Filterra® by Americast

An Advanced Sustainable Stormwater Treatment System

By Larry S. Coffman[1] and Terry Siviter[2]

I. Abstract

Filterra® is the latest advancement in Bioretention treatment technology for urban stormwater runoff. Americast, a Division of Valley Blox, Inc., working with the University of Virginia's Civil Engineering Department has optimized the treatment capacity of this innovative best management practice (BMP). Filterra® relies on a specially engineered high flow rate treatment system to provide exceptional pollutant removal. Monitoring data shows Filterra® can treat over 90% of the total annual volume of rainfall with maximum pollutant removal rates reaching 95% for total suspended solids, 82% total phosphorus, 76% total nitrogen and 91% heavy metals (measured as Cu).

The high pollutant removal efficiency is primarily due the multiple treatment systems inherent in its unique plant / soil / microbe treatment media. Its unique design and use of typical landscape plants also provides many added values such as low maintenance costs, enhanced aesthetics, improved habitat value, and easy / safe inspection. The "at-the-source" treatment strategy is highly adaptable for any urban setting to achieve multiple stormwater management water quality and quantity goals including combined sewer overflow control.

II. Background

Filterra® is based on Bioretention technology. Bioretention has been defined as filtering stormwater runoff through a terrestrial aerobic plant / soil / microbe complex to capture, remove, and cycle pollutants through a variety of physical, chemical, and biological processes. The multiple pollutant removal mechanisms of this technology make it the most efficient of all BMP's. The word "Bioretention" was derived from the fact that the biomass of the plant / microbe complex retains, degrades, uptakes, and cycles many of the pollutants / contaminants of concern including bacteria, nitrogen, phosphorus, heavy metals, and organics such as oil / grease and polycyclic aromatic hydrocarbons (PAH). Therefore, it is the "bio"-mass that ultimately "retains" and transforms the pollutants - hence "Bio-retention".

Treatment technologies using soils, sand, organic materials, microbes and plants have been used in both water and wastewater treatment. For example, wastewater effluent spray irrigation on fields and meadows has been successfully used for centuries throughout the world (Shuval et al.,

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1986). These systems have been shown to be both economically and environmentally sustainable (Feigin et al., 1991).

Bioretention was first developed by Prince George's County, Maryland's Department of Environmental Resources (PGCDER) in the early 1990's (Coffman et al. 1993). The PGCDER design manual provides basic Bioretention planning, design and maintenance guidance. The practice was originally developed to allow use of sites' landscaped and green space to filter and treat runoff. The original design was essentially an enhanced infiltration technique where the filtered water was allowed to infiltrate into the ground.

Since the introduction of Bioretention, the success of the practice has been mixed primarily due to the lack of detailed specific design and construction standards. This lack of specificity has lead to wide variations in the soil / filter mix, infiltration rates, plant materials, and sizing resulting in costly reconstruction and maintenance repairs. The advanced design of Filterra® has eliminated all of the past problems and liabilities of conventional Bioretention designs and greatly improved its performance, reliability, and ease of construction and maintenance.

III. Filterra® Physical Description

The system consists of a concrete container, a 3 inch mulch layer, 1.5 to 3.5 feet of a unique soil filter media, an observation / cleanout pipe, an under-drain system and an appropriate type of plant i.e., flowers, grasses, shrub, or tree (see Figure 1).

