STORMWATER FILTRATION OF A MUNICIPAL DETENTION POND

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ABSTRACT

Wood- and nonwood-based fibers have been found to have a significant sorption capacity for ionized copper, a heavy metal commonly found in stormwater. The USDA-FS Forest Products Laboratory (Madison, WI) is conducting research on the potential of utilizing natural wood- and nonwood-based fibers in stormwater treatment. The problem with the current practice of stormwater filtration is that it requires a large area, can be very expensive, and typically does not solve the problem of fine suspended particles or dissolved pollutants. The integration of these fibers into a stormwater filtration system can be advantageous due to its relatively low cost, biodegradability, and regenerative capacity. The objective of this research is to explore the potential use of kenaf bast and core fibers, and their associated efficiency variables as a filter for reduction of non-point pollution in stormwater.

INTRODUCTION

Heavy metals such as cadmium (Cd), copper (Cu), lead (Pb), and zinc (Zn) and nutrients such as nitrogen (N) and phosphorus (P) are major pollutants of water. In addition to heavy metals, a significant amount of pesticides and herbicides are washed into flowing water bodies from non-point sources. Finally, other non-point sources such as households, automobiles, and airports generate oils, grease, and glycols which can be collected by runoff and deposited in nearby bodies of water. The concentrations of these pollutants are relatively moderate, but the volume of contaminated water is large and flows can be irregular, especially in an urban environment. Removal of these pollutants in stormwater runoff is often difficult and expensive using conventional best-management practices (BMPs).

Wood- and nonwood-based water filters are currently being tested to reduce non-point source pollution. Efforts are being directed towards developing a water filtration system which is easy to install and maintain, is relatively inexpensive, and can be recycled or regenerated. The price of wood- and nonwood-fibers is inexpensive per metric ton (t) compared to some other filtration mediums (a metric ton of wood fiber at $72, kenaf at $166 versus activated charcoal at $3,333 U.S. currency), and there is less problem with disposal.

Continuous research on developing a wood- and nonwood-based fiber filtration system for stormwater is being conducted at the FPL in Madison, WI. The selection process between a wood- and nonwood-based fiber concentrated on cation-exchange capacity. According to a FPL study, highly purified cellulose has low cation-exchange capacity and the lignin portion of the plant fiber has almost zero capacity. The process of extraction decreases ion-exchange capacity in nonwood-based fibers. The most valuable information in regard to the ion-exchange capacity was learned accidentally during the course of studying the chemical and physical property of kenaf as a function of growth (Han et al. 1995). It was observed that the young plants possessed a higher ion-exchange capacity than the mature plants (49-day old kenaf had 60% higher capacity than 149-day old kenaf, and 98-day old had 20% more capacity than 149-day old kenaf). There are many ways of increasing the capacity by chemically modifying the plant fiber, but these processes are expensive (Kunin et al. 1984, Morita et al. 1987).

The goal of this research is to learn more about the fundamentals of filtration in order to improve the selection process for filter substrates and apply it to a working system in an urban environment. Once a filter substrate has been selected, its hydraulic properties must be studied in order to optimize flow in a real-world system.

REVIEW OF LITERATURE

Historically, one of the most efficient filters has been activated charcoal; the matrix is modified wood. Recent research of wood and nonwood-based fibers as filtration media started in early 1970s when the atomic absorption Spectrophotometer was introduced, making it easy for the analysis of metal ions. Obviously, filtration was targeted toward ionized heavy metals.

Randall et al. (1974) worked on removal of heavy metals using various barks and eventually expanded their work to peanut skins (Randall et al. 1975). Randall et al. (1978) chemically modified peanut skins using formaldehyde for heavy metal removal in aqueous waste solutions. Masri et al. (1974) also investigated binding of mecuric chloride and other metal salts by natural substances using x-ray analysis on a wider range of substrates. The work of Kumar and Dara (1979) included bagasse, acacia bark, husk, paddy straw, wheat flour, and waste peanut skin, and Kumar and Dara (1981) included onion skin.

Matis and Zouloulis (1994) used dead industrial biomass to remove cadmium and other heavy metals from wastewater. The works of Shukla and Sakhadande (1990, 1991, 1992) concentrated on treating cotton fibers, bamboo pulp, jute fibers, and sawdust with reactive dyes to remove cupric ion. Four more ions, Fe^{2+}, Fe^{3+}, Pb^{2+} and Hg^{2+}, were added for testing in 1991. Finally in 1992, copper and zinc metal ions were studied along with the previous metals using adsorption columns for a continuous process making it more economically efficient.

