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## Design Standards for Reducing Surface Contamination and Rainwater Run-off; a Recommendation for Eastern Shore of Maryland

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**ABSTRACT:** In construction, the growing emphasis is on environmentally friendly methods, equipment and operation. Facilitating a net-zero impact to the local environments of any project is a daunting and still under-researched task. In an industrialized nation, such as the United States, mitigating the effects of mechanical pollution is a high concern to the nearby ecosystems. One method by which a certain type of pollution, contaminated surface, rainwater runoff, can be processed and filtered is through the use of bio-swales or bio-retention ponds. Delaware and the eastern shore of Maryland and Virginia (commonly referred to as the Delmarva Peninsula) will greatly benefit from better design and implementation of bio-swales and bio-retention ponds. Current construction practices using bio-swales and bio-retention ponds could be improved if increased knowledge about plant and microbial functionality were incorporated into the current design standards.

**KEYWORDS:** Surface Contamination, Detention Ponds, Sustainable Sites, Pollution Control, Bio-Swale

### I. INTRODUCTION

The Delmarva Peninsula represents a large contributor to runoff pollution, especially to the contamination of the Chesapeake Bay. The major pollutant producers include fertilizers from farms and oil, grease and heavy metals from automobiles. According to the Chesapeake Bay Foundation, agriculture and storm water runoff represent 54% of the nitrogen and phosphorus runoff that contaminates the Chesapeake Bay (Polluted, 2). These two areas present the greatest concern for the Delmarva Peninsula since the majority of the economy is agriculture and the predominant mode of transportation is personal vehicles. Bio-swales and bio-retention ponds are currently mandated by state and local regulations to absorb and filter contaminants; however, state and local requirements designate that pollution must be reduced to a certain degree but not eliminated entirely. This mitigates pollution but become disincentive to design that would maximize filtration ability of bio-swales and bio-retention ponds.

The basis for examination of design must begin with a clear understanding of the design factors and theory that are included in bio-swales and bio-retention ponds. Swales are thin strips of land, that are usually dug 3 feet deep in a V-shape or U-shape with sloping sides (embankments) that increase in elevation at a 3:1 slope. The slope refers to a 3-foot horizontal run for every 1-foot rise in height. Making a swale a bio-swale includes implementing filtration methods for removing solid waste like trash and reducing nitrogen and phosphorus along with other heavy metals present in rainwater runoff. The filtration methods include plant filtration/ absorption, microbial absorption/ conversion, and ground storage either in filter media or ground absorption. Ultimately the design of a swale is for the conveyance of runoff to an outlet into a retention pond or overflow into a stream or tributary. Typically swales are located along the edges of parking lots, roadways and farm fields where they will convey water to a ditch or to a pond.

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Bio-retention ponds are similar to bio-swales in that it is a modification to a standard stormwater runoff practice. As the name implies, a retention pond is constructed to retain runoff and allow for natural absorption into the ground. Ponds can be in any shape and dug to any depth based on the size of the construction site and the runoff capacity required. In construction terms, ponds that are designed to always have visible standing water are called *wet ponds*; when the pond is not designed to have visible standing water, the pond is referred to as a *dry wet pond*. For the purposes of analysing bio-retention ponds, dry wet pond designs will be considered because they are the most common. A bio-retention pond is a modification of a retention pond in the same way a bio-swale is a modification of a swale; stormwater filtration methods include plant filtration/ absorption, microbial absorption/ conversion, and ground storage either in filter media or ground absorption. The difference is that the water in this design is to remain stagnant; therefore subsurface retention is preferred so that pests like mosquitos are deterred from breeding. Overflow, a channel or small swale, or a subterranean perforated pipe is incorporated into this design as well; large rainfall events (those in excess of a 10 year recurrence) will cause flooding because filter media and the soil cannot absorb a sudden, large volume of runoff efficiently. Because the filter media fills the pond, these applications provide a nicer appearance because they resemble a depressed garden.

