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.

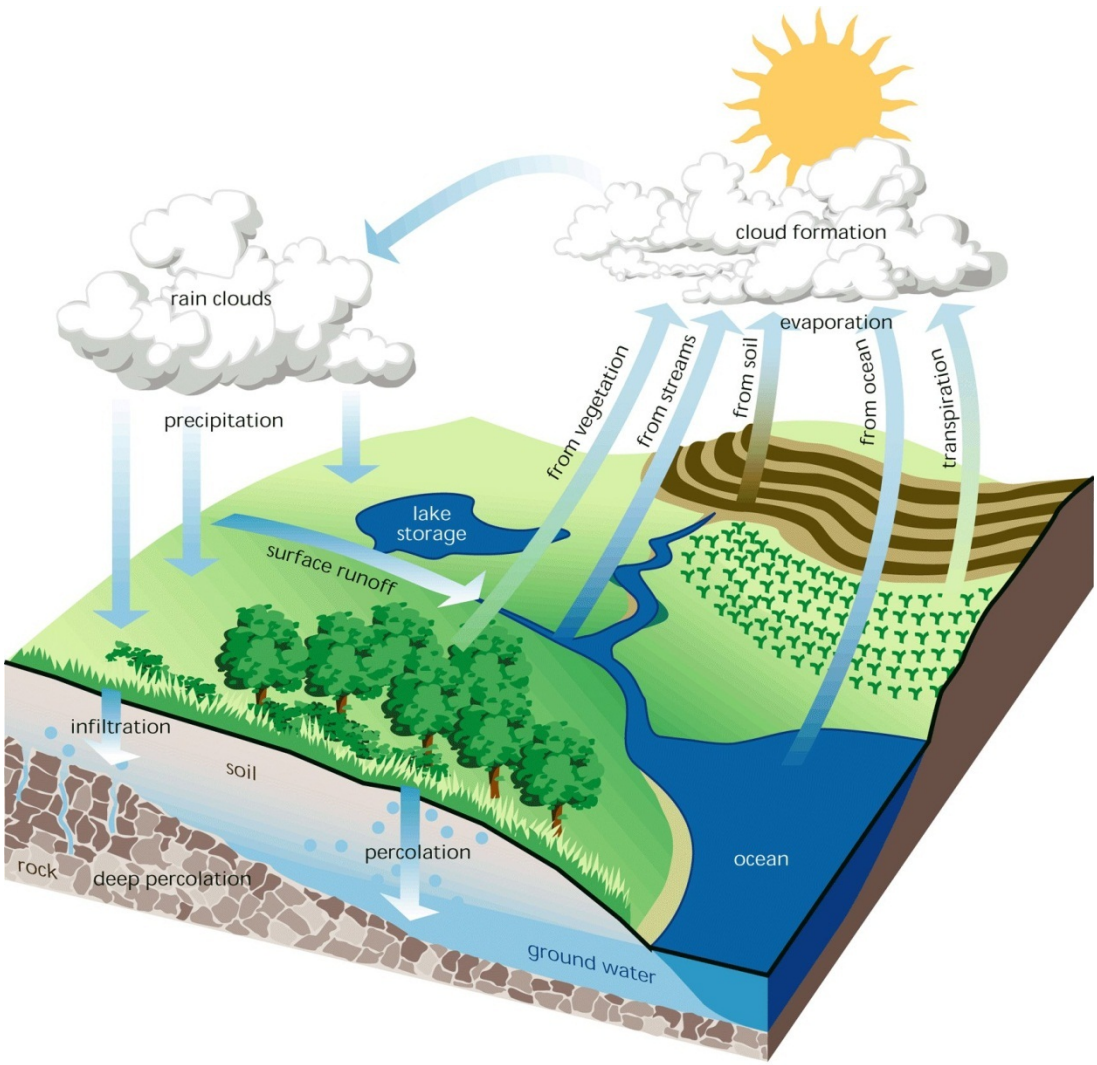

Figure 2-1. The Hydrologic Cycle
(Source: Federal Interagency Stream Restoration Working Group (FISRWG), 1998)

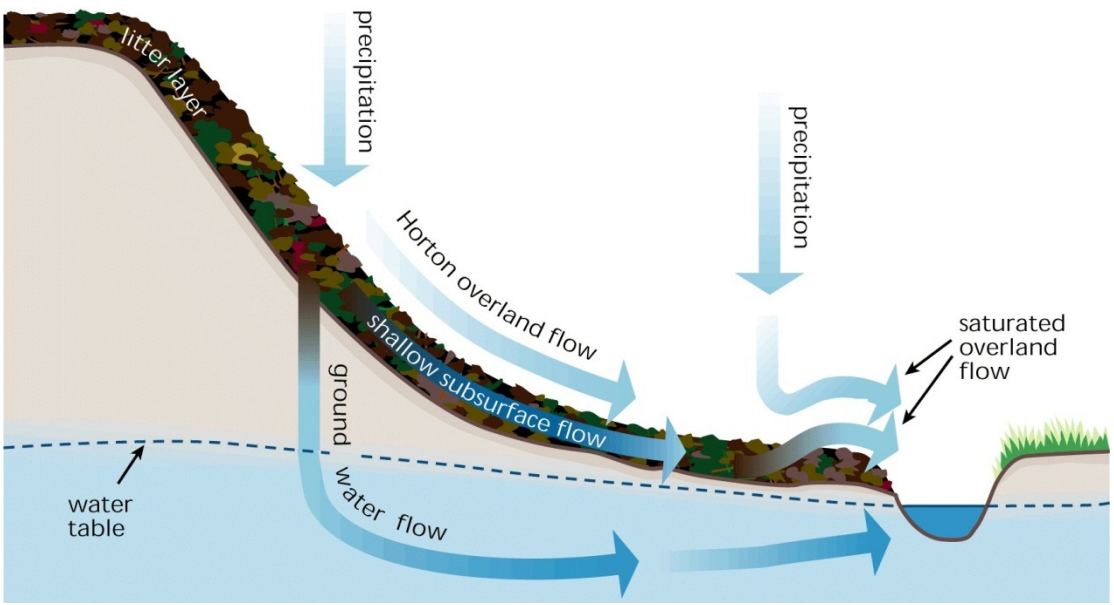

Figure 2-2. Stormwater Flow and Runoff
(Source: FISRWG, 1998)

