IMPACT OF SOIL MEDIA IN RAINGARDENS USED FOR CONTROL OF URBAN STORMWATER

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IMPACT OF SOIL MEDIA IN RAINGARDENS USED

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CHAPTER I

INTRODUCTION

1.1 OVERVIEW

Urban areas are “those areas where the ecosystem is significantly modified by (dense) human settlement and associated activities” (Taylor and Owens, 2009). Urbanization extensively affects the urban soil structure. Development of cities also leads to a steady increment in the amount of runoff generated from the impervious surfaces. The presence of impervious areas results in a decrease in infiltration and evapotranspiration and an increase in the runoff volume (Brown and Peake, 2006)**.** The diffuse sources of pollutants present in urban runoff includes pollutants derived from vehicle exhaust, gasoline and oil drippings, vehicle tire wear, asphalt road surfaces, paint marks, exposure of the building materials to rain, animal droppings, fertilizers and so on (Pitt et al., 1999). The contaminants of concern generated during the rainfall are heavy metals, hydrocarbons, nutrients and polycyclic aromatic hydrocarbons which are washed from roofs, roads and other impervious surfaces. Several studies on urban stormwater runoff indicate significantly high concentration of petroleum hydrocarbons and heavy metals in the runoff (Barbosa and Hvitved-Jacobsen, 1999; Pitt et al., 1999; Brown and Peake, 2006; Hong et al., 2006). The stormwater discharge flow rate and the volume together have a great impact on the nearby streams which receive the runoff. The use of conventional stormwater management methods such as gutters and pipe systems does not remove the contaminants present in the runoff. The runoff is usually directly discharged into the stormwater system without any pretreatment, which disturbs the overall ecological cycle (Brown and Peake, 2006). Also, the maintenance cost of the physical separation devices are more and the removal rate is lower for the soluble pollutants (Cho et al., 2009).

Raingardens or bioretention systems are recommended by EPA as structural best management practices (BMPs) which can be used to meet the requirements of the national stormwater program under section 402(p) of the Clean Water Act (CWA) (U.S EPA, 1999). Research was initiated in the Stormwater Management department at City of Stillwater, Oklahoma, to study the efficiency of different soil media for building a raingarden in order to solve the drainage issue at Stillwater Public Library so as to control the quantity of stormwater runoff arriving from the parking lot and to improve the quality of water reaching Stillwater Creek.

1.2 Concern for Pollution Control

A report on the Continuing Planning Process (2006) from the Oklahoma Department of Environment Quality (ODEQ), explains the application of water quality standards (WQS) to all of the waters of the state. As per the report, the water quality standards are designed for the state of Oklahoma in order to enhance the quality of waters, to protect their beneficial uses and to aid in the control, prevention and decrease of the level of water pollution for the state of Oklahoma.

In the year 2007, revisions were made by Oklahoma Water Resource Board (OWRB) to Oklahoma's Water Quality Standards (OWQS). According to the EPA's review of the revisions given in chapter 45 of Oklahoma Water Quality Standards, the following beneficial uses have been designated for waters of the state of Oklahoma:

1. EWS- Emergency Water Supply beneficial use.
2. PPWS- Public and Private Water Supply beneficial use.
3. F& W Prop. – Fish and Wildlife Propagation beneficial use.
    - (A) WWAC- Warm Water Aquatic Community subcategory.
    - (B) HLAC – Habitat Limited Aquatic Community subcategory.
    - (C) CWAC- Cool Water Aquatic Community subcategory.
    - (D) Trout- Trout Fishery subcategory.
4. Ag- Agriculture beneficial use.
5. Rec- Recreation beneficial use
    - (A) PBCR- Primary Body Contact beneficial use.
    - (B) SBCR – Secondary Body Contact beneficial use.
6. Navigation beneficial use.
7. Aes- Aesthetics beneficial use

The watershed area of this research project is limited to Stillwater Creek from Little Stillwater Creek to Sec.32, T19N, R3E, IM (OWQS Chapter 45: Appendix A.1). Therefore, consideration is given only to the designated beneficial uses of that reach. The designated beneficial uses for this reach include EWS, HLAC, Ag, PBCR and Aes only.

For attainment of these beneficial uses, the turbidity from other than natural resources shall not exceed 50 NTU for surface waters. In waters where background turbidity exceeds this value, turbidity from point sources shall be restricted to not exceed ambient levels. For swimming advisory and permitting processes, the E. coli geometric mean criterion is 126/100 ml and Enterococci geometric mean criterion is 33/100 ml. Nutrients from point source discharges or other sources shall not cause excessive growth of periphyton, phytoplankton, or aquatic macrophyte communities which impairs any existing or designated beneficial use.

1.3 Hydrologic Studies

The hydrological cycle describes the continuous movement of water above, on, and below the surface of the earth. On the surface of the earth, water occurs as streams, wetlands and lakes along with bays and oceans. The water below the surface of the earth is groundwater, which also includes soil water. The hydrological cycle, illustrated in Figure 1, includes the ecological processes of precipitation, infiltration, surface runoff, evaporation, and evapotranspiration. In predevelopment cases, the major portion of the rainfall runoff undergoes either infiltration or evapotranspiration, and therefore the amount of surface runoff is very low.

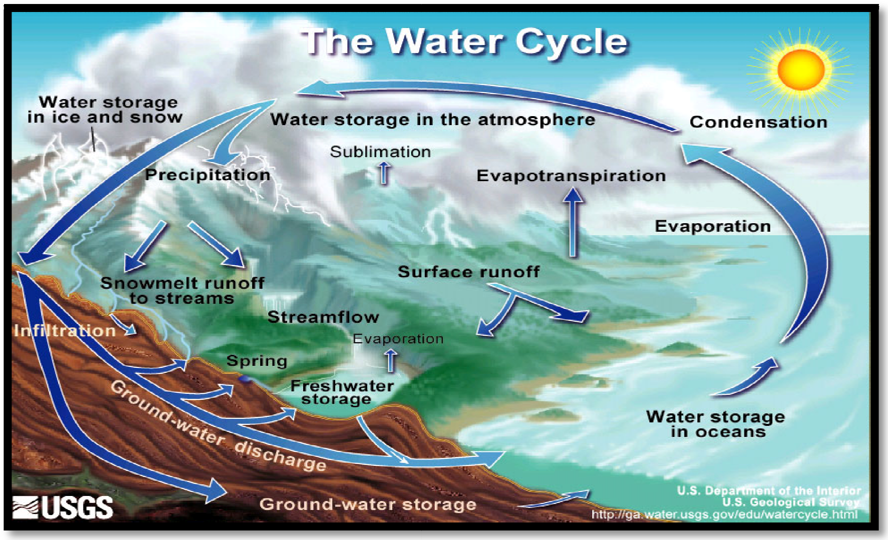


Figure 1. Hydrological Cycle

Source: The U.S Geological Survey (USGS), 2011

The hydrological cycle is disturbed due to conventional land development practices, as there is removal of vegetation followed by erection of buildings, leading to the compaction of soil, thereby resulting in less infiltration and evapotranspiration and increased generation of runoff (U.S. Geological Survey, 2010). Development practices result in change in both annual and seasonal water balance (EPA, 1999). The indirect relationship between the roughness of land surface and the velocity of flow leads to more rapid flow of stormwater over smooth urban surfaces than rough natural surfaces. Erosion of soil takes place with the conversion of potential energy to kinetic energy of the flowing stormwater, which changes the stream channel morphology and the riparian vegetation thereby resulting in overall reduction in groundwater (Jacobson, 2011). EPA reports the degradation of water quality and ecological integrity of streams is mainly due to alteration in site runoff characteristics, which increases the volume and frequency of runoff along with the velocity, contributing to flooding, accelerated erosion and lower groundwater recharge. The increase in the suspended sediments concentration not only reduces the oxygen delivery to the fish eggs, but also affects the behavior of fish, causing damage to the gills. The changes in the sediment supply and sediment quality have major impact on the biodiversity of the rivers, which in turn influences the river ecosystem (Taylor and Owens, 2009).

1.4 Soil Horizons

The Natural Resources Conservation Service (NRCS) defined soil as a *"dynamic natural body that is made up solids, liquids, and gases, occurs on the earth's surface, contains living matter, and supports or is capable of supporting plants"*(NRCS USDA, 2005).

The soil texture is based on the amount of sand, silt and clay present in the mineral soil.

Soil is made up of six major types of soil horizons or layers, as shown in Figure 2.

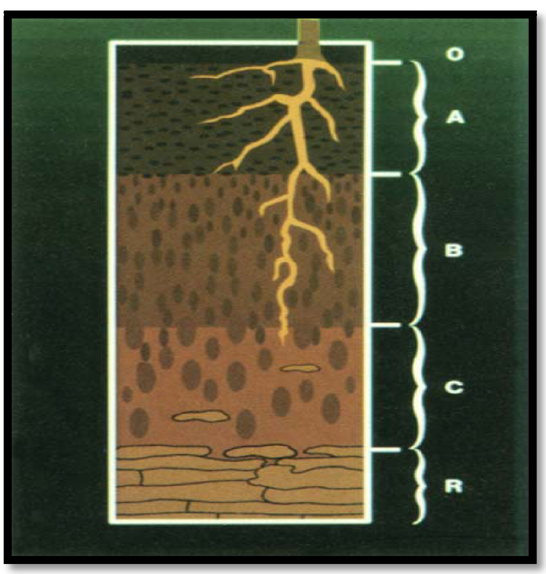


Figure 2. Natural soil profile with major horizons

Source: NRCS USDA, 2005

‘O’ horizons are the uppermost layers which are dark in color because of presence of humus produced by decomposition of plant and animal materials.

‘A’ horizons are commonly referred as top soils and they consist of mostly mineral and materials. They are dark in color due to addition of organic matter by the soil microorganisms loss of aluminum, iron and clay.

‘E’ horizon or alluvial horizons are not shown in Figure 2 but they are commonly present in forest areas. This horizon is light in color compared to both the above and the horizons which are below that, due to absence of iron, clay, organic matter and several other minerals.

‘B’ horizons are commonly referred to as sub soils. They are characterized by the presence of clay, iron, and aluminum.

‘C’ horizons or substratum are made up mainly of partially weathered parent material.

‘R’ horizons are made up of bed rock.

Soil characteristics in an urban area depend on the depth of excavation during construction at the particular site and the addition of any other material to the original soil. Alteration of soil properties takes place with change in the order of soil layers or by mixing of topsoil and sub soil. A dramatic change in the soil composition occurs due to vehicular traffic and pedestrian traffic, especially when the soil is wet. Figure 3 shows the general composition of soil before and after compaction. The components of soil which are most easily affected are the amount of soil air and water. With the squeezing of soil particles, there is reduction in size and number of the pores for air and water which in turn changes the water intake and the movement of water through the soil horizon. (USDA NRCS, 2005).

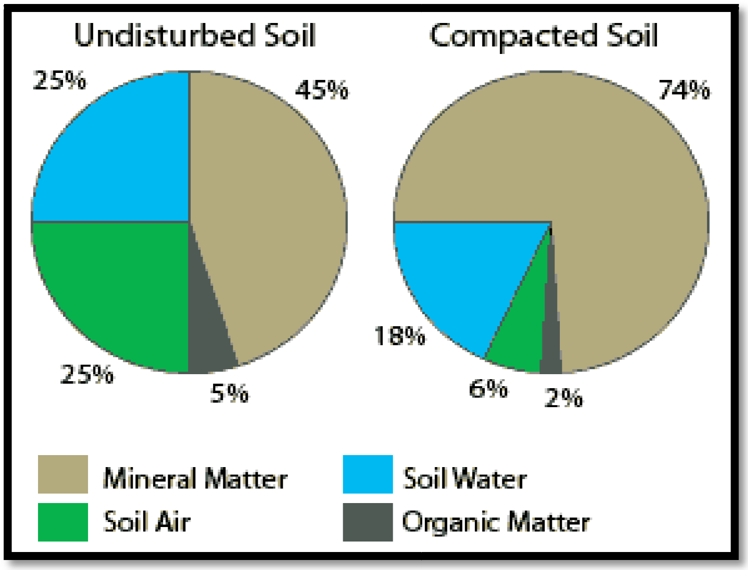


Figure 3. Soil components for disturbed and undisturbed soils.

Source: NRCS USDA, 2007

In addition to the reduction in porosity of soil, there is significant change in the pore size distribution. The loss of soil structure due to over compaction leads to poor absorption of high intensity rainfall, and the soil tends to become anaerobic. Studies show significant reduction in the infiltration rate especially of clayey soils. In the case of sandy soils, in spite of significant reduction of infiltration, the soil can withstand compaction (Whalley et al., 1995; Pitt et al., 2004).

1.5 Essential nutrients for plant growth

The soil profile plays a vital role in the growth of the plants. The soil texture and structure, the chemical nature of soil as well as the slope of land largely determines the growth potential of plants. The essential nutrients for plants can be grouped into three categories based on the relative amount required for the plants.

A) Primary nutrients – Nitrogen, Phosphorous and Potassium.

B) Secondary Nutrients – Calcium, Magnesium and Sulfur.

C) Micronutrients – Iron, Manganese, Zinc, Copper, Boron, Molybdenum and Chloride (Zhang and Raun, 2006).

The stormwater runoff from urban areas contains nutrients which contaminate the streams and rivers but at the same time they are helpful for the growth of the plants. Raingardens or bioretention areas are intended to be the landscape areas that treat stormwater runoff. Raingardens help in stormwater infiltration and groundwater recharge along with removal of pollutants from the parking lot and roof tops of commercial, residential and industrial areas.

The stormwater runoff from parking lots of the Stillwater Public Library runs to the adjoining low land area which consists of poorly drained soils with an infiltration period of more than 48 hours; the area is therefore subject to flooding. The aerial view of the Public Library site is shown in Figure 4.

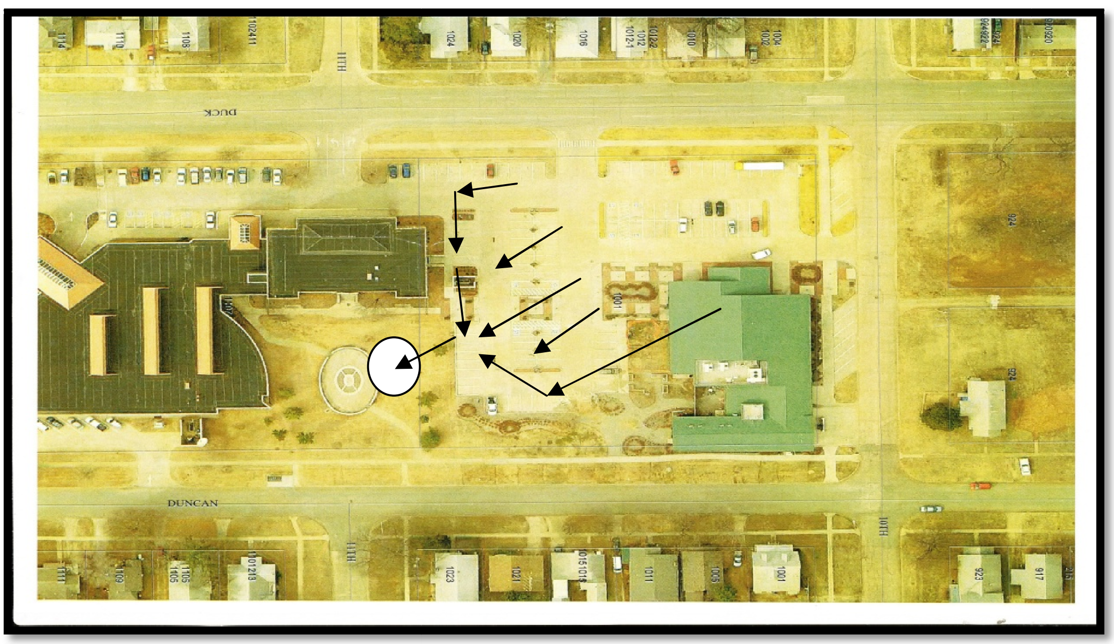


Figure 4. Stillwater Public Library site

Source: City of Stillwater, 2011

The topic of this thesis is an evaluation of soil media for use in raingardens in Stillwater, Oklahoma. It is part of a larger study that includes a raingarden built at the Stillwater Public Library. In this thesis, a synthetic parking lot runoff was leached through three different types of soil media and the leachate analyzed to assess the ability of the media to remove contaminants that impact stormwater quality. The media which is to be used for building a raingarden should remove the pollutants arriving from the adjoining parking lot runoff before discharging it into Stillwater Creek. Recommendations are made at the end of this thesis as to the best type of media to use considering stormwater quality and the ability to support plant growth.

CHAPTER II

LITERATURE REVIEW

2.1 Urban Runoff Pollutants and its discharge

Sediments: Sediment in itself is considered a major non-point source pollutant as it impacts stream turbidity and biological processes and hence the ecology. It plays an important role in contaminant transfer and water quality in rivers and streams. As a consequence of potential impact of road deposited sediments (RDS) on urban air quality and urban runoff, more attention is given to the presence of total suspended solids in the urban runoff. In addition to the RDS, the sediments derived from erosion of soil and channels needs to be considered. Urbanization leads to either increases or decreases in the sediment delivery. The risk of flooding may arise when there is increase in the sediment delivery causing channel aggradations, leading to the volume reduction of the channel (Taylor and Owens, 2009).

A compilation of typical pollutant loadings from different contaminant sources are shown in the Table 1. As per the trends shown in Table 1, the concentrations of sediments and floatables, pesticides and herbicides, organic materials, nutrients, metals, oil and grease and bacteria and viruses increases due to construction activities, atmospheric deposition, washouts from lawns, driveways and streets, commercial landscaping and animal wastes, illicit discharge to stormdrains, septic systems, automobile exhaust and soil erosion. The pollutants found in urban runoff are therefore directly related to degree of development within the watershed.

Contaminant	**Contaminant Sources**
Sediment and Floatables	Streets, lawns, driveways, roads, construction activities, atmospheric deposition, drainage channel erosion
Pesticides and Herbicides	Residential lawns and gardens, roadsides, utility right-of-ways, commercial and industrial landscaped areas, soil wash-off
Organic Materials	Residential lawns and gardens, commercial landscaping, animal wastes
Metals	Automobiles, bridges, atmospheric deposition, industrial areas, soil erosion, corroding metal surfaces, combustion processes
Oil and Grease/Hydrocarbons	Roads, driveways, parking lots, vehicle maintenance areas, gas stations, illicit dumping to storm drains
Bacteria and Viruses	Lawns, roads, leaky sanitary sewer lines, sanitary sewer cross-connections, animal waste, septic systems
Nitrogen and Phosphorus	Lawn fertilizers, atmospheric deposition, automobile exhaust, soil erosion, animal waste, detergents

Table 1. Sources of contaminants in urban stormwater runoff.

Sources : USEPA, August 1999.

<u>Nutrients:</u> Groundwater contamination through nitrate nitrogen is prominent in urban areas. Studies have reported the contribution of non point source pollution in the eutrophication of the water body receiving the polluted runoff (Bratieres et al., 2008; Cho

et al., 2009). Compared to phosphorous loadings, nitrogen loadings are much higher in urban areas. The heavily populated states in United States with large dairy and poultry industries or the states performing extensive irrigation are more prone to groundwater contamination. Studies show elevated concentrations of nitrate in groundwater in case of heavily industrialized areas. The amount of nitrogen available for leaching is in direct proportion to the impervious cover in the watershed. (Pitt et al., 1999; Cho et al., 2009).

Microbial Contaminants: Public waterborne illness is associated with contaminated stormwater runoff and as per the epidemiological evidence, the increase in the risk of adverse health effects are linked with swimming in recreational waters that are contaminated by urban stormwater. With the increase in the turbidity from suspended soil particles, there has been increase in the bacteria and other microorganisms in the surface water bodies receiving the urban runoff.

Generally, in surface waters, the fecal coliform bacteria exceed the standards for recreation. The exposure to microorganisms during swimming and other forms of recreation can cause ear and eye discharges, gastrointestinal diseases, skin rashes and several other physical illness (Gaffield et al., 2003; Rusciano and Obropta, 2007).

2.2 Best Management Practices for Stormwater Management.

A storm water best management practice (BMP) is a technique, measure or structural control that is used for a given set of conditions to manage the quantity and improve the quality of stormwater runoff in the most cost-effective manner. (USEPA, August 1999). BMPs can be classified into two groups:

A) Structural BMPs which include engineered systems are basically designed for control of water quality and quantity. The structural BMPs consist of different type of systems such as dry wells or infiltration trenches for capturing the runoff arriving from the roof top and driveways, detention and retention systems, grass filter strips or vegetated swales, porous pavements with reservoir structures and constructed wetlands.

B) Non-structural BMPs include management and development practices that are designed to limit the conversion of rainfall to runoff. Public education and pollution prevention planning are also considered non-structural BMPs.

