PDHonline Course C193 (4 PDH)

Introduction to Bioretention

Instructor: Cory L. Horton, P.E.

2020

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5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone: 703-988-0088
www.PDHonline.com

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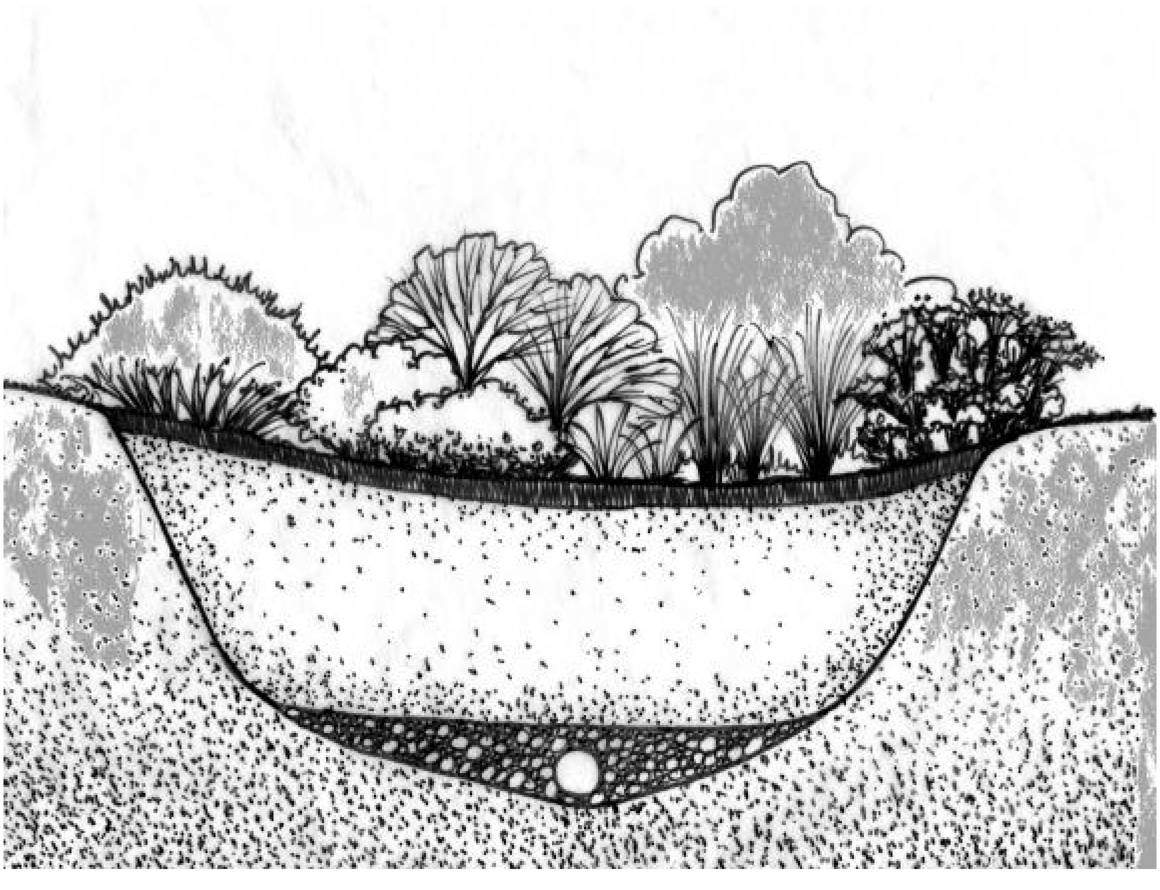
Chapter 1
Introduction to Bioretention



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Introduction to Bioretention

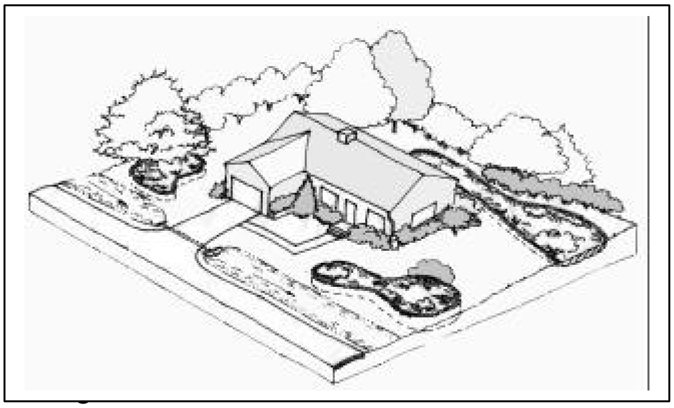
1.1 What Is Bioretention?

Bioretention is a terrestrial-based (up-land as opposed to wetland), water quality and water quantity control practice using the chemical, biological and physical properties of plants, microbes and soils for removal of pollutants from storm water runoff. Some of the processes that may take place in a bioretention facility include: sedimentation, adsorption, filtration, volatilization, ion exchange, decomposition, phytoremediation, bioremediation, and storage capacity. This same principle of utilizing biological systems has been widely used in the retention and the transformation of pollutants and nutrients found in agricultural and wastewater treatment practices. Bioretention may also be designed to mimic predevelopment hydrology. Consult the Prince George's County Low Impact Development Manual for specifics on how to accomplish this in conjunction with other LID practices and techniques.

Bioretention was developed to have a broad range of applications, necessitating early analysis of the overall site design. Early analysis allows the designer to place bioretention facilities integrated throughout a proposed site design. For this reason, bioretention is also referred to as a "Integrated Management Practice." (IMP). While integrating bioretention into a development site, the designer must consider and design for the following:

Note: See Chapter 2 for design specifics and Chapter 3 for landscaping information

- site conditions and constraints
- proposed land uses
- plant types
- soil types (gradation)
- stormwater pollutants
- soil moisture conditions
- proper drainage
- groundwater recharge
- overflows



Unlike various other practices that control only peak discharge, bioretention can be designed to mimic the pre-existing hydrologic conditions by treating the associated volumes of runoff. The bioretention technique has led to the creation of a new, holistic development philosophy known as Low Impact Development (LID). For more specifics on LID, please consult the County's Low Impact Development Design Manual.

The use of bioretention not only provides for water quality and quantity control, but also adds the many values of landscape diversity to a development. Bringing landscape diversity into the built environment:

- Establishes a unique sense of place (especially when plants native to the area are featured)

- Encourages environmental stewardship and community pride
- Provides a host of additional environmental benefits (habitat for wildlife and native plant varieties, improving air quality, reducing energy use, mitigating urban climates)
- Increases real estate values up to 20% by the use of aesthetically pleasing landscaping

By design, bioretention does not require intense maintenance efforts. Therefore, the transfer of the maintenance obligations to the individual homeowners is a viable alternative. The Kettering Urban Retrofit Study found that nearly 70% of the property owners would perform yard and garden maintenance activities that would help safeguard the environment. Proper maintenance will not only increase the expected life span of the facility, but will also improve aesthetics and property value. See Chapter 5 for specifics on maintenance responsibilities.

1.2 The Bioretention Concept

A conceptual illustration of a bioretention facility is presented in Figure 1.1. Bioretention employs a simplistic, site integrated, terrestrial-based design that provides opportunity for runoff infiltration, filtration, storage and for water uptake by vegetation. Bioretention facilities capture rainwater runoff to be filtered through a prepared soil medium. Once the soil pore space capacity of the medium is exceeded, stormwater begins to pool at the surface of the planting soil. When using the recommended engineered soil mix with underdrain, ponding will last for less then ½ hour- longer if the system is dewatered by infiltration alone.

Another conceptual element of bioretention is the control of runoff close to the source. Unlike end-of-pipe BMPs, bioretention facilities are typically shallow depressions located in upland areas. The strategic, uniform distribution of bioretention facilities across a development site results in smaller, more manageable subwatersheds, and thus, will help in controlling runoff close to the source where it is generated.

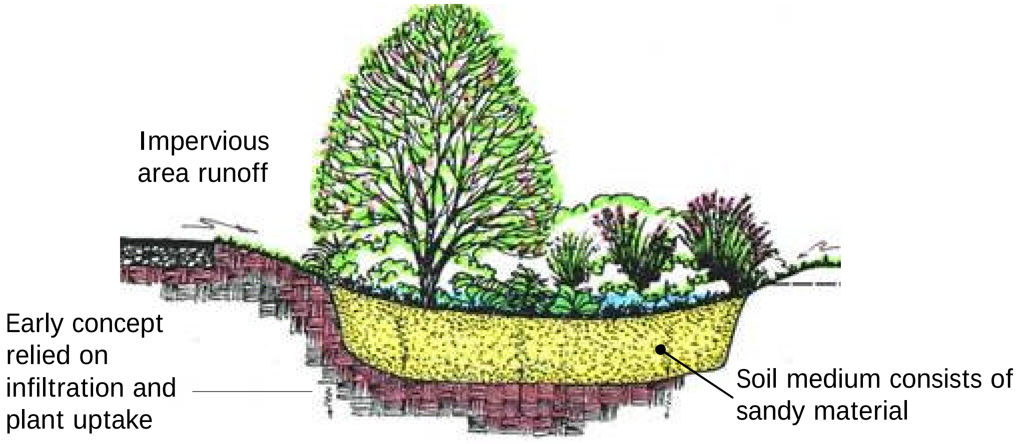


Figure 1.1 Bioretention facility Conceptual Cross-sectional Layout (early design)

1.3 Critical Processes of Bioretention –

Discussion of the Physical, Chemical, & Biological Functions

Bioretention facilities are designed to function in much the same way processes occur in the natural environment. In fact, it is this principal of following the physical, chemical, and biological processes that occur in nature that we are attempting to reproduce. Depending upon the design of a facility, different processes can be maximized or minimized with respect to the type of pollutant loading expected. In this section, we briefly introduce these processes as "critical processes."

The *major* critical processes that occur with respect to bioretention facilities include the following:

- **Interception** - The collection or capture of rainfall or runoff by plants or soils. Plant stems, leaves, and mulch within the bioretention facility intercept rainfall and runoff, which then pools at the center of the facility.

- **Infiltration** - The downward migration of runoff through the planting soil and into the surrounding insitu soils. Infiltration can be a major process in bioretention facilities. Infiltration will occur in bioretention facilities, with or without underdrain systems.

- **Settling** - As the runoff slows and ponds within the bioretention area, particles and suspended solids will settle out. This process occurs on the surface of the bioretention facility, providing pretreatment prior to entering the filter medium.

- **Evaporation** - Thin films of water are changed to water vapor by the energy of sunlight. Bioretention facilities have a very shallow ponding area—only 3-4 inches deep—to facilitate evaporation.

