USE OF COMPOST FILTER BERMS FOR SEDIMENT TRAPPING: PRIMARY FOCUS ON WATER QUALITY AND STRUCTURAL STABILITY

A Thesis

by

ADITYA B. RAUT DESAI

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2004

Major Subject: Civil Engineering

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Approved as to style and content by:

Timothy A. Kramer (Chair of Committee)	Roy W. Hann, Jr. (Member)
Harlow C. Landphair (Member)	Paul Roschke (Head of Department)

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ABSTRACT

Use of Compost Filter Berms for Sediment Trapping: Primary Focus on Water Quality
and Structural Stability. (August 2004)
Aditya B. Raut Desai, B.S., Goa University
Chair of Advisory Committee: Dr. Timothy A. Kramer

Runoff from road construction and maintenance sites is responsible for erosion and deposition of sediments in the receiving water bodies. In addition to soil particles from erosion, runoff also transports other pollutants such as rubber, toxic metals, automobile fluids, car exhausts (which settle with the rain), pesticides, fertilizers, and other debris. Compost has been used effectively as a valuable soil amendment to aid plant growth. Berms (mounds) of compost placed at the top or bottom of steep slopes can be used to slow the velocity of water and provide additional protection for receiving waters. However, a downside of the application of composted organic material is the potential degradation of runoff water quality. Overloading with nitrogen and phosphorus causes eutrophication, which reduces the suitability of waterways for beneficial uses. A field testing of the berms coupled with a laboratory analysis of the testing water will provide a basis for the impact of the compost berms on the runoff water quality. The study of the impact of compost on the runoff water quality was investigated. The objective of this study was to evaluate the performance of berms made from various materials such as dairy manure compost, yard waste compost and composted bio-solids mixed with wood chips in a ratio of 50:50 on the runoff water quality, as well as, the sediment removal efficiencies. Field tests were performed on the berms to simulate conventional rainfall runoff and the tested water was collected as time-weighted samples and analyzed in the laboratory. Several variables were investigated during this study. Results of this investigation demonstrated that the effectiveness of this application was hampered by the structural instability of the berm. A 100% failure rate was observed in the berms tested. Optimum performance was observed in yard waste compost berms, which introduced the least amount of contaminants into the water. However, some masking effect could be present due to berm failures. In fact, the actual sediment removal by the berms could not be determined. The study of compost filter berms showed some evidence of the existence of first flush effect.

DEDICATION

This thesis is dedicated to my parents

ACKNOWLEDGEMENTS

There are so many people to thank for their help. This is by no means a complete list, only a few thank yous to many with whom I have been blessed to be associated.

To Dr. Timothy A. Kramer, you have my eternal gratitude for your never-ending support and willingness to see me through this endeavor. Indeed, you are my mentor and friend. Your professional guidance will complement me for the remainder of my life.

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To my father, Babu Pundalik Raut Desai, no one gave me more inspiration to follow my dreams than you and no book could ever replace to knowledge I gained from the times we spent together. Many people have said I remind them of you; there is not a better compliment I could ever get. To my mother, Ashika Babu Raut Desai, you were always the rock I could lean on. You are a loving and caring mother. To my brother,

Ashutosh Babu Raut Desai, who encouraged me in my academic endeavors, thank you seems such an understatement.

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CHAPTER I

INTRODUCTION

Dislocation by rain and erosion from land are some of the mechanisms by which sediments are introduced into runoff and transported to surface waters. Vegetation provides a protective cover to the ground and retards the natural erosion process. However, when this land cover is cleared or disturbed for construction or maintenance work, the rate of erosion increases. Whenever the vegetation is disturbed and the soil is left exposed, proper care and prompt action should be taken to control erosion before the sediments are washed away.

According to the U.S. Department of Agriculture, more than 2 billion tons of topsoil is lost annually through erosion in the United States. Erosion occurs when topsoil from construction sites is dislodged by rain and subsequent runoff. The soil left behind is stripped of its valuable top layer, which contains many essential nutrients, and becomes too poor to sustain good plant growth. Eroded topsoil can also be carried into receiving water bodies like rivers, streams, and lakes. The health of aquatic organisms can be seriously threatened by the eroded sediments, which sometimes contain fertilizers or toxic materials. This can have economically adverse effects on commercial, recreational, and aesthetic value of water resources. All these factors call for the prevention of erosion and protection of waterways while maintaining the quality and productivity of soil.

This thesis follows the *Journal of Environmental Engineering* format.

Soil particles transported by surface water runoff settle out of the water in lakes, streams, or bays and are deposited onto aquatic plants, rocks, and the bottom. These sediments can have an adverse affect on the aquatic ecosystem. The sediments prevent sunlight from reaching aquatic plants, clog fish gills, choke other organisms, can smother fish spawning and nursery areas, and can interfere with navigation. Heavy metals and pesticides have a tendency to adhere to sediments and are carried along with them. These pollutants are known to interfere with basic life processes such as photosynthesis, respiration, growth, and reproduction and can prove detrimental to marine life while degrading water quality.

Road building and new construction activities exacerbate the naturally occurring erosion process. The removal of all vegetation and topsoil at the beginning of some construction projects leaves the subsoil vulnerable to the force of erosion.

Highways form a large part of the infrastructure of both urban and rural areas throughout the country. Wear and tear caused by traffic use and environment conditions necessitates the implementation of regular repairs and maintenance work. Runoff from roads, highways, and bridges is a source of substantial amounts of pollutants to the natural receiving waters. Rainfall induced runoff from roads and roadsides washes the contaminants from sites of road construction and maintenance activities. A considerable quantity of the runoff pollutants are transported straight to the water bodies. Runoff pollution associated with rainwater that washes off roads, bridges, parking lots, rooftops, and other impermeable surfaces is carried into lakes, rivers, streams, and ultimately to the coastal ecosystems.

The major factors that determine the amount of contaminants in runoff, other than traffic volume and climate, include road surfacing material, surrounding land use, bridge or roadway design, the presence of roadside vegetation, roadside application of pesticides and fertilizers, wear and tear due to traffic, maintenance practices, and the frequency of accidents and spills that can introduce hazardous chemicals. The amount of deicer applied to melt ice and snow, in colder climates, can significantly impact the concentration of certain pollutants in road runoff and consequently impair the local water quality.

Oils and grease leaked onto road surfaces from the engines of vehicles, spilled at fueling stations, or discarded directly onto pavement or into storm sewers instead of being taken to recycling stations can have harmful impact on aquatic life. These pollutants can be directly conveyed to surface waters by rain induced runoff.

Minerals in rocks, vegetation, sand, and salt are some of the natural sources of heavy metal pollution. Car and truck exhaust, worn tires and engine parts, brake linings, weathered paint, and rust are major anthropological sources of heavy metals in runoff. Heavy metals like lead, arsenic, etc. can have a detrimental effect on aquatic life. Ground water, a huge source of water, could be rendered unusable by contamination through runoff infiltration.

Grass and shrub trimmings, pet waste, agricultural waste from farm animals, food containers, household wastes and litter can pollute the receiving waters and ruin their aesthetics. The organic wastes are transported downstream to rivers and estuaries increasing their nutrient levels and contributing to over enrichment and oxygen depletion associated with eutrophication. Harmful bacteria (such as Escherichia coli and Fecal Streptococci) and other pathogens are also contained in these wastes and can be introduced into the aquatic systems through runoff.

Road salt used for deicing can enter into streams, ponds, lakes, and bays through snow runoff producing high sodium and chloride concentrations. Unnaturally high salinity can alter the chemical balance of water by increasing the concentration of free chloride ions and promoting acidity in waters. This can result in an increased mortality in fish and other aquatic biota.

Herbicides are transported from treated roadsides to the adjacent aquatic environment through surface runoff. Due to their high water solubility herbicides are readily transported from highway ditches to local waterways through runoff. Herbicides can have a disruptive effect on the aquatic ecosystem and biota when present in significant concentrations in rivers, streams, lakes, and bays. Due to limited dilution capacity, the small streams that run parallel to or cross roadways are at a greater risk of contamination. Storm water runoff quality can be adversely influenced by pollutants, which can be deposited on roadways and bridges through numerous sources and pathways.

Compost has been used effectively as a valuable soil amendment to improve plant growth. Compost-enriched soil reduces erosion, alleviates soil compaction, and helps control disease and pest infestation in plants. Cost effectiveness, reduction in the use of chemical fertilizers, a robust plant yield, and conservation of natural resources are some of the benefits of using compost. Compost, when used, has to be custom-made or specially designed for a specific purpose or a particular soil type. When customizing a compost mixture the technical parameters, which can be adjusted to fit a specific application and soil type, include maturity, stability, pH level, density, particle size, moisture, salinity, and organic content.

Compost can be more effective than traditional hydro-mulch when used on steep embankments along roads and highways. Due to its ability to improve the infrastructure of the soil, compost forms thicker, more permanent growth and reduces erosion while establishing turf. Compost has the ability to retain moisture and can thus help protect the soil from wind erosion, during droughts. Berms (mounds) of compost placed at the top or bottom of steep slopes can be used to slow the velocity of water and provide additional protection for receiving waters. The primary mechanism of the berm is sediment trapping, however berms also prevent erosion by reducing the velocity of the runoff water.

CHAPTER II

RESEARCH OBJECTIVES

Implementation of the Storm Water Pollution Prevention Plan (SW3P)/ National Pollutant Discharge Elimination System (NPDES) and Texas Pollutant Discharge Elimination System (TPDES) requires that the Texas Department of Transportation (TxDOT) adopt a variety of storm water quality measures to meet Clean Water Act requirements. In Texas alone, there are over 74,000 miles of state maintained right-of-way. According to current estimates, much of this existing system will have to be rebuilt or renovated within the next three decades. Thus, there is a need to explore means to minimize the costs of temporary storm water management systems and associated maintenance while meeting water quality standards set by legislation.

Several pilot efforts have been undertaken in Texas to demonstrate the benefit of using compost filter berms. The use of silt fencing and hay bales are already part of TxDOT's Best Management Practices (BMPs). The use of mulch filter berms has increased over the past years. Specific uses of composted materials on the roadside include erosion control, replacement of commercial fertilizer, stimulation and nurturing of vegetation, and as a soil amendment. Results from all these tests have shown compost to be a positive treatment. However, with the exception of the erosion control effectiveness study, none of the demonstrations were sufficiently controlled to allow quantification and comparison with other treatments as a storm water management system. Therefore, while the results of pilot efforts have been encouraging, only sketchy data exists that compares the hydraulic limits, proper site placement, and cost/benefit analysis for compost filter berms, hay bales, and silt fencing used as temporary storm water filtration devices on highway construction sites.

The goal of this research is to study the use of compost and wood chip berms as temporary erosion control devices. The primary focus in this study is to determine the impact of the berms on runoff water quality. Several parameters will be studied with a majority of the work focusing on the nutrients (phosphorous and nitrogen), bio-chemical oxygen demand (BOD) and dissolved oxygen (DO). The water quality parameters of the collected samples that will be analyzed are as listed in Table 1. The collected samples would be analyzed, in accordance to the APHA (American Public Health Association) (1999) *Standard Methods for the Examination of water and Waste and Wastewater (20th ed.)*, American Public Health Association, Washington, D.C., to determine the parameters.

There are two main objectives. The first objective is to examine the impact on the tested parameters of the water to determine the extent to which they are affected after passing through the berm.

The second objective of this research is to examine the performance of the compost/wood chip berms and determine whether they are capable of meeting the environmental quality standards and structural stability requirements.

CHAPTER III

LITERATURE REVIEW

INTRODUCTION

The 1987 Amendment to the Clean Water Act (CWA) established the Non-point Source Management Program, which mandated the control of storm water, erosion, and sediment at construction sites *(1)*. The Coastal Non-point Pollution Program was established by the 1990 Coastal Zone Act Reauthorization Amendments (CZARA) *(1)*.

The Federal Highway Administration (FHWA) was prompted to adopt of Erosion and Sediment Control Rules (23 CFR 65) in 1994, by the Intermodal transportation Efficiency Act of 1991 *(1)*.

Construction sites greater than five acres, are required by The EPA Phase I rules to have construction permits and pollution prevention plans *(2)*. The permitting and pollution prevention plans requirement will be extended to smaller construction sites between one and five acres by the upcoming implementation of EPA Phase II rules in 2003 *(2)*.

EROSION

Non-Point Source (NPS) Pollution occurs when a transport medium, such as water, moves pollutants from the land to a water body or into the groundwater supply *(1)*. USEPA recognizes sediments and nutrients as the most common NPS pollutants *(1)*. Sediments and nutrients released into the receiving waters as a result of soil erosion can become NPS pollution *(1)*. Traditionally, it has been perceived that the impact of soil erosion is restricted mainly to agricultural runoff which has motivated major research endeavors in this field *(1)*. In the recent years, construction sites attracted increased attention concerning soil erosion 1987 amendments to the CWA and CZARA *(1)*.

The soil exposed by site disturbances, caused by construction and developmental activities, are susceptible to erosion *(3)*. Highway construction sites can increase the soil loss rates 10 to 20 times those from agricultural lands, establishing them as potential sources of NPS pollution through soil erosion *(4)*. Techniques need to be devised to prevent erosion whenever a soil slope is exposed to rainfall or running water *(5)*. Some sites like buildings, roadways, developments only need protection during construction phase, while sites with barren slopes are a source of continuing challenge *(5)*. Wood residuals have been effective at curbing damage of waterways by fine silt and clay particles *(5)*.

Runoff from such sites could seriously threaten the quality of the receiving water and health of the residents in the surrounding areas *(6)*. A study conducted in Germany by Dierkes et al. (1999) showed that the winter multi-lane divided highway runoff, when sampled at the edge of the pavement, displayed the highest frequency of severe toxicity *(7)*. Erosion and fertilizer/herbicide runoff can greatly degrade the water quality in the surrounding areas *(1)*.

The water quality parameters for highway runoff and urban runoff are generally similar and hence the same type of runoff control could be used for both of them *(6)*. The impact of highway storm water runoff, though not adverse when considered alone, could result in degradation of water quality when combined with runoff from other sources *(6)*. Furthermore the type of drainage system affects the quality of runoff *(6)*.

A variety of particles of different sizes, textures and compositions are present in urban runoff *(8, 9)*. In urban environments, these solids may be considered as important carriers of nutrients, metals and toxic elements *(10)*.

EROSION CONTROL

A number of temporary and permanent control measures have been adopted by State Departments of Transport (SDOTs) to address the problem of erosion control on highway construction projects *(1)*. Use of silt fences, establishment of temporary or permanent crop cover, synthetic cover mats (geo-textile fabrics), straws and hay bales are some of the erosion control measures implemented *(1)*.

COMPOST APPLICATION IN EROSION CONTROL

Compost has successfully been used for vegetation establishment in the harshest of climatic and soil conditions along Texas roadways as well as for erosion control and moisture retention *(11)*. Use of natural materials to reduce erosion has been well established with composted feed stocks *(5)*. While successfully reducing pressure on landfills, the rapid increase in composting operations also has created a need for new markets that can utilize large amounts of composted materials *(12)*.

The use of compost as a mulch blanket has gained increased attention due to its multiple benefits *(1)*. The main advantage of using compost on highway right-of-way construction is protection against erosion and runoff, while providing an end-use for recycled compost *(1)*. This can be done at a reasonably low cost as compost, which needs to be disposed, is readily available *(1)*. Other benefits include stabilization of soil temperature and evaporation, as well as, an increase in soil nutrient levels *(1)*.

Reducing the quantity of materials entering landfills through recycling organic material has been emphasized by many states *(1)*. Solid waste composting facilities, help accomplish this reduction by prevent yard and garden wastes, sewage sludge and other organics from entering the landfill *(1)*. Compost use in erosion control on highway construction projects has been viewed as a potential beneficial utilization of organic wastes *(1)*.

Compost also facilitates revegetation of the disturbed sites *(1)*. Revegetation, while beneficial, can pose several risks in the early stages of crop establishment *(1)*. The main purpose of the use of compost mulch blankets, other than erosion control, is to enhance crop establishment, while controlling weeds *(1)*. A two-year study conducted in Iowa State University's (ISU) on bio-solids, yard waste and bio-industrial compost concluded that blanket applications have the potential to reduce runoff, minimize erosion and inhibit weed growth *(13)*. Richard et al. (2002) noted that composted organics, while not significantly promoting crop growth can considerably retard weed establishment and growth. The heat treated compost material contains fewer viable weed seeds than the sub soil and cover crops planted grow rapidly, establishing a canopy before the weeds in the underlying soil can penetrate through the treatment blankets *(12)*. However, the compost material should be used almost immediately so that it does not get contaminated.

A significant amount of research has been conducted to determine the impact of the surface application of composted organic on the reduction of soil erosion *(1)*. Persyn et al. (2002) showed that surface applied composted organics can reduce runoff rates, interrill erosion rate, interrill erodibility factors and increase infiltration. The depth of the compost mulch application had a no effect on the erosion control parameters like runoff and infiltration for vegetated treatments *(1)*. However, an increase in infiltration and decrease in runoff was observed in the case of unvegetated treatments *(1)*. Demars et al. (2001) reported that damage to waterways from silt and clay particles can be prevented effectively by use of mulch made from wood residuals.

The mean interill erosion rates displayed a trend similar to that of the mean runoff rates, with the topsoil and the control having the highest mean interill erosion rates and the bio-industrial and yard waste treatments having the lowest. The mean interill erosion rates for each treatment did not vary significantly with the different depth of the blanket applied or the vegetation *(12)*.

The application of composted organic material has the added benefit of facilitating the establishment of crop cover (grass swales). Vegetation can root and grow through the wood-residual mulch application, which reduces the amount of soil eroded *(5)*.

