Bioremediation of Stormwater Runoff

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ABSTRACT

In recent years, environmental biotechnology approaches to stormwater management have become increasingly important. An example of this is the use of bioremediation, which is a way to reduce pollution in water through biological processes. Bioremediation is not a new concept but it has become increasing significant since the Exxon Valdez oil spill in 1989. These processes can include microbial (microbes) or phytoremediation (plants) resources. Phytobial remediation combines the effectiveness of both techniques by means of unique rhizosphere activity. The goal of remediation is to remove or change the nature of the pollutants in such a way that they are not harmful to the environment that is receiving the treated waters. Urban contaminants are a leading cause of pollution in stormwater runoff. This paper looks at the use of swales next to roadways that contain engineered soils and plants in order to treat stormwater before it enters the groundwater or another water source.

KEYWORDS

Bioremediation, Phytoremediation, Phytobial Remediation, Vegetated Swales, Best Management Practices (BMPs), Non point source (NPS) Pollution, Rhizosphere

INTRODUCTION

Bioremediation. Bioremediation has been defined as “biological remedies for pollution reduction” (Shannon and Unterman, 1993). This can be done via “elimination, attenuation or transformation of polluting or contaminating substances” (Lynch and Moffat, 2005). Bioremediation has the ability to remove or lessen sediment, remove or lessen pollutants, and improve water quality. For these reasons, bioremediation has become a source for Best Management Practices (BMPs) for storm water runoff management (Barrett and Lantin, 2005; EPA, 1999; and SUDAS, 2005a). There have been many approaches to utilizing bioremediation in a capacity to manage and treat stormwater runoff.

Contamination. Stormwater runoff from urban areas is a major contributor to groundwater, river and lake contamination (Billow, 2002, SUDAS, 2005a, EPA, 1999, Zedler and Bonilla-Warford, 2002). Types of contaminants that are of concern are hydrocarbons, oil and grease, suspended solids, nitrogen, and heavy metals. These are common to areas with roadways, parking lots and other impervious surfaces such as urban areas. The goal of bioremediation is to remove, or at least to limit, contaminants like those listed above. This paper will discuss these contaminants and the successfulness of bioremediation efforts to remove or reduce them in stormwater runoff.

Phytobial remediation. Phytobial remediation combines the efforts of bioremediation and phytoremediation to reduce contaminants in water and soil. This is achieved through unique interactions between microorganisms and plant roots. This interaction takes place in the plants rhizosphere. Vegetated swales can be implemented in areas that use this concept to treat waters before they enter other water sources. The approaches that will be discussed in this paper are that of wet, dry and vegetated swales that service urban, suburban and highway areas.

STORM WATER RUNOFF AND MANAGEMENT

Non point source runoff. Non point source runoff is simply runoff that does not come from a point source such as a pipe discharge. It mainly comes from stormwater runoff which is generally a flow of rainwater over a large area of land. The rainwater runs off impervious and somewhat pervious surfaces until it reaches a body of water. This body of water can be contaminated by the non point source pollution that the traveling water picks up. These contaminants include nutrients, toxic substances, pathogens and sediments. Examples of these include (EPA, 1994, Virginia DCR, 2005):

- Nutrients – fertilizers, animal manure, herbicides, and insecticides that can come from agricultural or residential areas
- Toxic Substances – chemicals from household waste, gasoline, grease, oil, and roadway salts from urban runoff
- Pathogens – bacteria from livestock, pet and human waste
- Sediments – erosion of land, construction and development causes particles that can easily be carries away by rainfall

These contaminants can, and will, damage rivers, streams, and lakes that are both recreational and commercial waters. This damage will detract from the beauty of the natural environment. For this reason "stormwater runoff must be treated before it is discharged into water to meet the U.S. Environmental Protection Agency's National regulations" (EPA, 2005). The Clean Water Act (CWA) passed in 1972 provides for water quality management of non point sources of pollution.

Best Management Practices (BMPs). BMPs are processes are innovative ways to keep the environment pollution free. It is not a set standard for every situation, but rather site-specific efforts to reduce contamination to the environment. The application of BMPs to stormwater runoff deal with the prevention and treatment of contaminants in the water. Bioremediation of stormwater runoff is a viable and environmental friendly solution to dealing with stormwater contaminates and is considered a BMP.