- **Filtration** - Particles are filtered from runoff as it moves through mulch and soil. In bioretention facilities, filtration removes most particulates from runoff.

- **Absorption** - Water is absorbed into the spaces between soil particles and then is taken up by plant root hairs and their associated fungi.

- **Transpiration** - Water vapor that is lost through leaves and other plant parts. More than 90% of the water taken into a plant's roots returns to the air as water vapor.

- **Evapotranspiration** - Water lost through the evaporation of wet surfaces plus water lost through transpiration. The bioretention facility design maximizes the potential for this process to occur. This plant/soil/runoff relationship is one of the processes that set bioretention apart from conventional BMP practices.

- **Assimilation** - Nutrients are taken in by plants and used for growth and other biological processes. Plants used in bioretention facilities may be selected for their ability to assimilate certain kinds of pollutants.

- **Adsorption** - The ionic attraction holding a liquid, gaseous, or dissolved substance to a solid's surface. Humus, which can be found in bioretention facilities with the breakdown of mulch and plant matter, adsorbs metals and nitrates. Leaf mulch or compost is used as part of bioretention planting soils to provide humus. Soils with significant clay content are not used for bioretention facilities however, because clay soils impede infiltration and may actually promote clogging.

- **Nitrification** - Bacteria oxidize ammonia and ammonium ions to form nitrate (NO_3^-) a highly soluble form of nitrogen that is readily used by plants.

- **Denitrification** - When soil oxygen is low, temperatures are high, and organic matter is plentiful, microorganisms reduce nitrate (NO_3^-) to volatile forms such as nitrous oxide ($N_2$0) and Nitrogen gas (N_2), which return to the atmosphere. The designer may utilize various techniques outlined in this manual to maximize denitrification. One way to do this is to incorporate an anaerobic zone in the bioretention facility by raising the underdrain pipe invert above the base of the bioretention facility. Generally, mature soils with good structure denitrify more quickly.

- **Volatilization** - Converting a substance to a more volatile vapor form. Denitrification is an example of volatilization as well as the transformation of complex hydrocarbons to CO_2.

- **Thermal Attenuation** - Thermal attenuation is achieved by filtering runoff through the protected soil medium of a bioretention facility. One study showing thermal attenuation attributable to bioretention found that the temperature of input runoff was reduced from 33°C to about 22°C (Minami & Davis- 1999). Bioretention facilities have an advantage over shallow marshes or ponds with respect to thermal attenuation. Thermal pollution of streams from urban runoff increases the likelihood of fish kills and degraded stream habitat.

- **Degradation** - The breaking down of chemical compounds by microorganisms in the soil medium.

- **Decomposition** - The breakdown of organic compounds by the soil fauna and fungi.

All of the above processes will occur in varying degree within a bioretention facility. As one can see, bioretention is a complex process, not just a simple filtering practice. Bioretention retains pollutants thereby protecting receiving streams.

1.4 Pollutant Removal Efficiency of Bioretention

Studies have shown that the amount of pollutant runoff, in the form of sediment, nutrients (primarily nitrogen and phosphorus), oil and grease, and trace metals, increases substantially following the development of a site. Bioretention may be

Note: Studies performed on bioretention facilities to date show excellent attenuation rates for heavy metals. Additionally, good nutrient removal and thermal attenuation can also be attained.

incorporated into the landscape to remove pollutants generated from point and non-point sources. The University of Maryland, Engineering Department, recently completed an evaluation “Optimization of Bioretention”, of the effectiveness of pollutant removal. The experiment yielded valuable data on pollutant removal efficiency rates and processes for bioretention. This manual incorporates those findings into the design criteria. The following table summarizes the efficiency removal rates for various pollutants:

Cumulative Percent Removal by Depth*								
Laboratory/Field Summary								
Depth	Cu	Pb	Zn	P	TKN	NH4	NO3	TN
1’	90	93	87	0	37	54	-97	-29
2’	93	99	98	73	60	86	-194	0
3’	93	99	99	81	68	79	23	43

*Modified form experimentation performed by Dr. Allen Davis, University of Maryland

Previous studies have shown (for the Mid-Atlantic Region) that pollutant loadings are concentrated in the "first flush" of runoff from impervious areas. Other studies across the country have shown that this is only true in certain cases. In any event, bioretention areas can be used in the treatment of not only the "first flush", but can also be used for volumetric control of all storms by adjusting the ratio of the facility surface area to drainage area. In addition, when using a high flow rate media, most of the annual runoff volume can be filtered.

1.5 Biological Processes / Cycles in Bioretention

Bioretention gets it’s name from the ability of the biomass to retain nutrients and other pollutants. Bioretention depends upon the natural cleansing processes that occur in the soil/mulch/plant community. Proper bioretention design will allow these natural processes and cycles to occur and maintain a perpetuating system. The two main nutrient cycles of concern are those of nitrogen and phosphorus. Nitrates and phosphates are the two key target pollutants analyzed within the system. While these cycles are highly complex, their general application to bioretention is briefly explained below.

1.5.1 Nutrient Assimilation

Nutrients are required for plant growth to occur. Soils lacking in nutrients will stunt vegetative growth. However, the over use and/or incorrect use of fertilizers on lawns and gardens may result in excess nutrients leaving a site through groundwater transport or stormwater runoff. Atmospheric deposition, the dumping of yard and pet wastes, and urea used to melt ice add further nutrients into the urban environment. These loadings of nutrients such as nitrogen and phosphorus can have adverse impacts on downstream aquatic environments. For this reason, nutrients must be managed, regulated and used sparingly. Bioretention facilities can help in this regard, by capturing nutrients carried in runoff through filtration, biological uptake, and storage in the planting soils. Two nutrients (Nitrogen and Phosphorus) are examined more closely in the following paragraphs.

Bioretention has been shown to be effective in the treatment of phosphorus. Studies from laboratory and field experiments indicate that phosphorus is reduced by 60-80%. For nitrates, the removal rates have been far lower, a typical problem for many stormwater filter BMP's. However, the standard bioretention design may be customized to specifically treat expected runoff pollutants by increasing depth, adding anaerobic zones, changing the mulch layer, adding soil amendments, or by adjusting phytoremediation components.

1.5.2 The Nitrogen Cycle in Soils

The natural nitrogen cycle is very efficient. Almost all of the nitrogen that enters the soil community is recycled and made available for plant growth; a small amount is leached into groundwater, lost in runoff, or volatized. This was dramatically illustrated in the Hubbard Brook Forest study when clear-cutting the forest of one watershed increased nitrate loss 60-fold.

In undisturbed ecosystems, the minor amount of nitrogen lost is replaced through biological fixation of atmospheric nitrogen--and to a lesser extent through fixation by lightning. Nitrogen fixation converts nitrogen gas (N_2) to ammonium ions (NH_4^+). Decomposers (bacteria and fungi) break down the complex organic compounds (such as proteins) in dead plant and animal matter to form ammonia and ammonium ions. Other bacteria then oxidize the ammonia and ammonium ions to form nitrates—a process called nitrification. Nitrates (NO_3^-) are highly soluble and are readily absorbed and assimilated by plants.

Human activity, however, can alter this picture greatly. Many homeowners apply large amounts of chemical fertilizers, especially to lawns. Formulations high in nitrates are popular because they promise “quick greenup.” In addition, many homeowners overwater the lawn and/or apply fertilizers just before rain or snow is expected. Additional nitrates enter the soil system as rain deposits combustion residues from cars and power plants. Together, these factors set the scene for elevated rates of nitrogen leaching and runoff from the soil. Compacted soils tend to exacerbate matters by preventing infiltration and more importantly, destroying the soil’s ecosystem and it’s ability to assimilate nitrogen.

Moreover, decomposer and nitrifying bacteria populations decrease under heavy fertilization. When pesticides and fungicides are also heavily used, the entire spectrum of soil life is curtailed. Thus the system becomes progressively less able to process and utilize even natural nutrient inputs—this often manifests in home landscapes as excessive thatch buildup in the lawn. Since many wetlands and stream buffers have been lost to development; there is little to prevent the excess nitrogen from polluting waterways. By using bioretention, however, we can capture some of the excess nitrates carried in runoff and prevent the pollution of waterways.

Figure 1.3 presents the nitrogen cycle as it may apply to bioretention, together with the various natural processes.

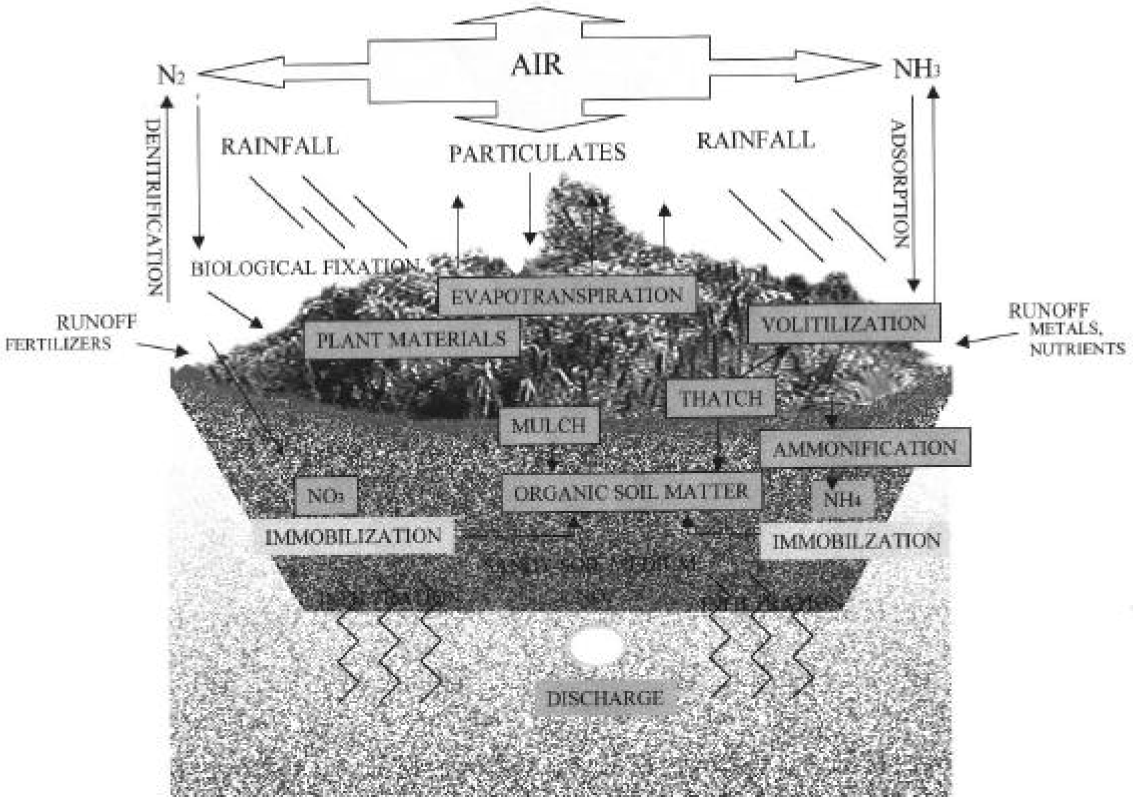


Fig. 1.3 Nitrogen Cycle for Bioretention

Nitrogen Transformation Formulas:

$$\mathbf{2NH_3 + 3O_2 \longrightarrow 2NO_2^- + 2H^+ + 2H_2O}$$

$$\mathbf{2NO_2^- + O_2 \longrightarrow 2NO_3-}$$

Compounds and Elements Defined:

NH_3	Ammonia	NH_4	Ammonium Ion
N_2	Nitrogen Gas	NO_3	Nitrates
NO_2	Nitrites	2H	Hydrogen Gas
$2H_2O$	Water	O_2	Oxygen

Nitrates are highly soluble and can infiltrate into and contaminate groundwater. To minimize this problem, an anaerobic area can be designed into a bioretention facility or it can be lined to prevent infiltration.