In case of new urban development, the design and implementation of BMPs should be such that peak discharge rate, pollutant loadings to the receiving water bodies and the volume are all equal to the pre-development. This can be achieved by utilizing site design techniques by incorporating infiltration and on-site storage, which can greatly reduce the amount of stormwater runoff. Complications arise for controlling the flow in case of the areas which are already developed, and retrofitting the existing systems can be very expensive. In existing areas, incorporation of on-site practices can be done which can help in reduction of runoff volume discharged to the storm sewers (USEPA, August 1999).

2.3 Background on Low Impact Development (LID)

Low impact development is an environmental sensitive approach for managing stormwater close to the source. It is a new approach which has evolved in order to lessen the effects and to reverse the damage caused by development (USEPA, 2009). LID is a technology which helps in achieving development without adverse impact on public health and the ecosystem. In addition to the improvement in environmental performance, use of LID reduces the development costs when compared with traditional stormwater management approaches (USEPA, 2007).

Figures 5 and 6 show the effects of large and small storm events in areas with development. The dotted line shows the effect of development, leading to higher volume and more rapid discharge compared to predevelopment.

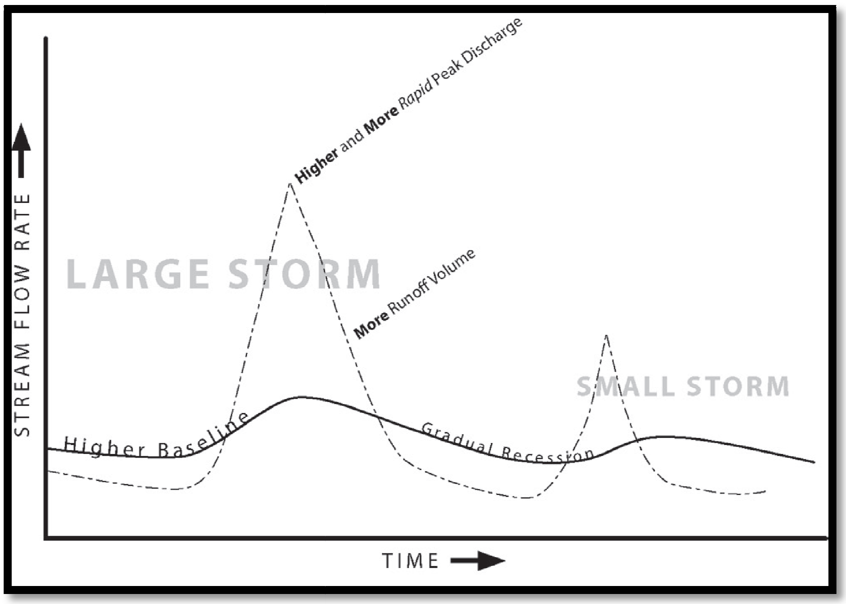


Figure 5. Comparison of pre-development (solid line) and post-development (dotted line) hydrographs.

Source: Low Impact Development- A guidebook for North Carolina, June 2009

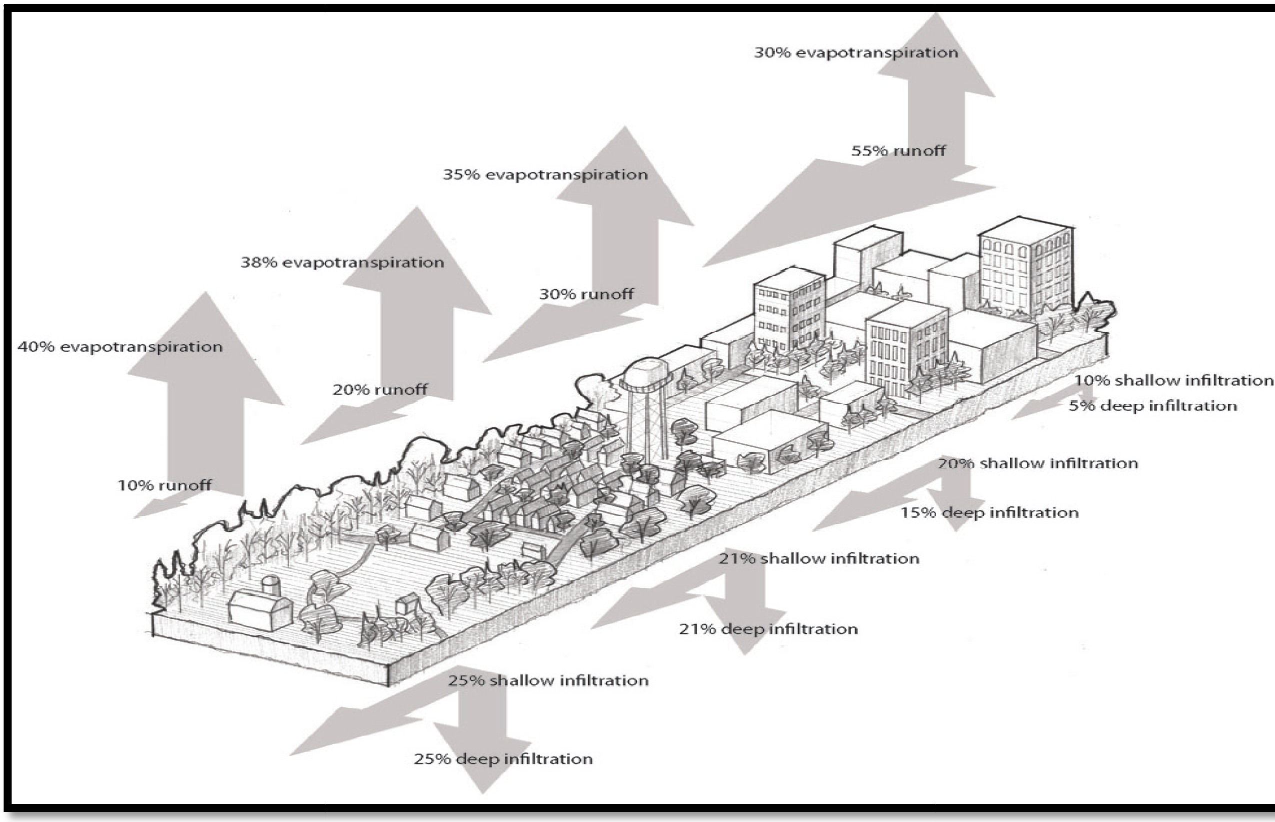


Figure 6. Dramatic increase of runoff with urbanization.

Source: Low Impact Development- A guidebook for North Carolina, June 2009

Figure 6 shows the effect of urbanization on the deep as well as shallow infiltration and evapotranspiration. It can be seen in the figure that, initially without development the deep infiltration was 25%, and after development it was only 5%. Before development, the evapotranspiration rate was 40% but after development it was only 30% along with generation of more volume of runoff.

The effects of construction and land development on water resources cannot be ignored. The approach towards stormwater management in the mid- 20th century using engineered systems of gutters, pipes, curbs and open channels resulted in damage to the quality of water. Under the federal Clean Water Act, one of the major state government responsibilities is to restore, protect and sustain the environment integrity and the use of the water resources. This new approach to land development or redevelopment works with nature so as to manage the stormwater at the source itself (USEPA, 2009; NCSU, 2009). In order to provide integrated treatment of runoff from the site, more than one type of practice or technique is incorporated (USEPA, 2007).

Use of LID for management of stormwater can help the municipalities meet five out of the six minimum requirements for NPDES phase II, which includes public education and outreach, post- construction runoff control, public participation and pollution prevention.

The benefits of LID over traditional, engineered stormwater approach include:

- Addressing stromwater at its source.
- Preservation of streams and watersheds.
- Promotion of recharge of groundwater.
- Allowing more flexible site layouts.
- Addition of green space and reduction of costs (USEPA, 2009).

2.4. Raingardens or Bioretention areas

A raingarden is a depression or a bowl that temporarily holds water, instead of shedding it away. The plants and shrubs growing in the raingarden are water tolerant. Water is directed to raingarden by means of pipes, curb openings or swales. By building a raingarden, the pollutants present in the stormwater are removed through physical, chemical and biological mechanisms which include absorption, microbial action, plant uptake, sedimentation and filtration. (NCSU , 2011). As shown in Table 2, the metals and soluble phosphorous are removed by absorption and plant uptake. Organic compounds are broken down by the microbes present in the raingarden, and exposure to sunlight kills the harmful pathogens. Raingardens remove the pollutants by allowing the stormwater to infiltrate. Once if the stormwater becomes part of shallow groundwater, the nutrients can be treated with its flow through riparian buffers.

Pollutant Removal Mechanism	**Pollutants**
Absorption to soil particles Plant uptake	Dissolved metals and soluble phosphorus Plant uptake Small amounts of nutrients including phosphorus and nitrogen.
Microbial processes	Organics, pathogens
Exposure to sunlight and dryness	Pathogens
Infiltration Runoff	Minor abatement of localized flooding, minor increase in localized base flow of groundwater, allowing some nutrients to be removed when groundwater flows through buffer
Sedimentation and Filtration	Total suspended solids, floating debris, trash, soil-bound phosphorus, some soil bound pathogens

Table 2. Pollutant removal mechanisms used in raingarden.

Source: NCSU, 2011

As the stormwater slows when it enters into a raingarden, the suspended particles settle at the bottom of raingarden. Vegetation aids in sedimentation thereby removing TSS, litter and debris and nutrients attached to the sediment particles (USEPA, 2000). Figure 7 shows a typical view of raingarden or bioretention system. Appendix C provides the list of plant species which can be used to build a raingarden.

Figure 7: A typical view of raingarden.

Source: USEPA, April 2009

Raingardens are designed to treat runoff from the first flush (1 inch). In the case of rainfall of more than 1 inch, an overflow pipe is installed in the center of the raingarden, and the top of the pipe is set at the desired maximum water depth or standard depth of 9 inches. (NCSU, 2001)

2.5 Importance of soil media

While designing a raingarden, there is need to consider both the physical and the chemical properties of soil. Along with quick drainage of the runoff, the soil medium should also allow enough detention time for proper treatment and growth of plants (Le Coustumer et al., 2009). In order to allow infiltration of large volumes of water from the impervious areas, the bioretention media should have high hydraulic conductivity. The conductivity primarily depends on the pore size, as larger pores conducts water more rapidly (Hsieh and Davis, 2005).

As per the “Drainage Design and Erosion Control Manual (DDECM)” for Thurston County, the soil which is used as a bioretention media should be homogenously mixed and shall be tested for cation exchange capacity which is the measure of the soils ability to remove dissolved metals. (Allen, 2010). The soil should also be tested for particle size, pH and the nutrients supporting plant growth (USEPA, 2000). The sieve analysis was conducted as per ASTM C136, “Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates” (Tao and Mancl, 2008).

CHAPTER III

METHODOLOGY

3.1 Engineered Soil Mix

Three different types of soils were obtained locally from Lowe's Garden Center in Stillwater. The soils were mixed in three different combinations. The first mix contained 50% sand and 50% peat, the second mix contains 50% sand and 50% compost. The third was 100% sand. Both of the mixed soils were homogenously combined in two separate buckets before filling the columns.

3.2 Experimental Raingarden Columns

Six bench-scale columns were built in the laboratory. Three columns, one each of sand, sand plus compost, and sand plus peat, were used to study the treatment of synthetic parking lot runoff. Three identical columns were used as controls, where deionized water was leached through the columns. Each column was a three foot long section of 4 inch inside diameter PVC pipe. The columns were constructed as illustrated in Figures 8 and 9 and detailed in Appendix A. Sampling of the columns is shown in Figure 10.

Figure 8. Building Columns

Figure 9. Study Columns

Figure 10. Sampling

3.3 Synthetic Runoff

Synthetic parking lot runoff was made with deionized water and chemical constituent as presented in the Table 3, according to the formation of Hsieh and Davis, (2005). The initial mixing was done in a 2-liter jar. The jar was filled with 1- liter of de-ionized water. After adding all the chemical constituents, the solution was mixed for 10 minutes using a magnetic stirrer as shown in Figure 10.

Parameter	**mg/l**	**Constituents**
TDS	120	$CaCl_2$
Phosphorous	3 as P = 13.7	Na_2HPO_4
Nitrate	2 as N= 11.80	$CaNO_3$
Suspended solids	150	Local soil sieved from 0.3 mm
Ammonium	2 as N = 7.64	NH_4Cl
Motor Oil	20	Unused engine motor oil ($C_{24}H_{50}$)

Table 3. Composition of synthetic runoff used in this study.

Source: Hsieh and Davis, 2005.

Figure 11. Mixing of synthetic runoff

This 1.0 liter of stock solution was then diluted with deionized water in a 6 gallon container to form synthetic runoff. A total of 2- liters of this synthetic runoff was passed through each column every day initially twice a day, and then it was increased to three times a day from June 14, 2011 to June 30, 2011. The quantity of suspended solids was also doubled from June 14, 2011 to June 30, 2011.

3.4 . Water Quality Parameters

The effluent samples were analyzed for turbidity as per method 2130 in Standard methods (APHA, 2010) for turbidity determination, using an electronic HACH 2100 N Turbidimeter. The influent synthetic runoff or deionized water was poured in all of the columns and turbidity was measured immediately after two hours. The effluent sample was poured into the sample tube and the tube was wiped so as to clean the drops on the outside of the tube. The turbidity was higher when the intensity of scattered light was high.

A) Conductivity

The Conductivity of the effluent samples from all the columns was measured within two hours using a Fisher Scientific C Model 30 conductivity meter. The conductivity was measured as per method 2510 in Standard methods (APHA, 2010). The conductivity meter was calibrated using sodium chloride. The probe was rinsed with distilled water and was then immersed in the effluent sample and the reading was recorded.

B) pH

A pH meter was used to measure sample pH. The effluent samples from all the columns were measured for pH, two hour after loading the columns. The pH of the samples was measured as per method 4500-H^+ Standard methods (APHA, 2010).

C) Chemical Oxygen Demand

COD was determined according to the method 5220 Standard methods (APHA, 2010). In low range COD tubes, 2 ml of effluent sample was mixed and was kept in the digester for two hours. The samples were cooled to room temperature and the results were read using HACH DR 5000 COD reactor. When the initial samples were tested, the instrument was unable to measure COD and showed "over range" as a reading. But with the use of high range COD tubes, the instrument measured COD.

D) Ion- Chromatograph

The effluent sample from all the columns was determined according to method 4110 Standard methods (APHA, 2010). The sample was filtered in order to remove the particles larger than 0.45µm and then injected in 5 ml autosampler tubes. The tubes were tightly closed. The samples were then analyzed on a Dionex model DX120 for detection of chloride, nitrate, phosphate and sulfate. The concentration of the anions was determined by preparing a calibration curve from the standard solution containing known concentration of all the anions of interest.

3.5 Physical and chemical parameters.

Sieve Analysis:

A 100-gram sample of sand, sand and compost mix, and sand and peat mix were heated in an oven at 105-115°C for two hours. The weight of dry sample with pan (Wo) was recorded. The weight of pan was then subtracted W_{DSO} = Wo- W_{PO}. All the samples were then washed separately with tap water using a No. 200 sieve. The samples were washed several times until the wash water was clear. The samples were again dried in the oven at 105-110°C for two hours. The weight of dry washed samples with pan was recorded. By subtracting the weight of pan, the weight of dry sample was obtained. The weight of fines W_F was then determined. The sieves were arranged from the largest opening to the smallest and the pan was kept below the bottom sieve. The sample was placed on the top sieve and was covered with a lid as shown in Figure 11. The sieves were shaken mechanically for 5 minutes and then percent retained on each sieve was determined. The results of the sieve analysis are in Table- 4. Table 5 shows the uniformity coefficient.

Figure 12. Sieve Analysis

Sr.no	Sieve no.	% retained (Sand)	% retained (Sand+ Peat)	% retained (Sand + Compost)	Diameter(mm)
1	10	11.47	7.5	11.84	2
2	20	17.65	16.4	14.8	0.85
3	40	38.6	40.14	35	0.425
4	50	17.33	21	21.7	0.3
5	pan	8.14	12.8	17.53	

Table 4. Percent retained on selected sieves

Sr.no	Soils	Pan (wp) (g)	Sample+pan(Wo) (g)	Weight of fines(Wf) (g)	d_{60}/d_{10}
1	Sand	91.9	190.12	1.35	1.5
2	Sand + Peat	94.51	193.78	2.07	1.6
3	Sand + Compost	61.35	158.25	3.94	1.95

Table 5. Uniformity Coefficient values

Graphs were plotted as shown in Figure 13, and uniformity coefficients were determined. In the graph shown in Figure 13 (a), it was assumed that for the line will extend and therefore value of d_{10} for sand was assumed to be 0.26 mm. The uniformity coefficient for sand = d_{60}/d_{10} = 0.39/0.26 = 1.5.

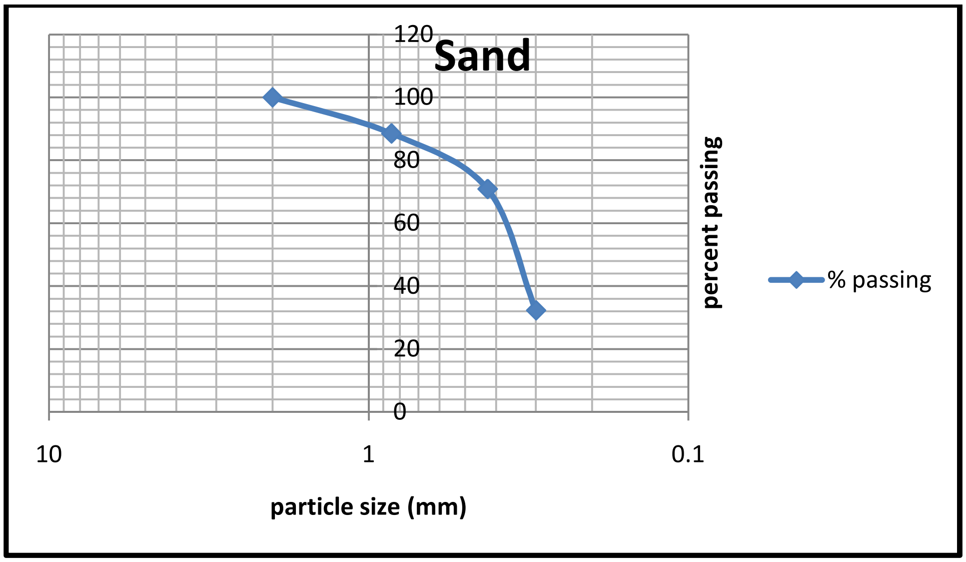


Figure 13 (a). Particle size analysis for sand

In the graph shown in Figure 13 (b), it was assumed that for the line will extend and therefore the value of d_{10} for sand + peat was assumed to be 0.24 mm. The uniformity coefficient for sand = d_{60}/d_{10}= 0.39 / 0.24 = 1.62.

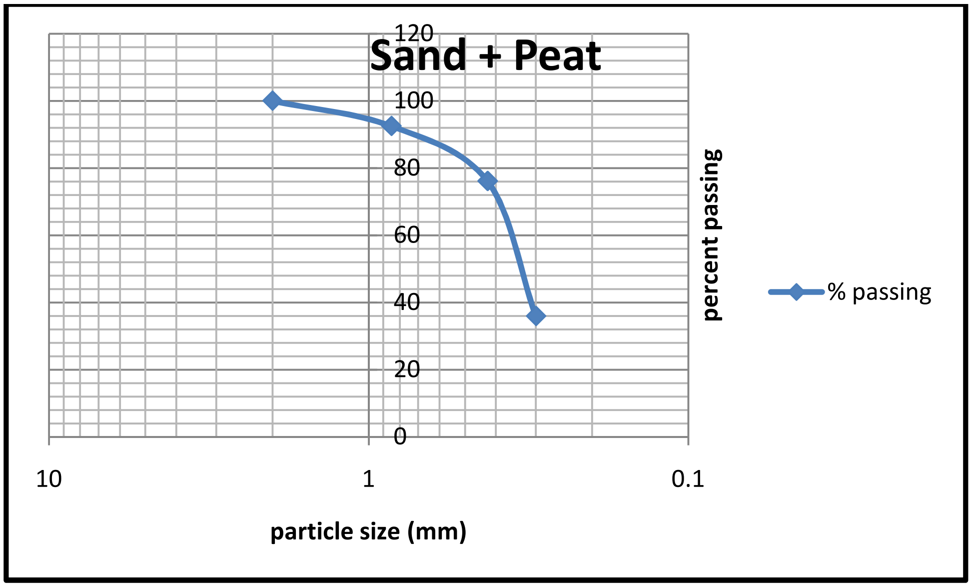


Figure 13 (b). Particle size analysis for mixture of sand and peat

In the graph shown in Figure 13 (c), it was assumed that for the line will extend and therefore the value of d_{10} for sand + compost was assumed to be 0.2 mm. The uniformity coefficient for sand = d_{60}/d_{10} = 0.39 / 0.2 = 1.95.

