Chapter 2

Development of Bioretention Practices for Stormwater Management

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This chapter introduces the concept of bioretention practices for stormwater management. Bioretention is a method of stormwater management using native plantings and soil conditioning. Bioretention areas are conceived to capture sheet flow from impervious surfaces and will be typically limited to small drainage areas from 0.25 to 1 acre. The material presented in this chapter is the result of a study to determine the technical feasibility of using bioretention for stormwater management. The following inter-related elements of bioretention

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are addressed:

1) hydrology/hydraulics,
2) plant materials suitability,
3) pollutant loading and nutrient balance, and
4) soil interaction.

The results of the study are reported including presentation of design or parameters for the following areas:

1) use of bioretention practices in the landscaped or graded green space areas for commercial and industrial sites,
2) development of plan and section details for bioretention practices in parking islands, parking edge, and perimeter areas, and
3) creation of guidelines for water storage for uptake by vegetation, and minimum surface area requirements.

A case study of the implementation of bioretention practices is also presented. The case study discusses bioretention area sizing, drainage, and cost considerations.

2.1 Bioretention Practices For Graded Areas

2.1.1 Bioretention Area Components and Functions

A typical detail for the bioretention site water quality control practices is presented in Figure 2.1. The components of the bioretention areas are:

- ponding area,
- root zone,
- sand bed, and
- organic layer.

The bioretention areas were designed to provide water storage for uptake by vegetation. The design of the bioretention area assumes that the in-situ material will have an infiltration rate lower than the soil that comprises the root zone. Water will be stored in the root zone and, over a period of days, infiltrated to the in-situ material.

The water storage and pollutant removal functions of a bioretention area is described in the following sections:
Figure 2.1
Plan and section view of a typical bioretention area.
Ponding Area

The ponding area over the root zone provides for surface storage of the storm water runoff, and provides for the evaporation of a portion of the runoff.

Root Zone

The root zone is the region which provides the source of water and nutrients for the plant to sustain growth. The voids in the soil also provide for stormwater storage.

Sand Bed

The sand bed provides for drainage and aeration of the root zone, and augments the infiltration capacity of the bioretention area. The drainage provided by the sand will assist in the flushing of pollutants from the soil material.

Organic Layer

The organic layer on the surface of the soil has the following functions:

- act as a filter for pollutants in the runoff,
- protect soil from drying and eroding,
- provide additional habitat for microorganisms,
- enable microorganisms within the organic layer to degrade petroleum-based solvents, and
- provide for the decomposition of leaves and other organic matter.

2.1.2 Bioretention Area Minimum Dimensions

The following dimensions are recommended for bioretention areas:

- minimum width should be at least 15 feet, and preferably 25 feet,
- length of bioretention areas should be at least twice the width, or a minimum of 40 feet,
- the ponded area should have a depth of 6 inches, and
- the root zone should have a minimum depth of 4 feet.

The minimum width criterion of 15 feet is especially important to attempt to replicate tree and shrub distribution patterns which exist in a forest community. Multiple rows of trees and shrubs form a microclimate which greatly reduces the effects of urban stresses resulting from the pollutants in storm
2.1 Bioretention Practices For Graded Areas

runoff, insect and disease infestations, solar radiation, and acid rain. To create densely planted areas, the bioretention areas must maintain a minimum width of 15 feet to support trees, shrubs, and herbaceous ground cover. This criterion is based on plant survival requirements and guidelines in the Prince George’s County Landscaping Manual (P.G. County, 1989).

The minimum depth of four feet was set to create space for the root system of the plants to provide for resistance from windthrow, and provide appropriate moisture capacity. The criterion of designing the length of bioretention areas to be twice the width was established for the following reasons:

- to allow sheet flow to be dispersed over a greater distance, reducing the likelihood of concentrated flow, and
- to allow for a greater edge-to-interior area ratio. Rectangles have a greater edge-to-interior ratio than circles or squares.

2.1.3 Plant Species

The bioretention plant species were selected to replicate the pollutant removal and water uptake functions of the terrestrial forest community ecosystem. Through the interaction among plants, soils, the surface organic layer, and associated biota, terrestrial ecosystems remove nutrients and pollutants from storm water runoff (Correll and Peterjohn, 1984). The soil composition used for bioretention is similar to that of mesic soils, which are a typical component of the deciduous forest ecosystem. The infiltration rate associated with mesic soils provides for periodic saturation, and allows the soils to be well drained, maintaining aerobic conditions. Appropriate species of trees, shrubs, and herbs have been selected based on the moisture regime, soil conditions, and tolerances required for the bioretention system implemented in the urban environment.