## II. RELATED WORK; DESIGN CONSIDERATIONS

The first aspect of the bio-swale and bio-retention pond are filter media. Typically, the top layer is an engineered mixture of soils that have an absorption rate in excess of the virgin soil underneath and is porous enough to hold water while the virgin soil percolates the runoff. After the overall pond has been excavated, the bottom and about one to two feet up the side slope is covered in geotextile. The filtering and absorption of the majority of pollutants covered in a geotextile. Geotextile is a material that resembles burlap and serves the purpose of providing structural cohesion of upper layers of soil or rocks that are laid on it; typical material specifications for construction on the Delmarva Peninsula require the material be MIRAFAI 140N ®. The lowest layer (or course) would have large rocks ranging from four inch to nine inch diameter (commonly referred to as rip-rap). This is where the majority of the runoff retention occurs because the riprap permits large volumes of voids without risk of collapse or sinking. The riprap course is also where the perforated pipe is laid, slightly covered at the top. Next would be the first course of filter media which is an engineered soil which constitutes some of the native soil and some pebbles and sand for quicker absorption without diminishing the inherent nutrient content for plant life. This accounts for two thirds of the fill. Finally after the filter media has been levelled and set, the vegetation is planted and a two to four inch layer of mulch course is applied. This is not necessarily true for bio-swales because the speed of the runoff current might wash away the mulch; instead, river stone, half to one inch gravel, or smaller diameter rip-rap courses are used. One additional component, which will be discussed, is to impregnate the engineered soil with microbes that digest nitrogen therefore denitrifying the soil will be done by the plant life; the optimization of the courses will begin by considering the impact of each course on the health of the plant life, in ascending order in the layering. But first the proper plants must be considered. In an article by the Natural Resources Conservation Service, native grasses are suggested (Bios wales, 2) and Qingfu Xiao and E. Gregory McPherson for the University of California in their research identified that trees are good processors of pollutants (Xiao, 242).

For the Delmarva Peninsula, a few the native grasses “for freshwater wetlands and other wet sites”, as documented by The National Park Service, are as follows: *Agrostis Perennans* (Walter Tuck Grass), *Calamagrostis Canadensis* (Blue Joint Grass), and *Elymus Riparius* (Riverbank Wildrye). Although grasses are not generally considered desirable because they largely lack ornamental appeal to the general public, they are useful at the centre of a swale and under a maximum of one foot of water (Maryland, 3.23); however temporary inundation beyond that depth will not disturb the plants if the velocity of the runoff does not produce a force in excess of the roots’ strength. As for tree selection, a few of the variety prescribed by The National Park Service are as follows: *Amelanchier Canadensis* (Shadblow Serviceberry), *Carpinus Caroliniana* (American Hornbeam), and *Crataegus Viridis* (Green Hawthorn).

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Trees need time to reach their maximum pollutant processing capability (Xiao, 242); this could be assumed to be when the taproot reaches the bottom of the riprap course. At the shallow depths of common bio-swales and bio-retention pond designs, the growth time could reasonably be assumed to be a five-year maximum. Trees are also well documented to reduce erosion and recommended for the stability of side slopes (Maryland, A.2). Whether the tree should be placed in the centre of a bio-retention pond depends on three factors: its location to the perforated pipe or any underground utilities (Maryland, A.1), its toleration of frequently saturated soil (a water loving plant), or when considering the location of overhanging branches with regard to parked cars or overhead utilities. The consideration for the last factor should lead the designer to analyse the strength of the tree to be planted; if the branches are generally weak, the overhand should be relegated to within the boundaries of the bio-swale or bio-retention pond as defined by the top of embankment. Finally, the addition of more ornamental plants, though generally not as efficient in filtering pollutants and heavy metals, may still be added in the design to appease aesthetic requirements of the owner.