The general approach at this point was pulverizing fibers into rather small particles, thereby maximizing the amount of contact between fibers and ionized heavy metal solution. Regeneration was performed by leaching out the adsorbed metals by dilute mineral acids. Finally, it was learned that the pH of the aqueous solution needed to be neutral or basic because tannins from the barks played a major role in ion-exchange, and extractives of the plants also contributed towards increased capacity of ion-exchange.

Chemical modification became popular and many researchers devised elaborate modification procedures (Morita 1987). Suemitsu et al. (1986) used dyestuff-treated rice hulls for removal of heavy metals. Odozi et al. (1985) polymerized corn cob, sawdust and onion. Sawamiappan and Krishnamoorthy (1984) replaced phenol-formaldehyde cationic matrices with sulfonated bagasse. Freeland et al. (1974) used polyethylenimine-modified wood to adsorb mercury. Snyder and Vigo (1974) modified cotton ethylenediamine with chlorodeoxycellulose to remove mercury. Gasparrini et al. (1976) captured mercury ions using cellulose derivatives. Marchant (1974) removed mercury using cellulose modified by changing the pH from 1 to 9. Treatment of soybean hulls and sugar beet fiber with epichlorohydrin to improve cation-exchange capacity was studied by Laszlo and Dintzis (1994).

Mechanisms and measurement of chemical modification were studied by Kunin et al. (1984). They developed a water treatment unit by combining filtration and ion exchange into a single unit. This unit had a disposable and non-regenerable basis. Later a U.S. patent was issued on this technique (Patent No. 109, 112, 777).

The role of lignin in removal of copper is controversial and inconclusive. Camire and Clydesdale (1981) found that lignin and pectin have a high metal binding capability. They also tested the effect of pH and heat on removal of the copper ions. Varma et al. (1989, 1990) removed copper between the pH 4.4 and 5.0. Yet, LeBow (1992) removed it at pH 10 to 12.

McFeeters, and Armstrong (1983) studied the measurement of pectin methylations in plant cell walls. Hutchinson and Bailar (1984) conducted adsorption of chiral metallized azo dyes on natural fibers. McKay et al. (1987, 1988) studied equilibrium and transport processes using bagasse pith. Platt and Clysdale (1985) studied binding of iron by lignin in the presence of other ions. Nasr and MacDonald (1978) did stoichiometric studies with carboxylic acids groups on lignin compounds toward aluminum and iron ions at lower pHs. Lignin was used in removal of copper at pH 5.5, cadmium at pH 6.5. Gergova et al. (1993) stated that under the same conditions of treatment, the physico-chemical and adsorption characteristics of activated carbon depends on the composition of the initial raw materials. This statement coincides with the approach in this study.

In a recent study by the FPL (unpublished) agro-based fibers such as kenaf, roselle, and tobacco fibers have been shown to have potential as effective materials for absorption of heavy metals in stormwater filtration systems. Conversely, most wood-based fibers have a relatively low capacity for filtering heavy metals. In the past, there have been attempts (Randall et al. 1974, Gasparrini et al. 1976, Randall 1977, Morita et al. 1987) to chemically modify wood-based fiber in order to increase its sorption capacity. However the process was either too expensive or it has resulted in creating another problem: bleeding of excessive quantities of colored organic compounds, odor, or further pollution of the environment due to application of toxic chemicals.

MATERIALS AND METHODS

Selection of Fibers

To determine the filtration capacity of various fibers on copper ion retention, a standard solution of about mg 40 mg kg^{-1} (ppm) copper sulfate was run through a 1 cm ID, 10 cm long chromatographic column containing 0.5 g of fiber. The copper ion concentration was measured before and after the elution using an atomic absorption spectrophotometer.

Monroe Street Wet Detention Pond-Madison, WI

A typical urban stormwater detention pond was selected in order to analyze various pollutants entering and leaving the pond, and how a fiber-based system can be utilized to increase the water quality of the effluent. A wet detention pond for stormwater runoff located in the University of Wisconsin-Arboretum in the City of Madison was selected to study the amount of pollutants generated in an urban watershed and to determine how effective wood- and nonwood-based systems can filter these pollutants. The primary purpose for a wet detention pond is to help reduce water-quality degradation of the receiving waters.