However, one downside of the application of composted organic material is the potential degradation of runoff water quality. Manures and composted material contain large amounts of nitrogen and phosphorus compounds. The nutrient-rich runoffs can enter the natural water bodies and cause eutrophication. Eutrophication is the word given to describe the effects that occur when a water body becomes rich in nutrients causing algal blooms and starving the water body of oxygen. Gilley et al. (2001) observed that there was a variation in nutrient concentrations in the runoff with soil type. Greater adsorption of nutrients was displayed in soils with larger clay content *(14)*.

The total soil-P levels influence the total P in the runoff. The use of manure in excess of crop requirement increases the soil-P levels. The use of feed supplements or selected corn hybrids reduces the P content of manure. Manure with reduced P-content decreases the amount of P accumulation in the soil consequently reducing the P transport by overland flow. However, if there is a rainfall event immediately on application of the manure, the soil P level had little effect on the P concentrations of the runoff *(14)*.

Grass swales have exhibited a high potential for TSS removal and particle trapping. Swales with dense turf, high infiltration rate, moderate slopes and larger swale lengths captured the most particles *(11, 7)*. However, Barret et al. (1998) noted that the high concentrations bacterial populations in the runoff from the grassy swale raised some concerns regarding human health risks.

Steep slopes exceeding a 4:1 gradient with high likelihood of erosion potential usually employ compost filter berms *(15)*. Runoff water continues to flow through the berm while sediments and pollutants are filtered from water *(15)*. Berms allow soil particles to settle out by slowing the flow down *(15, 16)*. The compost filter berms aid in increasing the infiltration of the water backed up behind it *(16)*. Slope severity and the amount of expected rainfall govern the berm size and construction method *(15)*. Compost berms are typically contoured at the base of slope with a second berm on the shoulder contour of steeper slopes for added protection *(15)*. The particle size distribution of the compost is critical for use in filter berms as too many smaller size particles would reduce the rate of flow through the berm while too many larger size particles would render the berm ineffective for particle trapping *(17)*. The trapezoidal shape of the berm allows maximum water penetration *(15)*. The berm should be placed un-compacted on bare soil as soon as possible *(15)*. Berm may be protected by having vegetation or compost in front or above them, however, vegetation should not be present under the berm *(15, 16)*. Compost filter berms must never be constructed in runoff channels, ditches or gullies *(15)*. Backhoe, bulldozer, or grading blade may be used for the application and construction of compost berms, however, manual application is an option in small areas *(15)*. Compost filter berms can be planted and seeded for permanent vegetation establishment at the time of application, or spread out and planted or seeded at the end of project. Compost berms can be left at the site with no waste product of cleaning up, because of its benefits for the soil *(15, 16, 18)*.

A study conducted at San Diego State University reported that the use of berms reduced runoff volume by approximately 31% and off-site sediment delivery by 100% *(19)*. Compost and mulch filter berms are approved as effective alternatives to silt fences for erosion control and storm water protection by the City of Eugene, Oregon *(20)*. Compost berms are less expensive than blankets and silt fences *(17)*.

FIRST FLUSH EFFECT

The concentrations of pollutants in the runoff are higher at the beginning of a runoff event. This phenomenon called first flush has been seen in many studies. First flush was most evident at high traffic density sites. The first flush effect was most pronounced for short duration storms, constant traffic volume and constant rainfall intensities. The vehicles provided a constant input of pollutant load during the storm event *(6)*.

CHAPTER IV

MATERIALS AND EXPERIMENTAL METHODS

ON-SITE TESTING

The testing of erosion control devices was conducted at the Texas Department of Transportation (TxDOT)/TTI Hydraulics, Sedimentation and Erosion Control Laboratory (HSECL) facility located at the Riverside Campus.

Two types of soil were used in the tests, a fine sandy loam and high PI clay. These soils are typical of those found on highway rights-of-way in the state and have been used in a variety of TxDOT testing.

Field data collections were done in accordance with an approved QAPP. The procedures generally followed ISO 9003 laboratory operation guidelines. Testing procedures for water quality were consistent with current EPA 23 CFR requirements.

Tests are to be carried out on three types of cross-channel Best Management Practices (BMPs). The three types of BMPs include Dairy Manure Compost (DMC) berm, Yard Waste Compost (YWC) berm, and Composted Biosoids (CBS) berms.

Elevation measurements were taken at various points in the testing basin upstream of the berm just before every test was conducted in order to confirm the channel slope as shown in the figure 4.1.

Figure 4.1 View of the channel with sand.

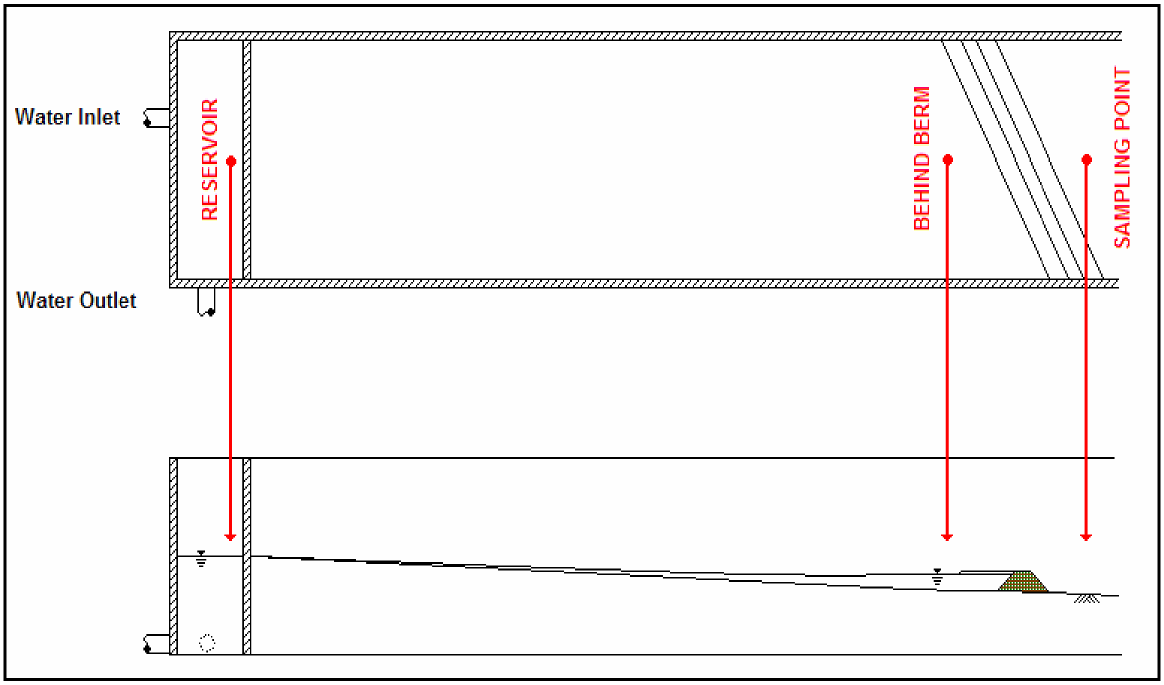

Figure 4.2 Experimental setup showing sampling locations.

Experimental Setup

The experiment setup consisted of a channel as shown in Figure 4.2. The channel was approximately 10 ft wide and 30 ft long, with a water reservoir at one end and the berm placed the other end.

Compost Berm

All compost mixtures used in the research study were in compliance with the quality standards set down in Texas Department of Transportation (TxDOT) Item 1034 Special Specification for Mulch/Compost Filter Berm for Erosion and Sedimentation Control.

Water Quality Tests

Each water quality tests repetition was conducted for a 15 minutes duration, with water being pumped at 110 gpm into the reservoir from where it over-flowed into the channel simulating a sheet-flow (of ~ 0.25 cfs) similar to natural runoff. The tests was conducted on the BMPs in the channel separately with two soils, sand and the other clay. It was planned to use two slopes, 3% and 7%, for each of the soil type during the testing. However, only 3% slope was used as all the BMPs failed at 3% slope making the use of 7% slope redundant. Three repetitions of the sheet flow water quality test were conducted using the same BMP in place.

A maximum of 4 time-weighted samples were collected for each water quality test repetition. The time of first infiltration and the time for each sample collection were noted. The samples were collected at a location (shown in Figure 4.3) downstream of the BMP structures 1, 7, 15 and 30 minutes from the time that the first infiltration is observed.

Figure 4.3 Sampling location for samples downstream of the berm.

In order to monitor the actual water quality during the tests, potable water was used. A sample was collected from the reservoir just before starting the test to determine the background concentrations of the contaminants to be measured that is originally present in the testing water (Figure 4.4). During the test, samples were also collected from behind the berm and at some distance downstream of the berm, before the water enter the receiving pond. The sampling locations are shown in Figure 4.2. Dissolved oxygen and temperature readings were taken on-site as they have a tendency to change with time.

Figure 4.4 Sampling from the reservoir.

Structural Integrity Tests of the Berm

Upon completion of each set of sheet flow test (2-3 repetitions), and, assuming the structure has maintained its integrity, multiple 30-minute continuous flow tests will be conducted at flows up to 0.35 CFS. For the structural integrity tests, water was pumped into the reservoir in the channel at the rate of 120 gpm. These tests used potable water. This test is to document how long the BMP structure can sustain overtopping flow. A maximum of three continuous flows were conducted. If a structure sustained all three tests, no further tests were conducted. The time for the first infiltration, infiltration along the berm and overtopping was noted in each case.

LABORATORY ANALYSIS OF WATER SAMPLES

Samples were preserved as necessary and transported directly to the TAMU Civil Engineering Water Laboratory (EWRL), where the remaining tests were performed in a timely manner. Water tests were run for the parameters shown in Table 4.1.

Table 4.1 Parameters for which the water would be analyzed.

Sr. No.	PARAMETER	METHOD OF ANALYSIS
1	Temperature	APHA 2550
2	Color	APHA 2120
3	Turbidity	APHA 2130
4	Specific Conductance	APHA 2510
5	Suspended Solids (TSS)	APHA 2540C
6	Dissolved Solids (TDS)	APHA 2540D
7	Dissolved Oxygen (DO)	APHA 4500-O
8	pH	APHA 4500-H
9	Alkalinity	APHA 2320
11	SO_4^{2-}, Cl^-, NO_2^-, NO_3^-, HCO_3^-, PO_4^{3-}	APHA 4500
12	BOD_5	APHA 5210
13	Total and Fecal Coliforms	APHA 9222

The Flowchart in Figure 4.5 outlines the timeline used for the laboratory analysis of the samples collected. Water samples were collected in 1 liter cubi-containers and transported to the laboratory in a cooler at approximately 4^0C, in accordance with *Standard Methods* (APHA, 1998). The samples were allowed to come to room temperature before any tests were carried out.

Temperature and dissolved oxygen (DO) were measured on-site right after the sample was obtained. The pH, color, turbidity, specific conductance, total suspended solids (TSS), total dissolved solids (TDS), total/ fecal coliform and 5-day biochemical oxygen demand (BOD_5) of the samples were analyzed immediately upon arrival to the laboratory. The rest of the sample was filtered through 1.5 micron Whatman filters and stored in two 15mL conical tubes for analysis using ion chromatography (IC). 300ml of the filtered sample was stored for the heavy metal analysis using the atomic absorption spectroscopy. About 150 mL of the filtered sample was stored for testing the alkalinity of the samples.

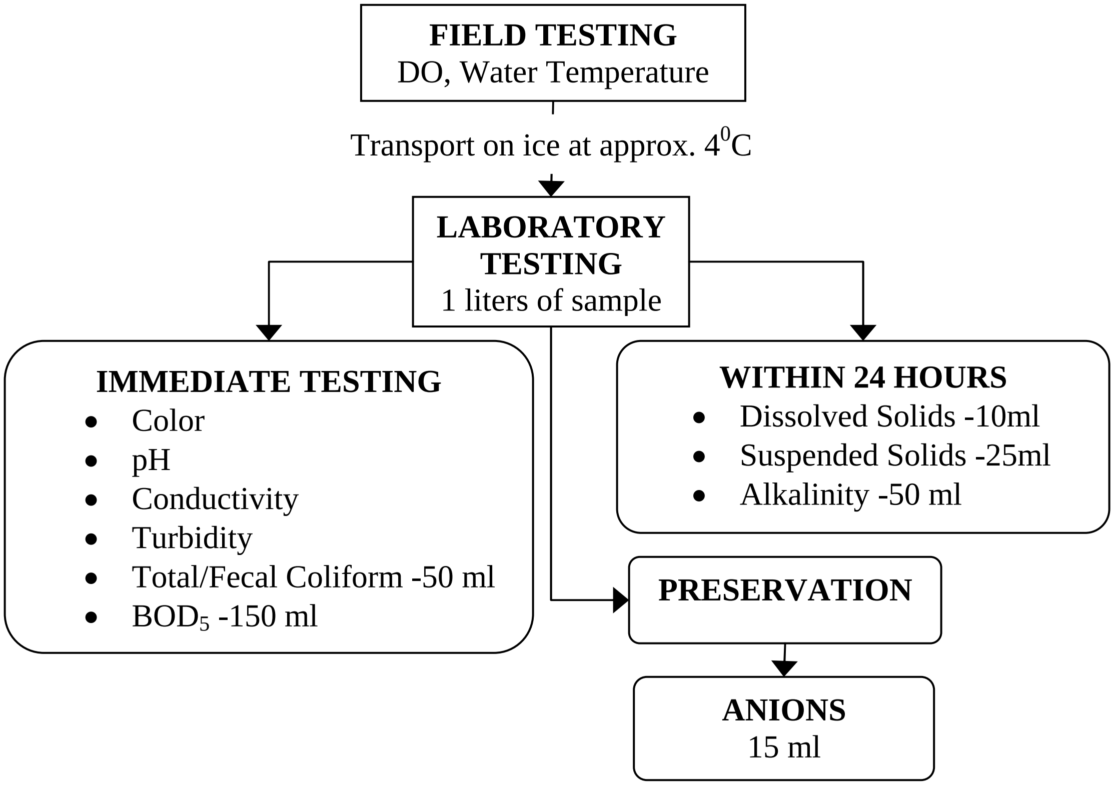

Figure 4.5 Flowchart for the laboratory analysis conducted on the samples collected.

Temperature

The temperature of the samples was measured immediately upon collection of the sample. The temperature readings were taken using the D.O. meter on-site as soon as the sample was grabbed. The results of the temperature readings were reported to the nearest 0.1^0C.

Color

The sample was filtered through a 1.5µm filter and then the color was measured using the HACH 2100AN turbidimeter calibrated using a set of predefined standards. The color was reported on a scale of 0 to 500.

Turbidity

The nephelometric method was used in the laboratory analysis due to its precision, sensitivity and application over a wide turbidity range. Turbidity was measured using a HACH 2100AN turbidimeter and the measurements results were reported as nephelometric turbidity units (NTU). The tubiditity meter was calibrated using a set of standard reference suspensions before analyzing any batch of samples.

Specific Conductance

The instrument used for measuring the specific conductance in the laboratory was a Corning conductivity-meter and a Corning probe. The equipment was calibrated using a standard KCl solution which is commercially available. The results were reported in µS/cm^2 units.

Total Suspended Solids and Total Dissolved Solids

Before starting the test, the filters were washed with three successive 20 ml portions of reagent-grade water through the vacuum filtering apparatus. The washed filters were then placed in well labeled aluminum weighing dishes and kept in the oven for drying to measure the total suspended solids. A separate set of well labeled aluminum weighing dishes were kept in the oven for measuring the total dissolved solids. Before commencement of the test the weighing dishes (with and without the filters) were removed from the oven and cooled in desiccators before weighing. The weights of the weighing dishes (with and without the filters) were recorded as B1 and B2, respectively. A 25 ml portion of the sample was measured using a pipette and deposited on the filter. Vacuum was applied and the sample was allowed to pass through the filter. A 10 ml volume of the filtrate was pipetted into the weighing dishes (without the filter). The filters were removed from the filtering setup and placed in their respective weighing dishes. The dishes were then kept in the oven at 108^{0}C to dry. On drying, the weighing dishes were removed from the oven, cooled in desiccators and weighed. The weights of the weighing dishes (with and without the filters) were recorded as A1 and A2, respectively.

The total suspended solids were then calculated using the following formula:

$$mg\ total\ suspened\ solids \Big/ L = \frac{(A1 - B1) \times 1000}{25}$$

The total dissolved solids were calculated using the formula:

$$mg\ \ total\ \ dissolved\ \ solids \Big/ L = \frac{(A2 - B2) \times 1000}{10}$$

Dissolved Oxygen

Dissolved Oxygen of the sample can change with time and temperature. So the dissolve oxygen of the sample was measured on-site immediately after the sample was collected. A field D.O. meter (YSI model 51B) was used for measurement purposes along with a YSI model 5740 D.O. probe.

pH

The pH of the samples was measured using an Orion pH meter model 420A along with a ThermoOrion combination pH probe.

Alkalinity

For determining the alkalinity 50 ml of the sample was titrated with 0.2N sulfuric acid and the pH decrease was noted for every 0.1 ml of acid added. The recorded data was fed into the online alkalinity calculator on the USGS website <http://or.water.usgs.gov/alk/>. This website also gave an estimated concentration of bicarbonates. The results were reported in mg/l as $CaCO_3$.

Anions

The anions such as sulfates, chlorides, nitrites, nitrates and phosphate were measured by ion chromatography using the DX-80 Ion analyzer. The DX-80 Ion analyzer carries out isocratic ion analysis using suppressed conductivity detection. The ion analyzer was calibrated using a standard solution before the samples were run. PeakNet, the computer running chromatography software, compared the peak measured from the sample to that from the standards and converted the peak to a sample concentration. The sample was injected through a 0.25µm filter to ensure that all suspended particles were removed. If high concentration (beyond the calibration curve) were observed the samples were diluted before analyzing. Each sample was run three times in order to ensure that there was no error in the readings. The results were reported in mg/l.