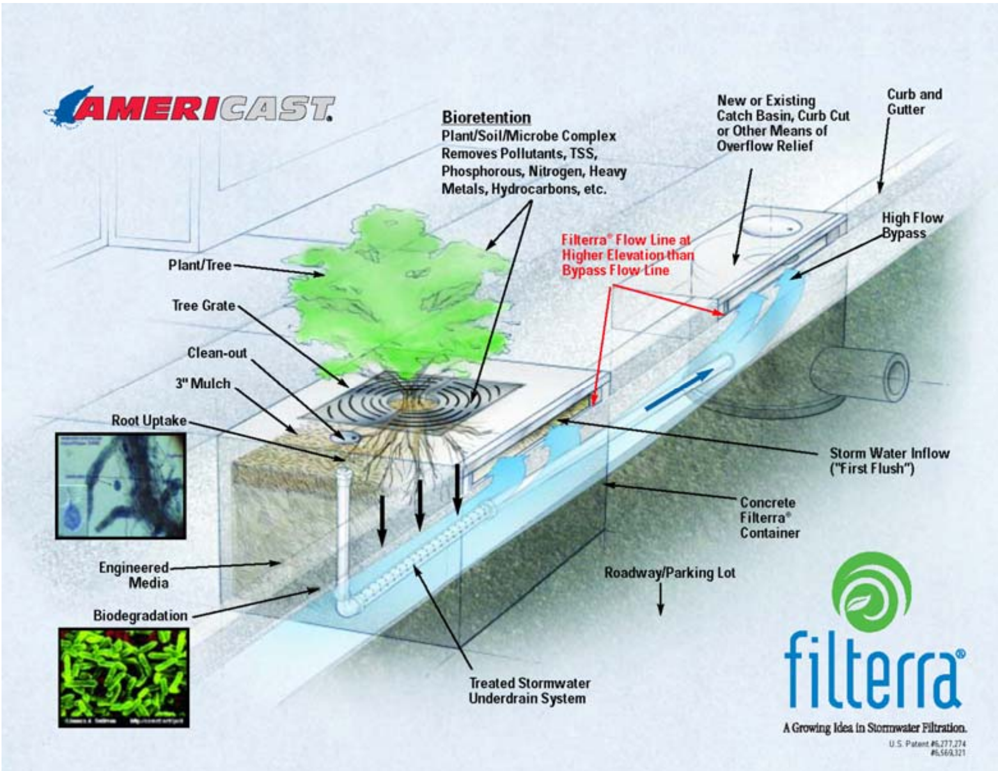


Figure 1

Stormwater runoff drains directly from impervious surfaces through an inlet structure in the concrete box and flows through the mulch, plant, and soil filter media. Treated water flows out of the system via an under-drain connected to a storm drain pipe or other appropriate outfall.

Filterra® can also be used to control runoff volumes / flows by adding storage volume beneath the filter box for either infiltration or detention control (e.g. a gravel infiltration trench area beneath the box).

Figure 2

The concrete container and treatment media are below grade with the only features visible being the top concrete slab, tree grate, plant, and inlet opening. Filterra® looks very similar to an ordinary tree box except that it is specially designed to treat runoff (see Figure 2). This is one of the few commercially available BMP that can also help to enhance the aesthetic value of the urban setting.

IV. Pollutant Removal Processes

Pollutants are captured, cycled, and removed by a wide variety of complex physical, chemical, and biological processes as the contaminated runoff flows onto and through the mulch / soil / microbe / plant treatment system. Suspended solids are removed through sedimentation as runoff is allowed to pond above the filter media with filtration of pollutants as the runoff passes through the media. Organic compounds are removed by chemical complexing with the organic constituents of the media, microbial degradation, filtration, and sedimentation. Nitrogen is captured through physical and chemical means and removed through nitrification, denitrification, and plant uptake. Phosphorus is removed through adsorption, sedimentation, precipitation and plant uptake. Heavy metals are removed through sedimentation, organic complexing, precipitation, adsorption, and plant uptake.

The pollutant removal mechanisms operate in two distinct time scales. The first time scale occurs during the storm event when pollutants come into contact with the media and are captured instantaneously through sedimentation, filtration, adsorption, absorption, infiltration, and chemical precipitation. The second time scale is between storm events. Pollutant removal and cycling occurs in a matter of hours, days, and weeks through biological degradation, biological uptake, and volatilization. The Filterra® filter media is designed to capture pollutants during the storm event while biological processes degrade, metabolize, detoxify, and volatilize the pollutants during and between storms.