A key element of the terrestrial forest system incorporated into the bioretention design is the use of native plants. Native plants indigenous to a region are considered important from an ecological perspective. The food sources, nesting habitat, and shelter provided by native trees and shrubs are key to the survival and success of wildlife, especially in urban areas where forest cover has been replaced with impervious surfaces. Most non-native species do not provide the same environment as native species. A common problem is the tendency of non-native plants to be invasive, and to compete with native plants for space.

The plant community for forest ecosystems is stratified into layers dominated by canopy or overstory trees (Schlesinger and Waring, 1985). The stratified forest ecosystem includes an understory tree layer, shrub layer, and an herbaceous layer. The purpose of replicating the forest stratification is to create a microclimate, and reduce the stresses that traditional landscaped areas are subjected to in urban areas, such as heat stress and drying winds. Individual
plants must be selected that can tolerate the influences of storm water runoff as well as the urban stresses. Bioretention areas should not consist of a single species or monoculture for either trees, shrubs, or groundcover (herbs). It is recommended that a combination of three tree species or more be planted in the bioretention areas. A minimum of two different types of groundcover should be used for each bioretention area.

2.2 Hydrology and Hydraulics of Bioretention Areas

2.2.1 Bioretention Area Water Balance

Methodology

A water balance was developed for the proposed bioretention area based on the precipitation, runoff, evapotranspiration and the infiltration for a commercial tract over a four-day time period. The four-day period was selected for hydrologic, horticultural, and maintenance constraints. Four days is the median time period between storms in the Washington area (USEPA, 1986), and it would be undesirable for the soil in a bioretention area to remain saturated for more than four days. A ponding time in excess of four days would severely limit the potential plant species for the bioretention areas. In addition, four days is a “rule of thumb” used by the Prince George’s County Department of Environmental Resources (DER) for the time period in which ponded water would be prone to breed mosquitoes and other undesirable insects.

The overall objective of the water balance was to determine the amount of water to be infiltrated and diverted from the bioretention area as a result of varying amounts of precipitation. The water balance was developed for the following bioretention area components:

- ponding area,
- root zone, and
- sand bed.

The bioretention area used in the analysis was 15 feet wide by 40 feet long, which is the minimum size for the area.

In the first part of the water balance simulation the site runoff enters both the sand bed surrounding the root zone and the root zone itself at the center of the bioretention area. The volume of ponded water is governed by the following relationship:

\[ V_p = V_r - V_{sb} - V_{rz} \]  
(2.1)
2.2 Hydrology and Hydraulics of Bioretention Areas

where:

\[ V_p = \text{volume of ponded water (cu. ft.)} \]
\[ V_r = \text{volume of runoff (cu. ft.)} \]
\[ V_{sb} = \text{volume of sand bed infiltration (cu. ft.)} \]
\[ V_{rz} = \text{volume of root zone infiltration (cu. ft.)} \]

Runoff is diverted from the bioretention area once the ponded volume is at its limit.

The water balance computations were run at one-hour intervals for the four-day (96-hour) time period using a spreadsheet computer program. The spreadsheet analysis was set up such that site, precipitation, and soil parameters can be varied. The development of the precipitation, evapotranspiration, and infiltration variables of the water balance are described in the following sections:

**Precipitation/Runoff**

The water balance was determined for rainfall events of 0.5 and 0.7 inches. The rainfall distribution in the Metropolitan Washington Council of Governments manual, *Controlling Urban Runoff* (Schueller, 1987) indicates that a rainfall of 0.7 inches would not be exceeded 80 percent of the time. The precipitation was assumed to occur over six hours, which is the median storm length for the (USEPA, 1986).

In determining the runoff to the bioretention area, it was assumed that the commercial tract was impervious over 80 percent of the surface. This is the maximum imperviousness for commercial tracts set by Prince George’s County development guidelines.