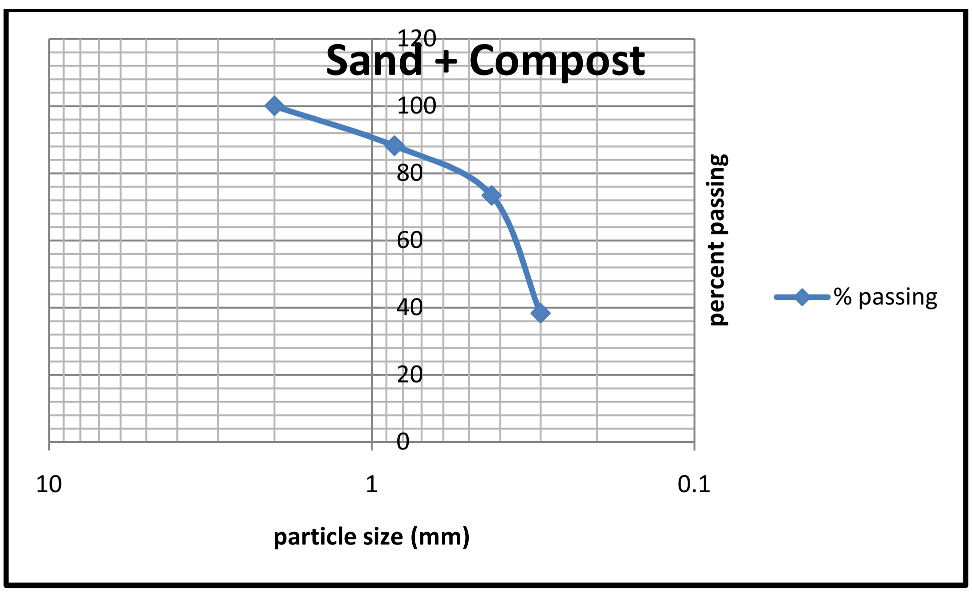


Figure 13 (c). Particle size analysis for sand and compost.

As shown in Table 6, Media Characterization was done by Soil Water and Forage Analytical Laboratory, Division of Agricultural Sciences and Natural Resources, Oklahoma State University.

Media	**pH**	**P (mg/100g soil)**	**K (mg/100g soil)**	**Mg (mg/100 g soil)**	**Ca (mg/100 g soil)**	**CEC (meq/100 g soil)**
Sand	8.2	0.2	3.2	9.7	390.5	20.4
Sand + Peat	7.1	0.2	3.3	9.7	249.85	13.38
Sand + Compost	8.6	32.6	98.9	44.35	654.95	306.9

Table 6. Media characterization

From Table 6 and from the graphs shown in Figure 13 (a), (b) and (c), it can be seen that the soils containing a mixture of sand and compost have higher Mg, Ca and K (cation) contents and cation exchange capacity.

CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 Effluent and Turbidity

Turbidity of the leachates from all the columns was determined. The graphs were plotted as shown in Figure 13 (a), (b) and (c). The influent turbidity was initially 19.5 NTU. The allowable stream range according to ODEQ is 50 NTU for surface waters.

In the column having just sand as media, turbidity was initially elevated due to the washing of fines from the sand. Turbidity reduced to about 4.1 NTU when synthetic runoff was used as an influent as shown in the Figure 14 (a). When deionized water was used as an influent the turbidity was reduced from 437 NTU to 55 NTU which was above the influent value due to washing out of sand media.

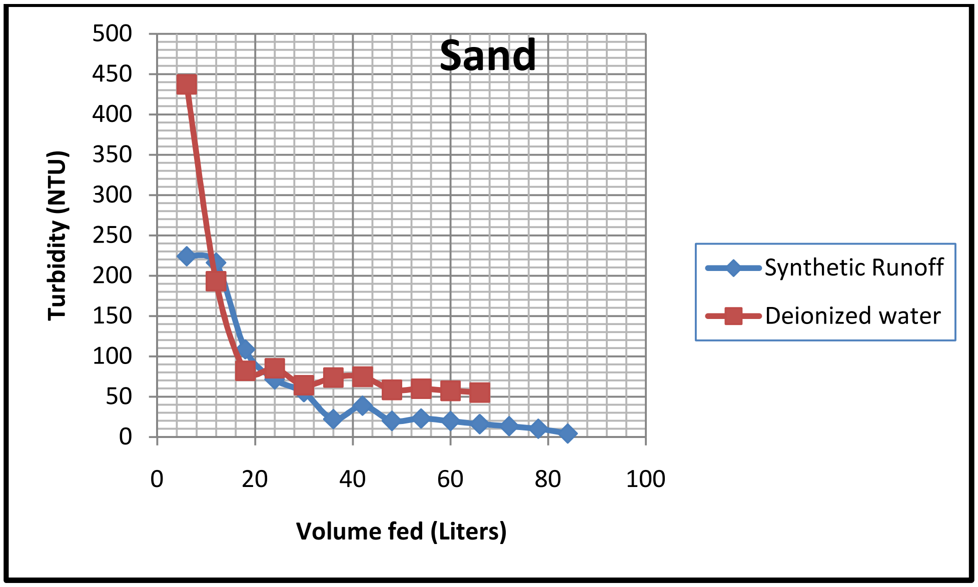


Figure 14(a). Turbidity for sand column.

Overall reduction in the turbidity was observed in all of the columns, but the turbidity was most significantly reduced in the column containing a combination of sand and peat. From Figure 14 (b), it can be seen that the turbidity was reduced to 1.5 NTU. When deionized water was used the leachate contains some turbidity due to washout of the material but it was eventually reduced to 3.7 NTU.

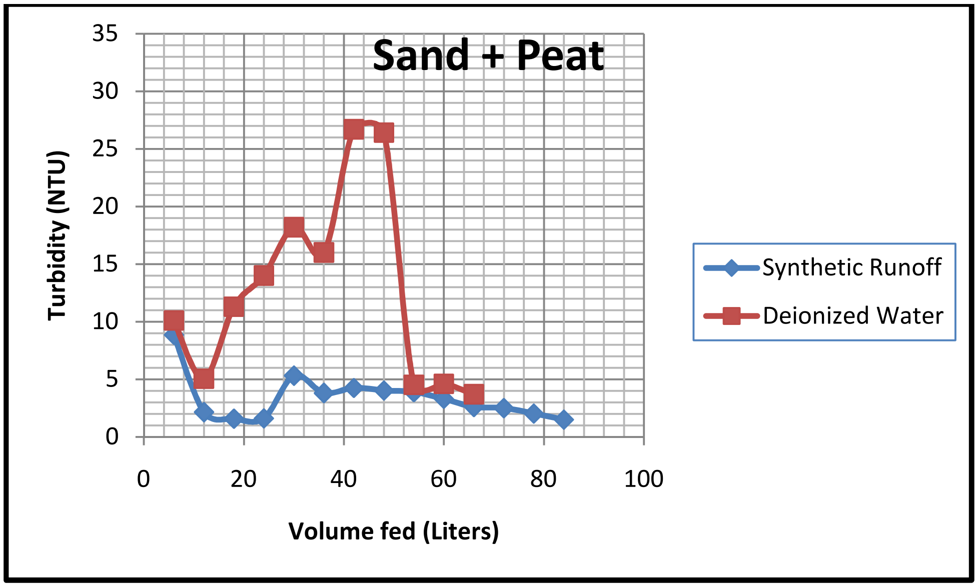


Figure 14 (b). Turbidity for sand + peat column

The sand and compost column reduced the turbidity of the synthetic runoff from a high of 1221 NTU to 17.8 NTU, which is a significant reduction. It is a lower reduction than achieved by the sand and peat column. However, in this column also there was initial increase in the value of turbidity in the effluent due to washout of the material or media as shown in Figure 14 (c)

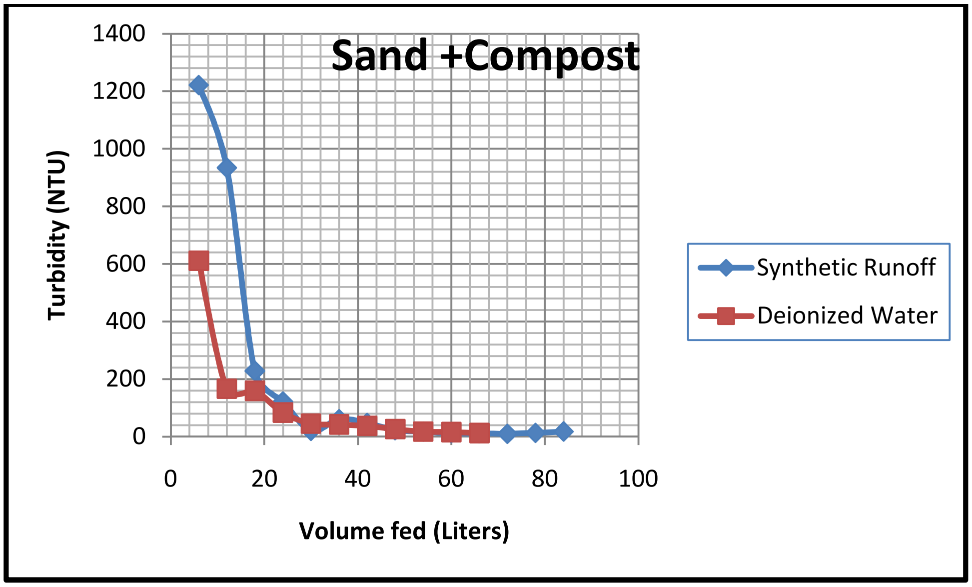


Figure 14 (c) Turbidity for sand+compost column

There is a considerable reduction in effluent turbidity for all the columns with an attainment of the state turbidity standard of 25NTU.

4.2 Effluent Conductivity

Conductivity of the effluent samples was measured as outlined in Chapter 3, and graphs were plotted as shown in Figures 15 (a), 15 (b) and 15 (c). The influent conductivity of the synthetic runoff was 264 µS/cm.

The conductivity of the leachate from the column containing sand as media was found to be increased when synthetic runoff was used as an influent. This can be seen in the graph shown in Figure 15 (a). There was an increase in the conductivity at 36 liters of throughput. It can be seen that the conductivity was reduced after 36 liters of throughput. At 84 liters of throughput, the conductivity value was reduced to 258.5 µS/cm. When deionized water was used, the same media showed initial increase in conductivity which eventually reduced to 53 µS/cm.

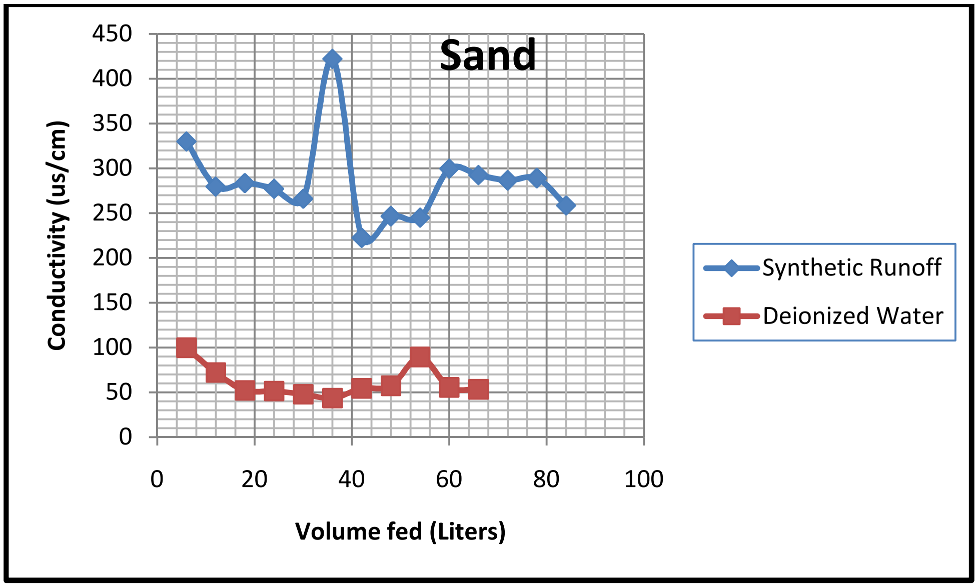


Figure 15 (a). Conductivity for sand column

As shown in Figure 15 (b), the column with sand and peat as media did not reduce the conductivity. It increased to about 414.5µS/cm when treating synthetic runoff. With deionized water, the same media shows initial increase and then reduction in the conductivity.

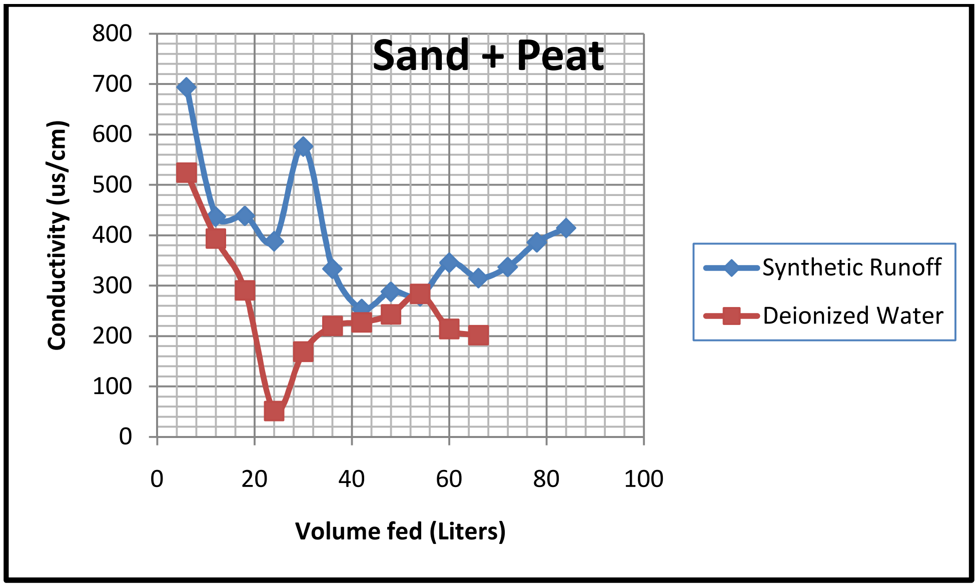


Figure 15 (b) Conductivity for sand + peat column

The conductivity of the sand and compost columns was found to be very high initially but was reduced with an increase in the leachate volume. From the graph shown in Figure 15 (c), at 84 liters of throughput, the conductivity was found to be 567 µS/cm, this is higher than the other two columns containing sand and a combination of sand and peat as media. When deionized water was leached through the same media, the conductivity reduced to 329 µS/cm.

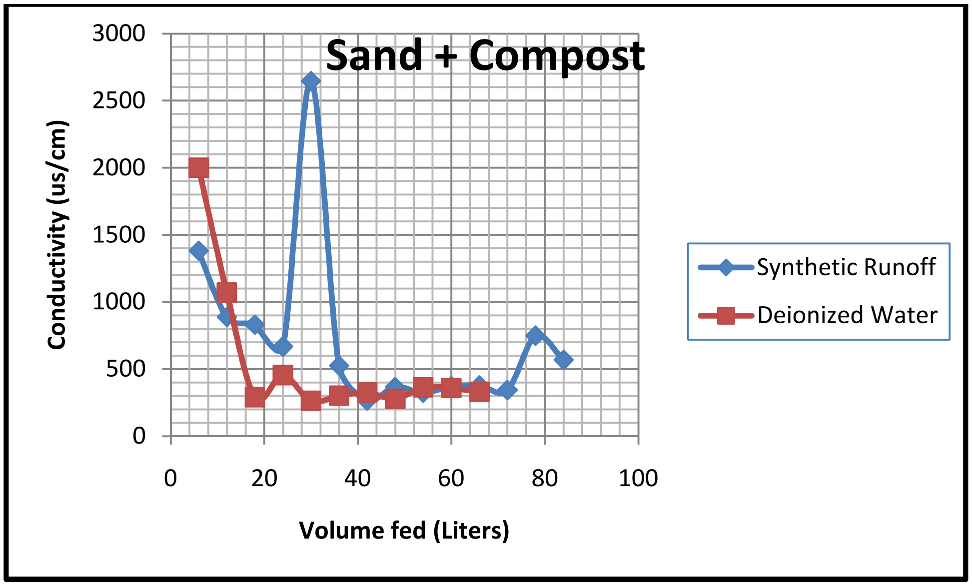


Figure 15 (c). Conductivity for sand + compost

The EPA's standard for conductivity for streams in the United States ranges between 150 and 500 μS/cm. Sand and compost column exceeded the EPA's standard conductivity range.

4.3 Effluent pH

The effluent samples were analyzed as outlined in Chapter 3. Graphs of results are shown in Figures 16 (a), (b) and (c). The influent pH value is 7.04.

Figure 16 (a), shows the leachate pH from the sand column. Effluent pH was found to be increased in both synthetic runoff and deionized water columns. From Table 6, it can be seen that the pH of the sand material itself was 8.2. As the influent pH was 7.04, the increase in the pH may be due to the presence of the sand media.

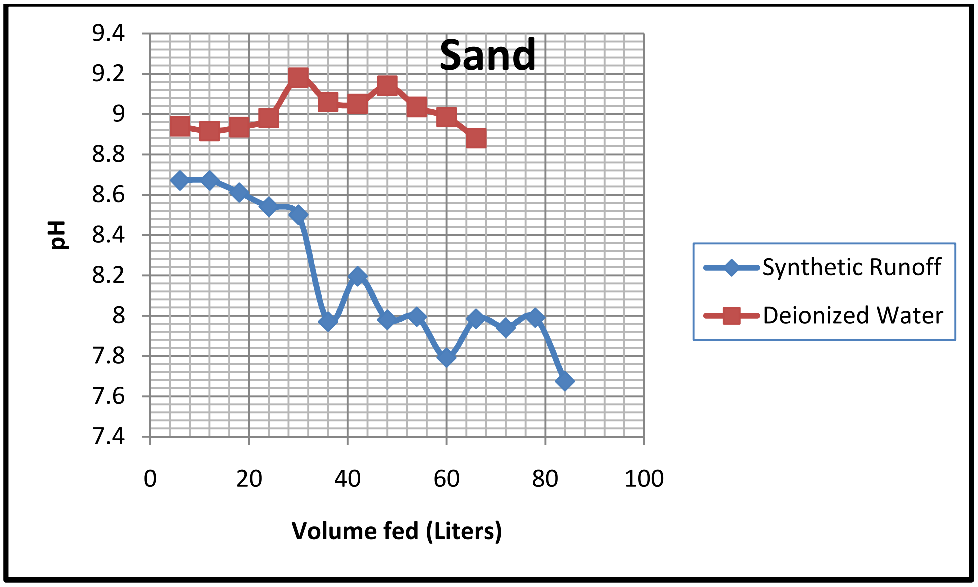


Figure 16 (a). pH of sand

In the column containing sand and peat as media, the leachate pH was in the range of 6.9 to 7, as can be seen in Figure 16 (b).

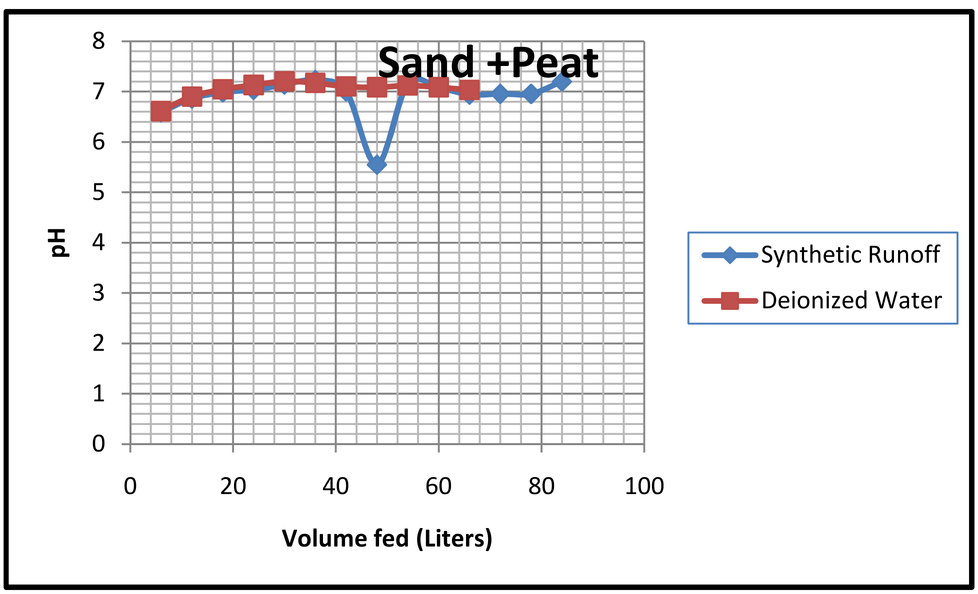


Figure 16 (b). pH for sand + peat

In the case of the column having sand and compost as media, the pH value increased, as can be seen in Figure 16 (c). The increase may be due to the material pH of 8.6.