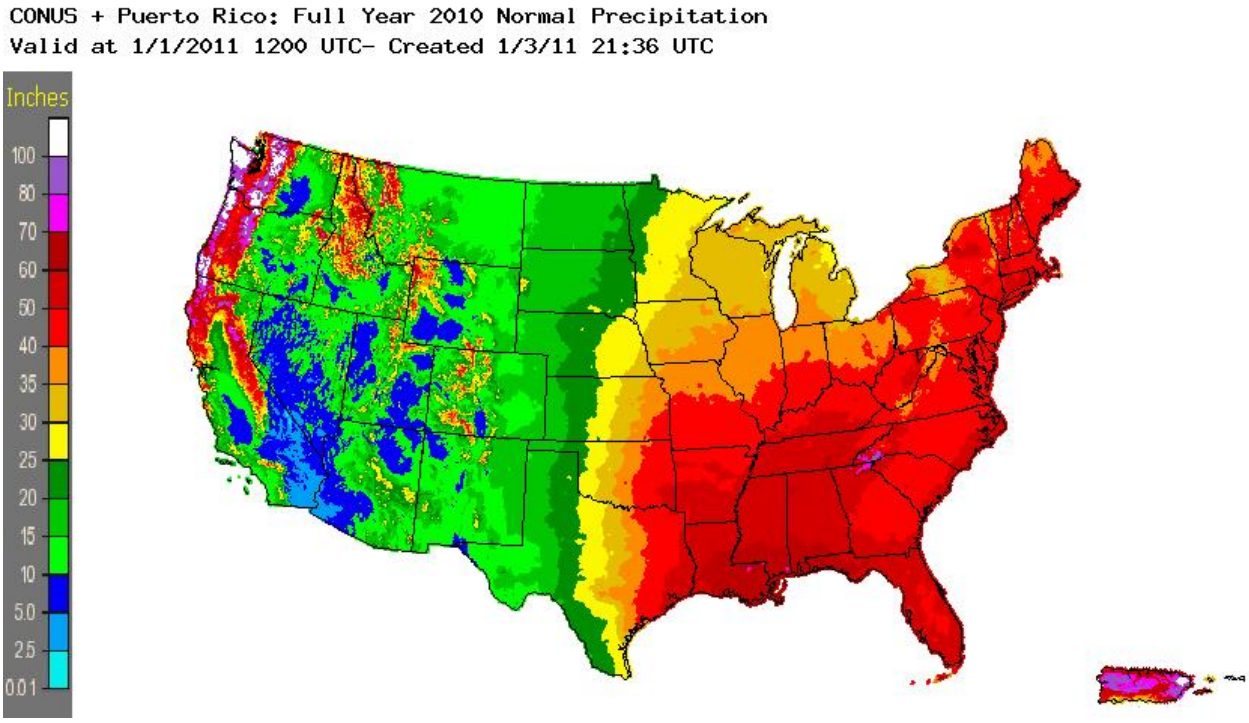

Figure 2-3. Representative Annual Precipitation
(Source: USGS, 2011)

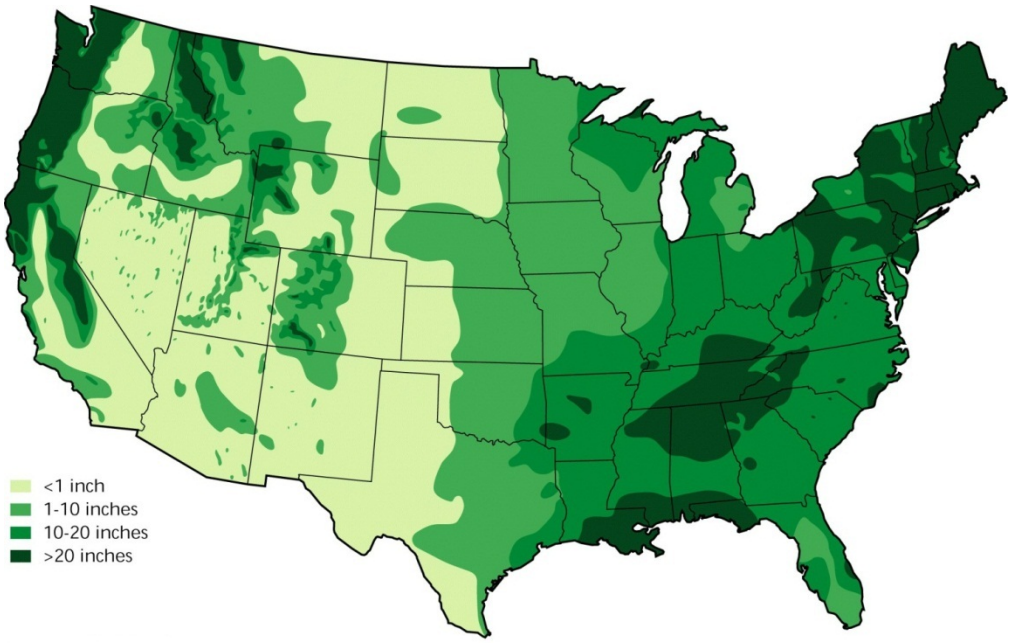

Figure 2-4. Average Annual Runoff in the Contiguous United States
(Source: USGS, 1986)

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.

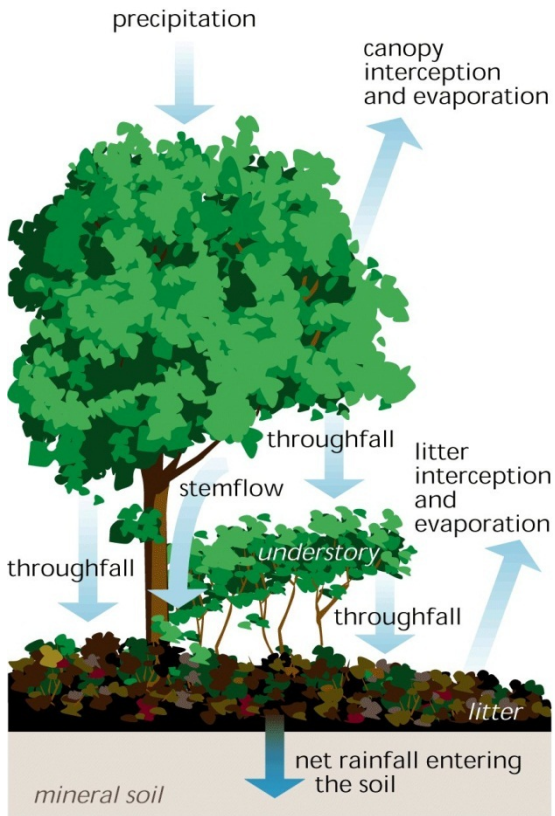

Figure 2-5. Precipitation Pathways in Forested Area
(Source: FISRWG, 1998)

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.

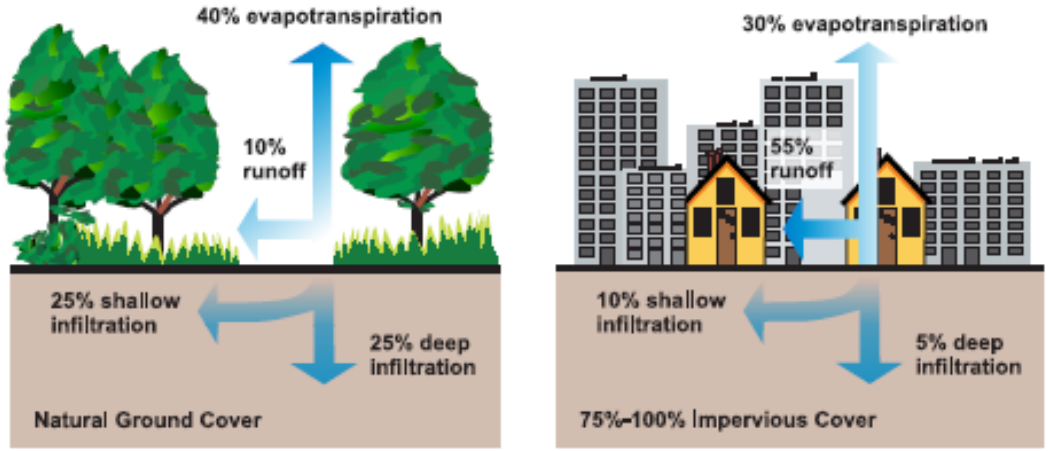

Figure 2-6. Pre-Development and Post-Development Hydrology
(Source: EPA Technical Guidance Manual, 2009)

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.