**Evapotranspiration**

Evapotranspiration (ET) is the aggregate term for the water use by the biological functions of plants, and the water loss from evaporation from the surface of the plant and the adjacent soil. There has been extensive research regarding the ET rate for various crops. It is general procedure to develop ET rates for “reference” crop species such as alfalfa, and adjust the ET rates for the species of interest. The monthly ET rates for alfalfa were computed using the Blaney-Criddle Potential Consumptive Use equation. The crop coefficient (K value) for alfalfa ranges from 0.80 to 0.85. The K Value for bioretention areas is comparable to the K value for deciduous orchards (0.6 to 0.7). Consequently, the ET rate for alfalfa was lowered by 15% to develop the bioretention rate.

The ET rate for alfalfa is summarized below in Table 2.1 for various months of the year. The ET rates were computed using mean monthly temperatures, wind speed, and other weather data compiled by the University of Maryland Agricultural Experiment Station for Prince George’s County (Moyer
Table 2.1
Evapotranspiration rates for reference crop species (Alfalfa), and for bioretention areas

<table>
<thead>
<tr>
<th>Bioretention Component</th>
<th>Evapotranspiration, inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>April</td>
</tr>
<tr>
<td></td>
<td>2.88</td>
</tr>
<tr>
<td></td>
<td>May</td>
</tr>
<tr>
<td></td>
<td>June</td>
</tr>
<tr>
<td></td>
<td>July</td>
</tr>
<tr>
<td></td>
<td>August</td>
</tr>
<tr>
<td></td>
<td>September</td>
</tr>
<tr>
<td></td>
<td>October</td>
</tr>
</tbody>
</table>

and Moyer, 1987). It should be noted that there is no appreciable ET for the months of November through March. The month of July had the maximum computed ET rate (7.36 in/month) for the year. It was found that the July ET rate comprised less than 5% of the water balance. Therefore, ET was not a significant component of the water balance.

Infiltration

Throughout the water balance, water infiltrates from the ponded area to the root zone, from the root zone onto the sand layer and finally from the sand layer into the in-situ material. The infiltration rates for the sand, soil, and in-situ material were taken from the State of Maryland Manual on Infiltration Practices (MDNR, 1984). The infiltration rates used in the water balance are given in Table 2.2 for the components of the bioretention area.

In the water balance, the rate of sand and soil infiltration was initially set at the maximum rate until 80 percent of the layer was saturated. After 80 percent saturation was achieved, the infiltration rate was set to:

\[ I = I_{(max)} \times (1 - S) \]  

(2.2)

where:

- \( I \) = infiltration rate (cu. ft./hr.)
- \( I_{(max)} \) = maximum infiltration rate (cu. ft./hr.)
- \( S \) = saturation percentage
Table 2.2
Infiltration rates for bioretention components

<table>
<thead>
<tr>
<th>Bioretention Component</th>
<th>Soil Type</th>
<th>Infiltration Rate (in/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand Bed</td>
<td>Sand</td>
<td>8.27</td>
</tr>
<tr>
<td>Root Zone</td>
<td>Loamy Sand</td>
<td>2.41</td>
</tr>
<tr>
<td></td>
<td>Sandy Loam</td>
<td>1.02</td>
</tr>
<tr>
<td></td>
<td>Loam</td>
<td>0.52</td>
</tr>
<tr>
<td>In-Situ Material</td>
<td>Silt Loam</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td>Sandy Clay Loam</td>
<td>0.17</td>
</tr>
<tr>
<td></td>
<td>Clay Loam</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Results

The results of the water balance indicate that the minimum sized bioretention area of 15 by 40 feet will infiltrate runoff for a site area of 0.2 acres for a rainfall of 0.7 inches. The runoff from a slightly larger site area of 0.3 acres can be infiltrated for a 0.5 inch rainfall. Under the most conservative scenario for the 0.7 inch rainfall, the bioretention area would comprise 7% of the site area. Since bioretention areas would be located in parking islands which are approximately 6% of the site area, bioretention would not significantly increase the existing landscape requirements.

The water balance is based on the root zone soil being composed of a loam having an infiltration rate of 0.52 inches per hour, and an in-situ soil infiltration rate of 0.2 inches per hour. In-situ or root zone soils with lower infiltration rates would lower the capacity of the bioretention area below design limits.