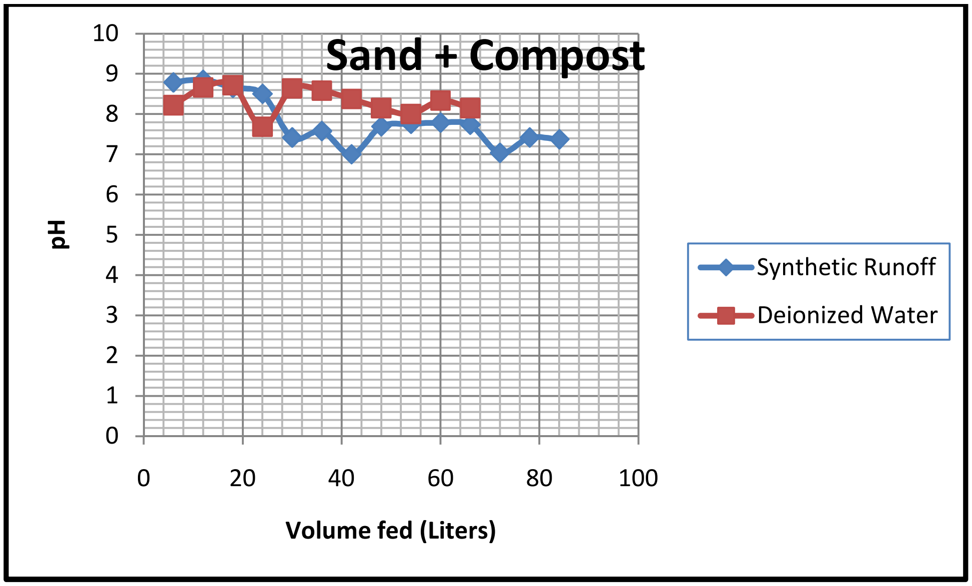


Figure 16 (c). pH for sand + compost

Since the EPA standard pH for streams in the United States ranges from 6.5 to 8.0, all the three columns have effluent pH in the acceptable range.

4.4. Effluent Chemical Oxygen Demand determination

The effluent samples for all the columns were measured for COD as discussed in chapter 3. The influent COD was measured as 22 mg/l. The therotical COD value with 20 mg/l of motor oil is

$C_{24}H_{50} + 36\ O_2 \longrightarrow 24\ CO_2 + 25\ H_2O$

(20 mg/l) (1milimole/338mg) (36milimole O_2/milimole $C_{24}H_{50}$) (32mgO_2/milimole O_2)

= 68 mg/l.

From the graph shown in Figure 16 (a) it can be seen that there is initial increase in the COD value and then decrease and once again increase in the COD value when synthetic runoff was leached through the sand column. There was a very high increase in the COD value initially and it eventually reduced to about 28 mg/l

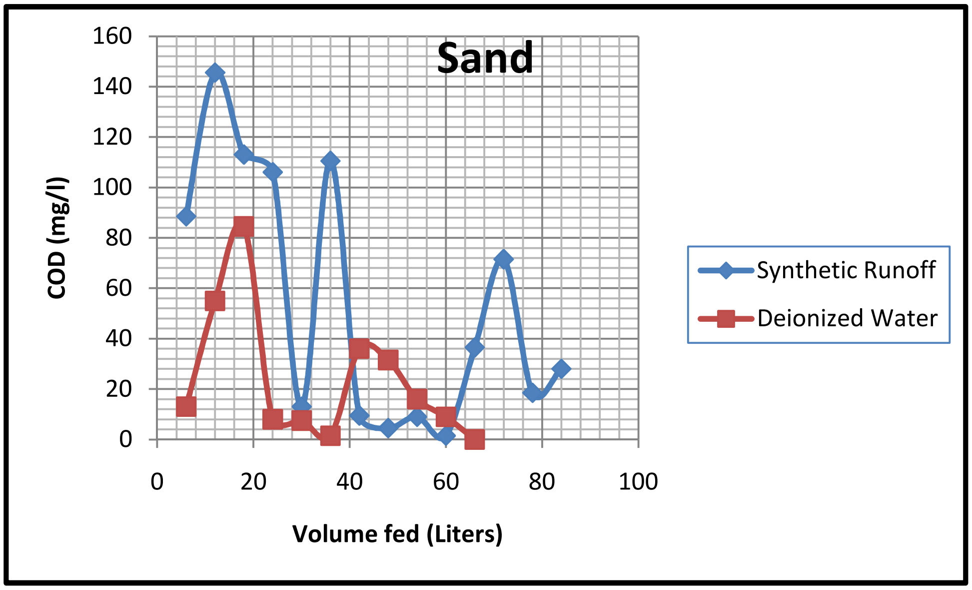


Figure 17 (a). COD for sand column

Figure 17 (b), shows a very high increase in the COD, initially which reduced over time for the sand and peat column.

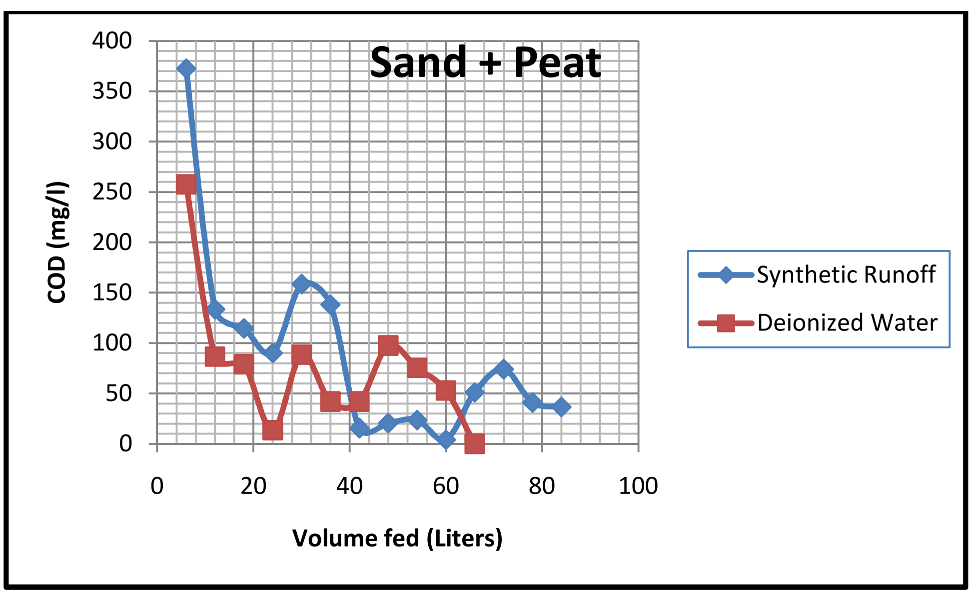


Figure 17 (b) COD for sand+peat column.

Figure 17 (c) shows a very high increase in the COD for the sand +compost column when compared with the graphs 17 (a) and 17 (b), but it also got reduced with the increase in the volume of throughput.

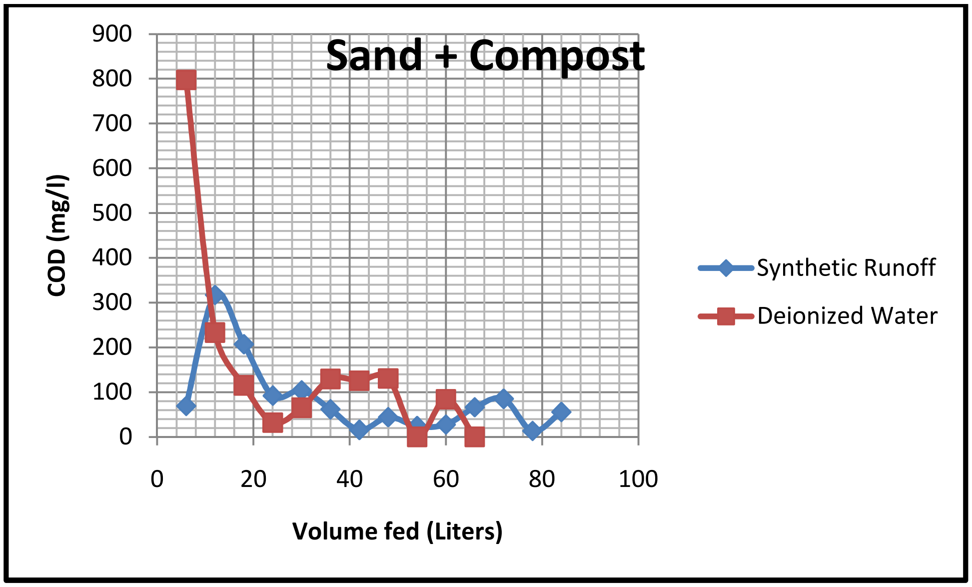


Figure 17 (c). COD for sand + compost column.

The overall results from all the three columns show considerable removal of COD when compared with the theoretical COD of 68mg/l. This should be considered here that the influent motor oil was floating at the top and the chances are that some of the motor oil can enter the burette while in most cases, even after vigorous shaking and immediate insertion of burette during sampling, the measured sample cannot contain much oil in it and therefore if we compare the measured value of 22 mg/l with the results shown by all the samples, then it can be seen, that the COD was not reduced in any column.

4.5 Effluent Chlorides

The effluent samples from all the columns were tested for chloride using an ion chromatograph. The plotted graphs are shown in Figure 18 (a), (b), (c).

The synthetic runoff contains 81.7 mg/l of chloride and after increasing the volume of leachate, the effluent chloride was reduced to 79 mg/l as shown in Figure 18 (a). With deionized water, the sand media shows 1.7 mg/l of chloride in the leachate, which may be due to the washing out of chloride from the sand column.

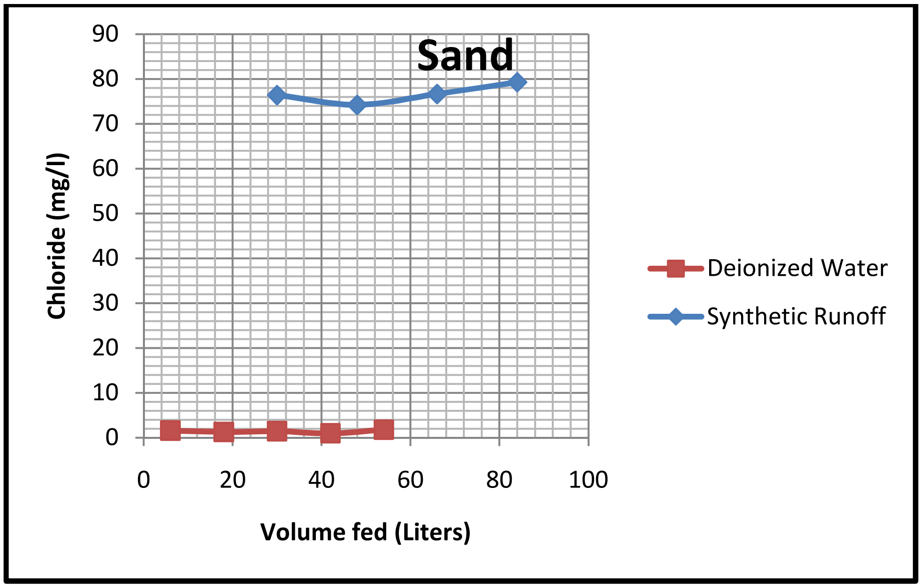


Figure 18 (a). Chloride removal in sand column.

From the graph shown in Figure 18 (b), the effluent sample shows 78 mg/l of chloride after passing synthetic runoff through the column which contains a combination of sand and peat. The removal is therefore negligible.

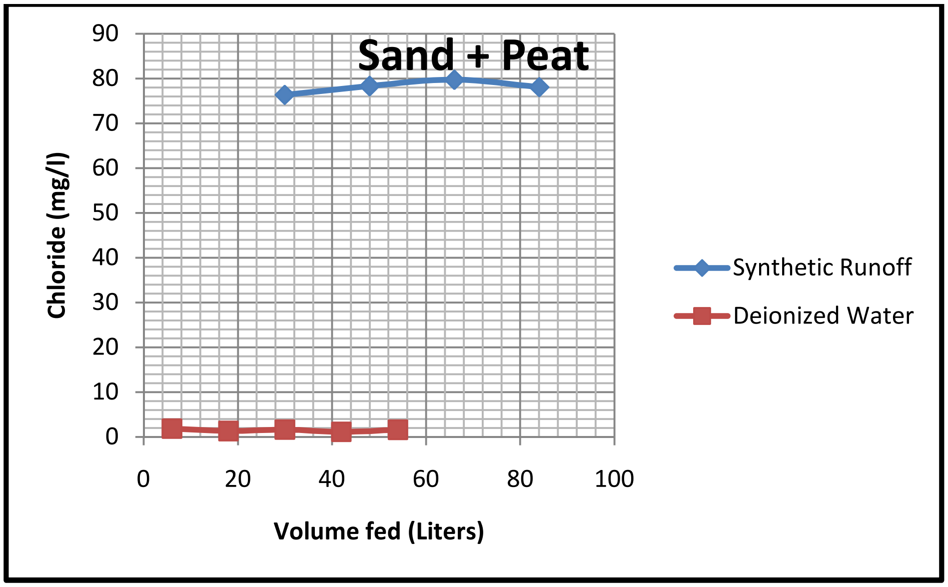


Figure 18 (b). Chloride removal in sand and peat column

As shown in Figure 18(c) for sand and compost column also there was negligible removal of chloride after 84 liters of throughput.

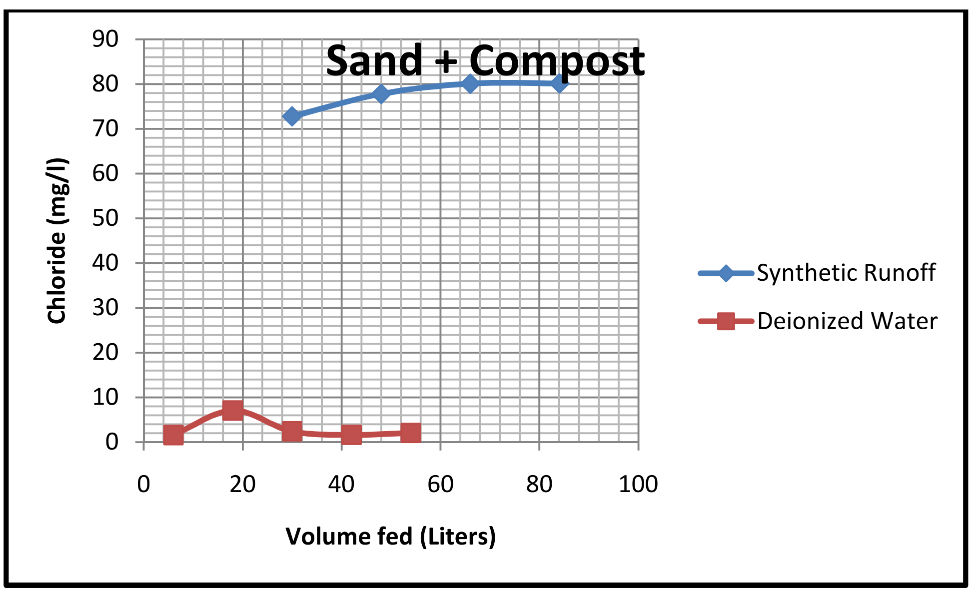


Figure 18 (c). Chloride removal in sand and compost column

The EPA stream water quality standard for chloride is 250 mg/l, which is greater than the concentration of the synthetic runoff. However, none of the experimental columns showed significant chloride removal when compared with the influent chloride concentration of 81.7 mg/l.

4.6 Effluent Nitrate

The effluent nitrate concentrations for all the three columns are shown in Figure 19 (a), (b) and (c) with influent nitrate concentration was12.1 mg/l.

As seen in Figure 19 (a), the nitrate concentration in the leachate from the sand column initially dropped, but then rebounded to the same concentration as the influent.

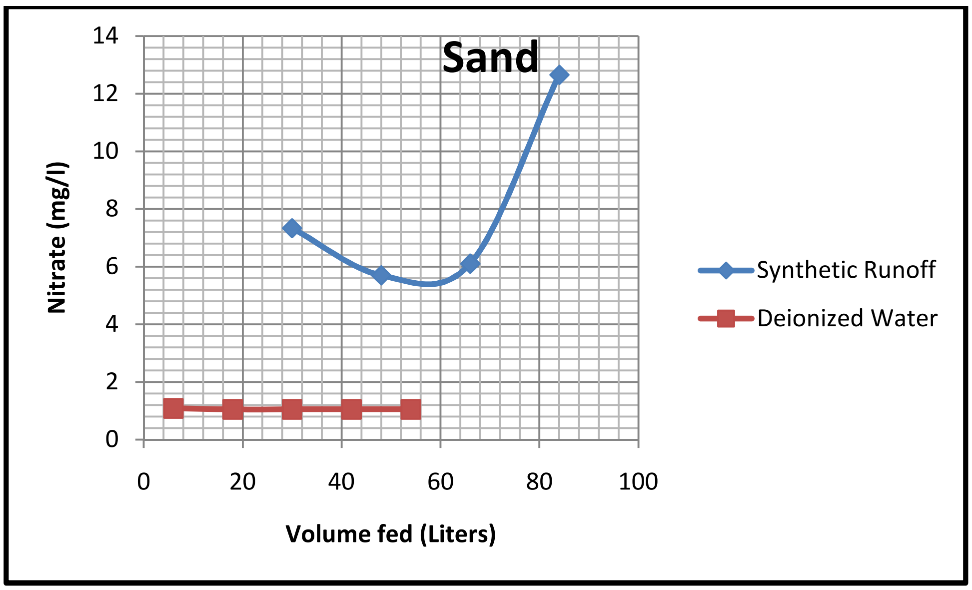


Figure 19(a). Nitrate removal in sand column

As shown in Figure 19(b), nitrate concentration from the sand and peat column rapidly dropped from a value of 23.53 mg/l. The concentration reduced to 12.5 mg/l at 84 liters of throughput.

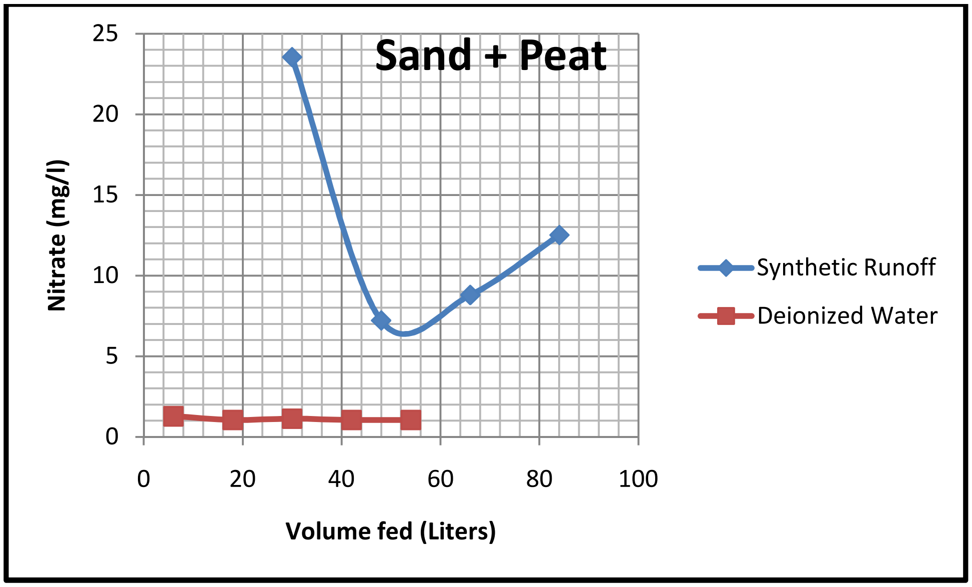


Figure 19(b). Nitrate removal in sand and peat column

In sand and compost column, nitrates were reduced to 3.99 mg/l at 84 liters of throughput, which is a significant removal. This is shown in Figure 19 (c).

