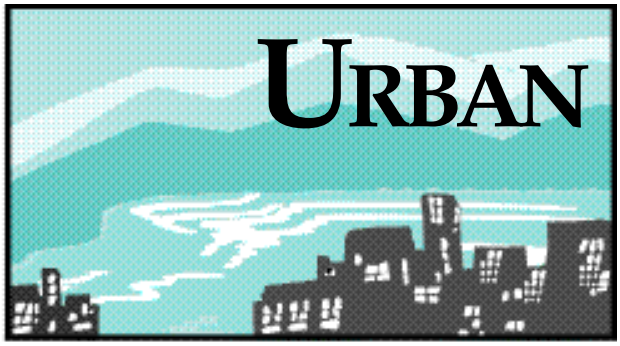

URBAN WATERWAYS

Urban Stormwater Structural Best Management Practices (BMPs)

Effects of Urbanization

North Carolina contains areas that are frequently considered among the best places to live in America. The state's growth rate is consistently one of the highest in the country. The resulting urban influx affects many facets of the state's infrastructure–more cars drive our roads, more children enroll in our schools, more people create higher wastewater discharges, and more development necessitates stormwater runoff controls.

How does urbanization affect stormwater runoff? Roads, parking lots, sidewalks, homes, and offices replace the natural–and permeable–landscape. Rainfall that once soaked into vegetated ground is now "available" for stormwater runoff. As surfaces become more and more impermeable, water simply moves across them. Impermeable surfaces connect to form a "stormwater superhighway" that allows runoff to reach streams more quickly. The effect is manyfold: (1) more stormwater reaches streams because there is less opportunity for it to infiltrate the ground; (2) peak flows increase because the "stormwater superhighway" transports runoff from large areas rapidly; (3) velocities in the stream increase, causing a larger erosion potential; and (4) baseflow is lower during dry weather due to a lack of infiltration. Using traditional analyses such as the Natural Resources Conservation Services' stormwater model, TR-55, or the U.S. Army Corps of Engineers' many versions of HEC, it can be shown that peak flows alone can increase by up to four-fold from pre- to post-development conditions. The public knows this effect of urbanization as flooding.

While an increase in stormwater runoff is an easily seen result of urbanization, there are many less visible water quality impacts associated with development. Erosion and sedimentation have long been recognized as water quality concerns. Although the North Carolina legislature passed laws to curb sedimentation in 1973, sediment remains the number one pollutant of N.C. waters. In addition, metals and organic chemicals from vehicles and industries pollute stormwater runoff in increasing amounts. These pollutants otherwise would only be found in trace amounts under forested conditions. By the mid-1990s the focus in many piedmont and eastern North Carolina watersheds turned toward excess nutrients in surface waters. Fish kills due to a lack of oxygen (hypoxia) caused by excess nutrients and the discovery of a fish-killing organism called *Pfiesteria piscicida*, which is stimulated by excessive nutrient levels, prompted action to reduce the amount of nutrients–particularly nitrogen and phosphorus–that is allowed to run off into water.

Nutrients are found in the urban environment in a variety of forms: fertilizer contains nutrients for plants to grow. But excess fertilizer or fertilizer that is inadvertently applied to pavement harms water quality. Even if

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proper amounts of fertilizer are applied, nutrients can enter our streams in other ways, including atmospheric deposition, wildlife and pet waste, and septic system malfunction.

There are numerous ways to reduce pollutant loadings. Some means include source reduction–including proper application of fertilizer and correctly maintaining septic systems. Structural devices can also help curb this problem. This publication will review a number of the structural Best Management Practices (BMPs) that can be constructed to treat runoff and thereby reduce the amount of pollution entering streams.

Best Management Practices

An urban stormwater best management practice, or BMP, is believed to be a "best" way of treating or limiting pollutants in stormwater runoff. It can be as simple as applying the proper amount of fertilizer to a home lawn or as complex as building an engineered structure such as a stormwater wetland. Certain practices are better under certain conditions than others. The pollutants to be treated, the size of watershed, the imperviousness of the watershed, and the amount of available land for the structure all influence the selection of a best management practice. Some of the BMPs are relatively well known and researched, while others are in their infancy. Several structural BMPs used to treat urban stormwater runoff are described in the following sections.

