2005 Project Abstract
For the Period Ending June 30, 2007

TITLE:	**7(h) Woodchip Biofilter Treatment of Feedlot Runoff**
PROJECT MANAGER:	**Dennis J. Fuchs**
ORGANIZATION:	**Stearns County Soil and Water Conservation District**
ADDRESS:	**110 2nd St. S. Suite 128, Waite Park, MN 56387**
WEB SITE ADDRESS:	http://www.soilandwater.co.stearns.mn.us

LEGAL CITATION:
ML 2005, First Special Session, Chap.1, Article 2, Section 11, Subd 7(h) Woodchip Biofilter Treatment of Feedlot Runoff.

APPROPRIATION AMOUNT: $270,000

Overall Project Outcome and Results

Animal agriculture has the potential to adversely affect surface water quality through the uncontrolled overland conveyance of manure particulates from feedlots to adjacent water bodies during the melting of the winter snow pack or from storm-water generated runoff. In undulating terrain of central Minnesota, more than half of the feedlots are located in close proximity to surface water and many of these locations have insufficient space for the installation of a vegetated filter strip. The two primary objectives of the two-year study financed by the Legislative Commission on Minnesota Resources (LCMR) were to: (I) characterize and evaluate the removal efficiency of nitrogen, phosphorus and *E.coli* from 10 different types of media in a controlled laboratory setting; and (II) construct a prototype woodchip biofilter and assess its performance at a feedlot site located at the West Central Research and Outreach Center in Morris. The initial studies both in the laboratory and field showed great potential for biofilters to serve as an alternative or addition to space-consuming vegetative filter strips (VFS) to treat feedlot runoff. The demonstration biofilter in Morris was able to reduce water discharge volume by 95% through absorption by the woodchip media. A subsequent potassium bromide injection test demonstrated the ability of the woodchip media to attenuate and absorb the conservative bromide tracer as it flowed through the biofilter. Based on the information learned in the laboratory and at Morris test site, refinements have been made to the biofilter design that should lead to increased nutrient removal and water absorption efficiencies at a dairy farm site in Melrose, Minnesota where additional design considerations will be evaluated. Based upon the positive results to date, it appears that a well-designed woodchip biofilter will provide a viable alternative option for some farmers with feedlots located near sensitive waters.

LCMR 2005 Work Program Final Report

Date of Report:	August 16, 2007 LCMR Final Work Program Report
Project Completion Date:	June 30, 2007

I. PROJECT TITLE: 7(h) Woodchip Biofilter Treatment of Feedlot Runoff

Project Manager:	Dennis Fuchs, District Administrator
Affiliation:	Stearns County Soil and Water Conservation District
Mailing Address:	110 Second Street South, Suite 128
City / State / Zip :	Waite Park, MN 56387
Telephone Number:	320-251-7800 ext. 132
E-mail Address:	dennis.fuchs@mn.nacdnet.net
FAX Number:	320-251-9171
Web Page address:	http://www.soilandwater.co.stearns.mn.us/

Location: *UM St. Paul Campus, UM West Central Research and Outreach Center (UM WCROC) Morris, MN and Stearns County.*

Total Biennial LCMR Project Budget:	**LCMR Appropriation:**	**$270,000.00**
(Note: UM budget not final as of report deadline of 8/17/07)	**Minus Amount Spent:**	**$253,055.49**
	Equal Balance:	**$16,944.51**

Legal Citation: ML 2005, First Special Session, Chap.1, Article 2, Section 11, Subd 7(h) Woodchip Biofilter Treatment of Feedlot Runoff.

Appropriation Language:
7(h) Woodchip Biofilter Treatment of Feedlot Runoff

$135,000 the first year and $135,000 the second year are from the trust fund to the commissioner of natural resources for agreements with Stearns County Soil and Water Conservation District and the University of Minnesota to treat feedlot runoff with woodchip biofilters to remove pollutants and assess improvements to surface water quality. This appropriation is available until June 30, 2008, at which time the project must be completed and final products delivered, unless an earlier date is specified in the work program.

II. PROJECT SUMMARY AND RESULTS AND III. FINAL PROJECT SUMMARY

The key objectives of this project were to develop and test a bio-filtering system to treat storm water runoff contaminated with dairy cattle manure from a feedlot. The study evaluated several types and combinations of high carbon materials configured into a biofilter in such a way as to reduce nitrogen, fecal coliform, and phosphorus with a result of improved water quality. The initial studies both in the laboratory and field showed great potential for biofilters to serve as an alternative or addition to vegetative filter strips to treat feedlot runoff even though the biofilter did not function according to its definition to remove N, P and E.coli by an active microbial community. The specific management details for this practice need additional investigation.

Animal agriculture has the potential to adversely affect surface water quality through the uncontrolled overland conveyance of manure particulates from feedlots to adjacent water bodies during the melting of the winter snow pack or from storm-water generated runoff. In undulating terrain of Minnesota, more than half of the feedlots are located in close proximity to surface water and many of these locations have insufficient space for the installation of an effective vegetated filter strip. The two primary objectives of the two-year study financed by the Legislative Commission on Minnesota Resources (LCMR) were to: (I) characterize and evaluate the removal efficiency of nitrogen, phosphorus and *E.coli* from 10 different types of media in a controlled laboratory setting; and (II) construct a prototype woodchip biofilter and assess its performance at a feedlot site located at the West Central Research and Outreach Center in Morris. The initial studies both in the laboratory and field showed great potential for biofilters to serve as an alternative or addition to space-consuming vegetative filter strips to treat feedlot runoff. The demonstration biofilter in Morris was able to reduce water discharge volume and associated nutrient and bacteria loads by more than 95% through water absorption by the woodchip media. A subsequent potassium bromide injection test demonstrated the ability of the woodchip media to attenuate and absorb the conservative bromide tracer as it flowed through the biofilter. Based on the information learned in the laboratory and at Morris test site, refinements have been made to the biofilter design that should lead to increased nutrient removal and water absorption efficiencies at a dairy farm site in Melrose, Minnesota where additional design considerations will be evaluated. Based upon the positive results to date, it appears that a well-designed woodchip biofilter will provide a viable alternative option for some farmers with feedlots located near sensitive waters.

On July, 14 2006, approximately 60 farmers and other interested persons had the opportunity to see and learn about the LCMR-funded biofilter project at the University of Minnesota West-Central Research and Outreach Center's Field Day. A representative from the Minnesota Milk Producers Association (MMPA) stated: "***This is exactly the type of research that we need*.**" In addition, seven meetings were held to discuss the project with consortium participants and interested attendees representing several agencies including the USDA Natural Resources Conservation Service (NRCS), Minnesota Department Agriculture (MDA), Minnesota Pollution Control Agency (MPCA), and Minnesota Department of Health (MDH). This LCMR-funded project also supported a graduate student at the University of Minnesota who received a M.S. in Soils degree for her biofilter media investigation research.

IV. OUTLINE OF PROJECT RESULTS*:*

Result 1: Literature Review, Laboratory Testing and System Design, UM St. Paul Campus

Result 1 was successfully completed and involved the evaluation of 10 different types of media (including soil) to evaluate their effectiveness for removing nitrogen, phosphorus, and E. coli from simulated feedlot runoff under controlled laboratory conditions. Complete details are found in the thesis contained in the accompanying Appendix.

Summary Budget Information for Result 1:

LCMR Budget	**$ 56,146.35**
Minus Amount Spent:	**$ 49,183.99**
Equal Balance:	**$ 6,962.36**

Result 2: Field Scale Woodchip Biofilter Installation and Surface Water Monitoring

For this investigation, a total of 12 runoff events were evaluated including 2 snow melts, and 1 rain simulation to assess the effectiveness of a woodchip biofilter in removing nutrients and E. coli from feedlot runoff. In addition a potassium bromide tracer test west conducted near the end of the project to determine transit times of simulated runoff passing through the woodchip media. The most significant finding of the field investigation is that woodchip biofilters can be highly effective in reducing nutrient and pathogen loads of feedlot runoff and therefore can be highly protective of sensitive surface waters. In some instances nearly 100 percent removal efficiencies were achieved under closely monitored conditions. Details of this study are also contained in the Appendix.

Summary Budget Information for Result 2:

LCMR Budget	**$ 180,853.69**
Minus Amount Spent:	**$ 170,871.50**
Equal Balance:	**$ 9,574.19**

Result 3 Demonstration Farm Site Suitability Analysis, Ranking and Selection for Stearns County

A dairy-feedlot site was selected in Stearns County and is located near Melrose. The dairy farm has approximately 130 animals and has both a calculated FLEval Rating and MinnFARM Index Ranking. In addition, the farmer/cooperator is most interested in the potential of the biofilter and has agreed to host this Field Demonstration Project (FDP). Based upon the information learned the initial Morris test site, considerable improvements have been made in media selection, layout, and monitoring components of the woodchip biofilter that will generate sufficient information for subsequent design criteria. The FDP project is funded by a 319 Grant.

Summary Budget Information for Result 3:	**LCMR Budget**	**$33,000.00**
	Minus Amount Spent:	**$ 33,000.00**
	Balance	**$0**

Final Report Summary:

V. TOTAL LCMR PROJECT BUDGET: $270,000

All Results: Personnel:	**$ 107,715.18**
All Results: Equipment:	**$ 26,484.68**
All Results: Development:	**$0**
All Results: Acquisition:	**$0**
All Results: Other:	**$135,800.14**

TOTAL LCMR PROJECT BUDGET: $270,000

VI. OTHER FUNDS & PARTNERS:

A. Project Partners:

Team Member and Affiliation	Role/Responsibilities	Requested	% Project Employment
Stearns County SWCD (Dennis Fuchs)	Principal investigator and site (cooperator) selection	$46,000	5% to 25%
USDA – NRCS (Craig Peterson)	Vegetated Filter Strip design and construction	$0	5% to 10%
University of Minnesota (Professors Tom Halbach, Satish Gupta, Chuck Clanton, and Greg Cuomo, Curt Reese, and students)	Laboratory tests to determine physical properties and nutrient removal rates for system design. Woodchip media monitoring for installed system.	$143,960	2% to 50%
Bob Guthrie and formerly GES	Technical coordination and surface water monitoring, system design and installation	$80,040	5% to 25%

B. Other Funds being Spent during the Project Period: Approval of a MPCA/EPA 319 grant “Feedlot Runoff Pollution Removal by Organic Biofilter Demonstration” of $150,000. Contract has been finalized, and project construction has begun.

C. Required Match (if applicable): 0

D. Past Spending: 0

E. Time: NA

VII. **DISSEMINATION**: Information from Result 1 and Result 2 will be published in scientific journals, professional meetings, and posted on the Stearns County SWCD website (http://www.soilandwater.co.stearns.mn.us/).

VIII. **REPORTING REQUIREMENTS:** Periodic work progress reports will be submitted in December 2005 (this progress report will include preliminary information from Result 1 literature review and lab analysis), July 2006, December 2006 and a final work program report and associated products by June 30, 2007 or as defined by the LCMR.

IX. **RESEARCH PROJECTS:** See Appendix.

Funding for this project was provided by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative Commission on Minnesota Resources (LCMR).

Appendix

Result 1 – Remediation of Nitrogen, Phosphorus and E.coli from Feedlot Runoff using Different Biofilter Media

Remediation of Nitrogen, Phosphorus and* E.coli *from Feedlot Runoff using Different Biofilter Media

A THESIS SUBMITTED

TO THE FACULTY OF THE GRADUATE SCHOOL

OF THE UNIVERSITY OF MINNESOTA

BY

Stephanie Patrizia Widmer

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

MASTERS OF SCIENCE

Thomas R. Halbach

July 2007

Acknowledgements

I would like to thank the Legislative-Citizen Commission on Minnesota Resources (LCCMR) for the support to carry out this preliminary study. I especially want to thank my advisor Prof. Thomas R. Halbach for his encouragement and support throughout the project. His questions helped me to focus and brought me back on track when I got lost. Thanks also go to my other committee members Prof. Satish Gupta and Prof. Russell Bey for their support. Furthermore, I would like to thank Holly Swanson[a] and Maria Correa for their help and heads up in the laboratories, as well as Aaron Rendahl[c] for his support and coaching in statistics. Thank also goes to the other members of the team that worked on the project among them Bob Guthrie, Curt Reese and Dave Fuchs. I would also like to thank Doug Lowry from the University of Minnesota Facilities Management Grounds and Landcare Division who provided the wooden media and the St. Paul Campus farm for providing some of the media.

Special thanks also go to my family and friends for the moral support during my time here in Minnesota. They helped me forget my work and enjoy Minnesota once in a while. Above all I want to thank Garry Stuber for being there when I needed support and a shoulder.

[a] Water Resource Graduate Student, University of Minnesota; [b] Visiting Scholar from INTA Experimental Station Famaillá of Tucumán, Argentina; [c] School of Statistic Graduate Student, University of Minnesota.

TABLE OF CONTENTS

LIST OF TABLES

TABLES OF FIGURES

TABLES OF EQUATIONS

Introduction

Water quality is an important environmental concern in Minnesota. Geologically and historically, Minnesota always had abundant water resources. With over 10,000 Lakes, the Great Lakes and the source of the Mississippi, Minnesota has the responsibility to keep the water clean for states downstream as well as countries on the golf of Mexico. Most farmers have realized long ago that exhaustive cultivation and poor farming practices deplete the soil and cause water and air pollution. Therefore, farmers in Minnesota are not only concerned with food production; they are also concerned with protecting and improving the quality of the environment by adopting sustainable agricultural practices. The worldwide environmental movement of the 1960's and 1970's heightened the concerns about the need to find better farming practices to improve environmental quality while balancing economic viability for farmers. Due to the greater awareness of consumers and people concerned with water and air quality, the U.S. conducts and supports research, extension programs and cost sharing related to Best Management Practices (BMPs). These actions help encourage farmers to practice sustainable farming methods that also protect the environment. Furthermore, the United States Department of Agriculture (USDA) and the United States Environmental Protection Agency (USEPA) put incentives and regulation in place to sway farmers to adopt manure handling plans that reduce the risk of water pollution through runoff as well as using best management practices to decrease air emissions from manure storing facilities. Together with erosion control, these practices help reduce nitrogen (N) and phosphorus (P) loads to water bodies. The real question however is how can we find better farming practices that are also economical and protect and conserve natural resources better than existing practices? The focus of this study was to evaluate biofilter as a mean to remediate feedlot runoff for N, P and *E.coli*.

The Minnesota Pollution Control Agency (MPCA) defines an animal feedlot as a lot or building or combination of both that is used to confine animals in certain areas. These areas are specially designed and allow the accumulation of manure which can potentially reach the water bodies (MPCA, 2006a). When correctly used, manure is a valuable resource and can supply plant nutrients. Manure contains nutrients, such as nitrogen (N), phosphorus (P) and potassium (K), which can improve soil quality through stabilization and development of aggregates, improved water-holding capacity and infiltration, and increased soil organic matter levels (MPCA, 2006b). However, if manure is not properly stored, handled and utilized but is allowed to contaminate surface or ground water, it can create severe water pollution hazards.

Runoff from feedlots includes an excess of N and P as well as elevated levels of solids, pathogens, hormones and trace elements which can be delivered to surface and ground water (MPCA, 2006b; Koelsch et al. 2006; Kizil & Lindley, 2001; EQB, 2001). Groundwater contamination can cause potential adverse human and animal health effects from high levels of nitrates and pathogens. Surface water contamination on the other hand results in conditions unsuitable for recreational purposes such as swimming and fishing. However, compared to surface water contamination, high P loads in groundwater are less of a problem (EQB, 2001). This might be explained because the majority of P in a feedlot runoff is adsorbed to solids, thus P removal is directly related to solid removal (Koelsch et al., 2006). Also P is adsorbed to soil particles and therefore is less prone to leaching.

Excess nutrients such as N and P have long been recognized as primary pollutants that cause eutrophication of lakes. Nutrients in feedlot runoff can lead to depletion of oxygen in surface waters as is the case in the hypoxic zone in the Gulf of Mexico (MPCA, 2006b; EQB, 2001; Brady & Weil, 2000a). As this "dead zone" in the Gulf of Mexico shows, the impact of water pollution from feedlot runoff as well as runoff from farmland and fertilizer application can reach international level. The magnitude of the pollution impact is site specific and depends on climate, landscape, soils, the intensity or management of land uses and the number and species of animals present (EQB, 2001; Brady & Weil, 2000a).

In 1998, MPCA identified approximately 140 rivers, streams or lakes in Minnesota with impaired water. According to MPCA, this list of impaired waters was based on a limited assessment of collected data. To continue and complete this survey, an additional 5 million dollars a year are needed (MPCA, 2002). In

2000, 19% of river and stream miles, 43% of lake acreage and 36% of estuarine square miles were assessed in the US (USDA, 2006). Based on those assessments, agriculture was found to be the leading cause of pollution for 48% of rivers and streams, 41% of lake acreage and 18% of estuaries in the US (USDA, 2006). To reduce the contribution of N and P from feedlots, the runoff is currently treated using vegetative filter strips (VFS). Due to the size, performance and cost requirements of VFS alternatives are needed. The two goals of the two-year study financed by the Legislative-Citizen Commission on Minnesota Resources (LCCMR), were to (I) characterize media suitable for biofilters and (II) develop selection criteria for media suited to remediate feedlot runoff. In the larger scheme, this study should help to improve removal rates for N, P and *E.coli* from feedlot runoff and search for a valid alternative to vegetative filter systems (VFS). The demonstration biofilter at the West Central Research and Outreach Center in Morris should help identify where further research is needed as well as simplify the use and handling of the biofilter.

Literature Review

Clean water is a requirement for human and animal life. To restore and maintain water quality in the US, congress passed the Clean Water Act (CWA) in 1972 (MPCA, 2002). In Minnesota, rivers, streams, and lakes are a valuable resource used for drinking water as well as industrial, agricultural, and recreational purposes. Clean water not only has a positive environmental impact but also benefits Minnesota's economy; tourism contributes as much as $10 billion to the annual state revenue. Point source pollution, such as discharges of municipal and industrial wastewater, has long been regulated and is controlled (MPCA, 2006b). MPCA permits as well as professional organizations such as International Organization for Standardization (ISO) allow the management of these point source pollutions in a comprehensive way. Moreover, MPCA and the Minnesota Department of Agriculture (MDA) are responsible for protecting the state's water quality and to control and permit both the point and nonpoint source pollution. Nonpoint source pollution, including pollutants transported by rain and snowmelt events, is more difficult to deal with than point source pollution. In 1987, congress enacted Section 319 of the federal CWA which established a national program to control nonpoint source (NPS) pollution of water (MPCA, 2006b). With Section 319, states are required to evaluate nonpoint source pollution. The Minnesota nonpoint source management pollution program (NSMPP) is updated every five years as required by section 319 of CWA. MPCA has to identify nonpoint source pollutants which contribute to water quality problems and set numeric standards for acceptable limits. As of April 2007, the NSMPP for the years of 2006 through 2010 was not yet available.

Vegetative Filter System

Currently, vegetative filter systems (VFS) are used to treat feedlot runoff. The national pollutant discharge elimination system (NPDES) permit regulates significant wastewater discharge into lakes, streams, wetlands, and other surface water bodies. In 2003, NPDES set the rule for the design of a VFS to withstand a 25-year storm event lasting 24 hours. The removal of pollutants from feedlot runoff is based on two major mechanisms. The first one is sedimentation which typically takes place in the settling basin which is either upstream of the actual VFS or is included in the first few meters of the VFS itself. The second mechanism is based on infiltration of runoff into the soil profile and nutrient uptake by the vegetation (Koelsch et al., 2006). According to Koelsch et al. (2006), VFS commonly show a removal rate of 70% to 90% for solids and 7% to 100% for P. On average the removal rate for both N and P is approximately 70% (Koelsch et al., 2006). Hunho et al. (2000) showed that VFS have proven limited in removing nitrate. Furthermore, the removal efficiency shows seasonal variability (Koelsch et al., 2006). However, the efficiency of VFS regarding pathogen removal such as *E.coli* is not clear. The VFS performance regarding pathogen removals varied greatly and often showed limited success in several studies (EQB, 2001). Koelsch et al. (2006) showed that an average fecal coliform removal rate is about 76%. According to Tate et al. (2006), the capacity of grassland buffers to attenuate *E. coli* from cattle manure is more significant under natural rainfall and hill slope conditions than so far reported in the literature. This is mainly due to the fact that most studies simulate worst case rainfall-runoff and microbial transport scenarios (Tate et al., 2006). Still, the buffer efficacy declined as total runoff volume increased (Tate et al., 2006).

The performance of a VFS depends highly on the design of the system. Among several criteria, the size requirement is a major factor. Koelsch et al. (2006) suggested a ratio of disposal to feedlot area of at least 1:1 or larger (up to 6:1) to achieve peak removal rates. Other design requirements include pre-treatment, discharge control, siting of VFS, and maintenance including vegetation removal. The pre-treatment is primarily used for solid particle settlement and consequently P removal. The main disadvantages of the VFS system are the large size requirement and maintenance which result in higher costs.

An alternative or addition to VFS is the use of a biofilter. The microbial population growing on natural as well as synthetic support media within the biofilter requires C, N and P for their growth. The organisms have the potential to remove those essential nutrients from feedlot runoff and incorporate them into their mass. Furthermore, due to the competitive nature of microorganisms, biofilters show the potential to reduce *E.coli* from the runoff (Brandy & Weil, 2000; Larney, 2003a; Larney et al., 2003b; Robertson et al., 2005). The overall goal is to find a combination of practices that generate more sustainable value for both the farmer and the environment

Biofilter Treatment of Feedlot Runoff

A biofilter is a pollution control device that uses microorganisms growing on the support media to treat contaminated gases or liquids. Common uses of biofiltration include microbial oxidation of air pollutants, treatment of wastewater and surface runoff (Devinny et al., 1999). The support media for the biofilter can be organic such as wood, compost and peat, inorganic such as clay or synthetic such as sinter glass. The natural support media provides the microorganisms with C and certain other nutrients, whereas with inorganic and synthetic material those nutrients need to be provided during the life of the biofilter (Wang & Govind, 1997). Additional C and N as well as other nutrients for the growth of microorganisms come either from the contaminated gases or liquids that are fed into the biofilter.

In urban storm water treatment, biofilters have been used with success. The bulking agents used include alfalfa, wheat straw, woodchips, and sawdust. Hunho et al. (2000) found good nitrate removal from synthetic storm water runoff containing the above mentioned media. Columns containing newspaper and woodchips performed best in remediating nitrate from runoff (Hunho et al., 2000). In another study, a sand-based filter system was used to remove total solids, P and metals from storm water runoff (DeBusk et al., 1997). The filters showed good initial efficiency which declined over time. Over a period of 16 months, DeBusk et al. (1997) found moderate abilities of the filter to remove solids, P, and copper. The authors further stated that peat was the most effective media in removing metal whereas wollastonite (calcium silicate mineral) was most effective in P attenuation (DeBusk et al., 1997). These findings indicate that organic based bulking agents as well as calcium silicate have the ability to remove P. In the agricultural field, carbon substrates are used to remove N from drainage effluent mainly tile drain. This anaerobic process of denitrification converts NO_3 into the nitrogen gasses N_2 and N_2O (Greenan et al., 2006). The authors compared four organic materials (wood chips, wood chips amended with soybean oil, corn stalks and card board fibers) for their performance. Corn stalks were found to be the most efficient in removing NO_3. However, the other three media showed steady removal rates that continued longer than in corn stalks (Greenan et al., 2006).

Morgan-Sagastume et al. (2003) looked at the changes of physical properties of compost biofilter treating H_2S in exhaust air. The two systems compared were a conventional or non-mixed compost biofilter and a periodically mixed compost biofilter. The authors found that over a 206 day period the conventional compost biofilter decreased H_2S removal efficiency from 100 to 90%. However, mixing of the biofilter regained a 100% removal efficiency (Morgan-Sagastume et al., 2003). Morgan-Sagastume et al. (2003) further stated that internal changes occurring in the biofilter system were closely related to moisture conditions inside the biofilter. The biofilter showed significant internal changes, particularly in the lower part of the vertical columns due to drying. The drying produced a large number of disintegrated particles and flow channels. The authors concluded that to attain optimum moisture content, particle size, gas distribution and general homogeneity in the biofilter, it should be thoroughly mixed (Morgan-Sagastume et al., 2003).

Biofilter Media

Since the biofilter has to provide growth conditions for microorganisms, the inside environment (temperature, moisture, pH, etc) needs to be maintained within specific ranges (Sadaka et al., 2002). Monitoring air content and air movement in a biofilter are important means to maintain optimal oxygen levels, remove excess moisture and carbon dioxide, and to limit excessive heat (Agnew et al., 2003). Filters made out of a variety of wood fibers have proven to be effective in removing P, N, pesticides, and oil from water. In one study, 90% of the particles and sediment were removed and 80% of the heavy metals and P were captured by the biofilter (US Forest Service, 2002). The study did not discuss whether the removal was due to microbial activity or retention of the compounds by binding to the soil particles. In potting media composed largely of wood waste, the immobilization of soluble N is accompanied by the immobilization of P (Handreck, 1996). The immobilization of N and P was mainly due to microbial activity. However, 10% of the soluble P could not be recovered after an incubation period of 30 days (Handreck, 1996). The author suspected that P was retained inside the bark particles or was fixed by small amounts of clay within the media.

A novel porous media filter for enhanced N removal was tested for septic systems by Robertson et al. (2005). The filter eliminated N by denitrification of septic tank effluent using a C source which was slowly soluble. Prior to the denitrification, the effluent was pretreated and nitrified. The reduction of nitrate ranged between 87 and 98% and showed a temperature dependency. The study demonstrated clearly that such wood-based filters have the potential to remove nitrate from water (Robertson et al., 2005).

The question remains as to what characteristics a biofilter media should have for maximum removal efficiency of N, P and *E.coli*. Based on Rynk's (1992) data, these characteristics include moisture content, bulk density as well as C/N ratio (Table 1). For some materials such as corn cobs, the range as well as the average value of those characteristics is given. Interestingly, small particle sized wood (sawdust), originating from both hardwood and softwood, shows a wider range of N concentrations compared with woodchips, wood shavings and other more bulky wood products from the same origin. Since the amount of cellulose and lignin has an important impact on the availability of C, they also influence the microorganisms which are able to use them. Table 2 lists several different media and their composition. To be able to comment on the influence of parameters such as cellulose and lignin content as well as ash and silica onto the performance of the media as bedding material, further research is required. However, the choice of media should not be based on cellulose and lignin only but should also consider other parameters such as C/N ratio and particle size distribution.

Table 1: N, C/N ratio, moisture content and bulk density of possible bulking agents (Rynk, 1992)

Material	Type of value	% N (dry weight)	C/N ratio (w/w)	Moisture content % (wet weight)	Bulk density (lb/cubic yard)
Corn cobs	Average	0.6	98	15	557
	Range	0.4-0.8	56-123	9-18	N/A
Corn stalks	Typical	0.6-0.8	60-73	12	32
Cattle manure	Average	2.4	19	81	1,458
	Range	1.5-4.2	11-30	67-87	1,323-1,674

Straw general	Average	0.7	80	12	227
	Range	0.3-1.1	48-150	4-27	58-378
Sawdust	Average	0.24	442	39	410
	Range	0.06-0.80	200-750	19-65	350-450
Woodchips	Typical	N/A	N/A	N/A	445-620
Hardwood (chips, shavings, etc.)	Average	0.09	560	N/A	N/A
	Range	0.06-0.11	451-819	N/A	N/A
Softwood (chips, shavings, etc.)	Average	0.09	641	N/A	N/A
	Range	0.04-0.23	212-1,313	N/A	N/A

Table 2: Chemical composition of selected lignocellulosic fibers

	Composition [a] (%)			
Fiber Type	**Alpha Cellulose**	**Lignin**	**Ash**	**Silica**
Rice straw [b]	28-36	12-16	15-20	9-14
Wheat straw [b]	38-46	16-21	5-9	3-7
Oat straw [b]	31-37	16-19	6-8	4-7
Bagasse [b]	32-44	19-24	2-5	1-4
Kenaf [b]	31-39	14-19	2-5	N/A
Cotton stalks [c]	N/A	22	5	3
Rice husks [d]	38	22	20	19
Softwoods [b]	40-45	26-34	<1	--
Hardwoods [b]	38-48	23-30	<1	--

[b] Source: Kocurek & Stevens, 1983; [c] Source: Fadl et al., 1978; [d] Source: Govindarao, 1980.

The carbon (C) to nitrogen (N) ratio influences the release of nutrients such as N from the media. Villegas-Pangga et al. (2000) found an increased N release with increased N content of the media whereas increasing concentrations of polyphenols and lignin, as found in wood, decreased the release of N from the media (Villegas-Pangga et al., 2000). Taylor et al. (1989) compared C/N ratio to N/lignin ratio as a predictor for leaf litter decay. The authors stated that the N/lignin ratio for low lignin substrates and substrates with a broad range of lignin contents was not as good an indicator of decay as the C/N ratio (Taylor et al., 1989). Larney (2003a) found significantly higher total N concentrations in woodchips compared to straw bedding. Furthermore, woodchips also have lower amount of soluble salts than straw, thus do not add as much salt to the soil as straw when used as an amendment (Miller et al., 2003).

Biofilters are often used to remove volatile organic carbons (VOC's) and other odor causing compounds from gas streams. Essential for the efficiency of those biofilters is the porosity of the media. The gas stream has to be able to pass through the media unobstructed. The same is true for the movement of liquids through biofilter material in treating feedlot runoff. Sadaka et al. (2002) conducted experiments to distinguish and correlate vertical and horizontal air flow rates and pressure drop in different media. The media included 100% wood aggregates, 100% wood mulch and different mixtures of those materials with compost. The authors stated that shape and size of the particles as well as the porosity of the bulk media was of particular interests. In a media with low porosity more energy is required to create the same flow as with high porosity material (Sadaka et al., 2002). Small particle sizes as well as moisture content and compaction were responsible for reduced porosity in the media. The pressure drop was linearly correlated with depth of the biofilter bed. Due to mechanical motion, the bed height decreased in all bedding mixtures, with the largest settling occurring in 100% wood aggregates. Furthermore, the authors found that in most cases the change of bed height had noticeable effect on the horizontal flow compared to the vertical flow. However, in biofilter beds containing both wood aggregates and compost differences in flow were not detected. Overall, the authors found no changes in airflow resistance due to slumping. Moisture content significantly influenced the pressure drop in the media. For example, the pressure drop was greatest when wood aggregates and mulch were wet. The authors suggested that the decrease in porosity and in turn the increase in bulk density were responsible for these results (Sadaka et al., 2002).