BOD$_5$

The BOD test was performed in a specially designed bottle with a flared cap which forms a water seal to keep out air. The bottles were filled completely with sample, which must be near neutral pH and free of toxic materials. Since some of the samples had BOD's much higher than the limited solubility of oxygen in water, two of dilutions containing 25ml and 50 ml of sample in a nutrient-containing, aerated "dilution water" were prepared. After an initial measurement of the D.O. (using YSI model 51B D.O. meter and YSI 5905 BOD probe), the bottles were sealed and stored in a dark incubator at 20 °C for five days. The bottles are kept in the dark because algae, which may be present in the sample, will produce oxygen when exposed to light. The D.O. is measured again after this incubation period. The measured difference in dissolved oxygen was multiplied by the appropriate dilution factors and reported as BOD. Samples which did not contain enough bacteria to carry out the BOD test were "seeded" by adding bacteria from another source.

Total and Fecal Coliform

Colilert™ analysis was used in conjunction with the QuantiTray system to enumerate both total coliform and fecal coliform. The trays are composed of individual pockets that were sealed with the sample and incubated at approximately 35^0C for 24 hours. After incubation, the number of positive (yellow and fluorescent) individual pockets were counted and interpreted into a Most Probable Number (MPN), for total and fecal coliform respectively, using a chart supplied by the manufacturer (IDEXX Laboratories Inc., Westbrook, Maine). A 25ml portion of the sample was diluted using 75ml of buffer water to produce 100ml of diluted sample the Colilert™ Analysis. The buffer water was composed of 1.25ml stock phosphate buffer solution and 5.0 ml magnesium chloride solution (81.1 g $MgCl_2.6H_2O$ in 1 liter of reagent grade water) added to 1.0 L reagent-grade water. The buffer water was autoclaved at 121^0C for 30 minutes and cooled prior to addition to ensure sterility.

CHAPTER V

RESULTS AND DISCUSSION

ENVIRONMENTAL QUALITY TESTING

Dairy Manure Compost (DMC), Yard Waste Compost (YWC) and Composted Bio-Solids (CBS) were the three BMPs tested for environment quality of the leachate. The BMPs were tested on sand and clay soils at 3 percent slope. All the berms failed within 12 minutes of the commencement of the flow. It was therefore decided that further testing on 7 percent slopes would be redundant. Due to the almost immediate failure of the berms, it was possible to acquire only one sample at 1 minute from infiltration.

No definite pattern was observed in the failure of the berm. Failure was not restricted to any particular location. The berms failed by different mechanisms. On clay soil, the primary mode of failure was breaking due to stresses caused in the berm resulting from the longitudinal displacement of the berm. The phenomenon of displacement can be seen in Figures 5.1 to 5.4.

Figure 5.1 Failure of the berm on clay soil due to displacement.

Figure 5.2 Failure of the berm on clay soil due to displacement.

Figure 5.3 Lack of friction between clay soil and berm leading to failure by displacement.

Figure 5.4 Displacement causing stresses leading to failure of the berm.

Figure 5.4 shows the cracks caused by the stresses due to displacement. Displacement as high as 19 inches was observed in the case of yard waste compost berm. The displacement could be attributed to the lack of friction between the clay soil base and the berm.

Numerous approaches were tried to prevent failure of the berm on clay soils. In one approach the berm was anchored in place by driving wooden stakes. As can be seen in Figure 5.5, the water eroded the compost material around the stake leading to the ultimate failure of the berm.

Figure 5.5 Failure around the stakes when the berm was anchored.

Another approach was to lay the berm in a 2 inch deep trench cut out in the soil. This approach also turned out to be ineffective as the berm was displaced even after laying it in the trench. In the final approach the berm was laid by compacting and tamping the compost in 6 inch thick layers. However, the tamping seemed to reduce the effective pore size of the berm leading to decreased infiltration. Figure 5.6 shows the effect of tamping on the performance of the berm. The berm, ultimately, failed due to overtopping. Covering the berm with a retaining net was not tried as it would negate the primary advantage of ease of installation in practical application of the berms.

Figure 5.6 Compaction of the berm leading to overtopping with very little infiltration.

On the sandy soil, the primary mode of failure was undermining of the soil beneath the berm. Substantial infiltration was observed through the soil under the berm in the case of sandy soil for all the berms. This indicated that the application to compost filter berms for erosion control is not suitable for sandy soils.

No surface water standards are set for storm water. The present assumption is that if a BMP is used then the water quality requirements are met.

Color

The water sample picked up a dark yellow color after passing through the berm. The dark yellow color was observed for the first 5 minutes after infiltration and gradually turned to a pale yellow color after 10 minutes of infiltration.

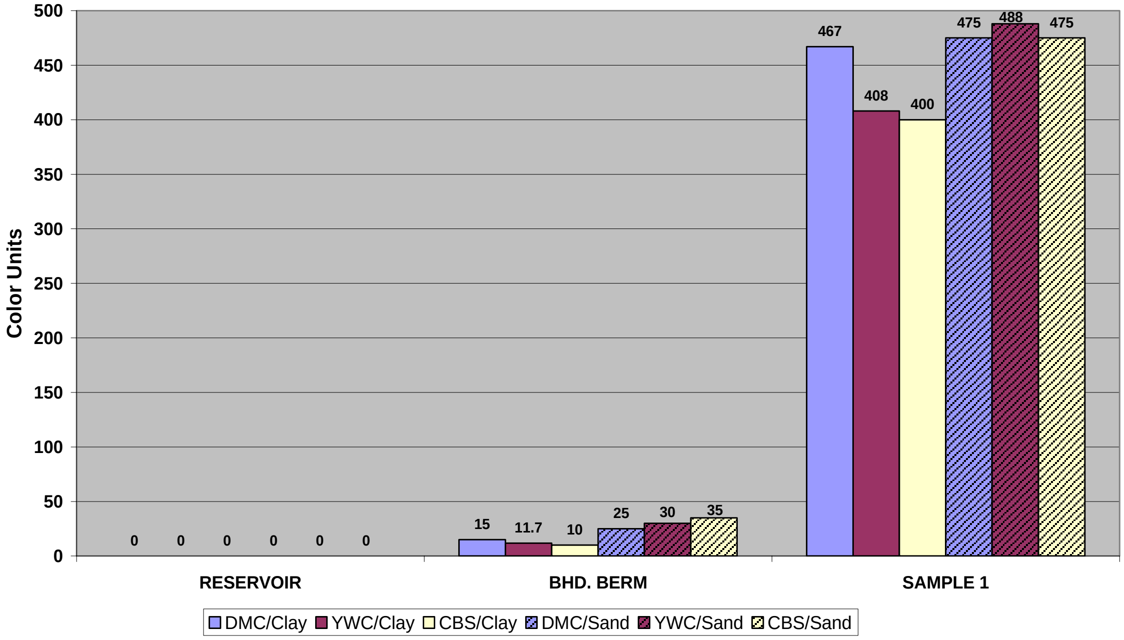

Figure 5.7 Color for tests on (DMC, YWC, CBS) on sand and clay.

This can be observed in Figure 5.7, where the color increases from less than 50 behind the berm to over 400 after passing through the berm. Color makes water unpleasant for sight and affects the aesthetics, and is most often caused by dissolved matter from decaying organic materials.

Turbidity

Turbidity is caused by material suspended in water and is an indirect measure of total suspended solids (TSS). The turbidity data, presented in Figure 5.8, indicates that the turbidity of the water increases in the case of clay soil for all the berms. However, for the sandy soil the turbidity is reduced considerably in the case of dairy manure compost and composted bio-solids and increases in the case of yard waste compost. . Turbidity in addition to depreciating the aesthetics, turbidity, can also be a health concern as suspended matter can carry pathogens with it.

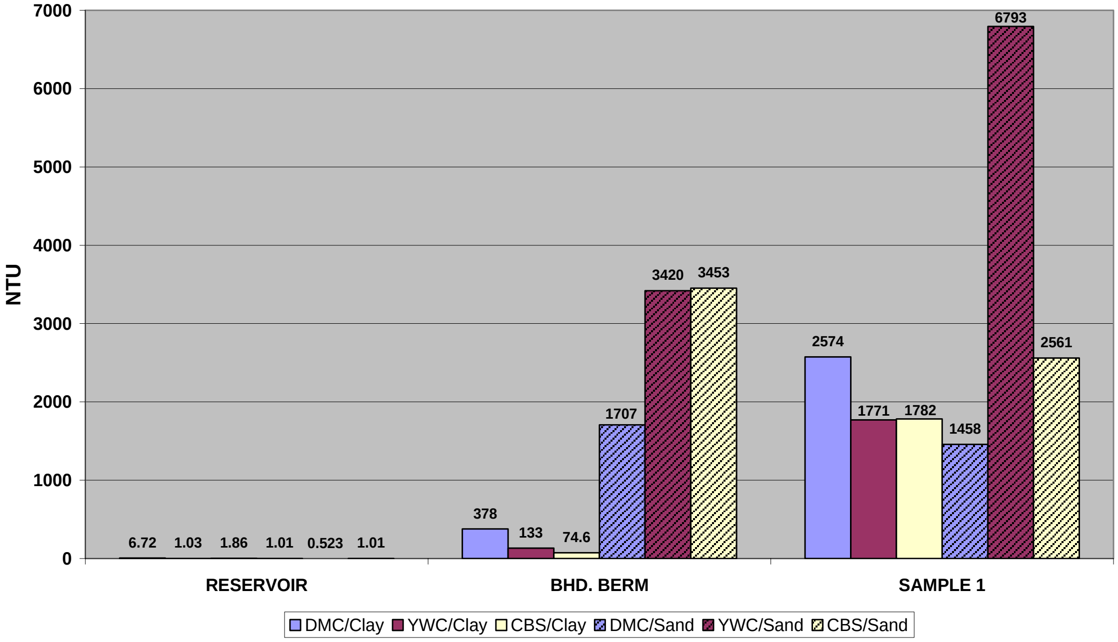

Figure 5.8 Turbidity for tests on (DMC, YWC, CBS) on sand and clay.

Specific Conductance

Specific conductance is an important water-quality measurement because it gives a good idea of the amount of dissolved material in the water. It is a measure of the dissociated salts present in the water. Specific conductance is a measure of the ability of water to conduct an electrical current. The specific conductivity results presented in Figure 5.9 indicate that the least amount of specific conductivity of the leachate was observed in the case of yard waste compost, while the conductivity for dairy manure compost was very high. The specific conductivity of the leachate was considerably higher when the berm was tested on sand as compared to that on clay.

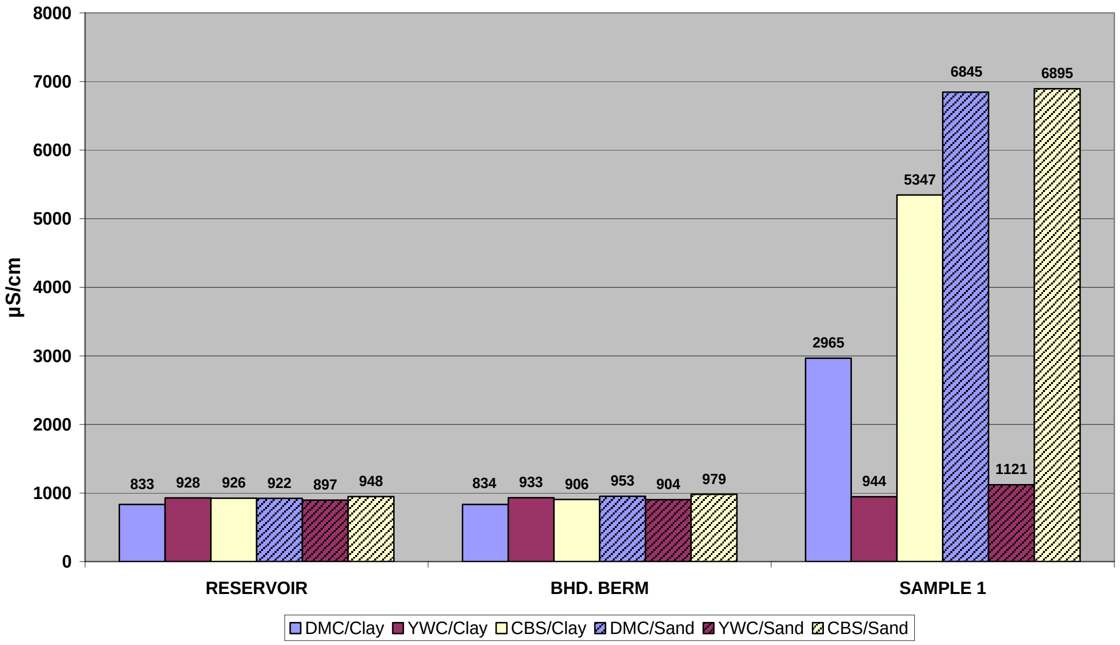

Figure 5.9 Specific Conductivity for tests on (DMC, YWC, CBS) on sand and clay.

Total Suspended Solids

Suspended material causes sedimentation and can decrease the depth of the water body. If there is a lot of biodegradable organic material in the sediment, it will become anaerobic and contribute to oxygen depletion. Figure 5.10 displays the total suspended solids (TSS) data, which indicates that none of the berms reduce the total suspended solids in the water. On the contrary, the berms add a significant amount of TSS to the water, with yard waste compost berm adding the most TSS to the water. However, this could be due to the fact that the berms were actually in the process of failing while the sample was being collected.

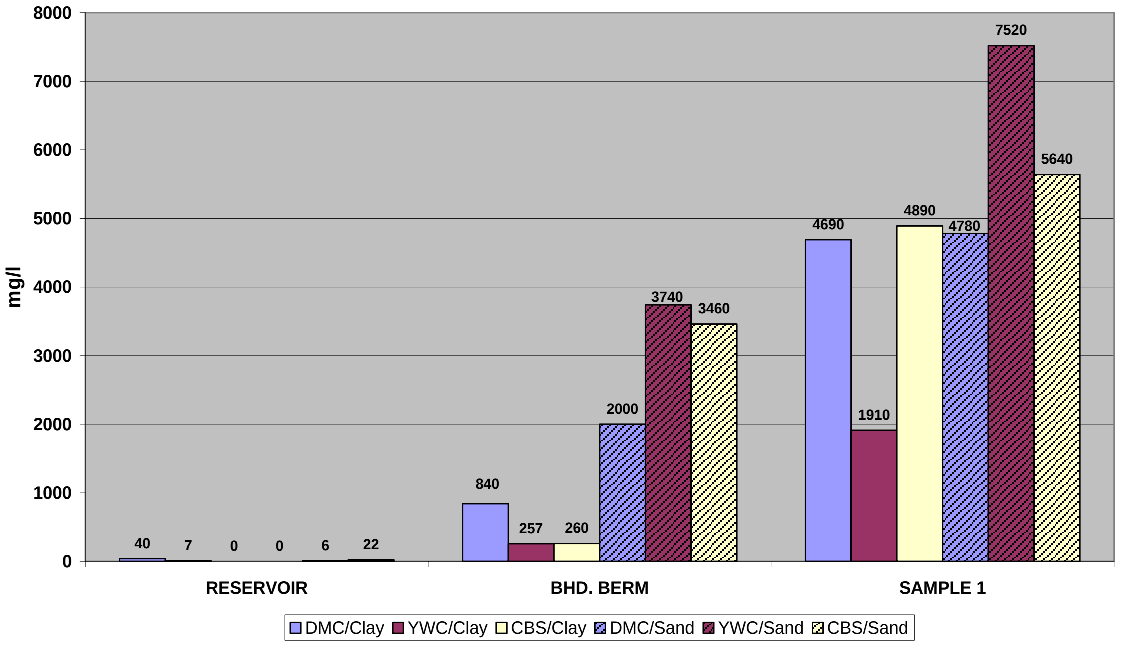

Figure 5.10 Total suspended solids (TSS) for tests on (DMC, YWC, CBS) on sand and clay.

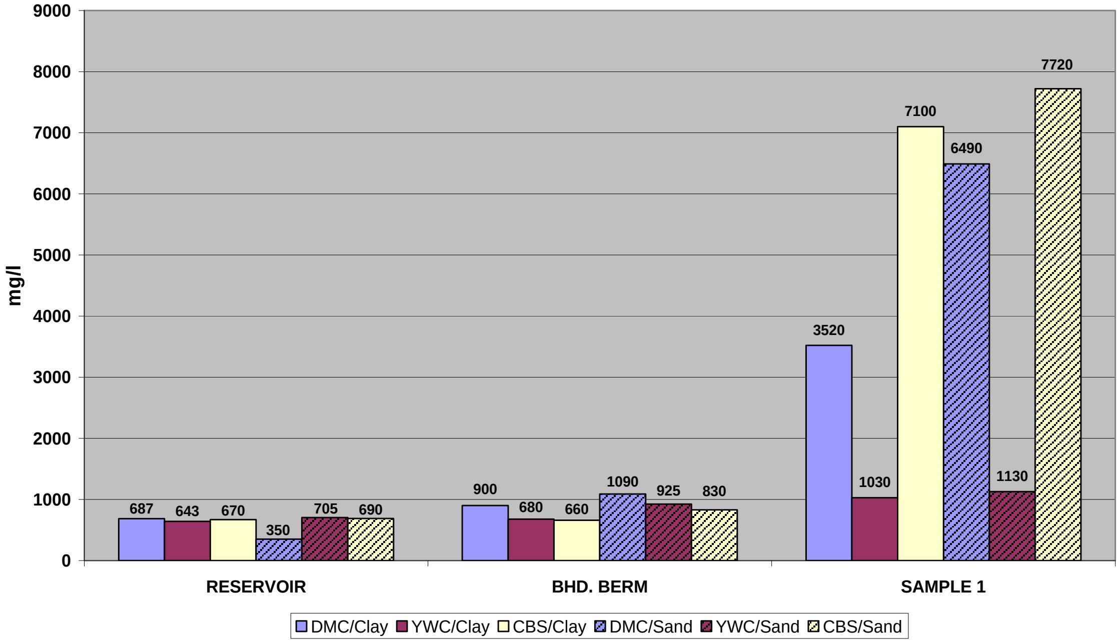

Figure 5.11 Total dissolved solids (TDS) for tests on (DMC, YWC, CBS) on sand and clay.