1.5.3 The Phosphorus Cycle in Soils

The natural cycle of phosphorus is even more efficient than the nitrogen cycle because phosphate is adsorbed on compounds containing iron, aluminum, and calcium. Thus, phosphate tends to be held within the soil instead of being leached away. Many homeowners do not realize this, however, and continue to apply excessive amounts of phosphorus-containing fertilizers year after year. Human activities have also dramatically increased soil erosion, which transports phosphorus-laden soil particles into waterways. Again, bioretention facilities can intercept and remove much of this phosphorus before it enters waterways.

Phosphorus is also necessary for plant growth and production, and most importantly in bioretention, lateral and fibrous rootlet development. Unfortunately, overuse of this element adversely affects the environment, while little or no gain is made for the intended purpose. Figure 1.4 shows the phosphorus cycle as it relates to bioretention.

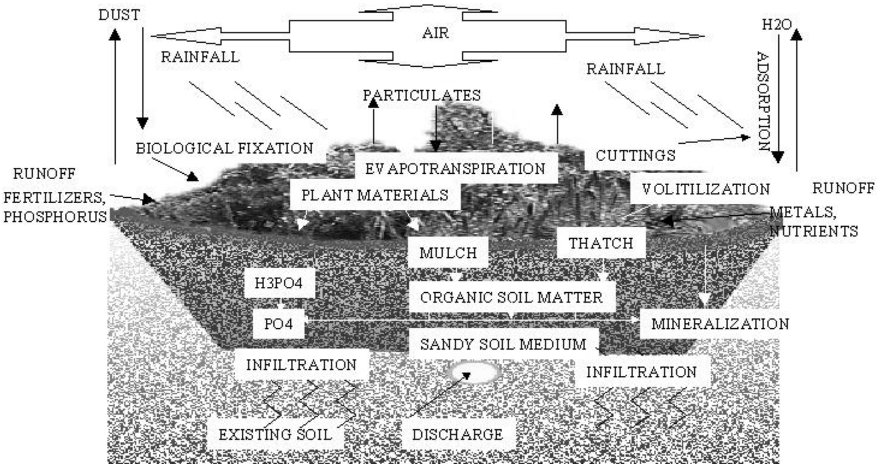


Figure 1.4 Phosphorus Cycle for Bioretention

1.6 Phytoremediation Bioretention Application & Concept

Phytoremediation is the use of vegetation for the in-situ treatment of contaminated soils and water. Typically used for sites that show shallow contamination of soils, phytoremediation has been highly successful. According to Ground-Water Remediation Technologies Analysis Center (GWRTAC) – an organization that compiles, analyzes, and disseminates information on innovative groundwater remediation technologies, this concept has been successfully applied to brownfield sites.

The phytoremediation concept has been adapted to stormwater management by transferring this technology to ultra-urban applications and stormwater management hotspot opportunities. Bioretention utilizes the same concept and applies it to stormwater management in the urban environment.

Phytoremediation can be implemented for contaminated retrofit sites. Essentially the same process as bioretention using in-situ soils, phytoremediation applications utilize plant species known for their specific ability to uptake high concentrations of toxic chemicals and process them to a less toxic state.

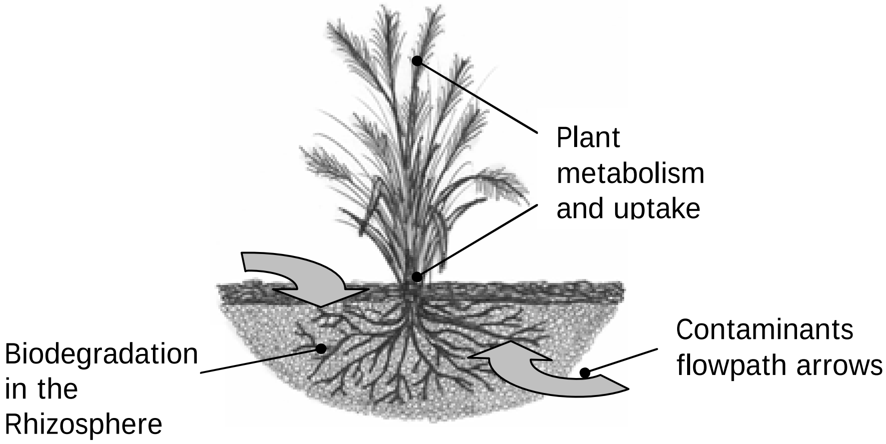


Figure 1.5 Phytoremediation

1.7 Bioretention Components

The bioretention system components have been selected to achieve and encourage biologic and physical processes mentioned in the above text to not only occur, but to **self perpetuate** as well. The components will blend over time with plant and root growth, organic decomposition, and the development of a macro and microorganism community. This in turn will help develop a natural soil horizon and structure that will lengthen the facilities life span and reduce the need for maintenance other then for aesthetics.

The bioretention area components have been combined to have complementary roles or functions to improve water quality and quantity control. The nine major *components* of the bioretention area are:

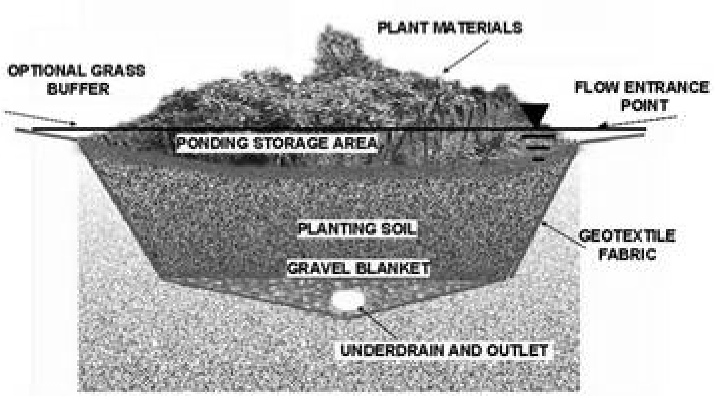


Figure 1.6 Basic Bioretention Components

- Pretreatment (optional)
- Flow entrance
- Ponding area
- Plant material
- Organic layer or mulch
- Planting soil and filter media
- Pea gravel diaphragm
- Underdrain and Outlet
- Surface Overflow

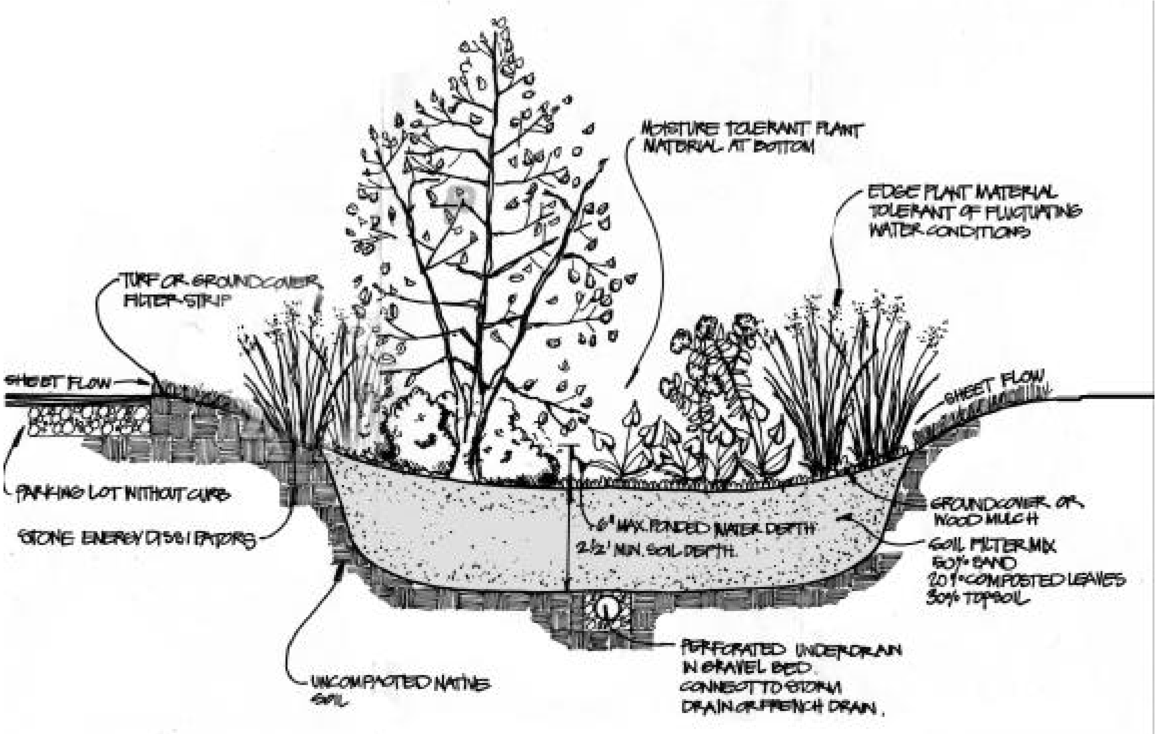


Fig. 1.7a: Typical bioretention cross-section

The bioretention components make up the overall design necessary for the biological processes to occur. The following overview of each component is provided for basic understanding. Chapter 2 provides the specific design criteria.