Free air space can be an adequate parameter to predict air movement through biofilter media. As mentioned earlier, air movement is important to control excessive heat, moisture content and carbon dioxide removal from the media. Free air space (FAS) can be calculated using Equation 1. This poses a problem since accurate particle density determination in situ in a compost/biofilter are difficult to obtain (Agnew et al., 2003).

$$FAS = 100 - BD\left(\frac{MC}{\rho_w} + \frac{100 - MC}{PD}\right)$$

where:
FAS = free air space (%)
BD = wet bulk density (kg/m^3)
MC = wet basis moisture content (%)
ρ_w = density of water (1000 kg/m^3)
PD = particle density (kg/m^3)

Equation 1: FAS calculated as a function of bulk density, moisture content and particle density (Agnew et al., 2003)

N-loss from manure through volatilization starts immediately after excretion (Tiquia et al., 2002). Domestic animals have been identified as a major source of the global ammonia emissions (Misselbrook & Powell, 2005; Chase & Van Amburgh, 2002; Barrington & Moreno, 1995). Chase and Van Amburgh (2002) stated that 40% to 60% of the N excreted in current dairy management systems is volatized in the barn and during storage and land application. Several authors stated that NH_3 loss is essentially influenced by pH and C/N ratio (Misselbrook & Powell, 2005; Tiquia et al., 2002; Lory et al., 2002; Eiland, 2001; Jeppsson, 1999; Anderson, 1995). Three potential mechanisms can help reduce ammonia emission from bedding material; immobilization and adsorption of ammonia/ammonium as well as pH manipulation of the manure/bedding material (Jeppsson, 1991). Eiland et al. (2001) found that with lower initial C/N ratio NO_3 is released earlier than with a C/N ratio of 50 and 54. The high initial decomposition rate of media with low C/N ratio, results in high peak temperatures compared to high C/N ratio media. In the composting process, nitrate is formed by nitrifying bacteria and made available to other microorganism (Dayegamiye & Isfan, 1991; Eiland et al., 2001; Larney, 2003a). This is especially true for low C/N ratio media. In media with high initial C/N ratio the decomposition is slower, leading to a shorter heating phase and no significant formation of nitrate (Eiland et al., 2001). Moreover, due to the initial lower pH of wood products (high C/N ratio), there is a potential to limit NH_3 loss from mixtures of manure with this bedding (Lory, 2002; Miller et al., 2003).

Biofilter Microbiology

Brady & Weil (2000b) stated that during the natural decomposition of organic matter (OM), carbon compounds are decomposed and nutrients such as N and P are conserved in the build up of microbial biomass. The decomposers need an initial C source together with essential macro- and micronutrients for good start conditions. Thus the C/N ratio is crucial to the decomposition process in compost (Brady & Weil, 2000b). N-limitation in soils covered with wood debris (high C/N ratios) is well known (Brady & Weil, 2000b; Sylvia, 2005; Zimmerman et al., 1995). Limited N-plant availability is mainly due to microbial activity, where N is used by the microorganisms to decompose C (Zimmerman et al., 1995). This interaction between C, N, and microorganisms can be used to extract N and P from the feedlot runoff through C rich biofilter media. N and P are essential compounds used by microorganisms for their growth on carbon rich material. The same principle will be used in this project.

The biofilter media has a major impact on the microbial flora, with higher C/N ratios favoring the development of fungi (Eiland et al. 2001). Fungi are more effective in removing P from soil and thus might also prove more effective in the biofilter. Furthermore, the microbiology of the biofilter will depend on climatic conditions such as temperature and precipitation, as well as the number of animals on the feedlot. The number of animals dictates the amount of manure excreted thus the number of animals is an indicator of the amount of feedlot runoff that can be expected.

Mycorrhiza are known to provide plants with P in exchange for energy (Brady & Weil, 2000; Sylvia, 2005). Also, they are more efficient in P uptake than bacteria. Zimmerman et al. (1995) found that cord-forming fungi have the potential to transfer P from soil into wood. Furthermore, this study suggested that the same principle might also be true for N and other nutrients (Zimmerman et al., 1995). Miller et al. (2003) found no relation between bedding with woodchips vs. straw and P retention. But he found significant seasonal effects; in summer P levels were higher in the bedding material (Miller et al., 2003). Additionally, P retention in compost under aerobic conditions seems to be stable, likely due to formation of complexes with organic compounds on the surface of the materials (Clark & Pitt, 2001).

Green et al. (2004) examined and compared the microbial community composition of sawdust and straw amended cow manure composts and found highly similar bacterial community profiles in the mature composts. However, there were significant differences in the compost process. For example, the peak temperature, the length of the heating phase and the pH were different, depending on the initial C/N ratio of the media (Green et al., 2004). This can be explained with the different requirements of bacteria and fungi regarding C/N availability. Furthermore, microorganisms have optimal pH ranges for their growth. In general, fungi tolerate a wider pH range than bacteria do. Whereas most bacteria have a pH range of 6.0 to 7.5, the fungi can grow between 5.5 and 8.0 (BioCycle, 1991). However, the media is not solely responsible for differences in microbial community structure. Miller et al. (2003) stated that more parameters of the manure (salts, total P, available P, total C, NO_3-N, and NH_4-N) were also significantly influenced by season compared to media. In low C/N ratio-media, low fungal biomass is found because fungi are less efficient in utilizing easily degradable C sources compared to bacteria (Sylvia et al., 2005). Fungi are good decomposers of wood because of their ability to degrade lignin (Brady & Weil, 2000b; Sylvia, 2005). However, high N levels and, more importantly, high temperatures result in lower fungal biomass (Eiland et al., 2001). Where N is the limiting factor (high C/N ratio), low initial decomposition rates with low microbial biomass values have been found (Eiland et al., 2001).

Several compost studies were concerned with the removal of potentially harmful microorganisms, mainly total coliforms (TC) and *E. coli* (Gattinger et al., 2004; Larney et al., 2003b; Miller et al., 2003). Larney et al. (2003b) and Miller et al. (2003) compared woodchip bedding to straw bedding. Certain tree species contain antibacterial phenolic compounds, which can inhibit the growth of microorganisms such as total coliforms in runoff. However, the studies showed no significant bedding effect in the attenuation of microorganisms (Larney et al., 2003b; Miller et al., 2003). A reduction of TC and *E. coli* greater than 99.9% was achieved in the first seven days of the composting process at a temperature range of 33.5 to 41.5 ºC (Larney et al., 2003b). During summer, total coliforms and *E. coli* in runoff were present in elevated levels, showing that seasonal effects must be considered in pathogen removal (Miller et al., 2003; Larney et al., 2003b).

Composting has the potential to reduce the levels of total coliforms and *E. coli* from feedlot runoff. Desiccation of the compost plays a minor role in their removal process from feedlot runoff (Larney et al., 2003b). Moreover, drying and rewetting of the compost did not seem to affect the size of microbial biomass significantly (Mondini et al., 2002; Larney et al., 2003b). Due to the large number of microorganisms in compost, numbers of *E.coli* could be lowered through the competition for the essential elements and the advantage of an already established microbial population in the biofilter.

Zehner et al. (1986) incubated five media (fine hardwood chips, recycled dried manure, chopped newspaper, softwood sawdust, and chopped straw) with bacteria at 37 ˚C and found rapid growth on straw and recycled manure. Less growth was observed on hardwood chips. Similarly, a rapid decline in bacterial counts was seen for paper and softwood sawdust (Zehner et al., 1986). This shows that microorganisms can substantially grow on clean material without addition of manure. Wood products such as sawdust generally contain more coliform bacteria, whereas straw bedding shows higher numbers of streptococci. Elevated levels of *Klebsiella* were found on green hardwood containing bark material (Gamroth, 2004; Hogan & Smith, 1997). Hogan et al. (1989) also found high *Klebsiella* counts on sawdust compared to chopped straw. More than 10^6 colony forming units (cfu/g) of coliforms were found on straw, corn fodder and sawdust (Hogan & Smith, 1997). The amount and type of bacteria were not only dependent on the bedding but also the season (Hogan et al., 1989). Higher coliform counts found in summer and fall, were most likely due to the higher ambient air temperatures. Tests showed that coliforms most rapidly multiply at temperatures between 30 and 40 ˚C (Hogan et al., 1989; Zehner et al., 1986). However, Brinton & Droffner (1994) found that *E. coli* and *Salmonella* were able to survive 50 days of composting with a single high temperature of 60 ˚C occurring during that time period.

Conclusion

Several studies showed that wood-based materials have the ability to retain N, P and certain heavy metals from water samples. In urban engineering, biofilters have long been used to treat storm water runoff (DeBusk et al., 1997; Brandy & Weil, 2000; Hunho et al., 2000). Currently for a farm with a 300-animal unit or less, feedlot runoff is either stored and land applied, or directly applied to a vegetative filter system (VFS). This system has proven to have some disadvantages. Different removal efficiencies of N and P depending on factors such as climate and VFS size have been reported (EQB, 2001; Koelsch et al., 2006). Also, the effective attenuation of pathogens in this system is controversial (Tate et al., 2006; Koelsch et al., 2006). No literature was found regarding the retention of N, P and pathogens from feedlot runoff through woody materials. According to the reviewed literature, C rich bulking agents show the potential to retain N and P from the feedlot runoff as well as attenuate pathogens such as fecal coliform and *E. coli* (Eiland et al., 2001; EQB, 2001; Larney, 2003a).

The goal of this project, funded by LCCMR, is to provide background on the performance efficiency of hardwood, softwood, corn stover, corn cobs, flax straw, mature compost, and soil in removing N, P and *E.coli* from feedlot runoff. The laboratory experiments should help determine whether the treatment of the feedlot runoff is due to the microorganisms present in the biofilter or due to the absorption.

Material and Methods

Ten potential biofilter materials were examined during the laboratory studies; corn cobs, corn stover, flax straw, spruce woodchips, spruce sawdust, elm woodchips, elm sawdust, and Morris woodchips as well as mature compost and soil. The corn cobs and the corn stover as well as the 3 month old mature compost were provided by the St. Paul Campus farm. The corn cobs were cut in 2cm x 2cm pieces using a hammer mill, whereas corn stover was passed through a chipper. The flax straw was supplied by Ken Reese, Flax Minnesota in Hancock, Minnesota 56244. Upon delivery, the flax was cut with a scissor into approximately 20 cm long pieces. The elm (hardwood) and spruce (softwood) were provided by the University of Minnesota Facilities Management Grounds and Landcare Division. The wood was delivered as woodchips; one part was used directly in the laboratory experiments. The other part was ground into sawdust. The wood designated Morris woodchips earlier in the paragraph was used in the biofilter prototype at the University of Minnesota Outreach Center in Morris, Minnesota. The wood used in Morris was storm damage wood with hardwood and softwood species. However, the exact wood species were not specified. The soil used in the study was collected from the Research Station Lamberton, Minnesota and belonged to the Normania soil series (fine-loamy, mixed, superactive, mesic Aquic Hapludoll). The soils belonging to this series show moderate permeability and are somewhat poorly drained. The clay content of this soil lies between 18% and 32% and sand is between 25% and 45%. Organic matter content of the soil was 3.9%.

Chemical and Physical Methodology

The main objective of this report was to determine the potential use of the above described media as biofilter material for remediating feedlot runoff. Chemical and physical properties of the media were determined both before and after the remediation experiment. The chemical analyses of the media included pH, electrical conductivity (EC), ash content, total nitrogen, total carbon, total sulfur and total phosphorus content as well as soluble phosphorus, mineral N and ICP extractable elements. For all chemical analyses, ground media samples were used. The media were ground using a Wiley mill with a 2 mm screen. Physical parameters included bulk density and water holding capacity measured on the original loose media as described above.

The bulk density was determined using the drop method, where the weight of a specific volume (2 L) was measured after the sample was systematically packed by dropping it on a bench. The loose media (original), dried at 70 °C ± 5 °C, was transferred to the container and filled to two liter. To obtain a representative compaction, the container was dropped ten times from 10 cm height giving a total of one meter. When the media settled, more media was added to assure a volume of 2 L. The container and the media were weighed and the bulk density was determined using the following equation:

$$Bulk\ \ Density = \frac{(weight\ \ container\ \ /\, media\,) - tare}{container\ \ volume}$$

Equation 2: Bulk density determination based on the dry weight and the volume of the media

The biofilter media needs to retain some water to support microbial growth. Also, the water content in the material influences its structural stability. Therefore, water holding capacity (WHC) was determined using the funnel method as described in Test Methods for the Examination of Composting and Compost (TMECC), method 03.10-E "Quick-Test to Approximate Water-Holding Capacity of Compost". The procedure included placing 10g of media in a funnel with filter paper, then the funnel was sealed on the bottom with paraffin and 150 mL of nano water were added. The media was allowed to sorb water for one hour after which it was drained by unplugging the funnel. After one hour of drainage, the wet weight was determined followed by oven drying the media at 60 °C until constant weight was reached, at which time the media was weight again. Maximum water holding capacity was calculated from wet weight and dry weight of the media.

The pH of the different bedding media was determined using ground samples in a 1:10 solid to liquid slurry ratio. The flasks with the 1:10 slurry were placed in a shaker for 1 hour at 180 rpm before running the pH test using a pH electrode (Page et al., 1984). EC was determined with a conductivity meter using the same 1:10 solid to liquid slurry that was made to measure pH.

Total C, N and S were determined using the Elementar Vario EL III analyzer. The analyzer works according to the catalytic tube combustion principle. The sample is combusted at high temperatures (1000+ °C) with an oxygenated atmosphere. The combusted gas is then injected in specific adsorption columns and the elements are measured with a thermal conductivity detector (Elementar Analysensysteme GmbH, 2003).

Mineral N (nitrate and ammonia) in the leachate sample was measured using Carlson's conductimetric method (Carlson, 1986; Carlson, 1978).

Total phosphorus analysis requires the transformation of insoluble phosphorus compounds to soluble forms which then can be measured using the colorimetric method. For this project, total phosphorus was measured on the ground media after performing the perchloric acid digestion (Page et al., 1984). The ortho-phosphate in the digested samples was then determined using the ascorbic acid method as modified by Watanabe & Olson (1965). The same ascorbic acid method was used to determine the soluble phosphorus content in the leachate samples from the pulse experiment.

Metals were analyzed at the Department of Soil, Water and Climate's Soil Testing Lab on the St. Paul Campus. Elemental analysis was performed by the Inductively Coupled Plasma (ICP) method (Munter, 1990). The ash content was also measured in the Soil Testing Lab through high temperature combustion (500+ °C).

Laboratory Scale Feedlot Runoff Remediation Experiment using Different High Carbon Materials

To determine the removal efficiency of the different media regarding N, P and *E.coli* from feedlot runoff, the media were tested in a pulse experiment. The bioreactor tubes were intended to simulate the active core of the biofilter and allowed the media to be tested over a time period of 22 days. Since 10 cm-diameter column did not provide enough insulation to maintain growth condition the experiment was conducted in a growth chamber set at 40 °C and a humidity of 99% to provide growth conditions for the microorganisms. These conditions are present in good performing compost piles. During this time, 300 mL of feedlot runoff was applied daily to the bioreactor tubes. The runoff was held in the tubes for 30 minutes, after which the tubes were drained and the drainage sampled on a daily basis. The daily samples were centrifuged and stored at -20 ˚C.

Design of Bioreactor Tubes and Holding Rack

The PVC tubes were 10 cm in diameter and 50 cm long. To the front of the tubes a lid with a drainage valve was attached. To make the sampling easier, a foot long flexible clear vinyl tubing (6.35 mm) was attached onto each valve (Fig. 1). The tubing was connected to the glass sampling container during the daily feedlot application and sampling. To hold the media in place and reduce the loss of media via the valve, a geotextile filter/drainage liner (Colbon, Enkadrain 3651R) with a diameter of 10 cm was placed right behind the lid (from front view). To avoid dripping of feedlot runoff out the back of the PVC tube, the lower halve of the PVC tube was taped with duck tape (Fig. 2). To provide a gradient that will allow the feedlot runoff to flow through the media, the tubes were placed inclined (10% slope) in a wooden rack (Fig. 3).

Figure 1: Front face of bioreactor tubes including drainage lid in holding rack

Figure 2: Back face of bioreactor tubes in the holding rack

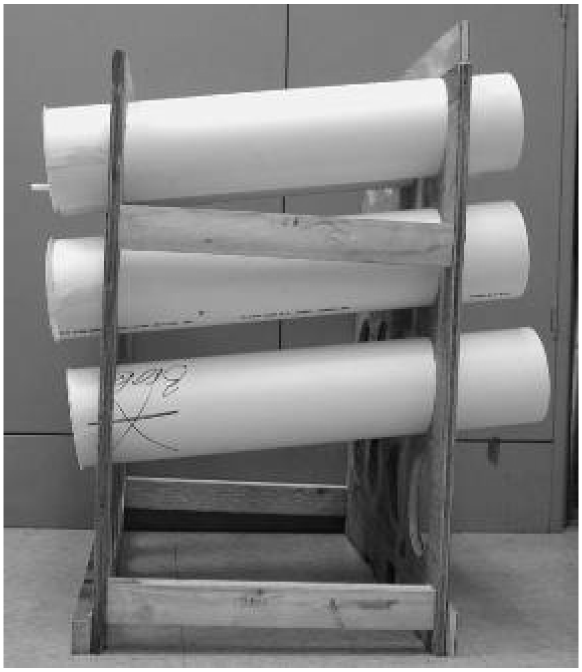


Figure 3: Side face of bioreactor in holding rack

The labeling scheme for the samples from the bioreactor consisted of three distinguished parts. The first part was a short notation for the media type (Table 3); the second part as well as the third part consisted of numbers separated by a period. The first number refereed to the number of the bioreactor tube (1 through 4) and the second number indicated the day the effluent was taken. For example, 1 and 2 were the conditioning samples on the first day, 3 referred to the conditioning sample with 500 mL DI water on the second day and 4 was the first day of actual feedlot runoff application. Thus the total numbering went from 1 to 26.

Table 3: Labeling scheme for bioreactor tubes

Media	Short notation	Media	Short notation
Elm woodchips	HW-WC†	Mature compost	Comp
Elm sawdust	HW-SD†	Corn cobs	CC
Spruce woodchips	SW-WC†	Corn stover	CS
Spruce sawdust	SW-SD†	Flax straw	FS
Woodchips from Morris	Morris	Normania soil	Soil

† HW = hardwood, WC = woodchips, SD = sawdust, SW = softwood

Feedlot Runoff Preparation

Cattle manure was obtained from the University of Minnesota West Central Research and Outreach Center in Morris, Minnesota. To limit the changes in N, P and *E.coli,* two five gallon buckets were stored at -4 ˚C. This ‘scrape’ manure was used to emulate the feedlot runoff used during the pulse experiment. To emulate feedlot runoff, the ‘scrape’ manure from Morris was diluted 1:100 with deionized (DI) water. To achieve this dilution, 70 mL of manure were placed into a 5000 mL container half filled with DI water and stirred for 60 minutes. The 5000 mL container was then filled to the 5000 mL mark. This mixture was stirred another 10 minutes before it was filtered into a 10 L container using a 2 mm sieve to remove large particle such as stones and straw. To achieve a dilution of 1:100, an additional 2000 mL of DI water were added. Afterward, the emulated feedlot runoff was stored at -4 ˚C until applied to the columns.

Experimental Design

Before any of the media were packed into the bioreactor tubes, they were oven dried at 60 ˚C until constant dry weight was reached. Two liters of each media were then filled into the bioreactor tubes and the tubes were then placed in the wooden holding racks (Fig. 1). For quality purpose and statistical reasons, each media was run in four replicates. The feedlot runoff leachate was analyzed for soluble P, mineral N, total coliform (TC) and *E.coli*. To determine the amount of N, P and TC/*E.coli* applied to the bioreactor tubes, a sample was taken from the prepared feedlot runoff. The control sample was analyzed for N, P, TC and *E.coli* using the procedures identical to that of drainage samples.

Before any feedlot runoff was applied, the media was conditioned with DI water to achieve conditions that sustain microbial growth. The conditioning was done for the first two days. Conditioning involved clamping the rubber tubing, adding 1000 mL of DI water and incubating the bioreactor for 60 min at 40 °C. After this incubation time, water was allowed to drain for 120 minutes from the bioreactors. After this drainage period, the media was rewetted with 1000 mL of DI water for 60 min and then drained for 24 hours. After the second drainage, another 500 mL of DI water was applied to the bioreactor tubes for 30 min and then drained. Every drainage period was sampled and the samples were frozen for future analysis. From the 3^{rd} to 25^{th} day consecutively, 300 mL feedlot runoff was applied daily to the media. The feedlot runoff was incubated in the tubes for 30 min followed by drainage for 24 hours. From each feedlot runoff drainage event, 50 mL leachate were sampled into falcon tubes, centrifuged (12,000 rpm for 30 min), decanted and frozen at -20 °C until analyzed for mineral N and soluble P. Four times during the 22-day pulse experiment, samples for total coliform and *E.coli* were obtained and sent to the Metropolitan Council Environmental Service Laboratory in St. Paul MN. For this bacterial analysis, 50 mL runoff was sampled into sterile falcon tubes. The falcon tubes were placed on ice and delivered directly to the laboratory where the bacterial analysis was done using the Colilert® method including most probable number (MPN) dilution series.

MPN was first developed in 1915 by McCrady to help estimate bacterial densities in liquid sample (Cochran W.G. 1950). This projected density is based on an elaborate application of probability theory. The theory is only valid under two assumptions. First, the organism is dispersed randomly throughout the liquid. Therefore before processing, the sample has to be stirred thoroughly. The second assumption is that if microorganisms are present in the culture, the incubation broth should show turbidity. This requires the culture media/broth to support the microbial growth (Cochran W.G., 1950). The dilution series was further used in the test system Colilert® which is based on a colorimetric method. There are two substrates, ortho-nitrophenyl-β-D-galactopyranosid (ONPG) and 4-methylumbelliferyl-β-D-glucuronide (MUG), which are metabolized by TC or *E.coli* respectively. Coliforms possess the enzyme β-galactosidase which is responsible for metabolizing the colorless ONPG and splitting the indicator (ortho-nitrophenyl) from the galactopyranosid, turning the sample yellow in presence of TC. *E.coli* contains the additional enzyme glucuronidase. This enzyme metabolizes MUG into the indicator methylumbelliferyl and the glucuronide portion. The indicator emits florescent wave length depending on the quantity of *E.coli* present in the sample (IDEXX Laboratories Inc., 2007). The 96-Well plates were incubated for 24 hours at 35 °C ±0.5 °C.

After 22 days of consecutive feedlot runoff application, the media was removed from the bioreactor tubes and dried at 60 °C until constant dry weight was reached. Part of this dried media was ground for chemical measurements (pH, EC, total C, total N, total P, and heavy metals). The media left over was used to determine particle size after the pulse experiment.

Data Analysis

To compare differences among media in physical and chemical measurements, analysis of variance (ANOVA) was performed for bulk density, ash content, maximum water holding capacity, moisture content (after pulse experiment), total C, total N, total S and total P. The data was tested for homogeneity of variance before running ANOVA. To meet the requirements for ANOVA, values for ash, moisture content after pulse experiment, maximum water holding capacity, total P as well as total C and N before and after pulse experiment were log transformed. Multi comparison tests (Tukey) were then performed for the above mentioned variables. A t-Test was performed to evaluate significant differences (increase or decrease) in pH, EC, total P and total C and N before and after the pulse experiment.

Data from the pulse experiment included, remediation of mineral N, soluble P and total coliform (TC)/*E.coli* from feedlot runoff over time. All variables (mineral N, soluble P, total coliform and *E.coli*) were log transformed. For mineral N (NH_4-N and NO_3-N) and soluble P a generalized additive model (gam) with integrated smoothness estimation was performed (R Development Core Team, 2007). The smoothing of the data set was necessary to compensate for missing data. On TC/*E.coli* data a linear model with mixed effects was used. To evaluate differences of *E.coli* and TC, the slopes of colony forming units (cfu) vs. time curves were statistically compared to 0. Tukey with Honest Significant Differences was used to compare the different media (R Development Core Team, 2007).

Results

All values given in results are mean values. Other statistical values such as median, mode, maximum and minimum are given in Appendix A.

Chemical and Physical Media Evaluation

Mean values of ash content, bulk density, C/N ratio, pH, EC, total P, maximum water holding capacity, moisture content and sulfur are summarized in Table A1 in Appendix A. All parameters were measured on a dry weight basis.

Elm Woodchips

Elm woodchips had a mean dry bulk density of 0.31 Mg m^{-3} and a mean ash content of 3.02%. Initial pH and electrical conductivity (EC) after a one-hour extraction were 4.93 and 0.31 dS/cm^2. After the 22-day pulse experiment, the pH and EC were 5.90 and 0.28 dS/cm^2 respectively. This implies a significant increase for pH ($p < 0.000$) but no changes in EC (Figs. 4 and 5). Maximum water holding capacity of the elm woodchips was 66% (Fig. 6) compared to a moisture content of 108.8% (Fig. 7) measured after the pulse experiment including an additional 36-hour drainage.

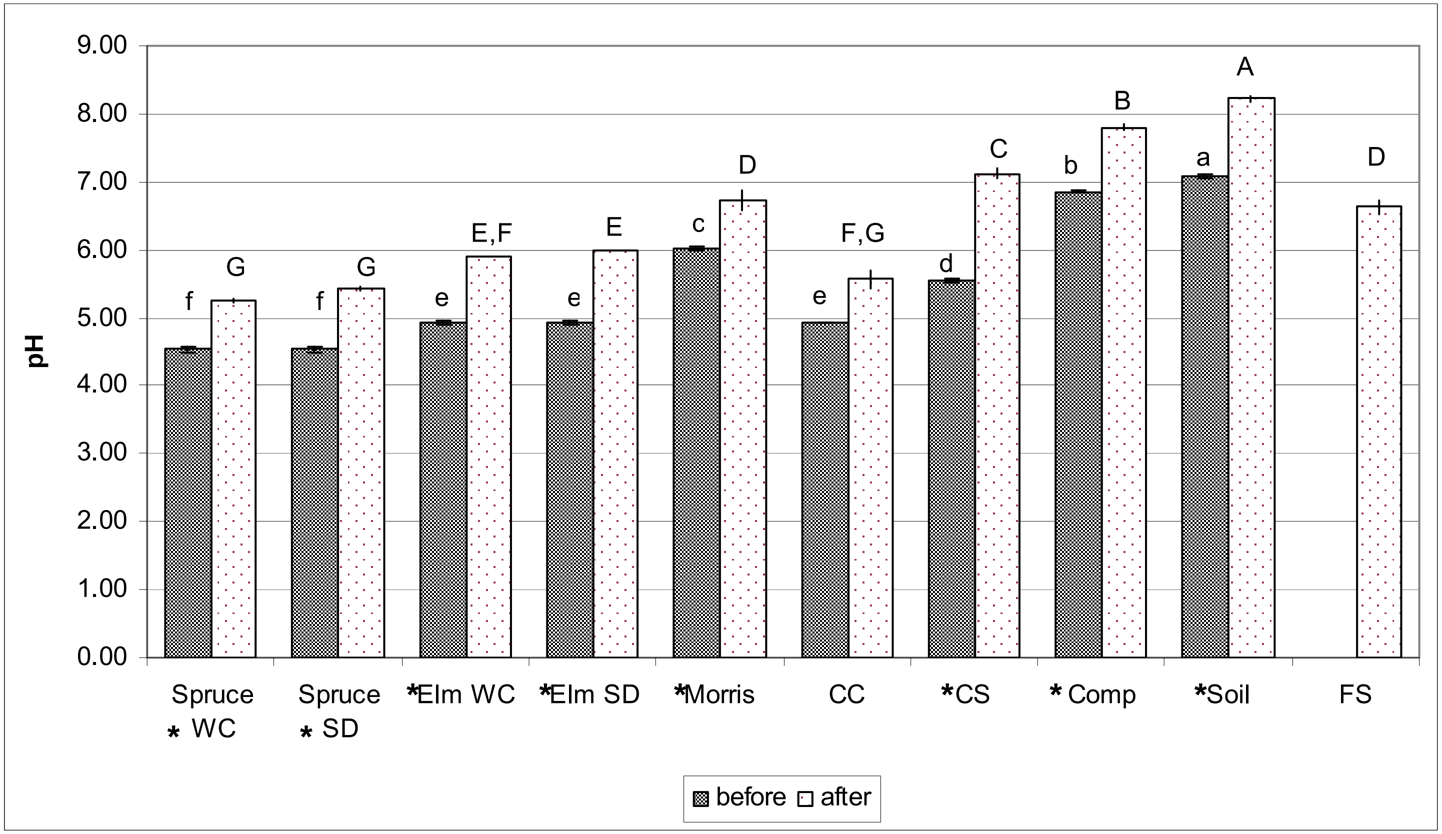


Figure 4: pH of media before and after pulse experiment. WC = woodchips, SD = sawdust, CC = corn cobs, CS = corn stover, Comp = compost, FS = flax straw

Lower case letters indicate significant differences of the media before the pulse experiment; capital letters indicate significant differences of media after pulse experiment. The asterisk (*) indicates significant differences of pH before and after the pulse experiment of the same media ($p<0.05$).

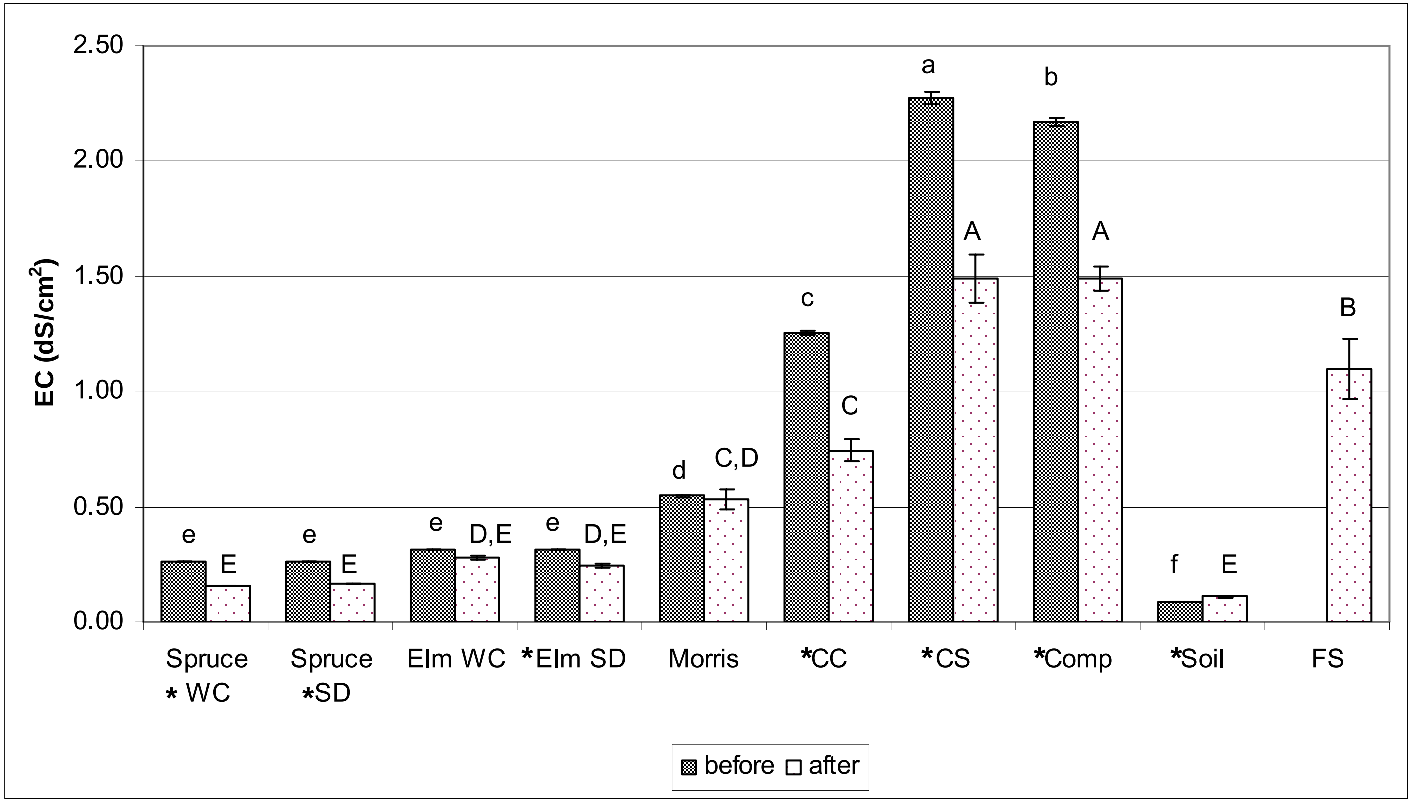


Figure 5: Electrical conductivity (EC) in dS/cm^2 of media before and after pulse experiment. WC = woodchips, SD = sawdust, CC = corn cobs, CS = corn stover, Comp = compost, FS = flax straw

Lower case letters indicate significant differences of the media before the pulse experiment; capital letters indicate significant differences of media after pulse experiment. The asterisk (*) indicates significant differences of pH before and after the pulse experiment of the same media ($p<0.05$).