Total Dissolved Solids

The data presented in Figure 5.11 for total dissolved solids (TDS) exhibited that the least amount of dissolved solids were introduced in the water from the yard waste compost, while the dairy manure compost and composted bio-solids introduced fairly large amounts of dissolved solids into the water. The TDS introduced in the water was considerably higher when the berm was tested on sand as compared to when it was tested on clay. This is concurrent with the specific conductivity results.

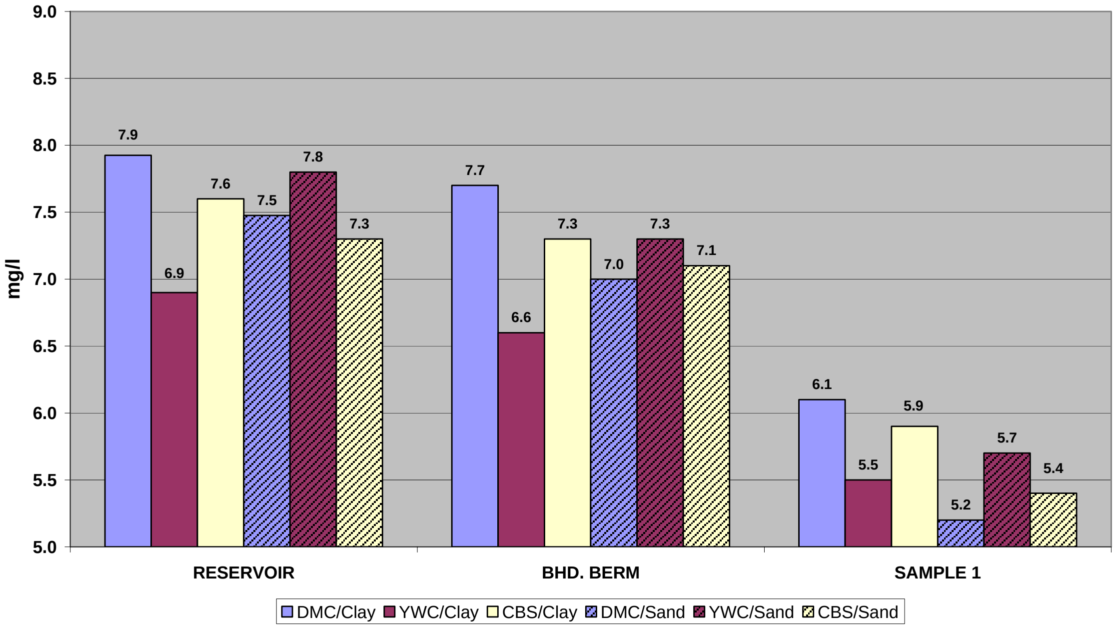

Figure 5.12 Dissolved oxygen (DO) for tests on (DMC, YWC, CBS) on sand and clay.

Dissolved Oxygen

Dissolved oxygen levels below 5.0 mg/l can put aquatic life under severe stress. The dissolved oxygen level in the water, shown in Figure 5.12, dropped considerably after passing through the berm. The DO in some cases was found to be less than 6.5 mg/l, which is less than the critical value for surface waters. This can be a source a concern in the application of the berm on construction sites.

pH

Water having a pH of about 8.5 was used for testing. A pH range of 6.0 to 9.0 is favorable for aquatic ecosystem. This high pH can be accounted for by the fact that College Station relies on groundwater for its supply, which has a high carbonate concentration. Figure 5.13 shows a sudden drop in pH after passing through the berm. The drop in pH may be caused by the presence of organic acids, which impart the compost an acidic nature.

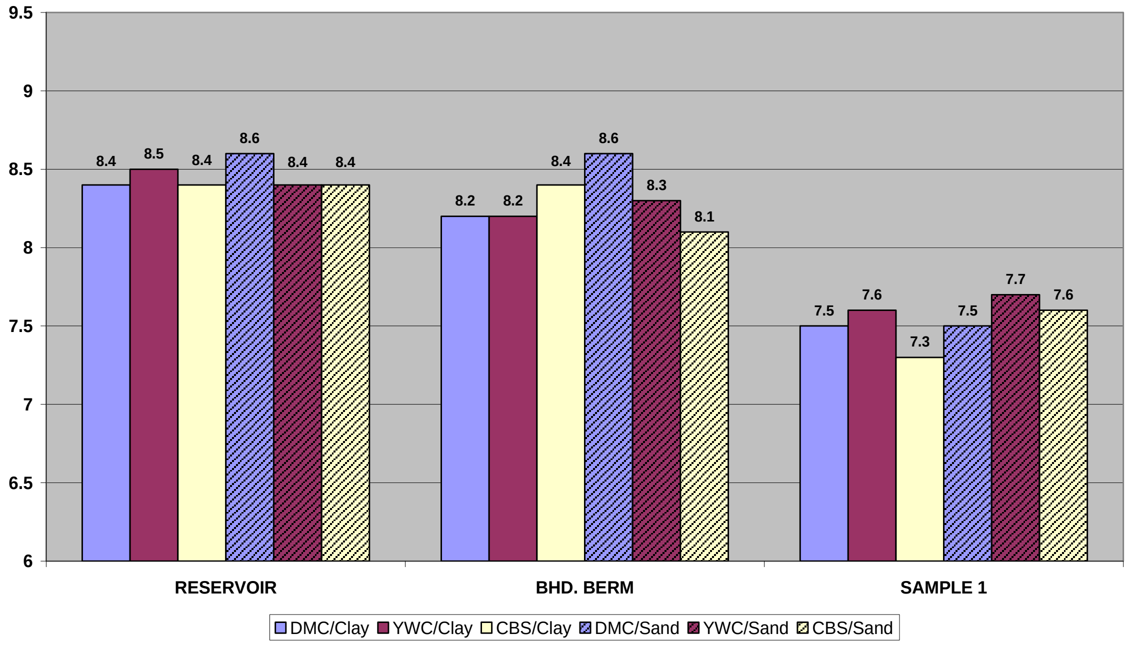

Figure 5.13 pH for tests on (DMC, YWC, CBS) on sand and clay.

Alkalinity

The water used for testing had a considerable amount of alkalinity which was about 358 mg/l as $CaCO_3$ on an average. The alkalinity was mostly due to the bicarbonates present in the water. The berms reduced the alkalinity of the water. However, the results displayed in Figure 5.14 were not consistent enough to draw any definite conclusions. The compost is acidic and probably reduced the alkalinity due to its acidic nature.

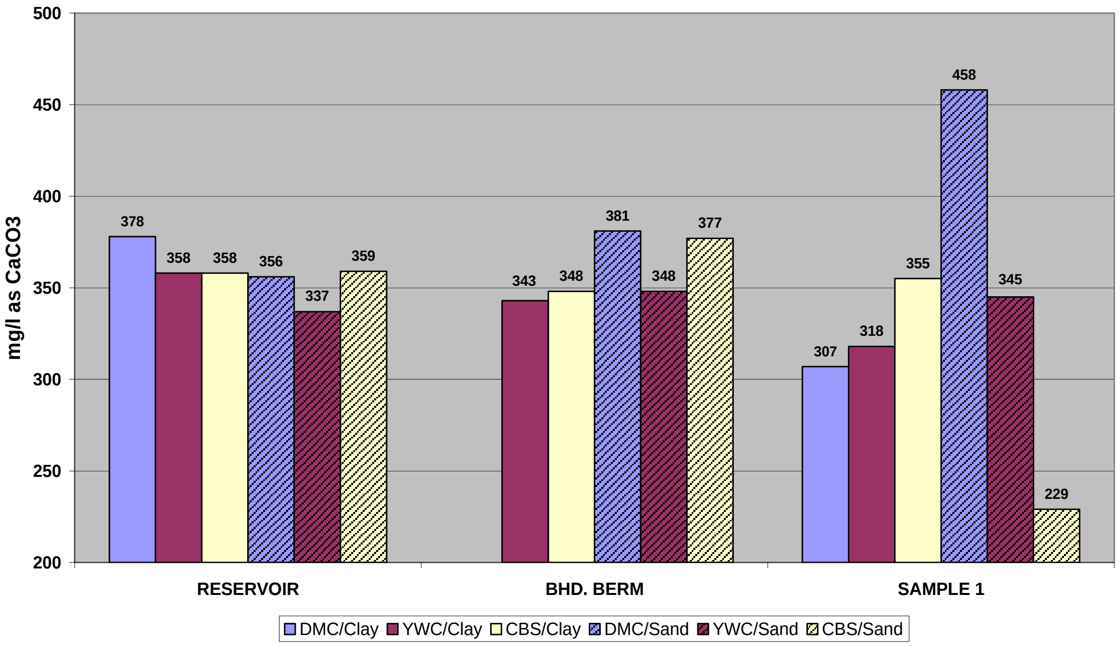

Figure 5.14 Alkalinity for tests on (DMC, YWC, CBS) on sand and clay.

Sulfates

The results of the sulphate analysis presented in Figure 5.15 show that a large amount of sulfates were introduced into the water by the composted bio-solids. The dairy manure compost berm also introduced a large amount of sulfates into the water; however, it was much less than that by composted bio-solids. The yard waste compost released a very small quantity of sulfates into the water. There was no appreciable difference in the results of the tests on sand as compared to that on clay.

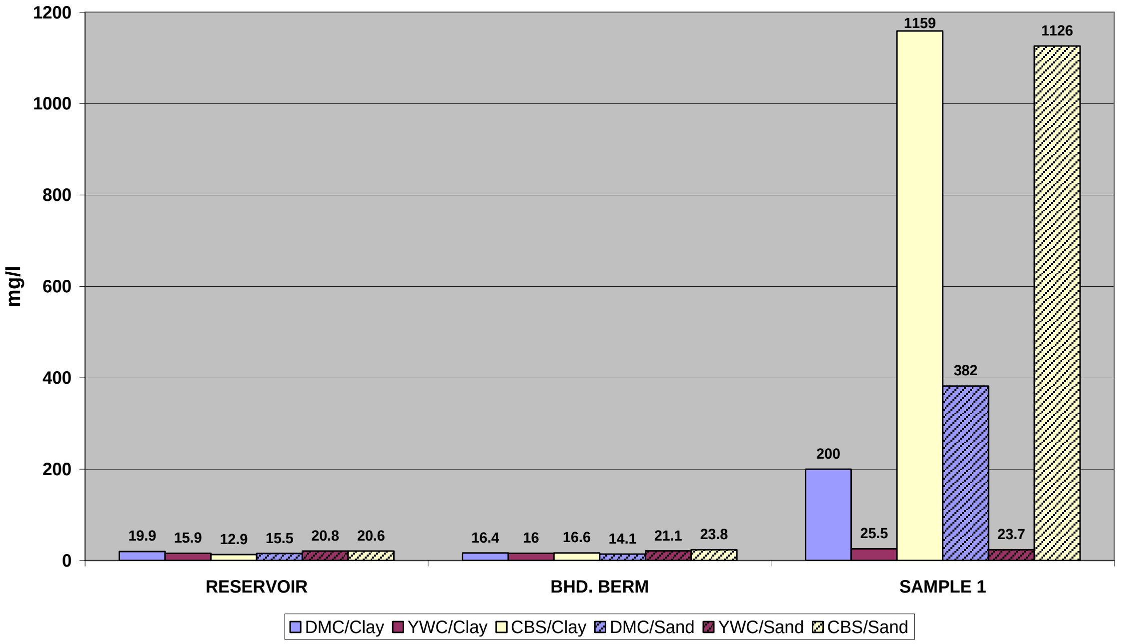

Figure 5.15 Sulfates (SO_4^{2-}) for tests on (DMC, YWC, CBS) on sand and clay.

Chlorides

The results from the chlorides test shown in Figure 5.16 were not conclusive. However, it appears as if the dairy manure compost inputs considerable amount of chlorides into the water when tested on sand.

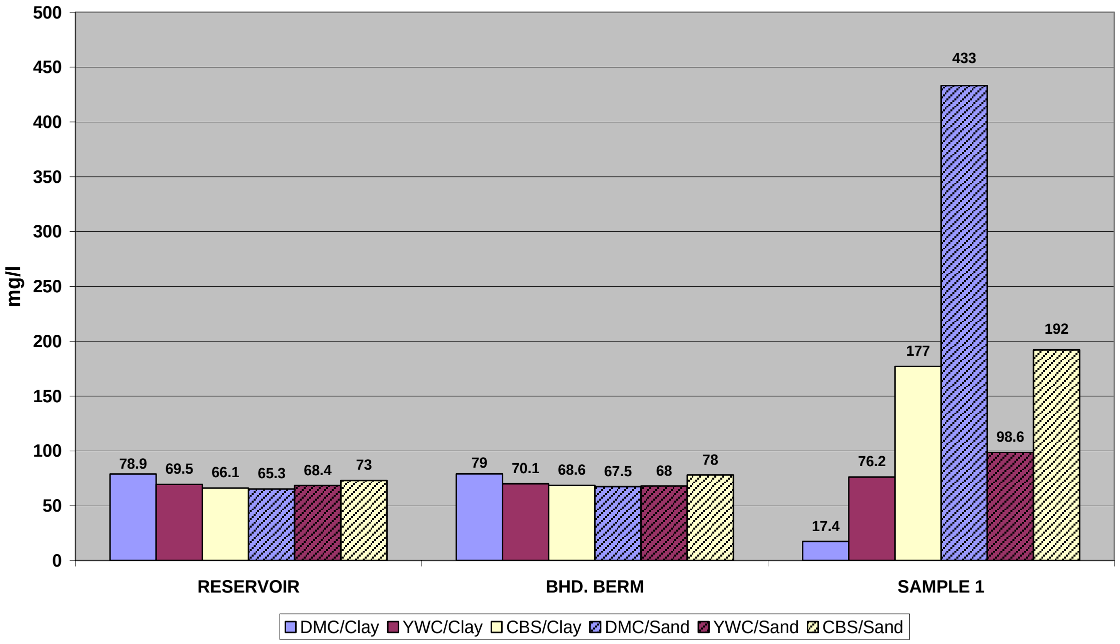

Figure 5.16 Chlorides (Cl^-) for tests on (DMC, YWC, CBS) on sand and clay.

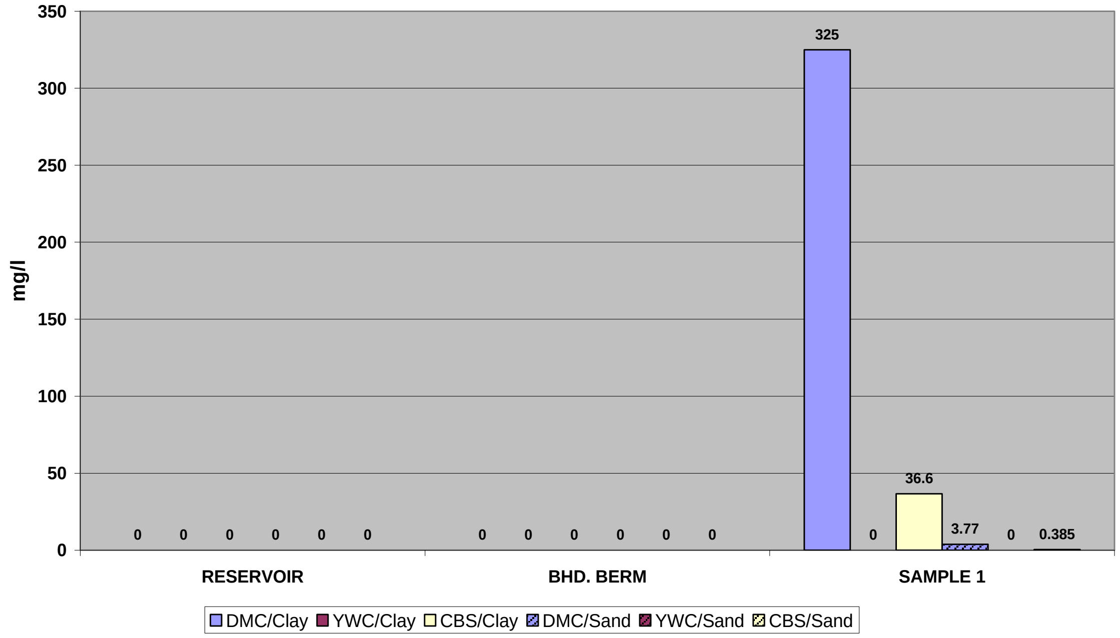

Figure 5.17 Nitrites as nitrogen (NO_2^--N) for tests on (DMC, YWC, CBS) on sand and clay.

Nitrites

Very little nitrites were observed in most of the samples as nitrites are very unstable and are immediately converted to nitrates. The nitrite results in Figure 5.17 do not warrant any conclusions. However, it may be noted that in YWC on clay the nitrite level is very high, while the nitrate level shown in Figure 5.18 is very low. So the total nitrogen in YWC on clay is consistent, only it exists as nitrites instead of nitrates.