Wet Ponds

Wet ponds are a very traditional BMP. They have been used to treat stormwater for many years. Initially, wet ponds were designed to control water quantity, or flooding. Reservoirs, such as Kerr Lake and Lake Norman, are, in a sense, very large wet ponds. These reservoirs, unlike typical wet ponds, also provide water for communities and are designed to hold enough water to last during droughts.

Currently, wet ponds are designed to enhance the water quality of stormwater runoff. A typical design is shown in Figure 1. The main body of the wet pond is a 4- to 8-feet-deep pool preceded by a forebay. The forebay is where stormwater enters the pond and where sediments and pollutants attached to sediments settle out. The forebay is designed so that it can be easily excavated, allowing any build up of sediments to be readily removed, by giving access to excavation equipment. Along the sides of the wet pond is an aquatic bench, or a shelf filled with wetland plants. The bench is shallow and gently sloping, such as 1:6 rise to run. A minimum shelf width of 12 feet is used for safety reasons. Stormwater exits the wet pond through a series of outlets, including risers and weirs. These outlets are designed so that water will not flow over the length of the dam.

The size of a wet pond varies with the watershed that it is serving. In North Carolina, wet ponds must be as large as 1 to 2 percent of the area draining into it. For example, a 100-acre watershed would require a 1- to 2-acre wet pond. Other factors influencing the size of a wet pond include the depth of storage and the amount of impervious surfaces in the watershed. A deeper pond allows for a smaller surface area wet pond. A watershed that is highly developed–with lots of impervious surfaces–will require a larger pond than a watershed that has more green spaces.

Excavation and land cost are the primary expenses. Other costs include designing and constructing the dam and associated outlets, regular maintenance on the forebay and outlets, and liability. In highly developed urban areas where land costs are high and where excavated soil may need to be hauled long distances, this practice may prove to be too costly.

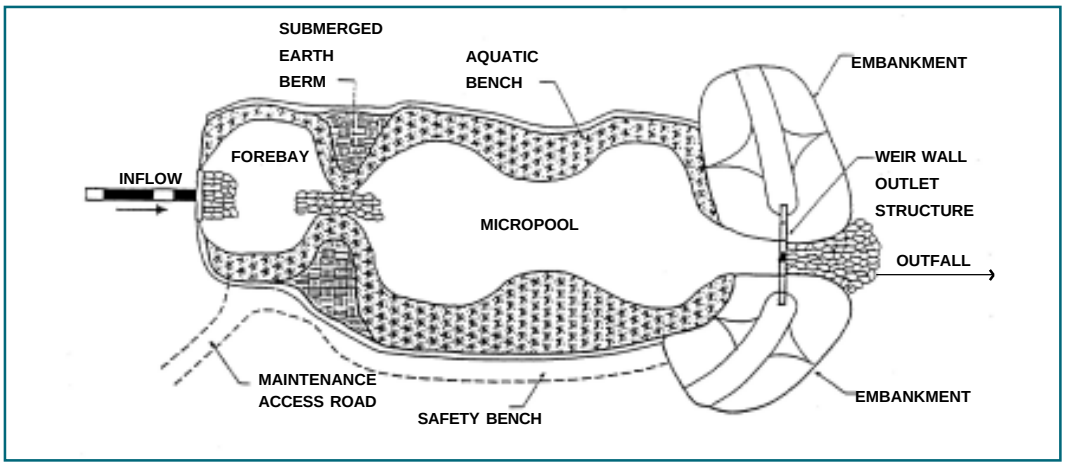

Figure 1. Plan view of wet pond.

Research has shown that wet ponds have a very high removal rate for sediment, often 70 percent and higher for total suspended solids (TSS), provided the pond is well-maintained. This is because the runoff slows down as it enters the wet pond, and slow-moving water cannot hold much of the solids that the fast-moving water had been carrying. Because other pollutants such as phos-

phorus and pesticides adsorb to sediment, wet ponds remove them, too, at a relatively high rate. Wet ponds do not, however, remove nitrate-nitrogen as well. A compilation of studies recently showed a wide variation in removal rates of nitrate with the median rate of between 20 and 25 percent.