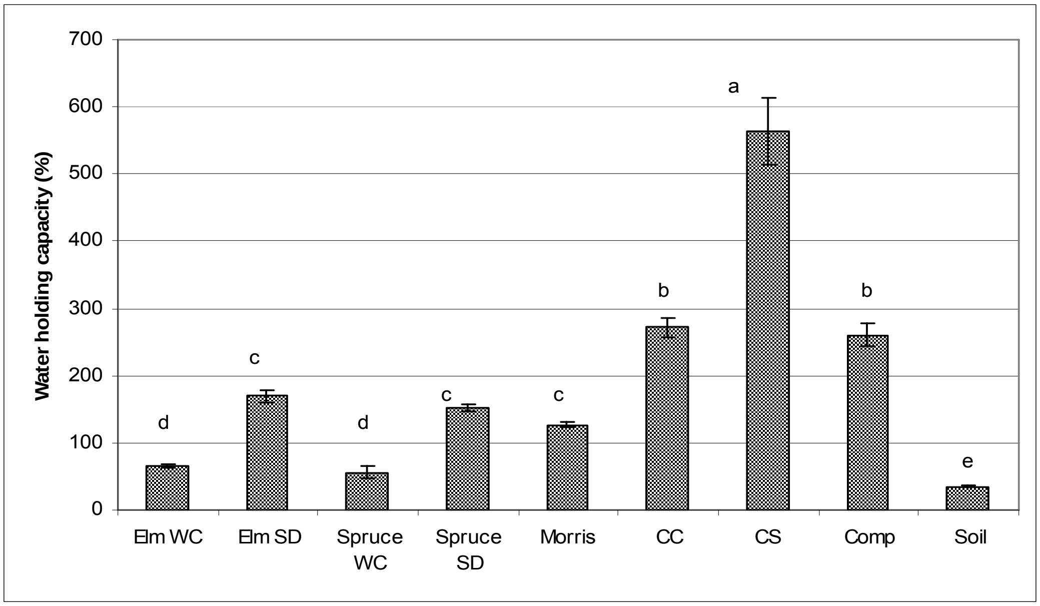


Figure 6: Water holding capacity (%) of various media. Different letters indicate significant differences ($p < 0.05$). CC = corn cobs, CS = corn stover, FS = flax straw, SD = sawdust and WC = woodchips

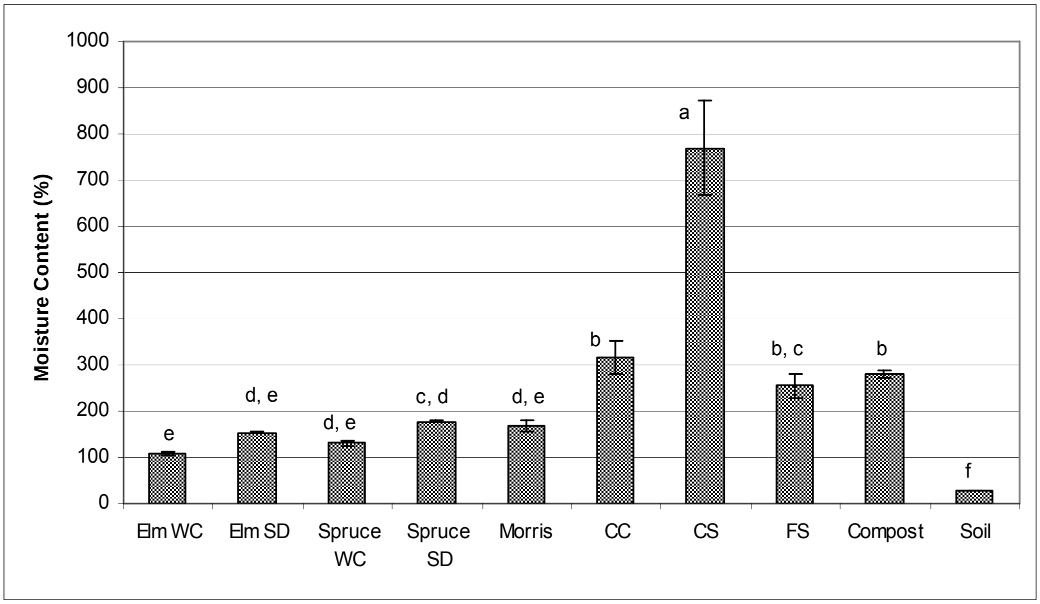


Figure 7: Moisture content (%) of various media measured 48hours after conclusion of the pulse experiment. Different letters indicate significant differences ($p < 0.05$). CC = corn cobs, CS = corn stover, FS = flax straw, SD = sawdust and WC = woodchips

The particle size analysis of the initial media showed 1.9% of particles with a diameter of larger than 25 mm, 31.9% for particle sizes between 12.5 mm and 25 mm, 53.5% for particle sizes between 5.6 mm and 12.5 mm, 10.6% for sizes between 2 mm and 5.6 mm and 2.1% smaller than 2 mm (Fig. 8). The same analysis after the pulse experiment showed 0.1% of larger than 25 mm, 13.6% for particle sizes between 12.5 mm and 25 mm, 54.9% for particle sizes between 5.6 mm and 12.5 mm, 25.3% for sizes between 2 mm and 5.6 mm and 6.1% smaller than 2 mm (Fig. 9). This indicates a shift to smaller particle sizes. The results show that particles with a diameter between 12.5 mm and 25 mm declined more than 50% whereas particles with a diameter between 2 mm to 5.6 mm gained more than 50%.

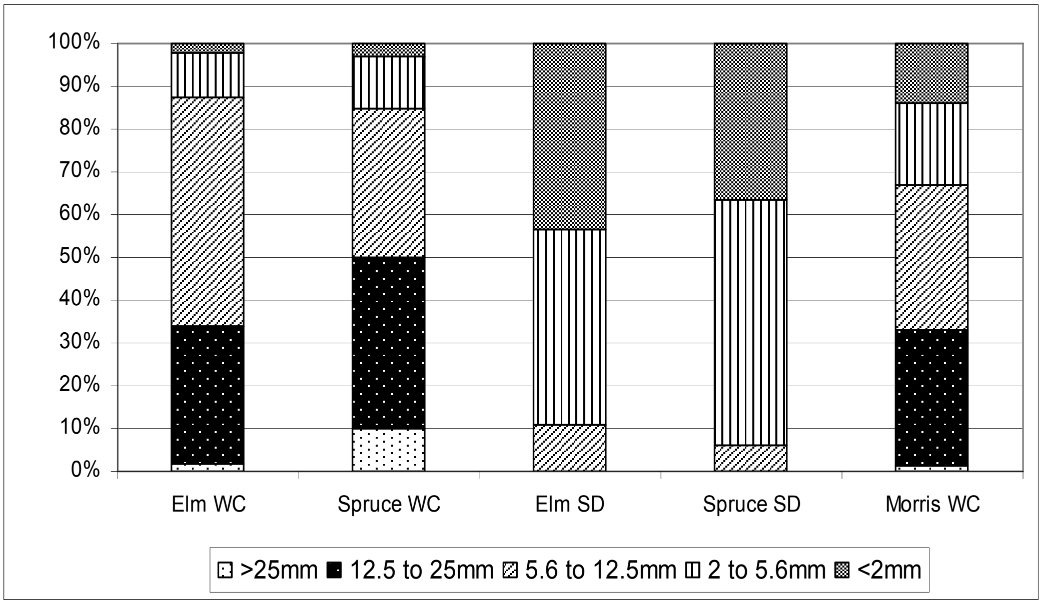


Figure 8: Initial particle size distribution of elm woodchips (WC), spruce woodchip (WC), elm sawdust (SD), spruce sawdust (SD) and Morris woodchips

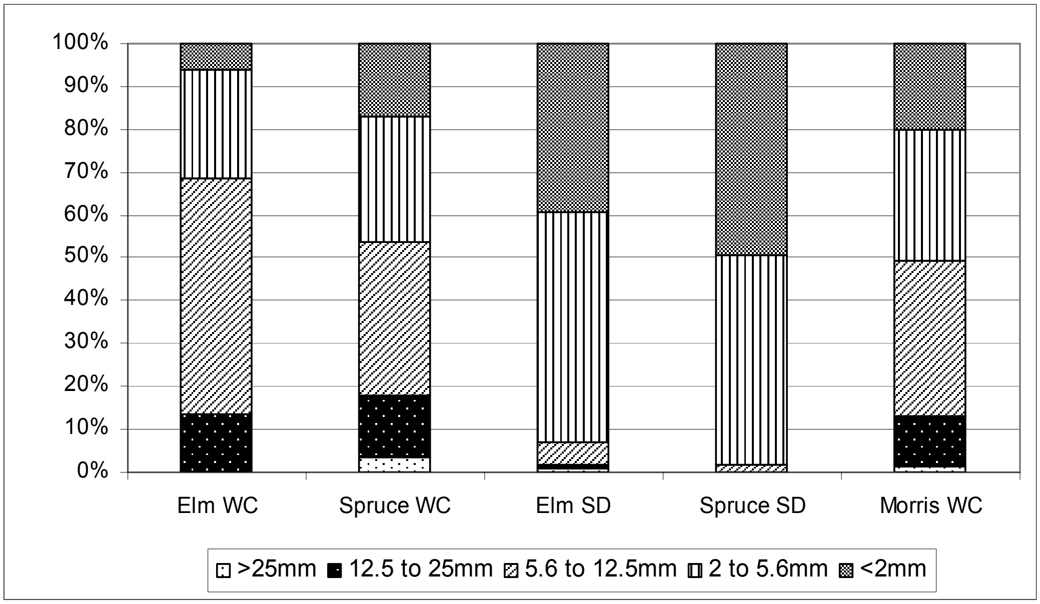


Figure 9: Particle size distribution of elm woodchips (WC), spruce woodchip (WC), elm sawdust (SD), spruce sawdust (SD) and Morris woodchips after Pulse Experiment

Total N and total C before and after the pulse experiment were 0.44%, 0.39%, 47.49% and 47.86% respectively. This translates to a C/N ratio of 108 before and 122 after the pulse experiment. The C/N ratio and total C were significantly different with p-values of 0.005 and 0.002. Initial total S content of the media was 0.064% (Table A4). The total P values before and after the pulse experiment were 321.5 mg/L and 251.6 mg/L indicating a significant difference ($p = 0.000$) (Tables A17 and A18).

Elm Sawdust

The dry bulk density for elm sawdust was 0.34 Mg m^{-3}. It had the same ash content (3.02%) as that of elm woodchips. The pH values before and after the pulse experiment were 4.93 and 6.00. EC was 0.31 dS/cm^2 and 0.24 dS/cm^2 before and after the pulse experiment respectively. Both pH and EC were significantly different before and after the 22-day pulse experiment with p-values of less than 0.000 for both measurements (Figs. 4 and 5). Elm sawdust with its smaller particles compared to elm woodchips had higher water holding capacity (169.1%) compared to woodchips (66%) (Figs. 6 and 7). The moisture content, of the sawdust after the pulse experiment was 153.0%.

The particle size distribution of elm sawdust showed 0% in both > 25 mm and 12.5 mm to 25 mm particle diameter categories. For the size class 5.6 mm to 12.5 mm, 2 mm to 5.6 mm and < 2 mm, the percentage were 11.1%, 45.4% and 43.6% respectively (Table A19). After the pulse experiment, particle size distribution was 0.7%, 1.2%, 5.1%, 53.5% and 39.4% for the classes of > 25 mm, 12.5 mm to 25 mm, 5.6 mm to 12.5 mm, 2 mm to 5.6 mm and < 2 mm respectively (Table A3). A shift in the categories > 5.6 mm and > 2 mm was observed with changes of -46% and +17% (Figs. 8 and 9).

Initially, total C and total N for the media were 47.49% and 0.44% resulting in a C/N ratio of 108. After the pulse experiment the values were 47.98% and 0.38% for total C and total N, with a C/N ratio of 129. Although there was a significant change in total C ($p = 0.004$), it did not result in any significant change in C/N ratio ($p = 0.121$) over the 22-day experiment. Initial sulfur content of the media was 0.064% (Table A4). Initial total P concentration of the media was 321.5 mg/L. After the pulse experiment, total P concentration changed to 252.3 mg/L a significant decrease ($p = 0.003$) over the 22-day period.

Spruce Woodchips

In spruce woodchips, the measured ash content and dry bulk density were 1.06% and 0.25 Mg m^{-3}. The initial pH and EC were 4.53 and 0.26 dS/cm^2. After the pulse experiment, pH and EC were 5.25 and 0.16 dS/cm^2. Both pH and EC were significantly different before and after the pulse experiment ($p = 0.000$) (Figs. 4 and 5). The maximum water holding capacity of the initial media was 56.1% (Fig. 6). The moisture content after the pulse experiment was 131.1% (Fig. 7), an increase of more than 100% compared to the maximum water holding capacity.

The particle size analysis of the initial media was 9.9%, 39.9%, 34.9%, 12.1%, and 3.2% for particles with a diameter of >25 mm, 12.5 mm to 25 mm, 5.6 mm to 12.5 mm, 2 mm to 5.6 mm and < 2 mm respectively. After the pulse experiment, the class distribution changed to 3.5% for > 25 mm, 14.4% for 12.5 mm to 25 mm, 35.6% for 5.6 mm to 12.5 mm, 29.3% for 2 mm to 5.6 mm and 17.1% for the < 2 mm particle diameter sizes respectively (Table A19). This indicates a shift from medium (12.5 mm – 25 mm) to smaller size particles (2 mm – 5.6 mm and < 2 mm) (Figs. 8 and 9).

Total N and total C content before and after the pulse experiment were 0.18%, 0.14%, 52.87%, and 50.41% respectively. The C/N ratios derived from those values are 293 before and 360 after the 22-day pulse experiment. This shows a significant decrease in total N ($p = 0.002$) and total C ($p = 0.000$), and a significant increase in C/N ratio ($p = 0.003$). Total P, before and after the pulse experiment, was 124.6

mg/L and 93.2 mg/L, indicating a significant decrease ($p = 0.001$). Initial total S content of the media was 0.082% (Table A4).

Spruce Sawdust

Spruce sawdust had a dry bulk density of 0.28 Mg m^{-3} and an ash content of 1.06%. pH and EC values before and after the pulse experiment were 4.53, 5.43, 0.26 dS/cm^2 and 0.17 dS/cm^2 respectively. Both the pH and EC were significantly different ($p = 0.000$) between the start and the end of the pulse experiment (Figs. 4 and 5). The media showed a maximum water holding capacity of 152.0% (Fig. 6) whereas the moisture content after the pulse experiment was 177.4% (Fig. 7).

The particle size distribution of the initial media showed 0% in both > 25 mm and 12.5 to 25 mm. For the classes 5.6 mm to 12.5 mm, 2 mm to 5.6 mm and < 2 mm, the percentage were 6.3%, 57.3% and 36.5% respectively (Table A19). After the pulse experiment, the class size distributions were: 0.0%, 0.1 %, 1.5%, 49.1% and 49.3% for > 25 mm, 12.5 mm to 25 mm, 5.6 mm to 12.5 mm, 2 mm to 5.6 mm and < 2 mm respectively indicating a shift toward smaller size particles, especially 2 mm to 5.6 mm and < 2 mm categories (Figs. 8 and 9).

Initial total C and total N of the media were 52.87% and 0.18% resulting in a C/N ratio of 293. After the pulse experiment total C and N were 50.19% and 0.15%, resulting in a C/N ratio of 332. All three parameters were significantly different ($p = 0.003$ for total N, $p = 0.000$ for total C, and $p = 0.006$ for C/N ratio) between the start and end of the pulse experiment. The initial sulfur content was 0.082% (Table A4). The total P concentration before and after the 22-day pulse experiment were 124.6 mg/L and 97.6 mg/L; a significant decrease ($p = 0.006$).

Morris Woodchips

For Morris woodchips the measured dry bulk density and ash content were 0.24 Mg m^{-3} and 15.53%. Initial pH and EC were 6.02 and 0.55 dS/cm^2. After the pulse experiment, pH and EC were 6.73 and 0.53 dS/cm^2 (Figs. 4 and 5). EC and pH of the media before and after the pulse experiment was not significantly different with a p-value of higher than 0.05. The maximum water holding capacity of the media and the moisture content after the pulse experiment were 126.4% and 166.5%, respectively (Figs. 6 and 7).

The particle size analysis of the initial media were 1.3%, 31.5%, 34.1%, 19.0%, and 14.1% for the size classes >25 mm, 12.5 mm to 25 mm, 5.6 mm to 12.5 mm, 2 mm to 5.6 mm and < 2 mm (Table A19). After the pulse experiment, the particle size distribution was 1.5% for the > 25 mm, 11.6% for 12.5 mm to 25 mm, 36.1% for 5.6 mm to 12.5 mm, 30.6% for 2 mm to 5.6 mm and 20.3% for the < 2 mm (Table A19). The shift was most prominent in particles with a diameter between 12.5 mm and 25 mm as well as 2 mm and 5.6 mm. It appears that the larger diameter particles (12.5 mm to 25 mm) decreased whereas the smaller size particles (2 mm to 5.6 mm) increased (Figs. 8 and 9).

Total C and total N of the initial media were 42.99% and 0.57% resulting in a C/N ratio of 76. After the pulse experiment the values were 40.70% and 0.59% for total C and total N with a ratio of 70. No significant changes occurred in total N, total C and C/N ratio over the 22-day period (Table A1). The initial sulfur content was 0.105%. Initial total P concentration of Morris woodchips was 846.1 mg/L, which decreased to 649.0 mg/L after the pulse experiment, a significant decrease ($p = 0.003$).

Corn Cobs (CC)

Corn cobs had a mean dry bulk density of 0.14 Mg m^{-3} and a mean ash content of 2.19%. The initial pH and EC were 4.93 and 1.26 dS/cm^2. After the 22-day pulse experiment, the pH and EC were 5.58 and 0.74

dS/cm^2 respectively. EC showed a significant decrease ($p = 0.010$) whereas pH was not significantly different ($p = 0.053$) (Figs. 4 and 5). The water holding capacity of the corn cobs was 271.5% (Fig. 6) whereas the moisture content after the pulse experiment was 316.4% (Fig. 7).

The particle size analysis of the initial corn cobs showed 4.0% of particles > 25 mm, 33.6% of the particles with a diameter between 12.5 mm and 25 mm, 41.3% between 5.6 mm and 12.5 mm, 13.7% between 2 mm and 5.6 mm, and 7.4% smaller than 2 mm, respectively (Table A19). After the pulse experiment the distribution changed to 1.4% for > 25 mm, 22.4% for 12.5 mm to 25 mm, 41.8% for 5.6 mm to 12.5 mm, 24.8% for 2 mm to 5.6 mm and 9.7% for particles < 2 mm (Table A19). The comparison showed a slight decrease in particles with a diameter of 12.5 mm to 25 mm and a increase in particles with a diameter between 2 mm to 5.6 mm (Figs. 10 and 11).

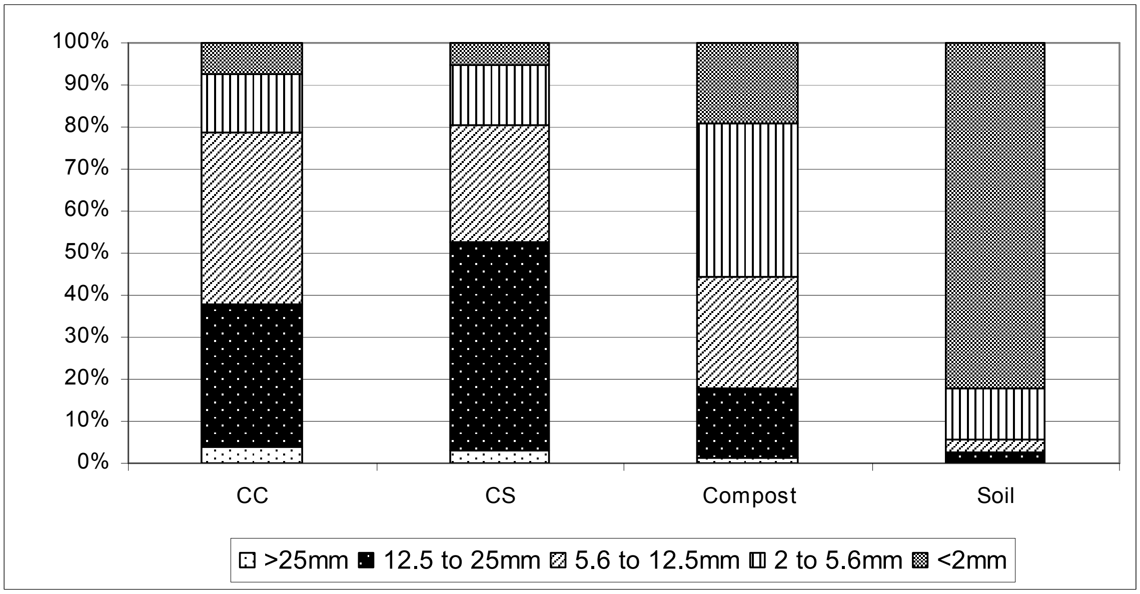


Figure 10: Initial particle size distribution of corn cobs (CC), corn stover (CS), compost and soil

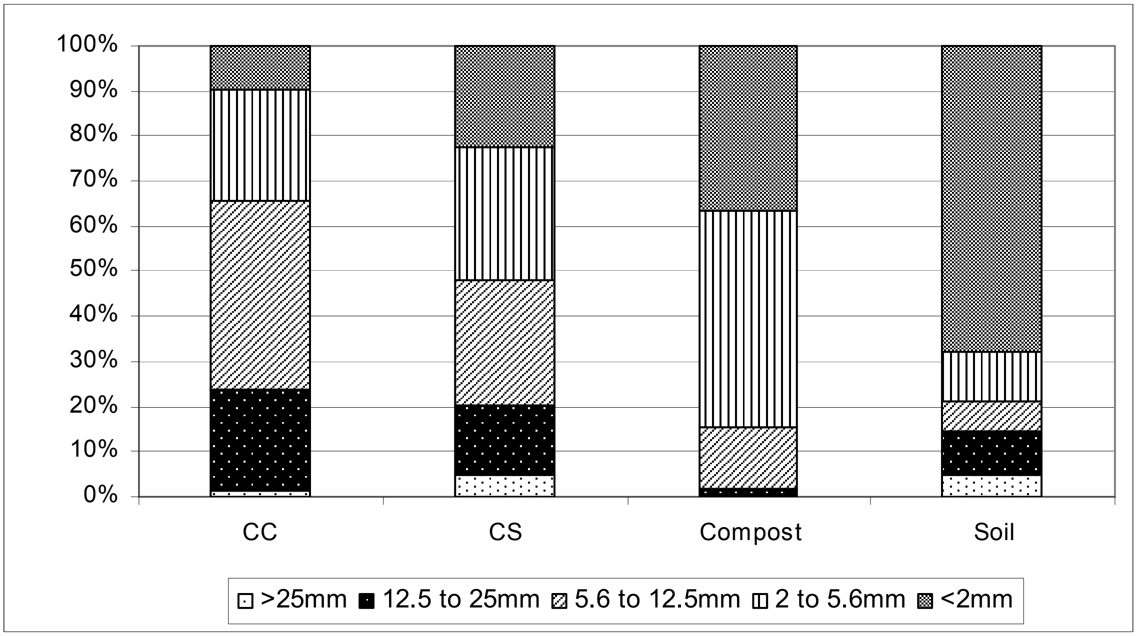


Figure 11: Particle size distribution of corn cobs (CC), corn stover (CS), compost and soil after Pulse Experiment

Total N and total C measured before and after the pulse experiment were 0.40%, 0.62%, 47.01%, and 47.26% respectively. These were equivalent to a C/N ratio of 119 before and 80 after the pulse experiment. This means a significant decrease in the C/N ratio (p = 0.005) but a significant increase in total N (p = 0.004) as a result of the pulse experiment. There was no change in total C before and after the pulse experiment (p = 0.059). Initial S content of the media was 0.073% (Table A6). Total P concentrations before and after the pulse were 345.0 mg/L and 447.5 mg/L resulting in a not significant change (p = 0.115).

Corn Stover (CS)

For corn stover the measured ash content and dry bulk density were 9.06% and 0.05 Mg m^{-3}. The initial pH and EC were 5.55 and 2.28 dS/cm^2. After the pulse experiment, pH significantly increased (p = 0.001) to 7.13 and EC significantly decreased (p = 0.024) to 1.49 dS/cm^2 (Figs. 4 and 5). The water holding capacity of the initial media was 563.8% (Fig. 6), whereas the moisture content measured as-is after the pulse experiment was 769.7% (Fig. 7).

The particle size analysis of the initial media were 3.3%, 49.5%, 27.8%, 14.2%, and 5.3% for the size classes > 25 mm, 12.5 mm to 25 mm, 5.6 mm to 12.5 mm, 2 mm to 5.6 mm and < 2 mm. The particle size distribution after the pulse experiment changed to 4.9% for > 25mm, 15.5% for 12.5 mm to 25 mm, 27.6% for 5.6 mm to 12.5 mm, 29.5% for 2 mm to 5.6, and 22.5% for the < 2 mm (Table A19). The shift is noticeable for the particles especially for particles with a diameter between 12.5 mm to 25 mm where it declined by 68% and particles with a diameter between 2 mm to 5.5 mm and < 2 mm where it inclined by 108% and 323% respectively (Figs. 10 and 11).

The total N and total C ratio for the media before and after the pulse experiment were 0.62%, 43.49%, 0.78% and 45.70% respectively. This is equivalent to C/N ratios of 70 before and 59 after the pulse experiment. Significant increase were observed for total N (p = 0.005) and total C (p = 0.001). C/N ratio with a p-value of 0.007 showed a significant decrease over the 22-day period. Total P concentration, before and after the pulse experiment, were 814.2 mg/L and 895.3 mg/L; which are not significantly different (p = 0.220). Total S measured initially in corn stover was 0.115%.

During the pulse experiment samples of the media were taken to qualitatively measure Coliforms, *Streptococcus*, *Staphylococcus* spp. and *Bacillus* from the first week and the fourth week of the pulse experiment. The results showed that initially Coliforms, *Strep*. and *Bacillus* were present in the media in the amounts of 148 x 10^5, 794 x 10^5 and 4.37 x 10^5 colony forming units (cfu) respectively (Table A20). In the fourth and last week of the experiment, 3.72 x 10^5, 5.89 x 10^5, 0.81 x 10^5 and 2.57 x 10^5 cfu were measured in the media for Coliforms, *Strep*, *Staph*. spp. and *Bacillus* respectively (Table A20). A comparison of initial and final values showed significant decrease in Coliforms (p = 0.001) and *Streptococcus* (p = 0.016) whereas *Staphylococcus* spp. (p = 0.000) significantly increased in the media (Figs. 12, 13, 14 and 15).