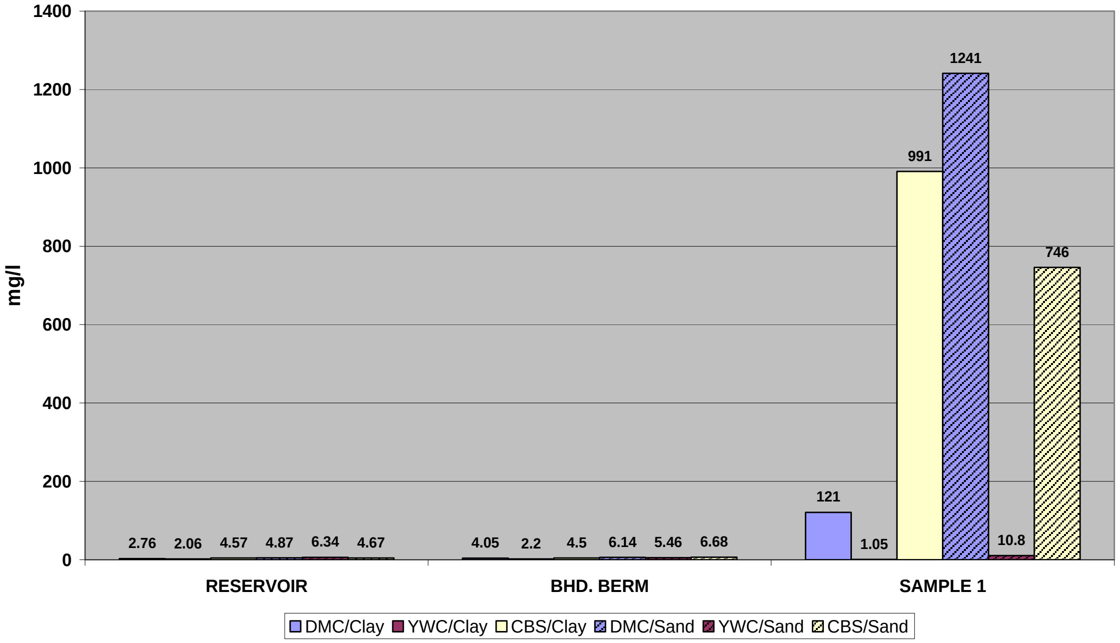

Figure 5.18 Nitrates as nitrogen (NO_3^--N) for tests on (DMC, YWC, CBS) on sand and clay.

Nitrates

The nitrate results in Figure 5.18 indicated that the yard waste compost berm was the least contributor of nitrates in the water. The yard waste compost berms and composted bio-solids berms introduced an incredibly large amount of nitrates into the water. This effect could be due to the fact that the samples were collected as the berm was failing. The nitrate anion NO^{3-} is not adsorbed by soil and moves with infiltrating water. A concentration limit for nitrate in drinking water is set as 25 mg/l.

Phosphates

Phosphates PO_4^{3-} is very toxic and is subject to bioaccumulation. The dairy manure compost berm was the largest contributor of phosphates in the water.

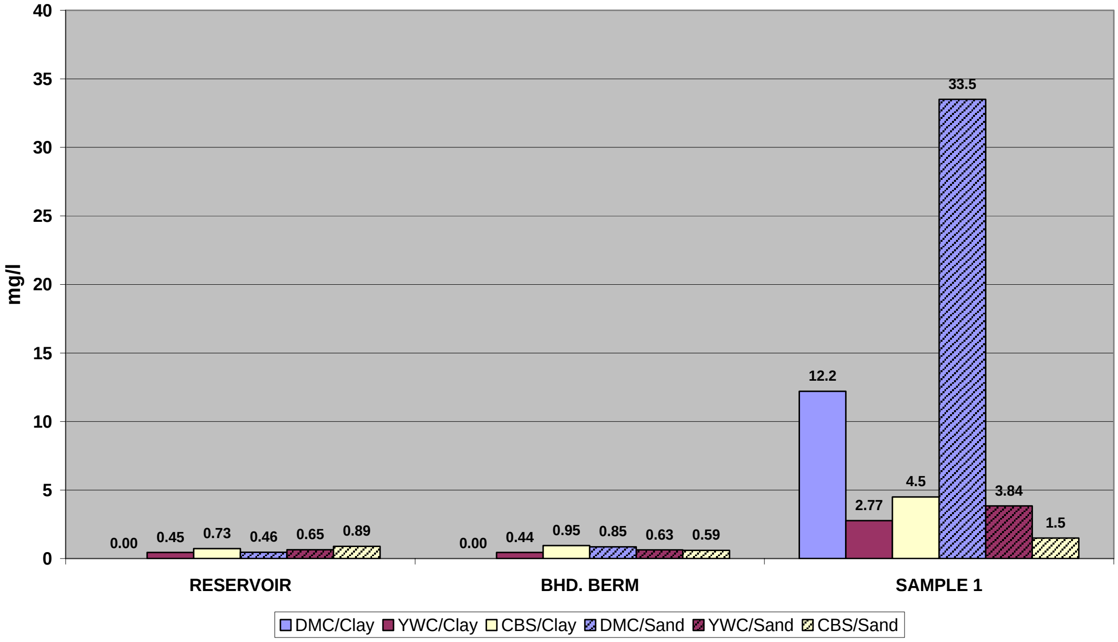

Figure 5.19 Phosphates (PO_4^{-3}) for tests on (DMC, YWC, CBS) on sand and clay.

The yard waste compost berms and composted bio-solids berms introduced very small amounts of phosphates in the water. Figure 5.19 shows the results of the phosphate concentration in the water.

Bicarbonates

There was a substantial amount of bicarbonates in the testing water. No definite conclusions can be drawn from the bicarbonate concentration data presented in Figure 5.20.

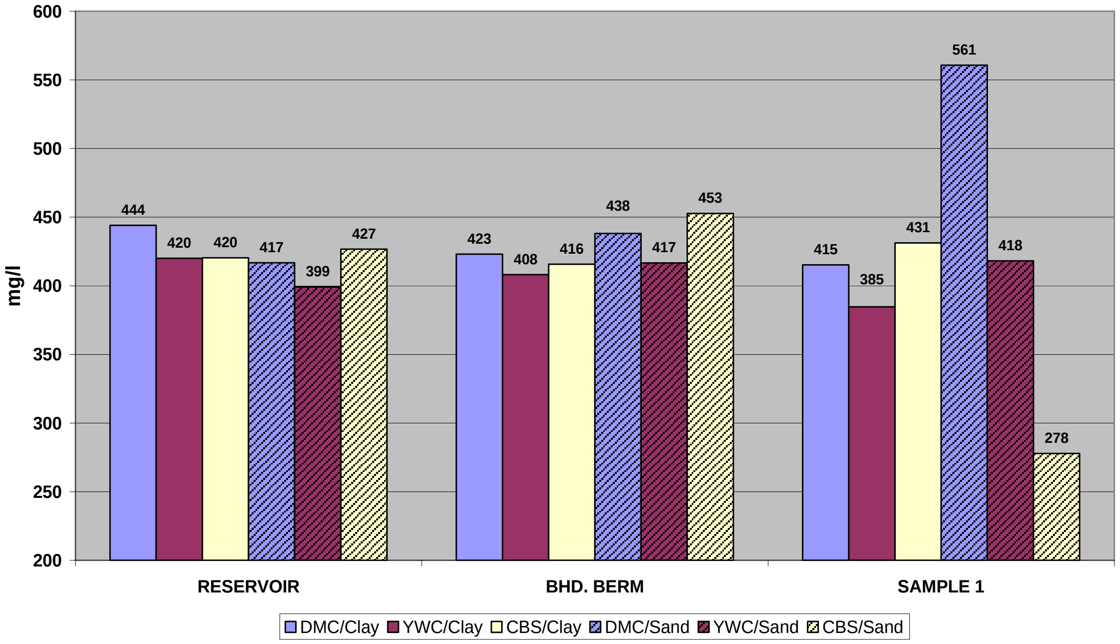

Figure 5.20 Bicarbonate (HCO_3^-) for tests on (DMC, YWC, CBS) on sand and clay.

5-day Biochemical Oxygen Demand (BOD$_5$)

The results presented in Figure 5.21 indicate that the berms introduced some amount of organic matter in the water. A large amount of organic matter seemed to be introduced in the water by the dairy manure compost and composted bio-solids when these berms were tested on the clay soil. However, the results are not very conclusive.

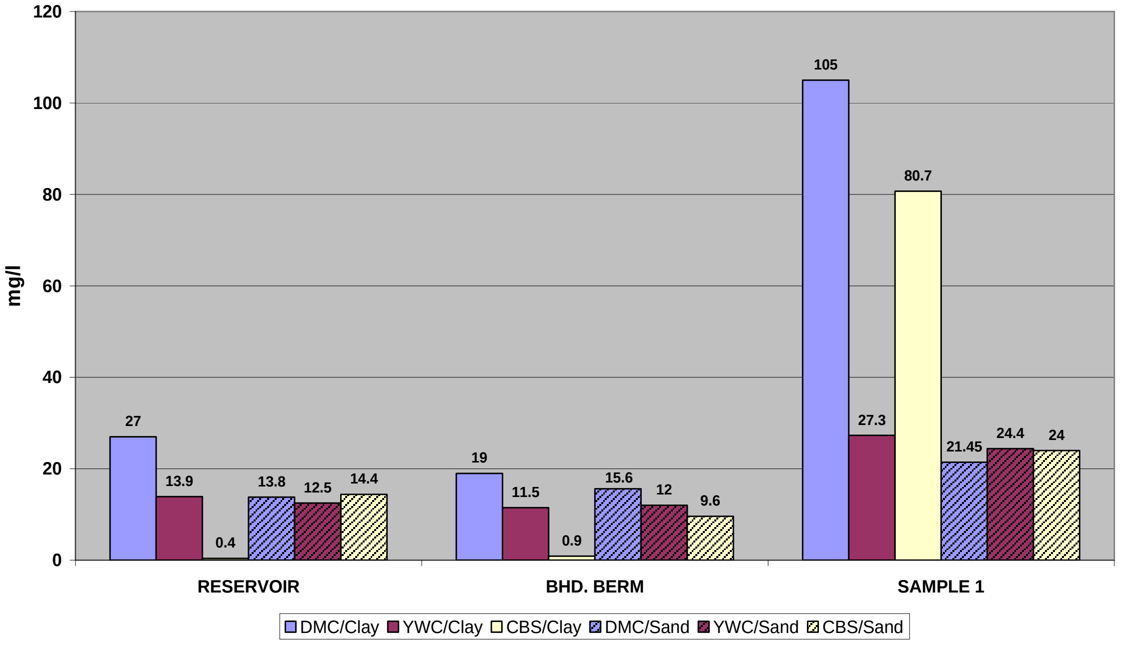

Figure 5.21 BOD$_5$ for tests on (DMC, YWC, CBS) on sand and clay.

Total Coliform and Fecal Coliform

A considerable increase in the total coliform concentration was observed in the water after it passed through the berms. The results are presented in Figure 5.22 and show that the MPN/100ml for the total coliforms was high for leachate through all the berms.

An increase in fecal coliform concentration also was observed in the water after it passed through the yard waste compost and composted bio-solids. When the composted bio-solids berm was tested on clay soil, the MPN/100ml of fecal coliform in the leachate was very high as compared to the rest of the test berms. No increase in fecal coliform was observed in the water after it passed through the dairy manure compost, implying that it had been disinfected.

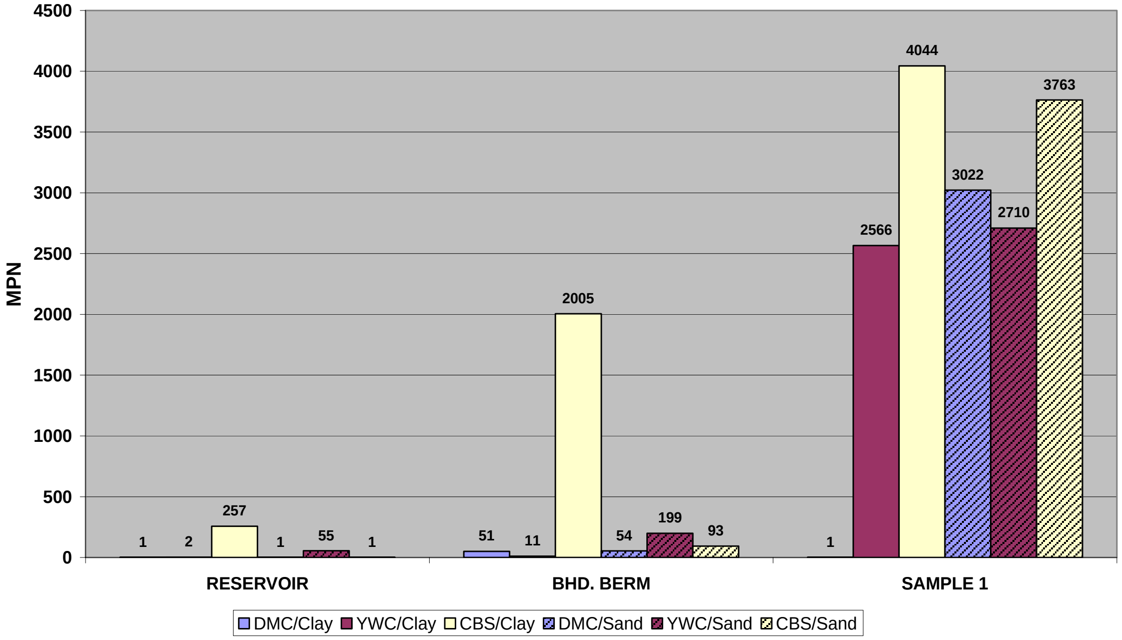

Figure 5.22 Total coliform for tests on (DMC, YWC, CBS) on sand and clay.

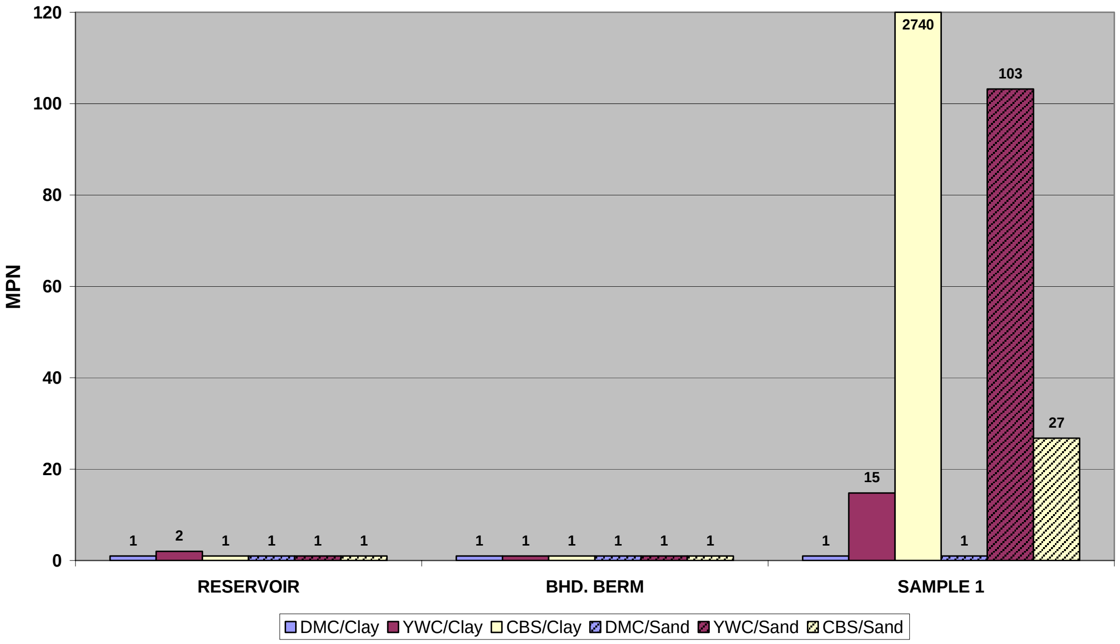

Figure 5.23 Fecal coliform for tests on (DMC, YWC, CBS) on sand and clay.

First Flush Effect

A set of trial runs were also conducted on locally acquired compost. The compost was a mixture of yard waste and bio-solids. However, the compost did not meet the TxDOT specifications. Testing was commenced within a week of laying the berm in the channel. The berm withstood the three rounds of environmental quality testing and three rounds of structural testing with minimal damage. The data from this testing had a complete set of data and has therefore been presented. Most of the parameters exhibited the effect of first flush.

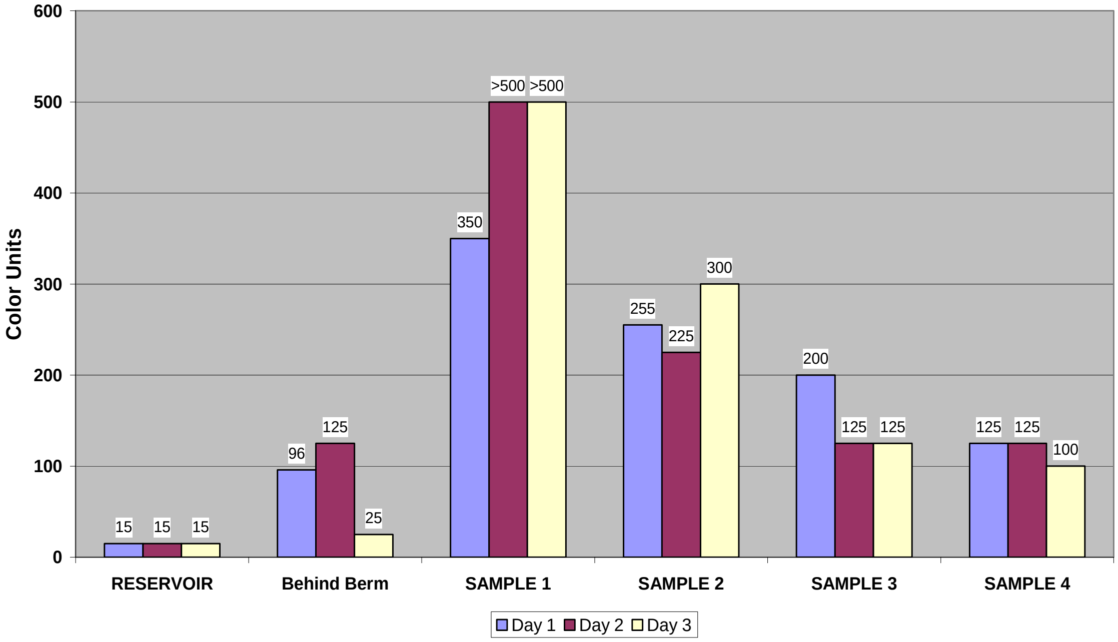

Figure 5.24 Color-the effect of first flush seen in the trial run.