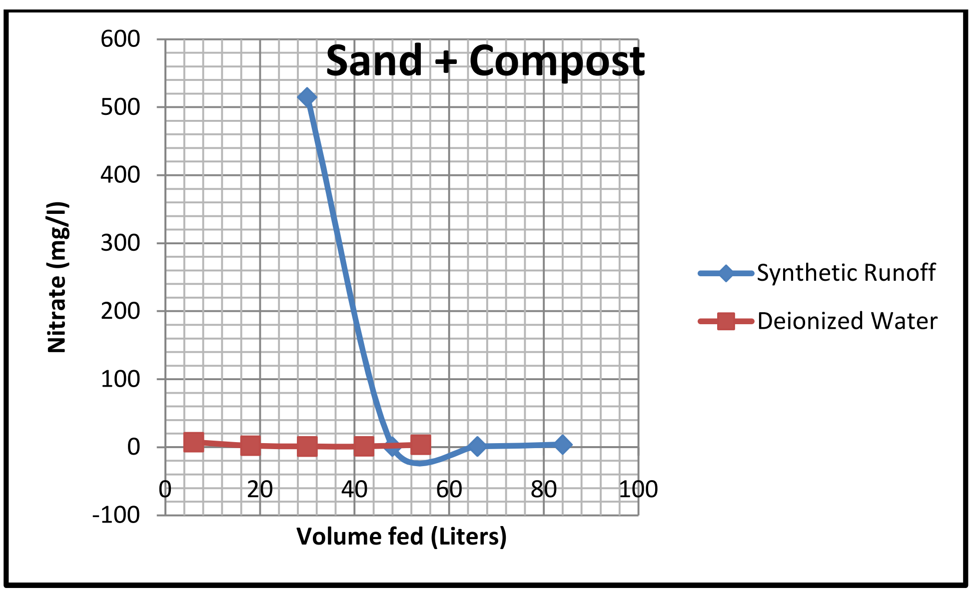


Figure 19(c). Nitrate removal in sand and compost column

EPA water quality standard for nitrate nitrogen is 10 mg/l which is equal to 45 mg/l as nitrate, and this is greater than the concentration in the synthetic runoff. The sand column and sand and peat column showed no significant removal of nitrates, making these media inefficient in nitrate removal.

4.7 Effluent Phosphate

The effluents obtained from the experimental columns were tested for phosphate and graphs were plotted as shown in Figures 20 (a), (b), (c). The influent synthetic runoff contained 9 mg/l of PO_4.

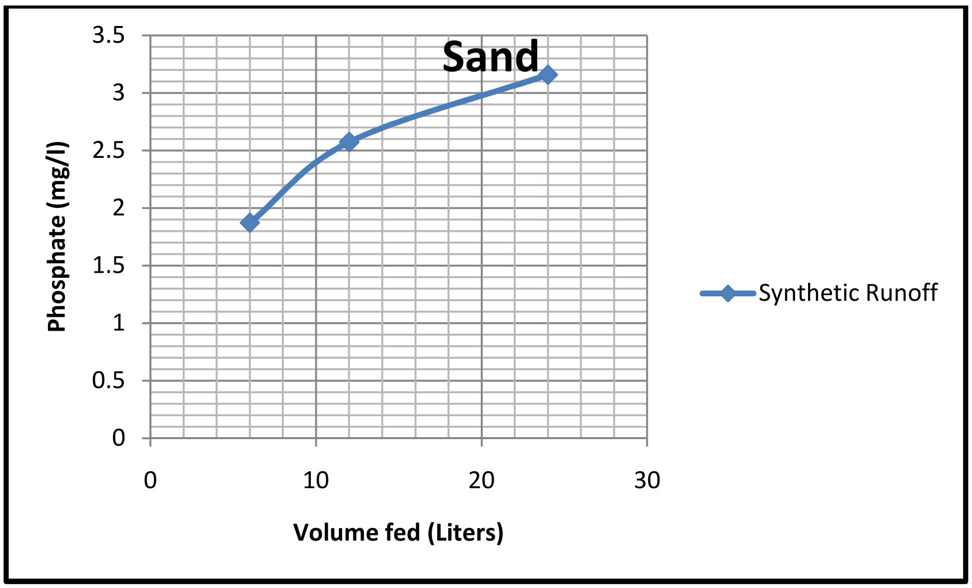


Figure 20 (a). Phosphate removal in sand column

The sand column initially reduced the influent PO_4 to 1.8 mg/l, as can be seen in Figure 20 (a) over time, the PO_4 increased to 3.15 mg/l.

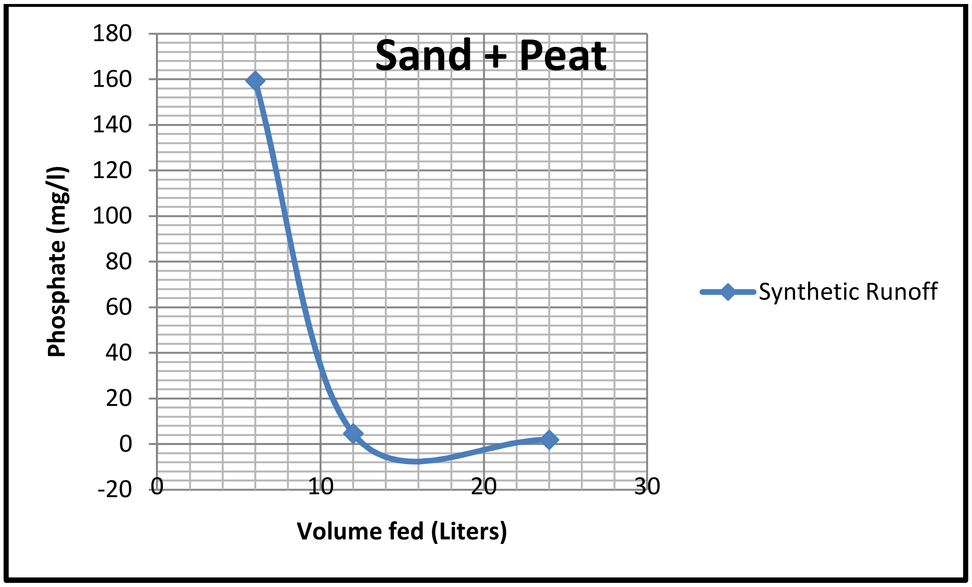
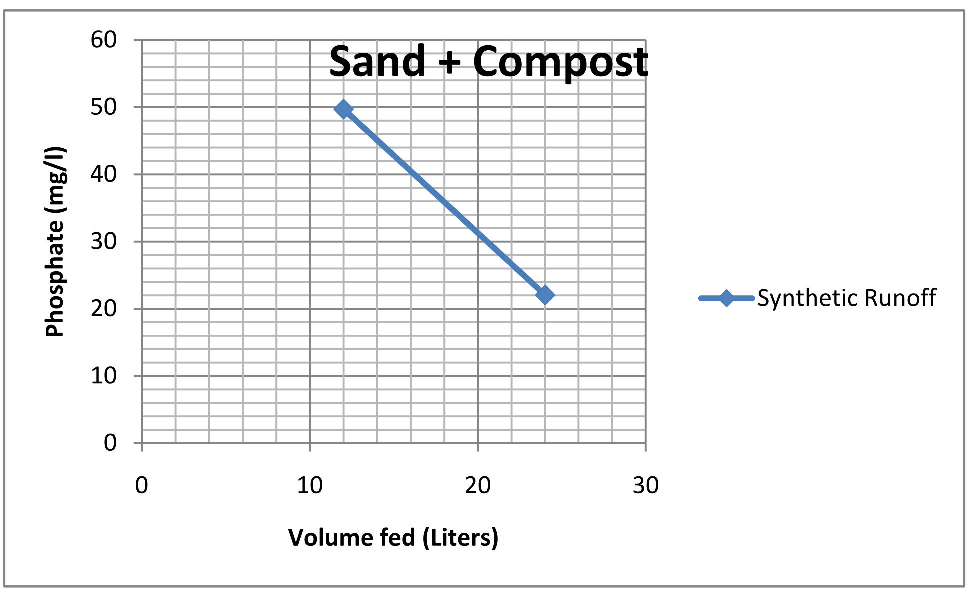


Figure 20 (b). Phosphate removal in sand and peat column

Significant leaching of phosphorus from sand and peat column can be seen in Figure 20



(b),

Figure 20(c). Phosphate removal in sand and compost column

In the column containing sand and peat, there was reduction of phosphate in the effluent as shown in Figure 20 (c).

The EPA water quality limit is 0.1 mg/l for phosphorous which is equal to 0.3 mg/l of phosphate. The effluent phosphorous in all columns was unable to meet the EPA stream standards.

4.8 Effluent Sulfate

The effluent sample from all the columns was tested for sulfate and the graphs were plotted as shown in Figures 21(a), (b) and (c). The influent sample does not contain any sulfate so any sulfate in the effluent came from the solid media.

Figure 21 (a) shows the amount of sulfate leaching from the sand media. The sand column with synthetic runoff as well as deionized water as an influent show increases in sulfate which probably came from the media.

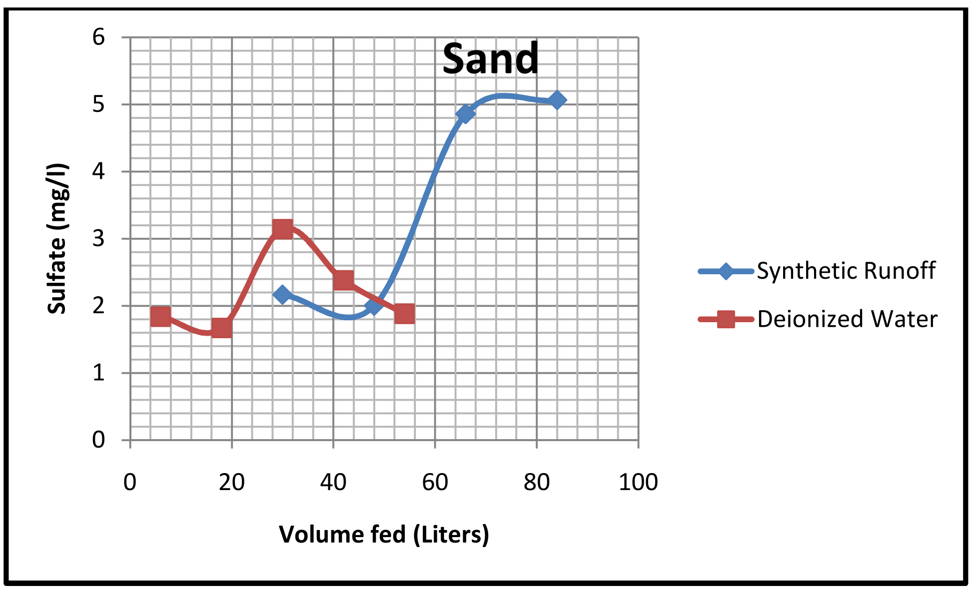


Figure 21. (a) Sulfate in sand column

In sand and peat column also effluent concentration of sulfate can be seen. There was a peak increase in the leaching followed by reduction as shown in Figure 21. (b).

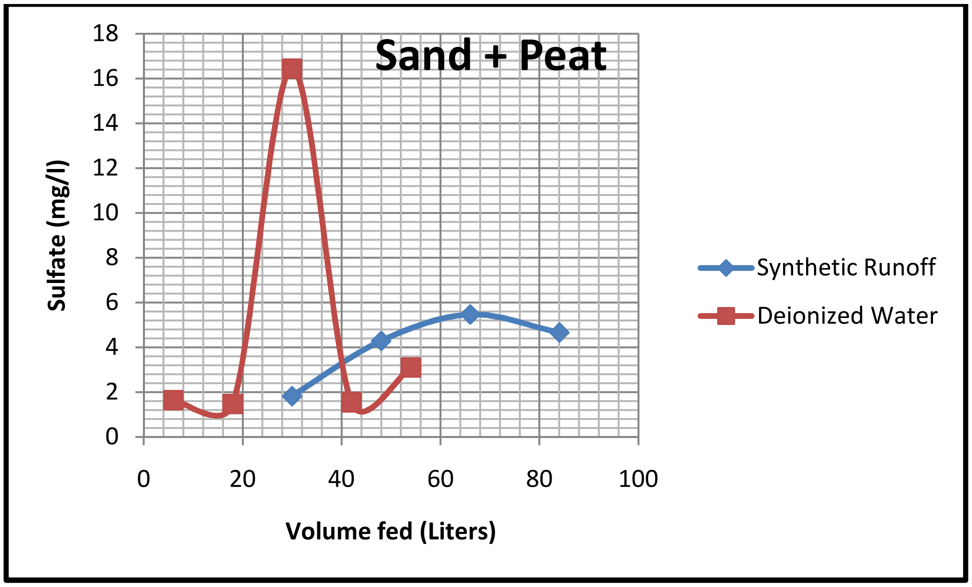


Figure 21. (b) Sulfate in sand +peat column.

The sand and compost column shows presence of a high amount of sulfate, which gradually reduced with increase in the volume of runoff as shown in Figure 21 (c).

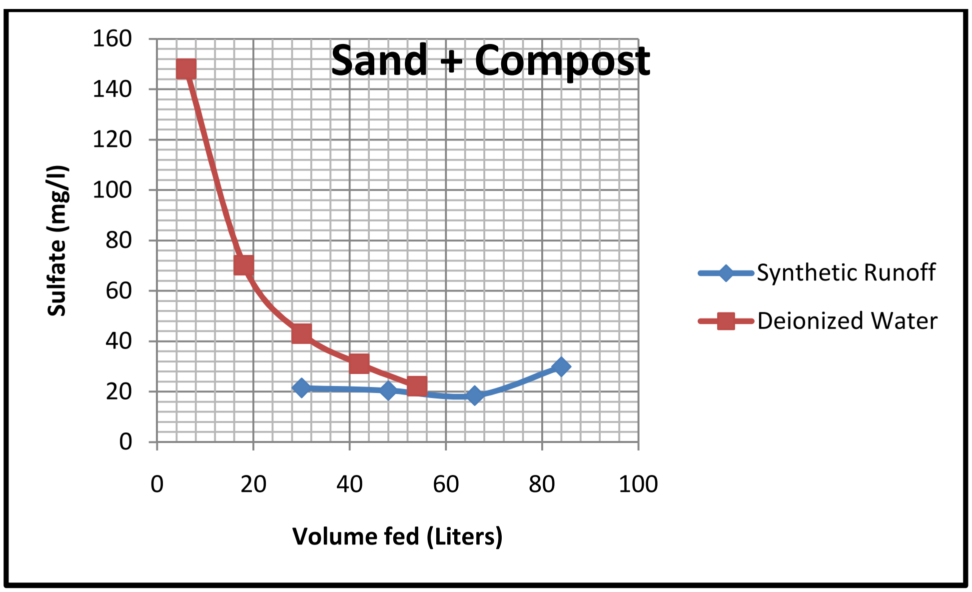


Figure 21. (c) Sulfate in sand and compost

The EPA stream water quality standard for sulfate is 250 mg/l and the effluent from all the columns are under this concentration.

4.9 Soil testing results.

Soils were analyzed by the Soil, Water and Forage Analytical Laboratory of Oklahoma State University, to evaluate the ability of the media to support growth of plants. The mobile and immobile nutrients present in all the three media mixtures are shown in Figures 22 (a), (b) and (c).

As shown in Figure 22(a), sand contains high concentration of calcium and magnesium but is deficient in nitrogen, phosphorous, potassium and sulfur which are essential for the growth of plants.

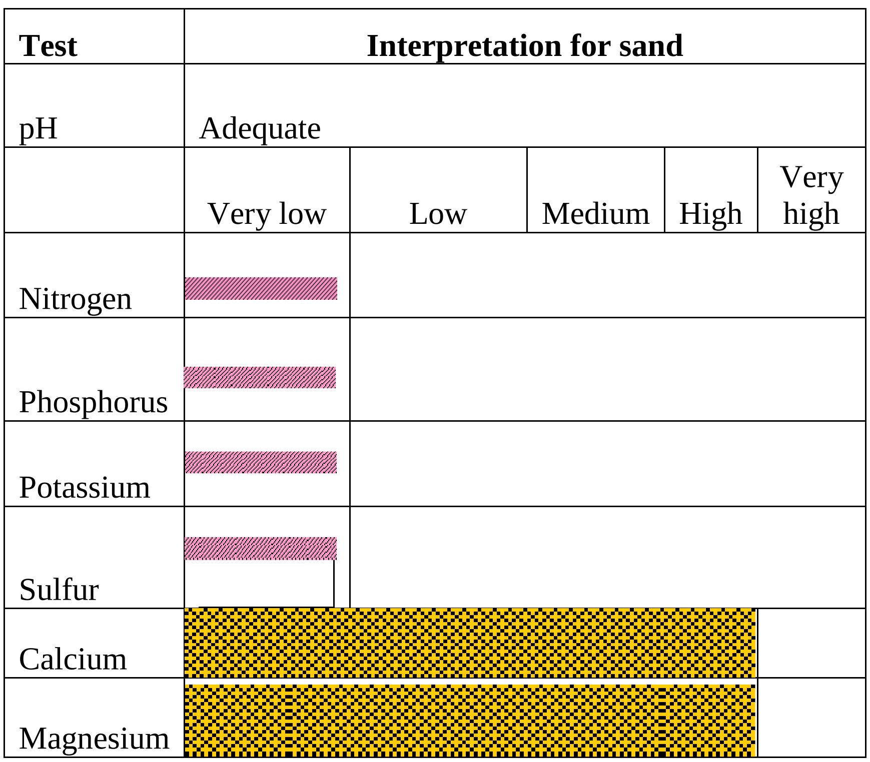


Figure 22 (a). Nutrients present in sand media

Source: Soil, Water and Forage Analytical Laboratory. Oklahoma State University

The combination of sand and peat media is also deficient in nitrogen, phosphrous, potassium and sulfur but it has high content of calcium and magnesium as shown in Figure 22 (b).

Test	**Interpretation for sand + peat**				
pH	Adequate				
Adequate	Very low	Low	Medium	High	Very high
Nitrogen					
Phosphorus					
Potassium					
Sulfur					
Calcium					
Magnesium					

Figure 22 (b). Nutrients present in sand and peat media

Source: Soil, Water and Forage Analytical Laboratory. Oklahoma State University

From the graph shown in Figure 22 (c), it can be seen that the sand and compost media is rich in nutrients with high nitrogen, very high phosphorous and potassium and low sulfur content and can therefore support the growth of plants.

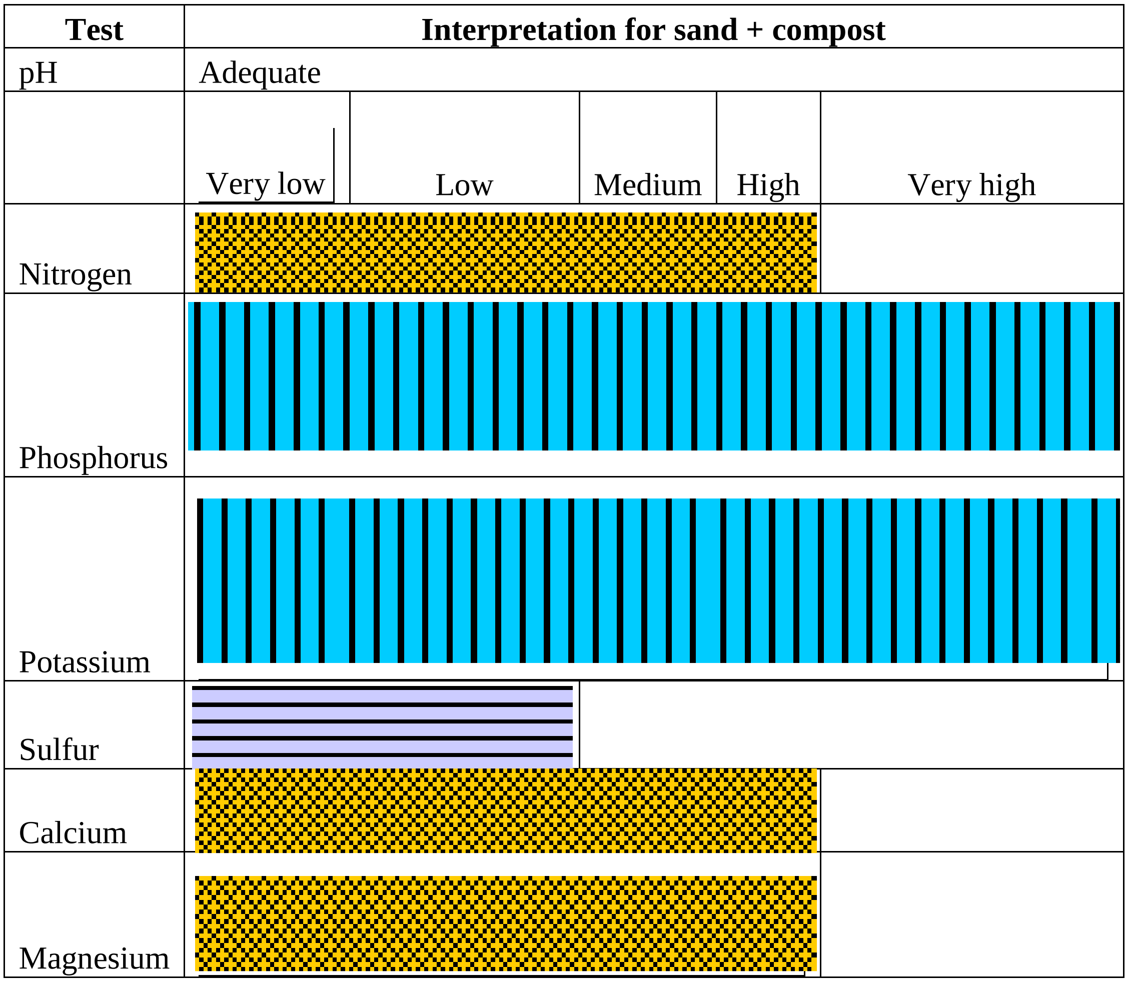


Figure 22 (c). Nutrients present in sand and compost media.