1.7.1 Pretreatment

Bioretention treatment is accomplished by pooling water on the surface of the facility and allowing settling and filtering of sediment and suspended solids at the mulch layer, prior to entering the soil media proper. Vegetated buffer strips provide an extra level of pretreatment when utilized in conjunction with the bioretention facility, and their use is optional. Designers are cautioned that the MDE requires additional surface vegetated area adjacent to the bioretention area to meet their stormwater management design criteria. For bioretention facilities in Prince George’s County, we do not require bioretention pretreatment because pretreatment is addressed as indicated above.

It should also be noted that the State's new stormwater management manual requires all BMP's to have pretreatment areas adjacent to the BMP. For retrofit projects and sites with tight green space constraints, it may not be possible to include a grass buffer strip. For example, parking lot island retrofits may not have adequate space to provide a grass buffer. In lieu of grass buffer strips, pretreatment may be accomplished by other methods such as sediment capture in the curbline entrance areas (see figure below). Additionally, the parking lot spaces may be used for a temporary storage and pretreatment area in lieu of a grass buffer strip.

1.7.2 Flow Entrance

The flow entrance of a facility is an important component of the bioretention. The best method of capturing and treating runoff is to allow the water to sheetflow into the facility over grassed areas. This is not always possible, especially where site constraints or space limitations impede such an approach. A remedy to this problem is to provide flow entrances that can reduce the velocity of the water. In the case of parking lot landscape islands, curb cuts protected with energy dissipators such as landscape stone or surge stone can be used. It is important to note that entrances of this type will tend to become obstructed with sediment and trash that settles out at lower velocities. This is not a problem as long as routine parking lot maintenance is performed. The trapped sediment along the curbline provides a convenient location for parking lot sweeping. On occasion, accumulated sediment and debris should be removed from the flow entrance area if the accumulation is obstructing flow into the facility itself.

Figure 1.7: Bioretention Curb-cut Entrance

1.7.3 Ponding Area

The ponding area provides surface storage of the storm water runoff, and provides for the evaporation of a portion of the runoff. Settling of the particulates occurs in the ponding area and provides an element of pretreatment. Ponding design depths have been kept to a minimum to reduce hydraulic overload of in-situ soils/soil medium and to maximize the surface area to facility depth ratio, where space allows. See Chapter 2 for sizing specifications.

1.7.4 Plant Materials

The role of plant species in the bioretention concept is to bind nutrients and other pollutants by plant uptake; to remove water through evapotranspiration; and to create pathways for infiltration through root development and plant growth. Root growth provides a media that fosters bacteriologic growth, which in turn develops a healthy soil structure.

A variable plant community structure is preferred to avoid monoculture susceptibility to insect and disease infestation and to create a microclimate, which ameliorates urban environmental stresses including heat and drying winds. Parking lot island bioretention is particularly susceptible to extended dry conditions. A layered planting scheme will help discourage weeds as well as creating suitable microclimates. There are many potential side benefits to the use of planting systems other than water quality and quantity treatment. Planting systems, if designed properly, can improve the value of the site; provide shade and wind breaks; improve aesthetics; support wildlife; and absorb noise. See Chapter 3 for recommended plant listings.

1.7.5 Organic Layer or Mulch

The organic layer (mulch) provides a medium for biological growth, decomposition of organic material, adsorption and bonding of heavy metals. Fresh bark mulch should be used when possible to maximize nitrogen retention. If aged mulch is used, use the shredded type instead of the "chip" variety to minimize floating action. The organic or mulch layer on the surface of the soil has several physical and biological functions. The surface layer acts as a filter for pollutants in the runoff; protects the soil from drying and eroding; and simulates the leaf litter in a forest community. The organic or mulch layer provides an environment for microorganisms to degrade petroleum-based solvents and other pollutants. The University of Maryland laboratory and field experiments have shown that the mulch layer provides a mechanism for extensive heavy metal capture through organic complexing.

The mulch layer should not exceed 3" in depth. Plants must be in contact with the soil to grow, and too much mulch can restrict oxygen flow to roots. In addition, mulch should not be mounded around the base of plants since this encourages damage from pests and diseases.

1.7.6 Planting Soil and Filter Media

The planting soil is the region that provides the water and nutrients for the plants to sustain growth. The upper soil zones are designed to enhance biological activity and encourage root growth. The macrofauna breaks up organic matter into smaller parts, preparing it for the next stage of decomposition. In addition, as these animals move through the soil, they provide aeration and redistribute soil components. This change in soil texture also allows more infiltration. The microbes (i.e., bacteria and fungi) break down complex organic compounds and transform nutrients into forms usable to plants. Symbiotic microbes living within plant roots enhance nutrient uptake and water retention. Clay particles that comprise a portion of the soil adsorb heavy metals, nutrients, hydrocarbons, and other pollutants. See Chapter 2 for soil specifications.

1.7.7 Pea Gravel Diaphragm

Earlier designs for bioretention with an underdrain system included a filter fabric to separate the soil medium from the gravel blanket around the underdrain. This type of system is susceptible to failure from premature clogging. Therefore, a pea gravel diaphragm is preferred. The pea gravel diaphragm provides a greater porosity and is less likely to block. The thickness of the diaphragm should be between 3” and 9” in thickness to be affective. In some cases, pea gravel is used in-place of the underdrain gravel blanket itself. If the designer utilizes pea gravel around the underdrain pipe, the perforations should not exceed ¼" in diameter.

Fig. 1.8: Pea gravel diaphragm installation

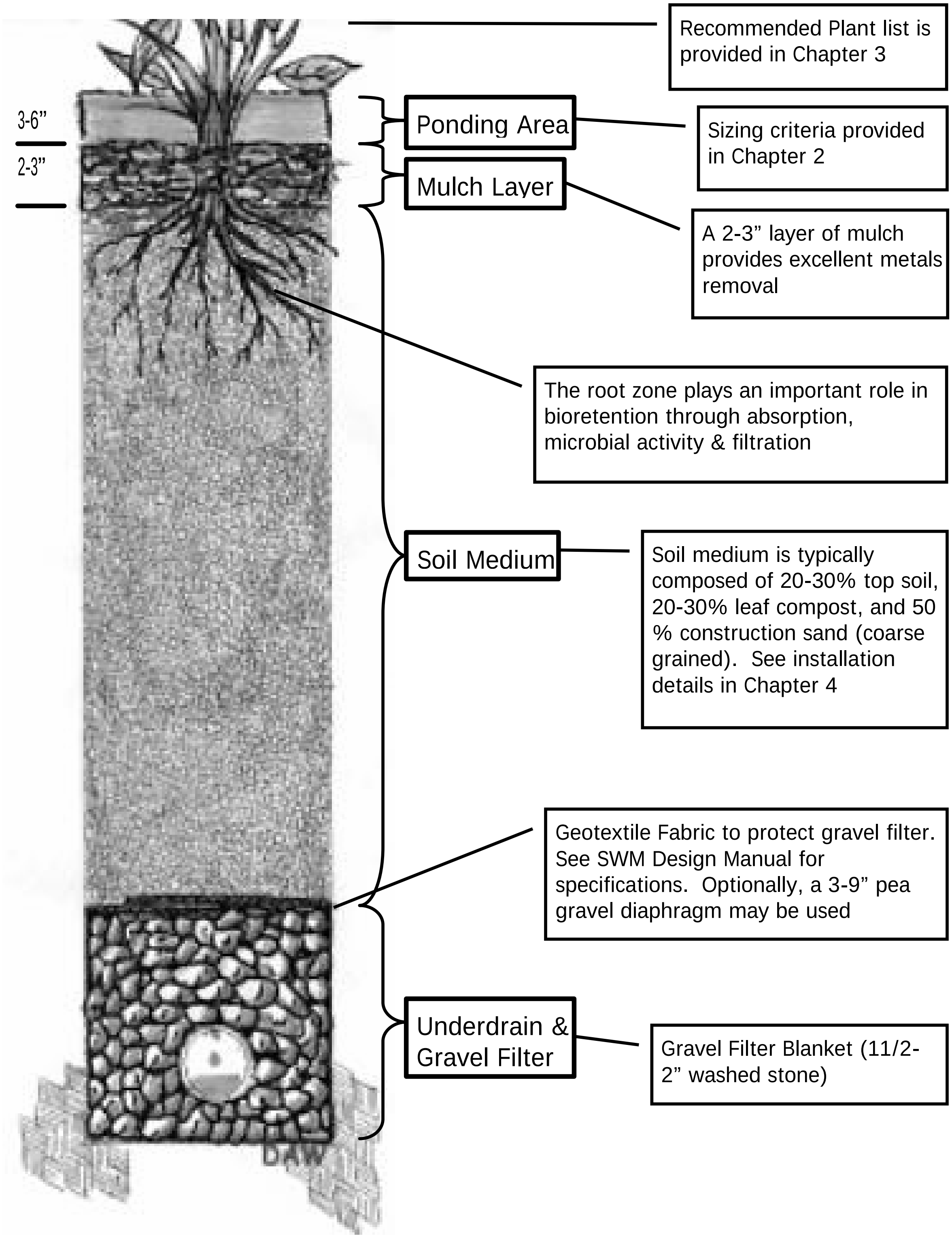
1.7.7 Underdrain or Outlet

The role of an underdrain in the bioretention facility is to ensure proper drainage for the plants and to ensure proper infiltration rates occur. The use of an underdrain system to provide a discharge point precludes the need for extensive geotechnical investigation. Typically, a bioretention facility located on a private lot will require an underdrain system to avoid drainage problems when facilities are located in prominent locations. Underdrains or other discharge methods are required when siting facilities on residential lots. Underdrains are configured in many different ways and typically include a gravel/stone "blanket" encompassing a horizontal, perforated discharge pipe. A pea gravel diaphragm as described above can be used to protect the underdrain from blocking. No underdrains are necessary for in-situ soils with infiltration rates greater than 1" an hour and where water table depths are known to be greater than 2' below the proposed invert of the bioretention facility. For added protection, the drainage area shall be less than 1 acre. A percolation test must be performed to ensure soil infiltration suitability.

Caution: Geotextile fabric may clog prematurely, resulting in limited infiltration. Fabric porosity should allow water to reach underdrain. The non-woven variety is recommended. Optionally,
Use a pea gravel diaphragm.

The use of an underdrain increases the ability of the soil to drain quickly. Underdrains keep the soil at an adequate aerobic state, allowing plants to flourish. Vertical adjustments to the location of the underdrain may be made to help establish anaerobic zones for the processing of nitrates. See Chapter 2 for underdrain details and placement criteria.

