts or roof drains to pre-screening devices and first flush diverters. Stormwater should not be diverted to the rainwater harvesting system until the overflow filter.

5.6.6.3 Final Inspection

Inspections during construction are needed to ensure that the cistern is built in accordance with manufacturer's specifications. The following items should be inspected prior to final sign-off and acceptance of a rainwater harvesting system.

- Rooftop area matches design plans
- Diversion system is properly sized and installed
- Pretreatment system is installed
- Screens and seals are installed on all openings
- Overflow device is directed as shown on design plans
- Tank foundation or platform is constructed as shown on plans
- Catchment area and overflow area are stabilized

5.6.7 Maintenance

Maintenance requirements for rainwater harvesting systems vary according to use. Systems that are used to provide supplemental irrigation water have relatively low maintenance requirements, while systems designed for indoor uses have much higher maintenance requirements (Table 5-15).

Rainwater harvesting systems, including all their components and accessories, should undergo regular inspection at least twice a year. An example maintenance inspection checklist for Rainwater Harvesting can be accessed in Appendix C of Chapter 9 of the *Virginia Stormwater Management Handbook* (2010). Replacement or repair of the unit as a whole, and any of its constituent parts and accessories should subsequently be undertaken if needed. Tanks must be "winterized" or drained prior to winter to prevent damage if freezing conditions prevail.

Table 5-15: Suggested Maintenance Tasks for Rainwater Harvesting Systems

Activity	Frequency
Clean gutters and downspouts of leaves and other debris and check for leaks.	Twice a year
Inspect overflow that it is draining in non-erosive manner	Twice a year
Inspect and clean pre-screening devices and first flush diverters.	Four times per year
Inspect and clean storage tank lids, paying special attention to vents and screens on inflow and outflow spigots. Check mosquito screens and patch holes or gaps immediately.	Once per year
Inspect condition of overflow pipes, overflow filter path and/or secondary runoff reduction practices.	Once per year
Inspect tank for sediment buildup and seal leaks.	Every third year
Clear overhanging vegetation and trees over roof surface.	Every third year
Inspect structural integrity of tank, pump, pipe, over flow preventer and electrical system. Replace damaged or defective system components.	Every third year
If mosquitoes become a problem, mosquito dunks (floating donut-shaped briquettes containing the biological insecticide) can be used.	As needed

(Source: Virginia DCR Stormwater Design Specification No. 6, 2011)

5.6.8 Benefits

When properly installed, cisterns reduce the peak discharge rate and runoff volume through detention. However, when compared to other stormwater BMP options, the peak discharge is minimally impacted by the use of rain barrels or cisterns. However, if many rainwater barrels or large capacity tanks are installed, then benefits may be seen in terms of reduced peak flows and volumes entering sewers and streams.

- Reduces stormwater runoff volume and flow rates
- Reduces erosion in urban environments
- Reduce on-site flooding
- Water conservation and supplemental water supply
- Increase water availability for non-potable uses
- Meet LEED Credit

5.7 GREEN ROOFS

5.7.1 Description

Green roofs (also known as vegetative roofs, living roofs, bio-roofs, or eco-roofs) are thin layers of living vegetation installed on top of conventional roofs (Photo 5-23). Green roofs typically consist of waterproofing and drainage materials and an engineered growing media that is designed to support plant growth.

The purpose of green roofs is to maximize nutrient and pollutant removal and runoff volume reduction. A portion of the captured stormwater evaporates or is taken up by plants and transpired, which helps reduce runoff volumes, peak runoff rates, and pollutant loads on development sites.

Photo 5-23. Green Roof – Washington, DC
(Source: Healthy Roofs for Healthy Cities (Photo by US DOT))

Green roofs filter particulate matter from the air, retain and cleanse stormwater and provide new opportunities for biodiversity preservation and habitat creation. They generate aesthetic benefits and help to reduce the urban heat island effect (the over-heating of cities in summer from dark roof surfaces, which contributes to air pollution and increased energy consumption).

5.7.2 Types of Green Roofs

There are two types of green roof systems: extensive and intensive green roofs. The variation in each type is the depth of growing media, which relates to the volume of stormwater that can be absorbed by the vegetation and soils.

5.7.2.1 *Extensive Green Roof*

Extensive roofs typically have much shallower growing media (3 to 8 inches) that is planted with carefully selected drought tolerant vegetation (Photo 5-24 and Photo 5-25). With shallower growing media, this type of green roof is lightweight and relatively easy to construct and maintain. Extensive roofs can be easily applied to Army construction.

The most common vegetated roof cover in temperate climates at Army facilities may in the future be a single un-irrigated 4 to 6 inch layer of lightweight soil growth media planted with succulent plants and herbs. In Germany, this simple design has demonstrated the highest benefit-to-cost ratio (Virginia Department of Conservation and Recreation, Stormwater Design Specification No. 5, 2011).

Photo 5-24. Green Roof – Washington, DC
(Source: Healthy Roofs for Healthy Cities (Photo by US DOT))

Photo 5-25. Hamilton Building Green Roof
(Source: Portland Stormwater Management Manual)

5.7.2.2 Intensive Green Roof

Intensive green roofs have a deeper growing media layer that ranges from 6 inches to 4 feet thick. These deep layer roofs are planted with a wider variety of aesthetically pleasing plants, including shrubs and shallow-rooted trees. The thick growing media and dense vegetation makes these green roofs heavy, which can put strain on the roof and building structure. Design must consider building structure, possibility of roof leaks, weight of the green roof, and high maintenance requirements. Intensive green roofs may not always be applicable on Army facilities nor cost effective for the volume of stormwater they may manage, thus, only the details for extensive green roofs are provided below. The extensive green roofs are much lighter and less expensive than intensive green roofs and are recommended on most development and redevelopment sites.

5.7.3 Planning Considerations

5.7.3.1 Applications

Green roofs are ideal for use on commercial, industrial, institutional, municipal and multi-family residential buildings. They are particularly well suited for use on ultra-urban development and redevelopment sites to reduce/prevent “urban heat island” effects.

5.7.3.2 Constraints

Green Roofs have several limitations, including:

- Structural Capacity – Consider structural capacity to support live and dead weight, including additional (15 to 30 psf) weight of stormwater for an extensive green roof.

- Roof Access – adequate access to the roof must be provided to deliver construction materials and perform routine repair and maintenance.

- Roof Type – can be applied to most conventional surfaces, although concrete roof decks are preferred.

- Setbacks – Green roofs should not be located near rooftop electrical and HVAC systems.

- Local Building Codes – Building codes often differ in each municipality and local planning and zoning authorities should be consulted to obtain proper permits.

- Leaky Roofs – Research on green roofs has demonstrated that a well designed and installed green roof would have fewer problems with roof leaks than that of with a traditional roof. A waterproof liner is recommended to prevent leaks.

5.7.4 Design Criteria & Specifications

In the United States, green roof designs are generally regulated using existing standards for ballasted roofs. In general, the municipalities follow "The International Code Council (ICC), formerly the BOCA, construction code that requires that "wet weight" of the green roof be treated as an additional dead load.

Specific design considerations may include energy efficiency, green building or LEED points, architectural considerations, visual amenities and landscaping features for human enjoyment.

5.7.4.1 General

All well-designed green roof focus on three main design criteria:

Drainage
Provision for drainage from the rooftop must be provided for stormwater not absorbed by the green roof. The drainage layer may include filter fabric, gravel, or it can be the growing (soil) media itself. An approved discharge location must be identified for every green roof and drain(s) provided. Design must both maintain optimum growing conditions in the plant soil growth media and manage heavy rainfall without sustaining damage due to erosion or ponding of water.

Plant Nourishment and Support
The engineered or manufactured soil growth media must meet requirements for void (porosity or open) ratio, moisture retention, and plant material containing adequate nutrients for sustainable plant establishment and continued growth. Plant species are selected so that the roof does not need supplemental irrigation or fertilization after vegetation is initially established.

Protection of Underlying Water Proofing Systems
The green roof design must provide protection measures for the underlying waterproofing system from human activities (including impacts of maintenance) and biological, weather, climatic and

other environmental impacts to prevent leaks from the roof into the building that could compromise the building.

5.7.4.2 Sizing Requirements

Green roofs should be sized to capture a portion of the stormwater runoff volume from the project site as required to be treated for compliance with EISA Section 438, called the treatment volume. The Treatment Volume (Tv) is estimated as below:

$$Tv = (RA * D * P)$$

Where:

- Tv = Required storage volume capacity, ft^3
- RA = Vegetated roof surface area, ft^2
- D = Soil media depth, ft
- P = Soil media porosity (usually 0.30, but may be higher, consult manufacturer)

Details are provided in Chapter 4, Hydrologic Modeling and Simulation, regarding estimating of water quantity runoff volumes to comply with EISA Section 438. The methods described in this section may be used to determine water quality requirements for use in designing of green roofs.

5.7.4.3 Structural Capacity

Green roofs can be limited by additional weight of the fully saturated soil and plants, in terms of physical/structural capacity to bear additional (15 to 30 lbs/sft) structural loads, a condition that may preclude retrofit applications.

5.7.5 Components of Green Roofs

As shown in the Figure 5-13, a green roof is composed of several different systems or layers. The generic cut-away shows common types of green roofs that utilize a lower granular drainage layer in combination with an upper growth medium or substrate.

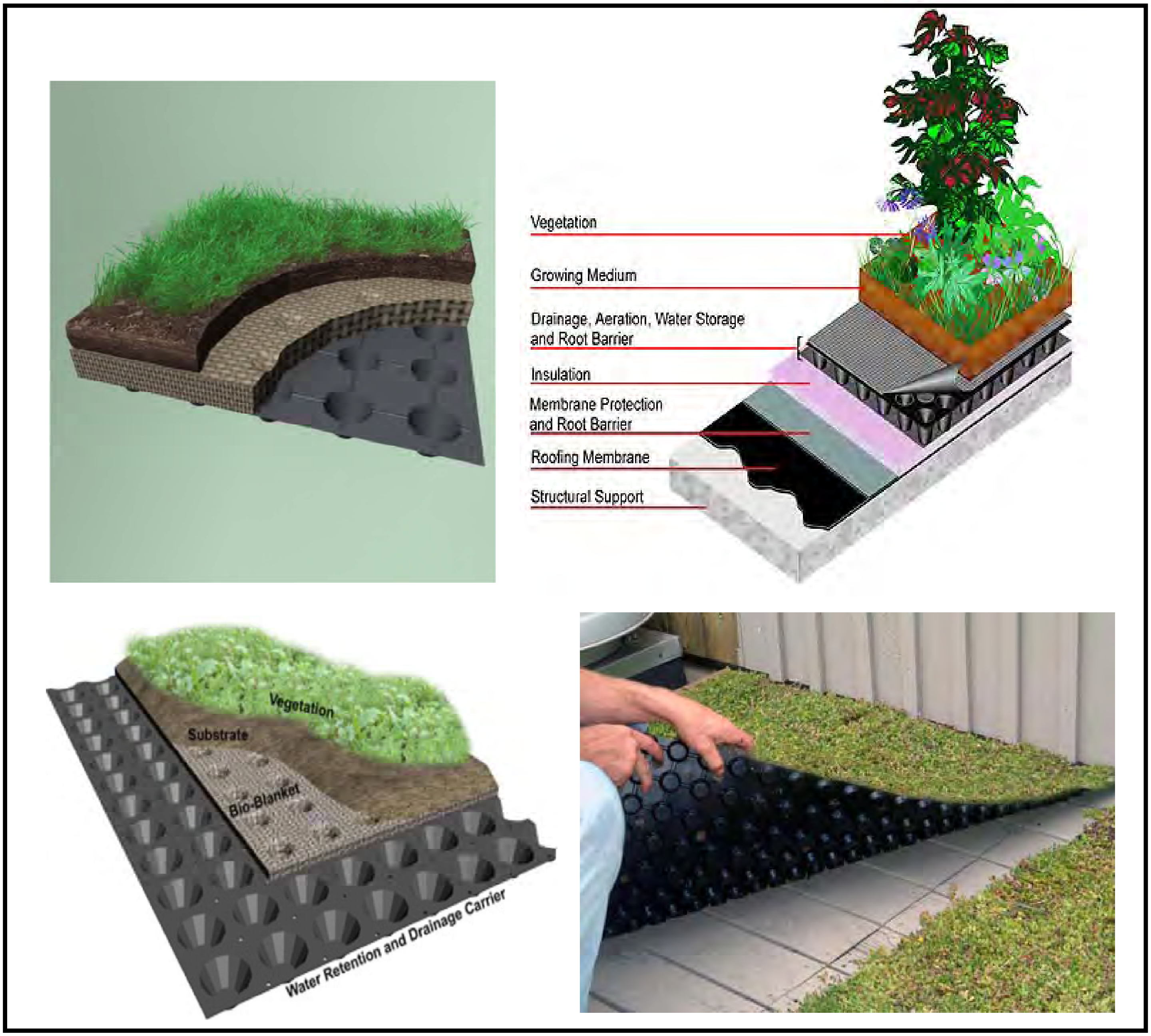

Figure 5-13. Various Layers of a Green Roof

Typical components of a green roof, as illustrated in Figure 5-14, include:

- Plant – Perennials and shrubs
- Erosion control blanket
- Plant Growth Media – 3” to 6” for Extensive and 6” to 4 feet for Intensive roofs
- Filter Fabric
- Drain: 4” to 6”
- Filter Fabric
- Aluminum Curbing
- Gravel (Optional)
- Vegetation-free strip gravel

- Thermal Insulation
- Leak Detection System
- Protection Layer
- Root Barrier
- Water Proof Membrane
- Root Deck with vapor Barrier and Root Structure
- Perforated aluminum Curb w/Drainage Fabric
- Roof Drain w/parapet well
- Emergency Overflow

Sizing

Green roofs replace impervious area at a 1:1 ratio. They are not allowed to receive runoff from other impervious areas.

Slope

Maximum roof slope shall be 25 percent, unless the designer provides documentation of runoff control on steeper slopes.

Waterproofing and Roofing Membrane

A good-quality waterproofing material, such as modified asphalt, synthetic rubber, or reinforced thermal plastics, shall be used on the roof surface. Some waterproofing materials also act as a root barrier. A roofing membrane covers the natural roof to protect the structural supports of the roof. The membrane protection and root barrier protects the roof membrane and prevents roots from penetrating the roof. Insulation helps insulate the building, keeping it cooler during the summer and warmer in the winter. The drainage section to insure the proper range of water content in the growing medium, aeration section is essential to promote optimal vegetation growth; the water storage section will provide more successful growth of vegetation.

Protection Boards or Materials (optional)

These materials protect the waterproof membrane from damage during construction and over the life of the system and are usually made of soft fibrous materials. They often are not needed, depending on the membrane selected.

Ballast (optional)

Gravel ballast is sometimes placed along the perimeter of the roof and at air vents or other vertical elements. The need for ballast depends on operational and structural design issues. It is sometimes used to provide maintenance access, especially to vertical elements that require regular, periodic maintenance. In many cases, very little, if any, ballast is needed.

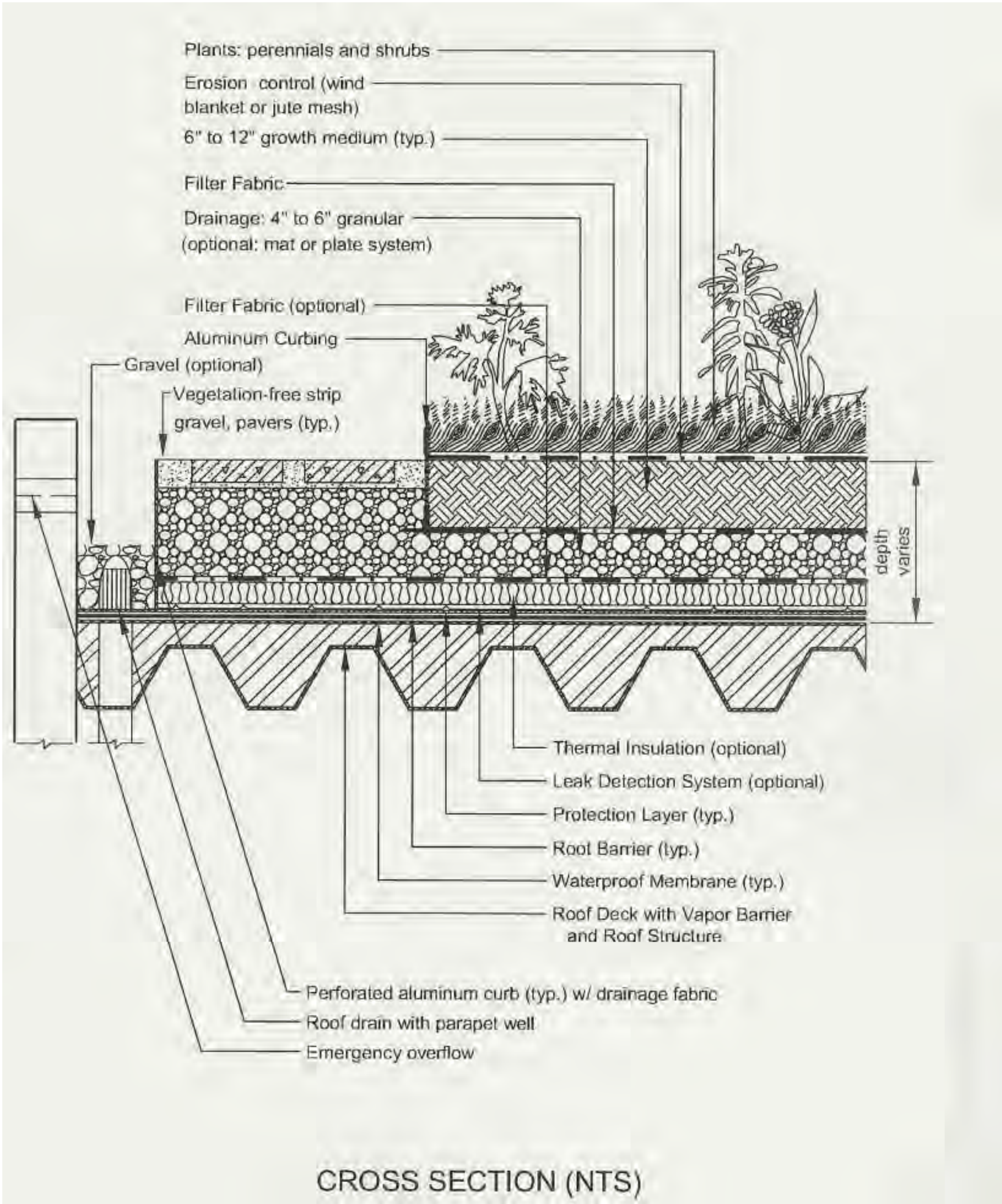

Figure 5-14. Cross Section of an Intensive Green Roof
(Source: Northern Virginia Regional Commission)

Header/Separation board (optional)
In some situations, a header or separation board may be placed between gravel ballast and adjacent elements (such as soil or drains), but pressure-treated lumber is prohibited. In many cases, a header is not needed, and designers are encouraged to use one only when necessary.

Root Barrier
A root barrier is sometimes required in addition to waterproofing material, depending on the type used and the types of vegetation proposed. Root barriers impregnated with pesticides, metals, or

other chemicals that may leach into stormwater are not permitted, unless the applicant can provide documentation that leaching would not occur. If a root barrier is used, it must extend under any gravel ballast and the growing medium and up the side of any vertical elements.

5.7.6 Materials

Table 5-16 provides guidelines for typical material specifications used for extensive green roofs. Always follow manufacturer's specifications.

Table 5-16. Extensive Green Roof Material Specification

Material	Specification	Notes
Roof	-Structural Capacity should conform to ASTM E-2397-05, Practice for Determination of Live Loads and Dead Loads Associated with Green Roof Systems. -ASTM E2398-05 for Water Capture and Media Retention of Geo-composite Drain Layers for Green Roof Systems -ASTM E 2399-05 for Maximum Media Density for Dead Load Analysis.	Architect, structural engineer, and civil engineer must coordinate design criteria
Vegetation	-Drought tolerant plants must achieve 90% coverage within 2 years. -Minimum 50% green roof must be composed of evergreen species -Maximum 10% green roof area may be non-vegetated (gravel ballast, pavers for maintenance access, etc.)	-Vegetation must be recommended by professional landscape architect, horticulturist, or the local USDA Natural Resources office -Succulent, herbaceous plants and perennial grasses that are shallow-rooted, self-sustaining, and tolerant of direct sunlight, drought, wind, and frost. See ASTM E2400-06, *Guide for Selection, Installation and Maintenance of Plants for Green (Vegetated) Roof Systems*.
Waterproof Membrane	In accordance with local county ordinances and laws	
Root Barrier	In accordance with local county ordinances and laws	
Drainage Layer	1 to 2 inch layer of clean washed granular material, such as ASTM D 448 size No. 8 stone.	Roof drains and emergency overflow should be designed in accordance with local county ordinances and laws.

Material	Specification	Notes
Filter Fabric	Needled, non-woven, polypropylene geotextile. -Density (ASTM D3776) > 16 oz./sq. yd., or approved equivalent. -Puncture resistance (ASTM D4833) > 220 lbs., or approved equivalent.	
Growth Media	-80% lightweight inorganic materials and 20% organic matter (well-aged compost). -Determine acceptable saturated water permeability using ASTM E2396-05.	Inorganic materials include expanded slates, shales or clays, pumic, scoria or similar.

5.7.7 Construction Considerations

5.7.7.1 Construction Sequence

Given the wide diversity of green roof designs, there is no typical step-by-step construction sequence for green roof installation that would cover all situations. The green roof manufacturer's instructions should always be followed. The following is a general construction sequence:

1. Construct the roof deck with the appropriate slope and material.

2. Install the waterproofing method, according to manufacturer's specifications.

3. Conduct a flood test to ensure the system is water tight by placing at least 2 inches of water over the membrane for 48 hours to confirm the integrity of the waterproofing system.