Stormwater Wetlands

Land that previously was not a wetland can be constructed to be a stormwater wetland. Stormwater wetlands are becoming a popular BMP in some urban environments. Their design is similar to that of a wet pond, except they are much shallower. Stormwater wetlands are rarely deeper than 1 to 1½ feet; therefore, their flood control ability is limited. Stormwater wetlands are designed to maximize the flow path. Note the sinuosity associated with the flow path design in Figure 2. This increases detention time and prevents water from short circuiting the wetland. A stormwater wetland typically consists of a forebay (or micropool) where solids initially settle. As with the wet pond, the forebay tends to be an area that is easily accessible for removal of settled debris. The main body of the wetland consists of high and low areas, which encourage a variation in vegetation type across the wetland.

A wetland uses multiple mechanisms to treat stormwater runoff. Similar to a wet pond, wetlands use settling of solids and their associated pollutants as one removal tool. Studies show that wetlands, on average, remove nearly 80 percent of TSS. Wetlands also remove more nitrate-nitrogen than wet ponds. Vegetation in the wetland uptake some of this soluble nutrient for plant growth, but, primarily, wetland vegetation provide a media for both aerobic and anaerobic microbes to digest nitrate, eventually converting it to harmless nitrogen gas through the process of denitrification. While nitrate removal rates are highly variable depending upon wetland design and antecedent conditions, wetlands have been shown to remove well over 40 percent of the nitrate that enters the system.

Wetlands are, by nature, land intensive, more so than ponds. Excavation costs are also higher than for other BMPs, but they are typically lower than for ponds because wetlands are not as deep. Design and construction of the outlet structure, often a shallow weir, is not as costly as that of a wet pond. However, the expense of planting wetlands is an additional cost that wet ponds do not have. Because wetlands are not as deep, the fear of people drowning is less; but wetlands do suffer from the "it's a swamp" mentality. A diverse wetland ecosystem may attract mosquitoes, but it will also attract mosquito predators such as dragon flies and frogs.

Infiltration Trenches/Wells

As described previously, one of the primary effects of urbanization is that water that once entered the groundwater through infiltration now becomes a part of stormwater runoff. It is important to maintain high levels of groundwater because groundwater supplies baseflow to streams. There are means of introducing surface water into ground water. Infiltration trenches and wells are specifically designed to do this. An infiltration trench and well are essentially the same thing, except for the design volume. Trenches are long and narrow, intercepting a greater swath of surface runoff. Wells are more like a pit, designed to take slightly more concentrated flow. Both are filled with large, very porous stones (Figure 3). The trench or well fills up during a storm and stores water until the runoff seeps

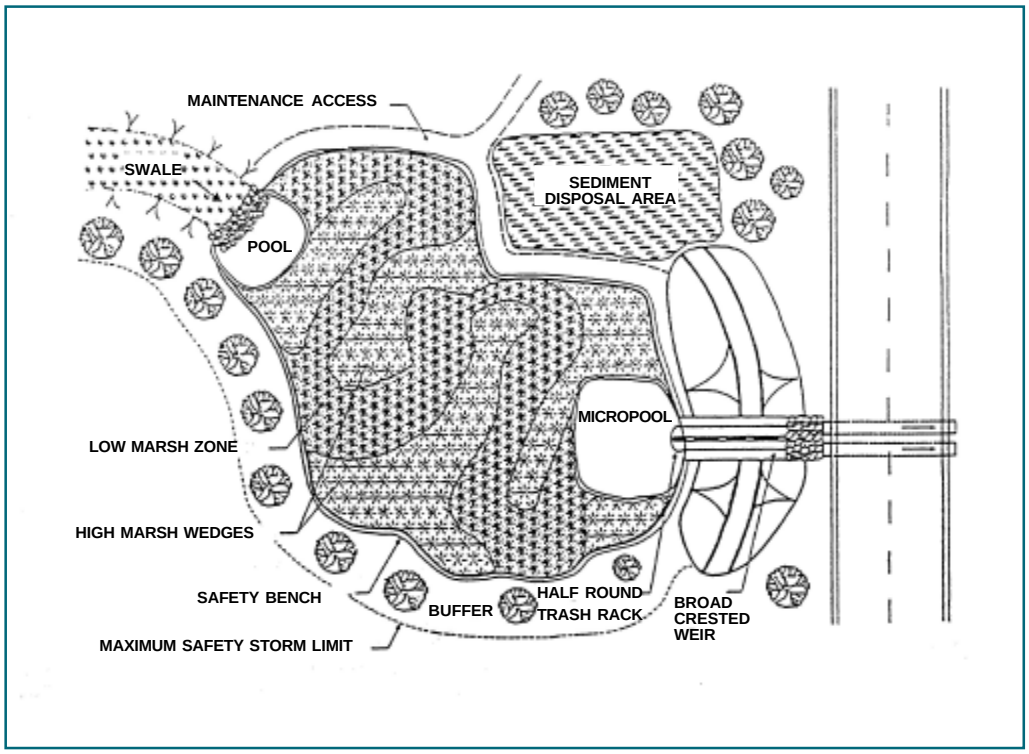

Figure 2. Plan view of stormwater wetland.