The water balance was also used to determine the ponding volume, and percentage of saturation for the sand and root zone soil, for the 0.5 inch rainfall events. These percentages are plotted for the simulation in Figure 2.2. The plots indicate that the total ponding time in the bioretention area is 16 hours, which is well below the four-day maximum time period allowed. The plots also indicate that the sand and soil are partially saturated for 70 hours of the 96-hour (4-day) time period, and aerobic conditions would exist in the soil for the 0.5 inch rainfall.
Figure 2.2
Percent sand and soil saturation versus time for a bioretention area.
2.2 Flow Attenuation

On a typical commercial/industrial site, the sheet flow from grass or impervious surfaces are collected by storm drain systems, and conveyed to a storm water management area or off site. Part of the concept of bioretention practices is to maintain sheet flow, which will increase the overland flow travel time for a typical site, and possibly result in attenuation of the site runoff. The travel time for sheet flow can be calculated using the methodology found in SCS TR-55 (U.S.D.A., 1987).

\[ T_t = \left(0.007 \times (n \times L)^{0.6}\right) / \left((P_2)^{0.5} \times S^{0.4}\right) \]  

where:
- \( T_t \) = flow time (hours)
- \( P_2 \) = 2 year rainfall (inches)
- \( L \) = flow length (feet)
- \( S \) = slope of flow path (feet/feet)
- \( n \) = the Manning’s roughness of the slope

Sheet flow times were computed for dense grass and wooded areas for lengths varying from 25 to 100 and for slopes from 1% to 35%. The results of the computations for wooded slopes are plotted in Figure 2.3. The figure indicates that 25 feet of woods (Manning’s “n” of value of 0.04) would add 0.15 hours to the time of concentration. For a one-acre commercial site that has a runoff curve number of 90, and a existing time of concentration of 0.1 hours, the time of concentration increase would reduce the 2-year runoff from 4 to 3 cfs.

2.2.3 Hydraulics

The runoff entering the bioretention areas will be in the form of sheet flow. The potential erosion created by the sheet flow is a major concern in the design of the bioretention areas. The criteria for maximum allowable velocity listed for vegetation in the Maryland Standards and Specifications for Soil Erosion and Sediment Control ranges from 2.5 feet/sec for Rye grass to 5.5 feet/sec for Kentucky Bluegrass (MD. WRA et al, 1983).

The sheet flow velocity for parking areas was determined using sheet flow relationships developed by Izzard (Linsley et al, 1958). The sheet flow velocity was computed by dividing the unit discharge by the flow area. The unit discharge for the strip is:

\[ q = (i \times L) / 43200 \]  

where:
Figure 2.3
Sheet flow slope versus time of travel for woods (Manning 'n' of 0.4).
2.3 Water Quality

\[ q = \text{the unit discharge (cfs/ft)} \]
\[ i = \text{rainfall intensity (inches/hour)} \]
\[ L = \text{sheet flow length (feet)} \]

The detention volume on a strip at equilibrium per unit width (cross section area) can be determined from the following equation:

\[ V = k \cdot L^{(4/3)} \cdot i^{(1/3)} / 35.1 \]

\( V \) is defined as:

\[ k = (0.007 \cdot i + c)/(5^{1/3}) \]

where:

\[ s = \text{slope of surface} \]
\[ c = \text{retardance coefficient} \]

Sheet flow velocity was computed for the 2-year storm for asphalt pavement (\( c=0.007 \)) and closely clipped sod (\( c=0.046 \)) for lengths of 25, 50, 100 and 200 feet, and for slopes varying from 0.01 ft/ft to 0.35 ft/ft. The 2-year storm intensity, 5.5 in/hr, used for the computations was taken from the Prince George's County Storm Water Manual (P.G. Co., 1991) for a storm duration of five minutes.

The computations indicate that the sheet flow velocity would be non-erosive to grass cover. Results of the computations indicate that for asphalt pavement, flow velocity exceeds 3 ft/sec only in the following situations:

- 100 foot lengths of asphalt pavement of slope exceeding 20%, and
- 200 foot lengths of asphalt pavement of slope exceeding 5%.

The flow velocity for the closely clipped sod did not exceed 1.2 feet/sec.

The sheet flow computations reflect laminar flow conditions. Flow in a parking or graded area varies with the incongruities found in the surface, and will have a tendency to concentrate in the depressions. The velocity of the concentrated flow would be higher than the laminar sheet flow velocity.