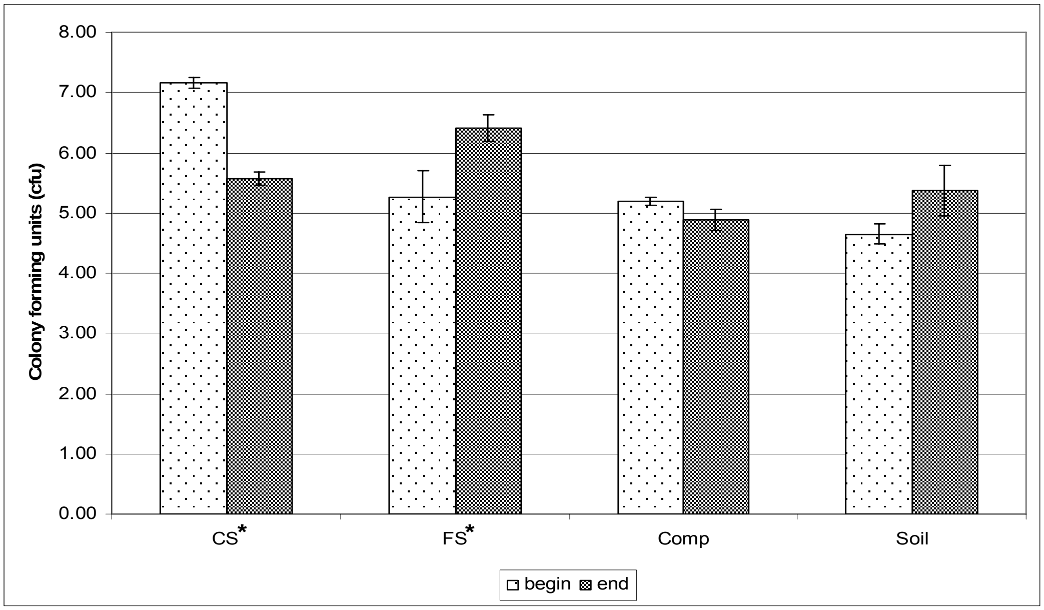


Figure 12: Colony forming units (cfu) of coliform measurements in corn stover (CS), flax straw (FS), compost (comp) and soil in the first and fourth week of the pulse experiment

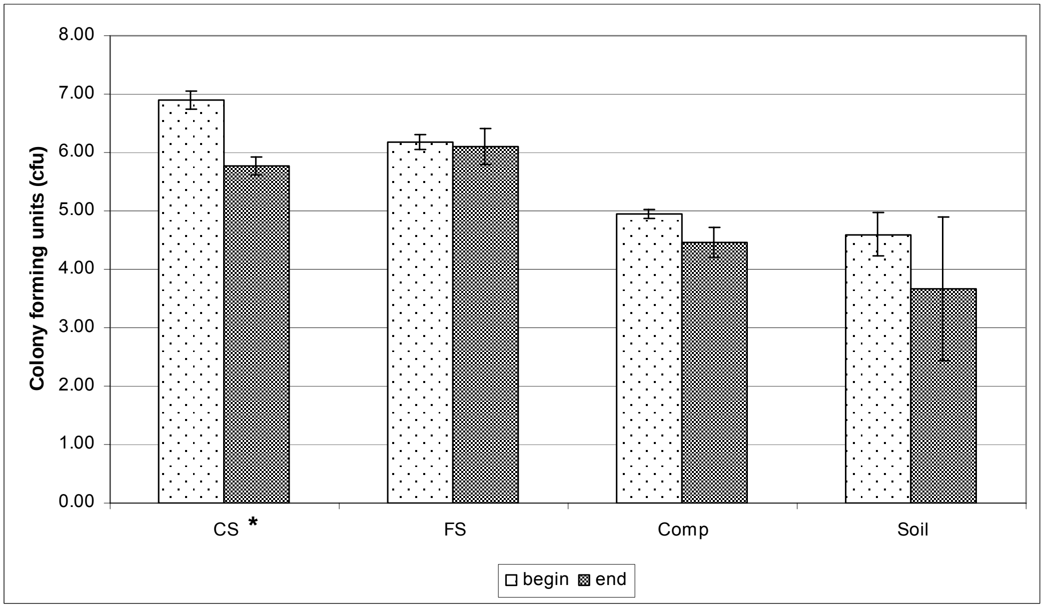


Figure 13: ***Streptococcus*** **colony forming units (cfu) in corn stover (CS), flax straw (FS), compost (comp) and soil in the first and fourth week of pulse experiment**

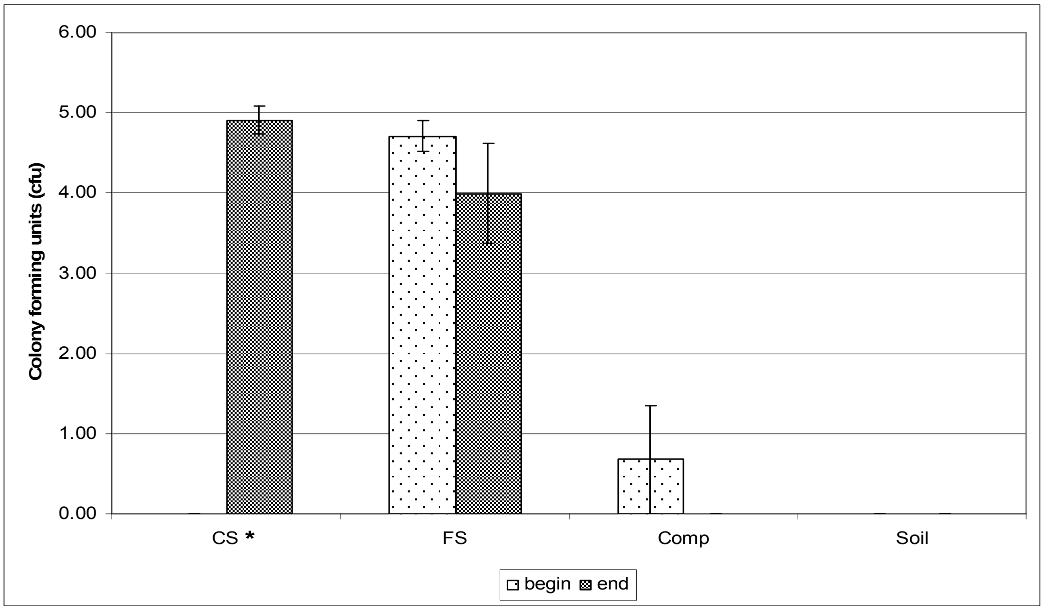


Figure 14: ***Staphylococcus*** **spp. cfu in corn stover (CS), flax straw (FS), compost (comp) and soil in the first and fourth week of pulse experiment**

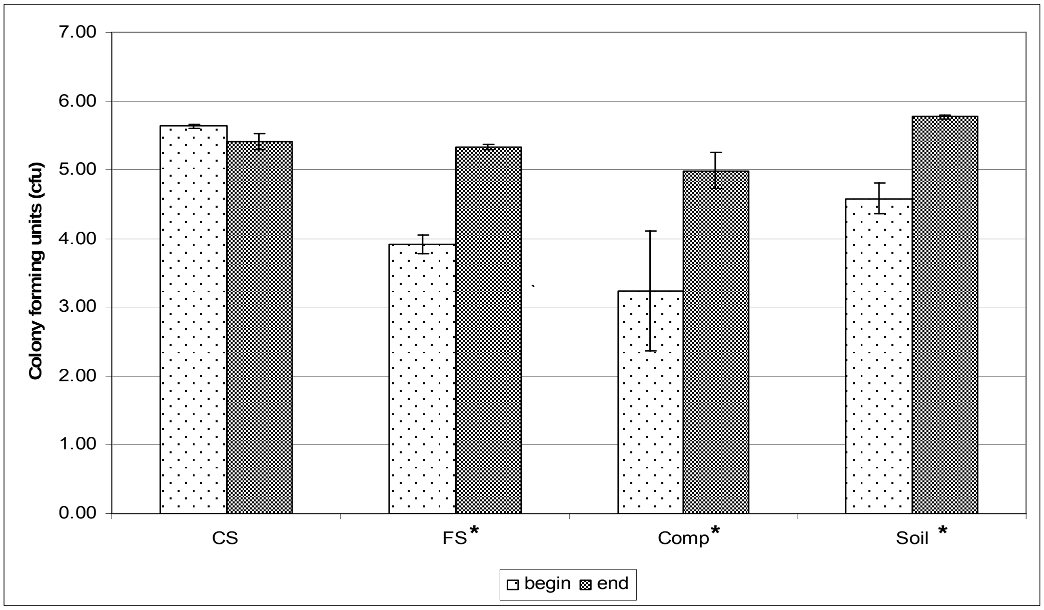


Figure 15: *Bacillus* cfu in corn stover (CS), flax straw (FS), compost (comp) and soil of the first and fourth week into the pulse experiment

Flax Straw (FS)

Flax straw had an ash content of 2.07%. EC and pH after the pulse experiment were 1.10 dS/cm^2 and 6.63 (Figs. 4 and 5). The water holding capacity of flax straw could not be determined due to the high oil content of flax. The moisture content after the pulse experiment was 254.1% (Fig. 7).

Initially, total C and total N of the media were 45.33% and 0.78% with a C/N ratio of 59. After the pulse experiment total C and N were 49.05% and 0.76% with a C/N ratio of 65. Total C significantly increased ($p = 0.000$) whereas total N significantly decreased ($p = 0.040$). However, no significant changes occurred in the C/N ratio ($p = 0.142$). The total P concentration after the pulse experiment was 872.2 mg/L.

The media samples after 1 week of pulse experiment showed the presence of 1.86 x 10^5, 15.1 x 10^5, 5.13 x 10^5, and 0.08 x 10^5 cfu for Coliforms, *Streptococcus*, *Staphylococcus* spp. and *Bacillus* respectively. Correspondingly, the cfu in the fourth week of pulse experiment were 25.7 x 10^5, 12.6 x 10^5, 0.10 x 10^5 and 2.14 x 10^5, a significant increase of coliforms ($p = 0.047$) and *Bacillus* ($p = 0.001$) and no change in *Streptococcus* and *Staphylococcus* spp. (Figs. 12, 13, 14 and 15).

Mature Compost

The measured ash content and dry bulk density of mature compost were 33.94% and 0.17 Mg m^{-3}. The pH before and after the pulse experiment were 6.86 and 7.80 indicating a significant increase ($p = 0.001$) (Fig. 4). EC before and after pulse experiment were 2.17 dS/cm^2 and 1.49 dS/cm^2, a significant decrease ($p = 0.005$) (Fig. 5). The water holding capacity of the media was 260.2% (Fig. 6) whereas the moisture content after the pulse experiment was 280.4% (Fig. 7).

Initially, particle size distribution of the media was 1.5%, 16.58%, 26.3%, 36.5% and 19.3% for the particle size classes of > 25 mm, 12.5 mm to 25 mm, 5.6 mm to 12.5 mm, 2 mm to 5.6 mm and < 2 mm (Table A19). After the pulse experiment the particles size distribution was 0.1%, 1.6 %, 13.6%, 48.1% and 36.6% for > 25 mm, 12.5 mm to 25 mm, 5.6 mm to 12.5 mm, 2 mm to 5.6 mm and < 2 mm diameter particles respectively, indicating a shift toward smaller size particles, especially the class size categories of 2 mm to 5.6 mm and < 2 mm (Figs. 10 and 11).

Initial total N and total C concentrations of the compost were 1.14% and 29.48% with a C/N ratio of 26. After the pulse experiment total N and C were 1.15% and 37.44% resulting in a ratio of 33. Although there was a significant decrease in total C ($p = 0.005$), no change in total N ($p = 0.051$) and C/N ratio ($p = 0.077$) were observed. Initial sulfur content was 0.257%. Total P concentrations before and after the 22-day pulse experiment were 3343.1 mg/L and 2724.2 mg/L indicating a significant decrease ($p = 0.002$).

One week after the pulse experiment, Coliforms, *Streptococcus*, *Staphylococcus* spp. and *Bacillus* were 1.55×10^5, 0.89×10^5, 4.68 and 1.74×10^3 cfu. The corresponding cfu in the fourth week were 0.77×10^5, 0.29×10^5, 0 and 0.98×10^5 respectively (Table A20). This suggests a significant decrease for *Bacillus* ($p = 0.030$) only (Fig. 15).

Soil

The dry bulk density of soil was 1.38 Mg m^{-3}. The values for pH and EC before and after the pulse experiment were 7.09, 8.23, 0.09 dS/cm^2 and 0.11 dS/cm^2. Whereas pH significantly increased ($p = 0.001$) over the 22-day period, EC significantly decreased ($p = 0.004$) (Figs. 4 and 5). The water holding capacity of the soil was 34.8% (Fig. 6) and the moisture content after the pulse experiment was 27.5% (Fig. 7).

Initial particle size distribution of the soil was 0%, 2.8%, 2.9%, 12.1%, and 82.2% for the size classes >25 mm, 12.5 mm to 25 mm, 5.6 mm to 12.5 mm, 2 mm to 5.6 mm and < 2 mm. Particle size distribution after 22 days changed to 5.0% for the > 25 mm, 9.6% for 12.5 mm to 25 mm, 6.5% for 5.6 mm to 12.5 mm, 11.3% for 2 mm to 5.6 mm and 67.7% for the < 2 mm particle diameter respectively (Table A19). The comparison of this data shows a moderate shift towards larger size particle (Figs. 10 and 11).

Initial total C and total N concentrations for the media were 2.16% and 0.15% resulting in a C/N ratio of 15. After the pulse experiment total C and total N changed to 2.06% and 0.14% giving a C/N ratio of 15. This was a significant decrease in total C ($p = 0.027$), total N ($p = 0.041$), C/N ratio ($p = 0.046$) over the initial value. Total initial sulfur content of the media was 0.055%. Initial total P of the soil was 444.9 mg/L which change to 413.2 mg/L after the pulse experiment. The difference between the initial and final total P was not significant ($p = 0.077$).

The cfu of the soil samples at week 1 were 4.47×10^4, 3.98×10^4 and 3.80×10^4 for Coliforms, *Streptococcus*, and *Bacillus* respectively. After 22 days, cfu for the three groups were 2.4×10^5, 0.46×10^4 and 5.89×10^5 (Table A20). No *Staphylococcus* spp. was measured in soil (Fig. 14). *Bacillus* counts at the end significantly increased in the soil as compare to the initial value ($p = 0.008$) (Fig. 15).

Pulse Experiment

Remediation of Mineral Nitrogen

Mineral Nitrogen measured in the leachate samples were NH_4-N and NO_3-N. However, the NO_3-N values were very small and therefore the graphs show mainly NH_4-N. The feedlot runoff applied to the media had a mineral N (NO_3 and NH_4) concentration of 1.6 mg/L (Table A28). This value was used as a reference to see whether or not mineral N was reduced by the media over the 22-day pulse experiment. The leachate collected from elm woodchips started with a mineral N concentration of 20.7 mg/L and decreased (p = 0.000) to 3.1 mg/L by day 22(Fig. 16). Since, this end concentration was significantly higher than the reference (p = 0.000) this suggests that no mineral N was reduced from the feedlot runoff. Comparatively, elm sawdust started with a mineral N concentration of 61.9 mg/L and ended with a concentration of 2.6 mg/L (Table A28). The rate of change in mineral N over the 22-day experiment was sharp (p = 0.000) (Fig. 16). The N concentration for elm sawdust on day 22 of the pulse experiment was not significantly different (p = 0.082) from the N concentration in the applied feedlot runoff.

Compared to elm, spruce woodchips and sawdust showed much lower mineral N concentrations in the leachate. Spruce woodchips started with a mineral-N concentration of 0.6 mg/L and reached an end concentration of 1.3 mg/L (Table A28). The beginning and end concentrations were not significantly different. Spruce sawdust had a starting concentration of 0.4 mg/L mineral-N and a final N concentration of 0.1 mg/L. These two concentrations were also not significantly different (p = 0.152). Even though no significant change was determined over time, the end concentration of 0.1 mg/L was significantly lower compared to the concentration in the feedlot runoff (p = 0.000).

Morris woodchips, had a start and end mineral-N concentrations of 6.4 mg/L and 0.9 mg/L, indicating a significant decrease in the N concentration over time (Fig. 16). Also, comparing the final mineral-N leached from the Morris woodchips with the N concentration in feedlot runoff, a significant decrease (p = 0.008) can be observed.

Corn cobs with its starting mineral-N concentration of 0.7 mg/L and its end concentration of 0.2 mg/L showed a non significant change over time (p = 0.092) (Fig. 16). However, the end concentration was significantly lower (p = 0.000) than the N concentration in the applied feedlot runoff. Corn stover had higher starting (1.1 mg/L) and end (0.9 mg/L) concentrations of mineral N compared to corn cobs. Over time, mineral N concentrations in the leachate from corn stover significantly decreased (p = 0.001) (Fig. 16). But there was no significant difference between the mineral N concentration of the applied feedlot runoff and the end concentration of mineral-N in corn stover leachate. Flax straw with a start mineral-N concentration of 3.7 mg/L and end concentration 3.2 mg/L showed no significant change (Fig. 16). However, comparing the end mineral-N concentration to the reference (1.6 mg/L), a significant increase was obvious (p = 0.003).

Compost started out with a high mineral-N concentration (41.4 mg/L) but after only six days the concentration decreased to 4.5 mg/L with a final concentration of 1.1 mg/L. With a p-value of 0.000, this decrease was significant. However, the end concentration of 1.1 mg/L was not significantly different from the mineral-N concentration measured in the feedlot runoff. The start and end mineral-N concentrations of soil were 7.7 mg/L and 6.3 mg/L which are not significantly different from each other (Fig. 16). Comparison of the soil end concentration to the feedlot runoff concentration indicated a significant increase (p = 0.000) of mineral N concentration in the leachate.

In conclusion, spruce sawdust, Morris woodchips, corn cobs and corn stover showed a significant reduction in mineral-N concentration from the applied feedlot runoff whereas elm woodchips, flax straw and soil demonstrated a significant increase of mineral-N concentration in the leachate when compared to the mineral-N concentration of the applied feedlot runoff.

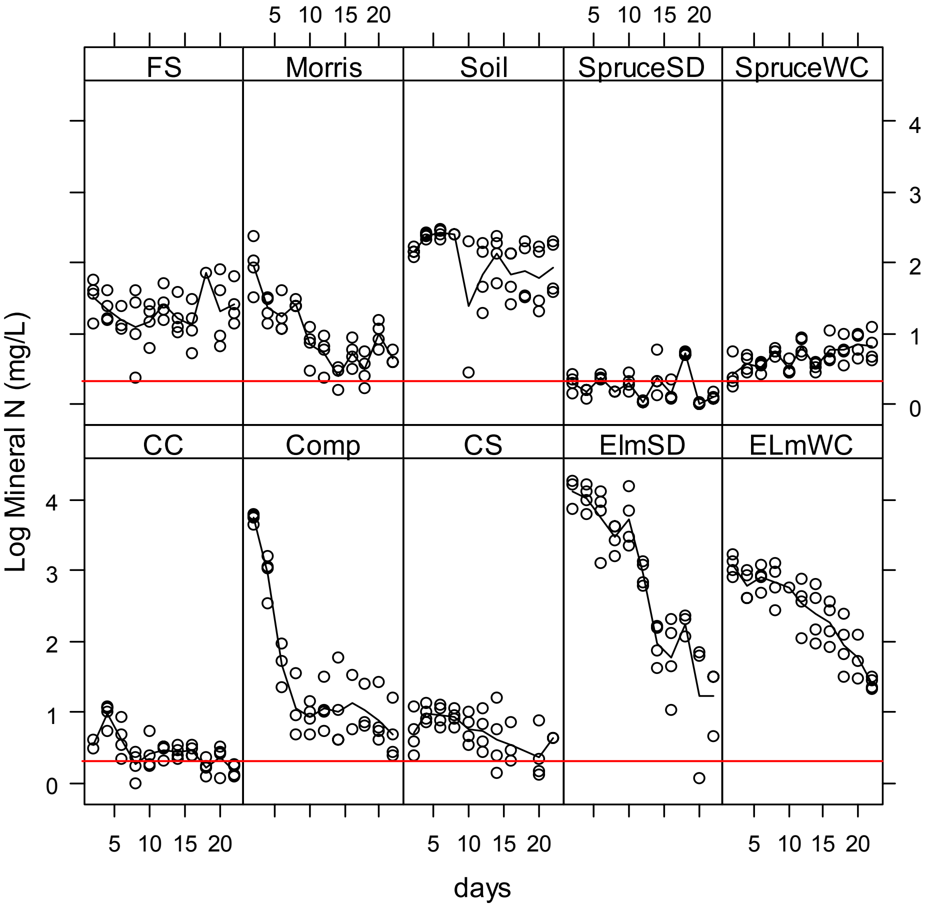


Figure 16: Variation in mineral N (NH_4-N and NO_3-N) of various media during the 22-day feedlot runoff application. FS = flax straw, CC = corn cobs, CS = corn stover, SD = sawdust and WC = woodchips). The red line indicates the mineral N input (1.6 mg/L) from the feedlot runoff.

Remediation of Soluble Phosphorus

The feedlot runoff (control) had a soluble P concentration of 6.6 mg/L. This was the concentration applied to the media during the 22-day leaching experiment. The start and end concentrations of soluble P for the elm woodchips were 9.2 mg/L and 3.8 mg/L respectively. This indicated a significant decrease in soluble P both over time (p = 0.000) and compared to the control (p = 0.000). Elm sawdust had a start concentration of 14.6 mg/L and a end concentration of 3.9 mg/L; a significant decreases over the 22 day pulse experiment and compared to the control (p = 0.000) (Fig. 17).

Spruce woodchips started with a concentration of 5.5 mg/L. Over the next 8 days the concentration went up to values between 9.02 mg/L and 8.3 mg/L before reaching a concentration of 6.6 mg/L on day 22. The temporal variation showed a significant increase of soluble P (p = 0.042) during the pulse experiment (Fig. 17). Spruce woodchips also failed to reduce soluble P from the feedlot runoff (p = 0.458). Spruce sawdust had a start and end soluble P concentration of 4.12 mg/L and 7.57 mg/L respectively; a significant increase (p = 0.000) (Fig. 17). Furthermore, soluble P concentration from spruce sawdust added a significant (p = 0.016) amount of soluble P to the feedlot runoff. Morris woodchips showed start and end of soluble P concentrations of 9.6 mg/L and 6.9 mg/L. With a p-value of 0.012, this media significantly decreased soluble P over the 22 days; yet, it failed to reduce P concentrations from the feedlot runoff (p = 0.306) (Fig. 17).

Corn cobs started with a soluble P concentration of 5.87 mg/L. After 22 days, the concentration was 3.71 (Fig. 17). This was a significant decrease (p = 0.019) from the initial soluble P and also a decrease (p = 0.000) compared to the soluble P in the feedlot runoff (Fig. 17). Corn stover, on the other hand, started with a soluble P concentration of 2.81 mg/L and had a significantly higher (p = 0.000) concentration (8.57 mg/L) at the end of the pulse experiment (Fig. 15). The same was true comparing soluble P end concentration to the concentrations measured in the feedlot runoff. Flax straw showed similar pattern as corn stover starting with a soluble P concentration of 3.03 mg/L and ending with a soluble P concentration of 9.75 mg/L. Both the temporal variation as well as the comparison with the control showed a significant increase of soluble P (p = 0.000) (Fig. 17).

Compost and soil had start and end soluble P concentrations of 62.6 mg/L, 17.2 mg/L, 0.3 mg/L and 0.4 mg/L respectively. For compost this translates into a significant decrease of soluble P over the 22-day pulse experiment, yet, a significant increase (p = 0.000) of soluble P in the leachate compared to the applied feedlot runoff (Fig. 17). Soil on the other hand had no significant temporal variation (p = 0.298) in soluble P concentrations but was significant lower (p = 0.000) when compared to the soluble P concentration in the applied feedlot runoff (Fig. 17).

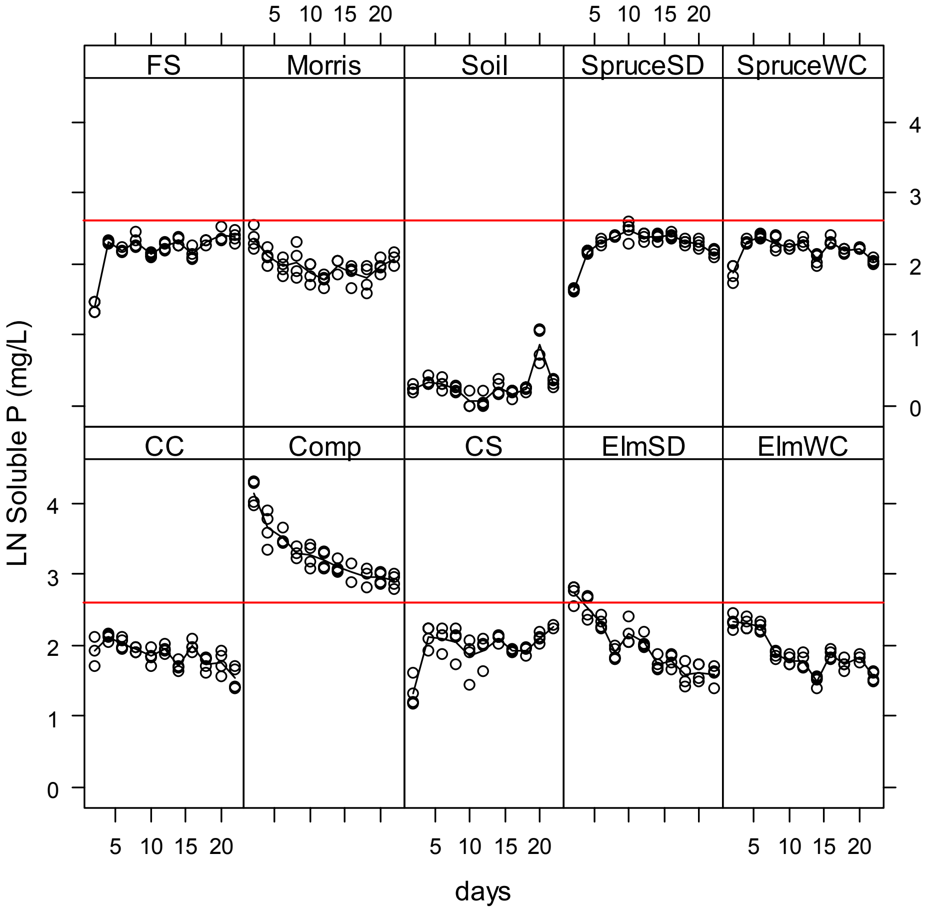


Figure 17: Mean soluble phosphorus measured during pulse experiment (FS = flax straw, CC = corn cobs, CS = corn stover, SD = sawdust and WC = woodchips). The red line indicates the P input (6.6 mg/L) from the feedlot runoff.

Remediation of Total Coliform and E.coli

Due to difficulties of the contract laboratory with the sampling procedures, total coliform (TC) and *E.coli* data was lost. This made it necessary to combine the two runs for elm woodchips, elm sawdust, spruce woodchips, spruce sawdust and Morris woodchips. Since the second run of elm woodchips, elm sawdust, spruce woodchips, spruce sawdust and Morris woodchips were constantly lower for both E.coli and TC an error term was calculated using the statistical software of "R". The data of corn cobs, corn stover, compost and soil were then adjusted using this error term. A linear model with mixed effects was used on the combined data (R Development Core Team. 2007).

All media except flax straw and soil showed significant decreases (Table 4) of total coliform over the 22-day pulse experiment (Fig. 18). Flax straw with a p-value of 0.335 showed no significant changes in total coliforms (Fig. 18). Soil was excluded from the statistical analysis because of incomplete data. Table 4 shows the p-values comparing total coliform at the beginning and at the end of the 22-day pulse experiment using different media (Fig. 18).

Table 4: p-values of temporal variation of total coliform

Elm woodchips	0.001
Elm sawdust	0.000
Spruce woodchips	0.000
Spruce sawdust	0.000
Morris woodchips	0.002
Corn cobs	0.000
Corn stover	0.000
Flax straw	0.335
Compost	0.013

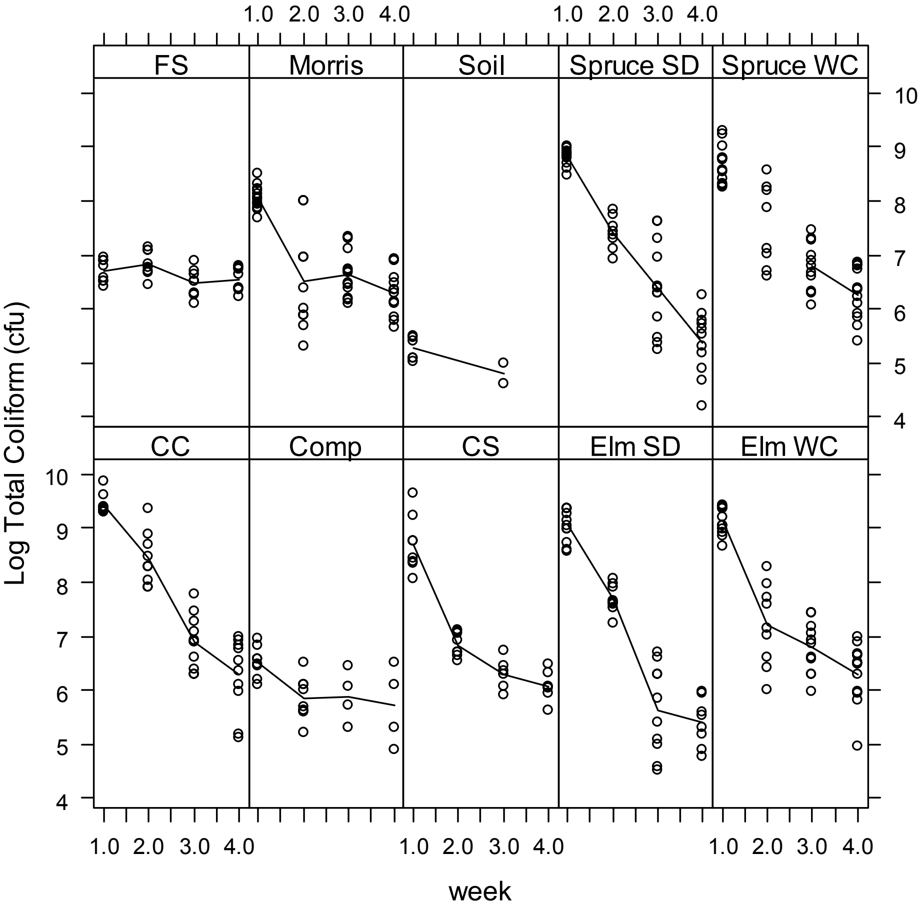


Figure 18: Mean total coliform cfu (log) in the leachate from feedlot runoff applications during the pulse experiment. FS = flax straw, CC = corn cobs, CS = corn stover, SD = sawdust and WC = woodchips

In contrast to total coliforms, the only two media that showed a significant decrease of *E.coli* using a mixed model were elm sawdust (p = 0.000) and corn stover (p = 0.026) (Fig. 19). Due to incomplete data, soil was excluded from statistical analysis.

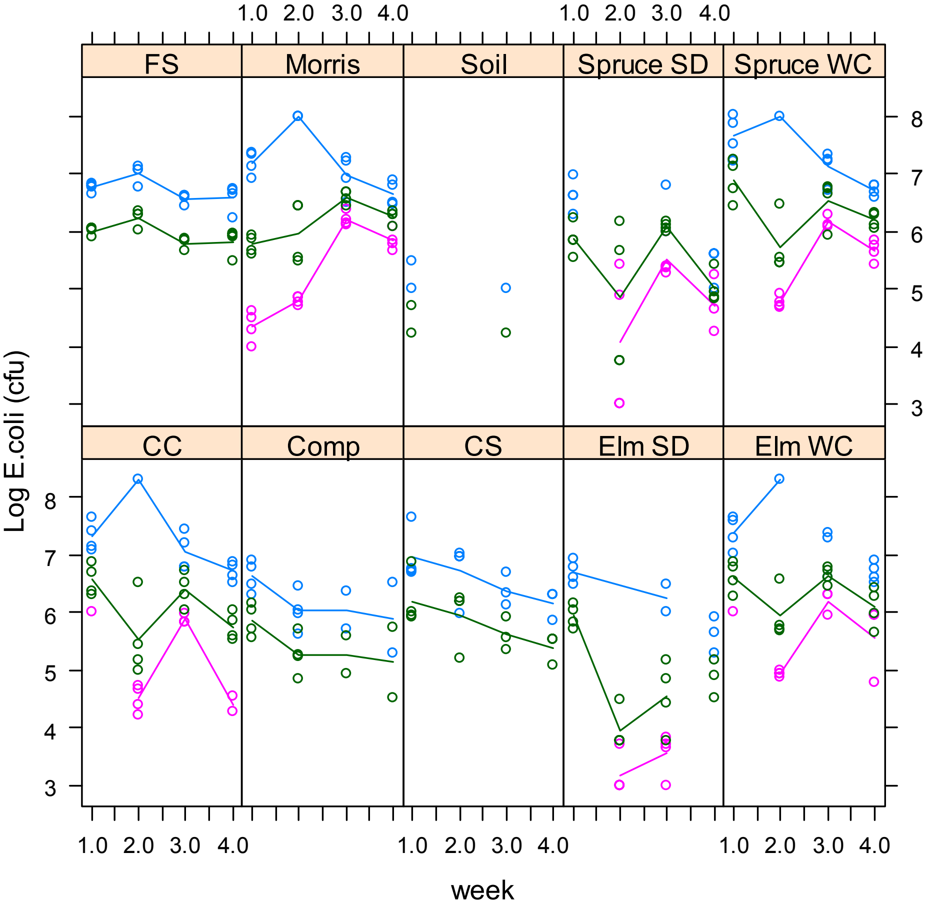


Figure 19: *E.coli* (log) cfu in the leachate from feedlot runoff applications during the pulse experiment. FS = flax straw, CC = corn cobs, CS = corn stover, SD = sawdust and WC = woodchips. The green line represents the corrected mean value.

Discussion

Chemical and Physical Media Evaluation

The carbon to nitrogen (C/N) ratio is an indicator of how fast the media will degrade and thus it provides information on the longevity of the biofilter. Media with low initial C/N ratios degrade faster in the first three month of composting compared to high C/N ratio material (Eiland et al., 2001). An explanation for this is that with high C/N ratios, the microorganisms are initially N limited and therefore do not grow as fast as on low C/N ratio media. With this lower microbial activity in high C/N ratio material this would result in a longer durability of the biofilter. In addition, C/N ratios higher than 50:1 have been found to reduce ammonia emission indicating that less N is lost to the atmosphere with high C/N ratio material (Villegas-Pangga, 2000). However, choosing a media with too high C/N ratio would limit incipient microbial growth and thus would initially make it difficult to reduce N, P and *E.coli*. Inorganic N could be added to overcome initial high C/N ratios. In the current study, spruce woodchips as well as spruce sawdust showed high C/N ratios both before and after application of feedlot runoff (Fig. 20). The significant increase of C/N ratio after the pulse experiment could be explained with the volatilization of N during the drying of the media after the experiment. This volatilization would most likely appear in all ten media and would therefore implicate that in all media the actual C/N ratio would be lower than measured. For future studies, total N should be measured on the media before drying. Methods such as total Kjeldahl Nitrogen could be used to achieve accurate measurements of total N.