4. Add additional system components (*e.g.*, insulation, root barrier, drainage layer, interior drainage system, and filter fabric, etc.), taking care not to damage the waterproofing. Drain collars and protective flashing should be installed to ensure free flow of excess stormwater.

5. The growing media should be mixed prior to delivery to the site. Media should be spread evenly over the filter fabric surface. The growing media should be covered until planting to prevent weeds from growing. Sheets of exterior grade plywood can also be laid over the growing media to accommodate foot or wheelbarrow traffic. Foot traffic and equipment traffic should be limited over the growing media to reduce compaction.

6. The growing media should be moistened prior to planting, and then planted with the ground cover and other plant materials, per the planting plan, or in accordance with

ASTM E2400. Plants should be watered immediately after installation and routinely so during initial establishment

7. Generally it takes 12 to 18 months for the vegetation to establish fully on the roof. An initial fertilization using slow release fertilizer (e.g., 14-14-14) with adequate minerals is often needed to support and promote plant growth and dense establishment. Temporary watering may also be needed during the first summer, if drought conditions persist. Hand weeding is also critical in the first two years.

8. All construction contracts should contain a "Care and Replacement Warranty" from the contractor that specifies a 75 percent minimum survival after the first growing season of species planted and a minimum effective vegetative ground cover of 75 percent for flat roofs and 90 percent for pitched roofs.

5.7.7.2 Inspections

Inspections during construction are needed to ensure that the vegetated roof is built in accordance with the designer of record specifications. Also, an experienced installer should be retained to construct the vegetated roof system. The vegetated roof should be constructed in sections for easier inspection and maintenance access to the membrane and roof drains. Careful construction supervision is needed during several steps of vegetated roof installation, as follows:

- During placement of the waterproofing layer, to ensure that it is properly installed and watertight
- During placement of the drainage layer and drainage system
- During placement of the growing media, to confirm that it meets the specifications and is applied to the correct depth
- Upon installation of plants, to ensure they conform to the planting plan
- Before issuing use and occupancy approvals; and
- At the end of the first or second growing season, to ensure desired surface cover specified in the Care and Replacement Warranty has been achieved.

5.7.8 Maintenance

Vegetated roofs are designed to have minimal maintenance requirements. Plant species are selected so that the roof does not need supplemental irrigation or fertilization after vegetation is initially established. Table 5-17 lists suggested maintenance activities for extensive green roofs.

A vegetated roof should be inspected twice a year during the growing season to assess vegetative cover, and to look for leaks, drainage problems and any rooftop structural concerns. In addition, the vegetated roof should be hand-weeded to remove invasive or volunteer plants, and soil media should be added to repair bare areas (refer to ASTM E2400). Many practitioners also recommend an annual application of slow release fertilizer in the first five years after the vegetated roof is installed.

If a roof leak is suspected, it is advisable to perform an electric leak survey (*i.e.,* Electrical Field Vector Mapping) to pinpoint the exact location, make localized repairs, and then reestablish system components and ground cover.

The use of herbicides, insecticides, and fungicides should be avoided, since their presence could hasten degradation of the waterproof membrane. Only non-chemical fertilizers may be used. Also, power-washing and other exterior maintenance operations should be avoided so that cleaning agents and other chemicals do not harm the vegetated roof plant communities.

Green roof maintenance may include watering, fertilizing and weeding, and is typically greatest in the first two years as plants become established. Maintenance largely depends on the type of green roof system installed and the type of vegetation planted. The use of native vegetation cannot be overemphasized in planting vegetation on roofs and is highly recommended in order to reduce plant maintenance in both extensive and intensive systems.

A green roof should be monitored after completion for plant establishment, leaks and other functional or structural concerns. Vegetation should be monitored for establishment and viability, particularly in the first two years.

Table 5-17. Suggested Maintenance Activities for Extensive Green Roofs

	Task	Frequency	Maintenance Notes
1	Inspect Vegetation	Twice during growing season	
2	Inspect for Leaks, Drainage Problems, Structural Concerns and Repair	Inspect Biannually Repair As Needed	
3	Remove Weeds and Replant Bare Areas	Regularly	
4	Watering for plant establishment	Regularly	In first two years

5.7.9 Benefits

Benefits of green roofs include:

- Controlling stormwater runoff peak flow and volume. Vegetative roofs are particularly effective at controlling runoff on large roofs typical of commercial and institutional buildings.

- Improving stormwater quality by mechanisms of bio-filtration and plant uptake.

- Mitigating unban heat-island effects and energy conservation (see Figure below).

- Green roofs may reduce cooling energy demands in summer and heating bills in winter because of up-roof insulation; they be less important in multi-story buildings.

- Prolonging the service life of roofing materials. Studies have shown that a roof assembly that is covered with a green roof is expected to outlast a comparable roof without a green roof by a factor of at least two, and often three.

- In urban areas, up to 30 percent of nitrogen and phosphorous released into receiving streams originates from dust that accumulated on rooftops. Acting on natural bio-filtration devices, green roofs reduce this nutrient contamination carried by roof-top runoff.

Figure 5-15 exhibits the stormwater runoff reduction benefits of a green roof.

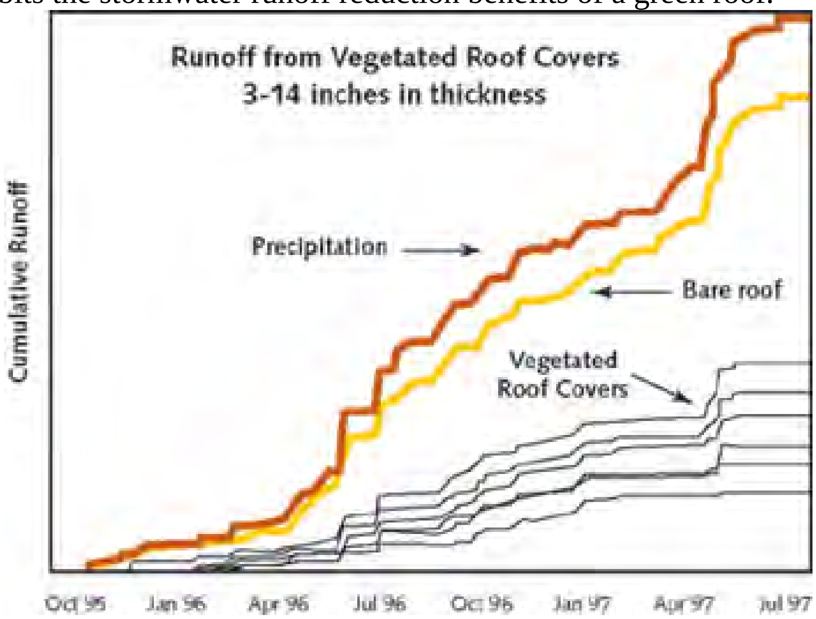

Figure 5-15. Runoff Reduction Benefits from Green Roods

6 REFERENCES

American Planning Association. 2006. Planning and Urban Design Standards. John Wiley & Sons, Inc. Hoboken, New Jersey.

Bicknell, Brian R., Imhoff, John C., Kittle Jr., John L., Jobes, Thomas H., Donigian Jr., Anthony S. 2005. "HSPF Version 12.2 User's Manual", Aqua Verra Consultants, Mountain View, CA. 94043.

Booth, Derek Direct Testimony. 2008. Pollution Control Hearings Board for the State of Washington, Puget Soundkeeper Alliance and People for Puget Sound; Pierce County Public Works and Utilities Department; City of Tacoma; The Port of Seattle; Snohomish County; Clark County; and Pacificorp and Puget Sound Energy, Appellants, vs. Department of Ecology, Respondent, and King County; City of Seattle; Port of Tacoma, and Washington State Department of Transportation, Intervenors, August 2008.

Galli, John. 1991. Thermal Impacts Associated with Urbanization and Stormwater Best Management Practices in Maryland, Anacostia Restoration Team for the Maryland Department of the Environment, Washington, DC.

Bureau of Environmental Services, City of Portland OR. 1999. Stormwater Management Manual. Chapter 2: Stormwater Management Facility Design. Retrieved from http://www.portlandonline.com/bes/index.cfm?a=55791&c=35122.

CAPT Robin Brake. 2008. Photo of Green Roof at the Pentagon Remote Delivery Facility. Office Deputy Assistant Secretary of the Navy, Environment Director Marine Science, 10 June 2008 Retrieved from http://www.fedcenter.gov/_kd/go.cfm?destination=ShowItem&Item_ID=10244.

Chino, Mike. 2008. The New Green California Academy of Sciences Unveiled! Retrieved from http://inhabitat.com/california-academy-of-sciences-unveiled/.

City of Saugatuck, MI. Photo of subsurface infiltration bed. Permission obtained via personal communication October 2011. Retrieved fromhttp://library.semcog.org/InmagicGenie/DocumentFolder/LIDManualWeb.pdf.

Claytor, R., and T. Schueler. 1996. Design of Stormwater Filtering Systems. The Center for Watershed Protection. Silverspring, Maryland. P 6–1, 6–14.

Coffman, Larry S. 2008. Photos of Bioretention. Permission obtained through personal communication. September 2011. Retrieved from http://www.water.rutgers.edu/Rain_Gardens/RainGardenSymp/1_coffman.pdf and http://www.texaslid.org/pdfs/AP_Coffman%20Bioretention.pdf.

Dunne, T. and L. B. Leopold. 1978. Water in Environmental Planning. W. H. Freeman: New York, pp.1-818.

Federal Interagency Stream Restoration Working Group (FISRWG). 1998. Stream Corridor Restoration: Principles, Processes, and Practices. GPOJ Item No. 0120-A; SuDocs No. A 57.6/2 EN3/PT.653. ISVN-0-934213-59-3.

Federal Legislation. (2007). Energy Independence and Security Act (EISA). Retrieved from http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_bills&docid= f%3Ah6enr.txt.pdf.

Garner, Birtice A. IV, The University of Georgia College of Environment and Design. Photo of Watershed Inventory of Natural Features. Permission obtained via personal communication September 2011. Retrieved from http://birtice.com/site-inventory-and-analysis.html.

Hawkins Partners, Inc. 2009. EPA to Test Porous Pavement and Raingarden Benefits. Permission obtained from Will Mark on September 2011. Retrieved from http://hpigreen.com/2009/11/.

Horton, R.E. 1933. The Role of Infiltration in the Hydrologic Cycle. Trans. AGU, 14th Ann. Mtg., p. 446–460.

InSite Design Studio. Photo of a Schematic of a Typical Level Spreader. Permission obtained via personal communication October 2011. Retrieved from http://library.semcog.org/ InmagicGenie/DocumentFolder/LIDManualWeb.pdf.

International Code Council, Inc. (ICC). 2009. ICC International Energy Conservation Code® (IECC). ICC, Country Club Hills, IL.

Interlocking Concrete Pavement Institute. 2010. Permeable Pavers: What is Permeable Interlocking Pavement? Retrieved from http://www.icpi.org/node/553

Kohler, M.A., T.J. Nordenson, and D.R. Baker. 1959. Evaporation maps for the United States. U.S. Weather Bureau Technical Paper 37.

Kosmowski, Christine. Environmental Programs Coordinator, City of Battle Creek, MI. Photo of a Level Spreader Used in Storm Drain Project. Permission obtained via personal communication September 2011. Retrieved from Retrieved from http://library.semcog.org/InmagicGenie/ DocumentFolder/LIDManualWeb.pdf.

Lemoine, Randel. 2011. "A Hydrology Model for Mimicking Pre and Post Development Runoff Volumes", Proceedings of the 2011 Georgia Water Resources Conference, Athens GA.

Low Impact Development Center, Inc. 2011. "Volume Based Stormwater Management Guidance", Beltsville, MD.

Low Impact Design Studio. 2010. Low Impact Development Technologies. Retrieved from http://www.wbdg.org/resources/lidtech.php#lidt.

Marywood Campus, Dominican Sisters, Grand Rapids, MI. Photo of native Prairie Vegetation in Natural Flow Pathway Permission obtained through communication with Karen Bidwell. September, 2011.

Low Impact Development Center, Inc. 2011. "Volume Based Stormwater Management Guidance", Beltsville, MD (under construction).

National Research Council. 2008. Urban Stormwater Management in the United States. The National Academies Press, Washington, DC. 20250.

New York State Department of Environmental Conservation (DEC). Latham Business Park Wet Swale. Retrieved from http://www.dec.ny.gov/lands/59310.html.

Parker, Tony. 2007. Classic Landscapes. Revisit a Project. Retrieved from http://www.classiclandscapesnc.com/project-revisit.asp

Pennsylvania Department of Environmental Protection (PA DEP), Bureau of Watershed Management. 2006. Pennsylvania Stormwater Best Management Practices Manual. Retrieved from http://www.elibrary.dep.state.pa.us/dsweb/View/Collection-8305.

Philadelphia Water Department. Photo of a Pervious Pavement Basketball Court. Permission and photograph obtained through personal communication with Stephanie Chiorean September 2011.

Pokagon Band of Potawatomi Indians. Photo of Permeable Concrete Pave Street in Dowagiac, MI. Permission obtained from Wade Hawes via personal communication October 2011. Retrieved from http://library.semcog.org/InmagicGenie/DocumentFolder/LIDManualWeb.pdf

Ponce, Victor Miguel. 1989. "Engineering Hydrology – Principles and Practices", Prentice Hall, Englewood Cliffs, New Jersey.

Prince George's County, MD. 1999. Low-Impact Development Design Strategies: An Integrated Design Approach. Retrieved from http://www.epa.gov/owow/NPS/lidnatl.pdf.

Prince George's County, MD. 1993. *Design Manual for Use of Bioretention in Stormwater Management.* Prince George's County, MD Department of Environmental Protection. Watershed Protection Branch, Landover, MD.

Prince George's County, MD Department of Environmental Resources. Photo of Downspout Disconnection into aVegetated Area. Permission obtained through personal communication September 2011. Retrieved from http://www.werf.org/livablecommunities/toolbox/downspout.htm.

Pudget Sound Action Team and Washington State University Pierce County Extention. 2005. Low Impact Development Technical Guidance Manual for Pudget Sound. Retrieved from www.psp.wa.gov/downloads/LID/LID_manual2005.pdf.

Rossman, Lewis A. 2010. "Storm Water Management Model User's Manual Version 5.0", EPA/600/R-05/040, U.S. Environmental Protection Agency (EPA), Cincinnati OH. 45268.

Schueler, T. and M. Helfrich. 1988. "Design of Wet Extended Detention Pond Systems," *Design of Urban Runoff Controls*, L. Roesner and B. Urbonas eds., American Society of Civil Engineers, New York, NY.

SEMCOG, the Southeast Michigan Council of Governments.2008. Low Impact Development Manual for Michigan. Permission for photos obtained through personal communication with Glenda Marks, September 2011. Retrieved from http://library.semcog.org/InmagicGenie/DocumentFolder/LIDManualWeb.pdf.

Shaver, E., R. Horner, J. Skupien, C. May, and G. Ridley. 2007. Fundamentals of Urban Runoff Management: Technical and Institutional Issues – 2nd Edition, North American Lake Management Society, Madison, WI.

Skabelund, Lee. 2006. Kansas State University. Photo of a Level Spreader Dispersing into a Wetland Area. Permission obtained through personal communication September 2011. Retrieved from http://www.asla.org/ppn/article.aspx?id=1374

Southwestern Illinois Resource Conservation and Development, Inc. 2006. Conservation Subdivision Design Handbook. Retrieved from http://www.swircd.org/pdf/conservation%20subdivision%20design%20handbook.pdf.

Thibaudeau, Steve. 2010. U.S. Corps of Engineers.The Importance of LID at USACE. Retrieved from http://posts.same.org/kentuckiana/Presentation%201%20--%20USACE.pdf

US Army. 2010. Assistant Secretary of Army (Installations, Energy & Environment) Policy Memo, Sustainable Design and Development Policy Update (Environmental and Energy Policy), 27 Oct 2010 (para5f). Retrieved from https://eko.usace.army.mil/_temp/6744A846-188B-313F-1B4C818188BC6FBA/Sustainable_Design_and_Dev_Policy_Update.pdf

US Army. 1988. Army Regulation 200-2. Environmental Quality: Environmental Effects of Army Actions. Retrieved from http://www.sustainability.army.mil/resources/libdocs_regulatory/army_regulations/AR%20200_2%2023%20Dec%201988.pdf.

US Army Corps of Engineers (USCOE). 2008. Public Works Technical Bulletin 200-1-62. Low Impact Development for Sustainable Installations: Stormwater Design and Planning Guidance for Development Within Army Training Areas. Retrieved from http://www.wbdg.org/ccb/ARMYCOE/PWTB/pwtb_200_1_62.pdf.

US Department of Agriculture (USDA), National Resources Conservation Service. No Date. Success Stories: Buffer Bonus from Bear Creek. Retrieved from http://www.ia.nrcs.usda.gov/news/successstories/successstories.html.

US Department of Agriculture (USDA). 2009. "Small Watershed Hydrology – WinTR-55 User's Guide", Natural Resources Conservation Service (NRCS), Conservation Engineering Division, Washington DC.

US Department of Defense (DoD). 2010. Unified Facilities Criteria (UFC): Low Impact Development. UFC 3-210-10. Retrieved from http://www.wbdg.org/ccb/DOD/UFC/ufc_3_210_10.pdf.

DoD. 2012. Unified Facilities Criteria (UFC): Installation Master Planning. UFC 2-100-01. Retrieved from http://www.wbdg.org/ccb/DOD/UFC/ufc_2_100_01.pdf.

DoD. 2004. Unified Facilities Criteria (UFC): Area Planning, Site Planning, and Design. UFC 3-210-01A. http://www.wbdg.org/ccb/DOD/UFC/ufc_3_210_01a.pdf

US Environmental Protection Agency (USEPA). 2011. Stormwater Management Techniques in Use at EPA Headquarters. Retrieved from http://www.epa.gov/oaintrnt/stormwater/hq_stormwater_techniques.htm.

US EPA 2010. Stormwater Management at EPA Headquarters. Retrieved from http://www.epa.gov/owow/NPS/lid/stormwater_hq/.

US EPA. 2009. Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act. Retrieved from http://www.epa.gov/oaintrnt/documents/epa_swm_guidance.pdf.

US EPA 2007a. National Pollutant Discharge Elimination System (NPDES), Stormwater Program. Retrieved from http://cfpub.epa.gov/npdes/home.cfm?program_id=6.

US EPA 2006. Reducing Stormwater Costs through LID Strategies and Practices. Retrieved from http://www.epa.gov/owow/NPS/lid/costs07/

US EPA. 2003a. Washington, D.C. "Protecting Water Quality from Urban Runoff." Document No. EPA 841-F-03-003. Retrieved from http://www.epa.gov/npdes/pubs/nps_urban-facts_final.pdf.

US EPA, 2003b. National Pollutant Discharge Elimination System: State Program Status. Retrieved from http://cfpub.epa.gov/npdes/statestats.cfm.

US Green Building Council (USGBC), 2011. About USGBC. Retrieved from www.usgbc.org/about.

US Geological Survey (USGS) 2011. USGS Real-Time Water Data for the Nation. Created from http://waterdata.usgs.gov/nwis/rt.

USGS. 1986. Average Runoff, 1951-1980. Retrieved from http://www.unl.edu/nac/atlas/Map_Html/Clean_Water/National/Average_Annual_Runoff/Average_Annual_Runoff.htm

U.S. Office of the President. 2009. Federal Leadership in Environmental, Energy, and Economic Performance. Executive Order 13514. Federal Register, vol 74, No. 194, http://edocket.access.gpo.gov/2009/pdf/E9-24518.pdf.

U.S. Office of the President. 2007. Strengthening Federal Environmental, Energy, and Transportation Management. Executive Order 13423. Federal Register, vol 72, No. 17, http://edocket.access.gpo.gov/2007/pdf/07-374.pdf.

Wayne County, MI Department of Public Works, Water Quality Management Division. Photos of a Two Chambered Sand Filter and a Vegetated Filter Strip. Permission obtained from Kelly Cave, September 2011. Retrieved from the SEMCOG LID Manual http://www.semcog.org/uploadedfiles/Programs_and_Projects/Water/Stormwater/LID/lid_manual_intro.pdf.

Western Michigan University. Photo of Protection of Existing Native Woodlands and Wetlands. Permission obtained via personal contact November 2011 from David Dakin. Retrieved from http://www.semcog.org/Data/lid.report.cfm?lid=141.

7 GLOSSARY

AASHTO – American Association of State and Highway Transportation Officials.

Adsorption – The process by which a solute is attracted to a solid surface. Adsorption is the process utilized in stormwater management BMPs to enhance the removal of soluble pollutants.

Alkalinity – A measure of the capacity of water to neutralize acids because of the presence of one or more of the following bases in the water: carbonates, bicarbonates, hydroxides, borates, silicates, or phosphates.

Ammonia Nitrogen (NH_4-N) – A reduced form of nitrogen produced as a by-product of organic matter decomposition and synthesized from oxidized nitrogen by biological and physical processes.

Anti-Seep Collar – A device constructed around a pipe or other conduit and placed into a dam, levee, or dike for the purpose of reducing seepage losses and piping failures along the conduit it surrounds.

Anti-Vortex Device – A device placed at the entrance to a pipe conduit structure to help prevent swirling action and cavitation from reducing the flow capacity of the conduit system.

Aquatic Bench – A 10- to 15-foot wide bench around the inside perimeter of a permanent pool that ranges in depth from 0 to 12 inches. Vegetated with emergent plants, the bench augments pollutant removal, provides habitats, protects the shoreline from the effects of water level fluctuations, and enhances safety.

Aquifer – A porous, water bearing geologic formation generally restricted to materials capable of yielding an appreciable supply of water.

As-Built (drawing) – A drawing or certification of conditions as they were actually constructed.