2.3 Water Quality

2.3.1 Pollutant Loading From Commercial Sites

The pollutant export of nitrogen and phosphorus from the commercial site was estimated using the simple method outlined in the Metropolitan Washington Council of Governments Manual for Controlling Urban Runoff.
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(Schueler, 1987):

\[ L = \left( (P) \times (P_j) \times \left( \frac{R}{12} \right) \times \left( \frac{C}{A} \times 2.72 \right) \right) \]  

(2.7)

where:

- \( L \) = yearly pollutant export (lbs)
- \( P \) = yearly rainfall depth (40 in)
- \( P_j \) = runoff factor (0.9)
- \( R \) = percent impervious (80%)
- \( C \) = flow-weighted mean concentration of the pollutant (mg/l), Phosphorus (.26), Nitrogen (2)
- \( A \) = area of the site, 1 acre

Using the above equation, the yearly nitrogen and phosphorus loading for a commercial site of one acre was estimated to be 12.57 and 1.63 lbs/year, respectively.

2.3.2 Nutrient Balance

The uptake of nitrogen and phosphorus by plant materials is part of the forest nutrient cycle. The inputs into the cycle include: precipitation, particulate atmospheric fallout, biotic immigration, fertilizer application and pollution. The cycle outputs include: runoff and stream outflow, release into atmosphere by plants, leaching loss, and harvesting by humans. In general, the imports and exports of nutrients are small in comparison with the amounts recycled within the forest. In an acre of mature forest, up to 40 to 60 pounds of nitrogen, and 10 to 20 pounds of phosphorus, are cycled per year (Gounin, 1992).

2.3.3 Nitrogen and Phosphorus Removal

The amount of nitrogen and phosphorus removal by bioretention is dependent on many factors: the area of the tree and shrub community created, the age of the plants, and the maintenance. Based on the zoning guidelines for Prince George’s County, a one-acre commercial site would have a minimum of .06 acres of traffic islands and landscape strips. If a mature forest community were created in these areas, the amount of nitrogen and phosphorus in the nutrient cycle would be as follows:

- nitrogen: 2.4 to 4.8 lbs/year
- phosphorus: 0.3 to 1.2 lbs/year

The amount cycled would represent from 19.1 to 38.2 percent of the nitrogen loading, and from 18.4 to 73.5 percent of the phosphorus loading in
storm water runoff from the commercial site. The nutrient balance percentages
given above show that at any given time most of the nitrogen and phosphorus
would be in the leaf litter or plant droppings. Periodic removal of the litter would
reduce the amount of nutrients reaching the ground water.

2.4 Soil Interaction

The characteristics of the soil play an important role in the improvement
of water quality through the use of bioretention systems. The soil is a three-phase
system composed of gas, liquid, and solid, each of which in the proper balance
is essential to the pollutant removal achieved through bioretention. The soil
anchors plants and provides nutrients and moisture for plant growth. Microorganisms inhabit and proliferate within the soil solution, and the unsaturated
pore space provides plant roots with the oxygen necessary for metabolism and
growth.

A desirable planting soil would:

- be permeable to allow infiltration of runoff,
- provide adsorption of organic nitrogen and phosphorus, and
- prevent the long term retention of heavy metals.

The recommended planting soil for bioretention would have the
following properties:

Soil Texture and Structure

It is recommended that the planting soils for bioretention have a sandy
loam, loamy sand, or loam texture. These soils have a clay content ranging from
10 to 25%. Water balance computations in this study indicate that soils with
infiltration rates greater than 0.5 in/hr are suitable for bioretention. Sandy loam,
loamy sand, and loam soils have minimum infiltration rates ranging from 0.52
to 2.41 in/hr. Other types of loamy soils such as silt loams, and sandy clay loams
have infiltration rates of 0.27 in/hr or lower and are not suitable for bioretention.

Soil Acidity

In a bioretention scheme, the desired soil pH would lie between 5.5 and
6.5. The soil acidity affects the ability of the soil to adsorb and desorb nutrients,
and also affects the microbiological activity in the soil. The pH for best crop
production has been considered to be between 6.5 to 7.0. The pH can be lower
than 6.5 since some studies have suggested that adequate plant growth can occur
at pH values between 5.5 and 6.5 (Tisdale and Nelson, 1975).
Soil Saturation

The percent of soil pore space occupied by water can significantly affect the level of pollutant removal. Partially saturated soils, or a soil moisture regime maintained at or near field capacity is recommended for the bioretention areas. In unsaturated soil aerobic conditions exist, and in completely saturated conditions the soil bacteria exist under anaerobic conditions. Aerobic conditions permit the mineralization of organic nitrogen to ammonia by bacteria. Ammonia, in turn, may be biologically degraded to nitrite and then to nitrate. Continuous soil saturation will inhibit the mineralization of organic nitrogen. For this reason, it is important that bioretention areas be well drained.