The C/N ratios given by Rynk (1992) in Table 1 are comparable to the initial C/N ratios measured for corn cobs, corn stover, flax straw and spruce (softwood). However, elm (hardwood) with a C/N ratio of 107 is clearly below Rynk's range of 451 to 819 for C/N ratios of hardwoods (Table 1). This implies that generalizing woods into categories of hardwood and softwood might not be valid and instead each individual species needs to be measured. Corn cobs, corn stover and soil showed a significant decrease of C/N ratio during the pulse experiment implying that microorganisms were active and degraded some of the carbon (Fig. 20). Eiland et al. (2001) designated a C/N ratio of 53 as a high C/N ratio. All media except compost and soil showed C/N ratios of over 53. However, keeping in mind that the durability of the biofilter is directly related to the C/N ratio and since N is provided from the feedlot runoff, higher C/N ratio material should be better suited for biofilter construction.

pH is a measure of hydrogen ion activity in solution and therefore a measure of alkalinity or acidity. It has a major influence on the microbial growth and thus on ammonia emission from the bedding (Misselbrook & Powell, 2005; Tiquia et al., 2002; Lory et al., 2002; Eiland, 2001; Jeppsson, 1999; Anderson, 1995). Microorganisms show their best growth in certain pH-ranges. . For example, bacteria generally grow better in a pH range of 6.0 to 7.5 whereas fungi usually grow over a wider pH range of 5.5 to 8.0. The pH also influences the volatilization of nitrogen; low initial pH will help reduce the emission of ammonia. For an effective biofilter, media should have a low enough pH to reduce ammonia emission without overly limiting microbial growth. The media tested in this study showed an initial pH range of 4.5 (spruce) to 7.1 (soil) with spruce, elm and corn cobs showing values below 5 (Fig. 4). After 22 days of feedlot runoff applications, the pH of all media increased and with the exception of corn cobs this rise was significant (Fig. 4). Since the pH of the manure is generally more alkaline than the media, this rise in pH was expected. However, how pH influences microbial growth was not measured in this study. Considering that microbial activity and possibly interactions are responsible for N and P reductions, further studies regarding the interaction of pH and N and P reduction are needed.

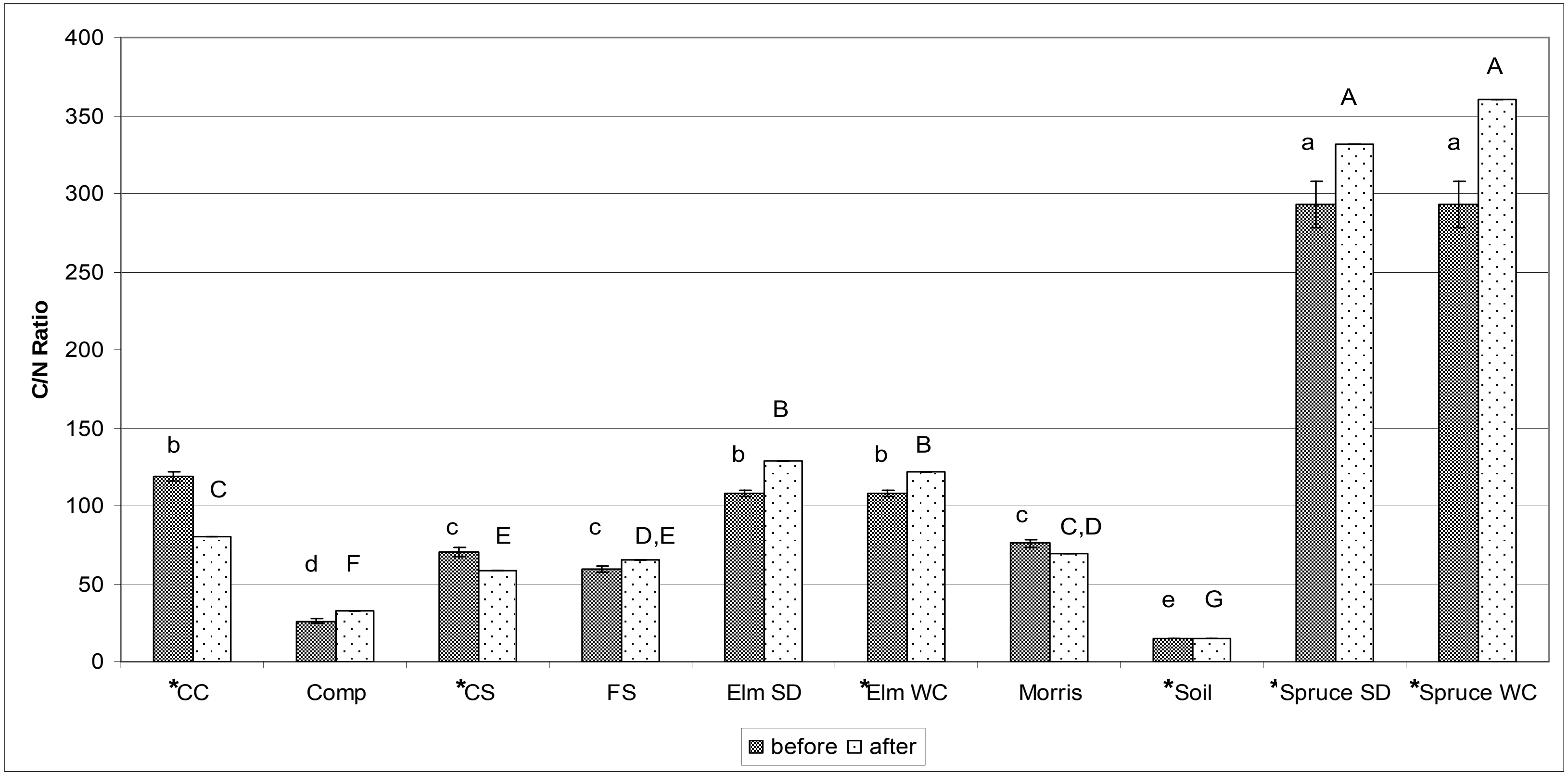


Figure 20: C/N Ratio of the media initially and after the pulse experiment (CC = corn cobs, Comp = compost, CS = corn stover, FS = flax straw, SD = sawdust and WC = woodchips)

Lower case letters indicate significant differences of initial media condition; capital letters indicate significant differences of media after pulse experiment. The asterisk (*) indicates significant differences of media over time ($p<0.05$).

Bulk density as a parameter is less important for the actual success of the media in reducing N, P and *E.coli* through biofilter. However, it has important implications in terms of economics of constructing biofilters. Today, wood is used in a variety of applications from dairy bedded pack to incineration for energy production. This competition between the different wood uses makes low transport costs important. Bulk density is directly related to the economical radius of delivery for the media with high bulk densities being more economical at longer distances. Comparing the measured bulk densities of the different media, soil showed by far the highest value followed by elm sawdust and elm woodchips (Fig. 21). Corn stover had the lowest bulk density and was significantly different from the other tested media (Fig. 21). Elm sawdust (0.34 Mg m^{-3}) and spruce sawdust (0.28 Mg m^{-3}) were outside the range of bulk densities outlined by Rynk (1992) for sawdust (Table 1). This is most likely due to different particle sizes of the sawdust in this study compared to Rynk's. The same can be said for the difference in the density of corn cobs (0.14 Mg m^{-3}) measured in this study compared to Rynk's value of 0.33 Mg m^{-3}. The corn cobs used in this study were cut in pieces whereas the ones used by Rynk (1992) (Table 1) were most likely whole cobs. The bulk densities of both elm woodchips and spruce woodchips were in the range of 0.26 to 0.37 Mg m^{-3} suggested in the literature (Table 1; Table A13).

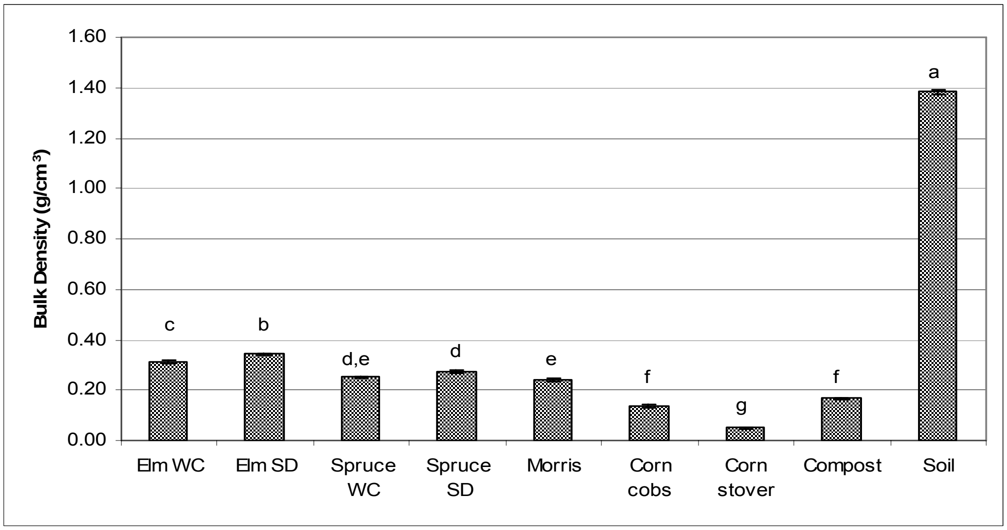


Figure 21: Mean dry bulk density of media. Letters indicate significant differences ($p < 0.05$). CC = corn cobs, CS = corn stover, FS = flax straw, SD = sawdust and WC = woodchips

Maximum water holding capacity and moisture content at the end of the pulse experiment provided information about how much moisture a media can retain. This is important because high water holding capacity can lead to anaerobic conditions and drainage problems. Also, depending on the media, high moisture content can negatively influence the structural stability. In the example of the cellulose based corn stover with its maximum water holding capacity of 564%, the media resembled a pulp after the 22 days of feedlot runoff application. Even after the pulse experiment and an additional drainage time of 48 hours, the moisture content was still 770%. The cell walls of the corn stover were partially disintegrated which resulted in a loss of structural stability. Compost had the next highest water holding capacity together with corn cobs (Fig. 6). However, compared to the moisture content after the pulse experiment, the changes were small (Figs. 6 and 7). Whereas compost lost part of its structural integrity during the pulse experiment, corn cobs were much less affected and their physical structure appeared to be nearly the same as that of the initial media. Differences in moisture content at the end of the pulse experiment and maximum water holding capacity can be explained depending on how easy media can be rewetted and the time available for the media to absorb water i.e. 24 hours compared to 24 days.

Particle size was difficult to interpret but a trend to smaller particles was observed (Figs. 8, 9, 10 and 11). This implies that microbial activity disintegrated larger particles to smaller sizes. Surprisingly, the particle sizes of all media were smaller after the 22-day pulse experiment even though only corn cobs, corn stover and soil showed a decline in C/N ratio; an indication of microbial degradation of C. Soil was the only media tested which showed a slight shift to larger particle sizes. This might be due to aggregation of clay particles in the soil.

Since one of the purposes of the biofilter was to remove P, measurement of total P helps understand the cycling of this nutrient. Compared to nitrogen, P mineralization by microorganism is slower. An increase in total P concentration of the media after the pulse experiment would indicate that P was absorbed from the feedlot runoff. Comparatively, a decline in total P of the media after the pulse experiment would imply that soluble P was leached out by the feedlot runoff application. This removal of total P from the media means that the runoff would contain more P than before it entered the biofilter. This is not desirable.

Since P is often associated with particulate removal, the biofilter should be able to capture fine particles such as soil. Alternatively, a settling basin could be installed in front of the biofilter. Elm woodchips and sawdust, spruce woodchips and sawdust as well as Morris woodchips and compost showed a significant loss of total P over the 22-day pulse experiment (Fig. 22). Compost had the absolute highest initial total P concentration (3343 mg/L). After 22 days of consecutive application of feedlot runoff, total P was significantly lower ($p = 0.002$) with a total P concentration of 2724 mg/L that was still higher than any of the other tested media (Fig. 22). Spruce woodchips and spruce sawdust showed the lowest total P concentrations, followed by elm woodchips and elm sawdust (Fig. 22). An unanswered question is whether microorganisms use P and in which form P gets integrate into the biomass. To answer this question, inorganic P of the media should also be measured.

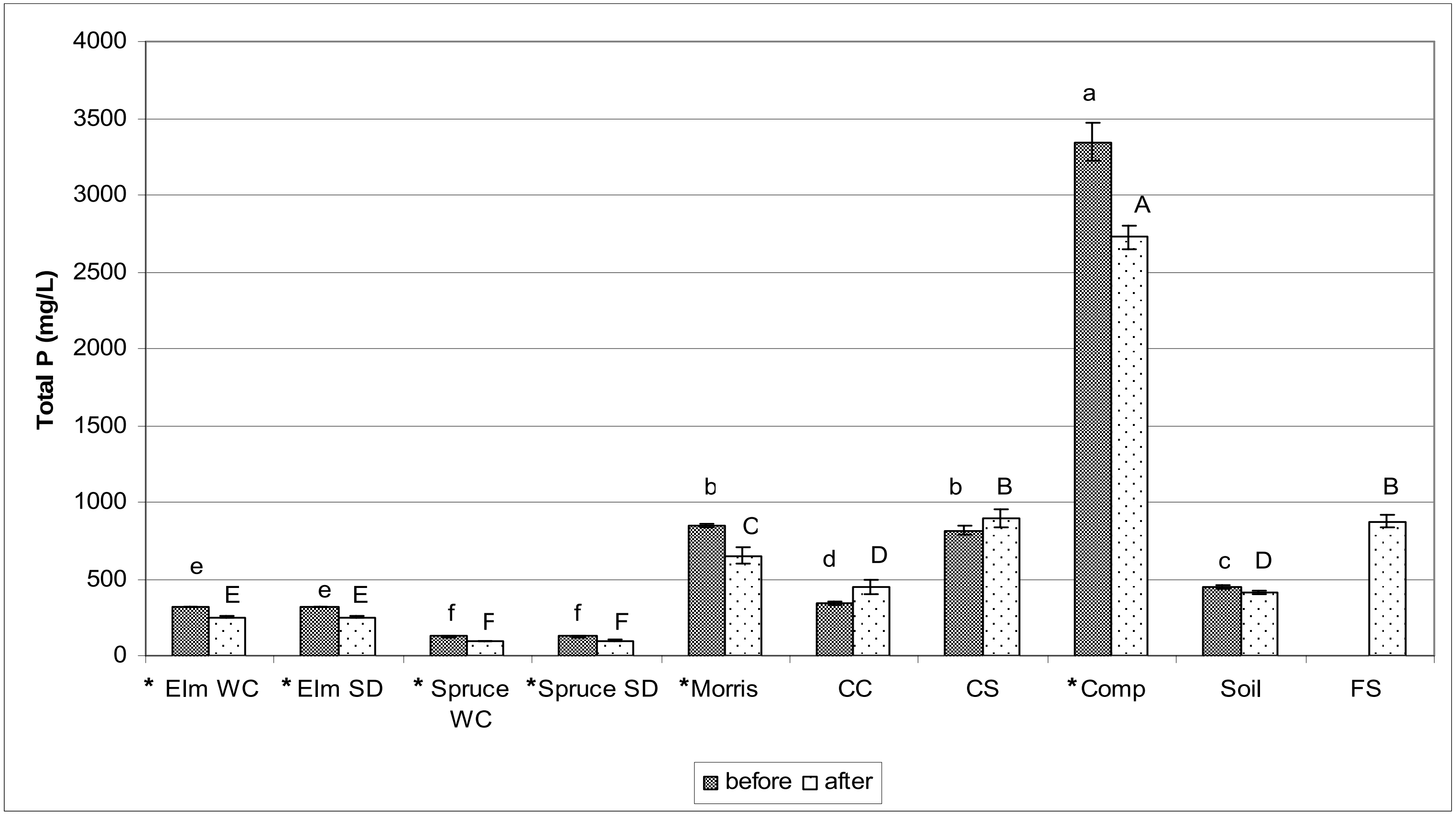


Figure 22: Total Phosphorus in mg/L of media before and after pulse experiment

Lower case letters indicate significant differences of the initial media (before); capital letters indicate significant differences of media after.

In soils, soluble salts refer to dissolved inorganic solutes which are present in the aqueous extract of the media (Page et al., 1984). Electrical conductivity (EC), a measure of the ability of the aqueous solution to conduct an electric current between two electrodes, is highly influenced by the presence of inorganic salts in the solution. Soluble salts are important for plant growth and soil fertility. Considering that the media could be land applied once it is no longer used in the biofilter, it was important to determine salt concentrations due to possible negative impact on plant growth and soil fertility. The measured electrical conductivity (EC) of all media showed acceptable levels of soluble salts. The application of feedlot runoff did not result in higher levels compared to the initial values. On the contrary, EC decreased in all media significantly except elm woodchips and Morris woodchips where the salt levels were down but not significantly. However one needs to keep in mind that during the pulse experiment feedlot runoff was applied to the media on a daily basis and this will not happen for an *in situ* biofilter. Comparing the different initial EC levels, corn stover showed the highest EC concentrations followed by compost and corn cobs (Fig. 5).

Ash content measured through loss on ignition was indirectly correlated with the organic C-fraction in the media. The lower the ash content, the more organic carbon was in the media. Since microorganisms can only use the organic portion of C, a higher amount is desirable for the remediation of feedlot runoff. Media with high mineral constituents i.e. soil, will have higher ash contents. As expected, compost had the highest ash content with 33.9% followed by the Morris woodchips with 17.5% (Fig. 23). The high ash content of the Morris woodchips is most likely due to contaminations of the woodchips with soil since they were derived from storm damaged wood. Spruce showed the lowest amount of ash followed by corn cobs (2.2%) and flax straw (2.1%) (Fig. 23).

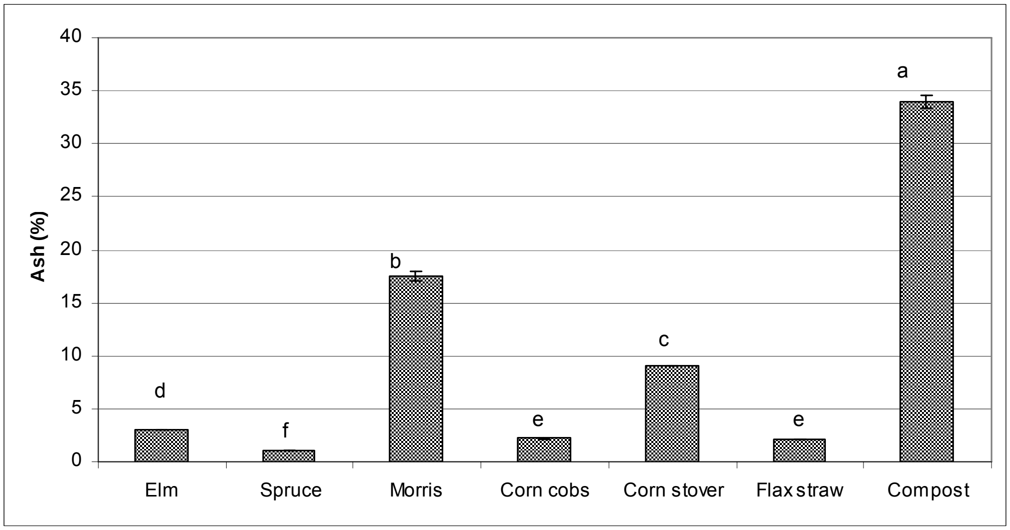


Figure 23: Mean values of ash analysis of the initial media. Different letters indicate significant differences ($p < 0.05$). CC = corn cobs, CS = corn stover, FS = flax straw

In the 1960's and 70's, people were concerned about heavy metal concentrations in sludge and their adverse impact on human health and the environment. Heavy metal concentrations are regulated by the State and certain requirements need to be met before material can be land applied. The EPA Part 503 biosolids rule requires that biosolids intended for land application must meet the so called ceiling concentration for pollutants. Ceiling concentrations are maximum concentration of the metals arsenic (41 mg/kg), cadmium (39 mg/kg), chromium (1200 mg/kg), copper (1500 mg/kg), lead (300 mg/kg), mercury (17 mg/kg), molybdenum, nickel (420 mg/kg), selenium (36 mg/kg) and zinc (2800 mg/kg) (EPA, 2006). The stricter ceiling pollutant concentration limits for exceptional quality were used for comparison (EPA, 2006). Molybdenum as the only heavy metal had no limit for exceptional quality (EPA, 2006). Seven of the ten heavy metals listed above were present in the initial media as well as after feedlot runoff applications over 22 day period but none of the media reached the ceiling concentrations.

Under anaerobic conditions, certain microorganism can produce hydrogen sulfide (H_2S) which is the reason for the 'rotten egg' smell. These undesirable odors can be limited by using media with low initial S contents and ensuring aerobic conditions in the biofilter. However, the later is not always possible so having media with low S should be preferred. Of the tested media, compost showed the highest S content at 0.26% (Fig. 24). Soil and elm had the lowest S contents of 0.055% and 0.064% respectively (Fig. 24). Currently there is no S limit for offensive odors.

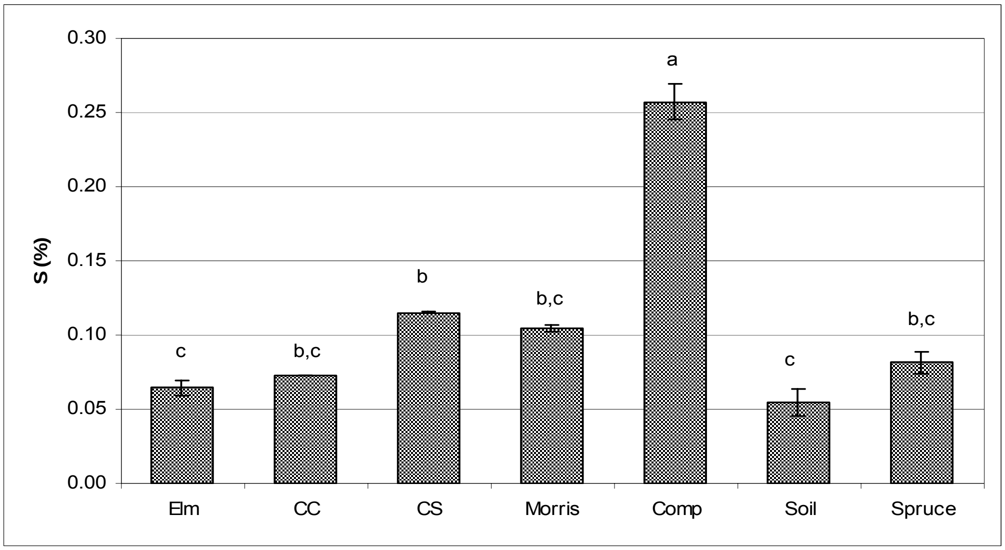


Figure 24: Mean values of sulfur of the initial media. Different letters indicate significant differences ($p < 0.05$). CC = corn cobs, CS = corn stover, Comp = compost

Pulse Experiment

The temperature in the growth chamber was set at 40 ºC throughout the 22-day pulse experiment. The growth chamber door was opened during the feedlot runoff application and then again after the incubation time of 30 min to take samples from the runoff as well as to open the valves to assure drainage. The door to the growth chamber was fully open during that time for about 30 minutes per day. The temperatures of the media, measured before the feedlot runoff application inside the bioreactor tubes, showed that elm woodchips as well as soil and corn stover were around 40 ºC. Similarly, spruce woodchips, spruce sawdust, Morris woodchips, corn cobs and compost had temperatures of 40 ºC to 41 ºC (Fig. 25). Elm sawdust with 41.4 ºC was the highest temperatures measured among the media tested in this study (Fig. 25). Flax straw on the other hand had the lowest recorded temperature of 36.6 ºC (Fig. 25). The flax straw contained a large number of pieces that were 10 to 20 cm long. Those pieces were responsible for building a 3-dimensional network with large interspaces. When the chamber door was opened, the media did not have the ability to hold the temperature at around 40 ºC as the other media which contained much smaller particle sizes. Furthermore, the other media also contained more water which acted like an insulator once it was heated to 40 ºC.

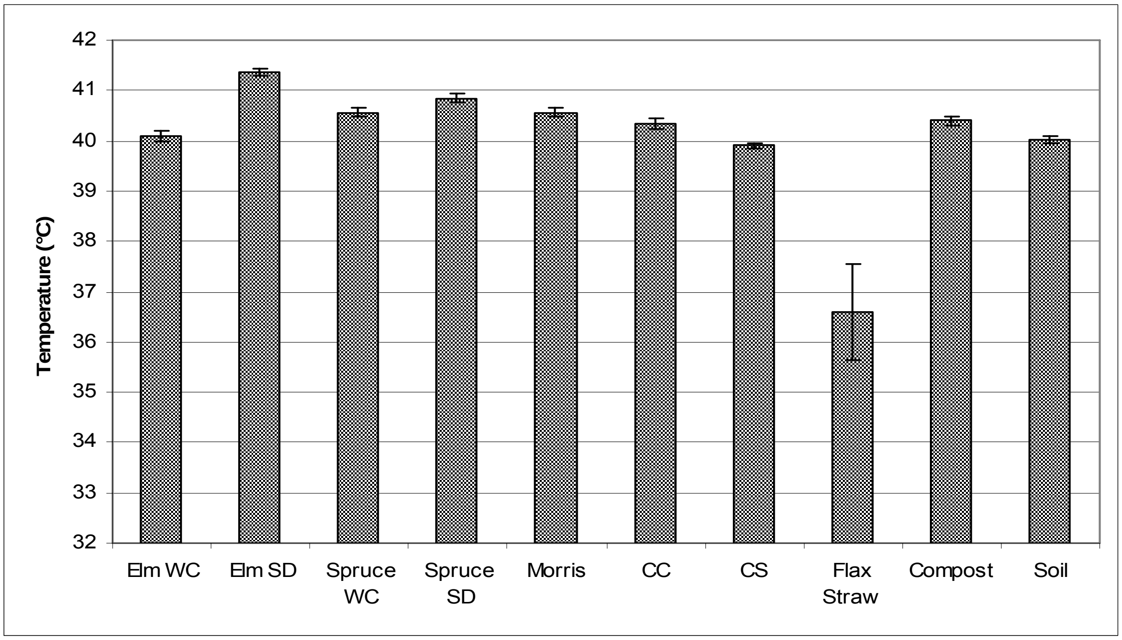


Figure 25: Temperature of media in growth chamber during 22 days of pulse experiments.

WC = woodchips, SD = sawdust, CC = corn cobs, CS = corn stover

Two hypotheses should be tested with the pulse experiment. First, how mineral N, soluble P, total coliforms and *E.coli* in different media behave over time and second whether or not the N and P are reduced from the feedlot runoff. Since the presence of both *E.coli* and TC indicate that potentially other pathogenic microorganisms are present in the runoff, those two parameters need to be reduce no matter whether they come from the feedlot runoff or from the media itself.

Mineral N measured in the leachate was mainly NH_4-N and therefore mineral N values are actually NH_4-N. Spruce sawdust, Morris woodchips, corn cobs and corn stover significantly reduced mineral N during the 22-day pulse experiment. A mean taken from all the measurements over 22 days indicates how much mineral N was released over the 22-day period. Biofilter media that releases very small amounts of mineral N would be best for the biofilter. Figure 26 along with table 5 shows a comparison of the mineral N released by the media over 22 days.

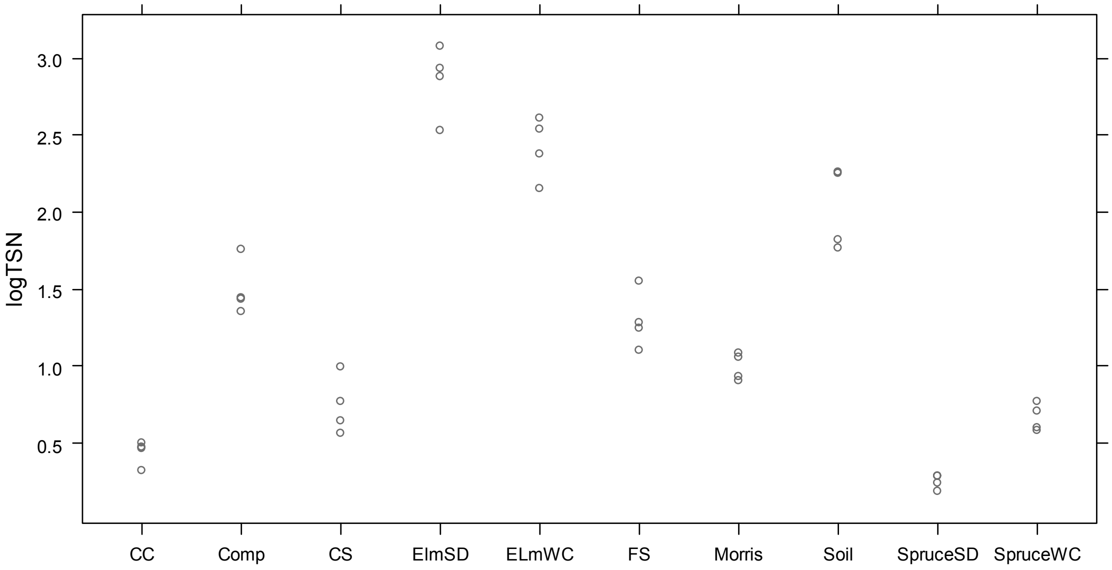


Figure 26: Multi comparison of mineral N of media. CC = corn cobs, Comp = compost, CS = corn stover, SD = sawdust, WC = woodchips

Table 5: Multi comparison of average mineral N released by various media over 22 days. Different letters indicate significant differences ($p < 0.05$)

Elm woodchips	B
Elm sawdust	A
Spruce woodchips	E
Spruce sawdust	F
Morris woodchips	D, E
Corn cobs	E, F
Corn stover	E
Flax straw	C, D
Compost	C
Soil	B

All measurements in Figure 26 are averages over the 22-day pulse experiment. In Table 5, letter "A" indicates the highest mean value for mineral nitrogen released by a media. Media with low release of mineral N are corn cobs, corn stover, Morris woodchips, spruce sawdust and spruce woodchips (Fig. 26). Those media should be chosen over elm sawdust and elm woodchips. Elm is known to have higher concentrations of mineral nitrogen as well as sugars compared to spruce (Anderson, 1933). This would explain the high initial mineral N that leached during the pulse experiment. Since the feedlot runoff only added 1.6 mg/L of mineral N, the 61.9 mg/L mineral N from the elm sawdust and the 20.7 mg/L mineral N from the elm woodchips are most likely due to microbial mineralization of the media. The conditioning with water added the necessary humidity which along with the high mineral N concentration allowed a fast activation of microbial metabolism and thus release of mineral-N.