Source: Soil, Water and Forage Analytical Laboratory. Oklahoma State University

4.10. Comparison of present study with previous research.

The study performed by Hsieh and Davis (2005) showed the removal efficiency of nitrate from 1% to 43% with the use of native soil. In their study, sand was ineffective in nitrate removal but the media dominated by mulch removed most of the nitrate. The present research showed a nitrate removal efficiency of about 67% when sand and compost was used as media, while for sand and a combination of sand and peat, there was no removal of nitrate.

4.11. Media ranking as per the pollutant removal efficiency and nutrient content.

Table 7 shows the comparison of the effluent parameters with the EPA's water quality standards. The table also shows the pollutant reduction in the effluent parameters when compared with its influent. The effluent turbidity, COD and pH from all the three columns meets the effluent water quality standard. The effluent conductivity from sand and compost column exceeded the water quality standard. This is to be noted here that the influent concentration of chloride nitrate and phosphate are lower than the effluent standards and therefore comparison the influent chloride and nitrate with the effluent shows complete leaching of chloride in all the columns and complete leaching of nitrate in sand and combination of sand and peat column. There was significant reduction of phosphate in sand and sand and peat column when compared with the influent. With no sulfate in the influent, all the columns shows sulfate leaching from the media.

Parameters	Influent	EPA Water Quality Standards	Sand	Sand + Peat	Sand + Compost
Turbidity	50 NTU	50 NTU (ODEQ)	4.1 NTU	1.5 NTU	17.8 NTU
pH	7.04	6.5 - 8.0	7.6	7.2	7.3
Conductivity	264	150 - 500 µS/cm	258 µS/cm	414 µS/cm	567 µS/cm
COD	68 mg/l	nil	28 mg/l	36.5 mg/l	55.5 mg/l
Chloride	81.7 mg/l	250 mg/l	80 mg/l	78 mg/l	79 mg/l
Nitrate	12.166 mg/l	45 mg/l	12.6 mg/l	12.5 mg/l	3.99 mg/l
Phosphate	9 mg/l	0.3 mg/l	3.15 mg/l	1.85mg/l	22 mg/l
Sulfate	0 mg/l	250 mg/l	5.06 mg/l	4.65 mg/l	29.84 mg/l

Table 7. Media evaluation versus water quality standards

Table 8 shows the ranking of all the three media according to the removal efficiencies. As per the table, sand and peat column contains low nutrients for the growth of plants while the media containing sand and compost is richer in nutrient but have lower removal efficiency compared with sand and peat.

Media Ranking						
Media	Phosphate Removal	Nitrate Removal	Chloride Removal	Sulfate Removal	COD Removal	Plant Nutrients
Sand	2	3,2	3	2	1	2,3
Sand+Peat	1	2,3	1	1	2	2,3
Sand+Compost	3	1	2	3	3	1

Table 8. Overall media ranking

The overall results showed high removal efficiency for the column containing sand and peat as a media as it showed efficient removal of phosphate, moderate reduction of COD and low sulfate leaching. This is to be noted here, that there was negligible removal of chlorides from all the columns and the only soil media which removed nitrate was combination sand and compost. The overall reduction in pollutants however, was more efficient in sand and peat column.

CHAPTER V

CONCLUSIONS

Results obtained from the laboratory rain garden columns indicate that some soil mixtures are effective at retaining or removing contaminants that originate in urban stormwater. The three mixtures tested in this study showed:

- Sand column: This column showed reduction in concentrations of phosphate and low sulfate leaching from media, but the column did not substantially reduce concentrations of nitrate and chloride. The column showed significant reduction in turbidity and the highest reduction in COD. However, a soil of 100% sand could not support the growth of most plants.
- Sand and peat column: This column showed reduction in concentrations of phosphate and low sulfate leaching from media, but the column did not substantially reduce concentrations of nitrate and chloride. The column was highly efficient in turbidity reduction and showed significant reduction in the COD.
- Sand and compost column: This column showed reduction in concentrations of

nitrate and high sulfate leaching. The column did not substantially reduce concentrations of phosphate and chloride. The column was not efficient in turbidity and COD removal. However; the mixture of sand and compost contains essential nutrients to support plant growth.

In conclusion, a raingarden built from a sand-peat soil mixture should provide effective for contaminant removal.

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CHAPTER VI

RECOMMENDATIONS

Future research should include the investigation of a soil media containing 50% sand, 25% compost, and 25% peat for higher infiltration, efficient removal of pollutants and better plant growth. Moreover, research needs to be done on the particular plant species that require low nitrogen for growth, so that the usefulness of a raingarden containing sand or a combination of sand and peat can be improved. Research should also be done by varying the percentage of sand, sand and peat and sand and compost for effective removal of urban pollutants.

It should be noted here that this research was for limited duration of time and showed the removal of pollutants after passing 84 liters of runoff. Longer-term monitoring of the columns should provide more reliable results.

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APPPENDICES

APPENDIX A

CONSTRUCTION OF LABORATORY COLUMNS

The columns were constructed by cutting the PVC pipes to 3.0 feet of length and then drilling hole in the upper portion at both the sides of the PVC pipe in order to hang the pipes to the wooden rod with the help of nylon rope. Fourteen empty soft drink bottles were cut into two pieces and the top portion of each piece was properly fixed to the other end of the PVC pipe column using silicon sealant as shown in Figure 8. The lid of each bottle was removed and was fixed with A-865 Pipe Reducing Coupling of size 3/4” FIP x 1/2” FIP. This pipe reducing coupling was fixed with A-828 - 1/2” MIP x 3/8” FIP Pipe Hex Bushing which was then attached to A-778 - 3/8” MIP x 1/4” FIP Pipe Bushing . This Pipe bushing was then finally fixed with an A-85 Hose Barb Adapter of size 1/8” Barb x 1/4” MIP. After fixing the bottle end with all these fittings, the columns were hanged upside down with the help of rods

On 24th of May, 4 columns were built. One of the columns was filled with the mixture of sand and peat while another one was filled with the mixture of sand and compost. The third column was filled with just sand and one of the column was kept empty. Each column was filled with the amended soil to the height of 3feet. At the top of each column another top half portion of the bottle was placed so as to avoid spilling out of the runoff during pouring. Synthetic runoff was passed through all the 4 columns and the effluent sample was tested for several different parameters. Three columns were built in the similar manner on 6^{th} of June with same soil mix as like the previous 4 columns. These 3 columns were placed parallel to the existing ones. De-ionized water was passed through these three columns.

APPENDIX B

EFFLUENT DATA OBTAINED FROM BIORETENTION COLUMNS

Sample No.	Date	Time	Turbidity (NTU)	Avg NTU	E.C (µS/cm)	Avg E.C	pH	Avg pH	COD (mg/L	Avg COD
1A	5/24/2011	11:45am-12:45pm	52.9		969		8.81		86	
1B	5/24/2011	11:45am-12:45pm	50.6	51.75	906	937.5	8.79	8.8	84	85
1A	5/24/2011	3:30pm-5:30pm	220		381		8.6		29	
1B	5/24/2011	3:30pm-5:30pm	239	229.5	373	377	8.8	8.7	26	27.5
1A	5/25/2011	3pm - 5pm	213		335		8.67		141	
1B	5/25/2011	3pm - 5pm	235	224	326	330.5	8.67	8.67	36	88.5
1A	5/25/2011	8pm-10pm	308		285		8.74		12	
1B	5/25/2011	8pm-10pm	311	309.5	279	282	8.77	8.755	21	16.5
1A	5/26/2011	12pm to 2pm	222		302		8.6		109	
1B	5/26/2011	12pm - 2pm	220	221	286	294	8.66	8.63	145	127
1A	5/26/2011	9pm - 11pm	216		275		8.64		163	
1B	5/26/2011	9pm - 11pm	216	216	284	279.5	8.7	8.67	128	145.5
1A	5/27/2011	12pm - 2pm	161		279		8.63		O.R	
1B	5/27/2011	12pm-2pm	160	133.5	272	279.5	8.7	8.665	77	80.5
1A	5/27/2011	9pm - 11pm	107		287		8.63		84	
1B	5/27/2011	9pm - 11pm	107	107	272	279.5	8.72	8.675	85	84.5
1A	5/28/2011	12:20pm-2:20pm	108		285		8.6		121	
1B	5/28/2011	12:20pm-2:20pm	109	108.5	282	283.5	8.62	8.61	105	113
1A	5/28/2011	8:30pm - 10:30pm	96.6		289		8.57		97	
1B	5/28/2011	8:30pm - 10:30pm	97.3	96.95	280	284.5	8.65	8.61	94	95.5
1A	5/29/2011	12:30 pm-2:30 pm	78.9		291		8.55		110	
1B	5/29/2011	12:30 pm-2:30 pm	78.2	78.55	290	290.5	8.61	8.58	127	118.5
1A	5/29/2011	9pm - 11pm	69.8		287		8.53		103	
1B	5/29/2011	9pm - 11pm	72.9	71.35	267	277	8.55	8.54	109	106

1A	5/30/2011	2pm- 4 pm	53.4		292		8.5		146	
1B	5/30/2011	2 pm- 4 pm	52.3	52.85	279	285.5	8.53	8.515	124	135
1A	5/30/2011	9pm - 11pm	56.1		273		8.52		93	
1B	5/30/2011	9pm - 11pm	54.7	55.4	259	266	8.48	8.5	99	96
1A	6/13/2011	3pm-5pm	11.4		426		8.07		15	
1B	6/13/2011	3pm-5pm	11.3	11.35	425	425.5	8.08	8.075	11	13
1A	6/14/2011	7:30- 9:30 am	34		310		8.13		134	
1B	6/14/2011	7:30- 9:30 am	34.5	34.25	304	307	8.07	8.1	111	122.5
1A	6/14/2011	11am - 1Pm	26.5		277		8.22		140	
1B	6/14/2011	11am - 1Pm	27.1	26.8	267	272	8.5	8.36	123	131.5
1A	6/14/2011	6- 8Pm	21.7		269		7.97		84	
1B	6/14/2011	6- 8Pm	22.3	22	575	422	7.97	7.97	137	110.5
1A	6/15/2011	7:30- 9:30 am	30.7		228		8.24		17	
1B	6/15/2011	7:30- 9:30 am	30.8	30.75	230	229	8.25	8.245	69	43
1A	6/15/2011	11am - 1Pm	34.4		213		8.21		13	
1B	6/15/2011	11am - 1Pm	34	34.2	228	220.5	8.21	8.21	38	25.5
1A	6/15/2011	2:30- 4:30Pm	38.2		215		8.15		4	
1B	6/15/2011	2:30- 4:30Pm	38.9	38.55	230	222.5	8.24	8.195	15	9.5
1A	6/16/2011	9-11am	22.7		219		7.95		26	
1B	6/16/2011	9-11am	23.3	23	221	220	8.13	8.04	32	29
1A	6/16/2011	3-5pm	24.6		232		8.12		19	
1B	6/16/2011	3-5pm	25.1	24.85	223	227.5	8	8.06	18	18.5
1A	6/16/2011	8-10pm	22		238		7.93		0	
1B	6/16/2011	8-10pm	17.7	19.85	255	246.5	8.03	7.98	9	4.5
1A	6/17/2011	8-10am	19		237		8.02		11	
1B	6/17/2011	8-10am	13.4	16.2	257	247	8.04	8.03	4	7.5
1A	6/17/2011	1-3pm	26.8		244		7.54		8	
1B	6/17/2011	1-3pm	24.9	25.85	250	247	6.79	7.165	3	5.5
1A	6/17/2011	7-9pm	22.5		244		7.93		10	
1B	6/17/2011	7-9pm	23.1	22.8	246	245	8.06	7.995	8	9
1A	6/18/2011	8-10am	16		254		8.13		4	
1B	6/18/2011	8-10am	16	16	242	248	8.02	8.075	9	6.5
1A	6/18/2011	1-3pm	23		385		7.96		4	
1B	6/18/2011	1-3pm	22.4	22.7	252	318.5	7.83	7.895	2	3
1A	6/18/2011	7-9pm	19.5		281		7.9		-1	
1B	6/18/2011	7-9pm	19.6	19.55	318	299.5	7.68	7.792	4	1.5
1A	6/19/2011	8-10am	14.9		263		8.07		4	

1B	6/19/2011	8-10am	14.6	14.75	318	290.5	8.02	8.045	9	6.5
1A	6/19/2011	1-3pm	21.2		270		7.99		6	
1B	6/19/2011	1-3pm	21.8	21.5	253	261.5	7.96	7.975	2	4
1A	6/19/2011	7-9pm	16.2		307		7.97		46	
1B	6/19/2011	7-9pm	15.4	15.8	278	292.5	8	7.985	27	36.5
1A	6/20/2011	8-10am	12.2		324		7.92		75	
1B	6/20/2011	8-10am	12	12.1	340	332	7.92	7.92	46	60.5
1A	6/20/2011	1-3pm	18		301		7.81		21	
1B	6/20/2011	1-3pm	18.1	18.05	300	300.5	7.77	7.79	49	35
1A	6/20/2011	7-9pm	13.1		321		7.96		70	
1B	6/20/2011	7-9pm	13.2	13.15	252	286.5	7.92	7.94	73	71.5
1A	6/23/2011	8-10pm	6.41		375		8.01		34	
1B	6/23/2011	8-10pm	6.51	6.46	353	364	8.02	8.015	41	37.5
1A	6/24/2011	4:30-6:30 pm	10.3		330		7.99		10	
1B	6/24/2011	4:30-6:30pm	9.96	10.13	268	299	7.92	7.955	11	10.5
1A	6/25/2011	8-10pm	9.87		323		8		25	
1B	6/25/2011	8-10pm	10.1	9.985	255	289	7.98	7.99	12	18.5
1A	6/26/2011	8-10pm	14.4		321		7.88		21	
1B	6/26/2011	8-10pm	14.5	14.45	317	319	7.73	7.805	20	20.5
1A	6/27/2011	1-3pm	8.24		314		7.92		30	
1B	6/27/2011	1-3pm	7.87	8.055	325	319.5	7.83	7.875	111	70.5
1A	6/28/2011	10:30-12:30 pm	4.22		281		7.72		32	
1B	6/28/2011	10:30-12:30 pm	4.05	4.135	236	258.5	7.63	7.675	24	28
1A	6/29/2011	1-3pm	10.1		241		7.67		21	
1B	6/29/2011	1-3pm	10.4	10.25	282	261.5	7.62	7.645	23	22
1A	6/30/2011	3-5pm	9.46		299		7.62		21	
1B	6/30/2011	3-5pm	9.48	9.47	312	305.5	7.61	7.615	22	21.5

Table 9. Water quality parameters for sand with influent synthetic runoff

Sample No.	Date	Time	Turbidity (NTU)	Avg NTU	E.C. (µS/cm)	Avg EC	pH	Avg pH	COD (mg/L)	Avg COD
1A	6/9/2011	11-2pm	738		430		7.28		94	
1B	6/9/2011	11-2pm	732	735	630	530	7.47	7.375	65	79.5
1A	6/10/2011	11-2pm	419		265		8.07		6	
1B	6/10/2011	11-2pm	291	355	170	217.5	8.02	8.045	26	16
1A	6/11/2011	11-2pm	490		104		8.89		14	

1B	6/11/2011	11-2pm	383	437	95.3	99.65	8.99	8.94	12	13
1A	6/12/2011	3-5pm	288		88.7		8.76		78	
1B	6/12/011	3-5pm	296	292	92.2	90.45	8.67	8.715	13	45.5
1A	6/13/2011	3-5pm	246		68		8.84		144	
1B	6/13/2011	3-5pm	300	273	71.3	69.65	8.91	8.875	119	131.5
1A	6/14/2011	7:30-9:30 am	183		73.7		8.9		62	
1B	6/14/2011	7:30-9:30 am	202	193	70.3	72	8.93	8.915	48	55
1A	6/14/2011	11am - 1Pm	336		62.8		9		29	
1B	6/14/2011	11am - 1Pm	148	242	62	62.4	9.16	9.08	44	36.5
1A	6/14/2011	6- 8Pm	128		68.3		9.08		32	
1B	6/14/2011	6- 8Pm	129	129	62.4	65.35	9.08	9.08	16	24
1A	6/15/2011	7:30-9:30 am	81.9		48.2		8.95		104	
1B	6/15/2011	7:30-9:30 am	82.2	82.1	56	52.1	8.92	8.935	65	84.5
1A	6/15/2011	11am - 1Pm	109		47.8		8.9		12	
1B	6/15/2011	11am - 1Pm	111	110	43.8	45.8	8.93	8.915	5	8.5
1A	6/15/2011	2:30-4:30Pm	112		47.8		9.17		12	
1B	6/15/2011	2:30-4:30Pm	112	112	44.9	46.35	9.34	9.255	13	12.5
1A	6/16/2011	9-11am	84.9		49.1		9.03		4	
1B	6/16/2011	9-11am	85.3	85.1	53.6	51.35	8.93	8.98	12	8
1A	6/16/2011	3-5pm	83		44.3		9.02		6	
1B	6/16/2011	3-5pm	85.7	84.4	46.6	45.45	9.04	9.03	0	3
1A	6/16/2011	8-10pm	123		1400		9.02		24	
1B	6/16/2011	8-10pm	122	123	2050	1725	8.27	8.645	10	17
1A	6/17/2011	8-10am	71.9		49.1		9.16		5	
1B	6/17/2011	8-10am	56.1	64	46.4	47.75	9.2	9.18	10	7.5
1A	6/17/2011	1-3pm	85.9		41		9.19		5	
1B	6/17/2011	1-3pm	83.3	84.6	41	41	9.33	9.26	0	2.5
1A	6/17/2011	7-9pm	82.6		47.3		9.09		25	
1B	6/17/2011	7-9pm	74.2	78.4	42.5	44.9	9.1	9.095	32	28.5
1A	6/18/2011	8-10am	75.9		43.1		9.12		1	
1B	6/18/2011	8-10am	71.5	73.7	44	43.55	9	9.06	2	1.5
1A	6/18/2011	1-3pm	70.9		37.6		9.13		9	
1B	6/18/2011	1-3pm	73	72	40.9	39.25	9.14	9.135	8	8.5
1A	6/18/2011	7-9pm	48.5		53.1		9.31		0	
1B	6/18/2011	7-9pm	47.9	48.2	51.9	52.5	9.27	9.29	8	4

1A	6/19/2011	8-10am	76.4		52.3		9		0	
1B	6/19/2011	8-10am	72.9	74.7	56.3	54.3	9.1	9.05	0	0
1A	6/19/2011	1-3pm	70.3		50		9.22		36	
1B	6/19/2011	1-3pm	69.8	70.1	53.5	51.75	9.29	9.255	53	44.5
1A	6/19/2011	7-9pm	77.3		35		9.05		30	
1B	6/19/2011	7-9pm	77.4	77.4	46.5	40.75	9.08	9.065	41	35.5
1A	6/20/2011	8-10am	57.5		56.3		9.07		25	
1B	6/20/2011	8-10am	59.3	58.4	58	57.15	9.21	9.14	38	31.5
1A	6/20/2011	1-3pm	60.2		40.4		9.1		28	
1B	6/20/2011	1-3pm	64.6	62.4	45.4	42.9	9.13	9.115	6	17
1A	6/20/2011	7-9pm	59.1		41.4		9.13		71	
1B	6/20/2011	7-9pm	59.4	59.3	348	194.7	9.04	9.085	62	66.5
1A	6/23/2011	8-10pm	59.5		97		9.04		22	
1B	6/23/2011	8-10pm	60	59.8	81.6	89.3	9.03	9.035	10	16
1A	6/24/2011	4:30-6:30pm	53.7		57.2		8.85		15	
1B	6/24/2011	4:30-6:30pm	52.2	53	52.2	54.7	8.88	8.865	14	14.5
1A	6/25/2011	8-10pm	58.4		59.7		8.79		10	
1B	6/25/2011	8-10pm	57.8	58.1	66.3	63	8.79	8.79	9	9.5
1A	6/26/2011	8-10pm	57.1		54.7		8.94		0	
1B	6/26/2011	8-10pm	57.3	57.2	56.2	55.45	9.03	8.985	18	9
1A	6/27/2011	1-3pm	58.7		69.4		8.98		15	
1B	6/27/2011	1-3pm	46.6	52.7	62.4	65.9	9.06	9.02	13	14
1A	6/28/2011	10:30-12:30 pm	63.8		56		8.8		38	
1B	6/28/2011	10:30-12:30 pm	52.1	58	66.3	61.15	8.62	8.71	27	32.5
1A	6/29/2011	1-3pm	54.9		55.9		8.88		30	
1B	6/29/2011	1-3pm	55.1	55	50.6	53.25	8.88	8.88	27	28.5
1A	6/30/2011	3-5pm	54		55.6		8.85		28	
1B	6/30/2011	3-5pm	59.1	56.6	57.7	56.65	8.75	8.8	14	21