### III. DESIGN IMPLEMENTATIONS

When designing the courses for a bio-swale or bio-retention pond, the porosity is a key factor for the accelerated growth of the larger with the deeper tap roots. This allows the bio-swale or bio-retention pond to aerate and act as a reservoir for runoff to be stored to either percolate or for use by the plants. Most of the aeration will occur in the riprap course. Large perforations (1" to 4") bored to or constructed above the course must be provided so that air can circulate to the roots drawing in the air. This can be achieved by designing vertical check-pipes near the outermost extent of tree root growth, based on the documented root ball sizes of each species; this will allow air access without risking clogging by the root systems throughout the life of the bio-swale and bio-retention pond. Since check-pipes are a standard element of design for inspection of subsurface properties, their use is effectively increased.

The filter media will comprise the main component of the filtering capacity of the bio-swale. Porosity will also be a main factor of the soil for plant growth as well as nutrient availability, clay content and the depth of the course. In sandier soils, like the majority of sites on the Delmarva Peninsula, the filter medium will average a mix of 40% native soil and 60% engineered soil which is typically determined by a geotechnical specialist or agency (Rovansek). Porosity will largely determine the time necessary for runoff to percolate through the medium. Time is critical for the efficiency of the bio-swale or bio-retention pond. As Qingfu Xiao and E. Gregory McPherson discuss in their study, increasing the amount of time for percolation is the design factor that will determine the efficiency of a bio-swale or bio-retention pond. Additionally, aeration procedures should be conducted to ensure that the proper volume of air reaches the roots of the grasses. Assuming that the design specification of the filter media is designated to not be thoroughly compacted, monthly perforation of the soil is beneficial to speed the growth of the plants and to make them stronger against erosion and uprooting (Aeration, 1). To reduce the effects of erosion, perforation should not be done at the centre of bio-swales where the most frequent movement of water occurs and in the spillway into the bio-retention pond.

Considering the nutrient availability factor, fertilizing the filter media (or the mulch layer) is not necessary because the design premise for the swale or pond is to collect runoff that will contain organic materials; small animal waste and foliage decomposition, if not designed next to a farm, will supply the plants with nutrients to strengthen and grow in resilience even though early stages of plant growth may leave the plants vulnerable to automotive runoff. When bordering a farm field, plant growth will be sped to a greater degree from the excess fertilizer because of its higher nitrogen and phosphate properties among its other synthetic benefits if the fertilizer has been modified.

Next, the clay content will adjust the time for a soil to percolate based on water content, heat exposure and molecular/atomic chemistry. Generally, clay is a broad classification of soils that become more cohesive in the presence of water. The molecules/elements present combine with other molecules/elements to cause the clay to take another form at the microscopic level. The chemical reactivity of clay is part of the reason that fertilizers and heavy metals can be held in the filter medium while letting the remaining runoff percolate. This cohesiveness creates a mass that inhibits or blocks the percolation of water. Clays continue to provide inhibition and blockage to percolation after the introduction of heat,

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specifically from the sun. Even in non-direct sunlight, the heating of the Earth will still cause evaporation; this adds to a three factor drying event: one from gravity pulling water into deeper strata of the soil, one from transpiration from plants absorbing water, and evaporation. The geotechnical specialist or agency will determine the proper amount of clay to be present, as stated before, but the designer's active role in considering the necessary percolation rate to allow for proper time for absorption by both the plants and the clay will aid the prescription of the media composition.

The final factor the media design will to be consider the depth of the course. It is the most basic way of controlling the time of percolation. Assuming that all courses above the virgin soil have a greater percolation rate, runoff can be held longer and in greater mass. The consideration must, again, be directed at the chosen species of plants, specifically the chosen species of trees. If the root ball cannot reach the riprap course then alternative aeration methods should be designed or the depth of the filter media should be reduced so as to not affect the effect of the aeration in the riprap course. Depth should also be considered alongside irrigation needs. Every plant will need weekly irrigation, when there is no rainfall, for the first year (Xiao, 242). The citation provided is descriptive of a rain garden but the basic principles apply concerning planting maintenance. Once the roots are established, the plant will be able to draw from the artificial aquifer created in the bio-retention pond; swales will require additional maintenance, therefore the maintenance of the plants should be treated as if they were planted in virgin soil. Refer to the American Standard for Nursery Stock published by the American Horticulture Industry Association for more information. The designer should also consider the trade-off between having a deeper bio-retention pond and using a greater area for the pond