The difficulty with removing pollutants in urban runoff is that they occur in a wide array of organic and inorganic forms and in various particle sizes from gross solids to dissolved molecules. Each of the various pollutant forms and particle sizes can require different processes and mechanisms for capture and treatment. Filterra® complex media structure provides for an array of physical, chemical, and biological treatment processes to handle a wide variety of pollutants. Each of these processes is described below.

A. Physical Processes

1. Sedimentation (Event Time Scale)

The storage area above the mulch layer is designed to allow a quiescent pooling of runoff within the filter box that encourages sedimentation. Most of the larger particles associated with gross and suspended solids are deposited on the surface and / or entrained within the 3-dimensional mulch layer. The amount of sedimentation is a function of particle density, size, and water density (Stokes Law). Heavy metals are commonly attached to these particles so the sedimentation process is effective in removing a portion of the heavy metals and other pollutants in particulate form.

2. Filtration (Event Time Scale)

The mulch and sandy organic media are designed to filter out many particulate pollutants. As runoff passes through the mulch layer and into the underlining sandy filter media, many smaller particles are captured in the media. The efficiency of the filtration process is a function of filter depth, media size, porosity, velocity, and nature of the particles. Studies at the University of Virginia helped to optimize the filter media to achieve both high flows and pollutant removal. Particles found in runoff range in size from trash and debris to less than 1 micron all of which can be captured in the media.

3. Infiltration (Event Time Scale)

When designed as an infiltration device, where soils permit, Filterra® removes pollutants from runoff by reducing the total annual runoff volume. This infiltrated runoff is further treated through additional chemical and biological processes occurring in the soils.

B. Chemical Processes

1. Adsorption (Event Time Scale)

The mulch and sandy / organic treatment media is complex and has a tremendous surface area. The process of adsorption is simply the preferential partitioning of a substance onto the surface of a solid substrate. This physical adsorption is caused mainly by electrostatic forces and is a function of surface area and the polarity of the materials. The media contains hydrophilic adsorbents such as aluminosilicates (sand) and hydrophobic adsorbents such as carbonaceous / organic matter that allow for wide range of pollutants to adhere to the surface of the media's components.

2. Absorption (Event Time Scale)

Absorption can be physical or chemical where the molecules of one substance are taken into the physical structure of another substance. For example, organic matter can act as a sponge to essentially soak up soluble molecules within its physical structure such as occurs with activated carbon.

3. Volatilization (Between Event Time Scale)

Volatile organic compounds (i.e., gasoline) found in runoff and captured in the filter media and will, over time, be volatized back into the atmosphere. Gases such as water, CO_2, and N_2, which are derived from metabolic processes, will also be volatized back into the atmosphere.

C. Biological Processes

1. Biological Adsorption and Capture (Event Time Scale)

The bacteria growing in the Filterra® media are encapsulated with a slime layer. This layer helps to protect the bacteria and provides a "sticky" surface to bind with particles containing organic matter and heavy metals. As the bacteria level increases in the filter media the greater the volume of sticky surface cell surfaces there are to capture pollutants.

2. Evapotranspiration

Plants also transpire or release gases to the atmosphere through openings in their leaf tissues. Phytoremediation technology has shown that plants can remove volatile substance from the soil and transpire them back into the atmosphere including volatile organic compounds VOC's (Zhang, et al., 2001).