into the ground. The ability of these devices rests upon the surrounding soil. It is imperative that the soil be as sandy as possible. Any soil tighter than a sandy loam will probably result in a failed infiltration trench or well. Thus, this BMP is most applicable in the coastal plain and sandhills regions of North Carolina.

Infiltration devices can easily fail even if installed in appropriate geographic regions. If debris is allowed to enter the system it can clog the device. The only way to unclog the devices would be to remove all the stones in the trench or well. Special care must be taken to ensure that only water be allowed to enter, and that suspended particles be kept out.

Very few studies have been performed to determine how well infiltration devices remove pollutants. Infiltration wells are not particularly costly, as long as care is taken to remove debris and other suspended particles before stormwater enters the device. The cost of excavation and of hauling and placing stone are the primary cost considerations.

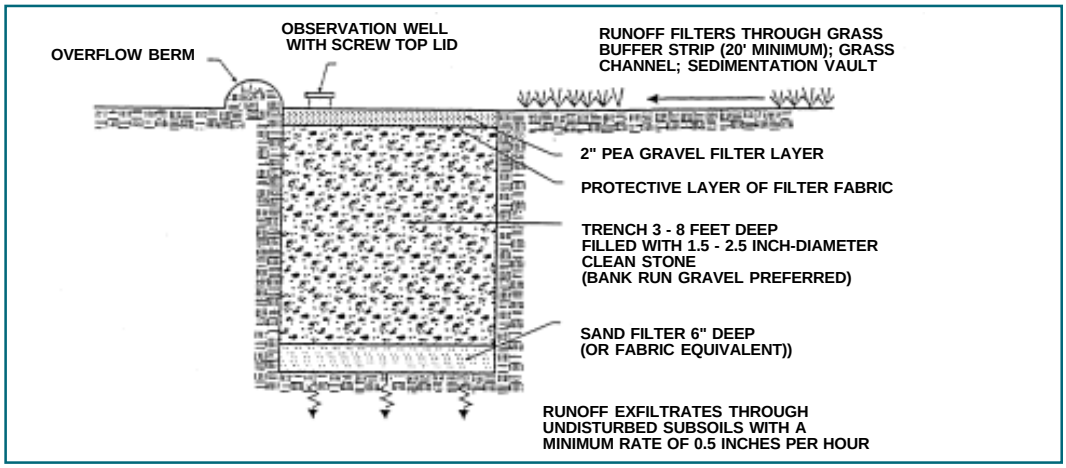

Figure 3. Profile of infiltration device.

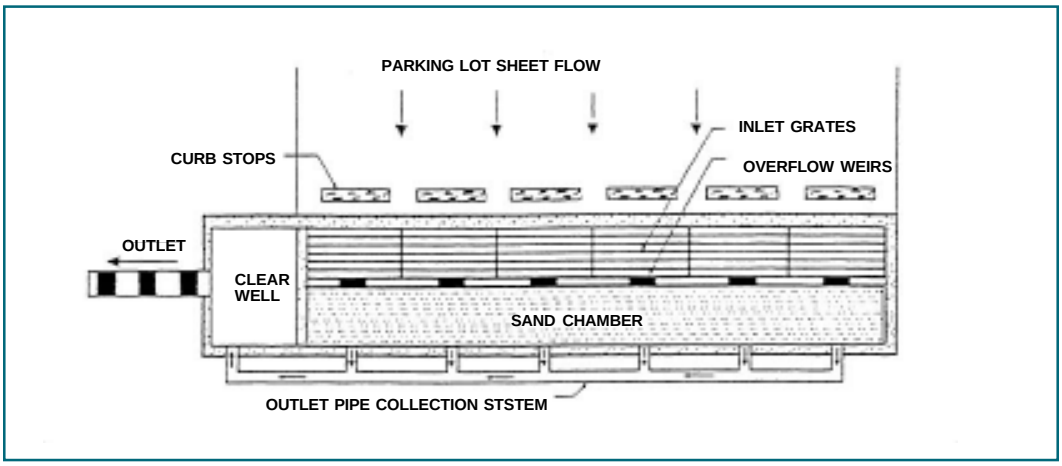

Figure 4. Plan view of sand filter ("Delaware Style").