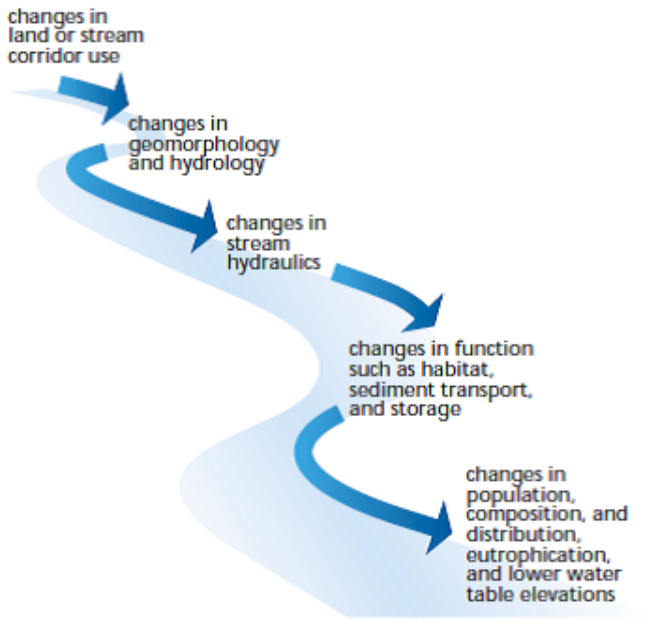

Figure 2-7. Impacts of Development on Stream Channels
(Source: FISRWG, 1998)

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.

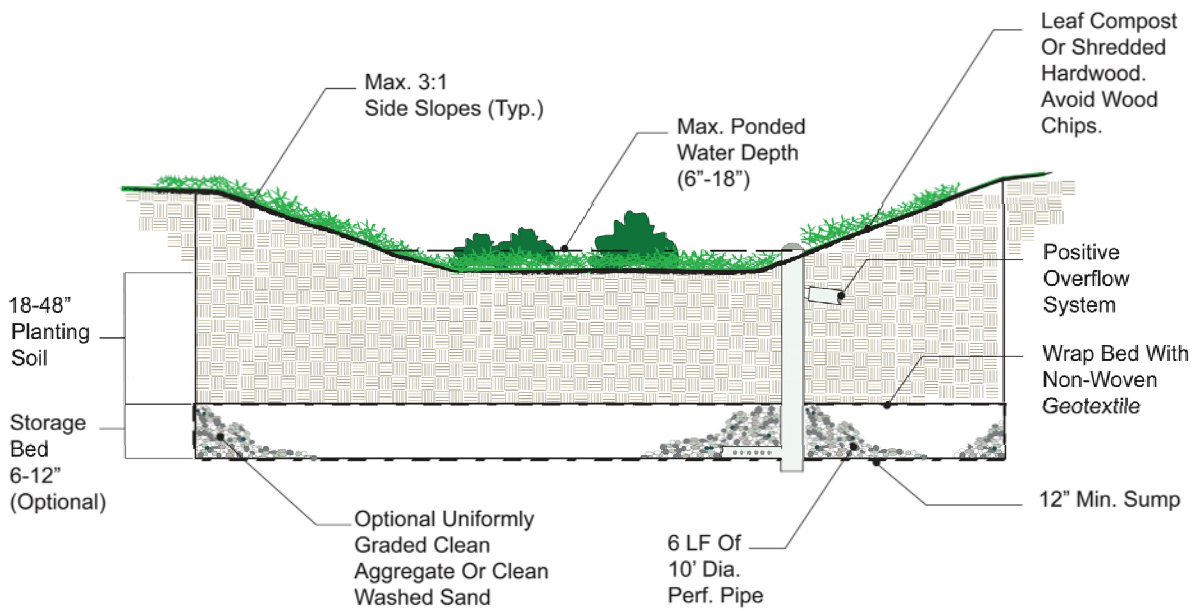

Figure 2-8. Cross-Section of a Bioretention Area

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)

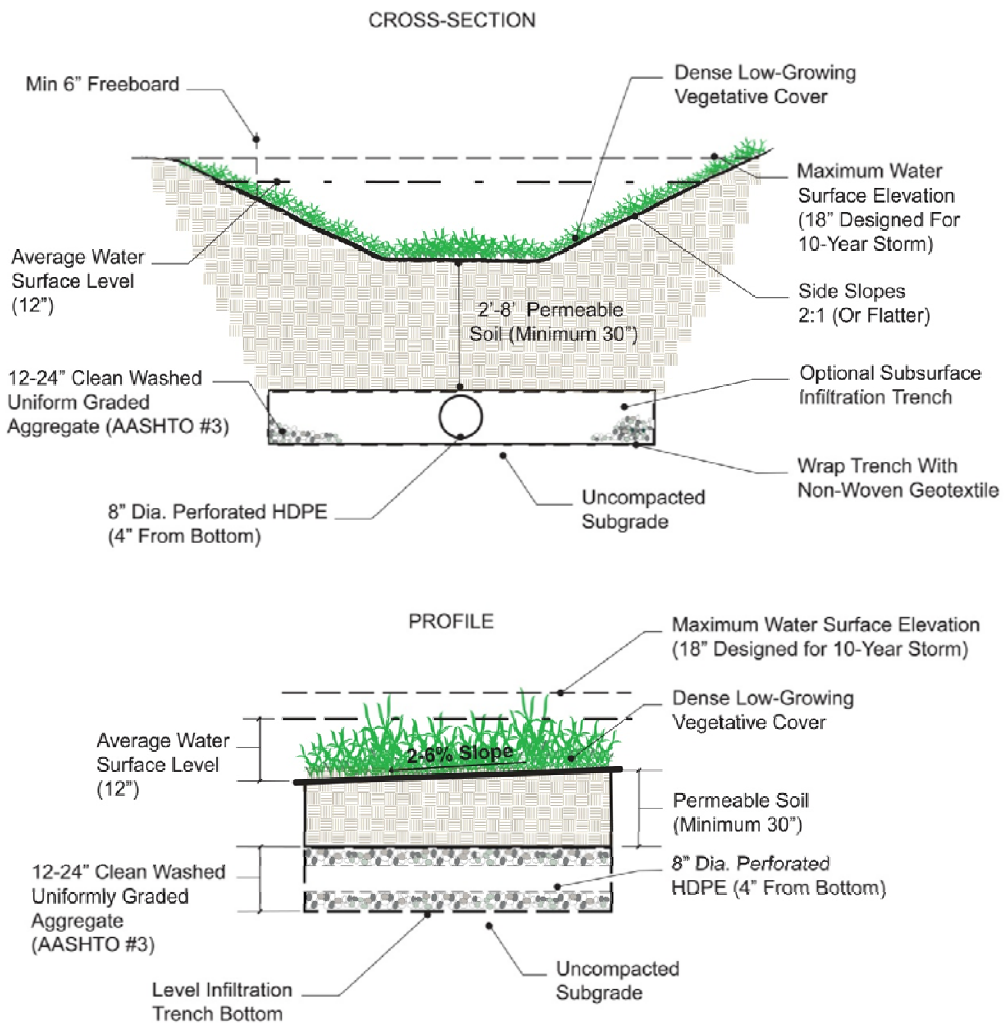

Figure 2-9. Schematic of a Vegetate Swale
(Source: Pennsylvania Stormwater IMP Manual, 2006)

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.