3. Biological Processes (Between Event Time Scale)

There are several biological processes that are important in the removing pollutants from the runoff. These processes are quite complex and vary as a function of moisture, temperature, pH, salinity, exposure to toxins, and the presence of or absence of oxygen. Basically, these processes transform pollutants into other less harmful chemicals and compounds or incorporate the pollutants into the microbe/ plant biomass to create new cell matter. Some of these processes are listed below and briefly defined.

a. Nutrient Assimilation – Biologically available forms of nitrogen, phosphorus, and carbon are actively taken into the cells of organisms and used for metabolic processes (energy production and growth). Bacteria will use all types of carbon sources for food including (oil products) breaking them down for a variety of metabolic processes and needs. Nitrogen and phosphorus are actively taken up by organisms as nutrients that are vital for a number of cell functions, growth, and energy production. These processes remove metabolites from the media during and between storm events.

b. Nitrification / Denitrification – Through a complex series of processes and reactions that occur with and without oxygen, bacteria transform various forms of nitrogen into cell tissue or nitrogen gas. These processes help to reduce the total nitrogen in the treated discharge.

c. Biodegradation – Organisms can break down a wide array of organic compounds into less toxic forms or completely break them down into CO_2 and water. This process is important in detoxifying or eliminating a number of toxic organic compounds of concern.

d. Bioremediation – Bacteria and plants have a wide array of mechanisms to immobilize and detoxify organic compounds and heavy metals. For example, bacteria can cause metals to precipitate out as salts, bind them in proteins in the cell and cell wall slime, and accumulate metals in nodules within the cells. Metals are captured in the bacteria and transformed in ways that are generally less toxic to them and the plants (Means et al, 1994).

e. Phytoremediation - Plants also have the ability to metabolize many pollutants such as the uptake and accumulation of metals in the cell tissue to make them less toxic (Reeves and Baker, 2000).

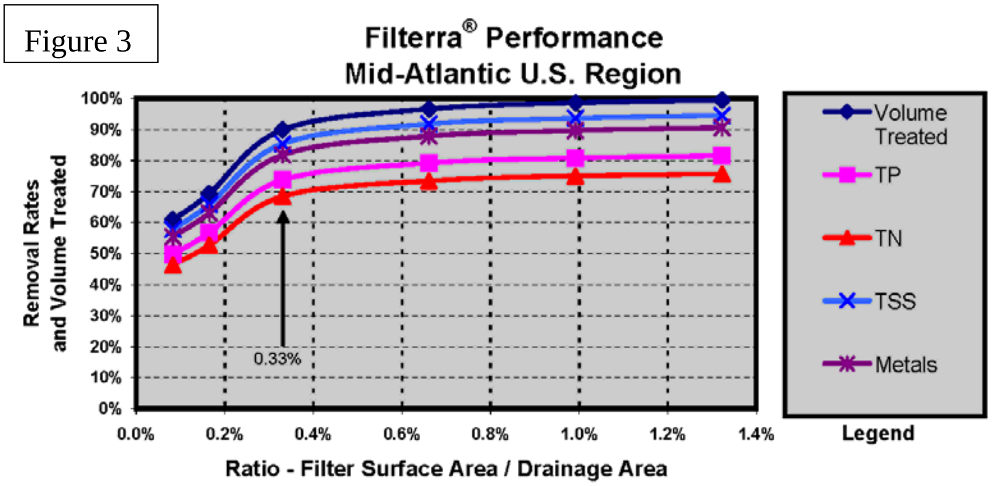
Filterra® is a living system that metabolizes volatizes, detoxifies, and cycles many pollutants in runoff. Nitrogen and phosphorus are used by the plants and bacteria to grow more cells. Organic matter is used as an energy source and metabolized into water and carbon dioxide. This means that as the biomass (plant and microbes) of the system increases in mass; so does the system's capacity to capture and process more pollutants.

Filterra® uses all of the natural process of the plant / soil complex possible to treat urban runoff. These processes can last many years as pollutants are simply recycled within the system and converted into biomass. The accumulation of debris and sediment can be removed with simple annual maintenance practices. If toxic substances should ever build to levels that may cause harm to the receiving water or wildlife, the media and plants can easily be replaced.