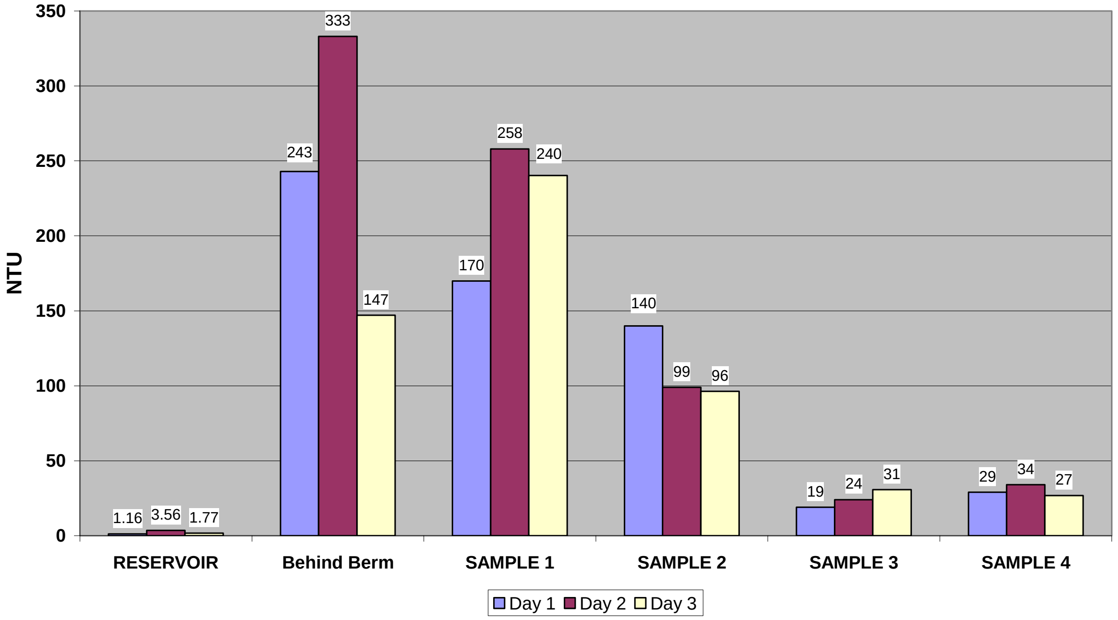

Figure 5.25 Turbidity-the effect of first flush seen in the trial run.

Figure 5.24 demonstrates the first flush effect in the three repetitions, where the color shoots up to over 500 color units and then reduces to 100 color units in 30 minutes.

The same effect can be seen in Figure 5.25 in the case of turbidity. The compost berm managed to reduce the turbidity of the water approximately 30 NTU from over 150 NTU behind the berm in 30 minutes.

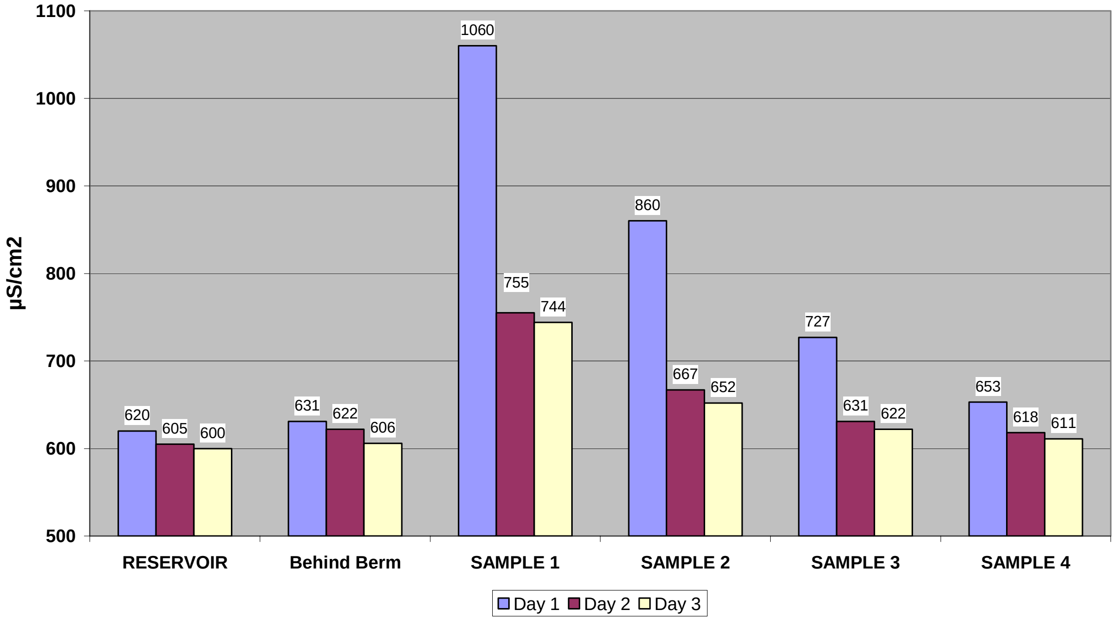

Figure 5.26 Specific conductivity-the effect of first flush seen in the trial run.

Figure 5.26 also shows the first flush effect, with the specific conductivity of the leachate approaching that of the original water during the 30 minute test duration.

Figure 5.27 shows that the berm is effective in removing the total suspended solids from the water. The TSS of the leachate decreases quickly to approximately 0.047 from over 0.3 g/l in 30 minutes.

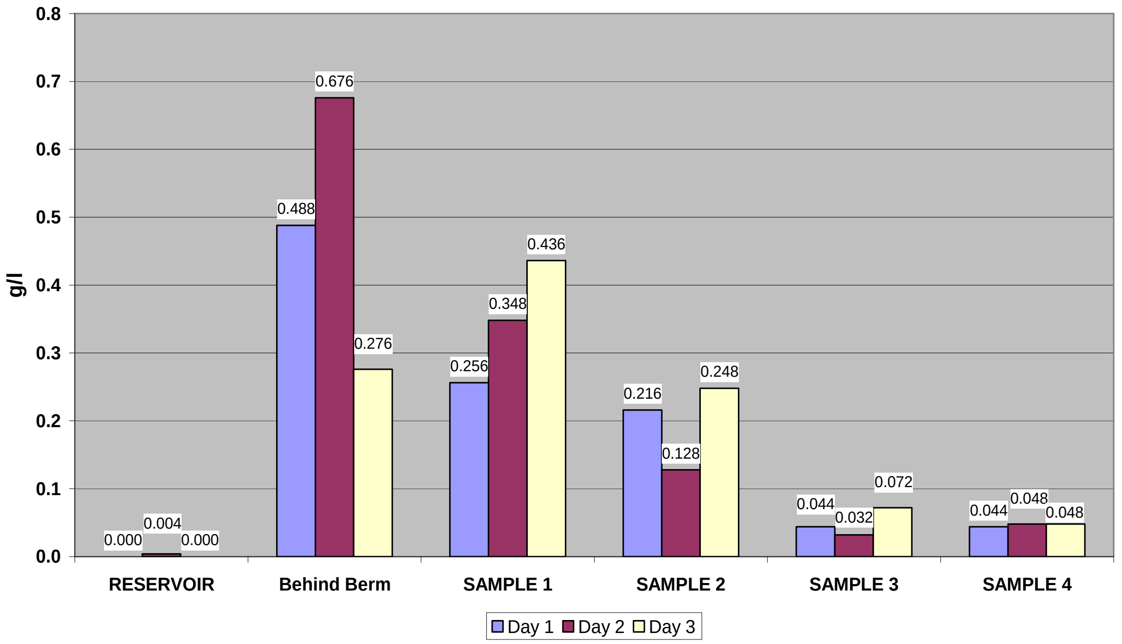

Figure 5.27 Total suspended solids (TSS)-the effect of first flush seen in the trial run.

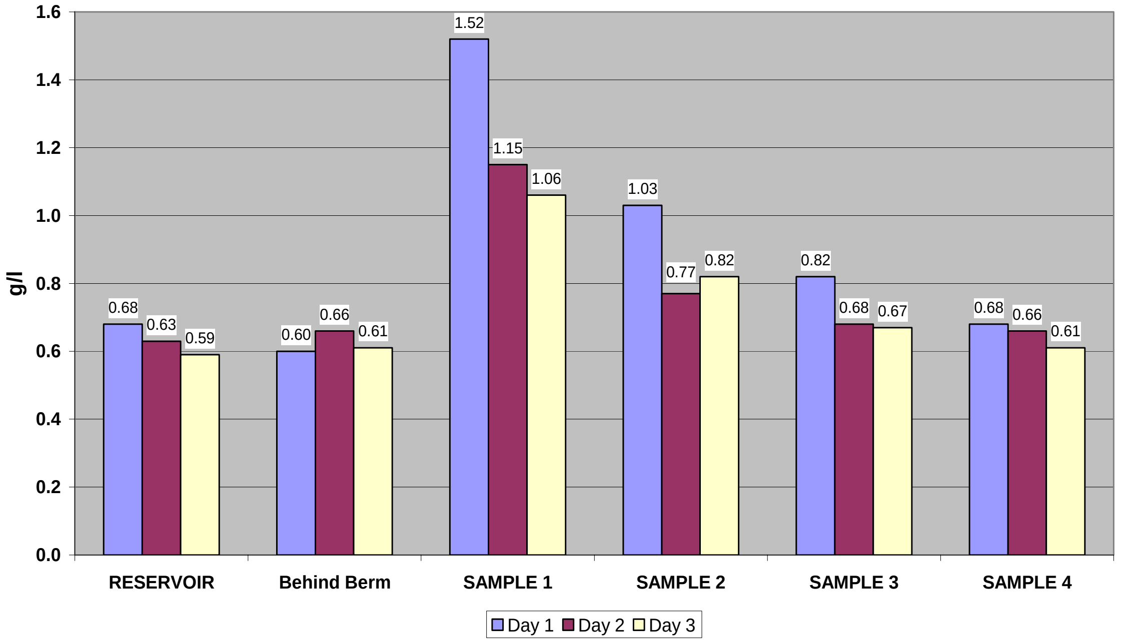

Figure 5.28 Total dissolved solids (TDS)-the effect of first flush seen in the trial run.

The total dissolved solids result in Figure 5.28 is similar to the specific conductivity result in Figure 5.26. Both the results distinctively demonstrate the first flush effect. In the first couple of minutes a large amount of TDS is contributed. However after 30 minutes the water passed through the berm without picking up significant amount of TDS.

In Figure 5.29 the dissolved oxygen dropped down by approximately 1.43 mg/l on an average in the first 1 minute. Over the next 30 minutes the dissolved oxygen dropped by a further 0.67mg/l to reach approximately 5.8mg/l on an average. The total average fall in dissolved oxygen was 2.1mg/l. However, the D.O. remained above 5.0 mg/l.

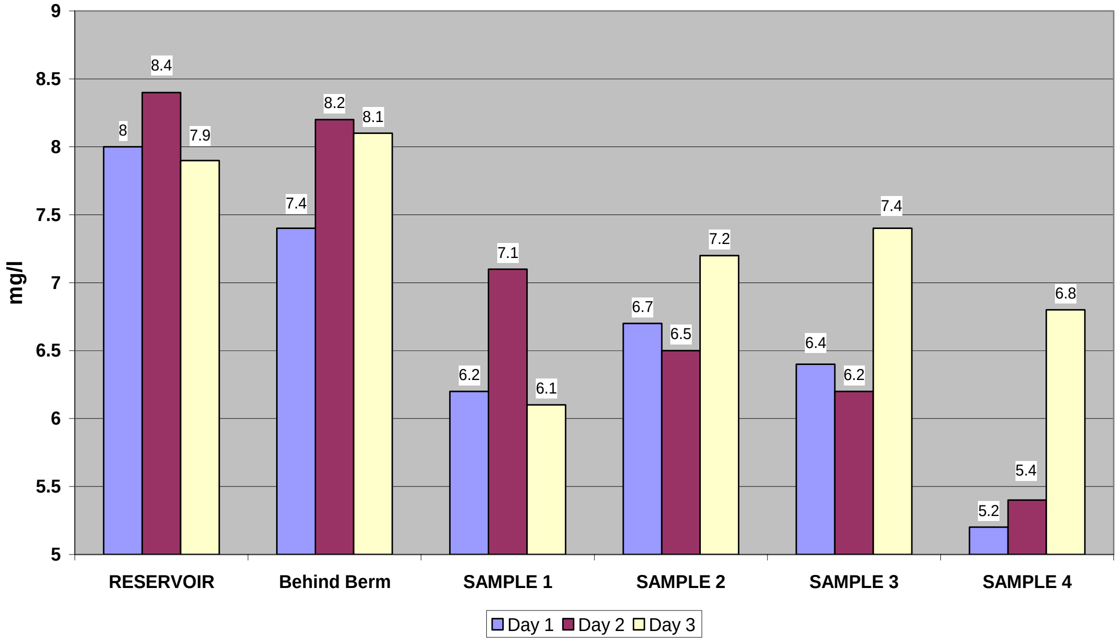

Figure 5.29 Dissolved oxygen (D.O.)-the effect of first flush seen in the trial run.

The water used for testing was potable water which had a pH of about 8.3. This pH is due to the fact that the water supplied in college station is groundwater and has a large amount of carbonate concentration. Figure 5.30 shows that the pH of the water dropped suddenly after passing through the berm. However, the pH of the water passing through the berm increased with time. The drop in pH may be due to the acidic nature of the compost due to presence of organic acids. The pH reducing capacity of the compost reduced with time as more volume of water passed through. Another interesting observation is that the pH reducing capacity of the compost reduced with each simulation run.

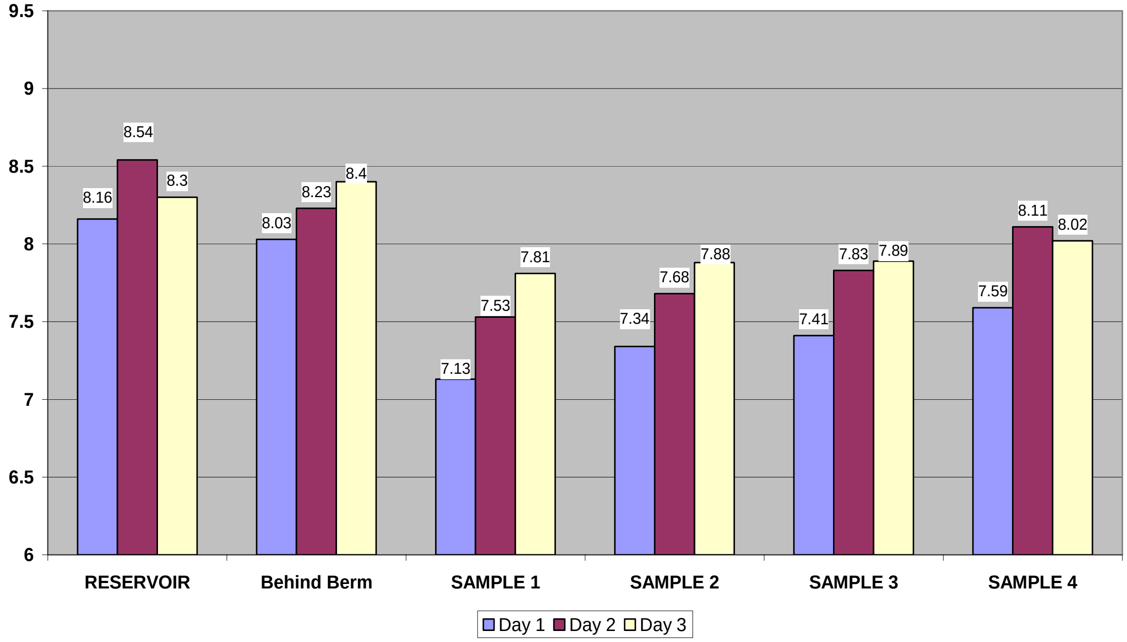

Figure 5.30 pH-the effect of first flush seen in the trial run.