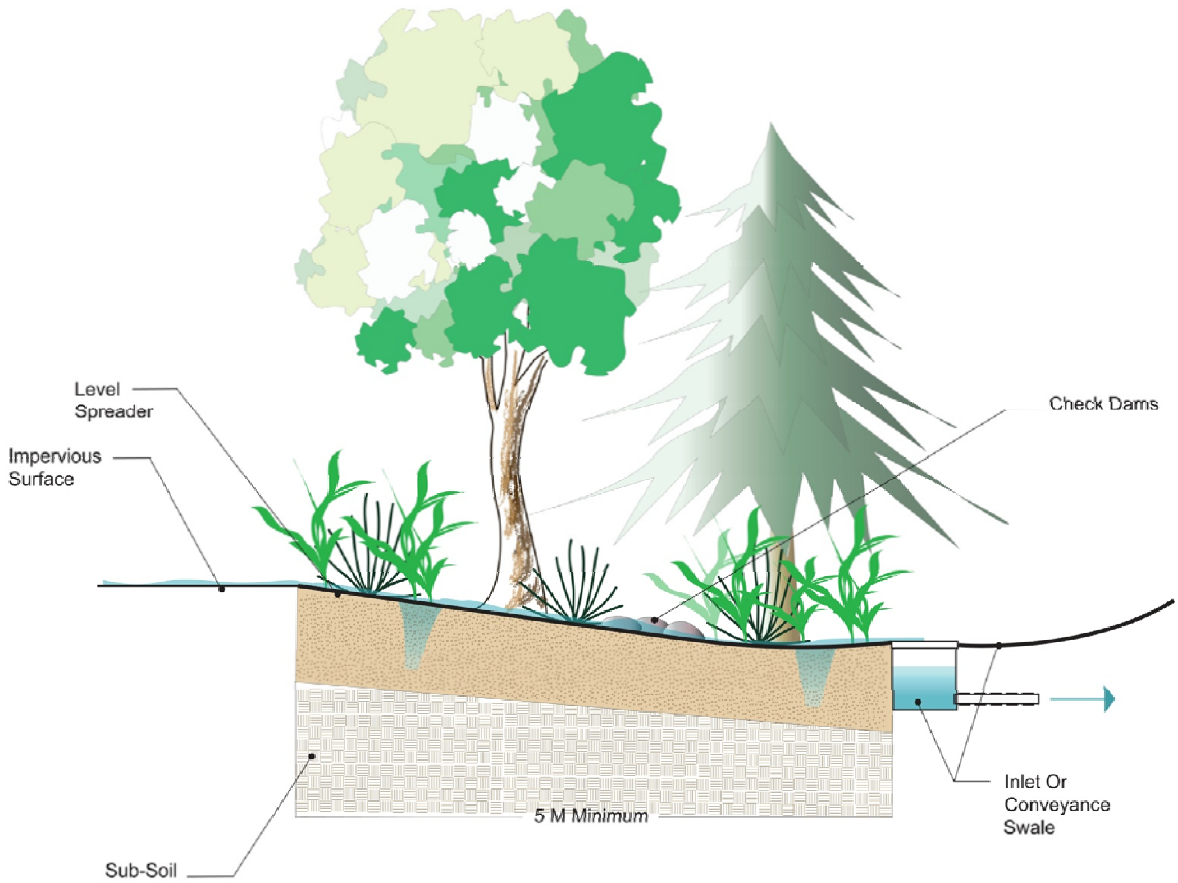

Figure 2-10. Vegetated Filter Strip
(Source: Landmark Design Group)

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.

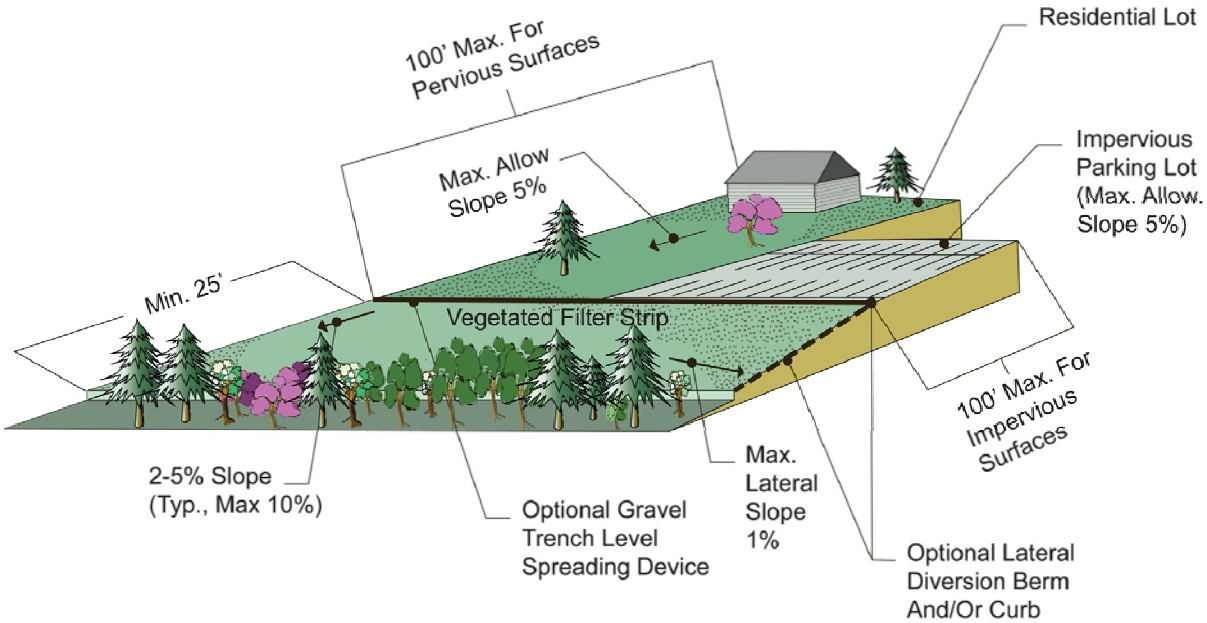

Figure 2-11. Diagram of a Vegetated Filter Strip
(Source: SEMCOG, 2008)