BIOREMEDIATION

Bioremediation. Bioremediation has been defined as "biological remedies for pollution reduction" (Shannon and Unterman, 1993). The basic idea is that all organisms and plants need nutrients to survive, and microorganisms break down compounds in the soil for their growth. This natural process "implies a biochemical change as harmful contaminants or pollutants are metabolized by microorganisms and broken down into harmless, stable constituents, such as carbon dioxide, water, and salts" (EPA, 1997). Bioremediation has the ability to remove or lessen sediment, remove or lessen pollutants, and improve water quality. The different types of bioremediation include ex situ bioremediation, in situ bioremediation and natural bioremediation or attenuation. Ex situ bioremediation involves removing contaminated waters or soil and treating it at another site. In situ bioremediation involves treating the contaminated waters or soil on the site. Natural attenuation involves letting natural biodegradation of contaminants occur without treatment. All types of remediation rely on microorganisms and/or plant life to decompose contaminants that are harmful to the environment into substances that have little to no negative impact. The types of bioremediation that will be discussed further are phytoremediation, and phytobial remediation. Phytoremediation involves the use of plants to degrade harmful substances, while phytobial remediation involves the use of plants in combination with symbiotic microorganisms to degrade harmful substances.

The main limitation of utilizing bioremediation is that the environmental conditions must support the growth and activity of microbial and plant communities. Microbes can be introduced that are known to enhance bioremediation, but it possible that they will not survive or will be outgrown by other microorganisms. This could be a result of lack of proper nutrition other than the substance that is the target of remediation (Lynch and Moffat, 2005). Another limitation is the need for maintenance and inspection of the bioremediation site.

PHYTOREMEDIATION AND PHYTOBIAL REMEDIATION

Phytoremediation. Phytoremediation has a similar goal to bioremediation, but it focuses on the use of plants rather than microorganisms in the soil. "'Phytoremediation' uses living plants to remove, degrade, immobilize or contain the contaminants in situ. The greater emphasis has been on metal as opposed to organic remediation" (Lynch and Moffit, 2005). This type of remediation depends on the type of plant utilized and its ability to survive in the given environment. Therefore it has been suggested to utilize plantings that are native to the area of implementation (Bonilla-Warford and Zedler, 2002, and SUDAS, 2005a). Attention has been placed on grasses, ferns and brassicas (Lynch and Moffit, 2005; Bonilla-Warford and Zedler, 2002; and EPA, 1999). The following will provide an explanation of how phytoremediation is used in conjunction with microbial remediation in the form of phytobial remediation. Specific metals, other contaminants and their removal will also be discussed.

Phytobial remediation. Phytobial remediation is a remediation type that combines the use of both microbes and plants in order to eliminate toxic substances from soil and water. Like phytoremediation, plants are grown that help uptake toxic substances, and like microbial remediation, microbes are introduced to help degrade toxic substances. The microbes exist with the plants and combine bioremediation techniques and phytoremediation techniques to attain the best of both traditional forms of remediation. "The whole concept of the phytobial process is that it utilizes the rhizodeposition products of the plant root as the energy source for the microorganisms to function" (Lynch and Moffit, 2005). Therefore the microbes that are implemented must be rhizosphere competent, meaning that they can multiply and thrive in the rhizosphere of the plant.

Rhizosphere. *Figure 1*. Root and Rhizosphere: soil influenced by plant roots, shows an annotated picture of a plant root and rhizosphere. The rhizosphere is the soil and environment that surrounds near the roots of plants. In this zone, nutrients are very abundant because of the plant, which in turn increases the activity and number of microorganisms present. The components of the system are the plant, the microorganisms and the soil. The activity takes place in the soil-plant-microorganism interactions which occur approximately 5mm from the rhizoplane. The rhizoplane is the soil in direct contact with the plant root, and can be seen on *Figure 1*. The unique rhizosphere relationship between the plant and microbes is facilitated by the compounds that the plant roots release. These compounds can be organic or inorganic, and they affect the rhizosphere activity. "Almost any plant metabolite has the potential to be exuded including carbohydrates, amino acids, organic acids and lipids, growth factors, enzymes, and miscellaneous compounds"

