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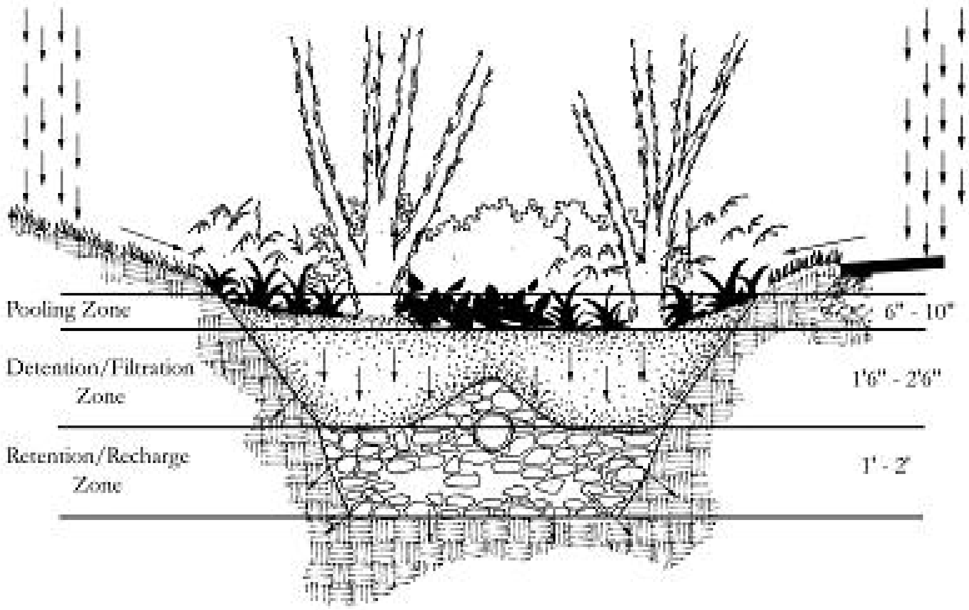
Low-Impact Development Use of Bioretention Basins

Land development modifies the natural lay of the land by removing natural vegetation andleveling soilto install impervious surfaces to accommodate the development of buildings. In developing land, the natural tendency of precipitation, or stormwater, to be filtered and to infiltrate into the land or runoff to a stream is disrupted by soil compaction, the removal of vegetation, and impervious surfaces. The impact on the land from development is high and stormwater cannot follow the previously existing hydrologic conditions. To help manage stormwater and to keep the land's natural tendency of infiltration and recharge of a watershed, a system must be designed to either allow the water to infiltrate back into the watershed or to move the water into the stream to which it would have naturally flowed.The state of New Jersey requires that peak runoff rates leaving a site after development must be equal to those that existed prior to development[1]. By removing natural vegetation that intercept stormwater and allow for infiltration and evapotranspiration, stormwater runoff rates are much higher in developed land with a large surface area of impervious surfaces, such as driveways, roofs, sidewalks, and parking lots. To meet the requirements of the state to control runoff rates, a best management practice has to be put into place. Low impact development is a stormwater management approach that applies integrated systems that allow stormwater to follow its previous hydrologic conditions. While conventional best management practices work to pipe and remove stormwater from developed land without treatment, low impact development systems, such as bioretention basins, work to manage stormwater while also filtering, storing, and allowing the water to infiltrate close to the source. Bioretention basins are also aesthetically pleasing as a landscape feature and cheaper than a detention basin for a similar drainage area.