The study showed that elm woodchips, elm sawdust, corn cobs and soil have a potential to significantly reduce soluble P from feedlot runoff. As mentioned before, P removal is often due to the removal of particulates in the water (Koelsch et al., 2006). Therefore, it would be reasonable to assume that sawdust and other media that minimized losses of particulates would also be able to reduce P. However, microbial activity is also partly responsible for P reduction, especially by fungi which are said to be more efficient in using P for their metabolism (Zimmerman et al., 1995; Sylvia et al., 2005). In our pulse experiment, both elm woodchips and corn cobs showed high fungal growth (Figs. 28 and 33). However, to establish this relationship between fungi growth and P reduction further research is needed. A mean of all measurements taken over 22 days showed how much soluble P on average may be released over this time period (Fig. 27). This average value can be a good indicator for selection of media for biofilters. For the biofilter a media with low release of soluble P would be preferable. Table 6 shows the comparison of the mean soluble P released during the 22-day pulse experiment (A = highest soluble P value).

Table 6: Multi comparison of average soluble P released by various media over 22 days.

Different letters indicate significant differences ($p < 0.05$)

Elm woodchips	C
Elm sawdust	C
Spruce woodchips	B
Spruce sawdust	B
Morris woodchips	C
Corn cobs	C
Corn stover	C
Flax straw	B
Compost	A
Soil	D

Not surprisingly, compost showed the highest release of soluble P over time and soil had the lowest soluble P output. The low amounts of soluble P might be due an attachment of P to clay. The other media were all in the middle between the two extreme compost and soil (Fig. 27).

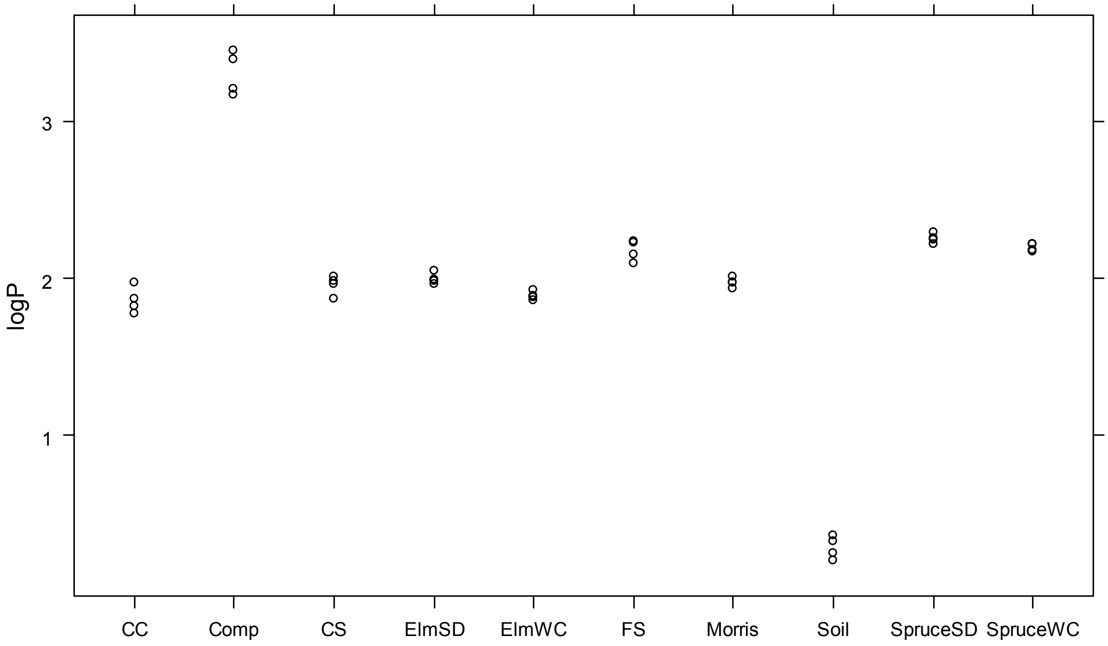


Figure 27: Multi comparison of soluble P averaged over time

All media except flax straw showed a significant reduction of total coliform (Fig. 16). The lack of reduction of TC by flax can be traced back to the temperature loss during the application of runoff in the pulse experiment; a temperature of 36.6 ºC was not high enough to reduce *E.coli* or total coliform. Furthermore, flax straw is coated with oils which make it difficult for microorganisms to grow, thus the microbial community on flax straw was most likely not strong enough to hinder TC and *E.coli* in their reproduction and could not out compete them.

E.coli reduction was only significant for elm sawdust ($p = 0.000$) and corn stover ($p = 0.026$). It is noticeable that often the *E.coli* values at the end of the pulse study corresponded to the end values of total coliforms (Figs. 16 and 17). This would suggest that total coliform were getting reduced and what was left over at the end of the 22-day pulse experiment was only *E.coli*. Bacteria most rapidly multiply at temperatures between 30 ˚C and 40 ˚C but were reported to survive at higher temperatures (Hogan et al., 1989; Zehner et al., 1986). Therefore, to reduce *E.coli*, a temperature of greater than 40 ºC is needed. Qualitative measurements of coliforms, *Streptococcus*, *Staphylococcus* spp. and *Bacillus* were also performed on media samples taken from corn stover, flax straw, compost and soil. The samples were taken at the beginning (week 1) and at the end (week 4) of the pulse experiment. In composting it has been long known that high temperatures can reduce pathogenic organisms thus sanitizing the compost and making it safe to use. Measuring *Bacillus*, *Streptococcus*, *Staphylococcus* spp. and Coliform population in the biofilter media should help identify whether they are suppressed or eliminated. The measurements of coliforms showed that they were present in all the media in the first week. At the end in week four, coliforms obviously decreased in corn stover whereas in compost the decrease was only slight. In flax straw, the numbers of coliforms increased by one order of magnitude compared to soil but the increase was relatively small. *Streptococcus* were present in all four media at the start and by week four they generally showed a downward trend which was more prominent in corn stover and soil than in flax straw and compost. *Staphylococcus* spp. showed a different picture all together. They were only present in flax straw (6.7×10^4 cfu/mL) and compost (125 cfu/mL) at the beginning. In soil, *Staphylococcus* spp. was not present either at the start or end of the pulse experiment. In corn stover *Staphylococcus* spp. were not present at the beginning of the 22-day pulse experiment but had the largest cfu/mL count of all the four media in week four. *Bacillus* was present in all four media at week one and at week four. Flax straw, compost and soil showed increasing numbers of *Bacillus* at the end in week four compared to the beginning in week one. With the current data on four bacterial groups, it is not possible to conclude which media would allow the highest reduction in these microorganisms. Further research is needed to shed light on this question.

After the pulse experiment, when the media was removed from the bioreactor tubes, pictures were taken of the microbial growth. Figure 28 shows the cotton-candy like fungal growth on elm woodchips. Comparing this to elm sawdust (Fig. 29), it can be seen that elm sawdust appears darker and moister than the woodchips. Furthermore, the microbial growth observed on the elm sawdust shows pinhead sized white colonies (Fig. 29).

Figure 28: Fungal growth on elm woodchips after 22 days of feedlot runoff application

Figure 29: Elm sawdust after 22 days of feedlot runoff application

Fungal growth on spruce woodchips (Fig. 30) was much less compared to elm woodchips (Fig. 28). Also, the amount of visible fungal growth is less (Fig. 30). Comparing spruce woodchips (Fig. 30) to spruce sawdust (Fig. 31) it was difficult to see any microbial growth on the sawdust. When spruce sawdust was compared to elm sawdust, the differences were prominent. Spruce sawdust (Fig. 31) looked more like the initial media whereas elm sawdust (Fig. 29) appeared pulpy and had a dark color. Also the odor was stronger from elm sawdust compared to spruce sawdust.

Figure 30: Spruce woodchips after the pulse experiment

Figure 31: Spruce sawdust after pulse experiment

Morris woodchips showed an entirely different microbial growth compared to the other media. The fungus appeared filamentous and grew through the media's interspaces (Fig. 32).

Figure 32: Fungal growth on Morris woodchips after the pulse experiment

Fungal growth on corn cobs was very compact (Fig. 33). But compared to elm woodchips where the growth could be observed throughout the whole bioreactor tube, corn cobs showed only sporadic infestation.

Figure 33: Corn cobs after 22 days of pulse experiment

Conclusion

There are several potential media that could be used as a biofilter to treat feedlot runoff. Several of the measured chemical and physical parameters can help decide the selection of a media that is effective in reducing N, P and *E.coli* in a biofilter settings. However, the study also showed how difficult is it to interpret those interwoven parameters and incorporate them into the decision making of which media to use. Parameters such as C/N ratio, pH, water holding capacity and soluble N, soluble P and *E.coli*/TC from the pulse experiment helped find some of these connections but still more work is needed before a frame work can be developed for the selection of media for biofilters.

In general, the C/N ratio of the media should be above 50 but not higher than 150. Also, pH should be acidic enough to reduce volatilization of ammonia without limiting microbial growth. Generally, pH should be below 7 and if possible below 6. It is important that the media have the possibility to retain water without loosing its structural stability. Furthermore, when choosing a medium, initial N and P should be low. The study showed that different media had different capabilities in removing N, P and *E.coli*. For example, spruce sawdust, Morris woodchips, corn cobs and corn stover showed significant reduction of mineral N whereas elm woodchips, elm sawdust and corn cobs significantly reduced soluble P. All media but soil and flax straw were successful in reducing total coliform but only elm sawdust and corn stover showed significant decreases in *E.coli*. This shows that using only one media in a biofilter might limit the complete success of remediating all constituents in the feedlot runoff, since different media showed different strength in removing N, P and *E.coli*. This suggests that it might be valuable to mix several different media to achieve the goal for complete remediation of the constituents. However, further research is needed to define what mixtures work best.

The observations on fungal and other microbial growth on the media after the pulse experiment need further investigation. For example, identifying the species of microorganism involved could provide some feedback on parameters that will optimize the reduction of N, P and *E.coli*. Green et al. (2004) found no differences in microbial community structure composition between straw and sawdust amended cow manure. However since the manure/media ratio is much smaller in the biofilter there is a potential that the communities may be different (as can be seen on Figs. 28 through 33).

The pulse experiment was performed in a growth chamber with a temperature of 40 ºC. This temperature is not high enough to eliminate unwanted microorganisms. Further studies with appropriate equipment are needed to establish a relationship between the kind of media used and the potential elimination of pathogens. Also, since the data delivered by the contract laboratory were incomplete, the experiment needs to be repeated to get complete data on temporal variation.

Morris Biofilter

The demonstration site for the biofilter prototype was located at the West Central Research and Outreach Center in Morris, Minnesota (45°35’39.66” N, 95°52’16.98” W). The biofilter was located at the down slope of the feedlot (Fig. 34). During the two years of operation, 40 cows were kept in the feedlot mainly during the winter month. The prototype had a length of 13.41 meters, a width of 4.27m and a height of 1.52m. The biofilter set-up was designed for a 25-year 24-hours storm event. The biofilter was enclosed between two layers of straw bales to keep the media in place, leaving only the front of the biofilter open (Fig. 35). A settling basin was installed upstream of the biofilter to allow settling of particulates. To minimize leaching of feedlot runoff into the ground, a liner was used to seal the bottom of the biofilter (Fig. 36). The runoff entered the biofilter through a PVC pipe (Fig. 36) and exited through a PVC discharge pipe (Fig. 37). The average slope of the biofilter was 1.3%, within the biofilter the slopes between the sampling ports ranged from 0.2% to 2.1%.

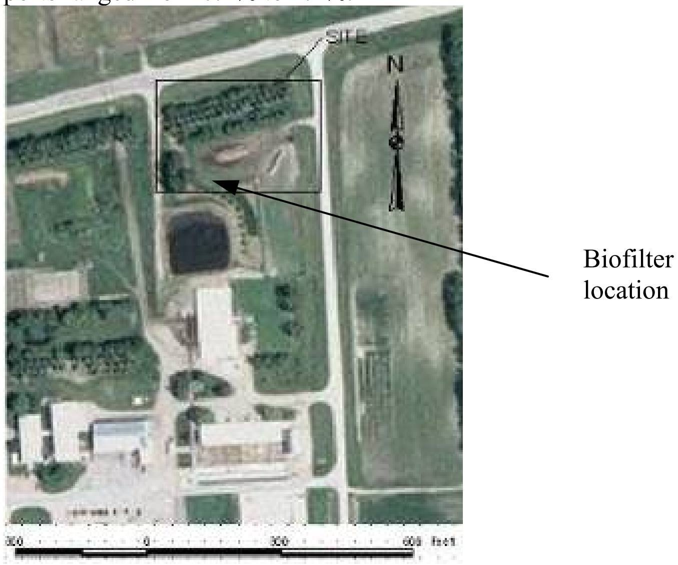


Figure 34: Arial photograph of feedlot site

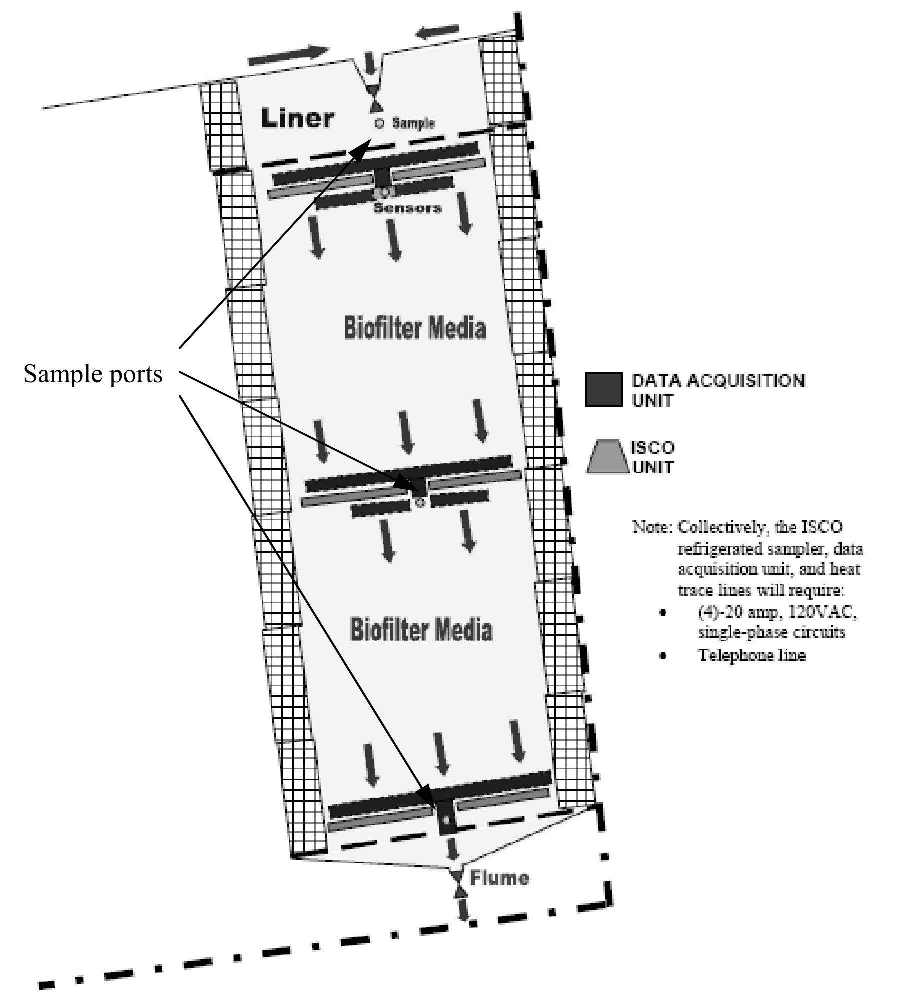
Figure 35: Completed biofilter installation

Figure 36: Front view of biofilter with intake pipe (front) and installation of "flow interceptor" H-pipes (back)

Figure 37: Biofilter discharge flume including flow sensors

A monitoring system was installed to allow continuous measurement of the runoff for pH, oxidation-reduction potential (ORP), temperature, conductivity and liquid presence. All those sensors were installed at the influent, midpoint and effluent sampling ports. Furthermore, a bromide ion-selective electrode (ISE) and an Iodide ISE were installed at the effluent point. In addition to thermocouples installed to measure temperature of the liquid in the biofilter, thermisters were also installed to acquire a temperature profile of the biofilter. Twelve thermisters were placed at depths of 31 cm, 61 cm, 91 cm and 122 cm at the influent, midpoint and effluent points in the biofilter.

Except for the influent sampling port, all sensors were placed next to the sampling ports (Fig. 38). The sensors for the influent sampling port were placed 50 cm downstream. Three automated sampling ports were installed at influent, midpoint and effluent point. Additionally manual samples were collected from the intake (post settling basin) as well as from the discharge of the biofilter. The sampling ports for influent, midpoint and effluent were located at the base of the biofilter at a distance of 1.83 m, 6.48 m and 11.05 m from the front. A modified ISCO sampler with refrigerating and heating capabilities (3700FR) was used along with two ISCO GLS units. The modification allowed the collection of two samples from each point using a programmed timer delay. From each sampling location, a direct feeding line was connected to the refrigerated containers. Samples from all three locations were collected automatically using a timer method. A peristaltic pump applied suction when initialized and transported the runoff into the sample containers.



Note: Collectively, the ISCO refrigerated sampler, data acquisition unit, and heat trace lines will require:

- (4)-20 amp, 120VAC, single-phase circuits
- Telephone line

Figure 38: Diagram of biofilter setup including flow diverter H-pipes, sensor location and sampling points

To obtain representative runoff samples from the biofilter at the 3 sampling ports, free flow conditions were needed. To achieve this objective, an AdvanEDGE flat paneled high density polyethylene (HDPE) pipe system from Advanced Drainage Systems (ADS) Inc. was used to divert the runoff flow (ADS, 2007). Figure 39 shows the principle of how the system is supposed to work in the biofilter.

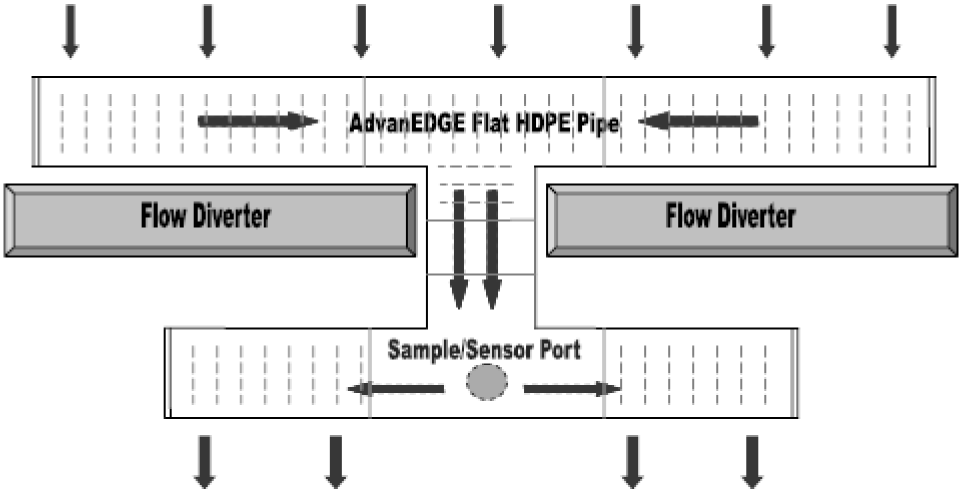


Figure 39: Close-up of AdvanEDGE HDPE pipe system

All samples were sent to Stearns County DHIA Central Laboratories to analyze the following 10 measurements: Ammonia, biochemical oxygen demand (BOD), chemical oxygen demand (COD), chloride, *E.coli*, total Kjeldahl nitrogen (TKN), nitrate, total phosphorus, total dissolved solids (TDS) and total suspended solids (TSS).

Discussion and Conclusion

The biofilter demonstration project at Morris, MN was designed to give first insight in the practical approach of constructing biofilters and to apply results from the laboratory study. We learned several things from this demonstration biofilter.

The period between October 2005 and May 2007 had fewer and lower intensity rainfall events compared to average years. This presented a problem in that there was never the appropriate rainfall events needed to evaluate the effectiveness of the biofilter. The absence of rain led to very dry woodchips which could not sustain effective microbial growth and probably limited their ability to reduce N, P and *E.coli* from the runoff. To get some information on water movement and residence time, a rainfall was simulated on August 26, 2006, with an application of 21,900 L of water to the biofilter. The residence time of the water was measured at 2 hrs 15 min. The water volume outflow volume was less than 95% (Fig. B1) of the amount applied mainly because the biofilter media was so dry that it absorbed the water in the biofilter. After the water application, the temperatures in the biofilter started to rise as high as 60 °C, most likely due to microbial activity. Even though the biofilter in Morris showed limited microbial activity, N, P and *E.coli* were reduced by the vast reduction of input to the surface water. Throughout the 2-year demo project, the team experienced difficulties with the sensors. During a severe storm event, the telephone line was hit by lightning. The power surge/lightning strike damaged the monitoring equipment to the point that the sensors needed to be replaced. Even after the sensors were rebuilt, they failed to perform as anticipated.

The triggering of the sample ports was administered using flow sensors (Fig. B2). The collection system triggered the sample in the order of influent, effluent and midpoint. In general, the midpoint samples were collected about 6 to 8 hours, in some cases even up to 24 hours, after the other two. This presented a problem since *E.coli* measurements are time sensitive and need to be performed within 6 hours after taking the sample.

Apart from the obvious difficulties there were also some good lessons learned. When the biofilter media got water and manure input, the temperatures started to climb in response to microbial growth and activity. But when the biofilter was left dry, the temperature matched the ambient temperature (Table B1). This also meant that during winter, parts of the pile were frozen. However, the biofilter did not freeze solid due to the large amount of woodchips and the pile height provided some insulation. Furthermore, when there was rain it seemed that there was preferential flow along the south side of the biofilter because the south side was lower compared to north side. During decommissioning of the biofilter, four distinct layers were seen. The top layer which got water from the rain through percolation showed partial degradation of the woodchips whereas the media in the second layer only got water sporadically through percolation of rainwater from the top (Fig. 40). The bottom layer (10-30 cm) was nearly saturated and showed the highest decomposition (Fig. 40). The woodchips were still recognizable but the color was dark, almost black indicating anaerobic conditions. Another indication of anaerobic conditions was the smell of ammonia upon decommissioning. Preferential capillary suction is present in the bottom layer thus the differences in height of the bottom layer from 10 to 30 cm (Fig. 40). The woodchips in the third layer, just above the 10-30 cm bottom, were dry and looked mummified (Fig. 40). It appeared that no or minimal changes in the media occurred in this layer during the two year field experiment indicating that this layer was the most dry and therefore inactive part of the biofilter. During decommissioning, fungal growth was observed by eye in the top layer and in the bottom layer.

Figure 40: Layering of the biofilter after two year field study

The most important thing to be learned from this pilot project was that the biofilter was over-sized since there was hardly any discharge. Of the 21,900 L of water applied in the simulated rainfall, over 95% was absorbed into the biofilter (Fig. B1). If moisture content of the biofilter would have been comparable to compost (46%- 64%), probably less water would have been absorbed. However, to get a biofilter of this size (87 m^3) to field capacity requires large amounts of water. Because of the dry conditions of the biofilter and the resulting low microbial activity, the media decayed slowly. This added 2 to 5 years to the live expectancy of the biofilter for similar rainfall conditions.

Overall Conclusion

In urban engineering, biofilters have long been used to treat storm water runoff (DeBusk et al., 1997; Brandy & Weil, 2000; Hunho et al., 2000). Currently farms with a 300-animal unit or less, have to either store and land apply feedlot runoff or they apply it directly to a vegetative filter system (VFS). Research showed that removal efficiencies for N and P differ depending on factors such as climate and size of the VFS (EQB, 2001; Koelsch et al., 2006). There is also some controversy on the effective attenuation of pathogens in this system (Tate et al., 2006; Koelsch et al., 2006). According to the reviewed literature, C rich bulking agents show the potential to retain N and P from the feedlot runoff as well as to attenuate pathogens such as fecal coliform and *E. coli* (Eiland et al., 2001; EQB, 2001; Larney, 2003a). Consequently limited data exist regarding different physical and chemical parameters of media and their importance in reducing N, P and *E.coli* from feedlot runoff. In this study, numerous parameters including C/N, pH, EC, particle size distribution, total P, soluble P and mineral N were measured on ten media. Several of the media showed the potential to achieve a reduction of N, P and *E.coli* from feedlot runoff. However, the study also showed clearly that there is not one media that possesses all the capabilities, rather some media showed significant reduction in P while others were able to reduce soluble N and *E.coli*. As mentioned earlier, there is a strong indication that a mix of different media might be more effective. But the media for the biofilter is only one piece of the puzzle. The conditions inside the biofilter are as important as the media itself. Adequate moisture, oxygen, temperature and sufficient N from the feedlot runoff are essential for the microorganisms to thrive in the biofilter. It is those microorganisms which will help reduce N and P. Furthermore, the competition of microorganisms could help reduce *E.coli*. Also, the reduction would be more efficient if both aerobic and anaerobic conditions were present in the biofilter. Nitrogen could be effectively removed through denitrification (anaerobic) rather than through aerobic microorganisms (Robertson et al., 2005). However, this presents a challenge. If the conditions for denitrification are not met, the potential greenhouse gasses nitrous oxides rather than the inert N_2 will be released. The goal of the biofilter is to capture and remove nitrogen from the runoff in an environmental friendly way without delivering greenhouse gases to the atmosphere.

During the pulse experiment it became evident, that the growth chambers were too small to effectively apply feedlot runoff and do the sampling. Furthermore, the temperature of 40 °C was not high enough since the bioreactor tubes were supposed to simulate the 10 to 15 cm layer in the biofilter which gets all the water. If this experiment were to be repeated, larger tubes both in length and diameter would be more desirable.

The demonstration biofilter at the West Central Research and Outreach Center in Morris was an initial field experiment to gain first insights. The woodchips used in this biofilter showed significant reduction of soluble N in the lab experiment. Unfortunately during October 2005 and the decommissioning in May 2007 10% fewer rainfall event occurred than on average. This was the reason that hardly any storm events could be sampled. Furthermore, the monitoring system installed in the biofilter did not perform as expected. During the decommissioning of the biofilter, four distinguished layers were visible. Samples were taken for further testing in the lab. Nevertheless, the biofilter successfully absorbed and transpired 95% of the water and resulted in reduced N, P and *E.coli* inputs into surface water. However, the 21,900 L of the feedlot runoff simulation represented only 10% of the rainfall that can be expected for a 25-year, 24 hour storm event.

One question that needs to be answered in future studies is how the microbial population performs in extreme conditions such as drought, flooding and in Minnesota winters. This is important since the microorganisms are responsible for the major portion of the reduction of N, P and *E.coli*. It would be important to determine if and how quickly the microbial community returns to an active state and what are the optimal condition to keep them in that state. Another question related to an earlier question is how effective is the biofilter during storms when the biofilter did not have optimal condition for microbial growth before hand. To be able to answer part of those questions, the temperature and moisture content in the biofilter would have to be monitored. Together with microbial testing to measure activity, this would provide answers to some questions.

Overall, this study allowed the characterization of some physical and chemical parameters of spruce woodchips, spruce sawdust, elm woodchips, elm sawdust, Morris woodchips, corn cobs, corn stover, flax straw, mature compost and soil. Measured values such as C/N ratio for elm (hardwood) did not match with the values form the literature (Rynk, 1992) thus implying that the categories softwoods and hardwoods are not the best indicators as to how well media works in a certain situation. The initial studies both in the laboratory and field showed great potential for biofilters to serve as an alternative or addition to VFS to treat feedlot runoff. The demonstration biofilter in Morris was able to reduce water by 95% even though the biofilter did not function according to its definition to remove N, P and *E.coli* by an active microbial community. The specific management details for this practice need additional studies.

REFERENCES

Advanced Drainage Systems Inc. 2007. AdvanEDGE®HDPE pipe. Available at http://www.ads-pipe.com/en/product.asp?productID=180 (verified June 10, 2007).

Anderson, E. 1933. The Mucilage from Slippery Elm Bark. *The Journal of Biological Chemistry* 104(1):163-170.

Andersson M. 1996. Performance of Bedding Materials in Affecting Ammonia Emissions form Pig Manure. *Journal of Agricultural Engineering Research* 65:213-222.

Agnew J.M., J.J. Leonard, J. Feddes, Y. Feng. 2003. A modified Air Pycnometer for Compost Air Volume and Density Determination. *Canadian Biosystems Engineering* 45:6.27-6.35.

Barrington S.F. and R.G. Moreno. Swine Manure Nitrogen Conservation in Storage using Sphagnum Moss. *Journal of Environmental Quality* 24:603-607.

BioCycle. 1991. The Biocycle Guide to the Art & Science of Composting. ISBN 0-932424-13-9. The JG Press, Inc.

Brady N.C. and R.R. Weil. 2002a. Soil Phosphorus and Potassium. p. 592-637. *In* The Nature and Properties of Soils, 13th Edition. ISBN 0-13-016763-0. Pearson Prentice Hall.

Brady N.C. and R.R. Weil. 2002b. Soil Organic Matter. p. 498-542. *In* The Nature and Properties of Soils, 13th Edition. ISBN 0-13-016763-0. Pearson Prentice Hall.

Brinton W.F. and M.W. Droffner. 1994. Microbial Approaches to Characterization of Composting Processes. *Compost Science & Utilization* 2(3):12-17.

Carlson, R.M. 1986. Continuous Flow Reduction of Nitrate to Ammonia with Granular Zinc. *Analytical Chemistry* 58(7):1590-1591.

Carlson, R.M. 1978. Automated Separation and Conductimetric Determination of Ammonia and Dissolved Carbon Dioxide. *Analytical Chemistry* 50(11):1528-1531.

Chase L. and M. Van Amburgh. 2002. Ammonia Emissions: the Next Regulatory Battleground. North East Dairy Business. Available at http://www.dairy-business.com/northeast/August02/F2%20p23%20PD08%20ammonia.pdf (verified 1 March 2007).

Clark S. and R. Pitt. 2001. Effect of Anaerobiosis on Filter Media Pollutant Retention. Presented at the Engineering Foundation and the American Society of Civil Engineers Conference. Snowmass, CO, USA.

Cochran W.G. 1950. Estimation of Bacterial Densities by Means of the "Most Probable Number". *Biometrics* 6(2):105-116.

DeBusk T.A., M.A. Langston, B.R. Schwegler, S. Davidson. 1997. An Evolution of Filter Media for Treating Stormwater Runoff. 5th Biennial Stormwater Research Conference. 5. -7. Nov. 1997.

Devinny J.S., M.A. Deshusses, T.S. Webster. 1999. Biofiltration for Air Pollution Control. ISBN 1-56-670289-5. Lewis Publishers.

Eiland F., M. Klamer, A.-M. Lind, M. Leth, E. Bååth. 2001. Influence of Initial C/N Ratio on Chemical and Microbial Composition during Long-Term Composting of Straw. *Microbial Ecol*ogy 41:227-280.

Elementar Analysensysteme GmbH. 2003. Operating Instructions for vario EL *III* CHNOS Elemental Analyzer. Serial-No.: 11014041.

Environmental Quality Board (EQB) Minnesota. 2001. Summary of Literature Related to Water Resources: Generic Environmental Impact Statement on Animal Agriculture. Available at http://www.eqb.state.mn.us/geis/LS_Water.pdf (verified 30 April 2007).

Environmental Protection Agency (EPA). 2006. A Plain English Guide to the EPA Part 503 Biosolids Rule. Available at: http://www.epa.gov/owm/mtb/biosolids/503pe/index.htm (verified June 24, 2007).