The Monroe Street detention pond was designed and constructed by the University of Wisconsin Arboretum to help settle larger particles which may carry some organic/inorganic pollutants. Unfortunately, smaller particles and dissolved pollutants have a tendency to pass through the pond and flow into the receiving waters of Lake Wingra.

The Monroe Street detention pond handles stormwater runoff from a 0.96 km^2 residential and commercial area. The pond has a surface area of 5,670 m^2 and was designed to handle a 10-year, 24-hour stomwater-runoff volume (House et. al. 1993). The pond has two outlet channels leading into Lake Wingra (Figure 39.1).

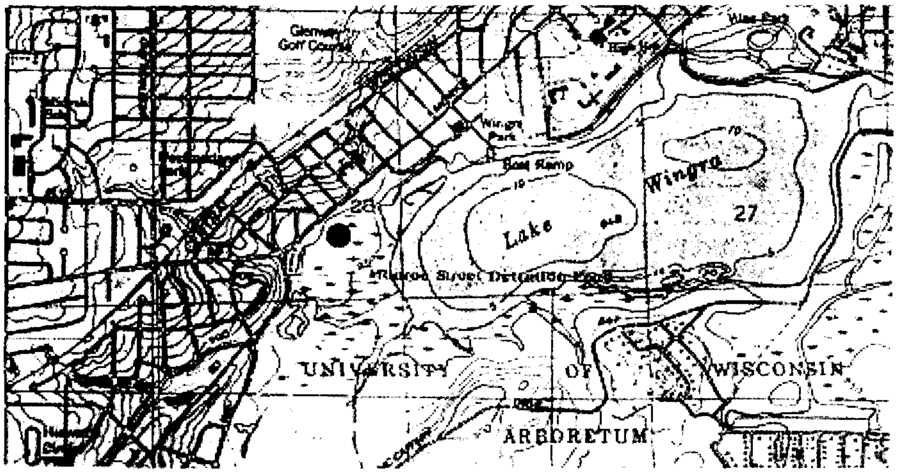

Figure 39.1. Monroe Street detention pond, Madison, Wisconsin (A black dot left side of Lake Wingra).

Kenaf Filtration System

The filtration system was designed by the U.S. Geological Survey (USGS) in cooperation with the FPL (Figures 39.2 and 39.3). The system was placed at the southern outlet of Monroe Street detention pond. The outlet from the detention pond into the tributary contains a 711-mm culvert. An outlet riser was retrofitted onto the existing culvert and reduced the culvert size to 610 mm. Finally the adoption was connected to the filtration system. The filtration system dimensions are 3.6 x 1.2 x 1.3 m which contained eight individual boxes packed with kenaf fiber and core. Each individual box is 1219 x 444 x 229 mm and contained approximately 6.8 kg of kenaf fiber/core at a 2:1 mixture.

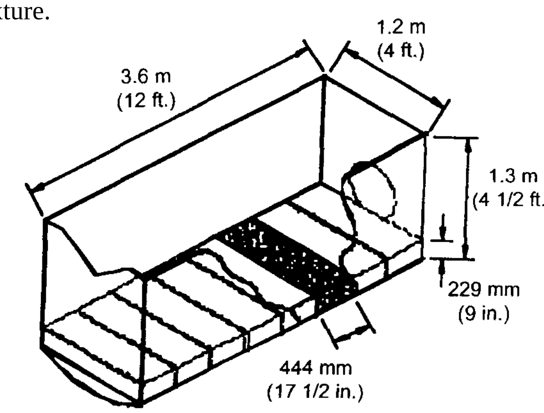

Figure 39.2. Dimensions of Monroe Street filtration box.

Figure 39.3. Photo – Monroe Street filtration box.

Several samples were collected by the USGS using an ISCO, Inc., Lincoln, NE (ISCO) sampler before the water enters and after the water leaves the filtration system. Samples were taken 3 hours apart each day for 14 days. Several grab samples were taken and split on site. The split samples were passed through a 0.4511 capsule filter and the dissolved fraction portion of the water sample was preserved in acid.