While land development increases runoff rates of stormwater, development also causes an increase ofnon source pollutants such as sediment, nutrients, bacteria, metals and other pollutants in stormwater[2]. Non source pollution makes its way into groundwater as it flows over impervious surfaces and grass and can end up in a stream, reducing water quality and causing sedimentation. While conventional systems such as detention basins are efficient at controlling water quantity, they lack an effective way of filtering stormwater and are generally used in high impact developments and require a sizeable tract of land. Detention basins are installed to control stormwater and prevent general flooding as they allow a large amount of water to be spread out evenly over the basin’s dug-out area and are discharged slowly to a stream through a channel and weir. At the end of the pipe, stormwater discharge into streams can cause bank erosion, sedimentation, and an increase in nutrients and other pollutants. Stormwater is a large cause of non sourcepollution in a stream and detention basins are not effective in removal such pollutants, unlike a bioretention basin, which can remove the majority of pollutants. A more effective and integrated approach to stormwater management, therefore, is low impact development and the use of bioretention basins.

Low-Impact Development requires and relies on engineering and management practices that mimic the natural tendencies of the land and the previous hydrologic conditions before development.A much lower impact system used in land developments for stormwater is the use of bioretention systems, or rain gardens, which are site specific designs that allow infiltration, filtration, water storage, and uptake by vegetation, and can also include an underdrain to discharge the treated water to a stream. Bioretention systems work effectively to control stormwater quantity as the system works to achieve the pre-development hydrologic conditions by treating the associated volumes of runoff.Bioretention systems also work effectively for controlling water quality by relying on biological, chemical, and physical principles to filter stormwater as it infiltrates into the site and is discharged into a stream. Bioretention systems are designed to handle the first flush during a storm which is the most important time for stormwater management as it carries the most pollutants into a system[5]. Overflow controls and excess drainage controls should be installed as well for the occurrence of a 50-100 year storm that could scour the bioretention media depending on the influents velocity.

A bioretention system is a rain garden—defined as such not because it grows rain, but rather the system is a garden of native plants that can live under very wet conditions.The soil medium is engineered to a certain mix so it contains porous particles, clay for adsorption and cation exchange, and sand for filtration and infiltration. Stormwater flows off impervious surfaces towards the bioretention systems, which can be placed in any open space, such as a median in a parking lot, or in a resident's front yard, and effectively waters the garden. A bioretention basin is designed site specific, but must follow some design requirements to ensure the success of the basin. The natural tendencies of the land play a vital role for bioretention basins since theycan only be used for an area less than five acres[4 5]. Firstly, bioretention basins are suitable for use on any development where the subsoil is sufficiently permeableto provide a reasonable rate of infiltration (six inches of infiltration in under 24 hours) and where the water table at least six feet sub-surface[6].As for the basin, it should be at least fifteen-feet wide, while the length should be atleast two times the width and the treatment area should be atleast 200 square feet and between five percent and ten percent of the impervious surfaces of the surrounding drainage area. A mulch layer of two to four inches should be laid on top of atleast three to four feet of planting soil with a twelve-inch layer of sand below[4]. An underdrain, which is a perforated pipe that discharges overflow slowly, can be installed below the sand layer in a gravel bed.




During a rain event, ponding—the puddling of water in the basin—should not be greater than six to nine inches and should drain within four days after a storm.A grass strip or gravel bed should be in between the impervious surface and the basin to pre-treat the stormwater and remove larger sediments that can clog the basin and reduce its effectiveness. After designing the system, native plants that thrive in wet conditions, including a mixture of trees, shrubs and herbaceous plants,such as ferns and grasses work to make the basin an attractive landscape feature in those developed areas. To keep a bioretention basin attractive and efficient, certain maintenance is required. A brand new system will have higher maintenance than an established system but as a system becomes established the level of maintenance will decrease. During a period of drought, the basin needs to be watered to keep the plants alive and in periods of heavy rain, the basin may need to be remulched due to erosion and voids in the layers. Like any garden, a little bit of work will go along way if done when needed and properly.