V. Treatment Capacity

The treatment capacity of Filterra® is dependant on the overall pollutant removal capabilities of the treatment media and the hydraulic properties of the media. Many of the pollutant removal processes were mentioned above. The hydraulic properties of importance are the flow rate through the media and the volume of runoff it can treat. Both the pollutant removal and hydraulic capacity of the system have been measured though monitoring conducted by the University of Virginia. Based on these measured values, a performance curve can be developed for various pollutants (see Figure 3). This curve shows that pollutant removal capabilities vary with the ratio of media's surface area to contributing drainage area. Increasing this ratio will increase the pollutant removal rate up to the maximum removal capacity of the media to capture and process the pollutants.

Figure 3



Based on test data and rainfall distribution of the Mid-Atlantic region of the U.S., the optimum media surface to drainage area ratio is about 0.33% or 36 square feet of media / 0.25 acres of contributing drainage area. Using the 0.33% ratio, the system will treat approximately 90% of the annual volume of runoff and can achieve maximum expected pollutant removals of 95% for total suspended solids, 82% total phosphorus, 76% total nitrogen, and 91% heavy metals (measured as Cu). The 0.33% ratio will vary from region to region as rainfall intensities varies. An explanation of the hydrology and hydraulic method for sizing the system is provided below.

VI. Hydrology and Hydraulic Analytical Method

Filterra® uses a unique and sound analytical method to determine the appropriate media surface area needed to achieve the desired treatment levels. The key is to appropriately match the media's flow rate to the unique rainfall / runoff characteristics of the drainage area. This is achieved by matching the volume of runoff treated by the media to the volume of runoff generated by the drainage area based on actual rainfall intensity distributions for any given region.

For the Mid-Atlantic region, 50 years of rainfall data was analyzed from Reagan National Airport from which the probability and frequencies of all rainfall intensities (inches/hour) were determined. Knowing this and the flow characteristics of the Filterra® media (from University of Virginia testing), one can determine the annual volume of runoff that can be treated and the optimum surface area for any given drainage area. The Filterra® performance chart for the Mid-Atlantic U.S. region (see Figure 4) summarizes the rainfall intensity distributions, predicted pollutant removal rates, and volumes treated for 36 sq. ft. of media surface area with a ¼ acre drainage area. The MS Excel based performance spreadsheet will automatically calculate the filter media surface area needed to treatment goals of any given drainage area. If other pollutant removals are required or certain annual pollutant load reductions are needed, the spreadsheet can also calculate the surface area needed.

Filterra® Performance for Mid-Atlantic U.S. Region

Drainage Area (DA) = 0.25 Acres — DA = 10,890 ft²
Filterra® Length = 6.00 feet
Filterra® Width = 6.00 feet — Filter Surface Area (FSA) = 36.00 ft²

Available Sizes	Total Contributing Drainage Area
4x6 or 6x4	0.17 ac
4x8 or 8x4	0.22 ac
Standard 6x6	0.25 ac
6x8 or 8x6	0.33 ac
6x10 or 10x6	0.42 ac
6x12 or 12x6	0.50 ac

FSA to DA Ratio = 0.331%
Flow Volume Filtered = 90.64%
TP Removal (Max 82%) = 74.33%
TN Removal (Max 76%) = 68.89%
TSS Removal (Max 95%) = 86.11%
Metal Removal (Max 91%) = 82.49%

Site Condition = Consider total contributing DA as 100% impervious
Filterra® Flow Volume = 0.01 x (LxW) / 4.276 x 3600 = 303.09 cu ft/hr
Volumetric Runoff Coefficient, R_v (use MDE Formula) = 0.95
Runoff Volume = P * R_v / 12 * DA = 862.125 P cu ft/hr