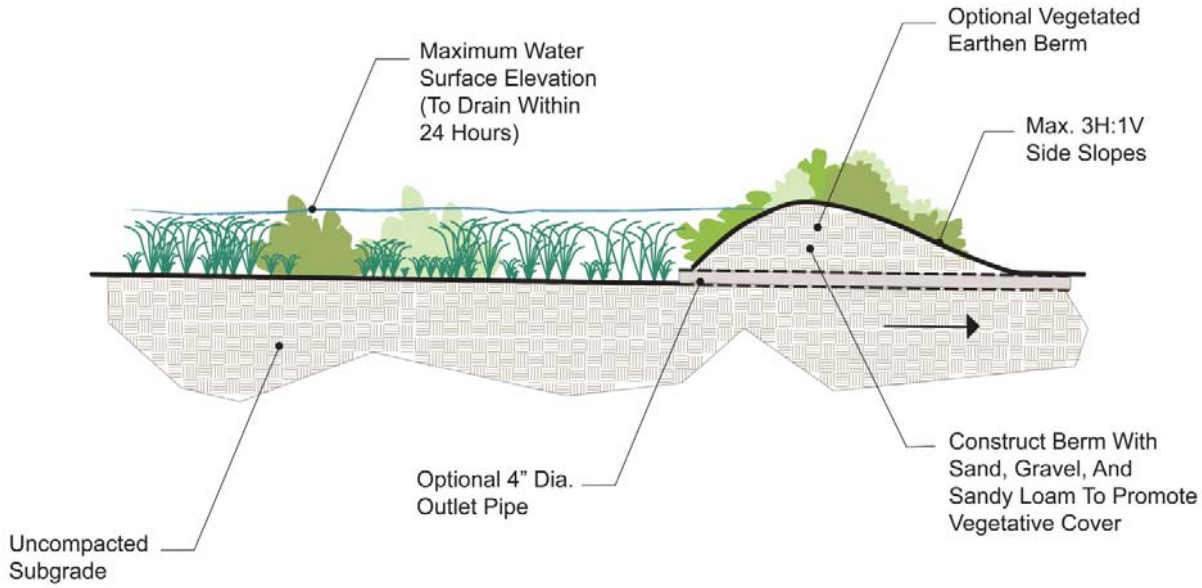

Figure 2-12. Cross-Section of Vegetated Filter Strip with an Optional Earthen Berm
(Source: SEMCOG, 2008)

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).

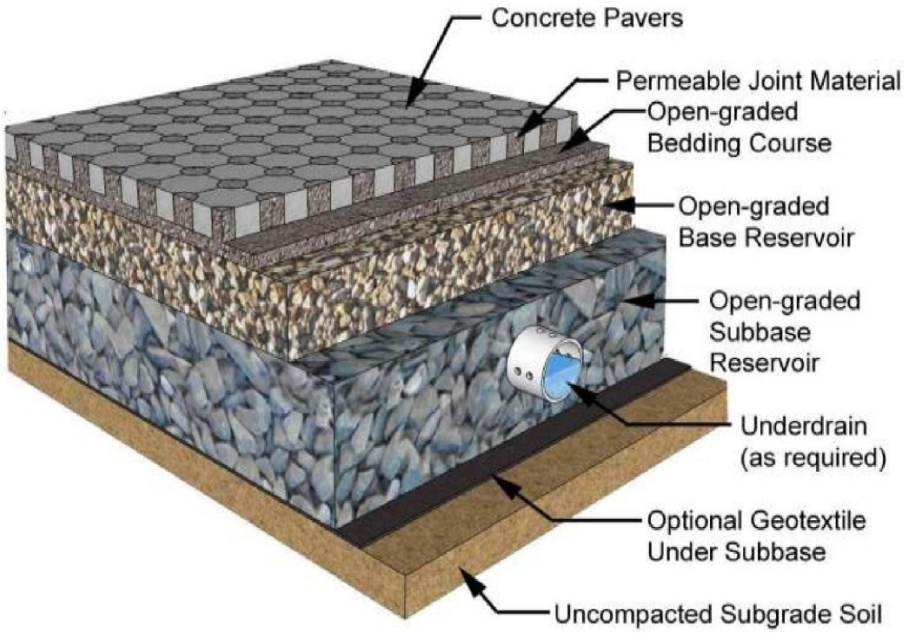

Figure 2-13. Cross Section of Permeable Pavement
(Source: Interlocking Concrete Pavement Institute)

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)

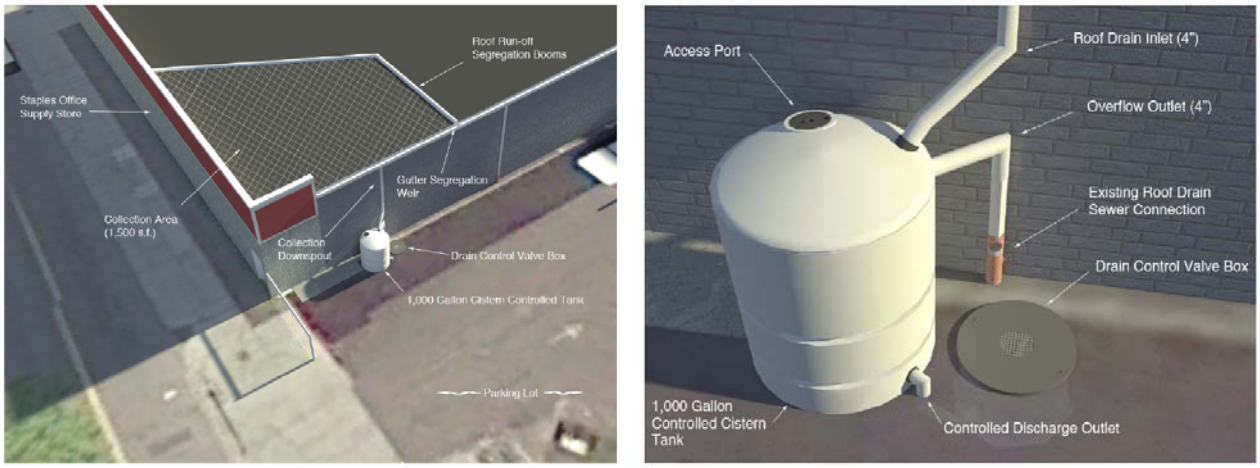

Photo 2-22. Cistern for Rainwater Harvesting

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)