Aspect Ratio – Ratio of wetland cell length to width.

Atmospheric Deposition – The process by which atmospheric pollutants reach the land surface either as dry deposition or as dissolved or particulate matter contained in precipitation.

Attenuation – Reduction in magnitude, as in the lowering of peak runoff discharge rates, in the case of dry ponds; or the reduction of contaminant concentrations, as in the action of biodegradation in wetlands or bioretention facilities.

Baffle – Guides, grids, grating or similar devices placed in a pond to deflect or regulate flow and create a longer flow path from the inlet to the outlet structure.

Bankfull Flow – Condition where flow fills a stream channel to the top of bank to the point where the water begins to overflow onto a floodplain.

Barrel – A closed conduit used to convey water under or through an embankment; part of the principal spillway.

Base Flow – Normally refers to the stream levels associated primarily with groundwater or subsurface contributions, as opposed to storm flow which corresponds to stream levels associated with recent precipitation and surface runoff.

Basin – A facility designed to impound stormwater runoff.

Bedrock – Layer of consolidated rock over which lies an overburden of soil (regolith), including unconsolidated rock.

Benthic – Pertaining to occurrence on or in the bottom sediment of wetland and aquatic ecosystems, including wetlands.

Best Management Practices (BMP) – Activities, facilities, measures, or procedures used to manage the volume, rate, and water quality of stormwater runoff.

Biodiversity – The number of species of plants and animals in a defined area. Biodiversity is measured by a variety of indices that consider the number of species and, in some cases, the distribution of individuals among species.

Biological Processes – A pollutant removal pathway in which microbes break down organic pollutants and transform nutrients.

Biomass – The total mass of living tissues (plant and animal).

Biochemical Oxygen Demand (BOD) – A measure of the concentration of aerobically degradable compounds in water. Measured as the oxygen consumed during degradation of organic and inorganic materials in water.

Bioretention Basin – A water quality BMP engineered to filter the water quality volume through an engineered planting bed consisting of a vegetated surface layer (vegetation, mulch, ground cover), planting soil, and sand bed (optional), and subsequently into the in-situ material. Also called rain gardens.

Bioretention Filter – A bioretention basin with the addition of a sand layer and collector pipe system beneath the planting bed.

BMP Fingerprinting – A series of techniques for locating BMPs (particularly ponds) within a development site so as to minimize their impacts to wetlands, forest, and sensitive stream reaches.

BOD_5 – Five-day biochemical oxygen demand.

Buffer – A vegetated strip immediately adjacent to a waterbody. The primary function of buffers is to protect the receiving water from sediment and pollutants derived from upstream areas. Ancillary benefits may include infiltration of rainfall and habitat enhancement. A buffer is a special case of a filter strip. Forested riparian buffers are one example of a best management practice related to the use of buffers.

Catch Basin – An inlet chamber usually built at the curb line of a street or low area, for collection of surface runoff and admission into a sewer or subdrain. These structures commonly have a sediment sump at its base, below the sewer or subdrain discharge elevation, designed to retain solids below the point of overflow.

Channel – A natural or man-made waterway.

Channel Stabilization – The introduction of natural or man-made materials placed within a channel so as to prevent or minimize the erosion of the channel bed and/or banks.

Channelization – The creation of a channel or channels resulting in faster water flow, a reduction in hydraulic residence time, and less contact between water and solid surfaces in the waterbody.

Check Dam – A small dam constructed in a channel for the purpose of decreasing the flow velocity, minimizing channel scour, and promoting deposition of sediment. Check dams are a component of grassed swale BMPs.

Chemical Oxygen Demand (COD) – A measure of the concentration of substances which can be oxidized in water. Expressed as the oxygen equivalent consumed when an aqueous sample is reacted of the organic matter in water, based on reaction with a strong chemical oxidant.

Choker Course – A filter layer of finer material, usually crushed stone, that is installed over a coarse road base material. The purpose of the choker course is to provide a stable foundation for the construction of pavement.

Chute – A high velocity, open channel for conveying water to a lower level without erosion.

Clay (SOILS) – 1. A mineral soil separate consisting of particles less than 0.002 millimeter in equivalent diameter. 2. A soil texture class. 3. (Engineering) A fine grained soil (more than 50% passing the No. 200 sieve) that has a high plasticity index in relation to the liquid limit (Unified Soil Classification System).

Coconut Rolls – Also known as coir rolls, these are rolls of natural coconut fiber designed to be used for streambank stabilization.

COE – The United States Army Corps of Engineers.

Compaction (Soils) – Any process by which the soil grains are rearranged to decrease void space and bring them in closer contact with one another, thereby increasing the weight of solid material per unit of volume, increasing the shear and bearing strength and reducing permeability.

Conduit – Any channel intended for the conveyance of water, whether open or closed.

Constructed Stormwater Wetlands – Areas intentionally designed and created to emulate the water quality improvement function of wetlands for the primary purpose of removing pollutants from stormwater.

Contour – A line representing a specific elevation on the land surface or a map.

Core Trench – A trench filled with relatively impervious material intended to reduce seepage of water through porous strata.

Cradle – A structure usually made of concrete shaped to fit around the bottom and sides of a conduit to support the conduit, increase its strength, and, in dams, to fill all voids between the underside of the conduit and soil.

Crest – The top of a dam, dike, spillway or weir, frequently restricted to the overflow portion.

Critical Depth – The depth of flow at which the specific energy is a minimum for a given discharge rate. Flow is critical when the Froude number is equal to one: where V is the velocity of the flow, g is the gravitational constant, and D is the hydraulic depth of the flow.

Crushed Stone – Aggregate consisting of angular particles produced by mechanically crushing rock.

Curve Number (CN) – A numerical representation of a given area's hydrologic soil group, plant cover, impervious cover, interception, and surface storage derived in accordance with Natural Resource Conservation Service methods. This number is used to convert rainfall depth into runoff volume. Sometimes referred to as Runoff Curve Number.

Cut – A reference to an area or material that has been excavated in the process of a grading operation.

Cut-And-Fill – The process of earth moving by excavating part of an area and using the excavated material for adjacent embankments or fill areas.

Cutoff – A wall or other structure, such as a trench, filled with relatively impervious material intended to reduce seepage of water through porous strata.

CZARA – Acronym used for the Coastal Zone Act Reauthorization Amendments of 1990. These amendments sought to address nonpoint source pollution issues by requiring states to develop Coastal Nonpoint Pollution Control Programs in order to receive federal funds.

Dam – A barrier constructed for the purpose of confining or impounding water.

Denitrification – The removal of nitrate ions from soil or water, anaerobic microbial reduction of oxidized nitrate nitrogen to nitrogen gas.

Dense Graded Material – Granular mixture characterized by a large range in particle sizes. Dense graded materials have superior structural properties to open graded materials. However, they are less permeable.

Design Storm – A selected rainfall hyetograph of specified amount, intensity, duration, and frequency that is used as a basis for design.

Detention – The temporary impoundment or holding of stormwater runoff.

Detention Basin – A stormwater management facility which temporarily impounds runoff and discharges it through a hydraulic outlet structure to a downstream conveyance system. While a certain amount of outflow may also occur via infiltration through the surrounding soil, such amounts are negligible when compared to the outlet structure discharge rates and, therefore, are not considered in the facility's design. Since an extended detention basin impounds runoff only temporarily, it is normally dry during nonrainfall periods.

Detention Structure – A structure constructed for the purpose of temporary storage of stream flow or surface runoff and gradual release of stored water at controlled rates.

Detritus – Dead plant material that is in the process of microbial decomposition.

Dike – An embankment, usually linear, to confine or direct water.

Discharge – Flow of water across the land surface or within the confines of a natural or man-made channel, or stream.

Dissolved Oxygen – A form of oxygen found in water that is essential to the life of aquatic species.

Distributed Runoff Control (DRC) – A stream channel protection criteria which utilizes a non-uniform distribution of the storage stage-discharge relationship within a SMP to minimize the change in channel erosion potential from pre-developed to developed conditions.

Disturbed Area – An area in which the natural vegetative soil cover or existing surface treatment has been removed or altered and, is therefore susceptible to erosion.

Diurnal – Occurring daily or during the daylight.

Diversion – A channel or dike constructed to direct water to areas where it can be used, treated, or disposed of safely.

Drainage – 1. The removal of excess surface water or groundwater from land by means of surface or subsurface drains. 2. Soils characteristics that affect natural drainage.

Drainage Area (Watershed) – All land and water area from which runoff may run to a common (design) point.

Drainage Basin – An area of land that contributes stormwater runoff to a designated point. Also called a drainage area or, on a larger scale, a watershed.

Drop Structure – A man-made device constructed to transition water to a lower elevation.

Dry Swale – An open drainage channel explicitly designed to detain and promote the filtration of stormwater runoff through an underlying fabricated soil media.

Duration – The length of time over which precipitation occurs.

Ecosystem – All organisms and the non-living environmental factors with which they interact.

Ecotone – The boundary between adjacent ecosystem types. An ecotone can include environmental conditions that are common to both neighboring ecosystems and can have higher species diversity.

Eh – A measure of the reduction-oxidation (redox) potential of soil according to a hydrogen scale.

Emergent Plant – A rooted, vascular plant that grows in periodically or permanently flooded areas and has parts of the plant (stems and leaves) extending through and above the water plane.

EPA – The United States Environmental Protection Agency.

Embankment – A man-made deposit of soil, rock, or other material used to form an impoundment.

Emergency Spillway – A channel, usually an open channel constructed adjacent to an embankment, which conveys flows in excess of the design capacity of the principal spillway.

Energy Dissipator – A device used to reduce the velocity or turbulence of flowing water.

Erosion – The wearing away of the land surface by running water, wind, ice, or other geological agents.

Accelerated Erosion – Erosion in excess of what is presumed or estimated to be naturally occurring levels and which is a direct result of human activities.

Gully Erosion – Erosion process whereby water accumulates in narrow channels and removes the soil to depths ranging from a few inches to 1 or 2 feet to as much as 75 to 100 feet.

Rill Erosion – Erosion process in which numerous small channels only several inches deep are formed.

Sheet Erosion – The spattering of small soil particles caused by the impact of raindrops on wet soils. The loosened and spattered particles may subsequently be removed by surface runoff.

Erosive Velocities – Velocities of water that are high enough to wear away the land surface. Exposed soil will generally erode faster than stabilized soils. Erosive velocities will vary according to the soil type, slope, structural, or vegetative stabilization used to protect the soil.

Eutrophic – Water containing an excess of plant-growth nutrients that typically result in algae blooms and extreme (high and low) dissolved-oxygen concentrations.

Eutrophication – The process of over-enrichment of waterbodies by nutrients often typified by the presence of algal blooms.

Evapotranspiration – The combined processes of evaporation from the water or soil surface and transpiration of water by plants.

Exceedence Probability – The probability that an event having a specified volume and duration will be exceeded in one time period, usually assumed to be one year. If a storm has a one percent chance of occurring in any given year, than it has an exceedence probability of 0.01.

Excessively Rapid Drainage – For purposes of this manual, corresponds to infiltration rates of soils in excess of 6 inches per hour. (Normally 6 inches is considered rapid drainage but the manual indicates that special precautions need to be taken with an infiltration rate of 6 inches per hour or more)

Exfiltrate – The leaking of water to surrounding ground through openings in structures.

Exfiltration – The downward movement of runoff through the bottom of a stormwater facility and into the soil.

Exotic Species – A plant or animal species that has been intentionally or accidentally introduced and that does not naturally occur in a region.

Extended Detention – A function provided by BMPs which incorporate a water quality storage. BMPs with extended detention intercept runoff and then release it over an extended period of time.

Extended Detention Basin – A stormwater management facility which temporarily impounds runoff and discharges it through a hydraulic outlet structure over a specified period of time to a downstream conveyance system for the purpose of water quality enhancement or stream channel erosion control. While a certain amount of outflow may also occur via infiltration through the surrounding soil, such amounts are negligible when compared to the outlet structure discharge rates and, therefore, are not considered in the facility's design. Since an extended detention basin impounds runoff only temporarily, it is normally dry during non-rainfall periods.

Extended Detention Basin-Enhanced – An extended detention basin modified to increase pollutant removal by providing a shallow marsh in the lower stage of the basin.

Extended Detention (ED) Pond – Temporarily detains part of stormwater runoff for up to 24 hours after a storm by using a fixed orifice. ED ponds normally are "dry" between storm events and do not have permanent standing water. An enhanced ED pond is designed to prevent clogging and re-suspension. It provides flexibility in achieving target detention times. It may be equipped with plunge pools near the inlet, a micropool at the outlet, and may have an adjustable reverse-sloped pipe at the ED control device.

Extended Detention Control Device – A pipe or series of pipes that extend from the riser of the stormwater pond that are used to gradually release stormwater from the pond over a 12- to 48-hour interval.

Extreme Flood (Q_f) – The storage volume required to control those infrequent but large storm events in which overbank flows approach the floodplain boundaries of the 100-year flood.

Fascine – Bundled willow cuttings used to stabilize stream banks. Bundling allows otherwise weak green twigs to reinforce each other and resist the forces of stream currents.

Field Capacity – The quantity of water which will not freely drain from the root zone of shallow soil layers. Usually measured as the moisture content (by volume) in soil at a capillary tension of .33 bars.

Fill – A reference to an area or material that has been placed by mechanical equipment in the process of a grading operation.

Filter Bed – The section of a constructed filtration device that houses the filtering media.

Filter Fence – A geotextile fabric designed to trap sediment and filter runoff.

Filter Media – The sand, soil, or other organic material in a filtration device used to provide a permeable surface for pollutant and sediment removal.

Filter Strip – A vegetated boundary characterized by uniform mild slopes. Filter strips may be provided down-gradient of developed tracts to trap sediment and sediment-borne pollutants and to reduce imperviousness. Filter strips may be forested or vegetated turf. Filter strips located adjacent to waterbodies are called buffers.

Fines (Soil) – Generally refers to the silt and clay size particles in soil.

First Flush – The first portion of runoff, usually defined as a depth in inches, considered to contain the highest pollutant concentration resulting from a rainfall event.

Flash Boards – Removable boards used in a weir to control water levels.

Floating Aquatic Plant – A rooted or non-rooted vascular plant that is adapted to have some plant organs (generally the chlorophyll-bearing leaves) floating on the surface of the water in wetlands, lakes, and rivers.

Flood Fringe – The flood fringe occupies the distal parts of the floodplain, outside of the floodway. Complete obstruction of the flood fringe will not significantly increase flood levels. The flood fringe boundary is typically based on an increase in flood level of one foot during the 100-year return frequency flooding event.

Flooding – When the volume or rate flow exceeds the capacity of the natural or man-made conveyance system and overflows onto adjacent lands, causing or threatening damage.

Floodplain – Lands adjoining a river or stream that have been or may be expected to be inundated by flood waters in a 100-year frequency flood.

Floodway – The channel of the watercourse and portions of the adjoining floodplains which are reasonably required to carry and discharge the 100-year frequency flood. Unless otherwise specified, the boundary of the floodway is as indicated on maps and flood insurance studies provided by FEMA. In an area where no FEMA maps or studies have defined the boundary of the 100-year frequency floodway, it is assumed, absent evidence to the contrary, that the floodway extends from the stream to 50 feet from the top of the bank of the stream.

Flow Splitter – An engineered hydraulic structure designed to divert a portion of storm flow to a BMP located out of the primary channel, or to direct stormwater to a parallel pipe system, or to bypass a portion of baseflow around a BMP.

Forebay – A stormwater design feature that uses a small basin to settle out incoming sediment before it is delivered to a stormwater BMP.

Fourth Order Stream – Designation of stream size where many water quantity requirements may not be needed. A first order stream is identified by "blue lines" on USGS quad sheets. A second order stream is the confluence of two first order streams, and so on.

Freeboard – The vertical distance between water surface elevation experienced during the design flood and the crest elevation of a dam, levee, floodwall, or other embankment.

French Drain – A type of drain consisting of an excavated trench filled with pervious material such as coarse sand, gravel or crushed stone. Water percolates through the voids in the material and exfiltrates into the soil.

Frequency (design storm frequency) – The recurrence interval of storm events having the same duration and volume. The frequency of a specified design storm can be expressed either in terms of exceedence probability or return period.

Fresh Water – Water with a total dissolved solids content less than 500 mg/L (0.5 parts per thousand salts).

Gabion – A wire cage used to contain rip rap and stone. Gabions are used to increase the resistance of rip rap to movement caused by flowing water.

Gabion Mattress – A thin gabion, usually six or nine inches thick, used to line channels for erosion control.

Geotextile – A fabric manufactured from synthetic fiber that is designed to achieve specific engineering objectives, including seepage control, media separation (e.g., between sand and soil), filtration, or the protection of other construction elements such as geomembranes.

GIS – Geographic Information System. A method of overlaying spatial land and land use data of different kinds. The data are referenced to a set of geographical coordinates and encoded in a computer software system. GIS is used by many localities to map utilities and sewer lines and to delineate zoning areas.

Grade – The slope of a specific surface of interest such as a road, channel bed or bank, top of embankment, bottom of excavation, or natural ground. Grade is commonly measured in percent (unit of measurement per one hundred units) or a ratio of horizontal to vertical distance.

Grass Channel – An open vegetated channel used to convey runoff and to provide treatment by filtering out pollutants and sediments.

Grassed Swale – An earthen conveyance system which is broad and shallow with check dams and vegetated with erosion resistant and flood tolerant grasses, engineered to remove pollutants from stormwater runoff by filtration through grass and infiltration into the soil.

Gravel – 1. Aggregate consisting of mixed sizes of ¼ inch to 3 inch particles which normally occur in or near old streambeds and have been worn smooth by the action of water. 2. A soil having particle sizes, according to the Unified Soil Classification System, ranging from the No. 4 sieve size angular in shape as produced by mechanical crushing.

Gravel Diaphram – A stone trench filled with small, river-run gravel used as pretreatment and inflow regulation in stormwater filtering systems.

Gravel Filter – Washed and graded sand and gravel aggregate placed around a drain or well screen to prevent the movement of fine materials from the aquifer into the drain or well.

Gravel Trench – A shallow excavated channel backfilled with gravel and designed to provide temporary storage and permit percolation of runoff into the soil substrate.

Green Alleys – A network of bioretention basins, infiltration trenches, or bioretention filters that provide both redundant water quality management and stormwater conveyance.

Greenway – A strip or belt of vegetated land that typically includes both upland and riparian areas. Greenways are often used for recreation, as a land use buffer, or to provide a corridor and habitat for wildlife.

Ground Cover – Plants that are low-growing and provide a thick growth which protects the soil as well as providing some beautification of the area occupied.

Gully – A channel or miniature valley cut by concentrated runoff through which water commonly flows only during and immediately after heavy rains or during the melting of snow. The distinction between gully and rill is one of depth. A gully is sufficiently deep and would not be obliterated by normal tillage operations, whereas a rill is of lessor depth and would be smoothed by ordinary farm tillage.

Habitat – The environment occupied by individuals of a particular species, population, or community.

Head (Hydraulics) – 1. The height of water above any plane of reference. 2. The energy, either kinetic or potential, possessed by each unit weight of a liquid expressed as the vertical height through which a unit weight would have to fall to release the average energy possessed. Used in various terms such as pressure head, velocity head, and head loss.

Headwall – A wall of stone, metal, concrete, or wood at the end of a culvert or drain to protect fill from scour or undermining, increase hydraulic efficiency of conduit, divert flow, retard disjointing of short sectional pipe, or serve as a retaining wall.

Heavy Metals – Metallic elements having atomic weights above 21 on the periodic table.

Head – The height of water above any plane or object of reference; also used to express the energy, either kinetic or potential, measured in feet, possessed by each unit weight of a liquid.

HEC-1 – Hydraulic Engineering Circular - 1; a rainfall-runoff event simulation computer model sponsored by the U.S. Corps of Engineers.

Herbaceous – Plant parts that contain chlorophyll and are non-woody.

Hi Marsh – A pondscaping zone within a stormwater wetland which exists from the surface of the normal pool to a six inch depth and typically contains the greatest density and diversity of emergent wetland plants.

Hi Marsh Wedges – Slices of shallow wetland (less than or equal to 6 inches) dividing a stormwater wetland.

Hot Spot – Area where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in stormwater.

Hydraulic Conductivity (K) – An expression of the readiness with which a liquid such as water flows through a soil in response to a given potential gradient. Hydraulic conductivity is a constant physical property of soil or rock, one of several components responsible for the dynamic phenomenon of flow.

Hydraulic Gradient – The slope of the hydraulic grade line. The slope of the free surface of water flowing in an open channel.

Hydraulic loading rate (HLR) – The ratio of the surface area of a hydraulic device and the average rate at which water is delivered to a land area with units of volume per area per time or simply reduced to depth per time (for example, $m^3/(m^2/d)$ or cm/d).

Hydraulic Residence Time (HRT) – A measure of the average time that water occupies a given volume with units of time. The theoretical HRT is calculated as the volume divided by the flow (for example, $m^3/(m^2/d)$). The actual HRT is estimated on the basis of tracer studies that used conservative tracers such as lithium or dyes.

Hydraulics – The physical science and technology of the static and dynamic behavior of fluids.

Hydric Soil – A soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions. Hydric soil that is in areas having indicators of hydrophytic vegetation and wetland hydrology is wetland soil.

Hydrodynamic Structure – An engineered flow through structure which uses gravitational settling to separate sediments and oils from stormwater runoff.

Hydrologic Cycle – A continuous process by which water is cycled from the oceans to the atmosphere to the land and back to the oceans.

Hydrograph – A record of the change in flow rate with time.

Hydrologic Soil Group – A designation developed by the NRCS which describes the infiltration capacity of soil. Soil associations are categorized in decreasing infiltration capacity from A to D.

Hydrology – Science dealing with the distribution and movement of water.