#### IV. RESULTED DESIGN RECOMMENDATIONS

The top of the bio-retention pond, the mulch or riprap/ gravel course, contributes to plant health and has a negligible impact on the percolation rate. Mulch provides nutrients to the soil from the substances that are mixed in by the manufacturer (Van Seters, 170) and by natural decomposition. Yearly maintenance will be required to keep the mulch layer clear of any unwanted weeds and for reapplication of a new mulch course. Maintenance workers or landscapers must be instructed, either in the design drawings or the design specifications, to check for signs of erosion; the finish elevation of the mulch must be restored to its design condition. A contingent fund must be allocated by the owner for maintenance in the event of a severe rainfall event; most occasions will only require the workers to redistribute the mulch to level the mulch bed but may require purchase of mulch if the original elevation cannot be reached (taking into account depression due to rot and settling). Mulch, as compared to riprap or gravel, provides a thermal barrier that protects the root ball of plants from dramatic swings in temperature that occur in the open air therefore the maintenance of the mulch layer is important for the protection of the plants during the winter months. By comparison, riprap or gravel provide virtually no benefit to the nutrient composition that the plants are given. Maintenance does not include replenishing the course.

Weeds, however, will need to be exterminated as necessary. Erosion will be negligible, although settling due to the weight will compact the upper depth of the filter media thereby depressing the top elevation of the bio-retention pond or bio-swale. The designer and the geotechnical professional should consider the effects on the porosity of the filter media; they should also consider that while being poorer at retaining water, compared to the filter media, the mulch/ gravel course has a high porosity. Also, maintenance on either a mulch course or a gravel course will include monthly trash removal. The stormwater runoff from more urban projects or projects near major roadways will carry litter that will get caught in the mulch/ gravel course; garbage disposal or recycling should be incorporated to the regular maintenance budget. Aside from functionality, either mulch or gravel provide a pleasing aesthetic to the bio-swale or bio-retention pond. The final design consideration is to impregnate the soil with microbes that digest phosphates, carbon molecules (like gas and oil), or other properties for the bio-chemical reconstitution of pollution into environmentally safer molecules. For the purposes of this paper, only denitrifying bacteria will be discussed. Denitrifying bacteria have been shown to convert nitrates into atmospheric nitrogen and hydrates (Anderson, 74). The study by Lu Xu-jie showed that the micro-organisms imbedded in the filter medium increased nitrate processing and also exhibited some phosphate processing capability (Xu-jie, 1). Generally, these microbes present no danger to human

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health. The downside is that as the temperature decreases, so does the efficiency of the microbes processing (Xu-jie, 1). One consideration that should be in the design specification, concerning agricultural use is the presence of chemicals in agricultural practices that attack denitrifying bacteria. Maintenance should factor in costs to re-impregnate the soil with denitrifying bacteria, based on soil test results at yearly intervals.

## V. CONCLUSION

We have implemented some standards for design to reduce surface contamination. Designing a bio-filtration facility must take exhibit the natural processes that can be mimicked from a wetland environment (Rovansek). Economic viability and infrastructure construction can be left unhindered by constructing more environmentally friendly remediation projects. The design considerations presented in this paper aid processing pollution from stormwater runoff in agrarian activities and automotive use on the Delmarva Peninsula. Runoff pollution negatively affects the Chesapeake Bay and reduces the natural resources available residents around the bay enjoy. Implementation of all design considerations, from organic to inorganic, chemical, bio-chemical and physical, will provide improved filtration and pollution processing in bio-swales and bio-retention ponds.

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