Fadl N.A., M.Z. Sefain, Z. Magdi and M. Rakha. 1978. Hardening of cotton stalks hardboard. *Indian Pulp and Paper* 33(2):3-4.

Gamroth M. 2004. Chemical and Environmental Treatment of Whole Tree Juniper Chips to Lower Fecal Coliform Counts. Department of Animal Sciences. Oregon State University.

Gattinger A., U. Bausenwein, C. Bruns. 2004. Microbial Biomass and Activity in Composts of Different Composition and Age. *Journal of Plant Nutrition and Soil Science* 167:556-561.

Goviandarao V.M.H. 1980. Utilization of rice husk – a preliminary analysis. *Journal of Scientific & Industrial Research* 39(9):495-515.

Green S.J., F.C. Michel Jr., Y. Hadar, D. Minz. 2004. Similarity of Bacterial Communities in Sawdust- and Straw-Amended Cow Manure Composts. *FEMS Microbiology Letters* 233:115-123.

Greenan C.M., T.B. Moorman, T.C. Kaspar, T.B. Parkin, D.B. Jaynes. 2006. Comparing Carbon Substrates for Denitrification of Subsurface Drainage Water. *Journal of Environmental Quality* 35:824-829.

Handreck K.A. 1996. Phosphorus Immobilization in Wood Waste-Based Potting Media. *Communication in Soil Science and Plant Analysis* 27(9&10):2295-2314.

Hogan J.S. and K.L. Smith. 1997. Bacteria Counts in Sawdust Bedding. *Journal of Dairy Science* 80:1600-1605.

Hogan J.S., K.L. Smith, K.H. Hoblet, D.A. Todhunter, P.S. Schoeneberger, W.D. Hueston, D.E. Pritchard, G.L. Bowman, L.E. Heider, B.L. Brockett, and H.R. Conrad. 1989. Bacterial Counts in Bedding Materials Used on Nine Commercial Dairies. *Journal of Dairy Science* 72:250-258.

Hunho K., E.A. Seagren, A.P. Davis. 2000. Engineered Bioretention for Removal of Nitrate from Stormwater Runoff. Water Environment Federation (WEFTEC).

Jeppsson K.-H. 1999. Volatilization of Ammonia in Deep-litter Systems with Different Bedding Materials for Young Cattle. *Journal of Agricultural Engineering Research* 73:49-57.

Kizil U. and J.A. Lindley. 2001. Feedlot Runoff and Manure Management Model. ASAE Annual International Meeting, Sacramento, CA. 29. Jul – 1. Aug. 2001.

Klute A. 1987. Methods of Soil Analysis, Part 1 – Physical and Mineralogical Methods. 2nd Edition. ISBN 0-89118-088-5. American Society of Agronomy, Inc.

Kocurek M.J. and C.F.B. Stevens (eds). 1983. Pulp and Paper Manufacture: Properties of Fibrous Raw Materials and their Preparation and Pulping. Volume 1. Joint Textbook Committee of the Paper Industry, Canada.

Koelsch R.K., J.C. Lorimor, K.P. Mankin. 2006. Vegetative Treatment Systems for Management of Open Lot Runoff: Review of Literature. *Applied Engineering in Agriculture* 22(1):141-153.

Larney F.J. 2003a. Carbon, Nitrogen and Phosphorus Dynamics during Composting of Beef Cattle Feedlot Manure. Proc. 9th Ann. Composting Conf., May 8-9, 2003, Olds College, Olds, Alberta, Canada.

Larney F.J., J. Yanke, J.J. Miller, T.A. McAllister. 2003b. Fate of Coliform Bacteria in Composted Beef Cattle Feedlot Manure. *Journal of Environmental Quality* 32:1508-1515.

Lory J., J. Adams, B. Eghball, T. Klopfenstein, J.F. Powers. 2002. Effect of Sawdust or Acid Application to Pen Surfaces on Nitrogen Losses from Open-Dirt Feedlots. *Nebraska Beef Report* 52, 53.

Miller J.J., B.W. Beasley, J. Yanke, F.J. Larney, T.A. McAllister, B.M. Olson, L.B. Selinger, D.S. Chanasyk, P. Hasselback. 2003. Bedding and Seasonal Effects on Chemical and Bacterial Properties of Feedlot Cattle Manure. *Journal of Environmental Quality* 32:1887-1894.

Misselbrook T.H. and J.M. Powell. 2005. Influence of Bedding Material on Ammonia Emissions from Cattle Excreta. *Journal of Dairy Science* 88:4304-4312.

Mondini C., M. Contin, L. Leita, M. De Nobili. 2002. Response of Microbial Biomass to Air-Drying and Rewetting in Soils and Compost. *Geoderma* 105:111-124.

Morgan-Sagastume J. M., A. Noyola, S. Revah, S.J. Ergas. 2003. Changes in Physical Properties of a Compost Biofilter Treating Hydrogen Sulfide. *Air & Waste Management Association* 53:1011-1021.

MPCA. 2002. Minnesota's Impaired Waters and Total Maximum Daily Loads (TMDL). Appendicies to Minnesota’s Impaired Waters Report. Available at http://www.pca.state.mn.us/publications/reports/lrwq-s-lsy03-appendix.pdf (verified 30 April 2007).

MPCA. 2006a. Minnesota State Water Rules, Chapter 7020: Animal Feedlots. Available at http://www.pca.state.mn.us/water/water_mnrules.html (verified 30 April 2007).

MPCA. 2006b. Minnesota 2001 - 2005 Nonpoint Source Management Program Plan (NSMPP), Chapter 7 Feedlots. Available at http://www.pca.state.mn.us/-water/nonpoint/nsmpp-ch7.pdf (verified 30 April 2007).

Munter R.C. 1990. Advances in soil testing and plant analysis analytical technology. *Communications in soil science and plant analysis* 21:1831-1841.

N’Dayegamiye A. and D. Isfan. 1991. Chemical and Biological Changes in Compost of Wood Shavings, Sawdust and Peat Moss. *Canadian Journal of Soil Sciences* 71:475-484.

Page A.L, R.H. Miller, D.R. Keeney. 1984. Methods of Soil Analysis, Part 2 – Chemical and Microbiological Properties. 2nd Edition. ISBN 0-89118-072-9. American Society of Agronomy, Inc.

R Development Core Team. 2007. The R Project for Statistical Computing. ISBN 3-900051-07-0. Available at http://www.r-project.org/ (verified 8 June 2007).

Robertson W.D., G.I. Ford, P.S. Lombardo. 2005. Wood-Based Filter for Nitrate Removal in Septic Systems. *American Society of Agricultural Engineers* 48(1):121-128.

Rynk R., editor. 1992. On-Farm Composting Handbook. ISBN 0-935817-19-0. Natural Resource, Agriculture and Engineering Service (NRAES), Cornell University, Cooperative Extension, Ithaca, New York 14852-4557.

Sadaka S., C.R. Magura, D.D. Mann. 2002. Vertical and Horizontal Airflow Characteristics of Wood/Compost Mixtures. *Applied Engineering in Agriculture* 18(6):735-741.

Sylvia D.M., J.J. Fuhrmann, P.G. Hartel, D.A. Zuberer. 2005. Principles and Applications of Soil Microbiology, 2nd Edition. ISBN 0-13-094117-4. Pearson Prentice Hall.

Taylor B.R., D. Parkinson, W.F.J. Parsons. 1989. Nitrogen and Lignin Content as Predicators of Litter Decay Rates: A Microcosm Test. *Ecology* 70(1):97-104.

Tate K.W., E.R. Atwill, J.W. Bartolome, and G. Nader. 2006. Significant Escherichia Coli Attenuation by Vegetative Buffers on Annual Grasslands. *Journal of Environmental Quality* 35:795-805.

Tiquia S.M., T.L. Richards and M.S. Honeyman. 2002. Carbon, Nutrient, and Mass Loss During Composting. *Nutrient Cycling in Agroecosystems* 62:15-24.

US Department of Agriculture (USDA). 2006. Agricultural Resources and Environmental Indicators, 2006 Edition, chapter 2: Water and Wetland Resources. Available at: http://www.ers.usda.gov/publications/arei/eib16/chapter2/ (verified 26 June 2007).

US Forest Service. 2002. A Cheaper Way to Clean Water. *NewsLine* 1(2):1,3.

Villegas-Pangga G., G. Blair, and R. Lefroy. 2000. Measurement of Decomposition and Associated Nutrient Release from Straw (*Oryza sativa* L.) of Different Rice Varieties Using a perfusion System. *Plant and Soil* 223:1-11.

Wang Z. and R. Govind. 1997. Biofiltration of Isopentane in Peat and Compost Packed Beds. *AIChE Journal* 43(5):1348-1356.

Watanabe F. S. and S. R. Olsen. 1965. Test of an ascorbic acid method for determining phosphorus water and $NAHCO_3$ extracts from soil. *Soil Science Society Proceedings* 29:677–678.

Zehner M.M., R.J. Farnsworth, R.D. Appleman, K. Larntz, and J.A. Springer. 1986. Growth of Environmental Mastitis Pathogens in Various Bedding Materials. *Journal of Dairy Science* 69:1932-1941.

Zimmerman J.K., W.M. Pulliam, D.J. Lodge, V. Quiñones-Orfila, N. Fetcher, S. Guzmán-Grajales, J.A. Parrotta, C.E. Asbury, L.R. Walker, R.B. Waide. 1995. Nitrogen Immobilization by Decomposing Woody Debris and the Recovery of Tropic Wet Forest Hurricane Damage. *OIKOS* 72: 314-322.

APPENDIX A – DESCRIPTIVE STATISTIC

Table A1: Result summary of ash, BD, C/N ratio, pH, EC, TP, max H_2O, moisture content and Sulfur. Presented are the means including standard error

ID		Ash (%)	BD (Mg/m^3)	C/N Ratio	pH	EC (dS/cm^2)	TP (mg/L)	Max H_2O (%)	w (%)	S (%)
Elm WC	initial	3.02 ± 0.007	0.31 ± 0.006	107.8 ± 1.7	4.93 ± 0.02	0.31 ± 0.000	321.5 ± 1.9	66.0 ± 3.3		0.064 ± 0.006
	after			*122.2 ± 0.002*	*5.90 ± 0.00*	*0.28 ± 0.009*	*251.6 ± 4.2*		*108.8 ± 4.0*	
Elm SD	initial	3.02 ± 0.007	0.34 ± 0.002	107.8 ± 1.7	4.93 ± 0.02	0.31 ± 0.000	321.5 ± 1.9	169.1 ± 8.5		0.064 ± 0.006
	after			*128.0 ± 0.002*	*6.00 ± 0.00*	*0.24 ± 0.008*	*252.3 ± 9.5*		*153.0 ± 2.5*	
Spruce WC	initial	1.06 ± 0.023	0.25 ± 0.004	293.2 ± 15.2	4.53 ± 0.03	0.26 ± 0.000	124.6 ± 4.4	56.1 ± 9.2		0.082 ± 0.007
	after			*360.2 ± 0.000*	*5.25 ± 0.03*	*0.16 ± 0.002*	*93.2 ± 3.4*		*131.1 ± 5.2*	
Spruce SD	initial	1.06 ± 0.023	0.28 ± 0.006	293.2 ± 15.2	4.53 ± 0.03	0.26 ± 0.000	124.6 ± 4.4	152.0 ± 5.1		0.082 ± 0.007
	after			*332.1 ± 0.000*	*5.43 ± 0.03*	*0.17 ± 0.003*	*97.6 ± 4.5*		*177.4 ± 1.9*	
Morris	initial	15.53 ± 0.501	0.24 ± 0.009	75.8 ± 2.6	6.02 ± 0.02	0.55 ± 0.000	846.1 ± 16.3	126.4 ± 4.5		0.105 ± 0.002
	after			*69.8 ± 0.002*	*6.73 ± 0.14*	*0.53 ± 0.045*	*649.0 ± 54.9*		*166.5 ± 11.8*	
CC	initial	2.19 ± 0.022	0.14 ± 0.006	118.8 ± 2.9	4.93 ± 0.01	1.26 ± 0.000	345.0 ± 11.2	271.5 ± 13.9		0.073 ± 0.000
	after			*80.2 ± 0.039*	*5.58 ± 0.13*	*0.74 ± 0.050*	*447.5 ± 49.1*		*316.4 ± 34.5*	
CS	initial	9.06 ± 0.064	0.05 ± 0.001	70.2 ± 3.2	5.55 ± 0.03	2.28 ± 0.001	814.2 ± 30.7	563.8 ± 51.0		0.115 ± 0.000
	after			*58.7 ± 0.021*	*7.13 ± 0.08*	*1.49 ± 0.108*	*895.3 ± 63.3*		*769.7 ± 101.7*	
FS	initial	2.07 ± 0.009		59.4 ± 2.3						
	after			*65.1 ± 0.010*	*6.63 ± 0.11*	*1.10 ± 0.130*	*872.2. ± 39.9*		*254.1 ± 27.5*	
Comp	initial	33.94 ± 0.614	0.17 ± 0.004	25.9 ± 1.4	6.86 ± 0.01	2.17 ± 0.001	3343.1 ± 122.4	260.2 ± 17.2		0.257 ± 0.012
	after			*32.7 ± 0.007*	*7.80 ± 0.04*	*1.49 ± 0.052*	*2724.1 ± 81.6*		*280.4 ± 8.5*	
Soil	initial		1.38 ± 0.008	14.9 ± 0.2	7.09 ± 0.03	0.09 ± 0.000	444.9 ± 11.3	34.8 ± 1.4		0.055 ± 0.009
	after			*14.7± 0.001*	*8.23 ± 0.05*	*0.11 ± 0.001*	*413.2 ± 12.3*		*27.5 ± 0.6*	

Table A2: Initial total N (%) of media

Name	Mean	Std Dev	Median	Min	Max	Var	Std Error	n
CC	0.396	0.014	--	0.386	0.406	0.000	0.010	2
Comp	1.139	0.023	--	1.123	1.155	0.001	0.016	2
CS	0.621	0.043	--	0.590	0.652	0.002	0.031	2
FS	0.766	0.049	0.750	0.726	0.821	0.002	0.029	3
Elm SD	0.441	0.006	--	0.436	0.445	0.000	0.005	2
Elm WC	0.441	0.006	--	0.436	0.445	0.000	0.005	2
Morris	0.568	0.018	--	0.555	0.580	0.000	0.013	2
Soil	0.145	0.007	--	0.140	0.150	0.000	0.005	2
Spruce SD	0.180	0.002	--	0.179	0.182	0.000	0.001	2
Spruce WC	0.180	0.002	--	0.179	0.182	0.000	0.001	2

Table A3: Initial total C (%) of media

Name	Mean	Std Dev	Median	Min	Max	Var	Std Error	n
CC	47.013	0.035	--	46.989	47.038	0.001	0.025	2
Comp	29.482	1.645	--	28.319	30.645	2.705	1.163	2
CS	43.490	0.215	--	43.337	43.642	0.046	0.152	2
FS	45.334	0.215	45.342	45.116	45.546	0.046	0.124	3
Elm SD	47.491	0.387	--	47.217	47.764	0.150	0.274	2
Elm WC	47.491	0.387	--	47.217	47.764	0.150	0.274	2
Morris	42.989	0.777	--	42.440	43.539	0.604	0.550	2
Soil	2.158	0.060	--	2.116	2.201	0.004	0.042	2
Spruce SD	52.873	3.283	--	50.551	55.195	10.780	2.322	2
Spruce WC	52.873	3.283	--	50.551	55.195	10.780	2.322	2

Table A4: Total sulfur (%) of media

Name	Mean	Std Dev	Median	Min	Max	Var	Std Error	n
Elm	0.064	0.008	--	0.059	0.070	0.000	0.006	2
CC	0.073	0.001	--	0.072	0.073	0.000	0.000	2
CS	0.115	0.000	--	0.115	0.115	0.000	0.000	2
Morris	0.105	0.003	--	0.103	0.106	0.000	0.002	2
Comp	0.257	0.017	--	0.245	0.269	0.000	0.012	2
Soil	0.055	0.013	--	0.045	0.064	0.000	0.009	2
Spruce	0.082	0.010	--	0.074	0.089	0.000	0.007	2

Table A5: Initial C/N ratio of media

Name	Mean	Std Dev	Median	Min	Max	Var	Std Error	n
CC	118.777	4.047	--	115.916	121.639	16.377	2.862	2
Comp	25.901	1.965	--	24.512	27.291	3.863	1.390	2
CS	70.210	4.567	--	66.980	73.439	20.860	3.230	2
FS	59.387	4.007	60.442	54.958	62.761	16.059	2.314	3
Elm SD	107.755	2.462	--	106.015	109.496	6.059	1.741	2
Elm WC	107.755	2.462	--	106.015	109.496	6.059	1.741	2
Morris	75.767	3.729	--	73.130	78.404	13.904	2.637	2
Soil	14.876	0.281	--	14.677	15.074	0.079	0.198	2
Spruce SD	293.202	21.434	--	278.046	308.358	459.404	15.156	2
Spruce WC	293.202	21.434	--	278.046	308.358	459.404	15.156	2

Table A6: Total N (%) after feedlot runoff application

Name	Mean	Std Dev	Median	Min	Max	Var	Std Error	CV	n
CC	0.623	0.168	0.542	0.480	0.909	0.028	0.049	27.05	12
Comp	1.151	0.085	1.153	0.998	1.282	0.007	0.024	7.35	12
CS	0.797	0.135	0.729	0.691	1.089	0.018	0.039	16.97	12
FS	0.763	0.095	0.743	0.648	0.958	0.009	0.027	12.46	12
Elm SD	0.376	0.038	0.383	0.305	0.449	0.001	0.011	10.05	12
Elm WC	0.394	0.034	0.392	0.366	0.493	0.001	0.010	8.61	12
Morris	0.586	0.035	0.594	0.522	0.632	0.001	0.010	6.03	12
Soil	0.140	0.014	0.138	0.117	0.171	0.000	0.004	9.90	12
Spruce SD	0.152	0.012	0.152	0.132	0.169	0.000	0.004	7.98	12
Spruce WC	0.141	0.010	0.136	0.129	0.160	0.000	0.003	7.39	12

Table A7: Total C (%) after feedlot runoff application

Name	Mean	Std Dev	Median	Min	Max	Var	Std Error	CV	n
CC	47.258	0.125	47.252	47.101	47.441	0.016	1.322	0.27	12
Comp	37.444	2.506	37.639	34.482	41.793	6.279	3.966	6.69	12
CS	45.703	0.370	45.790	45.028	46.207	0.137	1.983	0.81	12
FS	49.051	0.278	49.029	48.603	49.583	0.077	2.410	0.57	12
Elm SD	47.975	0.162	47.974	47.638	48.207	0.026	1.970	0.34	12
Elm WC	47.863	0.156	47.842	47.620	48.104	0.024	2.126	0.32	12
Morris	40.697	3.805	41.741	34.218	44.912	14.476	3.161	9.35	12
Soil	2.055	0.163	2.004	1.884	2.462	0.027	1.173	7.95	12
Spruce SD	50.193	0.107	50.206	49.956	50.368	0.012	1.383	0.21	12
Spruce WC	50.407	0.127	50.415	50.164	50.614	0.016	1.331	0.25	12

Table A8: C/N ratio after feedlot runoff application

Name	Mean	Std Dev	Median	Min	Max	Var	Std Error	CV	n
CC	80.186	17.432	87.199	51.846	98.372	303.863	0.039	21.74	12
Comp	32.720	3.626	32.236	28.092	38.328	13.151	0.007	11.08	12
CS	58.691	8.682	63.023	41.337	65.913	75.382	0.021	14.79	12
FS	65.100	7.305	65.792	51.380	75.388	53.366	0.010	11.22	12
Elm SD	128.983	13.409	125.163	106.274	157.199	179.800	0.002	10.40	12
Elm WC	122.202	8.982	122.129	97.637	131.328	80.684	0.002	7.35	12
Morris	69.762	8.511	71.451	54.999	81.163	72.430	0.002	12.20	12
Soil	14.720	0.784	14.448	13.978	16.827	0.615	0.001	5.33	12
Spruce SD	332.057	26.894	329.753	296.410	380.687	723.310	0.000	8.10	12
Spruce WC	360.155	25.527	370.890	316.005	391.702	651.613	0.000	7.09	12

Table A9: Initial pH of media after 1-hour extraction

ID	Mean	Std Dev	Median	Min	Max	Variance	Std Error	CV	n
Spruce WC	4.53	0.0424	--	4.50	4.56	0.0018	0.0300	0.9	2
Spruce SD	4.53	0.0424	--	4.50	4.56	0.0018	0.0300	0.9	2
Elm WC	4.93	0.0283	--	4.91	4.95	0.0008	0.0200	0.6	2
Elm SD	4.93	0.0283	--	4.91	4.95	0.0008	0.0200	0.6	2
Morris	6.02	0.0283	--	6.00	6.04	0.0008	0.0200	0.5	2
CC	4.93	0.0071	--	4.92	4.93	0.0000	0.0050	0.1	2
CS	5.55	0.0424	--	5.52	5.58	0.0018	0.0300	0.8	2
Comp	6.86	0.0141	--	6.85	6.87	0.0002	0.0100	0.2	2
Soil	7.09	0.0354	--	7.06	7.11	0.0013	0.0250	0.5	2

Table A10: pH after pulse experiment

ID	Mean	Std Dev	Median	Min	Max	Variance	Std Error	n
Spruce WC	5.25	0.0577	5.25	5.20	5.30	0.0033	0.0289	4
Spruce SD	5.43	0.0500	5.40	5.40	5.50	0.0025	0.0250	4
Elm WC	5.90	0.0000	5.90	5.90	5.90	0.0000	0.0000	4
Elm SD	6.00	0.0000	6.00	6.00	6.00	0.0000	0.0000	4
Morris	6.73	0.2754	6.75	6.40	7.00	0.0758	0.1377	4
CC	5.58	0.2630	5.65	5.20	5.80	0.0692	0.1315	4
CS	7.13	0.1500	7.20	6.90	7.20	0.0225	0.0750	4
Comp	7.80	0.0816	7.80	7.70	7.90	0.0067	0.0408	4
Soil	8.23	0.0957	8.25	8.10	8.30	0.0092	0.0479	4
FS	6.63	0.2217	6.60	6.40	6.90	0.0492	0.1109	4

Table A11: Initial EC (dS/cm^2) after 1-hour extraction

ID	Mean	Std Dev	Median	Min	Max	Variance	Std Error	CV	n
Spruce WC	0.26	0.0000	--	0.26	0.26	0.0000	0.0000	0.0	2
Spruce SD	0.26	0.0000	--	0.26	0.26	0.0000	0.0000	0.0	2
Elm WC	0.31	0.0000	--	0.31	0.31	0.0000	0.0000	0.0	2
Elm SD	0.31	0.0000	--	0.31	0.31	0.0000	0.0000	0.0	2
Morris	0.55	0.0071	--	0.54	0.55	0.0001	0.0050	1.3	2
CC	1.26	0.0071	--	1.25	1.26	0.0001	0.0050	0.6	2
CS	2.28	0.0354	--	2.25	2.30	0.0012	0.0250	1.6	2
Comp	2.17	0.0283	--	2.15	2.19	0.0008	0.0200	1.3	2
Soil	0.09	0.0000	--	0.09	0.09	0.0000	0.0000	0.0	2

Table A12: EC after pulse experiment

ID	Mean	Std Dev	Median	Min	Max	Variance	Std Error	n
Spruce WC	0.16	0.0033	0.16	0.16	0.16	0.0000	0.0017	4
Spruce SD	0.17	0.0054	0.16	0.16	0.17	0.0000	0.0027	4
Elm WC	0.28	0.0182	0.28	0.25	0.29	0.0003	0.0091	4
Elm SD	0.24	0.0159	0.24	0.23	0.26	0.0003	0.0079	4
Morris	0.53	0.0893	0.52	0.45	0.66	0.0080	0.0446	4
CC	0.74	0.1002	0.74	0.63	0.87	0.0100	0.0501	4
CS	1.49	0.2165	1.50	1.22	1.74	0.0469	0.1082	4
Comp	1.49	0.1040	1.50	1.37	1.58	0.0108	0.0520	4
Soil	0.11	0.0026	0.11	0.11	0.11	0.0000	0.0013	4
FS	1.10	0.2590	1.19	0.73	1.29	0.0671	0.1295	4

Table A13: Initial bulk density (Mg m^{-3})

ID	Mean	Std Dev	Median	Min	Max	Variance	Std Error	n
Elm WC	0.31	0.0125	0.31	0.30	0.33	0.0002	0.0062	4
Elm SD	0.34	0.0040	0.34	0.34	0.35	0.0000	0.0020	4
Spruce WC	0.25	0.0077	0.25	0.24	0.26	0.0001	0.0038	4
Spruce SD	0.28	0.0127	0.27	0.26	0.29	0.0002	0.0064	4
Morris	0.24	0.0195	0.24	0.22	0.26	0.0004	0.0087	5
Corn cobs	0.14	0.0123	0.14	0.12	0.15	0.0002	0.0061	4
Corn stover	0.05	0.0027	0.05	0.05	0.05	0.0000	0.0013	4
Compost	0.17	0.0081	0.17	0.15	0.17	0.0001	0.0040	4
Soil	1.38	0.0161	1.38	1.37	1.41	0.0003	0.0080	4

Table A14: Initial ash content (%)

ID	Mean	Std Dev	Median	Min	Max	Variance	Std Error	n
Elm	3.02	0.012	3.01	3.01	3.03	0.0001	0.007	3
Spruce	1.06	0.040	1.04	1.04	1.11	0.0016	0.023	3
Morris	17.53	0.868	17.40	16.74	18.46	0.7529	0.501	3
Corn cobs	2.19	0.038	2.21	2.15	2.22	0.0014	0.022	3
Corn stover	9.06	0.110	9.01	8.99	9.19	0.0121	0.064	3
Flax straw	2.07	0.015	2.07	2.06	2.09	0.0002	0.009	3
Compost	33.94	1.064	34.33	32.74	34.76	1.1322	0.614	3

Table A15: Maximal water holding capacity (%)

Media	Mean	Std Dev	Median	Min	Max	Variance	Std Error	n
Elm WC	66.0	6.603	69.4	58.4	70.2	43.6	3.301	4
Elm SD	169.1	16.929	171.2	150.0	184.1	286.6	8.465	4
Spruce WC	56.1	18.405	51.6	39.1	82.2	338.7	9.202	4
Spruce SD	152.0	10.184	151.9	143.1	161.1	103.7	5.092	4
Morris	126.4	8.956	127.3	114.8	136.3	80.2	4.478	4
CC	271.5	27.865	275.4	235.6	299.6	776.5	13.933	4
CS	563.8	101.897	568.4	435.9	682.4	10383.0	50.948	4
Comp	260.2	34.363	266.0	219.2	289.4	1180.8	17.182	4
Soil	34.8	2.854	34.0	32.3	38.9	8.1	1.427	4

Table A16: Moisture content (w) in % measured after pulse experiment

ID	Mean	Std Dev	Median	Min	Max	Variance	Std Error	n
Elm WC	108.8	6.93	112.4	100.8	113.2	48.047	4.002	3
Elm SD	153.0	4.90	152.5	148.7	158.3	24.034	2.451	4
Spruce WC	131.1	10.46	130.4	119.8	143.8	109.402	5.230	4
Spruce SD	177.4	3.79	177.9	172.5	181.2	14.390	1.897	4
Morris	166.5	23.52	160.1	146.3	199.4	553.051	11.759	4
CC	316.4	68.89	300.1	255.0	410.5	4745.736	34.445	4
CS	769.7	203.44	813.4	517.1	934.9	41389.310	101.722	4
FS	254.1	47.58	279.8	199.2	283.4	2263.872	27.470	3
Compost	280.4	16.95	278.9	262.4	301.4	287.410	8.477	4
Soil	27.5	1.11	27.5	26.2	28.8	1.232	0.555	4

Table A17: Initial total phosphorus (mg/L)

ID	Mean	Std Dev	Median	Min	Max	Variance	Std Error	n
Nano blanks	0.0	0	0.0	0.0	0.0	0	0.000	4
5ppm stand	4.9	0.115	4.9	4.7	5.0	0.013	0.058	4
Soil stand (439mg/Kg)	482.1	13.490	477.5	471.9	501.6	181.980	6.745	4
Elm WC	321.5	3.320	321.0	318.5	325.0	11.025	1.917	3
Elm SD	321.5	3.320	321.0	318.5	325.0	11.025	1.917	3
Spruce WC	124.6	7.658	124.4	117.0	132.3	58.639	4.421	3
Spruce SD	124.6	7.658	124.4	117.0	132.3	58.639	4.421	3
Morris	846.1	28.273	848.7	816.7	873.0	799.375	16.324	3
CC	345.0	19.447	336.7	331.0	367.2	378.172	11.228	3
CS	814.2	53.230	795.7	772.7	874.2	2833.413	30.732	3
Comp	3343.1	212.079	3368.5	3119.5	3541.4	44977.453	122.444	3
Soil	444.9	19.601	440.0	428.2	466.5	384.180	11.316	3

Table A18: Total P after pulse experiment

ID	Mean	Std Dev	Median	Min	Max	Variance	Std Error	n
Elm WC	251.6	9.36	255.3	235.3	258.6	87.6	4.2	5
Elm SD	252.3	19.06	259.5	224.2	266.2	363.1	9.5	4
Spruce WC	93.2	6.79	93.8	84.4	100.9	46.1	3.4	4
Spruce SD	97.6	9.07	97.1	87.2	109.3	82.2	4.5	4
Morris	649.0	109.80	658.0	510.8	769.4	12055.9	54.9	4
CC	447.5	98.26	404.5	386.9	594.0	9655.6	49.1	4
CS	895.3	126.56	912.7	726.9	1028.9	16018.5	63.3	4
Comp	2724.1	182.52	2710.9	2467.0	2978.5	33313.9	81.6	5
Soil	413.2	24.69	415.6	385.1	436.4	609.8	12.3	4
FS	872.2	79.77	857.0	803.8	970.9	6362.7	39.9	4