Five tests were conducted on both 9/29/96 and 10/18/96 and ten tests on 10/29/96, with each sample tested for chemical oxygen demand (COD), total suspended solids (TSS), phosphorus, nickel, and copper. Analysis on copper and nickel was done by FPL-Analytical Chemistry and Microscopy Laboratory and by the State of Wisconsin Lab of Hygiene. COD, phosphorus and total suspended solids analysis were performed at the FPL in cooperation with the Department of Civil and Environmental Engineering, University of Wisconsin-Madison. The standard methods of procedure for each sample were: COD Procedure 5220-D, TSS procedure 2540-D, and phosphorus procedure 4500-p(E) (Greenberg et al. 1992), and copper and nickel were analyzed by an Atomic Absorption Spectrophotometer-Furnace Procedure.

RESULTS AND DISCUSSION

Table 39.1 shows the sorbent capacity of copper with the last column displaying the fibering capacity (in mg) of copper ions to various fibers (g). It was determined that neither pure lignin nor cellulose alone was a good candidate in filtration of copper ions (Table 39.1); it seems that lignin or cellulose need to have some additiona1 chemical or physical components in order to behave as an ion-exchanger. However, there seems to be a trend that plants with low lignin content have higher ion-exchange capacities. The reason why some fibers have high ion-exchange capacity and some do not is not well understood. The most logical explanation could be the structure of the fiber combined with chemical compounds of the fiber surface (Tshabalala and Han 1997). This topic will be further explored at the FPL.

Table 39.1. Sorbent capacity of copper at pH 5.5, unit mg/g of substrate.

Common name	Botanical name	Classification	Lignin %	Capacity
Bagasse	*Saccharum officinarum*	Straw fiber	19.9	0.3
Oak	*Quercus spp.*	Hardwood fiber	23.2	0.7
Gum	*Liquidambar styraciflua*	Hardwood fiber	24.3	0.7
Aspen	*Populus grandidentata*	Hardwood fiber	21.8	0.9
Redcedar, Eastern	*Juniperus virginiana*	Softwood fiber	40.0	1.2
Loblolly Pine, core	*Pinus taeda*	Softwood fiber	36.4	1.5
Lecheguilla	*Agave lecheguilla*	Bast fiber	15.2	2.0
Coconut Shell	*Cocos nucifera*	Shell	35.7	2.6
Jute	*Corchorus capsularis*	Bast fiber	13.7	3.8
Sisal	*Agave sisalana*	Leaf fiber	12.7	4.9
Kudzu, Fiber	*Pueraria lobata*	Bast fiber	15.7	5.2
Abacca	*Musa textilis*	Leaf fiber	12.7	5.5
Roselle	*Hibiscus sabdariffa*	Bast fiber	9.7	7.3
Flax	*Linum usitatissimum*	Bast fiber	2.9	7.7
Kudzu, Bark	*Pueraria lobata*	Bast fiber	19.3	8.2
Kenaf, Fiber	*Hibiscus cannabinus*	Bast fiber	9.9	8.5
Hemp	*Cannabis sativa*	Bast fiber	3.0	9.7
Salicornia	*Salicornia bigelovii*	Bast fiber	13.5	10.1
Tobacco, Fiber	*Nicotina tabacum*	Bast fiber	16.5	10.7
Sunn Hemp	*Crotalaria juncea*	Bast fiber	11.1	11.8
Tobacco, Bark	*Nicotina tabacum*	Bast fiber	9.7	14.3
Lignin	Repap	--	--	0.1
Cellulose	Microcrystalline, Avicel PH-101	--	--	1.3

Tobacco fiber has the highest Cu^{++} capacity and there are several other types of fibers that would give higher capacity. It should be noted that kenaf was not the most efficient fiber. However, kenaf was selected as a candidate in this study because tobacco bark, even with a rather high capacity, smells of nicotine which was not desired, and also, it was difficult to only get the bark part of the plant. Sunn hemp and other plants were difficult to get in great quantity. Also, it was learned that kenaf fiber is fairly good sorbent for oil (Han and Lee 1997) and pesticides (unpublished FPL data). In this study, kenaf core, and kenaf bast fibers were selected as experimental substrates for the stormwater filtration system. It was also learned that the Cu^{++} sorbed by the fiber could be removed by dilute mineral acid, thus making regeneration of the filter possible.

The results obtained from the Monroe Street detention pond were inconclusive. Concentrations in the influent of each parameter were generally low. All of the measured parameters on each of the sampling days were in parts per billion. Table 39.2, Figures 39.4,39.5, and 39.6 summarize results from three independent rainfall events.