Typical Bioretention Component Column Detail



Recommended Plant list is provided in Chapter 3

Sizing criteria provided in Chapter 2

A 2-3” layer of mulch provides excellent metals removal

The root zone plays an important role in bioretention through absorption, microbial activity & filtration

Soil medium is typically composed of 20-30% top soil, 20-30% leaf compost, and 50 % construction sand (coarse grained). See installation details in Chapter 4

Geotextile Fabric to protect gravel filter. See SWM Design Manual for specifications. Optionally, a 3-9” pea gravel diaphragm may be used

Gravel Filter Blanket (11/2-2” washed stone)

Fig 1.9: Bioretention Components Column

1.7.8 Surface Overflow

The designer must address any consequences related to overflow of water from a bioretention facility. In a residential setting, overflow usually does not present a problem for two reasons: 1) the drainage area and facility capacity are relatively small, and 2) the system is located within grassy areas that provide a safe, non-erosive surface for any overflow conditions that may arise. Additionally, residential bioretention facilities are typically designed off-line, and already incorporate a safe overland flow path.

In commercial or industrial settings, design for overflow is more critical. Often, facilities in commercial settings are incorporated into the parking lot landscape islands. The paved surfaces flowing to the facilities can generate large quantities of runoff. Therefore, overland conveyance of overflow water and flow through bioretention facilities are discouraged. Designers are required to provide a safe discharge point.

1.8 Sizing Criteria

Although the following minimum widths are recommended, site restrictions such as on-lot available space and streetscape limitations do not preclude the use of bioretention. Therefore, the minimum sizing criteria does not need to be applied uniformly. The main purpose of specifying minimum dimensions at all, is to attempt to recreate the forest habitat and/or other upland habitats such as meadow or transition/buffer zones. Therefore, where possible and reasonable, the following physical dimensions are recommended for bioretention areas:

> The *maximum* ponding depth has been set to 6” in order to ensure that the hydrologic loading capacity is not compromised. Pooling times are kept below 4-6 hours by utilizing soil mediums with a high percentage of sand.

- The ponded area should have a maximum depth of 6 inches. A depth of 3-4 inches is preferable and allows for quicker dissipation of the pooled water.

- The planting soil should have a minimum depth of 2.5 feet +/- 0.5 feet. Root balls of many trees will require additional depths. If trees and large shrubs are to be installed, soil depths should be increased to 4-5’ deep. If shallow rooted plants are used, the soil depth may be reduced to 1.5'.

- The surface area of the facility may be adjusted as need to compensate for the expected flows.

This sizing criterion is provided for guidance only and is not intended to preclude facilities on a smaller scale.

The preferred ponding depth of 3-4 inches was established to provide for adequate surface storage of water, so that water would not pond for a period in excess of 3-4 hours. A short duration ponding time ensures that potential plant species for bioretention areas are not severely limited. Ponding depth may be increased in cases where it can be demonstrated (by geotechnical report) that the infiltration rate is sufficient enough to downdraw within the prescribed timeframe.

Although the bioretention pit may be excavated to a minimum depth of 2.5 feet, when tree rootballs are installed, the root ball may be placed below or above the facility invert to ensure adequate cover. Where gravel beds are used around underdrains, avoid placing the rootball within the gravel bed to reduce the effects of “wicking”.

The minimum planting soil depth guideline was established based on pollution removal efficiencies and construction considerations. The minimum planting soil depth of 2.5 feet was set to provide adequate moisture capacity, and to create space for the root system of the plants. The relatively shallow depth simplifies construction of the facility.

1.9 Bioretention Area Types

Conceptual illustrations of various types of bioretention areas are presented in the following figures. It should be noted that the layout of the bioretention area will vary according to individual sites, and to specific site constraints such as underlying soils, existing vegetation, drainage, location of utilities, sight distances for traffic, and aesthetics. Designers are encouraged to be creative in determining how to integrate bioretention into their respective site designs. With this in mind, the following conceptual illustrations are presented as alternative options.

1.9.1 Commercial/Industrial Bioretention

In Commercial/Industrial zoned areas, green space areas are often limited. This can present an opportunity to the designer to help their client obtain multiple credits for landscaping, green space, and stormwater management. However, even in industrially zoned areas, where traditionally, landscaping has not been a focal point, combining the stormwater management requirements with landscaping options can have a positive impact. Bioretention is a perfect way to achieve this. The following bioretention area types provide design ideas for various site conditions.

1.9.1.1 Curbless Parking Lot Perimeter Bioretention

The bioretention area featured in Figure 1.10, to be located adjacent to a parking area without a curb, has the lowest construction cost, since there is no curbing, and the drainage is sheet flow. In a paved area with no curb, pre-cast car stops can be installed along the pavement perimeter to protect the bioretention area. This application of

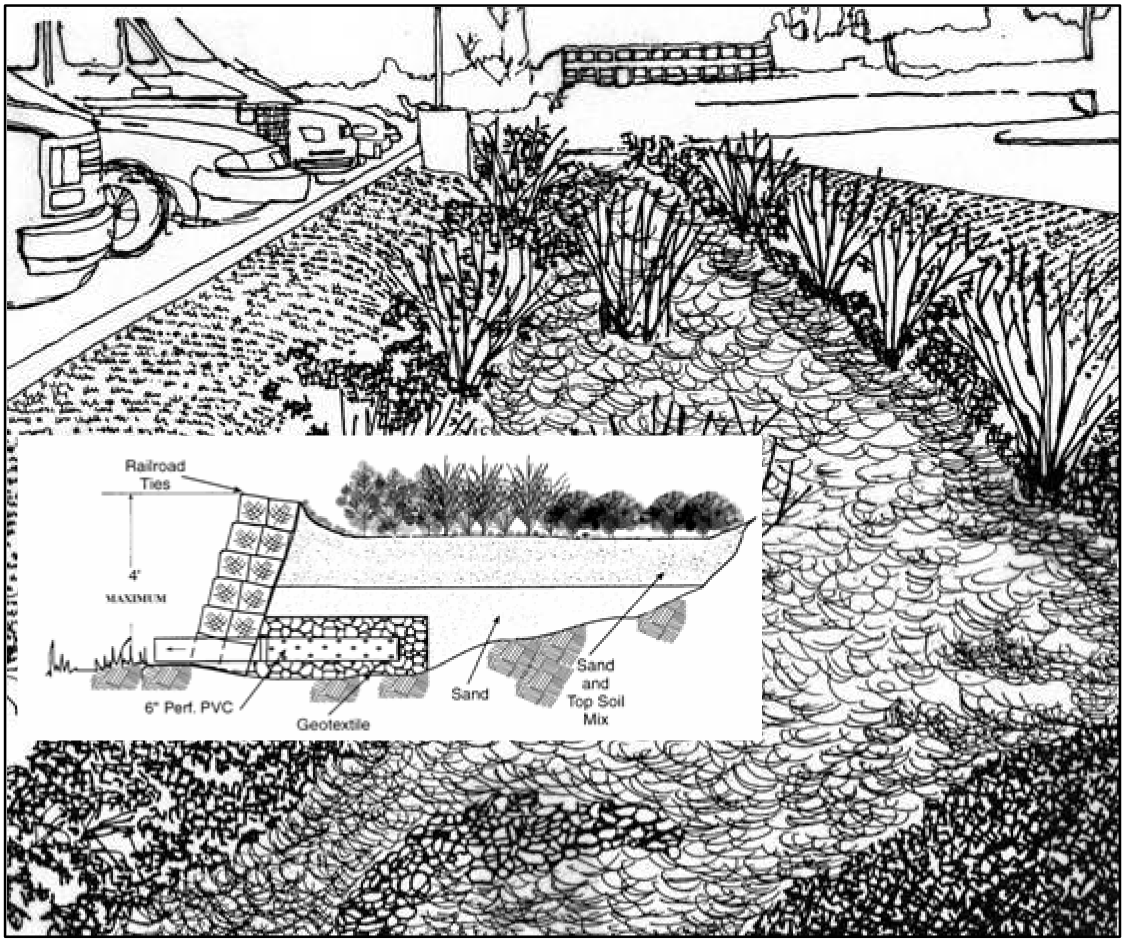


Figure 1.10: Curbless Perimeter Bioretention

bioretention should only be attempted where shallow grades allow for sheet flow conditions over level entrance areas. Water may be pooled into the parking area where parking spaces are rarely used, to achieve an element of stormwater quantity control beyond the confines of the bioretention surface area.

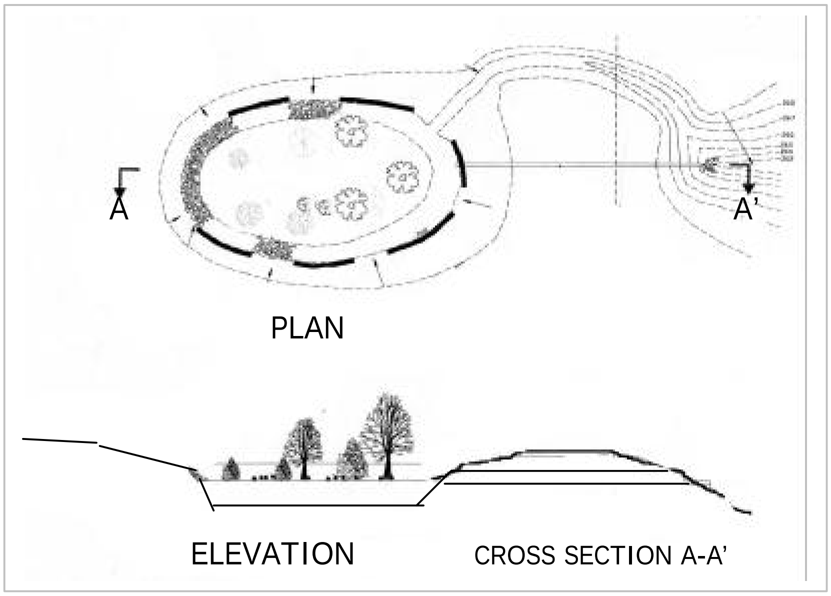


Fig. 1.11: Curbless "flow-through" bioretention

The facility pictured at the left is known as an "online facility" because the excess drainage will flow through the facility via the overflow outlet.

1.9.1.2 Curbed Parking Lot Perimeter Bioretention

A bioretention area suitable for parking lot or traffic island green space areas is shown in Figure 1.9. For curb-cut entrance approaches, the water is diverted into the bioretention area through the use of an inlet deflector block, which has ridges that channel the runoff into the bioretention area. A detail of the inlet deflector block is shown in Appendix A.