Hydroperiod – The period of wetland soil saturation or flooding. Hydroperiod is often expressed as a number of days or a percentage of time flooded during an annual period (for example, 25 days or 7%).

Hydroseed – Seed or other material applied to areas in order to revegetate after a disturbance.

Hyetograph – A graph of the time distribution of rainfall over a watershed.

Hypoxia – Lack of oxygen in a waterbody resulting from eutrophication.

Impervious cover – A surface composed of any material that significantly impedes or prevents natural infiltration of water into soil. Impervious surfaces include, but are not limited to, roofs, buildings, streets, parking areas, and any concrete, asphalt, or compacted gravel surface.

Impoundment – An artificial collection or storage of water, as a reservoir, pit, dugout, sump, etc.

Industrial Stormwater Permit – NPDES permit issued to a commercial industry for regulating the pollutant levels associated with industrial stormwater discharges. The permit may specify on-site pollution control strategies.

Infiltration – The entrance of surface water into the soil, usually at the soil/air interface.

Infiltration Facility – A stormwater management facility which temporarily impounds runoff and discharges it via infiltration through the surrounding soil. While an infiltration facility may also be equipped with an outlet structure to discharge impounded runoff, such discharge is normally reserved for overflow and other emergency conditions. Since an infiltration facility impounds runoff only temporarily, it is normally dry during non-rainfall periods. Infiltration basin, infiltration trench, infiltration dry well, and porous pavement are considered infiltration facilities.

Infiltration Rate (Fc) – The rate at which stormwater percolates into the subsoil, measured in inches per hour.

Infiltration Testing – Specific tests designed to measure the saturated movement of water into the soil in a single direction downward through a two dimensional soil surface.

Inflow Protection – A water handling device used to protect the transition area between any water conveyance (dike, swale, or swale dike) and a sediment trapping device.

Initial Abstraction – The maximum amount of rainfall that can be absorbed under specific conditions without producing runoff. Also called initial losses.

Intensity – The depth of rainfall divided by duration.

Invert – The lowest flow line elevation in any component of a conveyance system, including storm sewers, channels, weirs, etc.

Karst Topography – Regions that are characterized by formations underlain by carbonate rock and typified by the presence of limestone caverns and sinkholes.

Kjeldahl Nitrogen (TKN) – A measure of the ammonia and organic nitrogen present in a water sample.

Lag Time – The interval between the center of mass of the storm precipitation and the peak flow of the resultant runoff.

Land Development – A man-made change to, or construction on, the land surface that changes its runoff characteristics.

Landscaping – The placement of vegetation in and around stormwater management BMP's.

Level Spreader – A device for distributing stormwater uniformly over the ground surface as sheet flow to prevent concentrated, erosive flows and promote infiltration.

Limnetic – Relating to or inhabiting the open water part of a freshwater body with a depth that light penetrates. The area of a wetland without emergent vegetation.

Linear Development Project – A land development project that is linear in nature such as, but not limited to, (i) the construction of electric and telephone utility lines, and natural gas pipelines; (ii)construction of tracks, rights-of-way, bridges, communication facilities and other related structures of a railroad company; and (iii) highway construction projects.

Littoral Zone – The shoreward zone of a lake or wetland. The area where water is shallow enough for emergent vegetation to dominate.

Locality – A county, city, or town.

Low Impact Development (LID) – Hydrologically functional site design with pollution prevention measures to reduce impacts and compensate for development impacts on hydrology and water quality.

Macrophyte – Macroscopic (visible to the unassisted eye) vascular plants.

Manning's Equation – A formula for calculating the anticipated uniform flow in an open-channel flow, published by Manning in 1890.

Manning's Formula – An equation used to predict the velocity of water flow in an open channel or pipeline.

Marsh – A wetland dominated by herbaceous emergent plants.

Micronutrient – A chemical substance that is required for biological growth in relatively low quantities and in small proportion to the major growth nutrients. Some typical micronutrients include molybdenum, copper, boron, cobalt, iron, and iodine.

Micropool – A smaller permanent pool which is incorporated into the design of larger stormwater ponds to avoid resuspension of particles, provide varying depth zones, and minimize impacts to adjacent natural features.

Microtopography – The complex contours along the bottom of a shallow marsh system, providing greater depth variation which increases the wetland plant diversity and increases the surface area to volume ratio of a stormwater wetland.

Mitigation – The replacement of functional values lost when an ecosystem is altered. Mitigation can include replacement, restoration, and enhancement of functional values.

Modified Rational Method – A variation of the rational method used to calculate the critical storage volume whereby the storm duration can vary and does not necessarily equal the time of concentration.

Mulch – Any material such as straw, sawdust, leaves, plastic film, loose soil, wood chips, etc. that is spread or formed upon the surface of the soil to protect the soil and/or plant roots from the effects of raindrops, soil crusting, freezing, evaporation, etc.

Municipal Stormwater Permit – NPDES permit issued to municipalities to regulate discharges from municipal separate storm sewers for compliance with EPA regulations and to specify stormwater control strategies.

Nitrification – Biological transformation (oxidation) of ammonia nitrogen to nitrite and nitrate forms.

Nitrogen Fixation – A microbial process in which atmospheric nitrogen gas is incorporated into the synthesis of organic nitrogen.

Nitrogen-Fixing (Bacteria) – Bacteria having the ability to fix atmospheric nitrogen, making it available for use by plants. Inoculation of legume seeds is one way to insure a source of these bacteria for specified legumes.

National Pollutant Discharge Elimination System (NPDES) – The national program for issuing, modifying, monitoring, and enforcing permits under Sections 307, 402, 318, and 405 of the Clean Water Act.

Nonpoint Source Pollution – Contaminants such as sediment, nitrogen and phosphorous, hydrocarbons, heavy metals, and toxins whose sources cannot be pinpointed but rather are washed from the land surface in a diffuse manner by stormwater runoff.

Normal Depth – The depth of flow in an open conduit during uniform flow for the given conditions.

Off-line – A stormwater management system designed to manage a portion of the stormwater which has been diverted from a stream or storm drain. A flow splitter is typically used to divert the desired portion of the flow.

On-line – A stormwater management system designed to manage stormwater in its original stream or drainage channel.

One Year Storm (Q_P 1) – A stormwater event which occurs on average once every year or statistically has a 100% chance on average of occurring in a given year.

One Hundred Year Storm (Q_P 100) – An extreme flood event which occurs on average once every 100 years or statistically has a 1% chance on average of occurring in a given year.

Open Channels – Also known as swales, grass channels, and biofilters. These systems are used for the conveyance, retention, infiltration, and filtration of stormwater runoff.

Open Graded Material – Uniform granular mixture with a narrow distribution of grain sizes. Open graded material has higher permeability than dense graded material.

Organic Nitrogen (Org-N) – Nitrogen that is bound in organic compounds.

Outfall – Place where effluent is discharged into receiving waters.

Outlet – The point at which water discharges from such things as a stream, river, lake, tidal basin, pipe, channel, or drainage area.

Outlet Channel – A waterway constructed or altered primarily to carry water from man-made structures such as terraces, subsurface drains, diversions, and impoundments.

Palustrine Wetland – All nontidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens; and all such tidal wetlands in areas where salinity from ocean-derived salts is below 0.5 parts per thousand.

Peak Attenuation Storage – The volume set aside within a BMP for the purpose of attenuating the inflow runoff peak rate.

Peak Discharge – The maximum rate of flow associated with a given rainfall event or channel.

Peak Discharge Rate – The maximum instantaneous rate of flow during a storm, usually in reference to a specific design storm event.

Percolation – The downward movement under the influence of gravity of water under hydrostatic pressure through the interstices of the rock or soil.

Percolation Rate – The velocity at which water moves through saturated, granular material.

Perennial – Persisting for more than one year. Perennial plant species persist as woody vegetation from year to year or resprout from their rootstock annually.

Periphyton – The community of microscopic plants and animals that grows on the surface of emergent and submergent plants in waterbodies.

Permanent Seeding – Results in establishing perennial vegetation which may remain on the area for many years.

Permeability – The ability of rock, soil or other material to transmit a gas or liquid.

Permissible Velocity (Hydraulics) – The highest average velocity at which water may be carried safely in a channel or other conduit. The highest velocity that can exist through a substantial length of a conduit and not cause scour of the channel. A safe, non-eroding or allowable velocity.

Permittivity (cross-plane flow capacity) – The rate that water will flow freely through a thin layer, such as a geotextile. Equal to the hydraulic conductivity divided by the thickness of the layer. Permittivity is measured in units of inverse time (e.g., sec^{-1}).

pH – An expression of the intensity of the basic or acidic condition of a liquid. Natural waters usually have a pH range between 6.5 and 8.5. A pH of 7.0 denotes neutrality, higher values indicate alkalinity, and lower values indicate acidity.

Phosphorus – An element found in fertilizers and sediment runoff which can contribute to the eutrophication of waterbodies.

Photic Zone – The area of a waterbody receiving sunlight.

Piezometric Surface – The surface defined by elevation to which groundwater will rise in a well.

Piping – The removal of soil material through subsurface flow channels or pipes, developed by seepage water.

Planning Area – A designated portion of the parcel on which a land development project is located. Planning areas must be established by delineation on a master plan. Once established, planning areas must be applied consistently for all future projects.

Plant Community – All of the plant species and individuals occurring in a shared habitat or environment.

Plug Flow – Linear flow along the length of a wetland cell. Ideal plug flow does not involve the dispersion or diffusion of constituents. The flow can be perceived as a series of independent "packets" of water that do not interact with each other.

Plugs – Pieces of turf or sod, usually cut with a round tube, which can be used to propagate the turf or sod by vegetative means.

Plunge Pool – A small permanent pool at either the inlet to a BMP or at the outfall from a BMP. The primary purpose of the pool is to dissipate the velocity of stormwater runoff.

Pocket Pond – A stormwater pond designed for treatment of small drainage area (< 5 acres) runoff and which has little or no baseflow available to maintain water elevations and relies on groundwater to maintain a permanent pool.

Pocket Wetland – A stormwater wetland design adapted for the treatment of runoff from small drainage areas (< 5 acres) and which has little or no baseflow available to maintain water elevations and relies on groundwater to maintain a permanent pool.

Pollutant Removal – Removing pollutants by decomposing them or eliminating them from an area or system (e.g. volitize), or rendering them non-harmful or unavailable in a soil or medium by means of adsorption, chelation, and similar binding mechanisms.

Point Source – The discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, container, concentrated animal feeding operation, or landfill leachate collection system from which pollutants may be discharged. This term does not include return flows from irrigated agriculture or agricultural stormwater runoff.

Pond Buffer – The area immediately surrounding a pond which acts as a filter to remove pollutants and provide infiltration of stormwater prior to reaching the pond. Provides a separation barrier to adjacent development.

Pond Drain – A pipe or other structure used to drain a permanent pool within a specified time period.

Pondscaping – Landscaping around stormwater ponds which emphasizes native vegetative species to meet specific design intentions. Species are selected for up to six zones in the pond and its surrounding buffer, based on their ability to tolerate inundation and/ or soil saturation.

Pore Space – Open space in rock or granular material; also known as interstices.

Porosity – The ratio of pore or open space volume to total solids volume.

Post Development – Refers to conditions that reasonably may be expected or anticipated to exist after completion of the land development activity on a specific site or tract of land.

Precipitation – A deposit on the earth of hail, mist, sleet, rain or snow.

Pre-development – Refers to the conditions that exist at the time that plans for the land development of a tract of land are approved by the plan approval authority. Where phased development or plan approval occurs (preliminary grading, roads and utilities, etc.), the existing conditions at the time prior to the first item being approved or permitted establishes the pre-development conditions.

Pretreatment – The techniques employed in a stormwater management plan to provide storage or filtering to help trap coarse materials before they enter the stormwater BMP. Pretreatment is required on some BMPs to help avoid costly maintenance.

Principal Spillway - The primary spillway or conduit for the discharge of water from an impoundment facility; generally constructed of permanent material and designed to regulate the rate of discharge.

Protozoa – Small, one-celled animals including amoebae, ciliates, and flagellates.

Rational Method – Means of computing peak storm drainage flow rates based on average percent imperviousness of the site, mean rainfall intensity, and drainage area.

Receiving Water – A waterbody into which wastewater or treated effluent is discharged.

Recharge – Replenishment of groundwater reservoirs by infiltration through permeable soils.

Redevelopment – New development activities on previously developed land.

Retention – The amount of precipitation on a drainage area that does not escape as runoff. It is the difference between total precipitation and total runoff.

Retention Basin – A stormwater management facility which includes a permanent impoundment or normal pool of water for the purpose of enhancing water quality and, therefore, is normally wet, even during nonrainfall periods. Storm runoff inflows may be temporarily stored above this permanent impoundment for the purpose of reducing flooding or stream channel erosion.

Return Period (storm event) – The average period of time between the occurrence of storms of equal or greater magnitude. The probability that such a storm will occur in any given year is equal to the reciprocal of the return period (e.g. there is a 50% chance that a 2-year storm event will occur in any given year, but only a 10% chance that a 10-year storm event will occur).

Reverse-Slope Pipe – A pipe which draws from below a permanent pool extending in a reverse angle up to the riser and which determines the water elevation of the permanent pool.

Rhizosphere – The chemical sphere of influence of plant roots growing in flooded soils. Depending on the overall oxygen balance (availability and consumption), the rhizosphere can be oxidized, resulting in the presence of aerobic soil properties in an otherwise anaerobic soil environment.

Right-Of-Way – Rite of passage, as over another's property. A route that is lawful to use. A strip of land acquired for transport or utility construction.

Riparian – Pertaining to a stream or river. Also, plant communities occurring in association with any spring, lake, river, stream, or creek through which waters flow at least periodically.

Riparian Corridor – Narrow strip of land centered on a stream that includes the floodplain as well as related riparian habitats adjacent to the floodplain.

Rip-Rap – Broken rock, cobbles, or boulders placed on earth surfaces, such as the face of a dam or the bank of a stream, for protection against the action of water (waves); also applies to brush or pole mattresses, or brush and stone, or similar materials used for soil erosion control.

Riverine Wetlands – Wetlands associated with rivers.

Riser – A vertical pipe or structure extending from the bottom of a pond SMP and houses the control devices (weirs/orifices) to achieve the discharge rates for specified designs.

Roughness Coefficient (Hydraulics) – A factor in velocity and discharge formulas representing the effect of channel roughness on energy losses in flowing water. Manning's 'n' is a commonly used roughness coefficient.

Routing – A method of measuring the inflow and outflow from an impoundment structure while considering the change in storage volume over time.

Runoff (Hydraulics) – The portion of the precipitation on a drainage area that is discharged from the area in the stream channels. Types include surface runoff, groundwater runoff, or seepage.

Runoff Coefficient (R_V) – A value derived from a site impervious cover value that is applied to a given rainfall volume to yield a corresponding runoff volume.

Runoff Capture Design Storm – A benchmark rainfall event used to develop criteria for designing the groundwater recharge function of BMPs. The runoff capture design storm is the largest rainfall event from which no appreciable runoff is expected to occur. Complete specification of the storm includes the rainfall depth in inches, return frequency, and storm duration.

Runoff Capture Storage – The combined storage volume provided by BMPs on a site for the retention and eventual infiltration of rainfall.

Runoff Capture Volume – The minimum volume of rainfall that should be retained and completely infiltrated on-site during every storm. It is also equal to the rainfall quantity associated with the runoff capture design storm. The runoff capture volume is conveniently stated as a rainfall volume, in inches, over the area of the site.

Runoff Curve Number (CN) – A parameter developed by the NRCS which is an indicator of runoff potential. Curve number is related to hydrologic soil group and land use type. The larger the runoff curve number, the greater the percentage of rainfall that will appear as runoff.

Runoff Peak Attenuation Design Storm – A benchmark rainfall event used to develop criteria for the design of runoff peak attenuation BMPs. The design criteria generally requires that the predicted post development peak runoff rate for the selected runoff peak attenuation design storm will not exceed the peak associated with redeveloped condition. Complete specification of the storm includes rainfall depth in inches, return frequency, and storm duration.

SCS – Soil Conservation Service (now called Natural Resource Conservation Service, NRCS), a branch of the U.S. Department of Agriculture.

Safety Bench – A flat area above the permanent pool and surrounding a stormwater pond designed to provide a separation to adjacent slopes.

Sand – 1. (Agronomy) A soil particle between 0.05 and 2.0 millimeters in diameter. 2. A soil textural class. 3. (Engineering) According to the Unified Soil Classification System, a soil particle larger than the No. 200 sieve (0.074mm) and passing the No. 4 sieve (approximately ¼ inch).

Sand Filter – A contained bed of sand which acts to filter the first flush of runoff. The runoff is then collected beneath the sand bed and conveyed to an adequate discharge point or infiltrated into the in-situ soils.

Saturated Soil – Soil in which the pore space is completely filled with water.

Seasonally High Water Table – Shallow water tables associated with periods of recent high levels of precipitation and/or low levels of evapotranspiration. Frequently determined in the spring.

Sediment – Solid material, both mineral and organic, that is in suspension, being transported, or has been moved from its site of origin by air, water, gravity, or ice and has come to rest on the earth's surface either above or below sea level.

Sediment Forebay – A settling basin or plunge pool constructed at the incoming discharge points of a stormwater facility.

Sedimentation (or settling) – A pollutant removal method to treat stormwater runoff in which gravity is utilized to remove particulate pollutants. Pollutants are removed from the stormwater as sediment settles or falls out of the water column. An example of a BMP utilizing sedimentation is a detention basin.

Seed Bank – The accumulation of viable plant seeds occurring in soil and available for germination under favorable environmental conditions.

Seepage – 1. Water escaping through or emerging from the ground. 2. The process by which water percolates through the soil.

Seepage Length – In sediment basins or ponds, the length along the pipe and around the anti-seep collars that is within the seepage zone through an embankment.

Setback – A distance from the edge of a waterbody within which intensive development is restricted. Setbacks are established by local regulation for the purpose of maintaining open space next to streams, lakes, and other waterbodies. The area within setbacks is frequently used for flood control, recreation, preservation of drinking water supply, and wildlife habitat enhancement.

Shallow Marsh – A zone within a stormwater extended detention basin that exists from the surface of the normal pool to a depth of 6 to 18 inches and has a large surface area, therefore requiring a reliable source of baseflow, groundwater supply, or a sizeable drainage area to maintain the desired water surface elevations to support emergent vegetation.

Sheet Flow – Water flow with a relatively thin and uniform depth.

Short-Circuit – A faster, channelized water flow route that results in a lower actual hydraulic residence time than the theoretical hydraulic residence time. This may reduce the effectiveness of a BMP.

Side Slopes (Engineering) – The slope of the sides of a channel, dam, or embankment. It is customary to name the horizontal distance first, as 1.5 to 1, or frequently, 1 ½: 1, meaning a horizontal distance of 1.5 feet to 1 foot vertical.

Silt – 1. (Agronomy) A soil separate consisting of particles between 0.05 and 0.002 millimeter in equivalent diameter. 2. A soil textural class. 3. (Engineering) According to the Unified Soil Classification System a fine grained soil (more than 50% passing the No. 200 sieve) that has a low plasticity index in relation to the liquid limit.

Silviculture – A branch of forestry dealing with the development and care of forests.

Site – The parcel of land being developed, or a designated planning area in which a land development project is located.

Soil Science – Science dealing with soils as a natural resource on the surface of the earth including soil formation, classification, mapping; physical, chemical, biological, and fertility properties of soils per se; and these properties in relation to the use and management of soils.

Soil Test – Chemical analysis of soil to determine needs for fertilizers or amendments for species of plant being grown.

Soil Texture – Relative proportion of the physical components of any given soil. For instance, clay is defined as soil having > 40% clay, < 45% sand and < 40% silt.

Spillway – An open or closed channel, or both, used to convey excess water from a reservoir. It may contain gates, either manually or automatically controlled to regulate the discharge of excess water.

Spillway Design Flood (SDF) – A benchmark rainfall event used to develop criteria for the design of BMPs that incorporate emergency spillways or overflows. Complete specification of the storm includes rainfall depth in inches, return frequency, and storm duration.

Stabilization – Providing adequate measures, vegetative and/or structural, that will prevent erosion from occurring.

Stage – Water surface elevation above any chosen datum.

Stage-Area Curve – A line graph showing the relationship between the depth of water and the surface area of a pond, wetland, or lake.

Stage-Discharge Curve – A line graph showing the relationship between water depth and outflow from a body of water.

Stage (Hydraulics) – The variable water surface or the water surface elevation above any chosen datum.

State Project – Any land development project which is undertaken by any state agency, board, commission, authority or any branch of state government, including state supported institutions of higher learning.

Stilling Basin – An open structure or excavation at the foot of an outfall, conduit, chute, drop, or spillway to reduce the energy of the descending stream of water.

Storm Sewer – A system of pipes, separate from sanitary sewers, that only carries runoff from buildings and land surfaces.

Stormwater Filtering – Stormwater treatment methods which utilize an artificial media to filter out pollutants entrained in urban runoff.

Stormwater Hot Spot – An area where the land use or activities are considered to generate runoff with concentrations of pollutants in excess of those typically found in stormwater.

Stormwater Management Facility – A device that controls stormwater runoff and changes the characteristics of that runoff including, but not limited to, the quantity and quality, the period of release, or the velocity of flow.

Stormwater Management Plan – A document containing material for describing how existing runoff characteristics will be affected by a land development project and methods for complying with the requirements of the local program or this chapter.

Stormwater Ponds – A land depression or impoundment created for the detention or retention of stormwater runoff.

Stormwater Wetlands – Shallow, constructed pools that capture stormwater and allow for the growth of characteristic wetland vegetation.

Stream Buffers – Zones of variable width which are located along both sides of a stream and are designed to provide a protective natural area along a stream corridor.

Stream Channel Protection (C_pV) – A design criteria which requires 24 hour detention of the one year post developed, 24 hour storm event for the control of stream channel erosion.