While it seems like a simple process of merely watering a garden, the physical, biological, and chemical principles that underlie the process allow the stormwater to be filtered and treated, making it much more involved than it appears at a surface level.Stormwater that flows into a bioretention basin, depending on the amount of rain fall, will be a sheetflow of water.Sheetflow, the thin layer of water flowing over the surface, is first slowed as it enters the basin by vegetation and a layer of mulch.When the water enters the basin it may pond depending on the amount of runoff and the conditions of the basin, but will infiltrate into the basin, which is designed to be dug six inches below the surface. The ideal soil is a mixture of 30% sandy loam planting soil(50 -85% sand, 0-50% silt, 10-20% clay, 1.5-10% organic matter), 50% sand, and 20% shredded hardwood mulch to allow for filtration and the removal of pollutants[3]. At each site, the native soil may be amended to be an effective media or the previously mentioned soil can be used. The soil mixture and mulch layer is important for the biological and chemical processes that help treat the water.

As mentioned, stormwater coming off of an impervious surface will have pollutants in it such as phosphorus, lead, nitrogen, suspended solids, zinc, nickel, petroleum, and bacteria. The first level of treatment of water is the grass strip or gravel bed that filters the incoming stormwater and removes larger particles.

After being pre-treated, stormwater flows into the basin and onto the mulch layer which reduces erosion, helps maintain moisture levels for plants and aids in filtration and decomposition of organics.The mulch layer provides a suitable environment for microorganisms that can degrade petroleum-based solvents and other hydrocarbons that are found in stormwater. After settling through the mulch layer, the stormwater enters into the planting soil in which a handful of biological and chemical processes occur.

The clay in the retention media is vital for chemical processes because itoffers itself for both adsorption and cation exchange as a result of its physical properties. Clay is the soil's reservoir of water and cations, both of which are essential tools for pollutant removal by chemical processes.Adsorption is a process in which particulate pollutants attach to soil or vegetation surfaces and can remove metals, phosphorus, and hydrocarbons from the stormwater. For adsorption to occur there needs to be enough time for pollutants to attach to the clay, which proves the importance for the infiltration rate of the basin to follow the design for maximum pollutant removal[4]. Another property of clay and the media is its cation exchange, a measure of a soils nutrient holding capacity.Cation exchange makes nutrient and metal removal possible and is a major source of nutrients, some of which include $K^{+}$, $Ca^{2+}$, and $Mg^{2+}$, as well as $NH_4^{+}$ and micronutrient trace metals like $Zn^{2+}$, $Mn^{2+}$, and $Cu^{2+}$. By capturing nutrients and making it available for plants to uptake, stormwater is not only treated and slowly discharged but also improves basin appearance.

The vegetation of the bioretention system plays acentral role in a rain garden for aesthetics and efficiency, a symbiotic relationship. It is, after all, a garden and can provide a natural and enjoyable landscape feature while it also removes pollutants and nutrients that the plants can use. These three important processes areevapotranspiration, nutrient uptake, and microbial soil processes. When a plant's roots take up water, it is pumped into the stem and transpires out of the leaves. Choosing a good mixture of trees, shrubs and herbaceous materials make the garden appear attractive, provide habitats for wildlife, and also help manage stormwater. Evapotranspirationis greater in woody plants that have a deeper taproot rather than herbaceous plants which have a shallow root system.The root systems of the plants can uptake nutrients from the stormwater, which come available as it infiltrates through the basin. Nutrients such as phosphorus and nitrogen can cause problems in a stream because it can cause eutrophication and an increase in an ecosystem's plant growth and decay.The nutrient cycles of Nitrogen and Phosphorus are paramount in how the removal of non point source nutrients can occur.Another source of pollutant removal are microbial soil processes, which are the sign on good soil. Microbes can metabolize phosphorus and iron bonds and mineralize nutrients while at the same time, improve soil structure, all of which only make the bioretention media more effective.