Sand Filters

Many urban stormwater practices have been borrowed from the treatment of wastewater and drinking water. One of these is the sand filter. The use of sand filters for treatment of stormwater runoff was pioneered in Delaware and Maryland over a decade ago. Extensive work on new design features is ongoing in Virginia and Texas, as well.

Sand filters are a two-tiered system (Figure 4). Stormwater runoff first enters a sedimentation chamber where debris from the drainage area settles out. The water then flows to a sand chamber where it passes through a column of sand. It is here that most of the stormwater treatment occurs. The sand used in sand filters is most often ordinary concrete sand.

But sand filters can clog easily. Because of this tendency, they are primarily used to treat runoff from highly impervious areas, such as parking lots. In fact the best-designed sand filter will treat runoff from only impervious areas. The sand filter shown in Figure 4 requires a surface area of 360 square feet in each chamber to treat 1 acre of runoff.

Sand filters can be very expensive. They are typically made of concrete–either prefabricated or poured on site. Material costs can be lowered if the sand filters are constructed outside traffic-bearing areas. Another cost consideration of sand filters is their high need for maintenance. In Delaware, sand filters are serviced from every three years to every six months, depending upon the parking lot usage. Maintenance of sand filters usually includes removing the top 1- to 3-inch layer of sand once the filter is clogged. But sand filters do have a “competitive advantage” in that they do not require as much surface area as ponds or wetlands. In highly urban areas where land cost is substantial, sand filters may be the best alternative. Sand filters do not have as high a liability concern as their counterparts.

Sand filters are very effective at removing non-soluble pollutants, including TSS and sediment-adsorbed pollutants. Removal rates are around 80 percent for TSS and up to 60 percent for phosphorus in some studies. Sand filters, however, are nitrate creators due to their nature. They trap other forms of nitrogen, such as organic nitrogen, which under an aerobic environment can become nitrate. So, while total nitrogen removal rates are positive, nitrate-nitrogen levels increase through the use of sand filters. Researchers are currently experimenting with different media and sand filter designs to try to find ways to remove nitrate-nitrogen.

Bio-Retention Areas and Rain Gardens

Another infiltration device that is becoming prevalent is the rain garden, or bio-retention area. This BMP marries stormwater treatment with landscaping, which has led many homeowners to adopt this practice. Unlike ponds and wetlands, which retain–or keep–stormwater, rain gardens detain water for short lengths of time. Bio-retention areas are typically designed to drain down within 48 hours of a large storm. This lessens stress on plants caused by having submerged roots, meaning a number of plants can be grown in rain gardens that typically do not survive in wetlands and that have higher community acceptance than their wetland counterparts (such as phragmites and cattails). Some of the suggested bio-retention species include redbuds, dogwoods, cherry bark oaks, and irises.

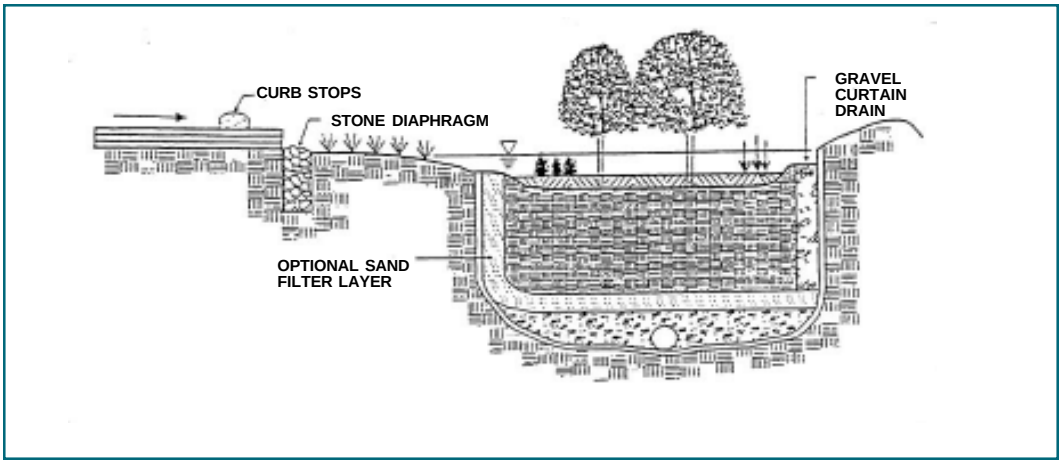

Figure 5. Cross-section of rain garden.