Structural SMPs – Devices which are constructed to provide temporary storage and treatment of stormwater runoff.

Subcritical Flow – The state of flow when the depth is greater than the critical depth.

Subgrade – Soil that is prepared and compacted to support a structure or a pavement system.

Substrate – Substances used by organisms for growth in a liquid medium. Surface area of solids or soils used by organisms to attach.

Succession – The temporal changes of plant and animal populations and species in an area that has been disturbed.

Super Critical Flow – The state of flow when the depth is less than the critical depth. Transitions between supercritical and sub-critical flow may result in turbulence associated with a hydraulic jump.

Surcharge – A flow condition occurring in closed conduits when the hydraulic grade line is above the crown of the sewer. This condition usually results localized flooding or stormwater flowing out the top of inlet structures and manholes.

Surface Infiltration Rate – The rate at which water enters the soil or other porous surface. The measurement of surface infiltration rates requires that the underlying soil be completely saturated and that infiltration occurs by gravity under a unit hydraulic gradient.

SWMM (Storm Water Management Model) – Rainfall-runoff event simulation model sponsored by the U.S. Environmental Protection Agency.

Tailwater – Water, in a river or channel, immediately downstream from a structure.

Tailwater Condition – minimum and maximum - The depth of water in the receiving water.

Technical Release No. 20 (TR-20) - A Soil Conservation Service (now NRCS) watershed hydrology computer model that is used to compute runoff volumes and route storm events through a stream valley and/or ponds.

Technical Release No. 55 (TR-55) – A watershed hydrology model developed by the Soil Conservation Service (now NRCS) used to calculate runoff volumes and provide a simplified routing for storm events through ponds.

Temporary Seeding – A seeding which is made to provide temporary cover for the soil while waiting for further construction or other activity to take place.

Ten Year Storm (QP 10) – The peak discharge rate associated with a 24 hour storm event that occurs on average once every ten years (or has a likelihood of occurrence of 1/10 in a given year).

Terrestrial – Living or growing on land that is not normally flooded or saturated.

Time of Concentration – The time required for water to flow from the most remote point of a watershed, in a hydraulic sense, to the outlet.

Toe (Of Slope) – Where the slope stops or levels out. Bottom of the slope.

Toe Wall – The downstream wall of a structure, usually to prevent flowing water from eroding under the structure.

Topsoil – Fertile or desirable soil material used to top dress roadbanks, subsoils, parent material, etc.

Total Nitrogen (TN) – A measure of all organic and inorganic nitrogen forms in a water sample. Functionally, TN is equal to the sum of TKN and $NO_3 + NO_2$-N.

Total Organic Carbon (TOC) – A measure of the total reduced carbon in a water sample.

Total Phosphorus (TP) – A measure of the total phosphorus in a water sample, including organic and inorganic phosphorus in particulate and soluble forms.

Total Suspended Solids (TSS) – A measure of the filterable matter in a water sample.

Tractive Force – The total cross-sectional force experienced by a rigid channel or conduit as a result of channel flow (expressed in units of force per length). This force tends to displace soil particles, rocks and channel liners in the downstream direction and must be resisted by friction or by structural anchors. The tractive force is equal to the unit tractive force multiplied by the wetted perimeter of the conduit.

Transition Zone – The area between habitats or ecosystems (see ecotones). Frequently, transition zone is used to refer to the area between uplands and wetlands. In other cases, wetlands are referred to as transitional areas between uplands and aquatic ecosystems.

Transmissivity (in-plane flow capacity) – Rate that water can be made to flow through the cross section of a thin layer or conduit under the influence of a unit hydraulic gradient. Measured as a volumetric rate per unit width (e.g., square feet meters per minute, or gallons per minute per foot). Equal to the hydraulic conductivity times the thickness of the layer or conduit.

Transpiration – The transport of water vapor from the soil to the atmosphere through growing plants.

Trash Rack – Grill, grate, or other device at the intake of a channel, pipe, drain, or spillway for the purpose of preventing oversized debris from entering the structure.

Travel Time – The time required for water to flow from the outlet of a drainage sub-basin to the outlet of the entire drainage basin being analyzed. Travel time is normally concentrated flow through an open or closed channel.

Trout Waters – Waters classified as (T) or (TS) by the New York State DEC.

Turbidity – Cloudiness of a liquid, caused by suspended solids; a measure of the suspended solids in a liquid.

Two Year Storm (Q_P 2) – The peak discharge rate associated with a 24 hour storm event that occurs on average once every two years (or has a likelihood of occurrence of 1/2 in a given year).

Type II Rainfall Distribution – One of the standard NRCS 24-hour rainfall distributions. The distribution allocates rainfall as a percentage of total rainfall over discrete time intervals.

Uniformity Coefficient – A measure of the range in particle sizes associated with a granular mixture. Materials with the lowest uniformity coefficients are most uniform. Uniform materials are also called open graded materials. If the uniformity coefficient is less than 4 or 5, the material is considered uniform in particle size. The uniformity coefficient is computed as follows: $C_u = (D_{60} / D_{10})$

D_{60} is the sieve opening size through which 60% of the layer material will pass. D_{10} is the sieve opening size through which 10% of the layer material will pass.

Ultimate Condition – Full watershed build-out based on existing zoning.

Urban Runoff – Stormwater from city streets and adjacent domestic or commercial properties that carries nonpoint source pollutants of various kinds into the sewer systems and receiving waters.

Ultra-Urban – Densely developed urban areas in which little pervious surface exists.

Unit Tractive Force (or tractive stress) – The stress (expressed in units of force per area) induced by open channel flow on the bottom and sides of its conduit or channel. This stress is responsible for sediment erosion and the downstream transport of streambed materials. The average unit force acting on a channel cross-section is equal to the product of the unit weight of water, the slope of the channel, and the hydraulic radius of the flow.

Upland – An area that is not an aquatic, wetland, or riparian habitat. An area that does not have the hydrologic regime necessary to support hydrophytic vegetation.

Velocity Head – Head due to the velocity of a moving fluid, equal to the square of the mean velocity divided by twice the acceleration due to gravity (32.16 feet per second per second).

Volumetric Runoff Coefficient (Rv) – The value that is applied to a given rainfall volume to yield a corresponding runoff volume based on the percent impervious cover in a drainage basin.

Water Quality Design Storm – A benchmark rainfall event used to develop criteria for the design of water quality BMPs. Water quality design storms are used to size BMPs that are intended to achieve specific quality treatment objectives. Criteria based on water quality storms generally require that the design treatment efficiency be achieved during the water quality design storm and all smaller events. Complete specification of the storm includes rainfall depth in inches, return frequency, and storm duration.

Water Quality Standards – State-adopted and EPA-approved ambient standards for waterbodies. The standards prescribe the use of the waterbody and establish the water quality criteria that must be met to protect designated uses.

Water Quality Storage – The volume set aside within a BMP to detain storm runoff. The detained water is released over an extended period of time. The water quality storage is frequently expressed as a multiple of the water quality volume.

Water Quality Velocity – The maximum flow velocity encountered in a water quality BMP during the course of the water quality design storm.

Water Quality Volume – The total volume of runoff which is delivered to the inlet of a water quality BMP during the course of the water quality design storm.

Watershed – A defined land area drained by a river, stream, or drainage way, or system of connecting rivers, streams, or drainage ways such that all surface water within the area flows through a single outlet.

Water Surface Profile – Longitudinal profile assumed by the surface of a stream flowing in an open channel; hydraulic grade line.

Water Table – The upper surface of the free groundwater in a zone of saturation.

Wattles – A fence or barrier constructed of interwoven twigs and branches used to stabilize soil from erosive forces.

Wedges – A design feature in stormwater wetlands which increases flow path length to provide for extended detention and treatment of runoff.

Weir – A device used to control and measure water flow.

Weir Gate – Water-control device used to adjust water levels and measure flows simultaneously.

Wetland – An area that is inundated or saturated by surface water or groundwater at a frequency, duration, and depth sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions, including swamps, marshes, bogs, and similar areas.

Wet Swale – An open drainage channel or depression, explicitly designed to retain or intercept water.

Wet Weather Flow – A combination of dry weather flows and stormwater runoff groundwater for water quality treatment.

Wetted Perimeter – The length of the line of intersection of the plane or the hydraulic cross-section with the wetted surface of the channel.

Wilting Point – The quantity of water which will not be removed from soil under normal conditions of evaporation and plant transpiration. Usually measured as the moisture content (by volume) in soil with a capillary tension of 15 bars.

Wing Wall – The side wall extensions of a structure used to prevent sloughing of banks or channels and to direct and confine overfall.

Zonation – The development of a visible progression of plant or animal communities in response to a gradient of water depth or some other environmental factor.

Glossary References

New York State Stormwater Management Design Manual, Department of Environmental Conservation, October 2001.

Pennsylvania Stormwater Best Management Practices Manual, Department Of Environmental Protection, December 30, 2006.

Virginia Stormwater Management Handbook, Volume II, Virginia Department of Conservation and Recreation, 1999.

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APPENDIX A

LID REFERENCES

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APPENDIX A
1 LID REFERENCES

1.1 ARMY AND DOD RESOURCES

1.1.1 Unified Facilities Criteria (UFC) System

The Unified Facilities Criteria (UFC) system provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities. UFC are used for all DoD projects and work for other customers where appropriate. They are living documents and are periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Center for Engineering and the Environment (AFCEE) are responsible for administration of the UFC system. UFC are effective upon issuance and are distributed only in electronic media from the following source: Whole Building Design Guide web site http://dod.wbdg.org/.

1.1.2 Public Works Technical Bulletins (PWTB)

Public Works Technical Bulletins are published by the U.S. Army Corps of Engineers, 441 G Street NW, Washington, DC 20314-1000. They are intended to provide information on specific topics in areas of Facilities Engineering and Public Works. They are not intended to establish new DA policy. All PWTBs are available electronically at the National Institute of Building Sciences' Whole Building Design Guide web page, http://www.wbdg.org.

PUBLICATION	SUMMARY
PTWB 200-1-62 1 OCTOBER 2008 Low Impact Development For Sustainable Installations: Stormwater Design And Planning Guidance For Development Within Army Training Areas	This Public Works Technical Bulletin (PWTB) provides information on techniques and technologies that can be applied in Army training area development and addresses stormwater management and nonpoint source (NPS) pollution control through small, cost-effective landscape features known as Integrated Management Practices (IMPs). The intent of this PWTB is to provide appropriate guidance for the planning and application of Low Impact Development (LID) technologies and practices specifically for Military Range and Training Area Development. This document is intended to be a practical field guide to LID Technologies and Practices for Army installations and to provide field personnel with operational information to mitigate the negative environmental impacts of training activities. This PWTB is a field guide to practices that addresses both NPDES and other Natural Resource regulatory issues http://www.wbdg.org/ccb/ARMYCOE/PWTB/pwtb_200_1_62.pdf

PUBLICATION	SUMMARY
PTWB 200-1-36 30 SEPTEMBER 2005 Sustainable Stormwater Storage Alternatives For Army Installations	This Public Works Technical Bulletin (PWTB) transmits current information on a variety of alternative methods to store stormwater and applicability of these methods to Army installations. This report summarizes the variety of storage alternatives available other than traditional detention ponds. The focus is on alternatives for smaller sites, addressing plastic, metal, and concrete-type structures with an emphasis on underground storage so that surface areas may be used for other purposes. Alternatives discussed include pipe networks of various materials (corrugated steel, plastic and concrete); interlocking plastic block structures; French drains; and concrete vaults. Appendix A: Stormwater Management Methods reviews LID and other potential options. Appendix B contains commercially available stormwater management systems and other alternatives for storage. Appendix C provides cost information for alternative stormwater systems. Appendix D provides a summary of stormwater management methods and costs. http://www.wbdg.org/ccb/ARMYCOE/PWTB/pwtb_200_1_36.pdf
UFC 3-210-10 15 NOVEMBER 2010 Low Impact Development	This UFC provides technical criteria, technical requirements, and references for the planning and design of applicable projects to comply with stormwater requirements under Section 438 of the Energy Independence and Security Act (EISA) enacted in December 2007. The criteria and design standards in this UFC are required for all Department of Defense construction in the United States and United States Territories. This document discusses Policy and General Requirements, Planning and Design considerations, and provides a list of LID Best Practices. http://www.wbdg.org/ccb/DOD/UFC/ufc_3_210_10.pdf

PUBLICATION	SUMMARY
UFC 4-030-01 21 December 2007 Sustainable Development	This UFC provides instruction, requirements and references for customers, DoD facility professionals—including planners, programmers, designers, and maintenance personnel—and architect/engineer and construction contractors to apply sustainable development principles and strategies consistently in DoD facilities throughout their life cycle: from planning to programming and securing of funds, to site selection, design and construction, to documentation and operations and maintenance, and to reuse, or deconstruction and removal. This document also provides the sustainable policies of the Military Departments to satisfy the Office of Management and Budget (OMB) Energy Management Scorecard requirement to demonstrate comprehensive implementation of a sustainability program for green. This UFC contains discussion on LEED requirements to Control Erosion, Sedimentation, and Water Quality, Manage Stormwater Runoff, and LID practices. http://www.wbdg.org/ccb/DOD/UFC/ufc_4_030_01.pdf
DoD Guidance on Minimizing TMDL Related Impacts to DoD: Understanding and Participating in the TMDL Development Process August 2005	The purpose of this document is to assist DoD installations in minimizing impacts from the establishment of Total Maximum Daily Loads (TMDLs), including associated compliance costs. Specifically, this document provides information on the TMDL process and the operational effects of TMDLs. It then identifies opportunities for DoD personnel participation in the TMDL development process to ensure that regulators will accurately analyze an installation's pollutant contribution(s), if any, to an impaired waterbody. DoD personnel who may benefit from this document include command and installation water program managers. This document answers the following frequently asked questions: A. What is a TMDL and what are the current regulatory requirements? B. Why should DoD installations care about TMDLs? C. How can an installation determine if it may be impacted by a TMDL? D. What can DoD personnel do to address potential TMDL impacts? This document was prepared by the DoD Clean Water Act Services Steering Committee (CWASSC), which is comprised of representatives from the Military Services and other DoD Components. http://www.usma.edu/dhpw/rci/documents/7.20.pdf

PUBLICATION	SUMMARY
ASHRAE Standard 189.1 High Performance Green Buildings	The purpose of this standard is to provide minimum requirements for the siting, design, construction, and plan for operations of high-performance green buildings to: a. balance environmental responsibility, resource efficiency, occupant comfort and well-being, and community sensitivity, and b. support the goal of development that meets the needs of the present without compromising the ability of future generations to meet their own needs.
Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act, EPA 841-B-09-001	The purpose of this document is to provide technical guidance and background information to assist federal agencies in implementing EISA Section 438. Each agency or department is responsible for ensuring compliance with EISA Section 438. The document contains guidance on how compliance with Section 438 can be achieved, measured and evaluated. In addition, information detailing the rationale for the stormwater management approach contained herein has been included. http://www.wbdg.org/ccb/EPA/epa_841b09001.pdf
USACE Army LEED Implementation Guide January 15, 2008	This implementation guidance is to assist USACE Project Delivery Teams (PDTs) meet the Army's Sustainable Design and Development policy.
Questions and Answers Re. Section 438 Guidance December 2009	This document provides a series of questions and answers regarding the definition and implementation of EISA Section 438. http://www.epa.gov/owow/NPS/lid/section438/pdf/final_sec438_qa.pdf
Installation Design Guide For A Sustainable Fort Bragg, U.S. Army Corps Of Engineers Savannah District September 2003	The Installation Design Guide for a Sustainable Fort Bragg (IDG) provides a guide for design and development decisions that will enhance the physical environment and sustainability of the installation. The IDG includes methodology that promotes spatial and visual order, consistent architectural character, and development sustainability. It consists of three parts: Chapter I, Fort Bragg Design and Development Principles; Chapter II, Implementation of Fort Bragg Principles; and Chapter III, Fort Bragg Guide Specifications and Fort Bragg Specific MILCON Transformation RFP (TRFP) Requirements. https://pwbc.bragg.army.mil/pwbc/idg/html/chapter1/1-1_intro.htm

PUBLICATION	SUMMARY
LEED 2009 For Neighborhood Development U.S. Green Building Council February 2011	The LEED Reference Guide for Green Neighborhood Development, 2009 Edition, is a user's manual that guides a LEED-ND project from registration to certification. This guide is specifically designed to provide the tools necessary for sustainable choices to be made by developers, planners, architects and others involved in the vertical and horizontal development of a neighborhood development project. The Reference Guide includes detailed information on the process for achieving LEED-ND certification, detailed credit and prerequisite information, resources, and standards for the LEED 2009 for Neighborhood Development Rating System. For each credit or prerequisite, the guide provides: intent, requirements, point values, environmental, economic and social issues, related credits, summary of referenced standards, credit implementation discussion, timeline, and team recommendations, calculation methods and formulas, documentation guidance, examples, exemplary performance options, regional variations, resources, and definitions. http://www.usgbc.org/DisplayPage.aspx?CMSPageID=148

1.2 OVERVIEW OF STANDARDS AND SPECIFICATIONS

1.2.1 ASTM

ASTM International, formerly known as the American Society for Testing and Materials (ASTM), is a globally recognized leader in the development and delivery of international voluntary consensus standards. ASTM International standards are developed in accordance with the guiding principles of the World Trade Organization for the development of international standards: coherence, consensus, development dimension, effectiveness, impartiality, openness, relevance, and transparency.

These standards are used in many different fields and are very common in the construction industry and for test methods for various construction materials. Some ASTM International standards are jointly published and duplicates of AASHTO (American Association of State Highway and Transportation Officials) standards.

1.2.2 ANSI

American National Standards Institute (ANSI) oversees the creation, promulgation, and use of thousands of norms and guidelines that directly impact businesses in nearly every sector from acoustical devices to construction equipment, from dairy and livestock production to energy distribution, and many more.

1.2.3 ASHRAE

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) develops standards for its members and others professionally concerned with refrigeration processes and the design and maintenance of indoor environments. ASHRAE writes standards for the purpose of establishing consensus for: 1) methods of test for use in commerce and 2) performance criteria for use as facilitators with which to guide the industry. ASHRAE publishes the following three types of voluntary consensus standards: Method of Measurement or Test, Standard Design, and Standard Practice. ASHRAE does not write rating standards unless a suitable rating standard will not otherwise be available.

Consensus standards are developed and published to define minimum values of acceptable performance, whereas other documents, such as design guides, may be developed and published to encourage enhanced performance.

1.2.4 IBC

The International Building Code (IBC) is a model building code developed by the International Code Council (ICC). A model building code has no legal status until it is adopted or adapted by government regulation. The IBC provides minimum standards to insure the public safety, health, and welfare insofar as they are affected by building construction and to secure safety to life and property from all hazards incident to the occupancy of buildings, structures, or premises.
It incorporates all aspects of building construction. It is made up of thirty-five (35) chapters and several appendices. Each chapter is broken down into sections and each section into sub-sections. Each section describes performance criteria to be met or references other sections of the IBC or other standards such as ANSI, ASTM, etc.

1.3 LEED AND LID

The following LEED credits can be achieved by employed LID BMPs in the project. Please refer to the US Green Build Council for further information.

1.3.1 Credit 5.1 – Site Development, Protect of Restore Habitat (1 point)

The intent is to conserve existing natural areas and restore damaged areas to provide habitat and promote biodiversity. The ability to earn this credit depends greatly on the size of the project site and land within the site boundary (but outside development footprint) that is made available for habitat.

OPTION 1
On greenfield sites, limit all site disturbance to 40 feet beyond the building perimeter; 10 feet beyond surface walkways, patios, surface parking, and utilities less than 12 inches in diameter; 15 feet beyond primary roadway curbs and main utility branch trenches; and 25 feet beyond constructed areas with permeable surfaces (such as pervious paving areas, stormwater detention facilities, and playing fields) that require additional staging areas in order to limit compaction in the constructed area.

OR

OPTION 2
On previously developed or graded sites, restore or protect a minimum of 50% of the site area (excluding the building footprint) with native or adapted vegetation. Native/adapted plants are plants indigenous to a locality or cultivars of native plants that are adapted to the local climate and are not considered invasive species or noxious weeds. Projects earning Sustainable Site Credit 2 and using vegetated roof surfaces may apply the vegetated roof surface to this calculation if the plants meet the definition of native/adapted.

1.3.2 Credit 5.2 – Site Development, Maximize Open Space (1 point)

The intent of this credit is to provide a high ratio of open space to development footprint to promote biodiversity.

1.3.3 Credit 6.1 – Stormwater Design, Quantity Control (1 point)

The intent of this credit is to limit disruption of natural water hydrology by reducing impervious cover, increasing on-site infiltration, reducing or eliminating pollution from stormwater runoff, and eliminating contaminants. Because the reduction of stormwater runoff reduces the amount of contaminants flowing into the soil, ecosystem health is promoted.

CASE 1: Sites with Existing Imperviousness 50% or Less

OPTION 1
Implement a stormwater management plan that prevents the post development peak discharge rate and quantity from exceeding the pre-development peak discharge rate and quantity for the 1- and 2-year 24-hour design storms.

OPTION 2
Implement a stormwater management plan that protects receiving stream channels from excessive erosion. The stormwater management plan must include stream channel protection and quantity control strategies.

CASE 2: Sites with Existing Imperviousness Greater Than 50%
Implement a stormwater management plan that results in a 25% decrease in the volume of stormwater runoff from the 2-year 24-hour design storm.

1.3.4 Credit 6.2 – Stormwater Design, Quality Control (1 point)

The intent is to limit disruption and pollution of natural water flows by managing stormwater runoff. Specifically, the goal is to reduce the runoff of total suspended solids and nutrients from the building site.

Implement a stormwater management plan that reduces impervious cover, promotes infiltration, and captures and treats the stormwater runoff from 90% of the average annual rainfall using acceptable best management practices (BMPs).