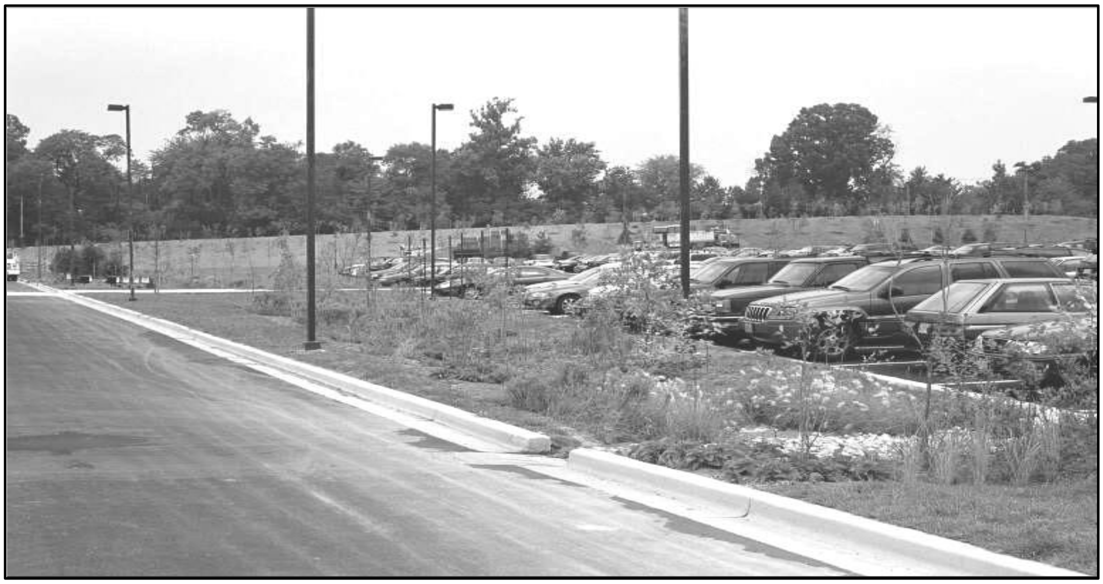


Figure 1.12: Curbed Parking Lot Island & Median Bioretention

1.9.1.3 Parking Lot Island and Median Bioretention

A concept for a bioretention traffic island is presented in Figure 1.12. There is no minimum width recommended for traffic islands from top of curb to top of curb. However, widths of the islands shall conform to standard traffic island detail specified in the Prince George's County Landscape Manual.

A two foot buffer is shown along the outside curb perimeter to minimize the possibility of drainage seeping under the pavement section, and creating "frost heave" during winter months. Alternately, the installation of a geotextile filter fabric "curtain wall " along the perimeter of the bioretention island will accomplish the same effect.

Fig. 1.13 Median Bioretention

Parking lot island bioretention designed with an underdrain system and high porosity soils (i.e., sand), can exhibit very high hydraulic capacity. Even though the filtration rate is high (>4" an hour), water quality improvements are still achievable.

1.9.1.4 Parking Swale Bioretention

The parking trench/swale bioretention technique utilizes vegetated soil/gravel trenches integrated into parking lot areas at strategic locations. This system provides an excellent means of capturing parking lot runoff by the use of trenches placed at the center of traveled ways and adjacent to parking lot spaces.

1.9.1.5 Swale-side Bioretention

A bioretention area suitable for installation adjacent to a swale is shown in Figure 1.10. A 1-foot high berm separates the swale

Figure 1.14: Swale-side bioretention

from the bioretention area. To maintain an off-line system, the bioretention area should be graded such that the overflow from the bioretention area discharges into or near the baseline of the swale. It is recommended that the bottom of the bioretention area invert be a maximum of 3-4" below the swale invert to provide for the appropriate depth of ponded water.

Figure 1.15: Rain Garden or Landscaped Garden Bioretention

Swale-side bioretention areas are typically shallow in depth and an underdrain may be installed to discharge into the adjacent swale line.

Figure 1.16 shows a plan view diagram and a cross-section of the swale-side bioretention area. Note that the bioretention depth is greater than the invert of the swale itself.

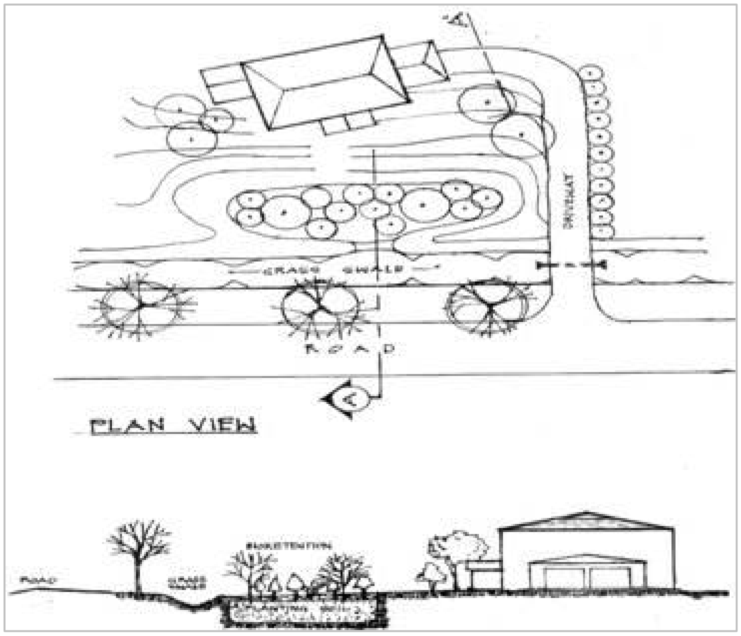


Fig. 1.16: Plan view and cross-section of a swale-side bioretention area

1.9.1.6 Rooftop Bioretention

The rooftop bioretention facility essentially follows a design available from many different manufacturers. Typically, the design employs a thin plant/membrane system designed for creating an aesthetically pleasing roof garden that also provides an element of stormwater management. This system is chiefly a filtration bioretention design that can compensate for the lost hydrologic characteristics of the building footprint. See figure 1.17.

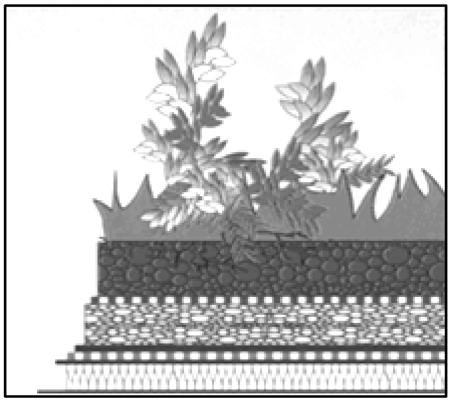


Figure 1.17: Roofmeadow^{tm}

1.9.2 Residential On-lot Bioretention

When placing bioretention within residential communities, the chief concern is aesthetics and visibility. Although underdrains ensure that the facilities will drain within the design time frame, soil analysis is still recommended to avoid drainage problems. Site constraints can limit applicability of bioretention in residential communities. However, with thoughtful design and consideration of local building codes, bioretention may be used on *any* size residential lot.

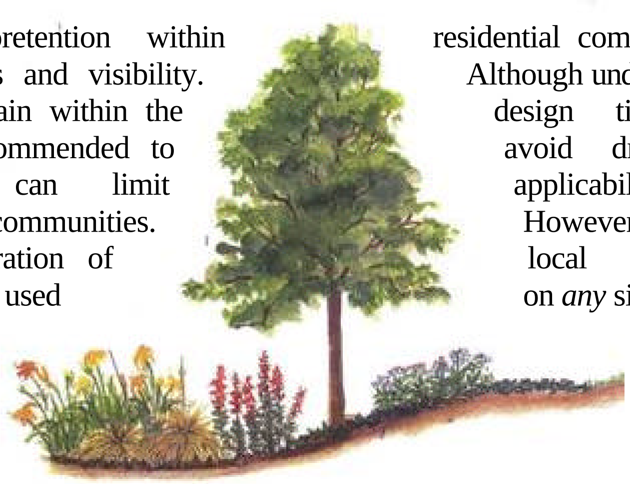


Fig 1.18: Rain Garden Layout

1.9.2.1 Landscaped Garden

Probably the most simplistic design, a landscaped garden bioretention facility employs the use of common flower gardens and planting arrangements. Instead of the area being mounded, the area is lowered (depressed) to intercept water and contain nutrient transport. Flower beds and other landscaped areas are depressed at least 2”-3” to contain runoff to allow seepage into the garden area.

1.9.2.2 Shallow-Dish Design

For bioretention facilities with small drainage areas (<1/2 acre), the designer may utilize a shallow-dish design method. This design method can be incorporated into final grading operations on the individual lot, thus minimizing the grading and excavation costs.

This bioretention area type may be implemented in areas that require bioremediation and phytoremediation techniques. See the construction details chapter for specific design criteria.

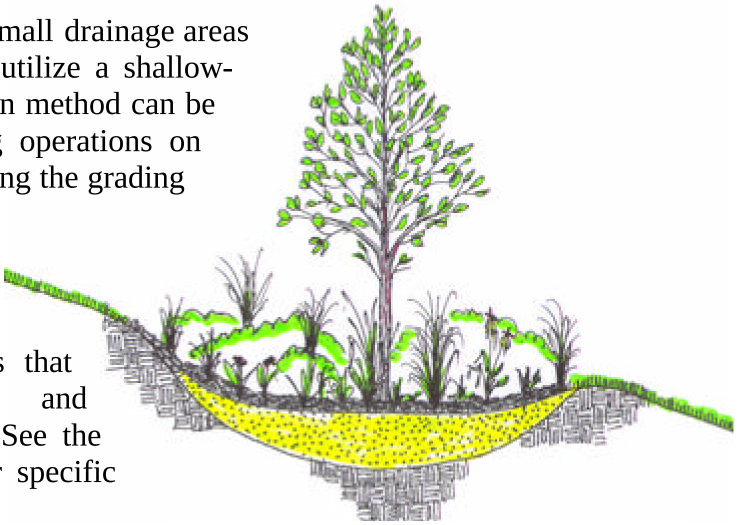


Fig. 1.19: Scalloped Bioretention

1.9.2.3 Tree and Shrub Pits

Ordinary "tree pits" may be used for bioretention needs for local drainage interception. This technique provides very shallow ponding storage areas in a "dished" mulch area around the tree or shrub. Typically, the mulched area extends to the dripline for the tree and is similar to conventional mulching practices with the exception of the mulch area being depressed at least 2-3” rather than mounded around the tree. See Figure below for additional detail.