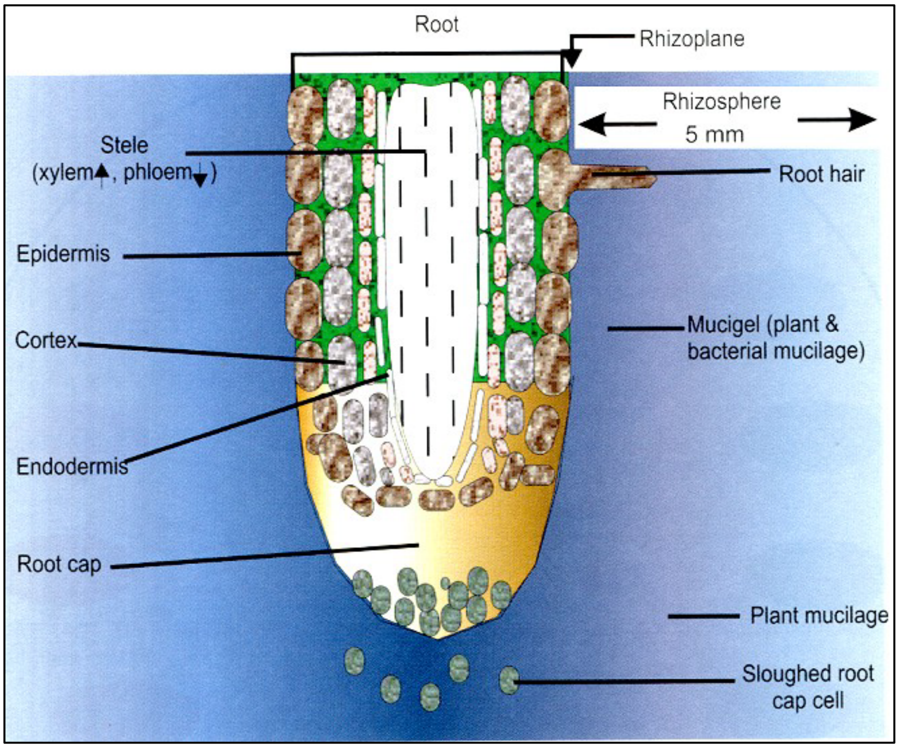

Figure 1. Root and Rhizosphere: Soil influenced by plant roots
(Source: http://biology.kenyon.edu/courses/biol272/agriculture/agriculture.htm)

(Maier et al., 2000). These exuded substrates can affect the soils pH, oxygen content, water content, nitrogen content, etc. Microbe populations can take advantage of the excess carbon and other compounds that plant roots excrete. Thus, the microbes help enhance bioremediation by utilizing contaminants as a food source.

REMOVAL OF CONTAMINANTS

The removal of metals and contaminants from stormwater runoff is a difficult task. Metals cannot be degraded and are very persistent in the environment. However, bioremediation techniques have been found useful in this endeavor (Maier et al., 2000; SUDAS, 2005a; Caltrans, 2004; EPA. 2005; and Walker and Hurl, 2002). For example, in the BMP Retrofit Pilot Program, Cu, Pb, and Zn were removed by 63%, 68%, 77% respectively (Caltrans, 2004).

Metals removal. As described above, plants excrete compounds into the rhizosphere. One such compound is a chelate that bonds to metals and allows the plant to absorb them. This is a process that occurs called phytoextraction, in which plants absorb the pollutants and then store them in their tissues. (Princeton.edu, 2005). Microbes in the soil environment can also help with the removal of metals.

Microbes in the soil serve as a way to reduce contaminant spreading by immobilizing metals. Microorganisms can produce something called a surfactant which is a low-molecular weight molecule that moves easily through soil and has a high affinity for metals. In order to immobilize metals, the solubility needs to be reduced. Organic particles and metals are electrostatically attracted to one another and solubility of metal can be reduced by attracting them to microorganisms. Contaminant removal as it pertains specifically to vegetated systems for pollutant removal in stormwater runoff will be discussed further.