BMPs used to treat runoff must be capable of removing 80% of the average annual post development total suspended solids (TSS) load based on existing monitoring reports. BMPs are considered to meet these criteria if (1) they are designed in accordance with standards and specifications from a state or local program that has adopted these performance standards, or (2) there exists in-field performance monitoring data demonstrating compliance with the criteria. Data must conform to accepted protocol (e.g., Technology Acceptance Reciprocity Partnership [TARP], Washington State Department of Ecology) for BMP monitoring.

1.3.5 Credit 7.1 – Heat Island Effect, Non-Roof (1 point)

The intent is to reduce heat islands (thermal gradient differences between developed and undeveloped areas) to minimize impact on microclimate and human and wildlife habitat.

OPTION 1
Provide any combination of the following strategies for 50% of the site hardscape (including roads, sidewalks, courtyards and parking lots):

- Shade (within 5 years of occupancy)
- Paving materials with a Solar Reflectance Index (SRI) of at least 29
- Open grid pavement system

OR

OPTION 2
Place a minimum of 50% of parking spaces under cover (defined as underground, under deck, under roof, or under a building). Any roof used to shade or cover parking must have an SRI of at least 29.

1.3.6 Credit 7.2 – Heat Island Effect, Roof (1 point)

The intent is to reduce heat islands (thermal gradient differences between developed and undeveloped areas) to minimize impact on microclimate and human and wildlife habitat.

OPTION 1
Use roofing materials having a Solar Reflectance Index (SRI) equal to or greater than the values in the table below for a minimum of 75% of the roof surface.

OR

OPTION 2
Install a vegetated roof for at least 50% of the roof area.

OR

OPTION 3
Install high albedo and vegetated roof surfaces that, in combination, meet the following criteria:

$$(\text{Area of SRI Roof} / 0.75) + (\text{Area of vegetated roof} / 0.5) \geq \text{Total Roof Area}$$

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APPENDIX B

CURRENT STATE NPDES AND REGULATORY PROGRAMS

Source: U.S. Environmental Protection Agency
Office of Water Office of Wastewater Management Water Permits Division
June 2011

http://www.epa.gov/npdes/pubs/sw_state_summary_standards.pdf

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EPA Region	Program	Date	Where required?	Size Threshold	Volume Control Requirement			Redevelopment Standard
					Retention	Treatment	Exception	
1	Connecticut	2009	MS4s	1 acre disturbed area		Capture and treat 1" (non-regulatory – only described in the manual)		Same as new development
1	Maine	2008	MS4s	1 acre disturbed area		Treat 1" times impervious area plus 0.4 times pervious area		No increase in current stormwater runoff
1	Massachusetts	2009	Wetland areas	1 acre disturbed area	Recharge (post development volume to predevelopment volume)	Treat 0.5" (1" in critical and other areas)		Post to pre, minimize recharge loss, follow Stormwater Management Standards
1	New Hampshire	2003	MS4s	1 acre disturbed area / 100,000 sf outside MS4s	Infiltrate, evapotranspire, or capture first 1"			Same as new development
1	Rhode Island	2011	State-wide	1 acre disturbed area		Capture and treat WQv equivalent to 1.2" rainfall runoff	WQv requirement may be waived or reduced by applying disconnection-based LID practices	Same as new development if < 40% IC; >40% IC then reduce IC by 50% or water quality and recharge for 50% of area
1	Vermont	2003 (Draft 2010)	State-wide	1 acre development, redevelopment and/or increase IC	Capture 90% annual storms		WQv may be reduced where non-structural practices are employed.	Reduce IC by 20% or treat 20% of WQv
2	New Jersey	2009	State-wide	1 acre disturbed area or increase IC by ≥ 0.25 acres	Maintain groundwater recharge volume or infiltrate runoff for 2-year storm (post development volume to predevelopment volume)			50% TSS reduction or equivalent to existing BMP; 80% TSS removal to new IC
2	New York	2010	State-wide	1 acre disturbed area	RR for post-development volume (0.8" – 1.2") to replicate pre-development hydrology	Remaining WQv not retained must be treated	Single family homes less than 5 acre disturbance	Same as new development but if not possible IC reduced by 25%, and/or 25% WQv treated
3	Delaware	2010 (Draft)	State-wide	5,000 sf disturbed area	RR for 1-year event (post-development runoff volume to predevelopment volume) or 0% effective IC		RR practices should be employed to the MEP.	RR to reduce runoff by 20% from existing conditions[2]
3	Maryland	2009 (2000)	State-wide	5,000 sf disturbed area	Manage 0.9" / 1" of rainfall			Same as new development if <40% IC, For >40% IC, volume control required for 50% of existing imperviousness, no channel protection for existing imperviousness

EPA Region	Program	Date	Where required?	Size Threshold	Volume Control Requirement			Redevelopment Standard
					Retention	Treatment	Exception	
3	Pennsylvania	2006	MS4s	1 acre disturbed area	For sites < 1 acre; Remove 1" of runoff from IC. All sites: No post development runoff volume increase for the 2-year storm	Sites <1 acre: Capture 2" of runoff from contributing IC.		Same as new development; modeling guidance for pre-development IC
3	District of Columbia	2004	State-wide	5,000 sq ft of land disturbance	Narrative standard			
3	Virginia	2008	MS4s	1 acre disturbed area	Narrative standard			20% (sites > 1ac) 10% (sites ≤1ac)P reduction from existing condition
3	West Virginia	2009	MS4s	1 acre disturbed area	Keep and manage on site 1" rainfall from 24-hour storm preceded by 48 hours of no rain			0.2" reduction of 1" on site retention standard and additional 0.2" reductions exist
4	Alabama	2009	MS4s	1 acre disturbed area	Narrative standard			
4	Florida	1995 - present	State-wide	4,000 sq ft imperv area	Must meet predevelopment volume in closed basins only	Varies by WMD – From first ½ inch runoff to 1.25 times percent imperviousness plus an additional one half inch of runoff for online retention systems.		Same as new development
4	Georgia	2007	MS4s	1 acre disturbed area		Treat runoff from 85% of storms (1.2" rainfall)		Same as new development
4	Kentucky	2010	MS4s	1 acre disturbed area		Manage 80th percentile precipitation event runoff (0.75")[2]		Same as new development
4	Mississippi	2009	MS4s	1 acre disturbed area	Narrative standard			
4	North Carolina	2006	In 20 coastal counties; Water supply watersheds, nutrient sensitive waters, ONRWs	1 acre disturbed area; Coastal-Non residential: 10,000 sf IC; Residential w/in ½ mile shellfish waters: 10,000 sf IC		Non-coastal: 1" rainfall; Coastal: 1.5" rainfall		Same as new development
4	South Carolina	2006	MS4s	1 acre disturbed area	1,000 ft from shellfish waters, retain 1.5" of rainfall	Volume control varies by practice		Same as new development
4	Tennessee	2010	MS4s	1 acre disturbed area	Infiltrate, evapotranspire, harvest, or use first 1" of rainfall		If retention standard cannot be met, 80% TSS removal standard applied to remaining volume	Same as new development

EPA Region	Program	Date	Where required?	Size Threshold	Volume Control Requirement			Redevelopment Standard
					Retention	Treatment	Exception	
5	Illinois	2009	MS4s	1 acre disturbed area	Narrative standard			Same as new development
5	Indiana	2003	MS4s	1 acre disturbed area		Phase I only: Treat runoff from first 1" of precipitation		Same as new development
5	Michigan	MS4 permit withdrawn in November 2010						
5	Minnesota	2006	State-wide	1 acre disturbed area		Treat ½ inch runoff from new imp. surfaces > 1 acre		Reduce IC and/or implement stormwater management practices
5	Ohio	2009	State-wide	1 acre disturbed area		Treat WQv equivalent to 0.75" rainfall runoff volume		20% WQv treatment and/or 20% IC reduction
5	Wisconsin	2010	State-wide	1 acre disturbed area	Infiltrate runoff to achieve 60% -90% of predevelopment volume based on IC level		Size of infiltration area is limited to 1%-2% of site area.	40% TSS reduction from parking areas and roads or MEP
6	Arkansas	2009	MS4s	1 acre disturbed area	Narrative standard			
6	Louisiana	2007	MS4s	1 acre disturbed area	Narrative standard			
6	New Mexico	2007	MS4s	1 acre disturbed area	Narrative standard			
6	Oklahoma	2005	MS4s	1 acre disturbed area	Narrative standard			
6	Texas	2007	MS4s	1 acre disturbed area	Narrative standard			
7	Iowa	2009	MS4s	1 acre disturbed area		Treat 1.25 inch WQv	WQv depth can be adjusted locally based on historical data	Same as new development
7	Kansas	2004	MS4s	1 acre disturbed area	Narrative standard			
7	Missouri	2008	MS4s	1 acre disturbed area	Narrative standard			
7	Nebraska	2005	MS4s	1 acre disturbed area	Narrative standard			
8	Colorado	2001	MS4s	1 acre disturbed area	Narrative standard			
8	Montana	2010	MS4s	1 acre disturbed area	Infiltrate, evapotranspire, or capture for reuse runoff from first 0.5"			Same as new development
8	North Dakota	2009	MS4s	1 acre disturbed area		Treat 0.5" runoff from IC		Same as new development
8	South Dakota	2003	MS4s	1 acre disturbed area	Narrative standard			

EPA Region	Program	Date	Where required?	Size Threshold	Volume Control Requirement			Redevelopment Standard
					Retention	Treatment	Exception	
8	Utah	2010	MS4s	1 acre disturbed area	Narrative standard			
8	Wyoming	2010	MS4s	1 acre disturbed area	Narrative standard			
9	Arizona	2002	MS4s	1 acre disturbed area	Narrative standard			
9	California	2003	MS4s	1 acre of disturbed area	Retain volume from 85th percentile storm event		Biofiltration may be used if retention is infeasible	Local program defined
9	Hawaii	2007	MS4s	1 acre disturbed area	Narrative standard			
9	Nevada	2010	MS4s	1 acre disturbed area		80% annual runoff volume treatment	Treatment volume may be locally determined based on historical records	Same as new development
10	Alaska	2009	MS4s	1 acre disturbed area	Retain first 0.52 inches of rainfall from 24 hr event preceded by 48 hrs of no precip.			Same as new development
10	Idaho	2000	MS4s	1 acre disturbed area	Narrative standard			
10	Oregon	2007	MS4s	1 acre disturbed area	80% average annual runoff volume reduction (for Phase I)			Capture and treat 80% annual average runoff
10	Washington	2007	MS4s	2000 sf of new and/or replaced IC or 7000 sf disturbed area	Infiltrate, disperse, and retain onsite to MEP	Volume predicted from 6 month 24 hr storm OR 91st percentile 24 hr runoff volume indicated by continuous runoff model. Max flow rate where 91% of runoff volume (determined by model) will be treated		Same as new development when size threshold is met.

APPENDIX C

GREEN STREETS

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APPENDIX C: GREEN STREETS

Municipal streets are key determinants of neighborhood livability. They provide access to homes and neighborhood destinations for pedestrians, and a variety of vehicle types, from bicycles and passenger cars to moving vans and fire apparatus. Urban streets provide a place for human interaction: a place where children play, neighbors meet, and residents go for walks and bicycle rides. The design of residential streets, together with the amount and speed of traffic they carry, contributes significantly to a sense of community, neighborhood feeling, and perceptions of safety and comfort.

1.1 DEFINITION

Defined as “Parks not Pipes, the “green streets” are a LID solution to stormwater runoff providing direct infiltration and evaporation of stormwater runoff close to its source, that can provide sustainable, LID stormwater management to new development, redevelopment, and high density urban retrofits. A “green” street is a stormwater management approach that uses soil, water, and plants to filter, infiltrate, evaporate, and treat stormwater from urban roads and streets.

Photo 1-1: Rendering of a Green Street

According to the "*Green Streets – Innovative Solutions for Stormwater and Stream Crossings,*" eco-friendly "green" streets may be defined as having the functional characteristics designed to:

- Integrate a system of runoff pollutant treatment within its right of way (ROW)
- Reduce the quantity of water that is piped directly to streams and rivers through traditional storm drain systems
- Reduce combined sewer overflow (CSO) infrastructure
- Be a visible component of the system of "green infrastructure" that is incorporated into the aesthetics of the community
- Maximize the use of street tree canopy coverage for rainfall interception as well as temperature (urban heat island) mitigation

1.1.1 Purpose

Urban stormwater runoff that isn't properly managed can pollute rivers and streams and contribute to CSOs. Green streets reduce the negative impacts of stormwater runoff. They mimic natural conditions by using soil, water and vegetation to manage runoff on the surface, at its source where the rain falls.

The main purpose is to retain and treat stormwater runoff generated by urban streets through a contiguous network of bioretention systems, vegetated swales, permeable pavements, infiltration trenches (planters), street trees and sediment filtered strips, etc.

Green streets use bioretention and soil filtration to collect and treat runoff pollutants through layers of mulch, soil media, plant roots, and grave. Pollutants such as oil, grease, bacteria, are retained, broken down or absorbed. Because the system is open bottomed, treated water is then infiltrated into the ground, or can be directed into a traditional stormwater collection system, or diverted directly to streams.

While curb-gutter-pipe systems transport and concentrate runoff problems elsewhere, ecologically-based green street solutions use landscape to absorb and treat runoff on-site. Among many, eco-friendly "green" streets provide function such as:

- Provide safety for walkers, bikers, buses, and cars
- Create a greener, more sustainable environment
- Provide runoff reduction and reduce combined sewer overflow (CSO) infrastructure demands
- Reduce stormwater runoff pollutant transport into downstream water
- Help reduce heat island effect
- Improve air quality and aesthetics
- Provide "on-site" source control for stormwater
- Reduce and treat stormwater close to the source, and
- Increased urban open space

1.1.2 Conditions Where Practice Applies

New construction and retrofits in residential, commercial, institutional, and industrial settings. This is to address issues such as runoff flow and volume; pollution transport; CSO infrastructure demands; and urban heat island effects.

The figures in the following page best illustrate some typical sustainable green street applications in some major cities within the country and the world around.

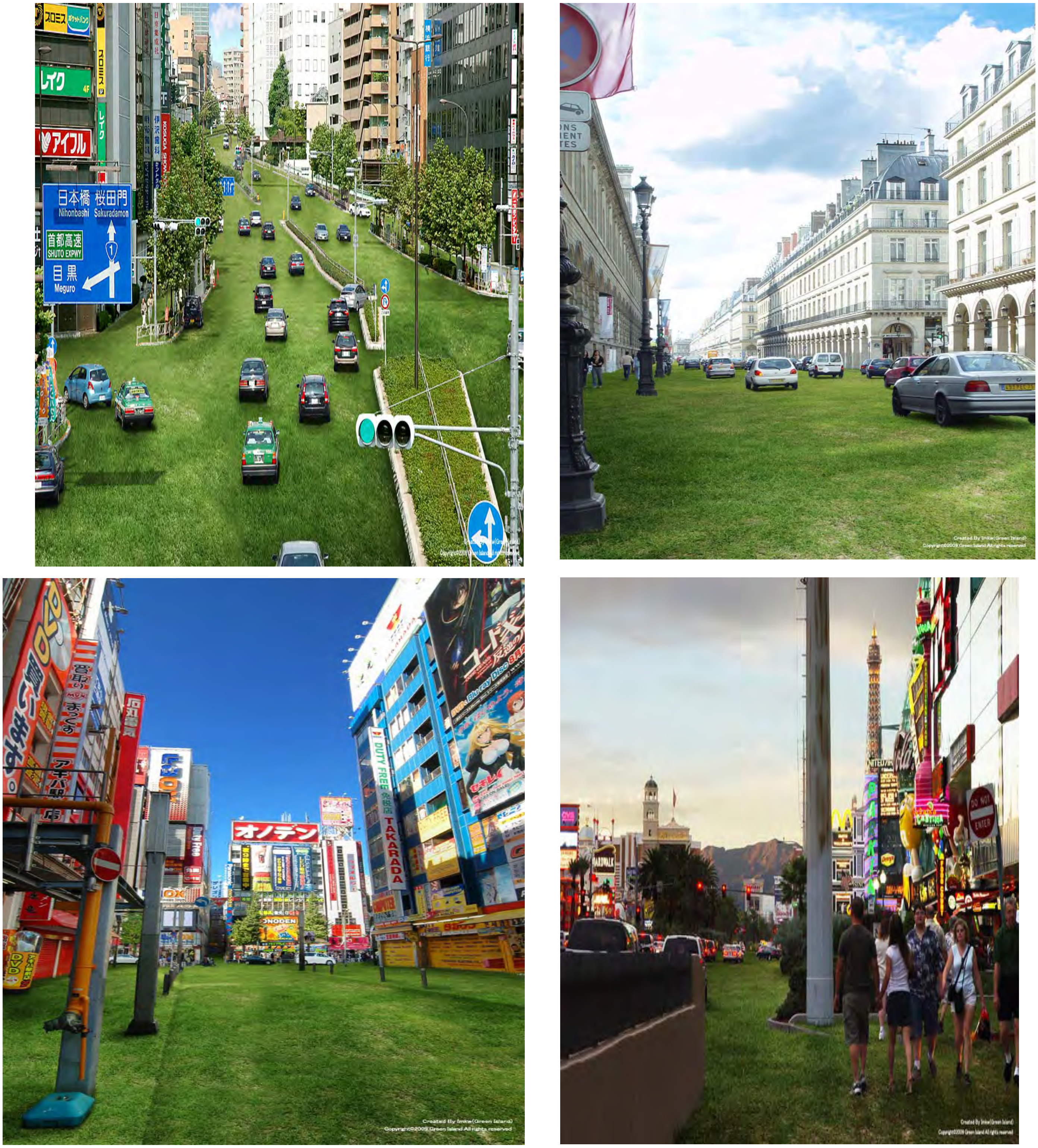

Photo 1-2: Typical Sustainable Green Street Applications in Major Cities

1.1.3 Planning Considerations

Urban roads and streets are the prime collection sites for myriad pollutants. The Federal Highway Administration estimates that more than 20 percent of U.S. roads are in urban areas. Urban roads, along with sidewalks and parking lots, are estimated to constitute almost two-thirds of the total urban impervious cover, and also contribute to a correspondingly similar ratio of polluted runoff generated from these municipal streets.

Urban roads and streets generate a significant amount of runoff that is transported to the municipal storm drain system through a huge and complicated network of curbs and gutters, drop inlets, buried pipes, and much more. Effective road drainage-disposal goal, which may be translated as moving stormwater runoff into the curb-gutter-pipe system as quickly as humanly possible, has been the usual design priority for cities while opportunities for “at-source” runoff control and enhanced environmental concerns have been overlooked, especially in the modern urbanized environment.

Compounding the deliberate rapid disposal of stormwater *via* curb-gutter-pipes, roads also have become the prime collection sites for urban pollutants. Since the roads are an integral component of total urbanscape, especially the stormwater runoff conveyance system, besides being a convenient carrier of runoff pollutants, they are also impacted by many pollutants such as trash (*e.g.,* cups, cans, and plastic bags), sediments, metals, organics associated with petroleum and widespread waste food products, etc. These pollutants result from many sources including: vehicle brake pads, vehicle tires, combustion byproducts, motor oil, vehicle emissions, brake linings, automotive fluids, gas stations, and atmospheric deposition, as well as myriad other waste products typical of metropolitan roads and streets. These are the concerns that must be addressed promptly and effectively by city officials for public safety and for providing clean, sustainable environment for the citizens.

Urban roads and streets present many opportunities for “green street” infrastructure applications to address such pollution and environmental problems, as stated above, cost-effectively and efficiently. Among many, following are the few guiding principles that may be considered for the planning and designing of eco-friendly “green” streets.

1. Modest, small, decentralized, distributed green infrastructure can have a cumulative effect.

2. Each distributed parcel must in some way contribute to the city green infrastructure.

3. Environmental impacts of developments must be mitigated at source .

4. Need to bring local zoning ordinances and codes in conformity with state and federal water quality and stormwater runoff control regulations such as Clean Water Act, 2002 (CWA) and subsequent 1987 Amendments to CWA, as well as recently passed Energy Independence & Security Act (EISA) of 2007.

New research conducted both at national and state levels points to opportunities for managing stormwater runoff and associated pollutants originating from roads and streets using “Green Street “practices, procedures, and approaches. Many of these practices use standard LID stormwater management BMPs, such as rain gardens, bio-retention basins, and vegetated swales, green roofs, permeable pavements and pavers, grass strips, trees, shrubs, planters, etc. Others methods go far beyond by advocating measures such as: changing site-design elements to maximize existing infrastructure by focusing on reducing parking spaces; narrower streets; efficient "green" street lighting; eliminating cul-de-sacs and dead-end streets; reducing impervious areas; and that of the re-designing of road surfaces such that the surface runoff is directed towards the center (i.e., reversed crown) instead of the conventional roadway center-crown surface design.

1.1.4 Design Criteria & Specification

The determining goal for "green" street design is to maximize removal of pollutants and runoff reduction by processes such as infiltration through soil matrix and evaporation and nutrient uptake by vegetation, respectively. Following LID design principles, the green street design approach tries to blend the natural hydrological cycle within the "engineered" design urbanscape infrastructure.

Before considering design criteria, an understanding of the basic functional differences between traditional and "green" street design goals as well as the outstanding institutional barriers in adopting this approach is important and discussed in the following two sections.

1.1.4.1 Green Streets vs. Traditional Streets

Green streets provide complete integration of design functions from different disciplines for achieving water quality treatment and runoff volume reduction goals; while improving community image, enhancing neighborhood friendliness, promote walkability, and access and safety to pedestrian and bikers. Green streets approach can have considerable savings compared with traditional streets by reducing costs for CSO infrastructure requirements and those resulting from reduced sewage treatment volumes. Contrary to reduced impervious area and "at-source" runoff control by green streets, the traditional streets are designed on the premise to dispose of rainwater as quickly as possible by using curb-gutter-pipe infrastructure that results in extra burden on storm drain and CSOs, and added sewage treatment volumes.