Table 10. Water quality parameters for sand with influent deionized water

Sample. No	Date	Time	Turbidity (NTU)	Avg NTU	E.C. (µS/cm)	Avg E.C	pH	Avg pH	COD (mg/L)	Avg COD
1A	5/24/2011	11:45am-1:45pm	9.35		1050		6.33		479	
1B	5/24/2011	11:45am-1:45pm	7.43	8.39	1030	1040	6.3	6.315	465	472

1A	5/24/2011	3:30pm-5:30pm	3.97		825		6.22		429	
1B	5/24/2011	3:30pm-5:30pm	3.2	3.585	852	838.5	6.29	6.255	428	428.5
1A	5/25/2011	3pm - 5pm	8.63		690		6.58		373	
1B	5/25/2011	3pm - 5pm	9.07	8.85	697	693.5	6.6	6.59	372	372.5
1A	5/25/2011	8pm-10pm	7.42		518		6.65		201	
1B	5/25/2011	8pm-10pm	7.4	7.41	498	508	6.67	6.66	245	223
1A	5/26/2011	12pm to 2pm	4.57		522		6.73		158	
1B	5/26/2011	12pm - 2pm	4.46	4.515	531	526.5	6.77	6.75	159	158.5
1A	5/26/2011	9pm - 11pm	2.18		437		6.88		122	
1B	5/26/2011	9pm - 11pm	2.12	2.15	437	437	6.84	6.86	145	133.5
1A	5/27/2011	12pm - 2pm	1.61		389		6.9		41	
1B	5/27/2011	12pm-2pm	1.73	1.65	474	439.5	6.95	6.935	114	123.5
1A	5/27/2011	9pm - 11pm	1.57		405		6.92		133	
1B	5/27/2011	9pm - 11pm	4.54	3.055	426	415.5	6.94	6.93	220	176.5
1A	5/28/2011	12:20pm-2:20pm	1.57		431		6.98		105	
1B	5/28/2011	12:20pm-2:20pm	1.58	1.575	446	438.5	6.99	6.985	124	114.5
1A	5/28/2011	8:30pm - 10:30pm	1.49		400		6.93		86	
1B	5/28/2011	8:30pm - 10:30pm	1.68	1.585	415	407.5	7.03	6.98	93	89.5
1A	5/29/2011	12:30 pm-2:30 pm	1.72		422		6.84		84	
1B	5/29/2011	12:30 pm-2:30 pm	1.62	1.67	412	417	7	6.92	106	95
1A	5/29/2011	9pm - 11pm	1.61		385		7.01		80	
1B	5/29/2011	9pm - 11pm	1.61	1.61	391	388	7.06	7.035	100	90
1A	5/30/2011	2pm- 4 pm	1.81		434		7.06		109	
1B	5/30/2011	2 pm- 4 pm	1.84	1.825	413	423.5	7.07	7.065	90	99.5
1A	5/30/2011	9pm - 11pm	1.79		367		6.98		80	
1B	5/30/2011	9pm - 11pm	1.74	1.765	350	358.5	7.12	7.05	72	76
1A	6/13/2011	3pm-5pm	5.48		586		7.03		167	
1B	6/13/2011	3pm-5pm	5.15	5.315	566	576	6.92	6.975	150	158.5
1A	6/14/2011	7:30- 9:30	437		437		7.14		148	

		am								
1B	6/14/2011	7:30- 9:30 am	427	432	427	432	7.14	7.14	115	131.5
1A	6/14/2011	11am - 1Pm	4.5		335		7.16		102	
1B	6/14/2011	11am - 1Pm	3.9	4.2	349	342	7.12	7.14	89	95.5
1A	6/14/2011	6- 8Pm	3.56		323		7.13		128	
1B	6/14/2011	6- 8Pm	4.06	3.81	344	333.5	7.33	7.23	149	138.5
1A	6/15/2011	7:30- 9:30 am	3.92		305		7.23		248	
1B	6/15/2011	7:30- 9:30 am	3.86	3.89	328	316.5	7.2	7.215	104	176
1A	6/15/2011	11am - 1Pm	4.06		246		7.18		8	
1B	6/15/2011	11am - 1Pm	4.3	4.18	262	254	7.13	7.155	17	12.5
1A	6/15/2011	2:30- 4:30Pm	4.1		246		7.16		24	
1B	6/15/2011	2:30- 4:30Pm	4.39	4.245	262	254	7.18	7.17	7	15.5
1A	6/16/2011	9-11am	4.03		304		7.2		16	
1B	6/16/2011	9-11am	3.85	3.94	305	304.5	7.16	7.18	12	14
1A	6/16/2011	3-5pm	4.42		269		7.2		12	
1B	6/16/2011	3-5pm	4.07	4.245	268	268.5	7.14	7.17	7	9.5
1A	6/16/2011	8-10pm	3.94		234		4.06		28	
1B	6/16/2011	8-10pm	4.11	4.025	342	288	7.03	5.545	13	20.5
1A	6/17/2011	8-10am	3.91		292		7.05		24	
1B	6/17/2011	8-10am	4.2	4.055	229	260.5	7.04	7.045	14	19
1A	6/17/2011	1-3pm	3.89		260		7.1		19	
1B	6/17/2011	1-3pm	4.1	3.995	280	270	7.1	7.1	17	18
1A	6/17/2011	7-9pm	3.82		285		7.18		27	
1B	6/17/2011	7-9pm	3.96	3.89	273	279	7.14	7.16	20	23.5
1A	6/18/2011	8-10am	3.37		368		7.16		31	
1B	6/18/2011	8-10am	3.98	3.675	299	333.5	7.15	7.155	10	20.5
1A	6/18/2011	1-3pm	3.61		273		7.07		26	
1B	6/18/2011	1-3pm	3.4	3.505	273	273	6.98	7.025	27	26.5
1A	6/18/2011	7-9pm	3.17		344		7.09		0	
1B	6/18/2011	7-9pm	3.43	3.3	347	345.5	7.07	7.08	8	4
1A	6/19/2011	8-10am	2.9		398		7.06		34	
1B	6/19/2011	8-10am	2.78	2.84	410	404	7.09	7.075	32	33
1A	6/19/2011	1-3pm	2.79		330		6.89		22	
1B	6/19/2011	1-3pm	2.85	2.82	323	326.5	6.84	6.865	0	11
1A	6/19/2011	7-9pm	2.86		337		6.97		48	

1B	6/19/2011	7-9pm	2.34	2.6	293	315	6.91	6.94	54	51
1A	6/20/2011	8-10am	2.27		326		6.96		66	
1B	6/20/2011	8-10am	2.33	2.3	363	344.5	6.91	6.935	57	61.5
1A	6/20/2011	1-3pm	2.32		342		6.94		44	
1B	6/20/2011	1-3pm	2.01	2.165	340	341	6.93	6.935	45	44.5
1A	6/20/2011	7-9pm	2.52		349		6.97		75	
1B	6/20/2011	7-9pm	2.48	2.5	325	337	6.94	6.955	73	74
1A	6/23/2011	8-10pm	3.04		419		6.99		47	
1B	6/23/2011	8-10pm	3.05	3.045	480	449.5	6.97	6.98	58	52.5
1A	6/24/2011	4:30-6:30 pm	2.24		453		6.98		0	
1B	6/24/2011	4:30-6:30 pm	2.61	2.425	458	455.5	6.94	6.96	43	21.5
1A	6/25/2011	8-10pm	2.13		406		6.97		47	
1B	6/25/2011	8-10pm	1.92	2.025	366	386	6.94	6.955	35	41
1A	6/26/2011	8-10pm	1.93		416		6.78		64	
1B	6/26/2011	8-10pm	1.64	1.785	410	413	6.78	6.78	46	55
1A	6/27/2011	1-3pm	1.6		434		6.93		76	
1B	6/27/2011	1-3pm	1.79	1.695	365	399.5	6.8	6.865	26	51
1A	6/28/2011	10:30-12:30 pm	1.65		435		6.73		38	
1B	6/28/2011	10:30-12:30 pm	1.43	1.54	394	414.5	7.2	6.965	35	36.5
1A	6/29/2011	1-3pm	1.43		356		6.73		25	
1B	6/29/2011	1-3pm	1.41	1.42	357	356.5	6.72	6.725	24	24.5
1A	6/30/2011	3-5pm	1.53		410		6.65		26	
1B	6/30/2011	3-5pm	1.34	1.435	365	387.5	6.74	6.695	25	25.5

Table 11. Water quality parameters for sand+peat with influent synthetic runoff

Sample No.	Date	Time	Turbidity (NTU)	Avg NTU	E.C. (µS/cm)	Avg EC	pH	Avg pH	COD (mg/L)	Avg COD
1A	6/9/2011	11-2pm	3.7		1470		6.17		474	
1B	6/9/2011	11-2pm	4.43	4.07	1530	1500	6.12	6.145	500	487
1A	6/10/2011	11-2pm	8.49		768		6.28		413	
1B	6/10/2011	11-2pm	6.13	7.31	709	738.5	6.39	6.335	398	405.5
1A	6/11/2011	11-2pm	10.5		526		6.64		257	
1B	6/11/2011	11-2pm	9.67	10.1	522	524	6.58	6.61	258	257.5
1A	6/12/2011	3-5pm	6.94		472		6.75		188	
1B	6/12/011	3-5pm	7.23	7.09	468	470	6.68	6.715	200	194

1A	6/13/2011	3-5pm	12.1		272		7		77	
1B	6/13/2011	3-5pm	11.7	11.9	271	271.5	6.92	6.96	65	71
1A	6/14/2011	7:30- 9:30 am	5.06		391		6.87		75	
1B	6/14/2011	7:30- 9:30 am	5.02	5.04	396	393.5	6.93	6.9	98	86.5
1A	6/14/2011	11am - 1Pm	14.3		253		7.01		69	
1B	6/14/2011	11am - 1Pm	14.3	14.3	273	263	7.1	7.055	75	72
1A	6/14/2011	6- 8Pm	13		242		7.21		94	
1B	6/14/2011	6- 8Pm	13.2	13.1	238	240	7.18	7.195	95	94.5
1A	6/15/2011	7:30- 9:30 am	11.2		289		7.05		75	
1B	6/15/2011	7:30- 9:30 am	11.3	11.3	292	290.5	7.04	7.045	83	79
1A	6/15/2011	11am - 1Pm	16.4		158		7.24		130	
1B	6/15/2011	11am - 1Pm	16.4	16.4	171	164.5	7.13	7.185	52	91
1A	6/15/2011	2:30- 4:30Pm	18.1		152		7.33		30	
1B	6/15/2011	2:30- 4:30Pm	18.4	18.3	157	154.5	7.34	7.335	19	24.5
1A	6/16/2011	9-11am	14		49.1		7.19		6	
1B	6/16/2011	9-11am	13.9	14	53.6	51.35	7.07	7.13	21	13.5
1A	6/16/2011	3-5pm	19.5		44.3		7.18		5	
1B	6/16/2011	3-5pm	19.6	19.6	46.6	45.45	7.2	7.19	14	9.5
1A	6/16/2011	8-10pm	21.1		1400		7.91		17	
1B	6/16/2011	8-10pm	22.1	21.6	2050	1725	6.98	7.445	1	9
1A	6/17/2011	8-10am	18		178		7.18		102	
1B	6/17/2011	8-10am	18.4	18.2	160	169	7.23	7.205	75	88.5
1A	6/17/2011	1-3pm	20.9		171		7.25		0	
1B	6/17/2011	1-3pm	20.9	20.9	151	161	7.4	7.325	41	20.5
1A	6/17/2011	7-9pm	22.3		162		7.28		38	
1B	6/17/2011	7-9pm	21.1	21.7	171	166.5	7.2	7.24	39	38.5
1A	6/18/2011	8-10am	16		213		7.18		43	
1B	6/18/2011	8-10am	15.9	16	227	220	7.16	7.17	41	42
1A	6/18/2011	1-3pm	27.4		167		7.14		49	
1B	6/18/2011	1-3pm	26.7	27.1	168	167.5	7.12	7.13	38	43.5
1A	6/18/2011	7-9pm	29.7		198		7.41		38	
1B	6/18/2011	7-9pm	29.5	29.6	205	201.5	7.38	7.395	39	38.5
1A	6/19/2011	8-10am	28.3		236		7.2		42	
1B	6/19/2011	8-10am	25.1	26.7	218	227	7.1	7.15	42	42
1A	6/19/2011	1-3pm	37		159		7.28		63	

1B	6/19/2011	1-3pm	34.7	35.9	217	188	7.32	7.3	69	66
1A	6/19/2011	7-9pm	36		165		7.16		62	
1B	6/19/2011	7-9pm	36.5	36.3	170	167.5	7.14	7.15	48	55
1A	6/20/2011	8-10am	26.2		237		7.1		113	
1B	6/20/2011	8-10am	26.6	26.4	249	243	7.07	7.085	82	97.5
1A	6/20/2011	1-3pm	32.5		150		7.13		45	
1B	6/20/2011	1-3pm	30.3	31.4	187	168.5	7.15	7.14	57	51
1A	6/20/2011	7-9pm	30		145		7.36		87	
1B	6/20/2011	7-9pm	27.9	29	185	165	7.08	7.22	98	92.5
1A	6/23/2011	8-10pm	4.25		296		7.11		68	
1B	6/23/2011	8-10pm	4.77	4.51	271	283.5	7.13	7.12	83	75.5
1A	6/24/2011	4:30-6:30pm	4.74		240		6.89		59	
1B	6/24/2011	4:30-6:30pm	4.76	4.75	203	221.5	6.92	6.905	72	65.5
1A	6/25/2011	8-10pm	5.04		214		6.99		51	
1B	6/25/2011	8-10pm	5.02	5.03	215	214.5	6.92	6.955	61	56
1A	6/26/2011	8-10pm	4.6		208		7.09		53	
1B	6/26/2011	8-10pm	4.59	4.6	220	214	7.08	7.085	53	53
1A	6/27/2011	1-3pm	3.61		224		7.13		46	
1B	6/27/2011	1-3pm	3.85	3.73	203	213.5	7.06	7.095	51	48.5
1A	6/28/2011	10:30-12:30 pm	2.95		244		6.83		48	
1B	6/28/2011	10:30-12:30 pm	2.94	2.95	203	223.5	6.8	6.815	27	37.5
1A	6/29/2011	1-3pm	3.65		194		7.02		50	
1B	6/29/2011	1-3pm	3.75	3.7	209	201.5	7.04	7.03	48	49
1A	6/30/2011	3-5pm	3.17		262		6.94		49	
1B	6/30/2011	3-5pm	2.77	2.97	265	263.5	6.93	6.935	41	50

Table 12. Water quality parameters for sand+peat with influent deionized water

Sample No.	Date	Time	Turbidity (NTU)	Avg NTU	E.C. (µS/cm)	Avg E.C	pH	Avg pH	COD (mg/L)	Avg COD
1A	5/24/2011	11:45am-1:45pm	1130		9290		8.25		50	
1B	5/24/2011	11:45am-1:45pm	1000	1065	9291	9291	8.18	8.215	38	44
1A	5/24/2011	3:30pm-5:30pm	702		1790		8.85		34	
1B	5/24/2011	3:30pm-5:30pm	727	714.5	1660	1725	8.86	8.855	42	38
1A	5/25/2011	3pm - 5pm	1232		1410		8.8		82	

1B	5/25/2011	3pm - 5pm	1210	1221	1350	1380	8.77	8.785	56	69
1A	5/25/2011	8pm-10pm	913		997		8.92		388	
1B	5/25/2011	8pm-10pm	959	936	982	989.5	8.93	8.925	433	410.5
1A	5/26/2011	12pm to 2pm	1062		1050		8.84		118	
1B	5/26/2011	12pm - 2pm	1073	1068	1040	1045	8.83	8.835	51	84.5
1A	5/26/2011	9pm - 11pm	937		898		8.86		325	
1B	5/26/2011	9pm - 11pm	931	934	877	887.5	8.84	8.85	309	317
1A	5/27/2011	12pm - 2pm	560		881		8.81		571	
1B	5/27/2011	12pm-2pm	563	477	925	846.5	8.79	8.785	338	273.5
1A	5/27/2011	9pm - 11pm	391		768		8.78		209	
1B	5/27/2011	9pm - 11pm	390	390.5	680	724	8.77	8.775	201	205
1A	5/28/2011	12:20pm-2:20pm	229		848		8.68		206	
1B	5/28/2011	12:20pm-2:20pm	227	228	812	830	8.66	8.67	208	207
1A	5/28/2011	8:30pm - 10:30pm	191		689		8.61		143	
1B	5/28/2011	8:30pm - 10:30pm	195	193	707	698	8.61	8.61	144	143.5
1A	5/29/2011	12:30 pm-2:30 pm	124		789		8.59		152	
1B	5/29/2011	12:30 pm-2:30 pm	124	124	777	783	8.56	8.575	144	148
1A	5/29/2011	9pm - 11pm	124		667		8.5		95	
1B	5/29/2011	9pm - 11pm	120	122	668	667.5	8.5	8.5	89	92
1A	5/30/2011	2pm- 4 pm	90		764		8.42		118	
1B	5/30/2011	2 pm- 4 pm	89.8	89.9	753	758.5	8.42	8.42	108	113
1A	5/30/2011	9pm - 11pm	72.4		600		8.35		88	
1B	5/30/2011	9pm - 11pm	71.2	71.8	613	606.5	8.3	8.325	77	82.5
1A	6/13/2011	3pm-5pm	20.1		2650		7.43		99	
1B	6/13/2011	3pm-5pm	20.6	20.35	2640	2645	7.4	7.415	108	103.5
1A	6/14/2011	7:30- 9:30 am	53.6		1140		7.43		98	
1B	6/14/2011	7:30- 9:30 am	53.2	53.4	1110	1125	7.46	7.445	100	99
1A	6/14/2011	11am - 1Pm	136		793		7.56		73	
1B	6/14/2011	11am - 1Pm	137	136.5	770	781.5	7.56	7.56	75	74
1A	6/14/2011	6- 8Pm	60.7		525		7.56		65	
1B	6/14/2011	6- 8Pm	60.6	60.65	525	525	7.59	7.575	58	61.5
1A	6/15/2011	7:30- 9:30 am	101		431		7.93			
1B	6/15/2011	7:30- 9:30 am	99.7	100.4	439	435	7.88	7.905		0
1A	6/15/2011	11am - 1Pm	46.5		462		7.78		8	

1B	6/15/2011	11am - 1Pm	46.3	46.4	491	476.5	7.73	7.755	17	12.5
1A	6/15/2011	2:30-4:30Pm	46.9		263		7.82		24	
1B	6/15/2011	2:30-4:30Pm	47.6	47.25	269	266	7.76	7.79	7	15.5
1A	6/16/2011	9-11am	48.6		360		7.95		16	
1B	6/16/2011	9-11am	50.2	49.4	363	361.5	7.97	7.96	22	19
1A	6/16/2011	3-5pm	28.4		470		7.81		11	
1B	6/16/2011	3-5pm	27.9	28.15	518	494	7.7	7.755	23	17
1A	6/16/2011	8-10pm	22.1		352		7.69		44	
1B	6/16/2011	8-10pm	22.3	22.2	380	366	7.69	7.69	44	44
1A	6/17/2011	8-10am	22.3		355		7.83		2	
1B	6/17/2011	8-10am	21.8	22.05	356	355.5	7.83	7.83	45	23.5
1A	6/17/2011	1-3pm	32.4		371		7.78		17	
1B	6/17/2011	1-3pm	32	32.2	360	365.5	7.75	7.765	32	24.5
1A	6/17/2011	7-9pm	17.4		325		7.78		22	
1B	6/17/2011	7-9pm	17.6	17.5	321	323	7.73	7.755	26	24
1A	6/18/2011	8-10am	17.5		340		7.86		42	
1B	6/18/2011	8-10am	17.1	17.3	346	343	7.88	7.87	37	39.5
1A	6/18/2011	1-3pm	19.8		369		7.93		36	
1B	6/18/2011	1-3pm	19.1	19.45	130	249.5	7.88	7.905	39	37.5
1A	6/18/2011	7-9pm	11.7		396		7.81		20	
1B	6/18/2011	7-9pm	11.9	11.8	347	371.5	7.76	7.785	35	27.5
1A	6/19/2011	8-10am	14.4		403		7.8		74	
1B	6/19/2011	8-10am	14.3	14.35	333	368	7.76	7.78	74	74
1A	6/19/2011	1-3pm	16.7		371		7.74		30	
1B	6/19/2011	1-3pm	16.3	16.5	379	375	7.69	7.715	24	27
1A	6/19/2011	7-9pm	11		384		7.76		63	
1B	6/19/2011	7-9pm	11.1	11.05	368	376	7.71	7.735	61	62
1A	6/20/2011	8-10am	21.7		385		7.65		98	
1B	6/20/2011	8-10am	21.5	21.6	406	395.5	7.65	7.65	60	79
1A	6/20/2011	1-3pm	13.1		478		7.87		71	
1B	6/20/2011	1-3pm	12.8	12.95	500	489	7.82	7.845	22	46.5
1A	6/20/2011	7-9pm	10.1		327		7.02		85	
1B	6/20/2011	7-9pm	9.61	9.855	359	343	7.05	7.035	85	85
1A	6/23/2011	8-10pm	5.49		904		7.55		71	
1B	6/23/2011	8-10pm	5.24	5.365	869	886.5	7.52	7.535	74	72.5
1A	6/24/2011	4:30-6:30pm	13.5		547		7.51		55	
1B	6/24/2011	4:30-6:30pm	12.9	13.2	769	658	7.49	7.5	0	27.5
1A	6/25/2011	8-10pm	13.4		745		7.43		13.4	
1B	6/25/2011	8-10pm	13	13.2	750	747.5	7.4	7.415	13	13.2