(a) Rainfall (in / hr)	(b) Runoff Volume (cu ft / hr)	(c) Runoff Treated (cu ft / hr)	(d) Cumulative Frequency	(e) Probability Frequency	(f) (c) x (e) (cu ft / hr)	(g) (b) x (e) (cu ft / hr)
0.020	17.24	17.24	0.4205	0.4205	7.25	7.25
0.040	34.49	34.49	0.6027	0.1822	6.28	6.28
0.060	51.73	51.73	0.7133	0.1106	5.72	5.72
0.080	68.97	68.97	0.7850	0.0717	4.95	4.95
0.100	86.21	86.21	0.8352	0.0502	4.33	4.33
0.125	107.77	107.77	0.8745	0.0393	4.24	4.24
0.150	129.32	129.32	0.9030	0.0285	3.69	3.69
0.200	172.43	172.43	0.9382	0.0352	6.07	6.07
0.250	215.53	215.53	0.9570	0.0188	4.05	4.05
0.300	258.64	258.64	0.9687	0.0117	3.03	3.03
0.350	301.74	301.74	0.9756	0.0069	2.08	2.08
0.400	344.85	303.09	0.9810	0.0054	1.64	1.86
0.450	387.96	303.09	0.9856	0.0046	1.39	1.78
0.500	431.06	303.09	0.9881	0.0025	0.76	1.08
0.550	474.17	303.09	0.9899	0.0018	0.55	0.85
0.600	517.28	303.09	0.9918	0.0019	0.58	0.98
0.650	560.38	303.09	0.9930	0.0012	0.36	0.67
0.700	603.49	303.09	0.9942	0.0012	0.36	0.72
0.750	646.59	303.09	0.9950	0.0008	0.24	0.52
0.800	689.70	303.09	0.9957	0.0007	0.21	0.48
0.900	775.91	303.09	0.9971	0.0014	0.42	1.09
1.000	862.13	303.09	0.9979	0.0008	0.24	0.69
1.500	1293.19	303.09	0.9999	0.0020	0.61	2.59
2.000	1724.25	303.09	1.0000	0.0001	0.03	0.17
			Totals	**1.0000**	**59.07**	**65.17**

Figure 4

Table is based on precipitation data obtained from NCDC (National Climatic Data Center).

Calculating the annual pollutant load removal is determined by simply multiplying the percent annual volume treated by the maximum pollutant removal percentage for each pollutant. These values can be found in the performance chart above.

Example: Annual volume treated = 90.64 %

Maximum TSS Removal = 95%

Annual TSS Removal = $\frac{(90.64\%)\,(95\%)}{100}$ = 86.11%

Typical sizing for the west coast is based on the Uniform Intensity Approach. The table below represents the commonly used 0.2 in/hr intensity. Please check with your regional sales manager for specific sizing for your area.

(Western Zone - 0.2 in/hr Uniform Intensity Approach)

Available Filterra® Box Sizes (feet)	Recommended Commercial Contributing Drainage Area (acres) where C = 0.85	Outlet Pipe
4x6.5 or 6.5x4	up to 0.35	4" SDR-35 PVC
4x8 or 8x4	0.36 to 0.44	4" SDR-35 PVC
Standard 6x6	0.45 to 0.49	4" SDR-35 PVC
6x8 or 8x6	0.50 to 0.65	4" SDR-35 PVC
6x10 or 10x6	0.66 to 0.82	6" SDR-35 PVC
6x12 or 12x6	0.83 to 0.98	6" SDR-35 PVC

Available Filterra® Box Sizes (feet)	Recommended Residential Contributing Drainage Area (acres) where C = 0.50	Outlet Pipe
4x6.5 or 6.5x4	up to 0.60	4" SDR-35 PVC
4x8 or 8x4	0.61 to 0.74	4" SDR-35 PVC
Standard 6x6	0.75 to 0.83	4" SDR-35 PVC
6x8 or 8x6	0.84 to 1.11	4" SDR-35 PVC
6x10 or 10x6	1.12 to 1.39	6" SDR-35 PVC
6x12 or 12x6	1.40 to 1.67	6" SDR-35 PVC