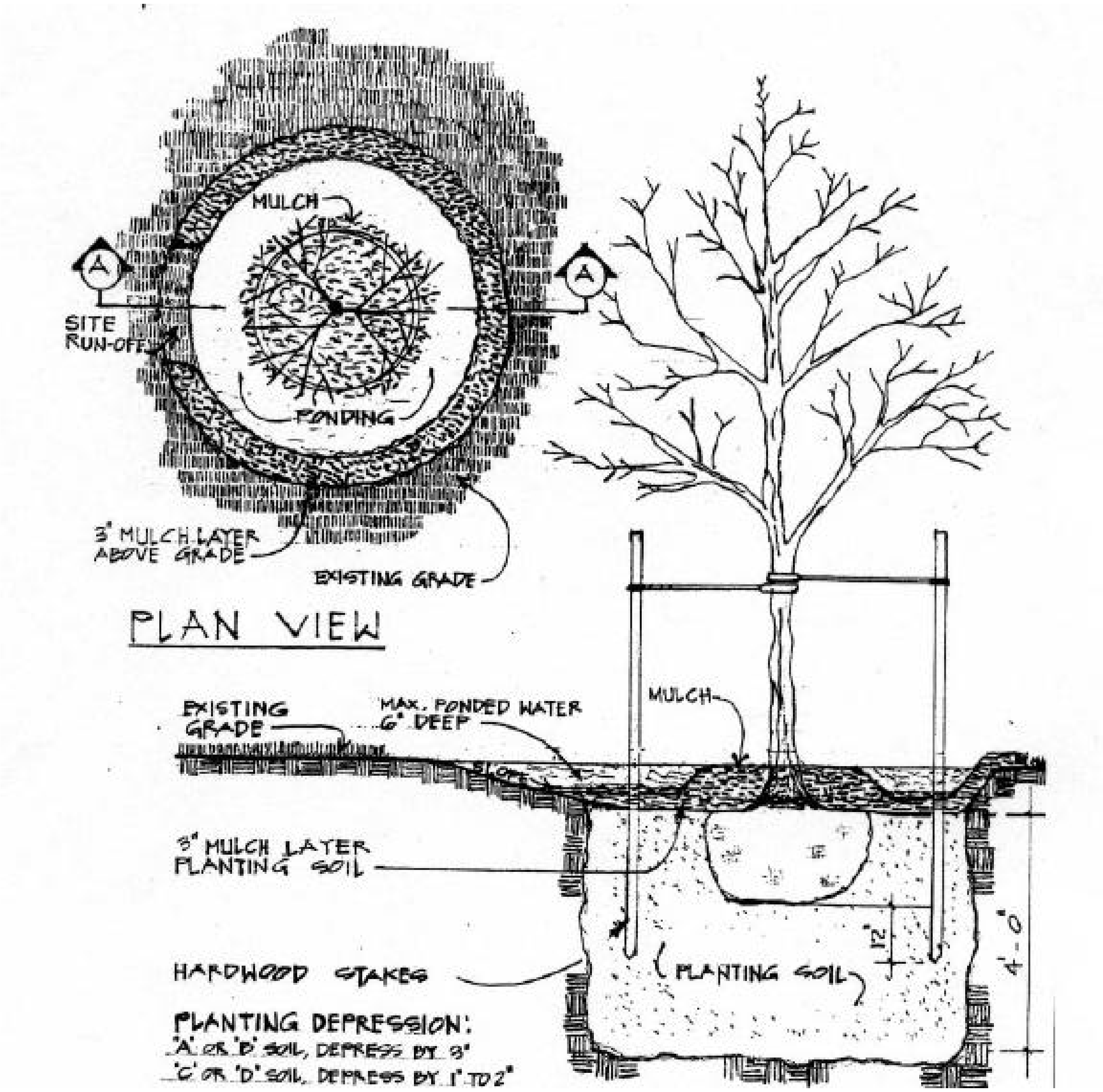


Fig. 1.20: Tree Pit Bioretention

1.9.2.3 Sloped “Weep Garden”

Bioretention facilities may be placed in areas that are sloped, if designed to accommodate the restrictive conditions. The use of a downstream side stone/wooden-retaining wall allows the soil-filtered water to slowly seep through the retaining wall. This type of design is also known as a "weep garden." See design limitations for weep gardens in Chapter 2.

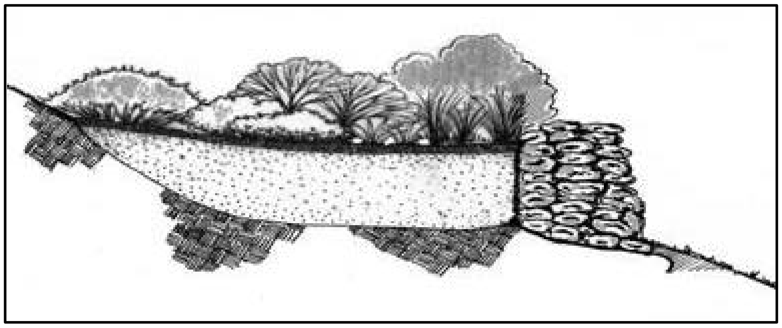


Fig. 1.21: Fieldstone weep garden design

The weep wall height should be kept below 3’ with drainage areas less than 1 acre. The weep wall may be made of fieldstone, gabions, or railroad ties.

1.9.2.5 Swale-side Garden

Fig. 1.22: Railroad Tie weep garden design w/ underdrain

Bioretention facilities can be placed next to roadside swales, complimenting the landscape features of a residential lot. By placing the facility off-line, storage depths are regulated by the flow depth in the swale centerline. For additional details, see Figure 1.14 and 1.16.

1.9.2.6 Bioretention Trap Areas

Bioretention "trap areas" may be used in tree box areas, behind curbing, sidewalks and pathways. This type makes use of manmade depressions designed to trap shallow pools of water. This technique can be simply applied by purposefully raising the sidewalk, curb or pathway elevation several inches higher than the adjoining grass areas (or alternately, lowering the treebox/grass areas. By doing so, the water traveling across the trap area will be intercepted prior to reaching a ditchline or gutter. Bioretention trap areas are typically applied in sites with limited open space areas and high flow rates such as ultra-urban environments.

1.10 Bioretention Design Themes

One of the unique qualities of the bioretention is the flexibility of design themes that a designer may employ when integrating into the site. Making multi-functional use of existing site constraints, bioretention can blend nicely with buffers, landscape berms, and environmental setback areas. Utilizing otherwise “wasted space,” bioretention can be applied in areas such as rooftops. The landscape chapter of this manual goes into more detail about plantings and should be consulted. Presented below are short definitions of some of the different design themes possible:

1.10.1 Forest Habitat

The most typical design theme, and the original concept for bioretention, the forest habitat is the most efficient in terms of mimicking pre-existing hydrologic conditions.

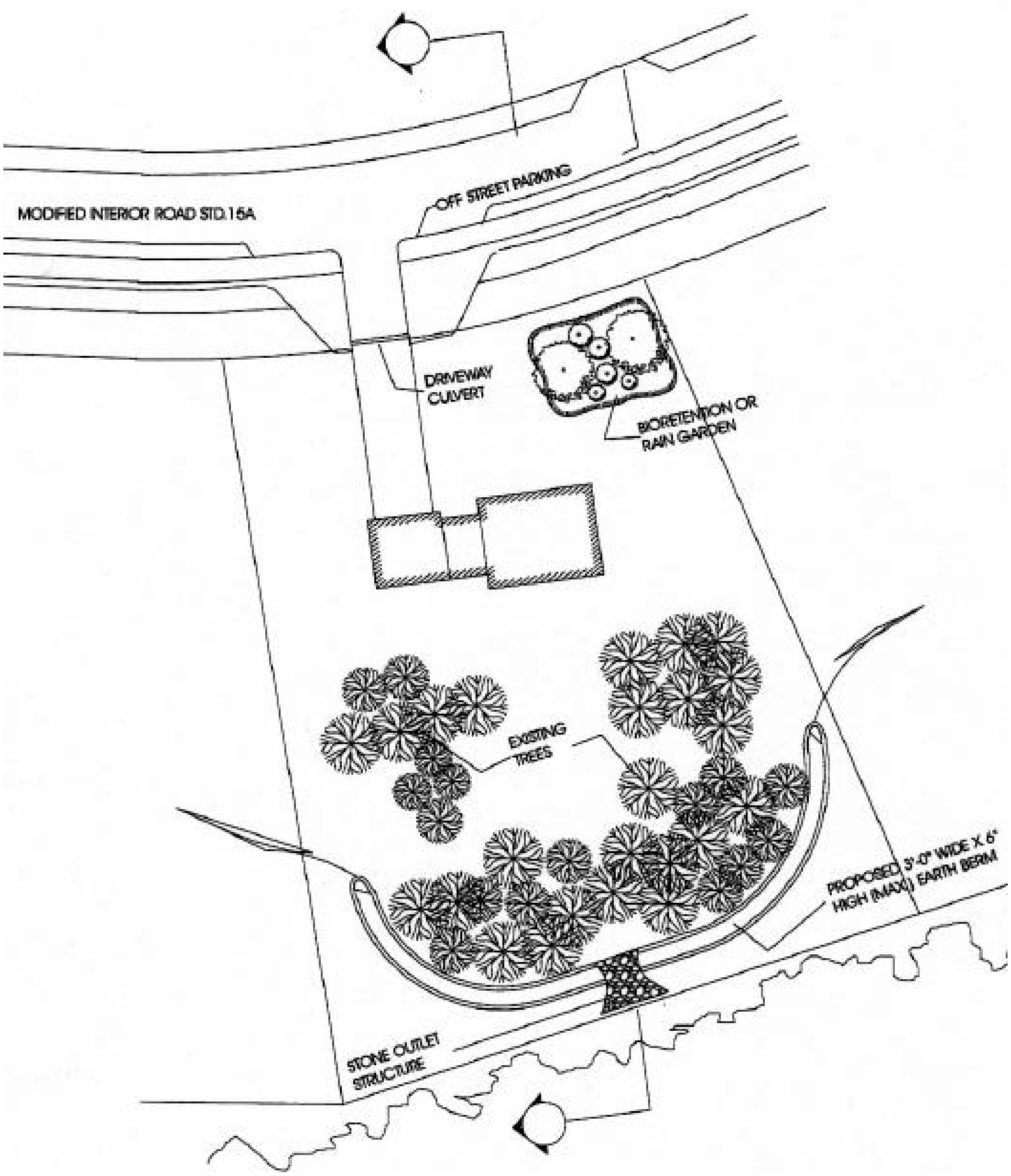


Fig. 1.23: Existing wooded area converted with berm

1.10.2 Forest Transition Zone

Forest transition zone bioretention areas are typically employed on large lots adjacent to existing forested areas or within common space areas.