Pollutant Removal Efficiencies

| Pollutant | Removal Rate |
|---|---|
| Total Phosphorus | 70-83% |
| Metals (Cu, Zn, Pb) | 93-98% |
| TKN | 68-80% |
| Total Suspended Solids | 90% |
| Organics | 90% |
| Bacteria | 90% |

Table from Source Six

Looking at bioretention research done at the University of Maryland, the efficiency of bioretention systems and other behavior is examined by Allan Davis. In assessing stormwater discharge and the effect of a bioretention system, a hydrograph shows that the peak flow is lower and later, and that a lesser volume of water is discharged. Davis conducted his research using two separate bioretention basins in Maryland with one in Silver Spring, Maryland, and one in College Park. By measuring and recording the effluent of an undercarriage pipe under the basin, a much lesser peak was recorded that showed a hydrograph that was delayed around six hours from the first flush into the basin. Davis was also able to measure water quality parameters such as total suspended solids, zinc, total phosphorus, total nitrogen, chloride, organic carbon, PAHs, and bacteria, all of which provide some insight on how effective and useful bioretention systems are. Throughout his research he has come to some conclusions about how bioretention systems that lead to both quality and quantity control of stormwater. While outlining the physical, chemical, and biological principals and hydrologic management that I have discussed earlier, Davis points out some points of weakness for implementingbioretention systems. Most of the points Davis brings up are just a sign of general lack of information, whether it be of performance, or of how it works. Also, regulations, utilities, contractor inexperience, and specification details are all challenges in implementing bioretention basins as a best management practice. That being said, many states, from Minnesota to Kansas to New Hampshire, are researching and experimenting with the basins for stormwater management. Some states, such as Minnesota, even give fee reductions for stormwater to residents if they implement some on site management such as bioretention basins and have an initiative of 10,000 rain gardens.

A problem of stormwater in Minnesota, and wherever it snows is, the use of de-icer, which contains salt to lower freezing temperature. The chloride found in de-icers can disturb a streams ecological health by harming certain genera. At the University of New Hampshire Stormwater Center, studies on the trends and effect of chloride have been done. It has been determined that porous asphalt is the only infiltration best management practice that can minimize chloride risk to water quality. The effect of temperature and chloride has been shown that the lower the temperature of chloride ladeninfluent doubles the settling time of the basin, causing greater ponding. Also the use of de-icers influence the vegetation selection for a rain garden and must include more woody plants.

Bioretention basins still function well as snow storage and a cold climate does not affect the pollutant removal but may be costlier[7].

The cost of a bioretention basin can vary greatly as it has some variables that are included in the cost of building and vegetation. Variables such as soil amendments, plant selection, size, control structures, curb, gutter, and pipe controls can add or lower the price. Also, it is hard to quantify the cost and savings of the additional pollutant removal from an efficient bioretention system. According to the Wisconsin Natural Resource Magazine, a typical rain garden costs somewhere between three and five dollars per square foot for someone who does it themselves and between 10 and 12 dollars per square foot for a professionally done garden. Somerset, Maryland, a subdivision of Prince George's County, the birthplace of rain gardens, are a prime example of using bioretention basins as stormwater management rather than the conventional detention basin. In a new development, 200 homes were built on 10,000 square foot lots, each with a rain garden of 300-400 square feet built on the low point of each lot. Each rain garden cost about 500 dollars total, and 350 dollars of that spent on plants. The total cost for installing rain gardens in Somerset comes to around 100,000 dollars, compared to 400,000 dollars that a detention basin costs, not including the cost of curbs, gutters, and sidewalks that is necessary for drainage towards the basin. Also, the savings in environmental benefits cannot be quantified and the reduce cost of combined sewer treatment and structures are hard to include.

Low-Impact Development techniques and the use of bioretention basins as best management practice are better than conventional best management practices such as detention basins because bioretention basins effectively manage water quantity and also water quality. By relying on physical, chemical, and biological principles and incorporating specific and integrated site design, stormwater can be successfully managed using low-impact techniques that not only are highly successful treatment options but also aesthetically pleasing and cost efficient. While challenges still exist in implementing bioretention basins, the functionality and benefits of rain gardens have been shown and hopefully will be continued to be studied and used as a best management practice.

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