VII. Unique Decentralized Placement of Filterra® Systems

Another unique feature of the design, sizing, and placement of Filterra® is that it utilizes a distributed design approach fundamental to the innovative Low Impact Development technology (LID). This design philosophy promotes at-the-source controls; off-line configuration of the units, treating relatively small drainage areas (less than ½ acre), and a more uniform distribution of controls throughout the site. This is opposed to conventional end-of pipe and in-line treatment approach used for most BMP designs. The LID approach reduces the effective hydraulic and pollutant load to each unit thereby increasing performance and reducing maintenance burdens. Controlling runoff as close to the source as possible also eliminates problems common to conventional BMP's such as concentrated high flows that cause erosion and resuspension of pollutants or expensive control structures to store, split, or divert high flows. Using small drainage areas ensures that runoff flows and velocities are always very low.

VIII. Ease of Design

Americast's recommend media surface area to drainage area ratio of 0.33% for the Mid-Atlantic region is adequate to meet current state and Federal NPDES pollutant removal requirements. For your convenience, Americast offers a variety of precast concrete Filterra® box sizes to meet most of your site design needs. As long as you follow the LID design principles by distributing the units and keeping the drainage area to each unit at or below ½ acres, all you have to do is to properly place the right size unit to match drainage area (see Figure 5).

Available Sizes	Total Contributing Drainage Area
4x6 or 6x4	0.17 ac
4x8 or 8x4	0.22 ac
Standard 6x6	0.25 ac
6x8 or 8x6	0.33 ac
6x10 or 10x6	0.42 ac
6x12 or 12x6	0.50 ac

Figure 5

IX. Off-Line / Bypass Design

Another unique design feature of Filterra® is its off-line design configuration. This design strategy improves treatment and avoids the possibility of resuspension of particulate matter. It is important that the site designer confer with Americast on the proper location of the unit to ensure that the site grading and placement are correct (see Figure 6). Example scenarios are available by contacting Americast.

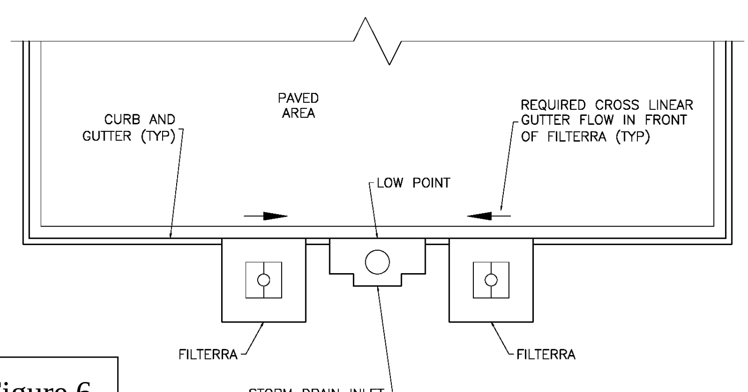


Figure 6

The site designer must also plan for the by-pass of high flows. Although the system will treat about 90% of the total rainfall events / volume, occasionally the flow capacity of the treatment media will be exceeded causing the unit to go into bypass mode. The bypass flows must be safely conveyed to a nearby inlet or other appropriate discharge point. Sump conditions must be avoided. If the unit is placed in a sump, bypass mode will result in flooding around the unit and cause resuspension of the debris collected in the unit.

X. Construction Considerations

Perhaps the most critical construction issue is proper location of the unit in relationship to the site grading. Generally, the units are placed in the curb line of parking lots and roadways. In this configuration, the site grading must direct runoff to the curb first to allow the flow to enter the unit from the curb in a cross linear manner along the face of the inlet. Filterra® looks very much like an inlet structure and often contractors will grade the site as if the unit is a standard inlet (i.e. placing it in a sump condition). The site engineer must ensure that this does not happen.

XI. Conclusions

Filterra® is one of the most advanced and adaptive BMP's on the market today. It has been carefully engineered and designed to meet all your water quality needs in the most cost effective manner possible.

XII. References

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