Several problems occurred at the test site. Although a detention pond is generally designed to settleout sediment, an increase in frequency of storm events may inhibit the settling rate of fine particulate matter. As a result, fine sediment is carried out of the detention pond and into the receiving tributaries. The filtration system was experiencing clogging due to the particulate matter and other materials such as trash and leaves. Meteorological factors also affected the filtration system. Towards the end of the sampling period, periodic freezing and thawing caused the wood to warp, therefore, significantly damaging the system. More analysis on this site will be available soon in regards to actual analysis of fiber rather than the influent and effluent waters which was the main goal of the study.

Table 39.2. Filtration of stormwater at Monroe Street detention pond, µg L^{-1}.

Date Sampled	Cu		Ni		COD		P		TSS[a]	
	in	out	in	out	in	out	in	out	in	out
9/29/96	1.9	1.5	8.0	5.0	34.2	35.8	0.31	0.24	34	32
9/29/96	2.1	1.0	11.0	7.0	27.7	24.4	0.26	0.26	31	26
9/29/96	2.8	1.9	16.0	10.0	30.9	16.3	0.25	0.14	39	26
9/29/96	1.9	1.8	10.0	6.0	24.4	11.5	0.21	0.14	22	22
9/29/96	2.2	3.0	7.0	9.0	24.4	17.9	0.22	0.16	24	17
Average	2.2	1.8	10.4	7.4	28.3	21.2	0.3	0.2	30.0	24.6
10/18/96	3.4	2.7	5.1	3.2	59.4	52.3	0.49	0.48	24	22
10/18/96	3.3	3.2	3.9	2.9	55.8	55.8	0.57	0.57	83	61
10/18/96	2.3	2.2	3.3	3.6	48.7	48.7	0.47	0.44	38	33
10/18/96	2.8	2.0	3.4	3.7	41.6	41.6	0.48	0.47	33	30
10/18/96	2.5	2.4	3.0	2.5	41.6	38.1	0.50	0.49	59	21
Average	2.9	2.5	3.7	3.2	49.4	47.3	0.5	0.5	47.4	33.4
10/29/96	2.2	2.6	2.7	2.8	77.2	59.4	0.83	0.82	23	21
10/29/96	1.5	1.9	3.8	3.7	70.1	52.3	0.92	0.78	38	37
10/29/96	2.8	2.1	3.5	3.9	70.1	55.8	0.92	0.92	44	42
10/29/96	2.0	1.5	3.4	3.2	52.3	66.5	0.89	0.86	38	37
10/29/96	2.5	1.4	3.5	2.6	73.6	59.4	0.85	0.81	33	32
10/29/96	2.0	3.2	3.3	2.1	72.6	59.4	0.83	0.83	25	23
10/29/96	8.8	3.7	2.8	0.7	66.5	55.8	0.87	0.82	57	54
10/29/96	2.3	2.7	3.0	1.0	59.4	55.8	0.83	0.78	30	31
10/29/96	4.0	3.1	4.2	1.1	66.5	70.1	0.81	0.81	38	34
Average	3.1	2.5	3.4	2.3	67.6	59.4	0.9	0.8	36.2	34.6

[a] TSS = total suspended solids

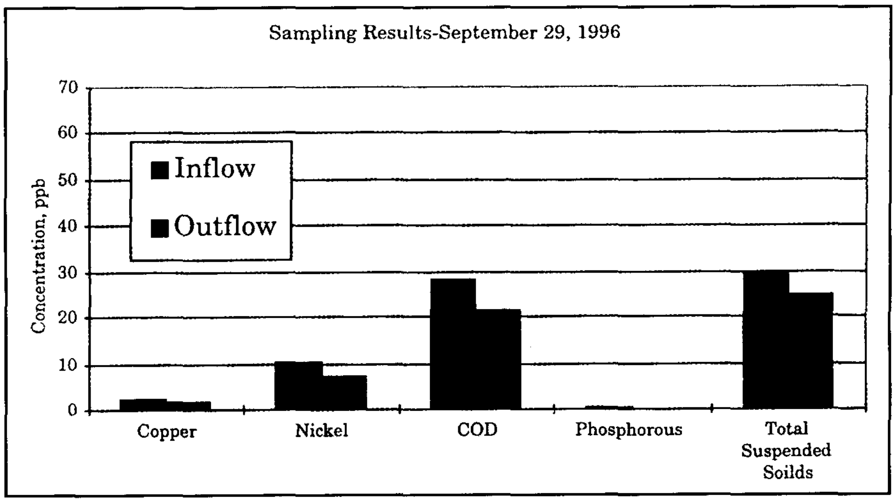

Figure 39.4. Sampling results from 9/29/96.