1.10.3 Existing Forested Area

An alternative method of employing bioretention in areas that are already wooded is to install an unobtrusive low berm (3-4") around a tree perimeter area to make use of the existing forest area. The bioretention trap area type can be used in conjunction with wooded pathway areas in common space property. Care must be taken with this approach not to cause excessive ponding around species that are intolerant to flooding. See the plant/tree listing in the Landscaping chapter for recommended trees tolerant to frequent ponding conditions.

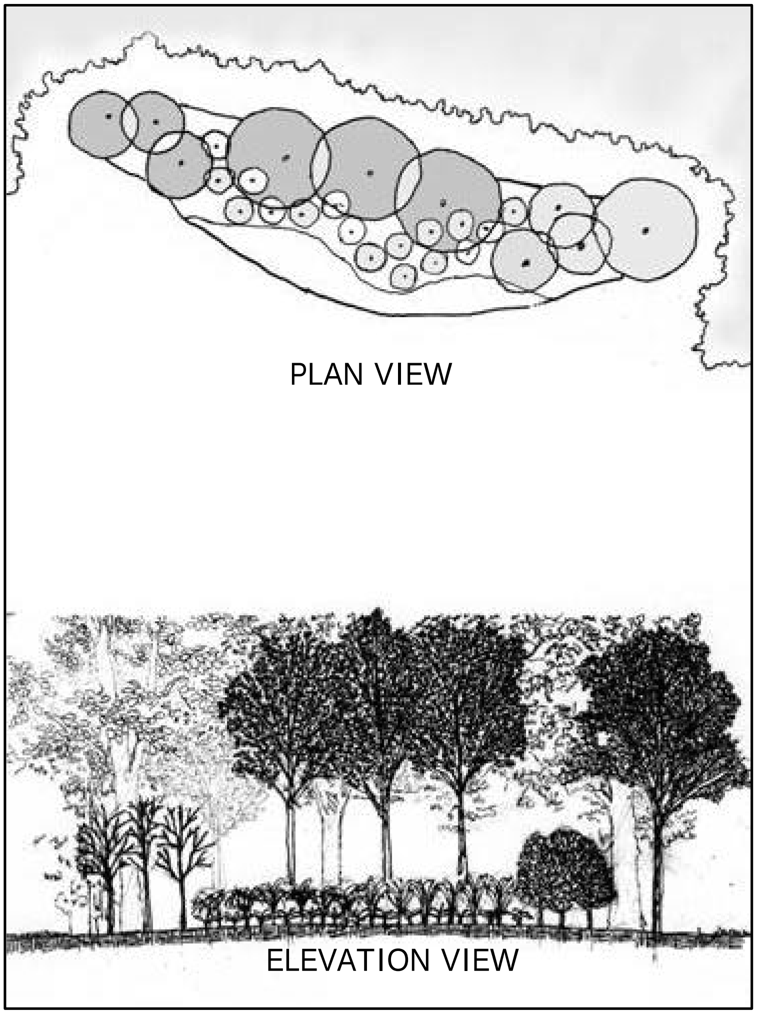


Figure 1.24: Forest Transition Bioretention Area (boundary exaggerated)

Caution: When excavating near trees or forested areas, grading and grading equipment should not encroach within the dripline zone defined by the extent of the tree canopy. Erect temporary tree protection devices during construction activities.

1.10.4 Meadow Habitat

Like a forest, a meadow is a structured community of plants occupying different levels above and below ground. A variety of grasses and wildflowers are generally interspersed throughout the site. Drifts of a particular species, however, may develop over time in response to variations in moisture or as a consequence of ecological succession. While it is not difficult to design and establish a meadow, it is important to use plant communities and techniques specifically adapted to local conditions. For guidance on developing meadow gardens consult the U.S. Fish and

Wildlife Service, Chesapeake Bay Field Office, BayScapes Program. Internet address: http://www.fws.gov/r5cbfo/Bayscapes.htm

1.10.5 Meadow Garden

A meadow garden is a more designed, less natural approach to using meadow plants. Plants may be seeded in sweeping bands of color within the meadow or zones of short, medium, and tall plant mixes can be seeded to provide height progression. In small enough areas, plants may be individually placed and arranged.

1.10.6 Ornamental Garden Design

This technique is identical to traditional formal gardening design except that the display is depressed in the landscape rather than mounded. See plant listing for recommended plants suitable for this condition.

1.11 Bioretention Site/Project Integration Opportunities

Bioretention facilities can be incorporated or integrated into any site to help improve water quality and contain increased quantities of runoff. The following site integration examples provide just a few of the various opportunities to employ the bioretention facility within a site.

- **New Residential Developments** - New developments provide perfect opportunities to employ bioretention facilities for meeting stormwater management requirements. Bioretention facilities may be placed on private lots and within common areas and combined with landscaping themes, resulting in aesthetically pleasing, multifunctional landscaping. See Chapter 2 for design criteria and conditions for siting bioretention in a residential community.

- **New Commercial/Industrial Developments** - Commercial and industrial sites again provide an excellent opportunity to employ the use of bioretention. Many commercial and industrial sites across the County already use bioretention. Here, designers can incorporate bioretention into the landscaping buffers, parking lot islands, perimeter landscaping, entrance gardens, treebox areas (green space area between sidewalk and roadway), or even rooftops.

- **Roadway Projects** - Often times, roadway improvement projects have severe site constraints imposed on the designer. Transportation safety, and Right-Of-Way limitations tend to take precedence over stormwater management concerns. For these types of situations, high hydraulic capacity bioretention facilities, strategically placed to intercept street runoff can be the solution. Locating bioretention facilities within, or just outside the treebox area can be low maintenance, yet effective way to treat and control stormwater runoff. Bioretention facilities have the additional benefit of providing roadside landscaping variety. Roadway projects have limited funding and landscaping options often get scaled back as a result. If, however, the landscape options also incorporate stormwater management control attributes, there is a value-added benefit and ultimate cost savings.

- **Institutional Developments** - Institutional settings are owned by government or private organizations and offer many opportunities for the installation of bioretention. For government facilities, no easements are necessary and access is usually not a major concern. Institutional facilities such as places of worship, schools, and community centers offer site conditions with "campus" green space areas, providing unlimited opportunity to employ bioretention facilities.

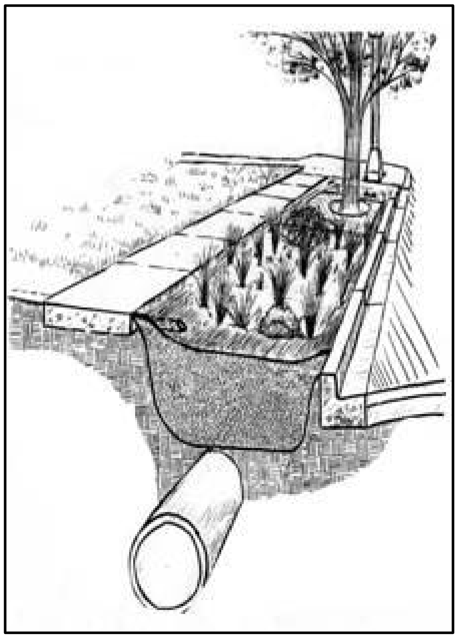


Fig. 1.25: Tree-box area bioretention

- **Redevelopment Communities** - For properties and communities that are being redeveloped, bioretention facilities are key to the environmental retrofit aspects of the redevelopment. Redeveloping communities were typically developed initially without stormwater management controls. The redevelopment process makes it possible to go back and capture lost stormwater management (SWM) options. For instance, where commercial districts are being redeveloped, greenspace areas required under County ordinances could also be used for stormwater management areas.

- **Revitalization and Smart Growth Projects** - Revitalization initiatives involve community stakeholders working in partnership. Economic revitalization includes environmental components to be incorporated into the project plan. Bioretention facilities work well to achieve successful initiatives in older communities by adding an element of landscaping aesthetics in visible public spaces.

- **Urban Retrofit Stormwater Management Projects -** A number of urban areas were initially constructed at a time when stormwater management requirements where non-existent. Urban retrofits can recapture lost stormwater management opportunities in incremental steps, one project at a time. By installing bioretention facilities in older developed watersheds, the stream degradation can begin to be ameliorated.

- **Streetscaping Projects** - Streetscaping typically involves infrastructure and façade improvements, but neglects to incorporate environmental concerns due to budget limitations. With bioretention, treebox areas can become stormwater management facilities. In this case, bioretention areas are sized as needed to fit the available space. They should also be designed to be off-line, high hydraulic capacity facilities so that at least a portion of the drainage is intercepted

- **Private Residential Landscaping** - Private property owners can also take the initiative to install bioretention facilities on private lots. Designers and Landscape Architects can incorporate bioretention facilities as part of the landscaping layout and design.

- **Parks and Trailways** - These areas encompass open space areas, making an excellent location to install bioretention facilities. Here, the designer should site facilities near park and trail parking facilities to intercept runoff. Meandering trails can incorporate small weirs (2" in height) to temporarily pond water on the upstream side of the trail.

1.12 Bioretention Economics

Why do bioretention? Beyond the environmental benefits, there are economic advantages as well. Bioretention methods modify existing site grading practices significantly compared to the conventional pipe and pond SWM approach. By intercepting runoff in bioretention areas near the source, the amount of the storm drainage infrastructure may be reduced, resulting in significant cost savings in site work.

Several case studies have been performed comparing conventional BMP design to bioretention layouts. The results indicate that integrating bioretention across a site can achieve a net reduction of between 15% and 50% of the site development costs compared with conventional BMP's. The case studies analysis demonstrates that bioretention can be an economical, environmentally effective, alternative for providing treatment and control for stormwater runoff. Key economic advantages of using bioretention for stormwater management include:

- SWM design costs and complexity reduced significantly

- Safety and risk factors lower during construction, maintenance and operation

- Grading and sediment control costs reduced by preserving dispersed drainage flow patterns

- Installation costs reduced by the use of a non-structural design

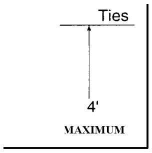
- Credit for subdivision landscaping

- Reduction or elimination of storm drainage Infrastructure

- Reduction in runoff quantity

- Reduction/elimination of need for land area to control stormwater by placing bioretention "on-lot"

- Reduction/elimination of large-scale SWM end-of-pipe treatment areas



- SWM maintenance responsibility manageable and shifted from the local government to the homeowner.

- Homeowner stewardship and ownership

Obviously, the design of the bioretention facility influences the economics greatly. For this reason, a simple and flexible design methodology has been established and is detailed in Chapter 2. The following chapter on design of bioretention attempts to incorporate value engineering where possible to keep design and construction costs to a minimum.