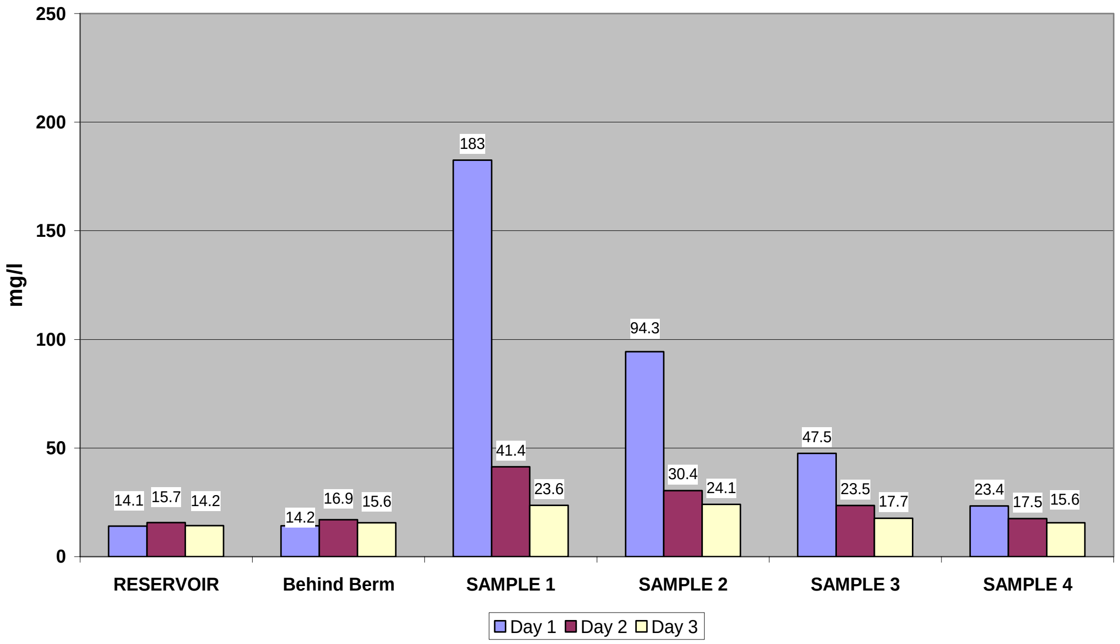

Figure 5.31 Sulfates (SO_4^{2-})-the effect of first flush seen in the trial run.

The sulfates results shown in Figure 5.31 indicated a pronounced first flush effect for the first run. The effect diminished with each run and was barely perceptible in the last run (third run). The decrease in the first flush effect was probably due to a washing effect, which reduced the concentration of sulfates in the berm compost.

The first flush effect is seen in Figure 5.32, displaying the chlorides results. The input water had a chloride concentration of about 65 mg/l. For the first run, there was a pronounced increase in concentration in the first 1 minute followed by a gradual decrease until the chloride concentration was almost the same as that in the input water. The effect of first flush reduced with each simulation run and was barely perceptible in the last run.

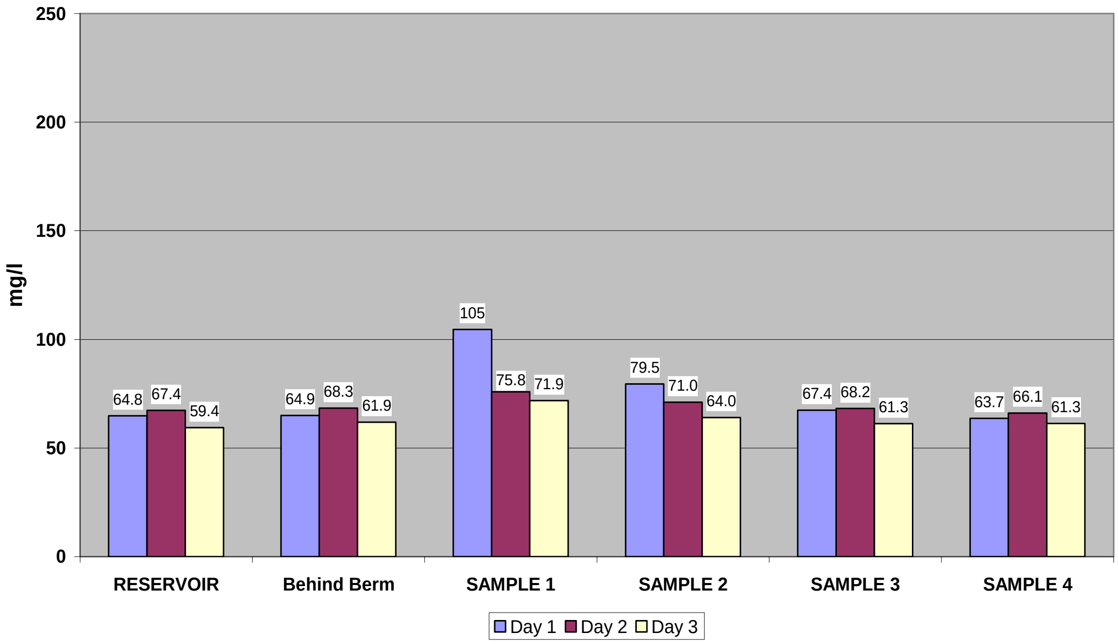

Figure 5.32 Chlorides (Cl^-)-the effect of first flush seen in the trial run.

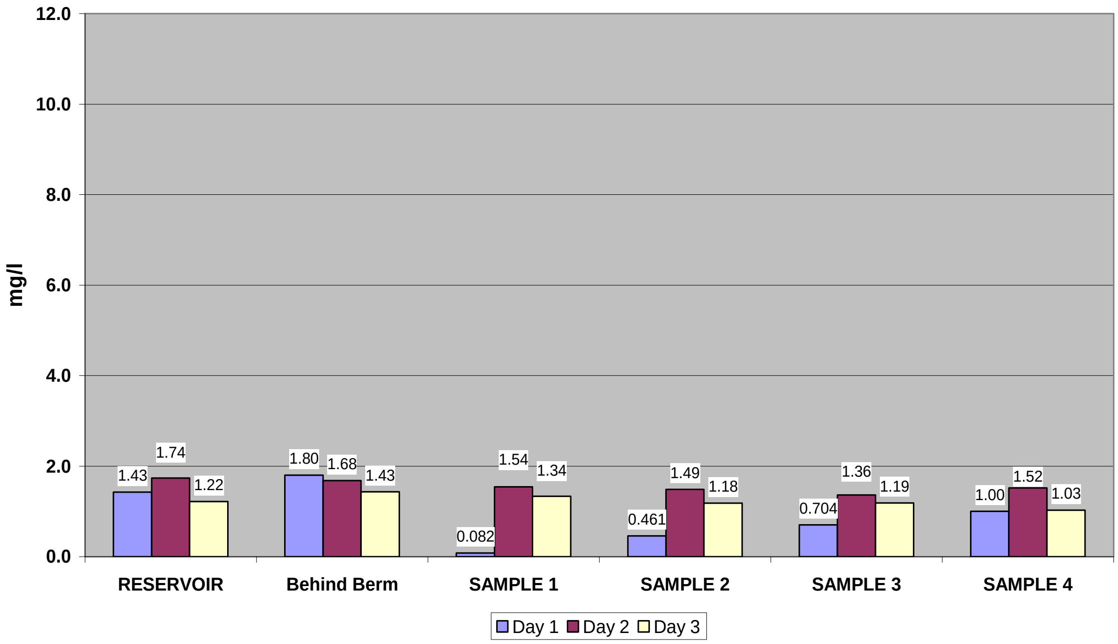

Figure 5.33 Nitrates as nitrogen (NO_3^--N)-the effect of first flush seen in the trial run.

The nitrate results are presented in Figure 5.33, indicate that the water used for testing had a substantial nitrate concentration. The berm seemed to remove considerable amount of nitrates from the water in the first run. The nitrate concentration increased in the next 30 minutes to 1 mg/l. The berm removed some amount of nitrate in the second and third run.

The Phosphate results presented in Figure 5.34 indicate the effect of first flush. There was no input of phosphates in the first minute for the first run. The amount of phosphates released into the water by the berm decreased over the 30 minute testing period. In the second run the amount of phosphates released by the berm was reduced to 0 mg/l within 30 minutes.

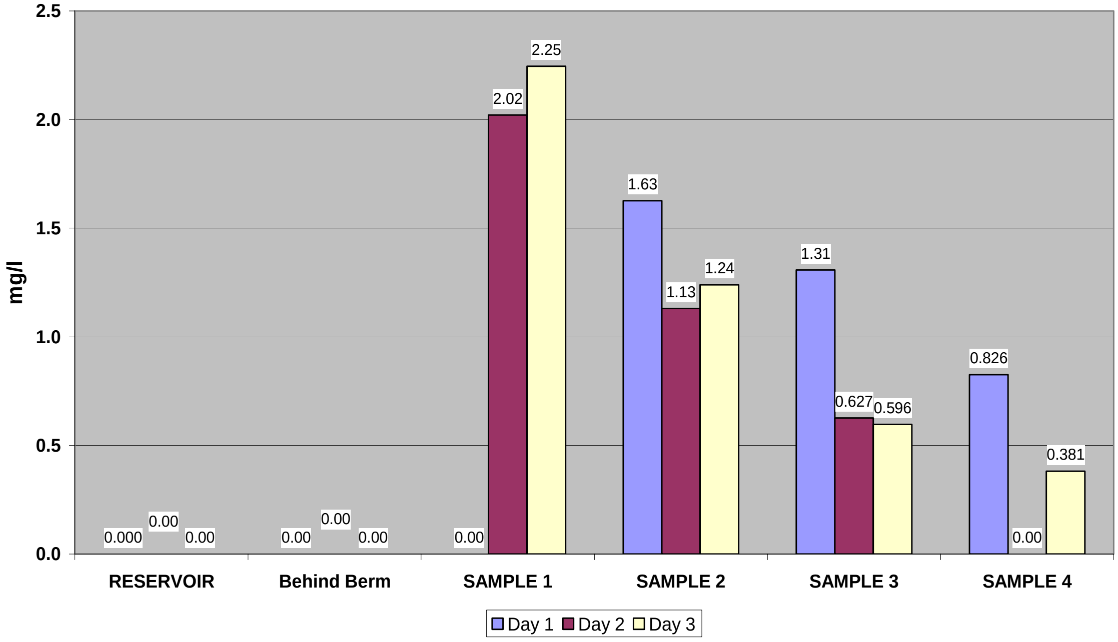

Figure 5.34 Phosphates (PO_4^{-3})-the effect of first flush seen in the trial run.

The 5 day biochemical oxygen demand results presented in Figure 5.35 show a pronounced first flush effect in the first run which gradually diminishes with each run.

These results indicate that the berm releases a large load of contaminants for the first minute. The amount of contaminants released in the water reduced gradually over the 30 minute testing period after which time negligible pollutants are released in the water. Also, with each run the capacity of the berm to release pollutants in the water reduces considerably. This can be explained by a washing effect that the water has over the berm. The water reduces the concentration of the contaminants in the berm by washing them away.

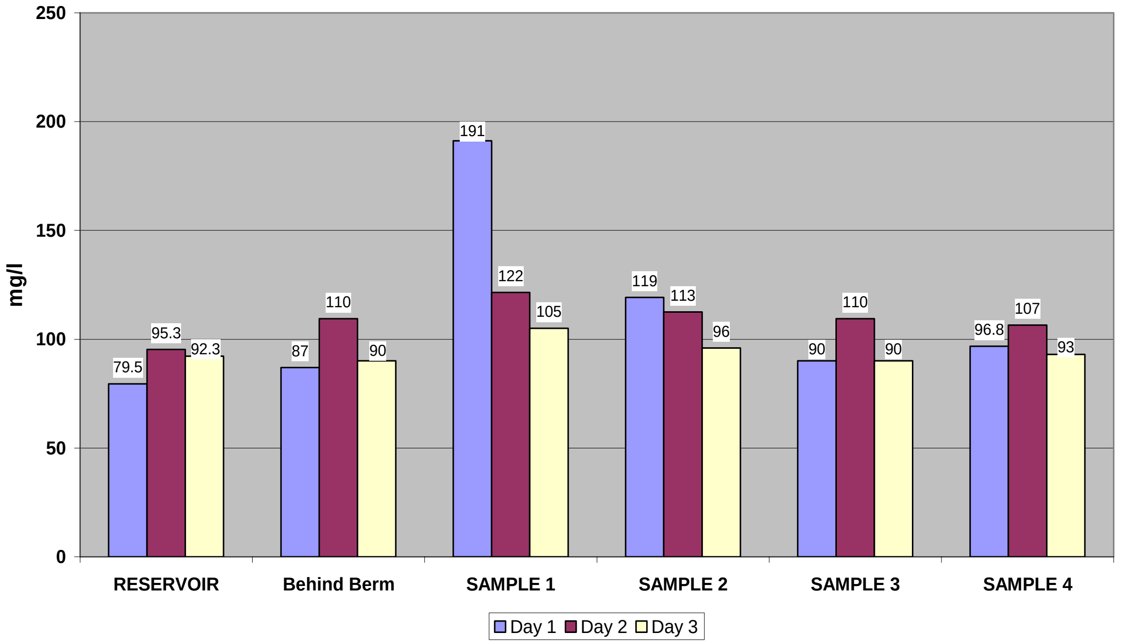

Figure 5.35 BOD_5-the effect of first flush seen in the trial run.

Another explanation for the pronounced first flush effect is the residence time of the water in the berm. For the first couple of minutes water is backing up behind the berm and the rate of infiltration is very slow. This gives the water ample time to remain in contact with the compost and extract contaminants. As the level of water backed up behind the berm rises the water flows or infiltrates through the berm at a much faster rate. This increase in the flow rate does not provide the water enough time to contact the compost and extract contaminants.

STRUCTURAL TESTING

The three berms, namely dairy manure compost, yard waste compost and composted bio-solids were laid and allowed to establish themselves in specially prepared channels for approximately 45 days.

Figure 5.36 Composted bio-solids berm before staring the structural testing.

The berms were vegetated and sprinkled with water to promote the growth of the vegetation. The berms were tested structurally on clay at 3 percent and 7 percent slope. Three runs were carried out with flows of approximately 120 gpm. There was substantial growth of vegetation observed on the composted bio-solids and dairy manure compost berms as can be seen in Figures 5.36 and 5.37.

Figure 5.37 Dairy manure compost berm before starting the structural testing.

However, as shown in Figure 5.38, no growth was observed on the yard waste compost berm. This could be explained by the lack of moisture retention capability of the yard waste compost.

Figure 5.38 Yard waste compost berm before starting the structural testing.

Figure 5.39 Composted bio-solids berm showing minor damages to the leading face.

Figure 5.40 Dairy manure compost berm showing minor damages to the leading face.

The berms withstood all three test runs. Slight damage was observed, as shown in Figure 5.39 and 5.40, in the case of dairy manure compost and composted bio-solids on the leading face where the vegetation was absent. The least damage was observed in the case of yard waste compost as illustrated in Figure 5.41. The slope of the channel seemed to have no effect on the berm. Overtopping was observed in the case of all the berms for both 3 percent and 7 percent slopes. However, there was insignificant damage to the structure of the berm due to overtopping. This showed that the berms could be used as a runoff control method if it were allowed to establish itself, undisturbed and vegetated, in the channel for approximately 45 days. No vegetation would be required in the case of yard waste compost.

Figure 5.41 Yard waste compost berm showing no damages to the leading face.

CONCLUSIONS

During the environmental quality testing a 100% failure was observed. The berms performed better on clay than on sand, where the failure was mainly due to scouring of the sand underneath the berm. This result indicates that the use of compost filter berms on sandy soils is not practicable. The use of compost filter berms in channels is not recommended unless the berm is allowed to establish itself for approximately 6 weeks.

The dairy manure compost and bio-solids promoted growth of vegetation. The yard waste compost inhibited any growth on the berm. However, all three compost berms performed very well in the structural integrity testing with a 0 percent failure. This was mainly due to the fact that the berms were allowed to establish themselves in the channel for approximately 45 days. So the compost in the berm had time to settle down, mature and anchor to the soil in the flume.

The sediment trapping capability of the berms could not be deduced from the results due to failure during sample collection. A drop in dissolved oxygen was observed for all the berms. The yard waste compost berm introduced the least amount of dissolved solids including sulfates, nitrates and phosphates. The nutrients released by yard waste compost were below the limits set for them respectively. The composted bio-solids and the dairy manure compost berm were equally unsatisfactory as both berms introduced substantial quantities of nutrient in the water.

The effect of first flush was evident from the tests on the locally available compost berm. There was a definite spike in the contaminants in the first few minutes of infiltration. The concentration dropped gradually over the 30 minute testing interval until negligible pollutants were released in the water. Also, with each run the capacity of the berm to release pollutants in the water reduces considerably. This can be explained by a washing effect that, by virtue of which, there is a reduction in the concentration of the contaminants in the berm. The marked first flush effect appears to be due to the residence time of the water in the berm. The more time that the water spent in the berm more the contaminants it dissolved from the compost.

RECOMMENDATIONS

For the establishment of this technology as a viable process of erosion control and sediment removal from runoff water, some further research needs to be conducted in the following general areas:

1) Testing on the berms after they have established in the channel to characterize the contaminant input,

2) A column study to characterize the contaminants concentration in the leachate,

3) Alternative method like use of compost sock or additives.

4) Alternative applications for the berm like for perimeter protection.

While the berms failed during the environmental quality testing, they withstood the structural testing. This was attributed to two reasons, the establishment of vegetation on the berms and the 45 day period for which the berm was allowed to establish itself in the channel. Specifically, an investigation into the possibility of allowing the berm to establish itself on-site before testing it for water quality impact on runoff needs to be considered.

Even though extensive tests were performed on the berms the various environmental quality parameters were not well-characterized. A column study will give an idea about the trends of the parameters over time for the various composted materials.

The erosion and sediment control objective can be achieved by using socks filled with the compost materials and anchored in place. Some thought is presently being directed in this direction. Further, investigation using these socks could yield in more conclusive results. Another area that needs to be investigated is the use of additives along with compost and wood chips in the manufacture of the berm compost mix. The study on berms conducted in San Diego State University reported use of additive along with the compost blend at the time of application *(19)*. The use of the compost filter berms in perimeter protection, where no direct stress would be exerted on the berm, should also be considered.