1A	6/26/2011	8-10pm	12.3		612		7.43		51	
1B	6/26/2011	8-10pm	12.1	12.2	637	624.5	7.43	7.43	46	48.5
1A	6/27/2011	1-3pm	14.7		594		7.61		56	
1B	6/27/2011	1-3pm	15.3	15	551	572.5	7.51	7.56	50	53
1A	6/28/2011	10:30-12:30 pm	17.8		590		7.38		47	
1B	6/28/2011	10:30-12:30 pm	17.8	17.8	545	567.5	7.36	7.37	64	55.5
1A	6/29/2011	1-3pm	19.1		577		7.2		50	
1B	6/29/2011	1-3pm	19.2	19.15	506	541.5	7.14	7.17	56	53
1A	6/30/2011	3-5pm	21.1		543		7.51		52	
1B	6/30/2011	3-5pm	22	21.55	532	537.5	7.51	7.51	52	52

Table 13. Water quality parameters for sand+compost with influent synthetic runoff

Sample No.	Date	Time	Turbidity (NTU)	Avg NTU	E.C. (μS/cm)	Avg EC	pH	Avg pH	COD (mg/L)	Avg COD
1A	6/9/2011	11-2pm	725		1420		7.82			
1B	6/9/2011	11-2pm	670	698	1550	1485	7.6	7.71		0
1A	6/10/2011	11-2pm	1062		4850		8.42			
1B	6/10/2011	11-2pm	1039	1051	4390	4620	8.47	8.445		0
1A	6/11/2011	11-2pm	592		1980		8.75		806	
1B	6/11/2011	11-2pm	630	611	2020	2000	7.69	8.22	789	797.5
1A	6/12/2011	3-5pm	4230		1690		8.64		533	
1B	6/12/011	3-5pm	670	2450	1540	1615	8.72	8.68	511	522
1A	6/13/2011	3-5pm	200		896		8.8		175	
1B	6/13/2011	3-5pm	541	371	990	943	8.74	8.77	243	209
1A	6/14/2011	7:30- 9:30 am	136		1080		8.68		201	
1B	6/14/2011	7:30- 9:30 am	196	166	1060	1070	8.64	8.66	265	233
1A	6/14/2011	11am - 1Pm	127		842		8.75		137	
1B	6/14/2011	11am - 1Pm	122	125	865	853.5	8.76	8.755	137	137
1A	6/14/2011	6- 8Pm	157		678		8.81		164	
1B	6/14/2011	6- 8Pm	163	160	674	676	8.84	8.825	180	172
1A	6/15/2011	7:30- 9:30 am	156		289		8.69		236	
1B	6/15/2011	7:30- 9:30 am	161	159	292	290.5	8.75	8.72	230	233

1A	6/15/2011	11am - 1Pm	89.2		158		8.74		38	
1B	6/15/2011	11am - 1Pm	89.4	89.3	171	164.5	8.75	8.745	4	21
1A	6/15/2011	2:30- 4:30Pm	66.5		152		8.86		21	
1B	6/15/2011	2:30- 4:30Pm	65.4	66	157	154.5	8.86	8.86	22	21.5
1A	6/16/2011	9-11am	81.7		432		8.67		23	
1B	6/16/2011	9-11am	85.2	83.5	478	455	6.7	7.685	41	32
1A	6/16/2011	3-5pm	59.9		375		8.7		16	
1B	6/16/2011	3-5pm	60	60	396	385.5	8.71	8.705	27	21.5
1A	6/16/2011	8-10pm	48.6		362		8.78		95	
1B	6/16/2011	8-10pm	50	49.3	365	363.5	8.79	8.785	418	256.5
1A	6/17/2011	8-10am	45.6		262		8.63		124	
1B	6/17/2011	8-10am	45.2	45.4	264	263	8.65	8.64	126	125
1A	6/17/2011	1-3pm	47.6		267		8.68		0	
1B	6/17/2011	1-3pm	48	47.8	289	278	8.72	8.7	0	0
1A	6/17/2011	7-9pm	39.8		283		8.66		86	
1B	6/17/2011	7-9pm	39	39.4	287	285	8.69	8.675	87	86.5
1A	6/18/2011	8-10am	41.6		305		8.58		126	
1B	6/18/2011	8-10am	42.9	42.3	298	301.5	8.59	8.585	133	129.5
1A	6/18/2011	1-3pm	40.2		276		8.62		97	
1B	6/18/2011	1-3pm	39.7	40	284	280	8.57	8.595	91	94
1A	6/18/2011	7-9pm	37.3		294		8.62		101	
1B	6/18/2011	7-9pm	36.8	37.1	293	293.5	8.54	8.58	73	87
1A	6/19/2011	8-10am	37.8		316		8.39		123	
1B	6/19/2011	8-10am	36.2	37	334	325	8.36	8.375	128	125.5
1A	6/19/2011	1-3pm	34.2		257		8.44		94	
1B	6/19/2011	1-3pm	34.2	34.2	273	265	8.42	8.43	89	91.5
1A	6/19/2011	7-9pm	32		262		8.15		123	
1B	6/19/2011	7-9pm	30.9	31.5	303	282.5	8.16	8.155	132	127.5
1A	6/20/2011	8-10am	26.1		249		8.19		137	
1B	6/20/2011	8-10am	26.1	26.1	306	277.5	8.11	8.15	124	130.5
1A	6/20/2011	1-3pm	29.4		298		7.99		100	
1B	6/20/2011	1-3pm	29.3	29.4	306	302	7.96	7.975	103	101.5
1A	6/20/2011	7-9pm	29		306		7.96		139	
1B	6/20/2011	7-9pm	28.9	29	312	309	7.97	7.965	119	129
1A	6/23/2011	8-10pm	14.7		373		8		O.R	
1B	6/23/2011	8-10pm	20.3	17.5	355	364	8	8	O.R	No
1A	6/24/2011	4:30- 6:30pm								
1B	6/24/2011	4:30-		0		0		0		0

		6:30pm								
1A	6/25/2011	8-10pm	17.3		336		8.24		82	
1B	6/25/2011	8-10pm	17.4	17.4	327	331.5	8.25	8.245	77	79.5
1A	6/26/2011	8-10pm	15.6		320		8.35		83	
1B	6/26/2011	8-10pm	15.7	15.7	397	358.5	8.32	8.335	85	84
1A	6/27/2011	1-3pm	16		348		8.33		71	
1B	6/27/2011	1-3pm	15.8	15.9	349	348.5	8.31	8.32	77	74
1A	6/28/2011	10:30-12:30 pm	14.7		264		8.07		150	
1B	6/28/2011	10:30-12:30 pm	14.9	14.8	308	286	8.09	8.08	69	109.5
1A	6/29/2011	1-3pm	12.1		343		8.16		65	
1B	6/29/2011	1-3pm	12.3	12.2	316	329.5	8.14	8.15	67	66
1A	6/30/2011	3-5pm	7.57		307		8.07		50	
1B	6/30/2011	3-5pm	7.73	7.65	298	302.5	8.08	8.075	55	52.5

Table 14. Water quality parameters for sand+compost with influent deionized water

Sample No.	Date	Time	Turbidity (NTU)	Avg NTU	E.C. (μS/cm)	Avg E.C	pH	Avg pH
1A	5/24/2011	11:45am-1:45pm	2.65		298		6.91	
1B	5/24/2011	11:45am-1:45pm	3.13	2.89	230	264	6.95	6.93
1A	5/24/2011	3:30pm-5:30pm	11.2		267		6.98	
1B	5/24/2011	3:30pm-5:30pm	12.6	11.9	259	263	7.05	7.015
1A	5/25/2011	3pm - 5pm	12.6		267		6.92	
1B	5/25/2011	3pm - 5pm	11.2	11.9	262	264.5	6.91	6.915
1A	5/25/2011	8pm-10pm	11.2		259		7.21	
1B	5/25/2011	8pm-10pm	11.8	11.5	255	257	7.28	7.245
1A	5/26/2011	12pm to 2pm	2.66		261		6.67	
1B	5/26/2011	12pm - 2pm	2.67	2.665	250	255.5	6.65	6.66
1A	5/26/2011	9pm - 11pm	8.74		252		6.88	
1B	5/26/2011	9pm - 11pm	8.4	8.57	246	249	6.93	6.905
1A	5/27/2011	12pm - 2pm	4.69		258		7.21	
1B	5/27/2011	12pm-2pm	4.74	5.955	263	262.5	7.17	7.105
1A	5/27/2011	9pm - 11pm	7.17		262		7.04	
1B	5/27/2011	9pm - 11pm	7.11	7.14	273	267.5	7.04	7.04
1A	5/28/2011	12:20pm-2:20pm	13.5		252		6.64	
1B	5/28/2011	12:20pm-2:20pm	13.5	13.5	265	258.5	6.63	6.635
1A	5/28/2011	8:30pm - 10:30pm	5.04		257		7.06	
1B	5/28/2011	8:30pm -	4.78	4.91	254	255.5	7.03	7.045

		10:30pm						
1A	5/29/2011	12:30 pm- 2:30 pm	4.12		265		6.76	
1B	5/29/2011	12:30 pm- 2:30 pm	4.06	4.09	262	263.5	6.78	6.77
1A	5/29/2011	9pm - 11pm	6.66		266		6.64	
1B	5/29/2011	9pm - 11pm	5.98	6.32	265	265.5	6.61	6.625
1A	5/29/2011	2pm- 4 pm	4.5		271		6.92	
1B	5/29/2011	2 pm- 4 pm	4.6	4.55	264	267.5	7	6.96
1A	5/29/2011	9pm - 11pm	6.66		266		6.64	
1B	5/29/2011	9pm - 11pm	5.98	6.32	265	265.5	6.61	6.625
1A	5/30/2011	2pm- 4 pm	4.5		271		7	
1B	5/30/2011	2 pm- 4 pm	4.6	4.55	264	267.5	8.42	7.71
1A	5/30/2011	9pm - 11pm	3.4		255		6.87	
1B	5/30/2011	9pm - 11pm	3.39	3.395	249	252	6.83	6.85
1A	6/13/2011	3pm-5pm	23.4		259		7.19	
1B	6/13/2011	3pm-5pm	23.6	23.5	277	268	7.17	7.18

Table 15. Water quality parameters for column without soil with influent synthetic runoff

Sr. No	**Parameter**	**mg/l**	**Constituents**	**Liters**	**mg**	**g**	**Liters**	**g**
1	TDS	120	Cacl2	11.36	1363.2	1.3632	22.72	2.7204
2	Phosphorous	3 as P = 13.7	Na2HPO4	11.36	155.5	0.1555	22.72	0.3114
3	Nitrate	2 as N= 11.80	CaNO3	11.36	134.133	0.134133	22.72	0.2686
4	S.S	150	Local soil seived from 0.3mm	11.36	1704	1.704	22.72	3.408
5	Ammonium	2 as N = 7.6	NH4CL	11.36	86.8	0.0868	22.72	0.174
6	Motor Oil	20	Local oil from garage	11.36	227.2	0.2272	22.72	0.4544

Table 16. Chemical quantity in synthetic runoff

APPENDIX C

RAW DATA FOR ION- CHROMATOGRAPH EXPERIMENT

Runoff (Liters)	Sample	Cl area	mg/L Cl	NO3 Area	mg/L NO3	PO4 area	mg/L PO4
	Influent	8424094	80.25286	289261	6.4644469	1534532	55.36726
6	Col1,5/24	8635696	82.24983	517878	10.745744	4491622	159.2341
12	col1,5/27	7762553	74.00967	242492	5.5886065	88460	4.574429
24	Col1,5/30	7116717	67.9147	241081	5.5621828	11099	1.857148
6	Col2,5/24	8114991	77.33575	312992	6.908856	166765	7.324868
12	Col2,5/27	7862977	74.95741	253321	5.7914006	123062	5.789814
24	Col2,5/30	8008466	76.33044	264843	6.0071724	109120	5.300105
12	Col3,5/27	8158978	77.75087	512809	10.650817	1372409	49.67274
24	Col3,5/30	7524372	71.76188	547731	11.3048	585954	22.04875
6	col4,5/24	8675134	82.62202	327283	7.1764827	11478	1.87046
12	Col4,5/27	7871267	75.03564	265843	6.0258994	31456	2.572181
24	Col4,5/30	7348580	70.10287	249417	5.7182906	48106	3.157007
Runoff (Liters)	**Sample**	**Cl area**	**mg/LCl**	**NO3 Area**	**mg/L NO3**	**SO4 area**	**mg/L SO4**
30	Col1,6/13	8007888	76.32498	1200505	23.529261	9973	1.817597
48	col1,6/16	8216144	78.29037	329246	7.2132437	80151	4.282578
66	col1,6/19	8363578	79.68175	413291	8.7871496	113779	5.463751
84	col1,6/28	8190693	78.05018	611671	12.5022	90796	4.656481
30	Col3,6/13	7631567	72.77351	27416194	514.46896	570423	21.50323
48	col3,6/16	8160853	77.76857	6044	1.1606584	539242	20.40801
66	col3,6/19	8403318	80.05679	12337	1.2785071	482963	18.43123
84	col3,6/28	8408594	80.10659	157303	3.993277	807959	29.84661
30	Col4,6/13	8016837	76.40944	335395	7.3283957	19781	2.1621
48	col4,6/16	7785524	74.22646	248230	5.6960617	15201	2.001229
66	col4,6/19	8042472	76.65137	269677	6.0976985	96470	4.855778
84	col4,6/28	8319741	79.26805	619600	12.650686	102350	5.062311
6	DW - S, 6/11	87120	1.57396	1686	1.0790464	10526	1.837021
18	DW- S, 6/15	55682	1.277269	0	1.0474728	5773	1.670074
30	DW-S, 6/17	72584	1.436779	0	1.0474728	47673	3.141798
42	DW - S , 6/19	22891	0.967809	0	1.0474728	25965	2.379312
54	DW- S, 6/23	108546	1.776165	0	1.0474728	11778	1.880998
6	DW-S+P,6/11	114622	1.833506	12018	1.2725332	4956	1.641377
18	DW-S+P,6/15	58349	1.302439	0	1.0474728	0	1.467299
30	DW -	90027	1.601395	3927	1.1210135	426246	16.43906

	S+P,6/17						
42	DW-S+P,6/19	38018	1.110568	0	1.0474728	2139	1.542431
54	DW-S+P,6/23	86723	1.570214	0	1.0474728	46422	3.097857
6	DW-S+C,6/11	667938	7.055341	346649	7.5391487	4173797	148.0706
18	DW-S+C,6/15	172551	2.380202	60800	2.1860709	1955517	70.15423
30	DW - S+C,6/17	93275	1.632047	2514	1.0945523	1182669	43.00818
42	DW-S+C,6/19	138427	2.058162	11600	1.2647053	841828	31.03625
54	DW-S+C,6/23	125790	1.938903	136375	3.6013596	590075	22.1935

Table 17. Peak areas and concentration.

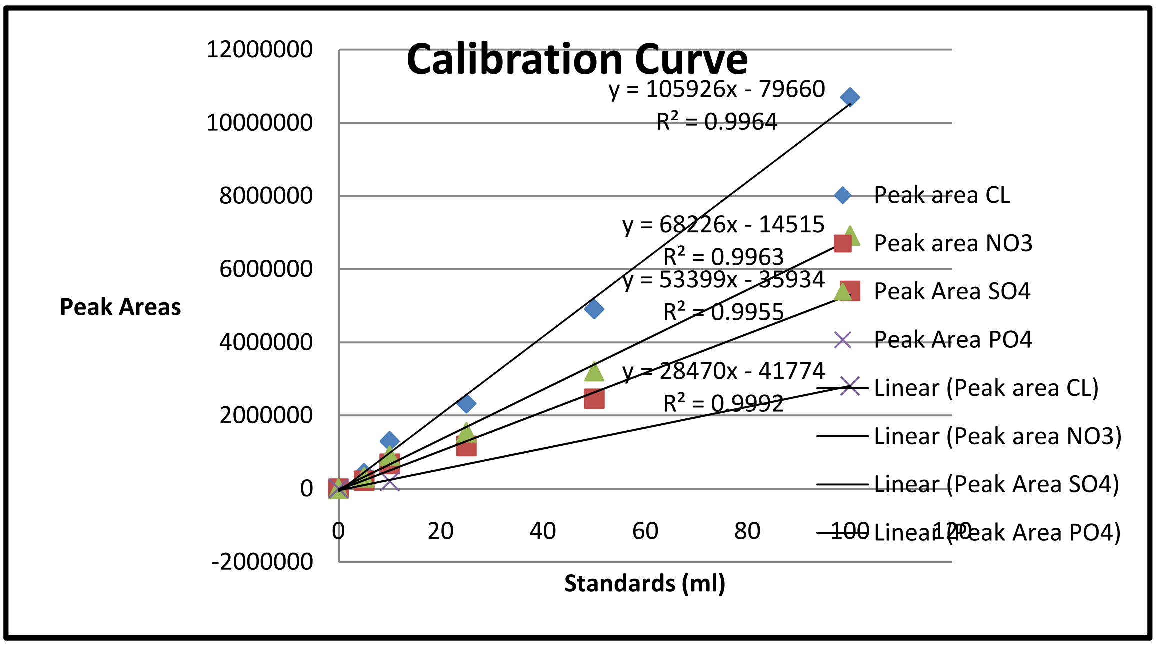

Figure 23. Calibration curve for Ion-Chromatograph

APPENDIX D

List of plant species that can be useful for raingarden.

Common name	Scientific name
Fern	
1. Cinnamon Fern	Osmunda
cinnamome	
2. Maidenhair Fern	Adiantum pedatum
3. Switch Grass	Panicum Virgatum
4. Northern Lady Fern	Athyrium filix-
femina	
5. Royal Fern	Osmunda regalis
6. Sensitive Fern	Onoclea sensibilis
Grasses & Sedges	
1. Broomsedge	Andropogon
virginicus	
2. Switch Grass	Panicum Virgatum
3. Tussock Sedge	Carex stricta
Herbaceous	
1. Beebalm	Monarda didyma
2. Blueflag Iris	Iris versicolor
3. Ginger, Wild	Asarum canadense
4. Cardinal Flower	Lobelia cardinalis
5. Common boneset	Eupatorium
perfoliatum	
6. Foamflower	Tiarella cordifolia
7. Goldenrod,	Wrinkled-leaf Solidago
rugosa	
8. Great Blue Lobelia	Lobelia siphilitica
9. Jacob's Ladder	Polemonium reptans
Shrubs	
1. Swamp Azalea	Rhododendron
viscosum	
2. Sweet Pepper Bush	Clethra alnifolia
3. Virginia Sweetspire	Itea virginica

4. Wax Myrtle — Myrica cerifera
5. Winterberry — Ilex verticillata
6. Witherod — Viburnum nudum

VITA

Pradnya. Bhimrao. More

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Three different types of soil media suitable for rain gardens were analyzed in the laboratory in order to evaluate the impact of soil type on stormwater quality. Synthetic parking lot runoff was used to dose laboratory-scale columns containing different media: 100% sand; 50% sand + 50% compost; and 50% sand + 50% peat. The effluent samples from all the columns were analyzed for turbidity, conductivity, pH, COD, chloride, nitrate, phosphate, and sulfate ions. The soil samples were analyzed for plant nutrients, cation exchange capacity, and select cations. The column study showed that the sand + compost media had the best combination of ability to remove contaminants and support the growth of rain garden plants.

ADVISER'S APPROVAL: Dr. Dee Ann Sanders