VEGETATED SYSTEMS

Biofilters. Biofilters are BMPs that utilize grasses or other forms of vegetation to “filter” stormwater before it reaches another body of water. These biofilters can include vegetated swales or filter strips. A swale is an open flow vegetated channel that can be dry or wet, and filter strips are vegetated areas of land that are not highly sloped and allow for filtration of water that is in a sheet flow. These two techniques can exist alone or in combination with one another. The focus of the paper will be on vegetated swales. Wet vs. dry swales will be discussed, then the effectiveness of a biofiltration swale pilot program will be summarized, and finally, a discussion will be done on how a vegetated swale is designed.

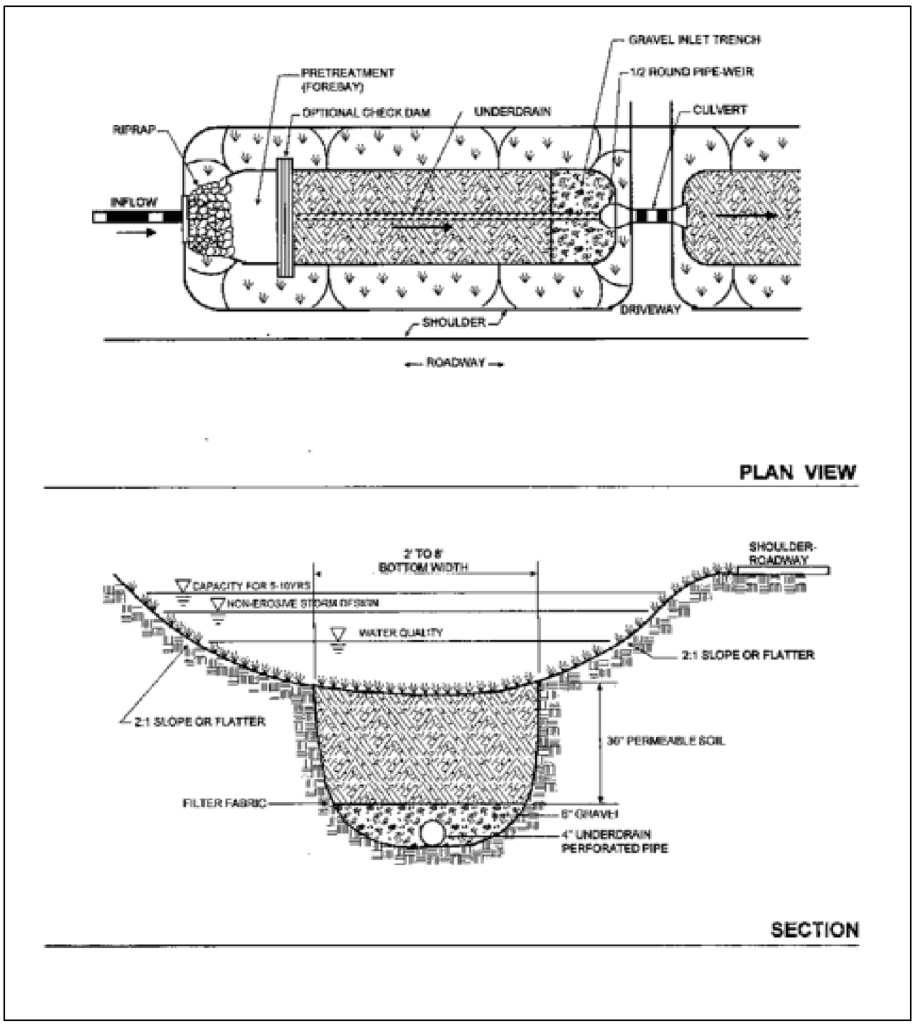

Figure 2. Dry Swale (Source: www.stormwatercenter.net)

Wet and Dry Vegetated Swales. Dry swales, as shown in *Figure 2*, are a type of open vegetated swale where water is temporarily stored to provide time for sedimentation and infiltration of runoff. Dry swales are desirable in residential areas and other areas where standing water is undesirable. Wet swales, as shown in *Figure 3*, are also open swales that are vegetated, but they are designed to retain a marshy like condition for an extended period of time. They are best in areas where standing water will not cause a nuisance.