Tree-lined eco-friendly green street approach, with landscaped vegetated strips alongside pedestrian walkways, may be another cost-effective alternative for retrofit and new construction over traditional street design. Though, they may not be able to filter all pollutants from the runoff effectively, the simple addition of trees and landscaped bioswales along streets does help in pleasing look, enhanced aesthetics, and improved environment in many ways including the following:

- Provide source control for stormwater by on-site stormwater harvesting using practices such as bioretention, bioswale, permeable paving, street trees and planters.
- Reduce impervious area by using narrower streets, redesigned roadside walkways, etc.
- Limit its transport and pollution conveyance to collection system
- Improve air and water quality
- Contribute towards enhanced aesthetics and improved environment

- Promote walkability and pedestrian friendliness
- Use the public right-of way for multiple purposes
- And much more

1.1.4.2 *Creating Institutional Framework for Success*

Technologies and engineering are no longer significant obstacles or barriers to successful implementation of the "Green Street" approach. Nevertheless, institutional issues can create the most daunting obstacles to broader acceptance and implementation of Green Street practices in new and existing urban developments. For example, narrower street design results in reduced impervious area (and thus less runoff and associated pollutants and problems) but Unified Fire Code (UFC) requirements and resistance by Fire Marshal and emergency access vehicles always overtakes the Green Street initiative. The concerns raised by opponents include that the standards for reducing street width would compromise access to larger vehicles of fire, police, ambulance, and garbage disposal, and similar service providers. There is a need to revisit UFC and local zoning codes to address and accommodate concerns raised by Fire Marshal and other service providers by providing alternative parking configurations, prohibiting parking near intersections, providing vehicle pullout space, and using smaller block lengths.

Urban roads and streets are generally in the public right of way. Therefore, their construction and implementation is the responsibility of the municipal public sector. Cooperation from transportation department, public works, police, and fire departments is essential and ideally they would play a leadership role, especially in new construction and for streets needing repair or retrofits. The city leaders and planning departments can also take the leadership to put implementation mechanisms in place such that encourage or require private developers to make "green" street concepts as in integral component of their developments.

1.1.4.3 Design Criteria

Alleys may be considered as the "low hanging fruit" of green street design. In many towns and cities, (*see* City of Chicago example below) alleys compromise a significant amount of impervious surface and are sometimes prone to flooding because they are often not connected to the storm drain system. Green street techniques like bioretention, swales, permeable paving, street planters, and curb extensions can effectively reduce and treat runoff, reduce and/or alleviate flooding, and are far less expensive than installing curb-gutter-pipe networks and connections to sewers.

As stated in the above paragraph, it is the responsibility of the cities and towns to design, construct, and maintain municipal roads and streets. Nonetheless, some or all of the following techniques should be considered and used when designing green streets.

<u>Stormwater Management</u>
Incorporating green streets as a feature of urban stormwater management requires matching road transportation functions with those of environmental performance. Enhancing roads with green

elements can improve their primary function as a transportation corridor, while simultaneously mitigating negative stormwater pollution and environmental impacts. Towns and cities are fast accepting and promoting bioretention (filtering & infiltration), bioswales, permeable paving, street tree, and other green-space programs along their urban transportation corridors; aiming to control runoff pollution and flow volumes as well as managing stormwater intelligently and efficiently.

Integrated Management Practices (IMPs)

The evolution from centralized stormwater management to greener, more sustainable BMPs necessitates a progression from installing small, distributed, individual practices to implementing broader water quality programs. Conventional end-of-pipe management practices are often installed myopically, focused primarily on collecting runoff from the drainage area and disposing it off as quickly as possible. The use of green streets allows stormwater integrated management practices (IMPs) to act in a broader environmental capacity than solely managing stormwater; wherein IMPs are defined as LID tools used for water quality treatment and flow control. For example, Chicago's Green Alley program, by using light-colored permeable and recycled concrete, addresses urban heat island effect and waste disposal issues simultaneously with stormwater management.

Green streets are an example of how individual stormwater IMPs are used as elements of a broader program aimed at mitigating a significant source of stormwater pollution. Urban roads, along with sidewalks and parking lots, are estimated to constitute almost two-thirds of the total impervious area in urban areas and contribute a similar ratio of runoff and urban stormwater pollution. Green streets use a combination of stormwater management features of bioretention, vegetated swales, and permeable pavers and pavements to enhance stormwater quality, runoff reduction, and improve the design and function of urban streets.

Reduction of Impervious Surfaces

Urbanization results in vast impervious landscapes which present challenges for the environmental sustainability of the nation’s towns and municipalities. Reducing the amount of impervious surface requirement in green street design would help in stormwater management and reduction in heat island effect and to realize many of the benefits as described later in Section 6.5.9 of this chapter.

Improved Water Quality

Urban stormwater runoff pollutes the natural water system flowing directly or through CSOs. The type of vegetative planting and biofiltration processes used in green street design help to treat and reduce runoff for improved water quality downstream.

Use of Public Right-of-Way (ROW)

The green street design approach recognizes and respects the finite limits between urban land use needs (such as efficient transportation requirements) and the protection of sustainable natural resources. By integrating stormwater infiltration/evaporation practices with other public utilities and opportunities for recreation, the design promotes shared uses within the public right of way.

Narrow Street Widths

The standards for the designing and construction of municipal streets, in particular the width of streets (for reducing stormwater pollution and “urban heat island” effect through reduced imperviousness), have been one of the most contentious issues in local jurisdictions across the country. The concerns raised by opponents include that the standards for reducing street width would compromise access to larger vehicles of fire, police, ambulance, and garbage disposal, and similar service providers.

Reasonable safety can be achieved by providing street widths such as those recommended for low, medium, or high density developments in level, rolling, or hilly terrains. Preferably, a street should be "no wider than the minimum needed" to safely and accommodate usual vehicular mix that the street will serve.

One reason that streets constitute such a significant source of stormwater volume and pollution is the impervious area associated with them. Green streets first reduce stormwater impacts by eliminating unnecessary impervious area. Many urban and suburban streets are sized to meet code requirements for emergency service vehicles, on-street parking, and free flow of traffic. These code requirements often result in streets being oversized for their typical everyday functions. The Uniform Fire Code requires that streets have a minimum 20 feet of unobstructed width; a street with parking on both sides would require a width of at least 34 feet. In practice, many suburban and urban streets may be much wider than this as local design practices have increased street widths to 40 and 50 feet. There is often a large percentage of street impervious area that serves no practical purpose other than generating stormwater runoff. In addition to stormwater concerns, wide streets have many detrimental effects on neighborhood livability, traffic conditions, and pedestrian safety.

Photo 1-3: A Green Street

Many communities have adopted narrower street width standards while also accommodating emergency vehicles by developing alternative street parking configurations, prohibiting parking near intersections, providing vehicle pullout space, and using smaller block lengths. A key to identifying and successfully codifying narrow street widths is coordination amongst departments, including fire, transportation, and public works.

Why Narrow Streets?
The width of streets also affects other aspects of livability. Narrow streets are less costly to develop and maintain and they present less impervious surface, reducing runoff and water quality problems. The topic of automobile speeds on neighborhood streets probably tops the list of issues. Where streets are wide and traffic moves fast, cities often get requests from citizens to install traffic calming devices, such as speed humps. However, these can slow response times of emergency service vehicles creating the same, or worse, emergency response concerns than narrow streets.

Safe and Livable
There is growing appreciation for the relationship between street width, vehicle speed, the number of crashes, and resulting fatalities. Deaths and injuries to pedestrians increase significantly as the speed of motor vehicles goes up. In 1999, planner Peter Swift studied approximately 20,000 police accident reports in Longmont, Colorado to determine which of 13 physical characteristics at each accident location (e.g., width, curvature, sidewalk type, etc.) accounts for the crash. The results are not entirely surprising: the highest correlation was between collisions and the width of the street. A typical 36-foot wide residential street has 1.21 collisions/mile/year as opposed to 0.32 for a 24 foot wide street. The safest streets were narrow, slow, 24-footwide streets.

Green streets can incorporate a wide variety of design elements including street trees, permeable pavements, bioretention, and swales. Although the design and appearance of green streets will vary, the functional goals are the same. Green streets techniques will encourage the interaction of stormwater with soil and vegetation to promote infiltration and retention.

The use of green streets offers the capability of transforming a significant stormwater and pollutant source into an innovative treatment system. Green streets optimize the performance of public space easing maintenance concerns and allowing municipalities to coordinate the progression and implementation of stormwater control efforts. In addition, green streets optimize the performance of both the transportation and water infrastructure. Effectively incorporating green techniques into the transportation network

Green streets have different shapes and sizes, but they all have stormwater management benefits (Section 6.5.9 in this Chapter) that help protect watershed integrity and health. Green street features include: vegetated curb extensions; sidewalk planters; landscaped medians; bioretention cell and rain garden; vegetated swales; permeable paving; and streets. Here below are provided some examples of typical green street features and characteristics.

Photo 1-4: A Green Street

1.1.4.4 Design Elements

Green streets are generally in the public right of way (ROW), and, thus, their implementation will largely depend on the public sector. Cooperation transportation, emergency, fire and other departments is essential and ideally they would play a leadership role, especially in retrofit decision-making. The city leaders and planning departments can also take the leadership to put implementation mechanisms in place that encourage or require private developers to participate in developing and supporting "green" sustainable street design in their retrofit and new construction.

Photo 1-5: A Green Street in the ROW

Green street design and its integration with surrounding buildings and open spaces attempts to mimic pre-development hydrologic functions. The design describes stormwater management strategies that allow infiltration and limit stormwater runoff. The effort provides guidance for designing environmentally sustainable and sound streets that can help protects streams and wildlife habitat. The guidance also describes basic stormwater management strategies and illustrates street designs with features such as street trees, landscaped swale, rain gardens, tree boxes, and special paving materials that allow infiltration and limit runoff.

Green street design and its integration with surrounding buildings and open spaces attempt to integrate various solutions by blending natural hydrological functions within the designed urbanscape. Green streets can incorporate a wide variety of design elements including bioretention, bioswales, permeable paving, street trees, boxes, and planters. Although design and appearance will vary depending on region and locality, the functional goals are the same such as described in the following:

(1) Provide stormwater control at source

(2) Reduce runoff flow and volume

(3) Minimize the transport of pollutant conveyance to downstream water by providing pollutant removal strategies and practices

(4) Reduce or minimize CSO loads, and

(5) Provide aesthetically, soothing, and pleasing roads and streets.

Although typical green street elements, as stated above, have already been described extensively in Chapter 2 and Chapter 5, and elsewhere, a brief description of the same is again given in the following paragraphs.

Bioretention, Bioretention Curb Extension and Sidewalk Planters

Bioretention is a versatile green street strategy. Bioretention features have been described in Section 5.1, *Bioretention*, in detail. Structural and functional characteristics of bioretention equally apply to green street features, including features such as tree boxes, planters, and curb extensions. Many natural processes occurring bioretention such as infiltration, runoff reduction, water quality, removal of pollutants, biological and chemical reactions occurring in mulch and soil matrix, nutrient uptake by plants, etc., also occur in the green street environment as well.

Photo 1-6: Bioretention

Vegetated Swales

Vegetated swales are long, shallow, vegetated depressions, with a slight longitudinal 1 to 2 percent slope. As water flows through the swale, it is slowed by vegetation, allowing sediment and pollutants to settle out. Water soaks into the soil and it is taken up by plants, and may infiltrate into the ground if the soil is well drained.

Swales or grass channels are vegetated open channels designed to accept sheet flow runoff and convey it in broad non-erosive shallow flow. The intent of swales is to reduce stormwater volume through infiltration, improve water quality through plant uptake and filtration, and reduce flow velocity by increasing channel roughness. In the simple roadside form, they have been a common historical component of road design. Additional benefits in green street design can be attained through more complex construction such as those with amended soils, underdrain, gravel storage, and thick diverse vegetation (See Chapter 5, Section 2 for Details on Vegetated Swales).

Photo 1-7: Vegetative Swale

<u>Permeable Pavement</u>
Alleys are typically slow-speed, low-traffic streets and therefore highly suitable locations for using permeable paving. The entire street surface could be constructed using permeable pavers. If heavier vehicles are anticipated for loading and unloading or the alley is “reversed crown” (sloping towards the center line), then only the middle section needs to be permeable. Permeable paving on commercial streets can be incorporated into sidewalks and parking lanes.

Photo 1-8: Permeable Pavement

Permeable pavement and pavers are described in Section 5.3 and their description equally applies to green street applications. Permeable pavements and pavers come in several forms: porous asphalt, porous concrete, permeable interlocking concrete pavers, and grid pavers, etc. Permeable asphalt and concrete are similar to their counterparts but are open graded or have reduced fines and typically have a special binder added. Methods for pouring, setting, and curing these permeable pavements also differ from the impervious versions. The concrete grid pavers are modular systems. The concrete pavers are installed with gaps between them that allow water to pass through to the base. Grid pavers are typically a durable plastic matrix that can be filled with gavel or vegetation. All of the permeable pavement systems have an aggregate base in common which provides structural support, runoff storage, and pollutant removal.

Permeable paving (pavers, porous asphalt, and pervious concrete) in the parking lane converts impervious surfaces to allow stormwater to infiltrate into the ground, which results in runoff reduction without any loss of parking on the street. The aesthetics of permeable paving can also give the illusion of narrower street and therefore help slow down traffic.

Street Trees

Street trees provide multiple benefits to the urban landscape by reducing the urban heat island effect, reducing stormwater runoff, improving the urban aesthetics, and improving air and water quality. Street trees catch and absorb/evaporate rainwater, and are important to city's sustainable stormwater efforts.

Correspondingly, they are also a critical component of green streets. However, urban environments are often inhospitable for tree growth. Trees are often given little space to grow, the soil around street trees often becomes compacted during the construction of paved surfaces, and underground utilities encroach on root space.

Photo 1-9: Street Tree

If tree roots are surrounded by compacted soils or are deprived of air and water by impervious streets and sidewalks, their growth will be impaired, their health will decline, and their expected life span will be cut short. By providing adequate soil volume and a good engineered soil mixture, the benefits obtained from a street tree would definitely multiply. To obtain a healthy soil volume, install larger tree boxes or use structural soils, root paths, or "silva cells" used under sidewalks or other paved areas. These options allow tree roots the space they need to grow to full size.

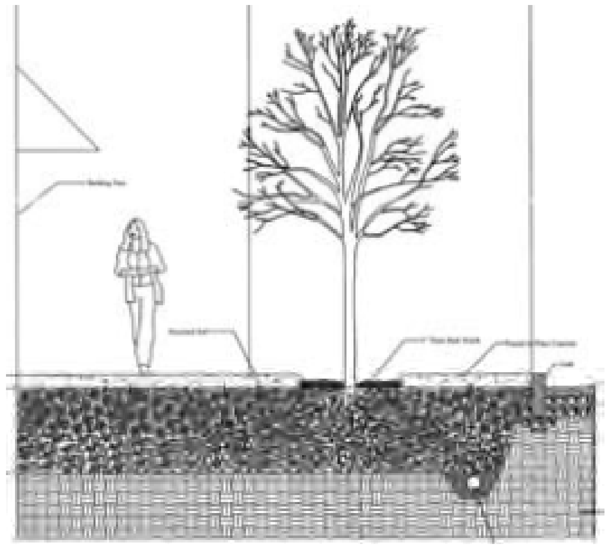

Photo 1-10: Street Tree Schematic

Street trees perform many functions and provide many benefits including calming traffic, improving air quality and conserving energy. Street trees perform a variety of functions that help reduce the amount and rate of stormwater runoff entering the piped stormwater system. Trees absorb water through their leaves, branches and roots. Trees planted in biofiltration swales slow down water flow even more by allowing water to infiltrate into the soil. While all street trees perform these functions, particular species may perform them better than others depending on characteristics such as the following:

- Foliage texture and spread characteristics
- Tree life span or longevity
- Growth rate and canopy density
- Drought tolerance and tolerance to saturated soils, compacted soils, poor soils
- Resistance to urban pollutants (air and water)

1.1.4.5 Sidewalk Tree, Tree Boxes, and Planters

Trees help reduce urban heat island effect, reduce stormwater by evaporation, and improve urban aesthetics and air quality. However, most often street trees are given very little space to grow in often inhospitable environments. The soil around street trees becomes compacted during the construction of paved surfaces and minimized as underground utilities encroach on root space. By providing adequate soil volume and a good soil mixture, the benefits obtained from a street tree multiply. To obtain a healthy soil volume, trees can simply be provided larger tree boxes, or manufactured soils, root paths, or "silva cells" can be used under sidewalk or other paved areas for roots to expand and grow. These allow tree roots expanded root zone and the space they need to grow to their full size.

1.1.5 Case Studies

Several townships and cities have started using "green" street approach to address their stormwater and related pollution problems and for realizing environmental benefits (*see* 6.5.9, *Benefits)* that green streets provide and are described in Section 6.5.9, *Benefits* of this Chapter. To illustrate the point further, successful stories from two cities, Portland and Chicago, are briefly narrated below.

1.1.5.1 *City of Portland, Oregon - - Green Streets Program*

City of Portland, Oregon, is the pioneer leader in using city-wide green street strategies that manage and treat stormwater runoff "Nature's Way" by using soil-water-plant microbial processes (as extensively described in Section 6.1, 6.2, 6.3, and 6.4), for enhancing Portland community and neighborhood livability, and strengthening the local economy.

Portland has received a great deal of recognition for the success of their green street stormwater program that was facilitated by the Green Streets Team (hereinafter Team), a local interdisciplinary team. The Team envisioned, initiated, and developed a comprehensive policy on implementing "Green Street" program in their city. The Team recognized the fact that two-third of the City's total runoff, and a similar amount of runoff pollution, was generated form within the streets and right-of-ways. The Portland city also recognized the opportunity to accomplish following goals and objectives to address both runoff and transportation problems.

- Satisfying numerous City goals for neighborhood livability, sustainable development, increased green space, stormwater management, and groundwater protection
- Integrating infrastructure functions by creating "linear parks" along streets that would provide access and safety to pedestrians and bikers
- Avoiding the key impacts of unmanaged stormwater typical of conventional urban streets
- Managing stormwater with investments that citizens can support, participate in, and lead by example
- Managing stormwater as a resource rather than an unwanted waste
- Reducing curb-gutter-pipe requirements and burden of CSOs
- Reducing impervious area by using methods as advocated by LID strategies, and
- Providing increased neighborhood amenities and value.

Photo 1-11: City of Portland, OR Green Street

The Team assembled the players who had a stake in the design, management, and maintenance of the city streets and allowed them to work together to propose and identify approaches to meet stated goals and objectives. The team first identified challenges and issues that would confront the green streets program including challenges such as local zoning ordinances, codes and standards that would disallow or discourage green street strategies and initiatives. The team members then focused on developing the necessary outreach, technical guidance, infrastructure and maintenance plans, and funding sources to address these barriers. The results of these efforts were then synthesized into a citywide Green Streets Policy, which was adopted by the Portland City Council in March 2007, and since then is being practiced and implemented successfully city-wide.

Portland Greet Street program includes the collection and treatment of polluted stormwater through using LID practices such as green roofs, planted gutters, and stormwater planters on terraces. For example, at the first floor, glass awnings are provided to collect storm runoff and funnel it directly into street cisterns. At the street level, pervious pavements are used to provide car parking and crosswalks.

1.1.5.2 *Chicago's Green Alleys Program*

Chicago's green alleys program is another example of institutional planning that developed the framework for a successful multi-benefit environmental program. The City's 13,000 publicly owned alleys consist of 1,900 miles, or equivalent of 3,500 acres of impermeable surfaces. The alley system preceded sewer connections and was originally unpaved. As the alleys were paved over time, the lack of a stormwater drainage system often led to flooding in adjacent garages and basements. The City's approach to managing stormwater from the alleys took the position that the most sustainable approach was one that did not add additional stormwater to an already overburdened sewer system, rather reduce it by on-site stormwater harvesting.

Photo 1-12: Before and After Drainage Improvement

The Green Alley Program is important for two main reasons. First, it marries green infrastructure practices in the public right-of-way with those of green infrastructure efforts on private property. This is carried out by encouraging private residents to install stormwater BMPs on their property adjacent to the green alleys to increase the environmental benefits. Second, the City used the alley retrofit efforts as an opportunity to address pollution and other environmental problems by using LID practices (described previously in Sections 6.1, 6.1, 6.3, and 6.4) of the chapter, thus, making the program truly multi-dimensional and multi-beneficial.

The main objectives of the Green Alley Program are:

- Changing the grade of the alley to drain to connecting streets rather than ponding water in the alley or draining toward garages or private property

- Using light colored paving material (concrete or asphalt) that reflects sunlight rather than adsorbing it, reducing urban heat island effect

- Incorporating recycled materials into the pavement mix to reduce the need for virgin materials and reduce the amount of waste going into the landfill; and

- Using green dark sky dark sky-compliant light fixtures to direct lamp light downward and outward where it is useful rather than upward where it wastes energy and contributes to glare and light pollution

Green alleys incorporate a variety of characteristics by using the following approaches:

- Permeable pavements (asphalt, concrete or pavers) that allow stormwater to filter through the pavement and drain into the ground, instead of collecting on hard surfaces or draining into the sewer system. The pavement can be used on the full width of an alley, or simply in a center trench.

- Recycle construction materials can be incorporated in a variety of ways in green alleys. Recycled concrete aggregate can be used in the concrete mix and as a base beneath surface paving. Also, slag, a byproduct of steel production, can be used as a component of the concrete mix, reducing industrial waste. Ground tire rubber can be used in porous asphalt and in reclaimed nonporous pavements.

- Open bottom bioretention catch basins--installed in alleys to capture and infiltrate runoff.