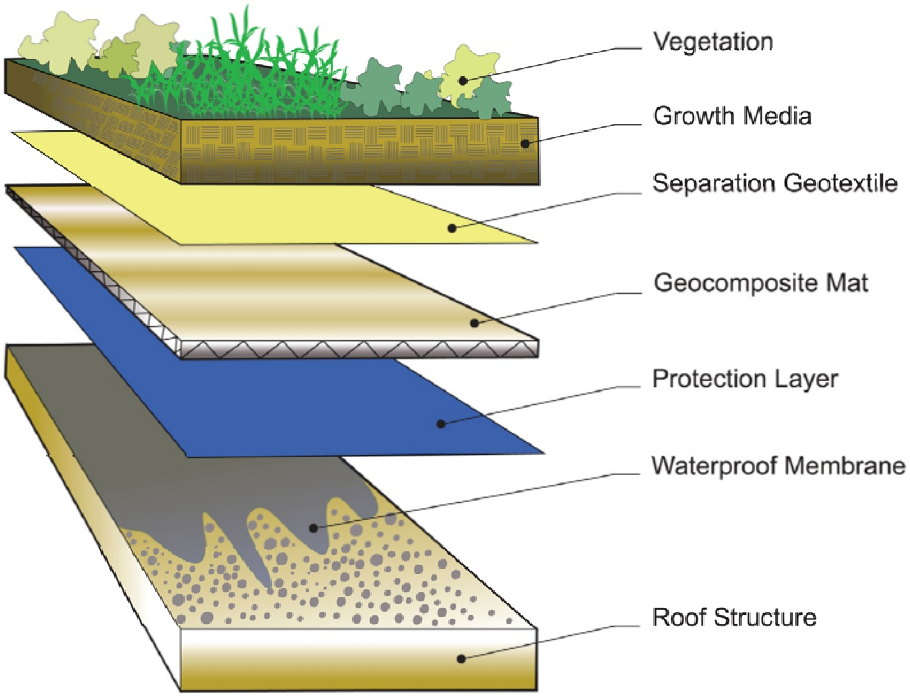

Figure 2-14. Cross Section of an Extensive Green Roof
(Source: SEMCOG, 2008)

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).

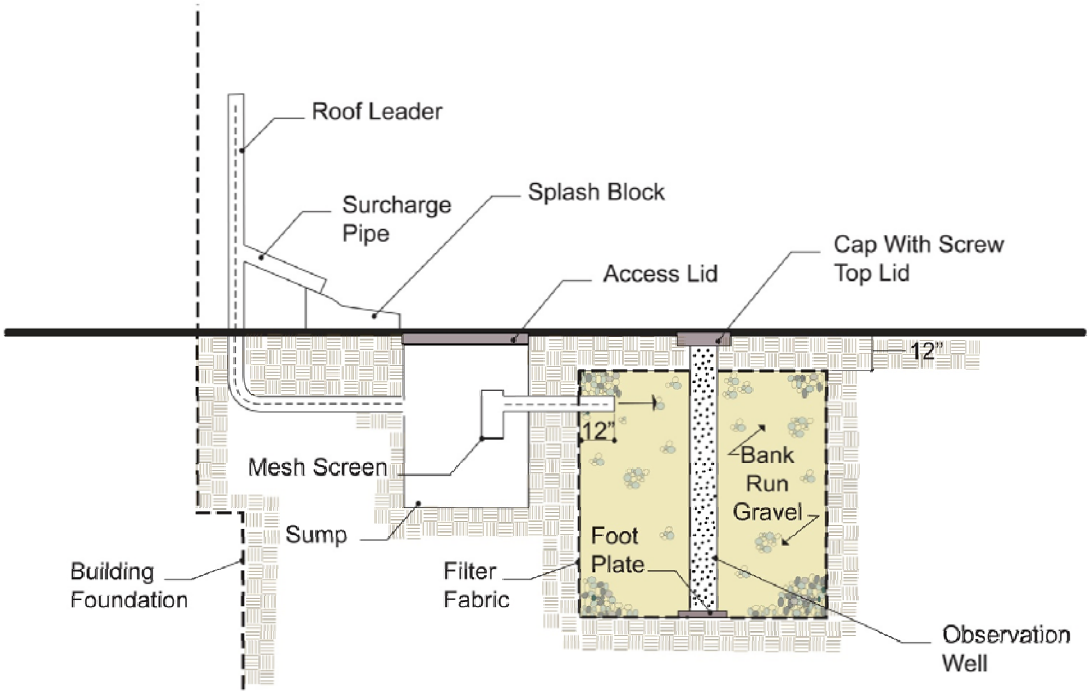

Figure 2-15. Dry Well Schematic
(Source: SEMCOG, 2008)

- **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.

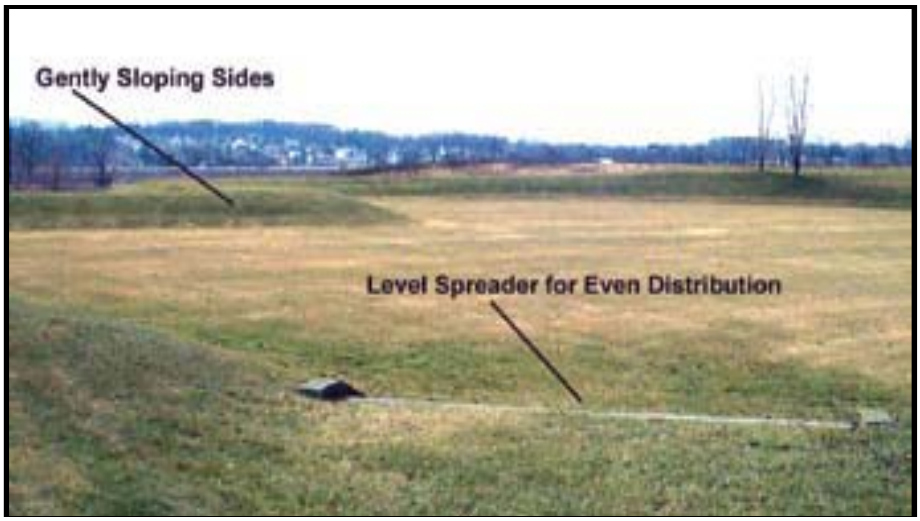

Photo 2-25. Infiltration Basin
(Source: SEMCOG, 2008)

- 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.

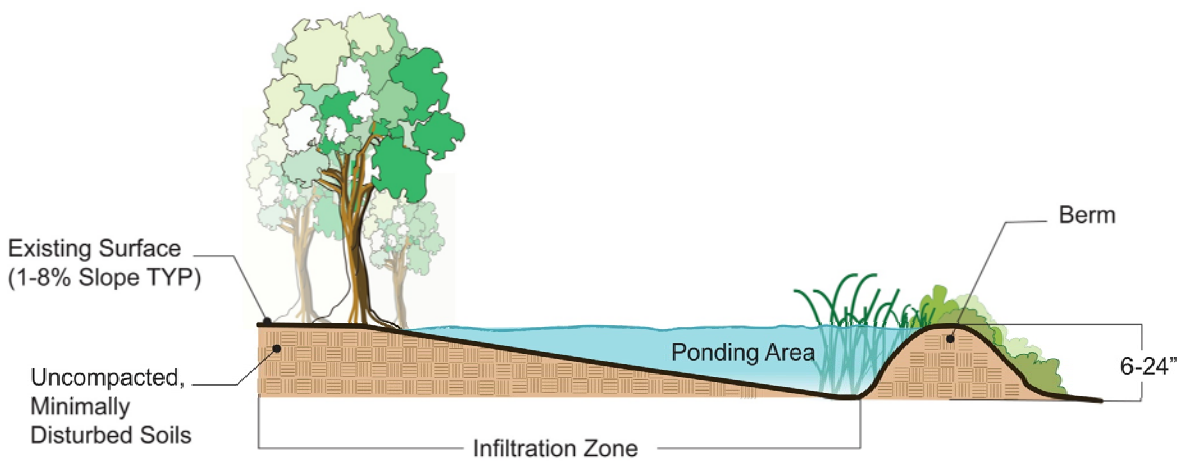

Figure 2-16. Infiltration Berm
(Source: SEMCOG, 2008)

- **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.