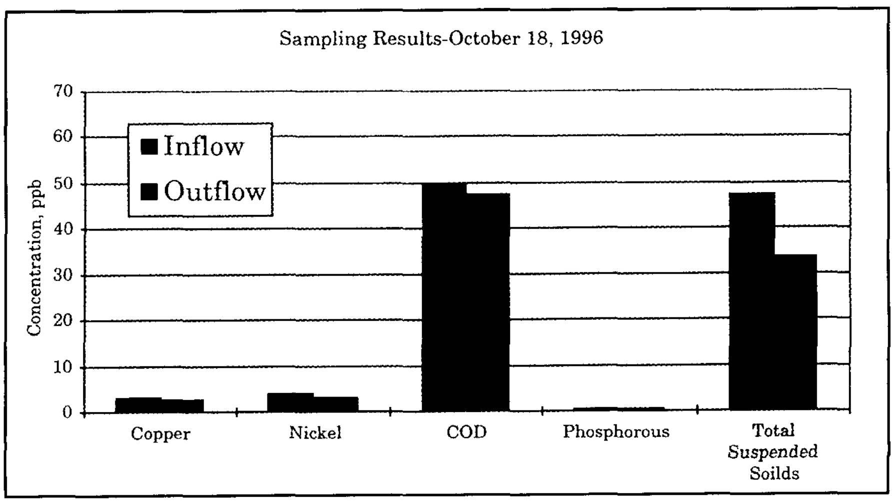

Figure 39.5. Sampling results from 10/18/96.

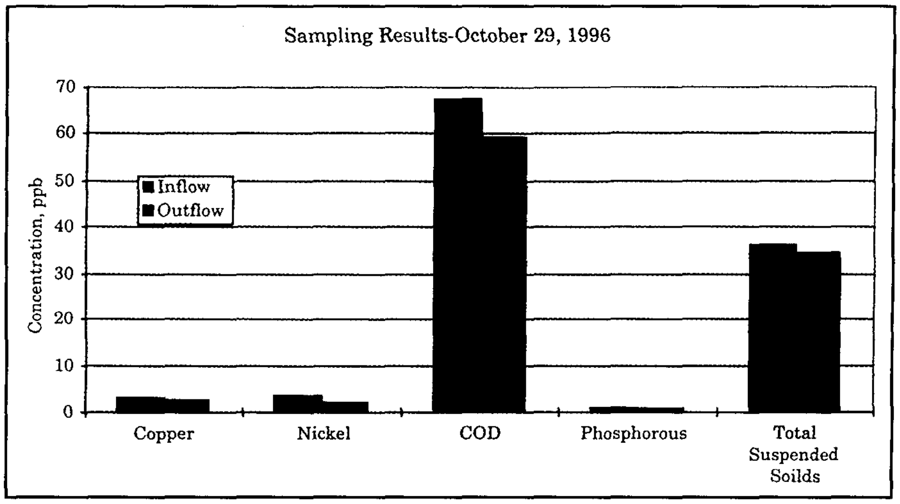

Figure 39.6. Sampling results from 10/29/96.

FUTURE STUDIES

The kenaf filtration system is still in the early stages of development. Future studies may concentrate on the engineering design of the system in materials, dimensions and layout. Ease of media replacement, algae growth and foreign debris minimization, and feasibility of installation are several design considerations which can enhance the effectiveness of the system. The construction materials should be selected based on the environmental factors and cost of the project.

In this case study, geotextile material, which is often used in silt fencing on construction sites, was used to encase the kenaf bast fiber and core. The geotextile effectively trapped debris from entering the media, but was often clogged due to fine particulate matter.

Other future studies may focus on the nature of the kenaf bast and core material. Optimum size, sorting, mixture and packing can significantly affect the performance of stormwater filtration. The "bunching" nature of the media created a piping effect for the water to quickly flow through the system bypassing much of the filtration mechanism. Studies are currently being done on enhancing flow and minimizing compaction by introducing PVC and geotextile materials.

In addition to the Monroe Street detention pond there are two more study sites in the Madison area. One is at a golf course studying pesticides, and the other at a river to study high volume of stormwater. The results of these two other sites and more analysis on this sites will complete this study.

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