A cross section of a rain garden is shown in Figure 5. On the surface is a layer of soil suitable for growing plants and trees. Under the top layer of soil is a sandy to sandy-loam mixture that is very porous and permeable. The designer then has the option of putting drain pipes in the bottom of the rain garden or simply allowing the water to infiltrate into the surrounding soil. As with infiltration trenches and wells, the surrounding soil is very important. Sandy soils work best. Any soil tighter than a sandy loam will probably require drains, or the system will fail.

The effectiveness of rain gardens is still relatively unknown because this practice is new and not much data are available. However, initial studies done in Maryland show that rain gardens do remove some amounts of most pollutants–though results indicate that they may be nitrate leakers.

Economic considerations include the cost of excavation, the drainage system, land needed, and vegetation.

Level Spreaders and Riparian Buffers

In North Carolina's Neuse River Basin, riparian buffers (forested or grassed areas alongside streams or rivers) are mandatory along most streams. It is probable that rivers and streams in other parts of the state will also eventually have mandatory riparian buffers. They have been shown to remove all types of pollutants, including sediment, phosphorus, and nitrate. Sediment and phosphorus are trapped as surface flow slows down as it passes through the buffer. Nitrate, found in groundwater, is converted to nitrogen gas by microbes found in underlying media by the same processes mentioned in the section on wetlands.

Riparian buffers are often short-circuited by ditches or pipes, which pass through them directly to the creek or stream. This short-circuiting substantially limits the effectiveness of buffers' ability to treat stormwater runoff. Instead of allowing the ditches or pipes to bypass the buffer, level spreaders can be used to spread the flow out, creating a thin sheet of flow to pass through the buffer. Level spreaders can be constructed as shallow rock-lined trenches, which are level from end to end, parallel to the stream. Other level spreaders may be a series of 2-inch-by-6-inch boards that are placed end to end along a similar contour.

Special design considerations need to be made when sizing the level spreaders–they can easily be overwhelmed by flow if underestimated. The purpose of the level spreader is to produce sheet flow; if one part of the level spreader is not level then the whole spreader will be ineffective.

This practice is essentially brand new in the urban environment, and little research data exists to show the effectiveness of level spreaders. In theory they will slow water down as it flows through the buffer, increasing the likelihood both that particles will settle out and that some surface water will infiltrate the ground.

Riparian buffers do require long swaths of land, which translates to large amounts of money. Level spreaders are rather simple to construct and do not take up much space. However, in certain steeper bank areas more than one level spreader may be needed to keep sheet flow passing throughout the buffer.

"Reinforced" Grassy Swales

Grassy swales (minor channels that are lined with grass) are used to transport runoff from less developed areas. They can also provide a small, but significant, amount of pollutant removal. This ability to remove pollutants can be increased with modifications such as turf reinforcement matting, small check dams, and a shallow underground treatment layer of soil beneath the base of the swale.

The primary reason to not use a grassy swale is high water flows and velocities. When water reaches a velocity of over 4 feet per second, grassy swales tend to erode.

Traditionally, when high velocities are present, it is necessary to line the swale or channel with concrete or rip-rap in lieu of grass. Under very high velocities either of these two channel linings (concrete or rip-rap) are still required; however, some studies show it is now possible to reinforce grass under high flows with turf reinforcement mats. The mat gives the grass additional support, holding it in place during heavy storms. The use of mats now allows for grass swales in some steeply sloped or high-flow areas that once were unable to support the growth of grass. While the use of mats is costlier than simply seeding the swale, the cost of mats plus grass, in place of rip-rap or concrete is often very favorable.

Check dams similar to those for sediment and erosion control can be built across grassy swales, creating temporary reservoirs of water during storms. The detained water can eventually seep into the groundwater. Some pollutant removal can occur in the root zone of these mini-detention areas. But the use of check dams is relegated to areas of rolling topography, such as areas of the upper coastal plain, piedmont, sandhills, and mountains of North Carolina.