With the present design of the berm, the practical use of the berm is a big environmental risk. On failure, not only will the erosion problem be exacerbated, but also the compost from the berm will be carried with the velocity of flow and eventually transported to the receiving water body. The contaminants in the compost would pollute the water bodies and the nutrients might lead to an accelerated eutrophication process. The compost debris would also have an adverse effect on the aesthetics of the surroundings. This would prove to be a significant environmental risk to the surrounding ecosystem. Even if the berms were structurally stable, the mere possibility of its failure negates the practical application of the compost filter berms as erosion control and sediment trapping devices.

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APPENDIX A

Figure A.1 Testing Channel at the Riverside Campus.

Figure A.2 Picture of the channel without soil.

Figure A.3 Reservoir without water

APPENDIX B

Table B-1: Color (Color Units)

	SOIL TYPE	RESERVOIR	BHD. BERM	SAMPLE 1
DMC-1	CLAY	0	No Sample	425
DMC-2	CLAY	0	No Sample	475
DMC-3	CLAY	0	15	>500
YWC-1	CLAY	0	15	>500
YWC-2	CLAY	0	5	225
YWC-3	CLAY	0	15	500
BS-1	CLAY	0	No Sample	350
BS-2	CLAY	0	10	450
BS-3	CLAY	0	No Sample	400
DMC-1	SAND	0	25	>500
DMC-2	SAND	0	No Sample	450
YWC-1	SAND	0	25	>500
YWC-2	SAND	0	35	475
BS-1	SAND	0	35	450
BS-2	SAND	0	No Sample	500

Table B- 2: Turbidity (NTU)

	SOIL TYPE	RESERVOIR	BHD. BERM	SAMPLE 1
DMC-1	CLAY	6.73	No Sample	350.33
DMC-2	CLAY	9.75	No Sample	2853.67
DMC-3	CLAY	3.67	378	4518
YWC-1	CLAY	1.21	2.39	1499
YWC-2	CLAY	1.057	278	742
YWC-3	CLAY	0.833	117	3072
BS-1	CLAY	1.795	No Sample	3383.5
BS-2	CLAY	2.74	74.55	145.5
BS-3	CLAY	1.057	No Sample	1816.5
DMC-1	SAND	0.592	1707	1334
DMC-2	SAND	1.42	No Sample	1582
YWC-1	SAND	0.849	3849	>10000
YWC-2	SAND	0.196	2991	3585
BS-1	SAND	0.951	3453	546
BS-2	SAND	1.06	No Sample	4575

Table B- 3: Specific Conductance (µS/cm^2)

	SOIL TYPE	RESERVOIR	BHD. BERM	SAMPLE 1
DMC-1	CLAY	$825^{17.6\ C}$	No Sample	$1836^{17.1\ C}$
DMC-2	CLAY	$827^{17.9\ C}$	No Sample	$4150^{17.2\ C}$
DMC-3	CLAY	$848^{18.5\ C}$	$834^{18.5\ C}$	$2910^{18.2\ C}$
YWC-1	CLAY	$926^{19.3\ C}$	$945^{19.3\ C}$	$895^{19.3\ C}$
YWC-2	CLAY	$934^{19.1\ C}$	$930^{19.2\ C}$	$931^{19.2\ C}$
YWC-3	CLAY	$925^{19.2\ C}$	$923^{19.1\ C}$	$1006^{19.1\ C}$
BS-1	CLAY	$947^{19.8\ C}$	No Sample	$3630^{20.0\ C}$
BS-2	CLAY	$904^{19.9\ C}$	$906^{19.9\ C}$	$6880^{20.2\ C}$
BS-3	CLAY	$927^{20.1\ C}$	No Sample	$5530^{20.1\ C}$
DMC-1	SAND	$902^{19.7\ C}$	$953^{19.7\ C}$	$5770^{19.7\ C}$
DMC-2	SAND	$941^{19.7\ C}$	No Sample	$7920^{19.7\ C}$
YWC-1	SAND	$897^{19.7\ C}$	$907^{19.7\ C}$	$1146^{19.7\ C}$
YWC-2	SAND	$896^{19.7\ C}$	$900^{19.6\ C}$	$1095^{19.5\ C}$
BS-1	SAND	$976^{19.7\ C}$	$979^{19.7\ C}$	$5250^{19.7\ C}$
BS-2	SAND	$920^{19.7\ C}$	No Sample	$8540^{19.7\ C}$

Table B- 4: Total Suspended Solids TSS (g/l)

	SOIL TYPE	RESERVOIR	BHD. BERM	SAMPLE 1
DMC-1	CLAY	0.0120	No Sample	0.5160
DMC-2	CLAY	0.1000	No Sample	8.8560
DMC-3	CLAY	0.0080	0.8400	3.7200
YWC-1	CLAY	0.0080	0.4760	1.4640
YWC-2	CLAY	0.0080	0.0560	0.7200
YWC-3	CLAY	0.0040	0.2400	3.5480
BS-1	CLAY	0.0000	No Sample	9.5920
BS-2	CLAY	0.0000	0.2600	4.5760
BS-3	CLAY	0.0000	No Sample	0.4960
DMC-1	SAND	0.0000	2.0040	3.2720
DMC-2	SAND	0.0000	No Sample	6.2840
YWC-1	SAND	0.0080	4.2320	9.3760
YWC-2	SAND	0.0040	3.2400	5.6600
BS-1	SAND	0.0080	3.4640	2.0760
BS-2	SAND	0.0360	No Sample	9.2000

Table B- 5: Total Dissolved Solids TDS (g/l)

	SOIL TYPE	RESERVOIR	BHD. BERM	SAMPLE 1
DMC-1	CLAY	0.74	No Sample	2.06
DMC-2	CLAY	0.67	No Sample	4.98
DMC-3	CLAY	0.65	0.90	1.90
YWC-1	CLAY	0.69	0.67	1.14
YWC-2	CLAY	0.61	0.71	0.98
YWC-3	CLAY	0.63	0.66	0.96
BS-1	CLAY	0.72	No Sample	3.63
BS-2	CLAY	0.60	0.66	8.40
BS-3	CLAY	0.69	No Sample	6.26
DMC-1	SAND	0.70	1.09	5.36
DMC-2	SAND	0.00	No Sample	7.62
YWC-1	SAND	0.72	0.88	1.18
YWC-2	SAND	0.69	0.97	1.07
BS-1	SAND	0.73	0.83	5.60
BS-2	SAND	0.65	No Sample	9.83

Table B- 6: Dissolved Oxygen DO (mg/l)

	SOIL TYPE	RESERVOIR	BHD. BERM	SAMPLE 1
DMC-1	CLAY	7.9	No Sample	6.0
DMC-2	CLAY	7.7	No Sample	5.8
DMC-3	CLAY	8.1	7.7	6.4
YWC-1	CLAY	6.8	6.5	5.3
YWC-2	CLAY	7.0	6.7	5.6
YWC-3	CLAY	6.9	6.6	5.6
BS-1	CLAY	7.4	No Sample	5.6
BS-2	CLAY	7.9	7.3	6.3
BS-3	CLAY	7.5	No Sample	5.8
DMC-1	SAND	7.2	7.0	4.8
DMC-2	SAND	7.8	No Sample	5.6
YWC-1	SAND	8.0	7.5	6.0
YWC-2	SAND	7.6	7.1	5.4
BS-1	SAND	7.6	7.1	5.8
BS-2	SAND	7.0	No Sample	5.0

Table B- 7: pH

	SOIL TYPE	RESERVOIR	BHD. BERM	SAMPLE 1
DMC-1	CLAY	8.17	No Sample	7.46
DMC-2	CLAY	8.20	No Sample	7.52
DMC-3	CLAY	8.78	8.23	7.41
YWC-1	CLAY	8.53	7.54	7.51
YWC-2	CLAY	8.23	8.59	7.63
YWC-3	CLAY	8.63	8.55	7.52
BS-1	CLAY	8.42	No Sample	7.23
BS-2	CLAY	8.33	8.36	7.34
BS-3	CLAY	8.45	No Sample	7.39
DMC-1	SAND	8.73	8.60	7.62
DMC-2	SAND	8.46	No Sample	7.39
YWC-1	SAND	8.31	8.23	7.70
YWC-2	SAND	8.46	8.39	7.59
BS-1	SAND	8.32	8.12	7.33
BS-2	SAND	8.41	No Sample	7.81

Table B- 8: Alkalinity (mg/l as $CaCO_3$)

	SOIL TYPE	RESERVOIR	BHD. BERM	SAMPLE 1
DMC-1	CLAY	377.3	No Sample	419.6
DMC-2	CLAY	384.1	No Sample	307.4
DMC-3	CLAY	371.9		378.1
YWC-1	CLAY	364.8	317.1	272.2
YWC-2	CLAY	358.7	359.5	349.1
YWC-3	CLAY	351.0	353.4	332.1
BS-1	CLAY	357.8	No Sample	389.6
BS-2	CLAY	349.2	347.9	338.6
BS-3	CLAY	365.6	No Sample	336.8
DMC-1	SAND	324.5	381.1	449.1
DMC-2	SAND	386.7	No Sample	466.5
YWC-1	SAND	329.2	354.8	344.2
YWC-2	SAND	344.1	340.7	345.3
BS-1	SAND	365.8	376.9	276.2
BS-2	SAND	352.9	No Sample	182.4

Table B- 9: Sulfates (mg/l)

	SOIL TYPE	RESERVOIR	BHD. BERM	SAMPLE 1
DMC-1	CLAY	28.747	No Sample	101.510
DMC-2	CLAY	14.927	No Sample	285.733
DMC-3	CLAY	16.058	16.346	213.763
YWC-1	CLAY	16.3528	16.9680	29.8397
YWC-2	CLAY	16.5455	16.2218	17.8290
YWC-3	CLAY	14.8385	14.9143	28.7516
BS-1	CLAY	14.404	No Sample	972.268
BS-2	CLAY	13.122	16.601	1308.323
BS-3	CLAY	11.093	No Sample	1195.233
DMC-1	SAND	15.546	14.075	609.470
DMC-2	SAND	15.493	No Sample	154.661
YWC-1	SAND	19.716	19.976	22.701
YWC-2	SAND	21.913	22.174	24.606
BS-1	SAND	21.943	23.833	1037.562
BS-2	SAND	19.331	No Sample	1214.432

Table B- 10: Chlorides (mg/l)

	SOIL TYPE	RESERVOIR	BHD. BERM	SAMPLE 1
DMC-1	CLAY	79.013	No Sample	0.000
DMC-2	CLAY	79.554	No Sample	36.223
DMC-3	CLAY	78.119	78.987	15.949
YWC-1	CLAY	70.2234	71.6854	78.2779
YWC-2	CLAY	70.4016	70.9253	72.3936
YWC-3	CLAY	67.7182	67.6534	77.9481
BS-1	CLAY	66.361	No Sample	103.877
BS-2	CLAY	66.088	68.546	233.422
BS-3	CLAY	65.774	No Sample	192.956
DMC-1	SAND	65.264	67.522	654.287
DMC-2	SAND	65.289	No Sample	211.690
YWC-1	SAND	67.883	67.322	100.622
YWC-2	SAND	68.897	68.683	96.486
BS-1	SAND	76.503	78.026	163.088
BS-2	SAND	69.448	No Sample	221.726

Table B- 11: Nitrites (mg/l)

	SOIL TYPE	RESERVOIR	BHD. BERM	SAMPLE 1
DMC-1	CLAY	0.000	No Sample	483.513
DMC-2	CLAY	0.000	No Sample	285.980
DMC-3	CLAY	0.000	0.000	204.127
YWC-1	CLAY	0	0	0
YWC-2	CLAY	0	0	0
YWC-3	CLAY	0	0	0
BS-1	CLAY	0.000	No Sample	102.986
BS-2	CLAY	0.000	0.000	0.000
BS-3	CLAY	0.000	No Sample	6.65
DMC-1	SAND	0.000	0.000	5.660
DMC-2	SAND	0.000	No Sample	1.875
YWC-1	SAND	0.000	0.000	0.000
YWC-2	SAND	0.000	0.000	0.000
BS-1	SAND	0.000	0.000	0.000
BS-2	SAND	0.000	No Sample	0.000

Table B- 12: Nitrates (mg/l)

	SOIL TYPE	RESERVOIR	BHD. BERM	SAMPLE 1
DMC-1	CLAY	2.243	No Sample	256.970
DMC-2	CLAY	2.269	No Sample	68.181
DMC-3	CLAY	3.774	4.050	37.414
YWC-1	CLAY	2.1288	2.3066	0.5249
YWC-2	CLAY	2.1744	2.1888	2.2268
YWC-3	CLAY	1.8674	2.1152	0.3854
BS-1	CLAY	3.505	No Sample	425.908
BS-2	CLAY	5.695	4.496	1514.269
BS-3	CLAY	4.516	No Sample	1033.573
DMC-1	SAND	4.981	6.141	1935.602
DMC-2	SAND	4.766	No Sample	547.094
YWC-1	SAND	7.488	4.642	8.712
YWC-2	SAND	5.19	6.281	12.779
BS-1	SAND	5.985	6.677	1305.075
BS-2	SAND	3.357	No Sample	187.412

Table B- 13: Phosphates (mg/l)

	SOIL TYPE	RESERVOIR	BHD. BERM	SAMPLE 1
DMC-1	CLAY	0.000	No Sample	0.000
DMC-2	CLAY	0.000	No Sample	22.369
DMC-3	CLAY	0.000	0.000	14.330
YWC-1	CLAY	0.5883	0.4456	2.7445
YWC-2	CLAY	0.5101	0.5395	1.6363
YWC-3	CLAY	0.2494	0.3448	3.9253
BS-1	CLAY	0.708	No Sample	4.982
BS-2	CLAY	0.757	0.946	4.210
BS-3	CLAY	0.71	No Sample	4.294
DMC-1	SAND	0.464	0.849	42.692
DMC-2	SAND	0.448	No Sample	24.249
YWC-1	SAND	0.737	0.616	3.657
YWC-2	SAND	0.557	0.633	4.013
BS-1	SAND	0.833	0.593	2.130
BS-2	SAND	0.951	No Sample	0.867

Table B- 14: BOD_5 (mg/l)

	SOIL TYPE	RESERVOIR	BHD. BERM	SAMPLE 1
DMC-1	CLAY	28.2	No Sample	>106.8
DMC-2	CLAY	26.4	No Sample	>106.8
DMC-3	CLAY	26.4	19.0	>100.8
YWC-1	CLAY	16.8	9.8	37.1
YWC-2	CLAY	9.8	12.3	12.0
YWC-3	CLAY	15.0	12.3	32.8
CBS-1	CLAY	1.2	No Sample	35.7
CBS-2	CLAY	0.0	0.9	>105.6
CBS-3	CLAY	0.0	No Sample	>100.8
DMC-1	SAND	14.4	15.6	24.6
DMC-2	SAND	13.2	No Sample	18.3
YWC-1	SAND	14.4	9.6	30.8
YWC-2	SAND	10.6	14.4	18.0
CBS-1	SAND	14.4	9.6	22.8
CBS-2	SAND	14.4	No Sample	25.2

Table B- 15: Total Coliform (MPN/100ml)

	SOIL TYPE	RESERVOIR	BHD. BERM	SAMPLE 1
DMC-1	CLAY	<1	No Sample	<1
DMC-2	CLAY	<1	No Sample	<1
DMC-3	CLAY	<1	50.6	<1
YWC-1	CLAY	<1	<1	3481.6
YWC-2	CLAY	4	<1	172.8
YWC-3	CLAY	<1	29.6	4044.4
BS-1	CLAY	383.6	No Sample	4044.4
BS-2	CLAY	4	2004.8	4044.4
BS-3	CLAY	383.6	No Sample	4044.4
DMC-1	SAND	<1	53.6	3022
DMC-2	SAND	<1	No Sample	3022
YWC-1	SAND	<1	319.2	4044.4
YWC-2	SAND	108.8	79.6	1376.4
BS-1	SAND	<1	93.2	3481.6
BS-2	SAND	<1	No Sample	4044.4

Table B- 16: Fecal Coliform (MPN/100ml)

	SOIL TYPE	RESERVOIR	BHD. BERM	SAMPLE 1
DMC-1	CLAY	<1	No Sample	<1
DMC-2	CLAY	<1	No Sample	<1
DMC-3	CLAY	<1	<1	<1
YWC-1	CLAY	<1	<1	4
YWC-2	CLAY	4	<1	8
YWC-3	CLAY	<1	<1	32.4
BS-1	CLAY	<1	No Sample	131.2
BS-2	CLAY	<1	<1	4044.4
BS-3	CLAY	<1	No Sample	4044.4
DMC-1	SAND	<1	<1	<1
DMC-2	SAND	<1	No Sample	<1
YWC-1	SAND	<1	<1	168.4
YWC-2	SAND	<1	<1	38
BS-1	SAND	<1	<1	45.6
BS-2	SAND	<1	No Sample	8

VITA

Aditya B. Raut Desai, son of Babu and Ashika Raut Desai, was born July 17, 1977 in Bombay, the economic hub of India.

He graduated from Dhempe High School in 1994, and then attended Goa University in Farmagudi, Goa, India. After graduating with honors from Goa University, with a B.S. degree in civil engineering in June 1998, he worked in IITM as a research associate.

In September 2001, the author enrolled in graduate school at Texas A&M University in College Station, Texas. Since then he has worked as a teaching assistant in the Civil Engineering Department, as well as a research assistant for the Texas Transportation Institute (TTI).

The author’s permanent address is:
F-2, Periera Apartments,
Behind PWD, Div-4,
Murida, Fatorda,
Margao, Goa,
India 403-601