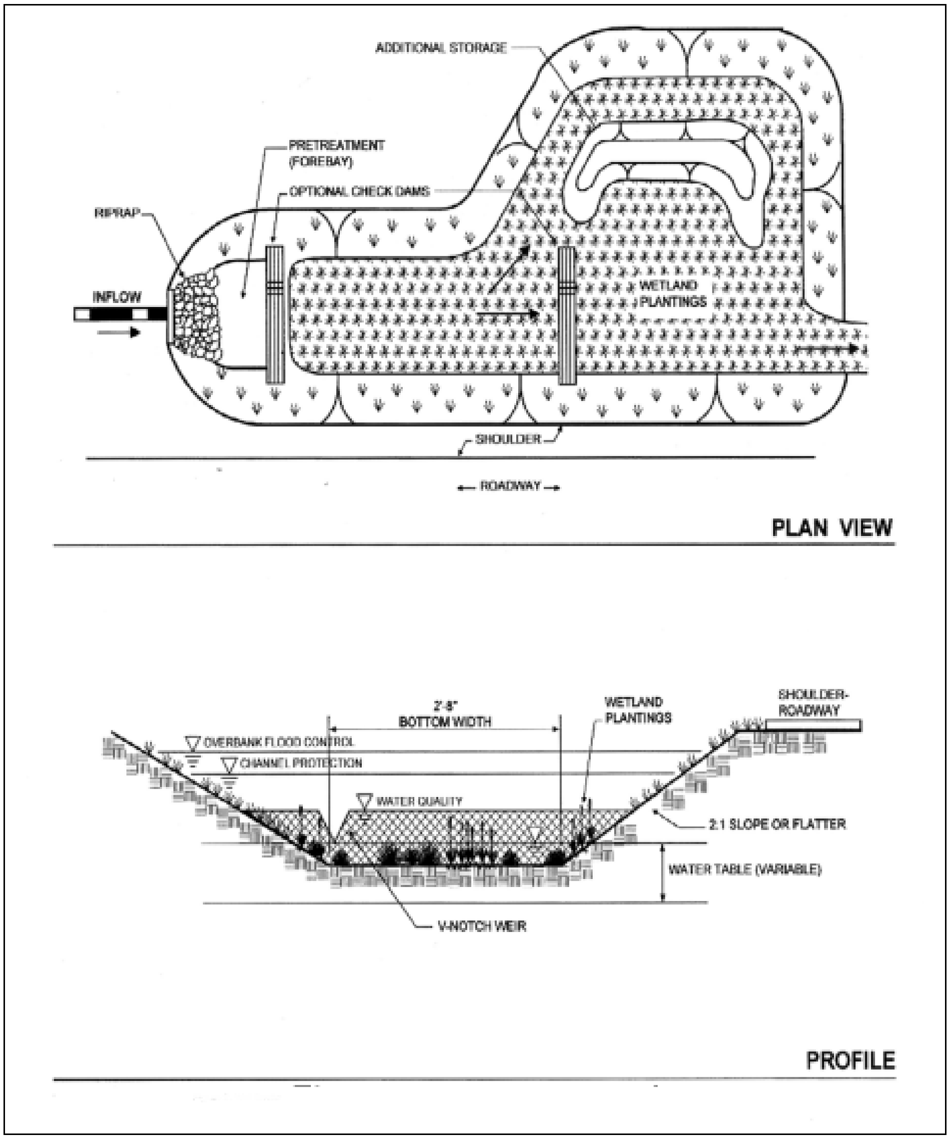

Figure 3. Wet Swale (Source: www.stormwatercenter.net)

Typical uses of vegetated swales are as follows (SUDAS, 2005a, and EPA, 1999):

- Manages runoff from residential sites, parking areas, and along perimeter of paved roadways
- Located in a drainage easement at the rear of side of residential parcels
- Road shoulder rights-of-ways; used adjacent to paved roadways in place of curb and gutter, or used in conveyance channel on the back-side of curb-cut openings
- Depends on the area, slope and perviousness of the contributing watershed
- Depends on the dimensions, sloe and vegetative covering in the swale area

Some advantages of vegetated swales are as follows (SUDAS, 2005a, and EPA, 1999):