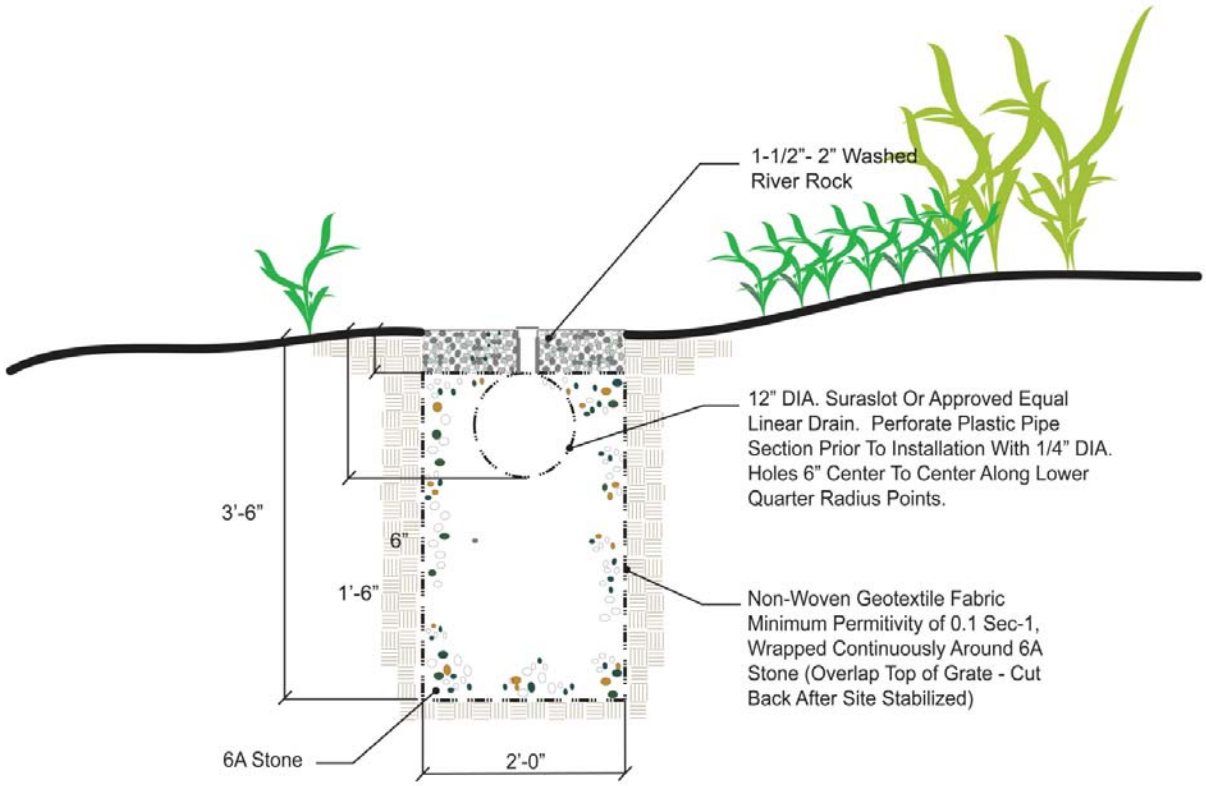

Figure 2-17. Schematic of a Typical Level Spreader
(Source: InSite Design Studio)

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.

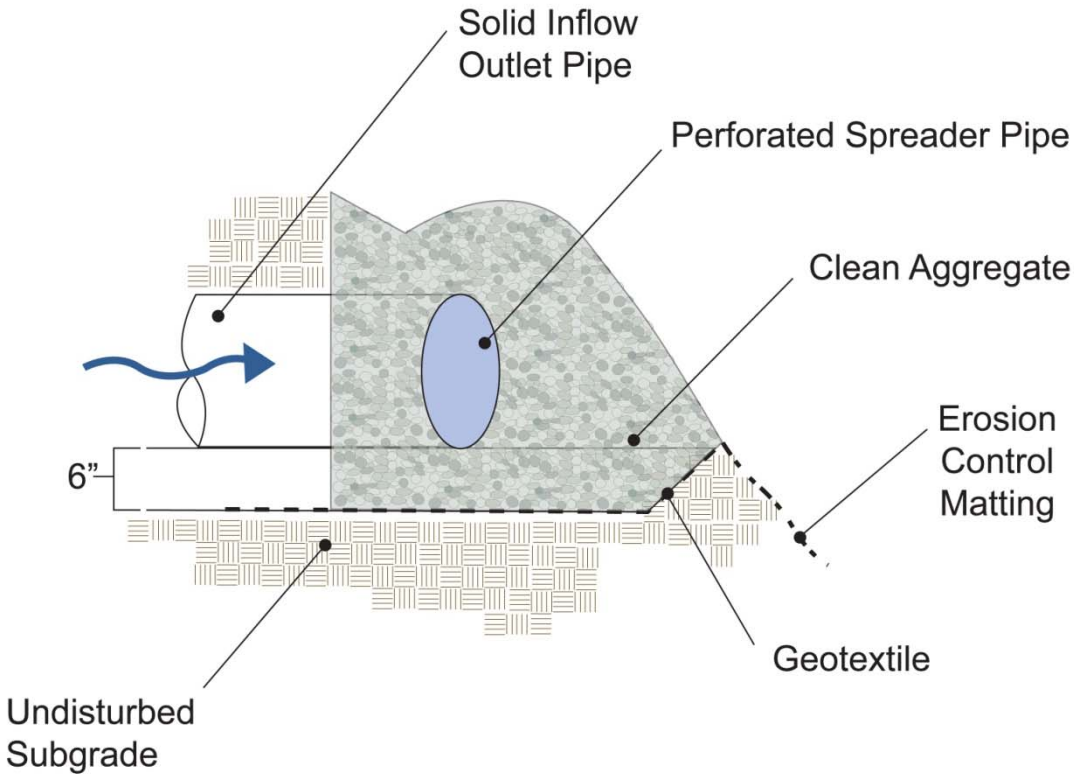

Figure 2-18. Level Spreader with an Inflow Pipe
(Source: SEMCOG, 2008)