2.5 Kettering Case Study

2.5.1 Background

The Kettering subdivision, located in a 500 acre watershed of the Western Branch of the Patuxent River, was targeted by Prince George's County, Maryland, to demonstrate and showcase a wide variety of non-point source pollutant control techniques and community participation environmental programs. As part of the Kettering project, construction plans were prepared for bioretention areas to be retrofitted into the perimeter, and interior areas of a shopping center parking lot, and the green space area of a residential portion of the subdivision.

The case study presents the methodology for the sizing, design, and the preparation of the grading plan for a bioretention area within the perimeter of the shopping center parking lot. The cost of bioretention area is also discussed.

2.5.2 Grading Plan Development

The first step in developing the grading plan is determining the size of the bioretention area. A drainage area map of the site should be created delineating the drainage areas contributing to the bioretention areas. Ideally, bioretention should be sited in a location which would allow drainage to be treated before it leaves the site, to prevent untreated runoff from discharging into existing drainage systems.

The grading plan for a bioretention area is shown in Figure 2.4. The bioretention area shown in the figure, 975 square feet, was designed to treat the runoff from a 0.8 acres of a site which contained a parking lot having an impervious percentage of 70 percent. As indicated in the figure, sheet and gutter flow is diverted into the bioretention area through an opening in the curb. Inlet deflector blocks are located in front of the curb openings to channel the flow into the bioretention area. Water is allowed to pond to a one half foot depth before runoff bypasses the bioretention area and flows into the storm drain system. The
Figure 2.4
Plan and profile for Kettering Case Study bioretention area.
bioretention area in the figure features a grass buffer strip and a sand bed to filter the fine material from the runoff which would tend to clog the planting soil.

2.5.3 Estimated Cost

The costs associated with bioretention will vary according to the size of the bioretention area, and the plants used. The estimated construction cost (Prince George’s County, Maryland costs) for the bioretention area shown in the Figure 2.1 is $6,500. The construction cost was developed assuming that the planting soil would be imported onto the site. The excavation and disposal of the existing site material, and the import of the planting soil comprised one third of the overall construction cost ($2,200). The next major cost, landscaping, was $1,400 or 20% of the total cost. The remaining construction costs included sediment and erosion control, ground cover, and miscellaneous concrete work.

2.6 Conclusions

The results of the study indicate that bioretention can be a viable method for the water quality treatment of site runoff. The treatment of the first half inch of runoff from impervious areas is the minimum water quality standard required by the State of Maryland and Prince George’s County for storm water management. The study demonstrated that a bioretention area comprising five percent of a commercial or industrial site would be able to infiltrate the first half inch of runoff. For a typical commercial and industrial site in Prince George’s county, green space comprises approximately six percent of the site area, and incorporating bioretention into the site plan would not modify the area available for parking and buildings.

Where applicable, bioretention promises to be an on-site treatment technique which can be easily integrated into new commercial or industrial landscape schemes. Bioretention can also be applied as a retrofit technique for existing development. Because of the terrestrial plant materials and the ability of the materials to tolerate greater variation in the hydrologic regime this practice could have wider applications than typical wetland systems.

Using the design criteria developed as part of this study, bioretention can be a cost effective treatment for the “first flush” of pollutants from impervious areas. The cost for a bioretention area treating 0.8 acres of a parking lot is $6,500. A water quality inlet treating the same area would cost approximately $20,000, or have approximately three times the bioretention area cost.

Bioretention methods may modify existing site grading practices. In applying bioretention to a site, a designer would use sheet flow as a stormwater conveyance rather than inlets and storm drain pipe. The reduction of the number of inlets and storm drains will have the benefit of lowering site grading costs.
References


Maryland Department of Natural Resources (MDNR), Water Resources Administration (WRA), 1984."Maryland Standards and Specifications for Stormwater Management Infiltration Practices", Stormwater Management Division, Tawes State Office Building, Annapolis, Md. 21401. p. 2-23.


Further Reading


Prince George’s County. 1987, 1990 Supplement. Zoning Ordinance of Prince George’s County, Maryland. Prince George’s County, Maryland.