- High-albedo pavement, a lighter-colored surface that reflects sunlight instead of absorbing it, helping reduce the urban heat island effect.

The Program incorporates design flexibility as alleys installed are tailored to local conditions. For instance, permeable pavement is used for the entire alley surface. In other situations where buildings come right up to the edge of pavement and infiltrated water could threaten foundations, or to save on construction costs, impermeable pavement strips are used on the outside with a permeable pavement strip down the middle of medians. In areas where soils do not provide much infiltration capacity, the alley is re-graded to drain properly by directing flow to streets.

The design provides that if an alley is crowned in such a way that water flows to the side (center crown), then stormwater runoff can be accommodated by simply planting edges of the alley with swales and planters for increased infiltration and evaporation. Alternately, the alley design features advocate that all alleys, whether permeable or not, should be properly graded and pitched towards the center to allow water to run towards the center of the alley and then flow directly into the street. This prevents the need for additional CSO infrastructure and prevents adjacent buildings from flooding.

Green Street Design Issues

Green street design elements may be applicable to both new construction as well as retrofits. Typically, designing green streets in new developments are less complicating than retrofitting in existing development. below describes some of these issues. Green street design solutions may be applicable to both new streets and existing streets. Typically, designing green streets in new development are less complicated than retrofitting in existing development. The Table below from "*Green Street – Innovative Solutions for Stormwater Crossings*" describes some of these issues.

Table 1-1: Green Street Design Issues for Retrofit and New Construction

	Issue	Retrofit	New Construction
1	Planning implications	Installation of appropriate designs are restricted to existing Right of Way and any easements onto private property need to be negotiated	Creation of new road system that incorporates designs can lay framework for new development. A "system" of treatment facilities can be designed from the outset to adhere to particular site conditions, and existing drainage systems (streams).
2	Right of way requirements	"Right of Way (ROW)" restricted by adjacent development. Must ensure that installation of designs does not come at expense of pedestrian and bicycle facilities.	Dedication of new ROW can incorporate designs. Pedestrian and bicycle accommodations can be incorporated from the outset of street design.
3	Edge of roadway condition	Substantial modification to edge of roadway may be met with public resistance.	Edge treatments can be designed in accordance with chosen stormwater design.
4	Street trees	Proposed system must adapt itself to existing street trees due to expected public resistance to tree removal. Provide opportunity for increased street planting but location and species choice should reflect available planting areas.	Tree placement and species can be fully incorporated into the system
5	Utilities	Installation of designs would generally have to work around existing utilities due to prohibitive expense in removing utilities	Utilities can be consolidated and localized to eliminate conflict with designs
6	Overflow contingencies	Existing storm drain system can serve as overflow	Overflow regime must be considered
7	Stream crossing	Replace culverts with clear-space bridges (or at minimum bottomless culverts). The abutments should be set back from the river bank and outside the active floodplain so that the edge remains undisturbed and flood risks are not increased.	Opportunity for clear-span bridges set back from the river bank and outside the active floodplain, preferably with an arch to increase span/depth ration and resulting in high aesthetic appeal.

8	Cost	Structural BMP retrofit of existing development is expensive requiring retrofit to existing storm drain facilities, to existing municipal open space (*i.e.,* detention ponds) or to other developed sites (*i.e., underground storage in downtown area). Retrofits are typically funded by a municipality.*	With exception of major streets, structural designs for new construction are typically funded by a private land developer.

1.1.6 Benefits

Green streets reduce peak stormwater flows, free capacity in the pipes to carry more wastewater to sewage treatment plant, and stop sewer backups in basements. They can reduce and/or eliminate the need to install or replace expensive underground collection, conveyance, and treatment systems.

Green streets offer many benefits that curb-gutter-sewer pipes can't. They replenish groundwater supplies, absorb carbon, improve air and water quality, and improve neighborhood livability and aesthetics, and provide green connection between parks and open space.

Photo 1-13: Green Streets Improve Bicycle Safety

Photo 1-14: Green Streets Improve Pedestrian Safety

The following is a brief summary of typical benefits that green streets provide:

- Enhance neighborhood livability
- Increase community and property values
- Enhance pedestrian access and safety
- Reduce impervious surface
- Reduce stormwater in sewer system and reduce demand on City's CSO infrastructure
- Improve air quality and reduce air temperature
- Improve urban heat island effect
- Add urban green space and wildlife habitat

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APPENDIX D
STANDARD HYDROLOGIC MODELING AND SIMULATION REFERENCE TABLES

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APPENDIX D: STANDARD HYDROLOGIC MODELING AND SIMULATION REFERENCE TABLES

Table D-1: Average Rational Method Runoff Coefficients for Urban Areas: 5-y and 10-y frequency based on Description of Area

DESCRIPTION OF AREA	RUNOFF COEFFICIENTS
Business	
Downtown areas	0.70 to 0.95
Neighborhood areas	0.50 to 0.70
Residential	
Single family areas	0.30 to 0.50
Multiple units, detached	0.40 to 0.60
Multiple units, attached	0.60 to 0.75
Suburban	0.25 to 0.40
Apartment dwelling areas	0.50 to 0.70
Industrial	
Light areas	0.50 to 0.80
Heavy areas	0.60 to 0.90
Parks, Cemeteries	0.10 to 0.25
Playgrounds	0.10 to 0.25
Railroad yard areas	0.20 to 0.40
Unimproved areas	0.10 to 0.30

Source: (Ponce, 1989)

Table D-2: Average Rational Method Runoff Coefficients for Urban Areas: 5-y and 10-y frequency based on Character of Surface

CHARACTER OF SURFACE	RUNOFF COEFFICIENTS
Streets	
Asphaltic	0.70 to 0.95
Concrete	0.80 to 0.95
Brick	0.70 to 0.85
Drives and Walks	0.70 to 0.85
Roofs	0.70 to 0.85
Lawns, sandy soil	
Flat (2 percent)	0.05 to 0.10
Average (2 to 7 percent)	0.10 to 0.15
Steep (7 percent)	0.15 to 0.20
Lawns, heavy soil (clay soil)	
Flat (2 percent)	0.13 to 0.17
Average (2 to 7 percent)	0.18 to 0.22
Steep (7 percent)	0.25 to 0.35

Source: (Ponce, 1989)

Table D-3: Average Rational Method Runoff Coefficient for Rural Areas

TOPOGRAPHIC AND VEGETATION	SOIL TEXTURE		
	OPEN SANDY LOAM	CLAY AND SILT LOAM	OPEN SANDY CLAY
Woodland			
Flat (0 to 5 percent)	0.10	0.30	0.40
Rolling (5 to 10 percent)	0.25	0.35	0.50
Hilly (10 to 30 percent)	0.30	0.50	0.60
Pasture			
Flat (0 to 5 percent)	0.10	0.30	0.40
Rolling (5 to 10 percent)	0.16	0.36	0.55
Hilly (10 to 30 percent)	0.22	0.42	0.60
Cultivated Land			
Flat (0 to 5 percent)	0.30	0.50	0.60
Rolling (5 to 10 percent)	0.40	0.60	0.70
Hilly (10 to 30 percent)	0.52	0.72	0.82

Source: (Ponce, 1989)

Table D-4: Seasonal Rainfall Limits for Three Levels of Antecedent Moisture Conditions (AMC) – SCS Method

AMC	TOTAL 5 DAY ANTECEDENT RAINFALL (cm)	
	DORMANT SEASON	GROWING SEASON
I	Less than 1.3	Less than 3.6
II	1.3 to 2.8	3.6 to 5.3
III	More than 2.8	More than 5.3
Note: This table was developed using data from the Midwestern U.S. Therefore, caution is recommended when using the values supplied in the table for AMC determination in other geographic or climatic regions.		

Source: Ponce, 1989

Table D-5: SCS Runoff Curve Numbers for Urban Areas (Ponce, 1989)

Cover Description		Curve Numbers for Hydrologic Soil Group:			
Cover Type and Hydrologic Condition	Average Percent Impervious Area[2]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.)[3]:					
Poor condition (grass cover less than 50%)		68	79	86	89
Fair condition (grass cover 50 to 75%)		49	69	79	84
Good condition (grass cover greater than 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curves and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only)[4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-in. sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
$\frac{1}{8}$ ac. or less (town houses)	65	77	85	90	92
$\frac{1}{4}$ ac.	38	61	75	83	87
$\frac{1}{3}$ ac.	30	57	72	81	86
$\frac{1}{2}$ ac.	25	54	70	80	85
1 ac.	20	51	68	79	84
2 ac.	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation)[5]		77	86	91	94
Idle lands (curve numbers (CNs) are determined using cover types similar to those in Table 5-2(c)).					

Notes:

[1]Average antecedent moisture condition and $I_a = 0.2S$.

[2]The average percent impervious area shown was used to develop the composite *CN*s. Other assumptions are as follows: Impervious areas are directly connected to the drainage system; impervious areas have a $CN = 98$; and pervious areas are considered equivalent to open space in good hydrologic condition. *CN*s for other combinations of conditions may be computed using Fig. 5-16 or 5-17.

[3]*CN*s shown are equivalent to those of pasture. Composite *CN*s may be computed for other combinations of open space cover type.

[4]Composite CN's for natural desert landscaping should be computed using Figs. 5-16 or 5-17 based on the impervious area percentage ($CN = 98$) and the pervious area *CN*. The pervious area *CN*s are assumed equivalent to desert shrub in poor hydrologic condition.

[5]Composite *CN*s to use for the design of temporary measures during grading and construction should be computed using Figs. 5-16 or 5-17, based on the degree of development (impervious area percentage) and the CNs for the newly graded pervious areas.

Table D-6: SCS Runoff Curve Numbers for Rural Areas (Ponce, 1989)

Cover Description		Curve Numbers for Hydrologic Soil Group:			
Cover Type	Hydrologic Condition	A	B	C	D
Pasture, grassland, or range-continuous forage for grazing[2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow-continuous grass, protected from grazing and generally mowed for hay	—	30	58	71	78
Brush—brush-weed grass mixture with brush being the major element[3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30[4]	48	65	73
Woods—grass combination (orchard or tree farm)[5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods.[6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30[4]	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

Notes:

[1]Average antecedent moisture condition and $I_a = 0.2S$.

[2]*Poor:* less than 50% ground cover on heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: more than 75% ground cover and lightly or only occasionally grazed.

[3]*Poor:* less than 50% ground cover.
Fair: 50 to 75% ground cover.
Good: more than 75% ground cover.

[4]Actual curve number is less than 30; use $CN = 30$ for runoff computations.

[5]*CN*s shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the *CN*s for woods and pasture.

[6]*Poor:* Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

Table D-7: SCS Runoff Curve Numbers for Arid and Semi-Arid Rangelands (Ponce, 1989)

Cover Description		Curve Numbers for Hydrologic Soil Group:			
Cover Type	Hydrologic Condition[2]	A[3]	B	C	D
Herbaceous—mixture of grass, weeds, and low-growing brush, with brush the minor element.	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen—mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush.	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Pinyon-juniper—pinyon, juniper, or both; grass understory.	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sagebrush with grass understory.	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub—major plants include saltbrush, greasewood, creosotebush, blackbrush, bursage, palo verde, mesquite, and cactus.	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

Notes:

[1]Average antecedent moisture condition and $I_a = 0.2S$. For range in humid regions, use Table 5-2(c).

[2]*Poor:* less than 30% ground cover (litter, grass, and brush overstory).

Fair: 30 to 70% ground cover.

Good: more than 70% ground cover.

[3]Curve numbers for group A have been developed only for desert shrub.

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APPENDIX E
USING LID TO MEET TMDLS AND OTHER REGULATORY REQUIREMENTS

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APPENDIX E
1 USING LID TO MEET TMDLS AND OTHER REGULATORY REQUIREMENTS

1.1 USING LID FOR VOLUME CONTROL TO MEET TMDLS

Reducing runoff volume is one of the most powerful tools available for reducing pollutant loading to receiving waters (LID, 2011). Load reductions are straightforward to estimate, as they are based on the volume of runoff captured rather than the pollutant removal performance of a particular BMP. Capture of all storms smaller than a specified value, for example the 95th percentile storm, means that no runoff, and therefore no pollutant loading, occurs for storms smaller than the design storm. For storms exceeding the design storm, runoff from the early part of the storm, which often contains higher concentrations of pollutants, is captured, and only runoff from later in the storm, which is often less polluted, is discharged. There is some debate as to whether this concept of a "first flush" is accurate; that is, whether storms exhibit a characteristic pattern of high pollutant loads at the onset of runoff, and lower pollutant loading as the storm event continues, but even if runoff pollutant concentrations are assumed to be constant, capturing the majority of small storms greatly reduces pollutant loads.

For planning purposes, annual loads with and without 95th percentile capture can be estimated by (LID, 2011):

$$L = \frac{PC_p R_v C}{100} \tag{D.1}$$

Where,

L = annual load (kg/ha-yr)

P = annual precipitation (mm/yr)

C_p = correction factor for events that do not produce runoff (0.9 for impervious areas)

R_v = runoff coefficient for drainage area

C = pollutant event mean concentrations (EMC, mg/L)

Whereas for design purposes a continuous model such as SWMM or HSPF may be more appropriate in order to assess pollutant loads across a variety of meteorological conditions. For estimating pollutant loads from urban areas with storm pipe networks the SWMM model will be most appropriate, whereas for areas with more natural land use types and no storm drains, the HSPF model will be most appropriate.

1.2 REGIONAL STORMWATER MANAGEMENT REQUIREMENTS

Stormwater management requirements may be established at the state or local level and vary throughout the country. Often specific design requirements or general guidelines are provided by state and local agencies. Common requirements are provided below.

1.2.1 Quantity control

Most stormwater management programs began at the local level and required developments to address peak flow attenuation. These ordinances typically require that post construction peak flow rates do not exceed pre-construction peak flow rates for a series of storm events. These events can include some or all of the following: 2-year, 5-year, 10-year, 25-year, 50-year and or 100-year storm events. This results in a requirement for detention (quantity control). The specific requirements may be established by cities, counties, regional or State agencies.

1.2.2 Extreme Flood Protection

The Extreme Flood Protection criterion specifies that all stormwater management facilities be designed to safely handle the runoff from a large (extreme) storm event, typically the 100-year, 24-hour return frequency storm event, denoted Q_f. This may be accomplished either by:

1. Controlling Q_f through on-site or regional structural stormwater controls to maintain the existing 100-year floodplain. This is done where residences or other structures have already been constructed within the 100-year floodplain fringe area; or

2. By sizing the on-site conveyance system to safely pass Q_f and allowing it to discharge into a receiving water whose protected full build out floodplain is sufficiently sized to account for extreme flow increases without causing damage.

The intent of the extreme flood protection is to prevent flood damage from infrequent but large storm events, maintain the boundaries of the mapped 100-year floodplain, and protect the physical integrity of the structural stormwater controls as well as downstream stormwater and flood control facilities.

It is recommended that Q_f be used in the routing of runoff through the drainage system and stormwater management facilities to determine the effects on the facilities, adjacent property, and downstream. Emergency spillways of structural stormwater controls should be designed appropriately to safely pass the resulting flows.

1.2.3 Water Quality

The Water Quality sizing criterion, denoted WQV, specifies a treatment volume required to remove a significant percentage of the total pollution load inherent in stormwater runoff by intercepting and treating between the 80^{th} and 90^{th} (typically the 85^{th}) percentile storm event, which varies from approximately 0.5 inches in arid regions to 1.5 inches in humid regions. The Water Quality Volume is a runoff volume that is directly related to the amount of impervious cover at a site. This criterion is often specified by the local or state agency.

Hydrologic studies show that small-sized, frequently occurring storms account for the majority of rainfall events that generate stormwater runoff. Consequently, the runoff from these storms also accounts for a major portion of the annual pollutant loadings. Therefore, by treating these frequently occurring smaller rainfall events and a portion of the stormwater runoff from larger events, it is possible to effectively mitigate the water quality impacts from a developed area.
A water quality treatment volume (WQV) is specified to size structural control facilities to treat these small storms up to a maximum runoff depth and the "first flush" of all larger storm events. The 85th percentile volume has traditionally been considered the point of optimization between pollutant removal ability and cost-effectiveness. Capturing and treating a larger percentage of the annual stormwater runoff would provide only a small increase in additional pollutant removal, but would considerably increase the required size (and cost) of the structural stormwater controls.

The most common approach to determining this volume is to use the volumetric runoff coefficient (Rv) which was derived from a regression analysis performed on rainfall- runoff volume data from a number of cities nationwide and is a shortcut method considered adequate for runoff volume calculation for the type of small storms normally considered in stormwater quality calculations.

Some states allow a maximized stormwater quality capture volume for the area, based on historical rainfall records, determined using the formula and volume capture coefficients set forth in Urban Runoff Quality Management (WEF Manual of Practice No. 23/ASCE Manual of Practice No. 87, 1998, pages 175-178).

The Urban Runoff Quality Management approach is based on two regression equations. The first regression equation relates rainfall to runoff. The rainfall to runoff regression equation was developed using 2 years of data from more than 60 urban watersheds nationwide. The second regression equation relates mean annual runoff-producing rainfall depths to the "Maximized Water Quality Capture Volume" which corresponds to the "knee of the cumulative probability curve". This second regression was based on analysis of long-term rainfall data from seven rain gages representing climatic zones across the country. The Maximized Water Quality Capture Volume corresponds to approximately the 85th percentile runoff event, and ranges from 82 to 88%.

The two regression equations that form the Urban Runoff Quality Management approach are as follows:

$$C = 0.858i3 - 0.78i2 + 0.774i + 0.04 \quad (4.13)$$

$$P0 = (a \cdot C) \cdot P6 \quad (4.14)$$

Where,

C = runoff coefficient

i = watershed imperviousness ratio which is equal to the percent total imperviousness divided by 100

P_0 = Maximized Detention Volume, in watershed inches

A = regression constant, a=1.582 and a=1.963 for 24 and 48 hour draw down, respectively

P_6 = mean annual runoff producing rainfall depths, in watershed inches

The Urban Runoff Quality Management Approach is simple to apply and usually results in a smaller WQV. The following steps describe the use of the approach:

1. Identify the "BMP Drainage Area" that drains to the proposed BMP. This includes all areas that will contribute runoff to the proposed BMP, including pervious areas, impervious areas, and off-site areas, whether or not they are directly or indirectly connected to the BMP.

2. Calculate the "Watershed Imperviousness Ratio" (i), which is equal to the percent of total impervious area in the "BMP Drainage Area" divided by 100.

3. Calculate the "Runoff Coefficient" (C) using the following equation:

$$C = 0.858i3 – 0.78i2 + 0.774i + 0.04$$

4. Determine the "Mean Annual Runoff" (P_6) for the "BMP Drainage Area".

5. Determine the "Regression Constant" (a) for the desired BMP drain down time.
Use a = 1.582 for 24 hrs and a=1.963 for 48 hr draw down.

6. Calculate the "Maximized Detention Volume" (P_0) using the following equation:

$$P_0 = (a \bullet C) \bullet P_6$$

7. Calculate the required capture volume of the BMP by multiplying the "BMP Drainage Area" from Step 1 by the "Maximized Detention Volume" from Step 6 to give the BMP volume. Due to the mixed units that result (e.g., ac-in., ac-ft) it is recommended that the resulting volume be converted to ft^3 for use during design.

1.2.4 Flow-Based BMP Design

Flow-based BMP design standards apply to BMPs whose primary mode of pollutant removal depends on the rate of flow of runoff through the BMP. Examples of BMPs in this category include swales, screening devices, and many proprietary products. Typically, a flow-based BMP design criteria calls for the capture and infiltration or treatment of the flow runoff produced by rain events of a specified magnitude.

The following are examples of flow-based BMP design standards from current municipal stormwater permits. The permits require that flow-based BMPs be designed to capture and then to infiltrate or treat stormwater runoff equal to one of the following:

- 10% of the 50-yr peak flow rate (Factored Flood Flow Approach)

- The flow of runoff produced by a rain event equal to at least two times the 85th percentile hourly rainfall intensity for the applicable area, based on historical records of hourly rainfall depths

- The flow of runoff resulting from a rain event equal to a pre-determined intensity (Uniform Intensity Approach)

1.2.5 Volume Control

The criteria for maintaining recharge is often based on the average annual recharge rate of the hydrologic soil group(s) (HSG) present at a site as determined from USDA, NRCS Soil Surveys, or from detailed site investigations. More specifically, each specific recharge factor is based on the USDA average annual recharge volume per soil type divided by the annual rainfall in a particular state and multiplied by 90%. This keeps the recharge calculation consistent with the WQV methodology. Thus, an annual recharge volume requirement is specified for a site as follows:

The intent of the recharge criteria is to maintain existing groundwater recharge rates at development sites. This helps to preserve existing water table elevations thereby maintaining the hydrology of streams and wetlands during dry weather. The volume of recharge that occurs on a site depends on slope, soil type, vegetative cover, precipitation and evapo-transpiration. Sites with natural ground cover, such as forest and meadow, have higher recharge rates, less runoff, and greater transpiration losses under most conditions. Because development increases impervious surfaces, a net decrease in recharge rates is inevitable.

1.2.6 Channel Protection (Stream Stability)

The Channel Protection sizing criterion often specifies that 24 hours of extended detention be provided for runoff generated by the 1-year, 24-hour rainfall event to protect downstream channels. The required volume needed for 1-year extended detention, denoted *CPv*, is roughly equivalent to the required volume needed for peak discharge control of the 5- to 10-year storm.

The increase in the frequency and duration of bankfull flow conditions in stream channels due to urban development is one of the primary causes of stream bank erosion and the widening and downcutting of stream channels. Therefore, it is believed that channel erosion downstream of a development site can be significantly reduced by storing and releasing stormwater runoff from the channel-forming runoff events in a gradual manner to ensure that critical erosive velocities and flow volumes are not exceeded.

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