Swales can also have a filter region along the bottom that is similar to that of bio-retention areas. The filter region introduces the surface water to groundwater.

The effectiveness of these BMPs is relatively marginal, with 15 percent nutrient removal possible. TSS removal rates average around 30 percent. If the swales are improperly maintained, such as if grass clippings are not removed from the swale, swales may even be a contributor of nutrients.

Summary

Many best management practices are available to treat a variety of pollutants such as sediment, nitrate, phosphate, and heavy metals. BMPs range in size from relatively large, multi-acre approaches such as wet ponds and wetlands, to small site-specific projects such as a rain garden designed to catch runoff from a ½-acre yard. Size and selection depend upon the watershed's size and characteristics, land values, cost of construction, and the type of pollutant desired to be treated. Table 1, on the following page, summarizes the BMPs discussed in this publication. Further publications in this series will examine individual BMPs more closely.

For More Information

Contact your county Cooperative Extension center or the N.C. Department of Environment and Natural Resources, Water Quality Division, for information on these and other Best Management Practices.

Other Publications

Brown, W. and T. Schueler. 1997. *National Pollutant Removal Performance Database for Stormwater Best Management Practices.* Ellicott City, MD: Center for Watershed Protection.

Claytor, R. A. and T. R. Schueler. 1996. *Design of Stormwater Filtering Systems*. Ellicott City, MD: Center for Watershed Protection.

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Environmental Protection Agency. 1992. *Sand Filter Design for Water Quality Treatment*. Washington, D.C.: U.S. Environmental Protection Agency, Watershed Management Unit. 6 pp.

Environmental Protection Agency. 1996. *Protecting Natural Wetlands: A Guide to Stormwater Best Management Practices*. Washington, DC: U. S. Environmental Protection Agency. (EPA-843-B-96-001)

Northern Virginia Planning District Commission and Engineers and Surveyors Institute. 1992. *Northern Virginia BMP Handbook: A Guide to Planning and Designing Best Management Practices in Northern Virginia*. Annandale, VA: Northern Virginia Planning District Commission. 302 pp.

Table 1. Summary of Best Management Practices (BMPs) used in North Carolina

Practice	Advantages	Disadvantages	Pollutant Removal
Wet Ponds	Traditional. Can double as recreational facility.	Relatively land-intensive. Safety issues.	Suspended particles (TSS)—very high (70%) Nitrate-Nitrogen moderate (20%)
Stormwater Wetlands	Highest pollutant removal option. Good educational site.	Most land-intensive. Public opinion can be negative.	Suspended particles (TSS)—very high (80%) Nitrate-N — high (40-45%)
Infiltration Trenches/ Wells	Relatively low design and construction cost. Introduces surface water to ground water.	Limited application (sandy soils). High potential for clogging.	Limited data suggests that removal of suspended particles is initially high—but this causes infiltration practices to fail. Very little Nitrate-N is removed by this practice.
Sand Filters	Can fit in high land-cost situations. Removes pollutants found in parking areas.	Most expensive per square foot of device. Maintenance can be cumbersome.	Suspended particles (TSS)—very high (75-80%), but operators must maintain to keep high efficiency. Nitrate-N leaker (negative removal). High metal removal.
Bio-Retention/ Rain Gardens	Aesthetically pleasing. Can double to meet landscape and water quality objectives.	Very new practice with little data to prove effectiveness. Plants must be removed if soil clogs or becomes polluted.	Suspended particles (TSS)—initially high but will result in clogging. Total nitrogen appears high, but Nitrate-N may be negative.
Level Spreaders/ Riparian Buffers	Construction cost very low. Effective pollutant removal. Aesthetically pleasing.	Land-intensive. Effectiveness of level spreader relatively untested.	Note: data from agricultural research Suspended particles (TSS)—very high (80%) Nitrate-N — moderate (20%)
“Reinforced” Grassy Swales	Can carry higher flow than traditional grassy swales. More aesthetic and cheaper to construct than rip-rap alternative.	Construction and maintenance costs higher than for traditional grassy swales. Relatively new device with limited long-term testing.	Highly variable removal efficiencies. Suspended particles (TSS)—moderate (median of 40%) Nitrate-N–low (10-15%)

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