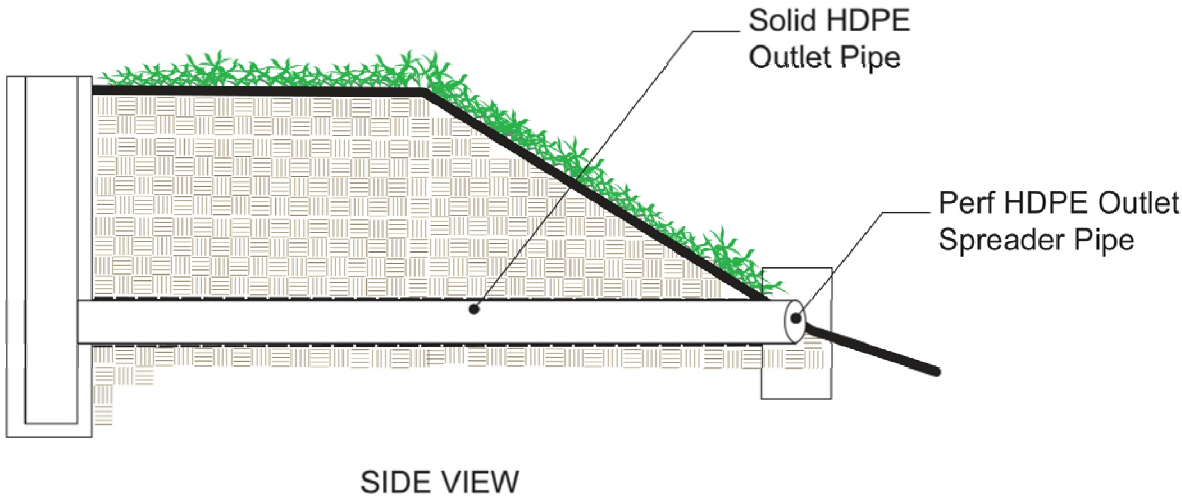

Figure 2-19. Level Spreader with a Perforated Outflow Pipe
(Source: SEMCOG, 2008)

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.

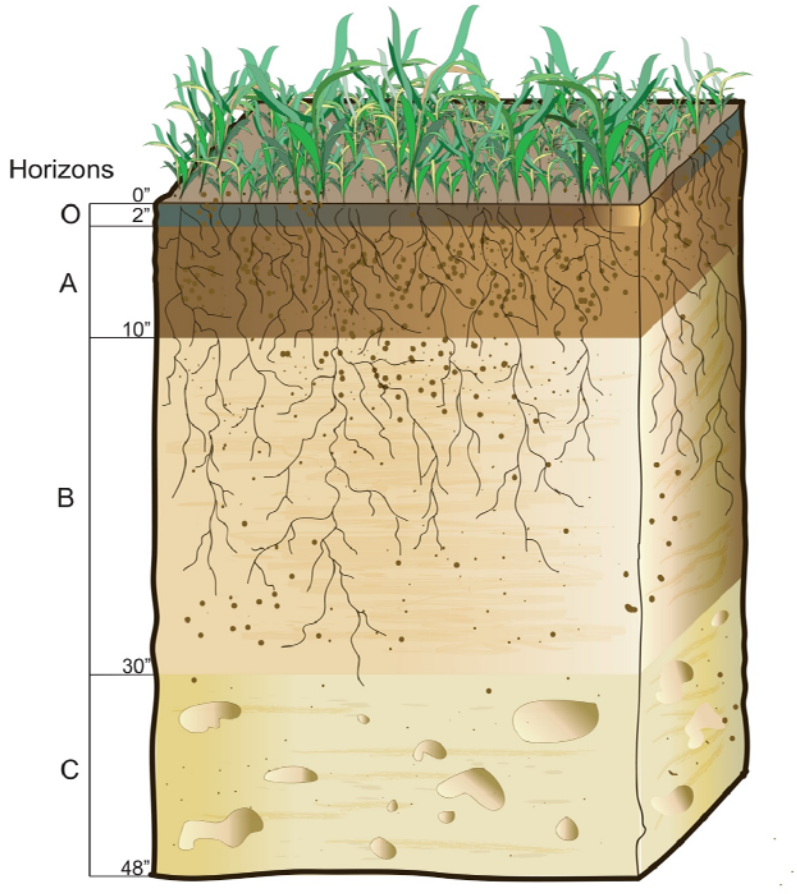

Figure 2-20. Profile of a Healthy Soil
(Source: USDA NRCS)

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

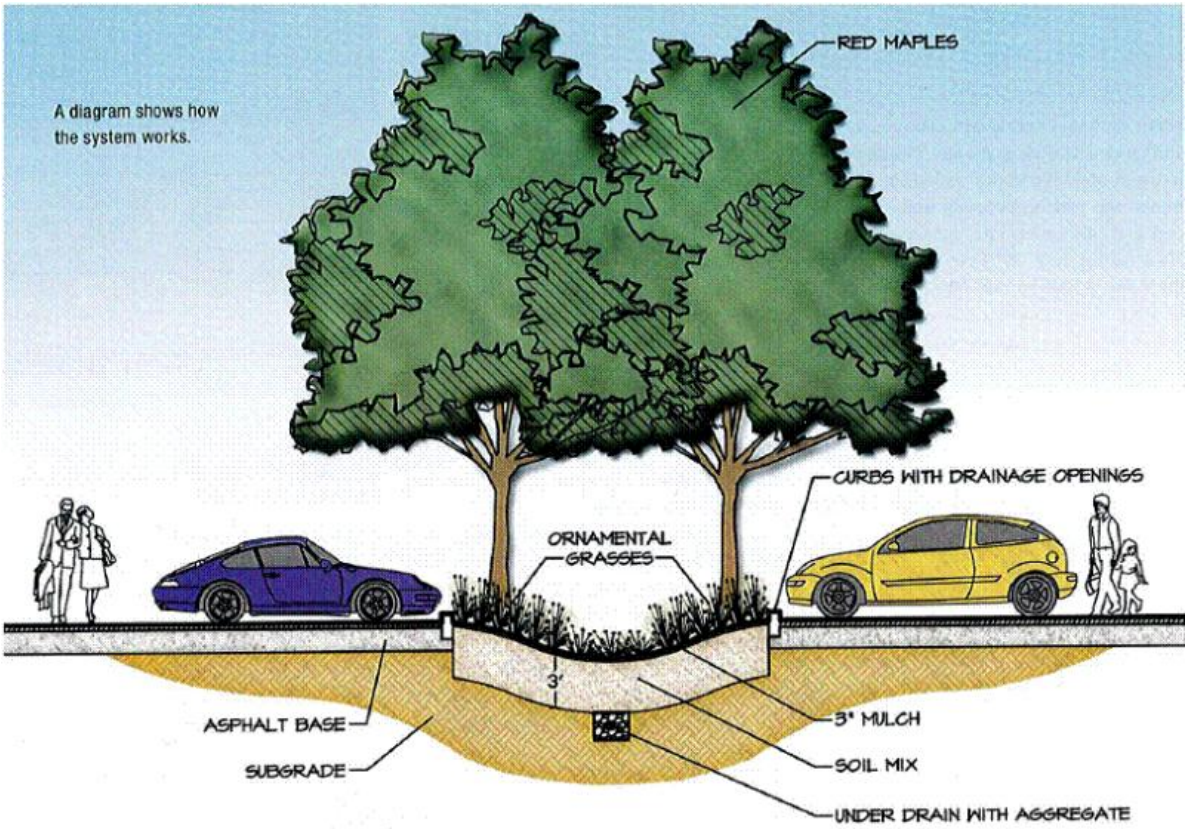

Figure 2-20. Treatment Train - Permeable Pavers and Vegetated Swale

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