- Mitigates runoff from impervious surfaces
- Removes sediment and pollutants in order to improve water quality
- Reduces runoff rate and the volume in highly impervious areas, and reduces runoff velocity
- Provides some for groundwater recharge if design and site soils provide sufficient infiltration
- Good option for BMP retrofits
- Good option for residential and institutional areas of moderate density
- Linear configuration works well with urban, suburban and highway streets
- Cost effective when design properly

Some limitations of vegetated swales are as follow (SUDAS, 2005a, and EPA, 1999):

- Sediment and pollutant removal sensitive to proper design of slope and maintaining sufficient vegetation density
- Limited to smaller areas
- Cannot be used on steep slopes
- Must run parallel with contour with steeper slopes in order to be effective
- Requires and higher level of maintenance than curb and gutter systems
- Possible re-suspension of sediment
- Not effective and may erode when flow volumes and/or velocities are high
- They can become drowning hazards
- Can be subject to mosquito breeding or odors

Biofiltration Swale Study. The final report for the BMP Retrofit Pilot Program done by Caltrans in January of 2004 includes the implementation of six biofiltration swales that were constructed and monitored for the study. Each swale was used in an area with 90% or more impervious cover and was placed parallel to a highway. For their study, salt grass was selected as vegetation, but they later discovered that a mix of plant species would have been a better choice. They inspected the sites weekly and trimmed vegetation to desired height. *Table 1*. below shows some of the constituents and their removal percentage reported by Caltrans (2004).

Table 1. Reduction in Concentration of Constituents in Biofiltration Swales (Caltrans, 2004)

Constituent	Removal %
TSS	49
TKN	31
Total N	30
Total Cu	63
Total Pb	68
Total Zn	77

Caltrans also reported that about 50% of stormwater runoff was filtered into the swales and therefore only 50% was discharged into another water body. “This is an interesting finding and highlights the importance of vegetation and soil in managing storm runoff quantity and quality” (Caltrans, 2004). Therefore not only did the swale reduce the contaminants in the runoff, but it also reduced the amount of excess water entering into other water bodies. This study is a demonstration of the benefits that come from implementing phytobial remediation efforts to improve the quality of stormwater runoff.

Vegetated Swale Design. The design of a vegetated dry swale according to the SUDAS standard of 2005 is meant to handle the water quality volume (WQv) and if necessary hold up to a 25 year storm volume as an overflow protection. The WQv is simply the volume of water that will be entering the swales during a typical storm event. This volume of water should be able to completely infiltrate within a maximum of 48 hours, and a standard of 24 hours. To help filter the water, and to reduce sediments and contaminants, a gravel layer as well as a permeable soil layer will incorporated. The gravel layer will be approximately six inches deep and the soil layer will be approximately 30 inches deep above the gravel. These two layers exist in the center, lowest portion of the swale at a maximum of eight feet wide. The slopes on either side of the swale are to be a 2:1 slope or flatter. After the appropriate sizes is completed, native vegetation should be planted that has a high affinity for reducing contaminants. The soil should also be rich in microbes that are rhizosphere competent as discussed previously.

Maintenance. Maintenance of in situ bioremediation sites that are in the form of open vegetated swales involves general upkeep of the site. The vegetation may need to be trimmed, or replanting may be necessary. The sloped sides should be monitored for erosion, and the density of the vegetation should be monitored in this area. The upkeep could also involve regular litter removal.

CONCLUSION

This paper has defined and reviewed bioremediation, phytoremediation, and phytobial remediation as well as their ability to reduce water contamination. Efforts such as these to reduce contaminants in stormwater runoff are important BMPs in places with large impervious areas. This is very applicable in urban areas with numerous roadways, parking lots, buildings, etc. Non point source runoff from these large impervious areas picks up many contaminates that could be detrimental to the receiving water body. By implementing an engineered vegetated swale, these pollutants can be greatly reduced. The engineered swale can incorporate the best of both bioremediation and phytoremediation via phytobial remediation. The chosen pervious soil should contain a healthy microbial population, and dense vegetation will interact with this population to reduce contamination in the stormwater runoff before it reaches another water body. More research should be done to better conclude the benefits of phytobial remediation and the use of bioremediation of stormwater runoff. Further research should be done on the interactions that take place in the rhizosphere of the soil and plant interface.

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