Table A19: Particle size distribution before and after pulse experiment

		Before					After				
		% >25	*% >12.5*	*% >5.6*	*% >2*	*%<2*	*% >25*	*% >12.5*	*% >5.6*	*% >2*	*%<2*
Elm WC	*Average*	1.87%	31.94%	53.50%	10.61%	2.09%	0.14%	13.59%	54.85%	25.29%	6.12%
	Median	0.40%	32.07%	52.70%	10.17%	1.98%	0.00%	13.25%	54.76%	23.86%	6.79%
	Max	6.67%	36.15%	57.28%	12.34%	2.87%	0.58%	19.04%	62.09%	31.18%	8.11%
	Min	0.00%	27.46%	51.33%	9.75%	1.52%	0.00%	8.81%	47.81%	22.28%	2.79%
	Stand. Deviation	3.22%	3.93%	2.64%	1.19%	0.59%	0.29%	4.20%	5.84%	4.04%	2.31%
	Variance	0.10%	0.15%	0.07%	0.01%	0.00%	0.00%	0.18%	0.34%	0.16%	0.05%
Spruce WC	*Average*	9.94%	39.85%	34.90%	12.11%	3.20%	3.53%	14.41%	35.58%	29.33%	17.14%
	Median	6.43%	36.48%	35.02%	12.67%	3.26%	2.91%	11.97%	35.87%	30.45%	16.17%
	Max	21.80%	51.97%	39.12%	14.62%	4.97%	8.31%	24.20%	41.77%	32.68%	24.86%
	Min	5.11%	34.44%	30.45%	8.49%	1.30%	0.00%	9.52%	28.83%	23.74%	11.37%
	Stand. Deviation	7.93%	8.14%	4.28%	2.74%	1.94%	3.52%	6.72%	5.42%	4.25%	5.71%
	Variance	0.63%	0.66%	0.18%	0.08%	0.04%	0.12%	0.45%	0.29%	0.18%	0.33%
Elm SD	*Average*	0.00%	0.00%	11.09%	45.37%	43.55%	0.74%	1.22%	5.11%	53.51%	39.41%
	Median	0.00%	0.00%	12.24%	46.74%	40.38%	0.00%	0.89%	5.18%	53.50%	38.03%
	Max	0.00%	0.00%	14.40%	50.09%	56.62%	2.97%	2.61%	6.40%	56.69%	45.27%
	Min	0.00%	0.00%	5.46%	37.91%	36.81%	0.00%	0.50%	3.69%	50.34%	36.32%
	Stand. Deviation	0.00%	0.00%	4.15%	5.58%	8.91%	1.49%	0.95%	1.32%	3.59%	4.01%
	Variance	0.00%	0.00%	0.17%	0.31%	0.79%	0.02%	0.01%	0.02%	0.13%	0.16%
Spruce SD	*Average*	0.00%	0.00%	6.26%	57.27%	36.48%	0.00%	0.12%	1.45%	49.09%	49.34%
	Median	0.00%	0.00%	6.49%	57.01%	37.77%	0.00%	0.07%	1.19%	48.87%	49.94%
	Max	0.00%	0.00%	9.31%	67.18%	46.86%	0.00%	0.33%	2.54%	51.81%	52.17%
	Min	0.00%	0.00%	2.73%	47.85%	23.51%	0.00%	0.00%	0.88%	46.81%	45.32%
	Stand. Deviation	0.00%	0.00%	2.87%	7.90%	9.83%	0.00%	0.16%	0.77%	2.59%	3.38%
	Variance	0.00%	0.00%	0.08%	0.62%	0.97%	0.00%	0.00%	0.01%	0.07%	0.11%
Morris	*Average*	1.31%	31.53%	34.06%	18.97%	14.12%	1.48%	11.60%	36.09%	30.58%	20.25%
	Median	0.43%	31.42%	33.82%	18.97%	14.69%	0.44%	9.91%	39.13%	29.63%	15.29%
	Max	4.39%	38.15%	37.73%	23.39%	20.81%	5.03%	17.05%	45.50%	36.93%	38.66%
	Min	0.00%	25.14%	30.87%	14.57%	6.31%	0.00%	9.53%	20.59%	26.14%	11.77%
	Stand. Deviation	2.09%	6.77%	3.21%	3.72%	6.02%	2.40%	3.65%	10.99%	4.65%	12.48%
	Variance	0.04%	0.46%	0.10%	0.14%	0.36%	0.06%	0.13%	1.21%	0.22%	1.56%
CC	*Average*	4.00%	33.62%	41.29%	13.70%	7.39%	1.37%	22.35%	41.83%	24.79%	9.66%
	Median	3.20%	34.65%	40.99%	12.55%	6.07%	0.00%	21.82%	40.08%	23.51%	10.38%
	Max	9.59%	42.10%	51.73%	19.50%	13.09%	5.47%	36.00%	52.08%	32.79%	13.50%
	Min	0.00%	23.09%	31.44%	10.21%	4.32%	0.00%	9.78%	35.08%	19.35%	4.37%
	Stand. Deviation	4.06%	9.52%	8.72%	4.03%	3.92%	2.73%	10.73%	7.35%	5.78%	3.88%
	Variance	0.17%	0.91%	0.76%	0.16%	0.15%	0.07%	1.15%	0.54%	0.33%	0.15%
CS	*Average*	3.25%	49.47%	27.81%	14.17%	5.30%	4.87%	15.54%	27.63%	29.49%	22.47%
	Median	3.14%	48.97%	29.10%	14.77%	4.80%	4.25%	15.77%	28.10%	29.70%	21.72%
	Max	5.32%	66.00%	33.03%	19.30%	10.77%	10.99%	23.06%	40.99%	37.44%	38.46%
	Min	1.39%	33.94%	19.99%	7.83%	0.85%	0.00%	7.55%	13.33%	21.13%	7.97%
	Stand. Deviation	1.68%	15.69%	6.10%	5.85%	4.94%	4.74%	7.54%	11.49%	7.96%	13.90%
	Variance	0.03%	2.46%	0.37%	0.34%	0.24%	0.22%	0.57%	1.32%	0.63%	1.93%
Compost	*Average*	1.46%	16.48%	26.28%	36.46%	19.32%	0.06%	1.61%	13.59%	48.12%	36.62%
	Median	0.97%	16.91%	27.31%	36.31%	20.57%	0.00%	1.58%	14.15%	48.05%	36.35%
	Max	3.90%	18.89%	29.03%	37.71%	22.87%	0.25%	2.50%	14.83%	49.81%	39.88%
	Min	0.00%	13.22%	21.45%	35.52%	13.26%	0.00%	0.77%	11.22%	46.58%	33.90%
	Stand. Deviation	1.87%	2.67%	3.44%	1.04%	4.47%	0.12%	0.81%	1.63%	1.57%	2.99%
	Variance	0.03%	0.07%	0.12%	0.01%	0.20%	0.00%	0.01%	0.03%	0.02%	0.09%
Soil	*Average*	0.00%	2.78%	2.94%	12.05%	82.23%	5.01%	9.55%	6.45%	11.30%	67.69%
	Median	0.00%	3.03%	2.97%	12.22%	82.73%	2.55%	10.11%	6.43%	11.60%	65.18%
	Max	0.00%	4.20%	3.80%	13.02%	84.49%	14.93%	14.75%	7.69%	12.85%	80.24%
	Min	0.00%	3.31%	3.55%	11.89%	81.24%	0.00%	3.23%	5.27%	9.14%	60.15%
	Stand. Deviation	0.00%	1.42%	0.87%	0.99%	2.62%	7.04%	4.96%	1.27%	1.61%	8.70%
	Variance	0.00%	0.02%	0.01%	0.01%	0.07%	0.50%	0.25%	0.02%	0.03%	0.76%

Table A20: Coliform, *Streptococcus*, *Staphylococcus* spp. and *Bacillus* cfu in corn stover (CS), flax straw (FS), compost (comp) and soil in week 1 and week 4 of pulse experiment

Coliform

ID		Mean	Std Dev	Median	Min	Max	Var	Std Error	n
CS	begin	7.17	0.178	7.17	6.96	7.38	0.032	0.089	4
CS	end	5.57	0.238	5.59	5.30	5.80	0.056	0.119	4
FS	begin	5.27	0.855	5.38	4.15	6.17	0.731	0.427	4
FS	end	6.41	0.443	6.48	5.83	6.83	0.196	0.222	4
Comp	begin	5.19	0.130	5.17	5.06	5.35	0.017	0.065	4
Comp	end	4.89	0.358	4.91	4.43	5.30	0.128	0.179	4
Soil	begin	4.65	0.331	4.55	4.40	5.10	0.110	0.166	4
Soil	end	5.38	0.836	5.41	4.40	6.30	0.699	0.418	4

Strep

ID		Mean	Std Dev	Median	Min	Max	Var	Std Error	n
CS	begin	6.90	0.325	7.00	6.42	7.16	0.106	0.163	4
CS	end	5.77	0.326	5.79	5.40	6.11	0.106	0.163	4
FS	begin	6.18	0.242	6.24	5.83	6.39	0.058	0.121	4
FS	end	6.10	0.632	6.16	5.35	6.73	0.399	0.316	4
Comp	begin	4.95	0.136	4.91	4.83	5.14	0.018	0.068	4
Comp	end	4.46	0.501	4.44	3.88	5.10	0.251	0.250	4
Soil	begin	4.60	0.747	4.64	3.68	5.44	0.558	0.373	4
Soil	end	3.66	2.466	4.70	0.00	5.24	6.081	1.233	4

Staph Spp

ID		Mean	Std Dev	Median	Min	Max	Var	Std Error	n
CS	begin	0.00	0.000	0.00	0.00	0.00	0.000	0.000	4
CS	end	4.91	0.360	5.00	4.40	5.24	0.130	0.180	4
FS	begin	4.71	0.375	4.64	4.40	5.16	0.141	0.188	4
FS	end	4.00	1.237	3.57	3.10	5.76	1.531	0.619	4
Comp	begin	0.67	1.350	0.00	0.00	2.70	1.822	0.675	4
Comp	end	0.00	0.000	0.00	0.00	0.00	0.000	0.000	4
Soil	begin	0.00	0.000	0.00	0.00	0.00	0.000	0.000	4
Soil	end	0.00	0.000	0.00	0.00	0.00	0.000	0.000	4

Bacillus

ID		Mean	Std Dev	Median	Min	Max	Var	Std Error	n
CS	begin	5.64	0.064	5.63	5.57	5.72	0.004	0.032	4
CS	end	5.41	0.221	5.48	5.10	5.60	0.049	0.110	4
FS	begin	3.92	0.266	3.95	3.63	4.15	0.071	0.133	4
FS	end	5.33	0.076	5.35	5.24	5.40	0.006	0.038	4
Comp	begin	3.24	1.738	3.78	0.72	4.70	3.019	0.869	4
Comp	end	4.99	0.529	5.03	4.40	5.51	0.280	0.264	4
Soil	begin	4.58	0.455	4.70	3.93	5.00	0.207	0.228	4
Soil	end	5.77	0.054	5.78	5.70	5.83	0.003	0.027	4

Table A21: Initial Aluminum, Boron, Calcium, Cadmium, Chromium, Cooper and Iron concentration in media

Element	Material	Mean	St. Dev.	n	St. Err.	CV	Min.	Max.
		---------- ppm	----------		ppm		---------- ppm	----------
Aluminum	Elm	22.25	1.19	3	0.69	5.35	20.90	23.15
	Spruce	33.18	1.96	3	1.13	5.91	31.01	34.83
	Morris	1086.60	57.33	3	33.10	5.28	1020.70	1125.00
	CC	33.32	0.82	3	0.47	2.46	32.38	33.90
	CS	727.66	14.18	3	8.19	1.95	712.13	739.91
	Comp	1254.13	21.28	3	12.29	1.70	1241.30	1278.70
Boron	Elm	7.08	0.01	3	0.01	0.21	7.07	7.09
	Spruce	3.50	0.01	3	0.01	0.31	3.49	3.51
	Morris	11.57	0.18	3	0.11	1.57	11.37	11.72
	CC	2.01	0.03	3	0.02	1.68	1.98	2.05
	CS	5.32	0.03	3	0.02	0.63	5.28	5.35
	Comp	11.79	0.25	3	0.14	2.11	11.55	12.05
Calcium	Elm	10924.33	128.32	3	74.09	1.17	10828.00	11070.00
	Spruce	2409.77	37.70	3	21.77	1.56	2366.70	2436.80
	Morris	14067.00	268.92	3	155.26	1.91	13762.00	14270.00
	CC	250.95	9.56	3	5.52	3.81	244.80	261.97
	CS	3277.70	16.17	3	9.34	0.49	3261.10	3293.40
	Comp	28418.33	2924.45	3	1688.43	10.29	25336.00	31154.00
Cadmium	Elm	0.28	0.00	3	0.00	0.00	0.28	0.28
	Spruce	0.28	0.00	3	0.00	0.00	0.28	0.28
	Morris	0.28	0.00	3	0.00	0.00	0.28	0.28
	CC	0.28	0.00	3	0.00	0.00	0.28	0.28
	CS	0.28	0.00	3	0.00	0.00	0.28	0.28
	Comp	0.28	0.00	3	0.00	0.00	0.28	0.28
Chromium	Elm	1.17	0.20	3	0.11	16.90	0.99	1.38
	Spruce	0.52	0.09	3	0.05	16.89	0.47	0.63
	Morris	1.56	0.11	3	0.06	6.76	1.44	1.64
	CC	3.98	0.33	3	0.19	8.29	3.64	4.29
	CS	9.14	1.23	3	0.71	13.43	8.38	10.56
	Comp	3.38	0.18	3	0.10	5.35	3.18	3.51
Cooper	Elm	2.20	0.02	3	0.01	1.03	2.18	2.23
	Spruce	4.10	0.21	3	0.12	5.22	3.90	4.32
	Morris	9.53	0.44	3	0.25	4.57	9.03	9.80
	CC	2.29	0.03	3	0.02	1.14	2.27	2.32
	CS	5.29	0.15	3	0.09	2.92	5.12	5.40
	Comp	20.39	1.00	3	0.57	4.88	19.26	21.12
Iron	Elm	71.89	2.59	3	1.49	3.60	69.00	74.01
	Spruce	108.00	5.07	3	2.93	4.70	105.05	113.86
	Morris	1235.13	55.21	3	31.87	4.47	1183.90	1293.60
	CC	99.18	2.86	3	1.65	2.88	97.27	102.46
	CS	623.34	12.38	3	7.15	1.99	610.71	635.45
	Comp	2077.23	87.51	3	50.53	4.21	1995.70	2169.70

Table A22: Initial Potassium, Magnesium, Manganese, Sodium, Nickel, Phosphorus, Lead and Zinc concentrations in media

Element	Material	Mean	St. Dev.	n	St. Err.	CV	Min.	Max.
		---------- ppm ----------			ppm		---------- ppm ----------	
Potassium	Elm	1451.60	7.80	3	4.50	0.54	1443.80	1459.40
	Spruce	622.37	4.25	3	2.45	0.68	617.51	625.42
	Morris	2727.87	37.55	3	21.68	1.38	2688.30	2763.00
	CC	5552.73	80.54	3	46.50	1.45	5493.80	5644.50
	CS	10782.67	47.54	3	27.45	0.44	10734.00	10829.00
	Comp	12526.67	103.83	3	59.95	0.83	12457.00	12646.00
Magnesium	Elm	273.32	1.13	3	0.65	0.41	272.44	274.60
	Spruce	338.47	5.69	3	3.29	1.68	332.78	344.16
	Morris	2229.30	96.61	3	55.78	4.33	2152.00	2337.60
	CC	361.27	4.22	3	2.44	1.17	356.46	364.36
	CS	1510.63	7.02	3	4.05	0.46	1503.00	1516.80
	Comp	12429.33	1521.30	3	878.32	12.24	10723.00	13644.00
Manganese	Elm	6.98	0.07	3	0.04	1.01	6.93	7.06
	Spruce	7.45	0.34	3	0.20	4.54	7.06	7.68
	Morris	111.54	7.06	3	4.07	6.33	103.49	116.65
	CC	8.18	0.11	3	0.06	1.29	8.09	8.29
	CS	50.70	1.33	3	0.77	2.63	49.17	51.61
	Comp	225.28	16.89	3	9.75	7.50	208.33	242.11
Sodium	Elm	55.23	1.08	3	0.63	1.96	54.07	56.22
	Spruce	110.38	6.77	3	3.91	6.13	102.61	114.99
	Morris	69.80	1.69	3	0.98	2.43	68.40	71.68
	CC	32.96	0.90	3	0.52	2.74	32.15	33.93
	CS	34.33	1.39	3	0.80	4.04	32.95	35.72
	Comp	1933.90	30.37	3	17.54	1.57	1906.40	1966.50
Nickel	Elm	1.20	0.05	3	0.03	4.39	1.14	1.24
	Spruce	0.80	0.00	3	0.00	0.00	0.80	0.80
	Morris	2.41	0.18	3	0.10	7.29	2.21	2.55
	CC	3.26	0.04	3	0.02	1.32	3.22	3.30
	CS	8.11	0.48	3	0.28	5.92	7.72	8.64
	Comp	3.17	0.32	3	0.18	9.94	2.94	3.53
Phosphorus	Elm	318.25	0.33	3	0.19	0.10	317.91	318.56
	Spruce	133.60	2.56	3	1.48	1.92	131.39	136.41
	Morris	742.93	6.17	3	3.56	0.83	736.96	749.28
	CC	370.10	14.32	3	8.27	3.87	358.33	386.04
	CS	799.32	15.90	3	9.18	1.99	786.66	817.16
	Comp	3015.80	90.12	3	52.03	2.99	2941.90	3116.20
Lead	Elm	4.40	0.00	3	0.00	0.00	4.40	4.40
	Spruce	4.40	0.00	3	0.00	0.00	4.40	4.40
	Morris	4.40	0.00	3	0.00	0.00	4.40	4.40
	CC	4.40	0.00	3	0.00	0.00	4.40	4.40
	CS	4.40	0.00	3	0.00	0.00	4.40	4.40
	Comp	4.42	0.03	3	0.01	0.57	4.40	4.45
Zinc	Elm	6.42	0.10	3	0.06	1.60	6.31	6.51
	Spruce	25.63	0.33	3	0.19	1.30	25.37	26.01
	Morris	28.47	0.44	3	0.25	1.54	27.97	28.80
	CC	26.33	0.84	3	0.49	3.21	25.46	27.14
	CS	20.06	0.77	3	0.45	3.85	19.17	20.51
	Comp	81.80	1.58	3	0.91	1.94	79.99	82.94

Table A23: Al, B, Ca, and Cd concentration of media after feedlot runoff application

Element	Material	Mean	St. Dev.	n	St. Err.	CV	Min.	Max.
		---------- ppm ----------			ppm		---------- ppm ----------	
Aluminum	Elm WC	53.76	10.52	5	4.70	19.56	39.33	64.83
	Elm SD	84.47	11.66	4	5.83	13.80	69.34	95.58
	Spruce WC	55.32	9.76	4	4.88	17.64	44.63	66.13
	Spruce SD	73.77	5.63	4	2.81	7.63	69.98	82.13
	Morris	4270.65	2321.23	4	1160.61	54.35	2304.80	7107.90
	CC	172.66	46.12	4	23.06	26.71	143.50	241.42
	CS	1486.28	484.22	4	242.11	32.58	1137.20	2176.50
	FS	348.57	64.91	4	32.45	18.62	271.24	423.04
	Comp	3046.88	85.00	5	38.01	2.79	2965.40	3170.40
	Soil	10466.00	101.28	4	50.64	0.97	10347.00	10563.00
Boron	Elm WC	81.13	7.12	5	3.19	8.78	75.20	90.20
	Elm SD	81.30	4.14	4	2.07	5.09	76.20	86.35
	Spruce WC	74.27	4.91	4	2.46	6.61	68.25	80.23
	Spruce SD	77.30	4.17	4	2.08	5.39	72.75	81.51
	Morris	83.07	4.75	4	2.38	5.72	79.12	89.98
	CC	75.50	3.39	4	1.70	4.49	72.76	80.10
	CS	69.32	3.23	4	1.62	4.66	66.67	73.81
	FS	82.58	2.26	4	1.13	2.74	79.89	84.56
	Comp	71.87	5.47	5	2.45	7.61	67.03	80.70
	Soil	54.83	5.65	4	2.82	10.30	48.42	62.09
Calcium	Elm WC	9633.60	1186.81	5	530.76	12.32	8332.80	11238.00
	Elm SD	10423.45	1321.84	4	660.92	12.68	9132.50	12157.00
	Spruce WC	1880.93	145.08	4	72.54	7.71	1665.40	1981.10
	Spruce SD	1860.28	123.34	4	61.67	6.63	1722.10	1971.00
	Morris	14870.50	3691.86	4	1845.93	24.83	11851.00	19424.00
	CC	979.00	203.54	4	101.77	20.79	793.80	1267.40
	CS	3811.13	225.59	4	112.79	5.92	3641.20	4121.70
	FS	5576.00	310.32	4	155.16	5.57	5135.50	5811.90
	Comp	41238.20	3988.55	5	1783.73	9.67	35588.00	46662.00
	Soil	17866.75	873.73	4	436.87	4.89	16604.00	18524.00
Cadmium	Elm WC	0.28	0.00	5	0.00	0.00	0.28	0.28
	Elm SD	0.28	0.00	4	0.00	0.00	0.28	0.28
	Spruce WC	0.28	0.00	4	0.00	0.00	0.28	0.28
	Spruce SD	0.28	0.00	4	0.00	0.00	0.28	0.28
	Morris	0.28	0.00	4	0.00	0.00	0.28	0.28
	CC	0.28	0.00	4	0.00	0.00	0.28	0.28
	CS	0.28	0.00	4	0.00	0.00	0.28	0.28
	FS	0.54	0.05	4	0.03	9.77	0.50	0.62
	Comp	0.28	0.00	5	0.00	0.00	0.28	0.28
	Soil	0.28	0.00	4	0.00	0.90	0.28	0.28

Table A24: Cr, Cu, Fe, and K concentrations of media after feedlot runoff application

Element	Material	Mean	St. Dev.	n	St. Err.	CV	Min.	Max.
		---------- ppm	----------		ppm		---------- ppm	----------
Chromium	Elm WC	0.88	0.16	5	0.07	17.62	0.69	1.12
	Elm SD	1.11	0.25	4	0.13	22.98	0.92	1.47
	Spruce WC	2.73	0.64	4	0.32	23.35	1.94	3.27
	Spruce SD	2.04	0.61	4	0.31	29.93	1.69	2.96
	Morris	8.63	4.30	4	2.15	49.82	4.90	14.43
	CC	3.43	1.52	4	0.76	44.34	1.84	5.11
	CS	6.17	0.88	4	0.44	14.32	5.11	7.02
	FS	2.88	0.22	4	0.11	7.77	2.69	3.20
	Comp	14.78	2.52	5	1.13	17.03	12.82	18.50
	Soil	30.45	7.97	4	3.98	26.17	20.37	37.57
Cooper	Elm WC	3.65	0.40	5	0.18	10.96	3.03	4.09
	Elm SD	3.16	0.44	4	0.22	14.06	2.50	3.43
	Spruce WC	5.19	0.59	4	0.29	11.37	4.36	5.75
	Spruce SD	4.74	0.93	4	0.47	19.64	3.38	5.48
	Morris	15.90	3.15	4	1.58	19.82	12.26	19.89
	CC	11.58	1.48	4	0.74	12.81	9.99	13.50
	CS	8.95	0.93	4	0.47	10.40	7.70	9.94
	FS	9.41	1.21	4	0.61	12.87	8.12	10.48
	Comp	17.92	1.12	5	0.50	6.23	16.26	19.23
	Soil	6.63	0.49	4	0.25	7.40	6.00	7.12
Iron	Elm WC	82.52	16.93	5	7.57	20.51	55.68	96.84
	Elm SD	142.52	18.46	4	9.23	12.95	116.66	156.34
	Spruce WC	99.56	14.05	4	7.03	14.12	87.09	117.18
	Spruce SD	149.63	8.17	4	4.09	5.46	141.97	161.14
	Morris	4232.20	2245.38	4	1122.69	53.05	2253.40	6973.90
	CC	331.17	54.82	4	27.41	16.55	279.32	408.60
	CS	1426.93	448.56	4	224.28	31.44	1096.70	2056.00
	FS	394.26	57.18	4	28.59	14.50	322.82	450.12
	Comp	5078.14	369.00	5	165.02	7.27	4684.90	5515.30
	Soil	12392.67	54.37	3	31.39	0.44	12332.00	12437.00
Potassium	Elm WC	1052.50	105.92	5	47.37	10.06	951.84	1214.80
	Elm SD	825.05	50.40	4	25.20	6.11	750.23	858.60
	Spruce WC	430.19	23.37	4	11.68	5.43	402.77	458.59
	Spruce SD	345.88	47.85	4	23.93	13.83	297.06	411.52
	Morris	2917.93	478.96	4	239.48	16.41	2280.20	3317.60
	CC	3229.48	355.31	4	177.66	11.00	2934.90	3742.60
	CS	7304.10	864.94	4	432.47	11.84	6094.20	7930.70
	FS	4410.50	1433.07	4	716.54	32.49	2263.50	5208.90
	Comp	7224.56	254.96	5	114.02	3.53	6866.20	7581.10
	Soil	2088.15	68.44	4	34.22	3.28	2013.80	2179.50

Table A25: Mg, Ma, Na, and Ni concentration after feedlot runoff application

Element	Material	Mean	St. Dev.	n	St. Err.	CV	Min.	Max.
		---------- ppm	----------		ppm		---------- ppm	----------
Magnesium	Elm WC	316.87	13.53	5	6.05	4.27	294.70	326.59
	Elm SD	327.53	9.90	4	4.95	3.02	316.05	339.81
	Spruce WC	345.02	16.93	4	8.46	4.91	322.91	361.91
	Spruce SD	348.20	9.65	4	4.82	2.77	338.79	360.15
	Morris	3505.53	1829.42	4	914.71	52.19	1741.40	6046.00
	CC	580.45	112.39	4	56.19	19.36	515.03	748.55
	CS	1689.05	29.61	4	14.81	1.75	1645.50	1711.50
	FS	1338.28	172.28	4	86.14	12.87	1189.60	1518.10
	Comp	14315.80	2134.37	5	954.52	14.91	12510.00	17999.00
	Soil	6312.23	360.85	4	180.43	5.72	5791.20	6624.20
Manganese	Elm WC	8.18	0.70	5	0.31	8.54	7.34	9.08
	Elm SD	9.85	0.53	4	0.26	5.37	9.09	10.28
	Spruce WC	7.57	0.79	4	0.40	10.46	6.70	8.27
	Spruce SD	10.62	0.36	4	0.18	3.39	10.12	10.97
	Morris	162.53	96.20	4	48.10	59.19	80.49	266.65
	CC	17.62	4.18	4	2.09	23.71	14.94	23.81
	CS	64.94	11.22	4	5.61	17.28	54.17	77.78
	FS	51.34	5.23	4	2.62	10.19	44.42	57.12
	Comp	252.32	13.50	5	6.04	5.35	242.33	274.11
	Soil	211.88	10.16	4	5.08	4.80	203.70	226.14
Sodium	Elm WC	57.59	9.44	5	4.22	16.38	49.90	72.88
	Elm SD	63.51	9.44	4	4.72	14.86	50.13	72.23
	Spruce WC	35.11	4.71	4	2.35	13.40	31.64	41.98
	Spruce SD	39.78	3.88	4	1.94	9.76	35.23	44.63
	Morris	84.27	18.14	4	9.07	21.53	67.71	104.45
	CC	49.72	3.60	4	1.80	7.24	45.30	53.68
	CS	71.96	3.09	4	1.54	4.29	69.00	76.02
	FS	142.49	46.64	4	23.32	32.73	74.72	179.96
	Comp	940.96	36.65	5	16.39	3.89	894.54	981.30
	Soil	240.63	44.56	4	22.28	18.52	200.50	296.13
Nickel	Elm WC	0.85	0.08	4	0.04	9.11	0.80	0.96
	Elm SD	0.96	0.08	4	0.04	8.10	0.80	0.96
	Spruce WC	2.14	0.35	4	0.17	16.26	1.74	2.44
	Spruce SD	1.53	0.52	4	0.26	33.78	1.05	2.24
	Morris	5.87	2.90	4	1.45	49.49	3.12	9.68
	CC	2.95	1.14	4	0.57	38.59	1.82	4.25
	CS	4.32	0.80	4	0.40	18.43	3.24	4.95
	FS	2.25	0.17	4	0.08	7.51	2.11	2.49
	Comp	11.25	1.79	5	0.80	15.93	9.36	13.69
	Soil	25.95	6.00	4	3.00	23.12	18.89	31.20

Table A26: P, Pb, and Zn concentrations of media after feedlot runoff application

Element	Material	Mean	St. Dev.	n	St. Err.	CV	Min.	Max.
		---------- ppm	----------		ppm		---------- ppm	----------
Phosphorus	Elm WC	251.63	9.36	5	4.19	3.72	235.30	258.64
	Elm SD	252.34	19.06	4	9.53	7.55	224.20	266.22
	Spruce WC	93.22	6.79	4	3.39	7.28	84.41	100.93
	Spruce SD	97.65	9.07	4	4.53	9.28	87.19	109.29
	Morris	649.05	109.80	4	54.90	16.92	510.82	769.41
	CC	447.48	98.26	4	49.13	21.96	386.90	593.96
	CS	895.29	126.56	4	63.28	14.14	726.87	1028.90
	FS	872.17	79.77	4	39.88	9.15	803.75	970.90
	Comp	2724.14	182.52	5	81.63	6.70	2467.00	2978.50
	Soil	413.18	24.69	4	12.35	5.98	385.08	436.37
Lead	Elm WC	4.40	0.00	5	0.00	0.00	4.40	4.40
	Elm SD	4.40	0.00	4	0.00	0.00	4.40	4.40
	Spruce WC	4.40	0.00	4	0.00	0.00	4.40	4.40
	Spruce SD	4.40	0.00	4	0.00	0.00	4.40	4.40
	Morris	4.63	0.45	4	0.23	9.78	4.40	5.31
	CC	4.40	0.00	4	0.00	0.00	4.40	4.40
	CS	4.40	0.00	4	0.00	0.00	4.40	4.40
	FS	4.40	0.00	4	0.00	0.00	4.40	4.40
	Comp	5.59	0.25	5	0.11	4.44	5.29	5.82
	Soil	4.99	0.60	5	0.27	11.99	4.40	5.70
Zinc	Elm WC	21.45	0.86	5	0.38	4.00	19.92	21.89
	Elm SD	25.18	0.93	4	0.47	3.71	23.91	26.00
	Spruce WC	30.21	1.47	4	0.73	4.86	28.70	31.87
	Spruce SD	39.39	1.05	4	0.53	2.68	38.16	40.50
	Morris	51.80	10.12	4	5.06	19.54	41.40	61.89
	CC	49.80	7.11	4	3.56	14.28	44.98	60.36
	CS	51.18	5.18	4	2.59	10.12	44.66	56.84
	FS	52.91	4.78	4	2.39	9.04	47.21	57.05
	Comp	111.09	6.67	5	2.98	6.00	101.13	119.05
	Soil	42.66	2.14	4	1.07	5.02	41.00	45.55

Table A27: Temperature (°C) in columns during pulse experiment

ID	Mean	Std Dev	Median	Min	Max	Var	Std Error	n
Elm WC	40.1	0.611	40.3	38.9	41.3	0.373	0.115	28
Elm SD	41.4	0.329	41.3	40.8	42.1	0.108	0.062	28
Spruce WC	40.6	0.513	40.6	39.1	41.6	0.263	0.097	28
Spruce SD	40.9	0.481	40.8	40.0	41.8	0.231	0.091	28
Morris	40.6	0.474	40.5	39.4	41.3	0.224	0.090	28
CC	40.4	0.545	40.5	39.2	41.4	0.297	0.103	28
CS	39.9	0.082	39.9	39.8	40.0	0.007	0.041	4
Flax Straw	36.6	1.918	36.2	34.8	39.2	3.680	0.959	4
Compost	40.4	0.183	40.4	40.2	40.6	0.033	0.091	4
Soil	40.0	0.150	40.0	39.9	40.2	0.023	0.075	4

Table A28: Mineral nitrogen (NH_4-N and NO_3-N) from elm WC, elm SD, spruce WC, spruce SD and Morris WC, measured during 22-day pulse experiment. WC = woodchips, SD = sawdust

ID	#	Mean	Std Dev	Median	Min	Max	Variance	Std Error	n
Blank	**all**	1.633	0.725	1.763	0.520	2.801	0.525	0.171	18
Elm WC	**1**	7.318	1.574	7.160	5.658	9.294	2.476	0.787	4
Elm WC	**4**	20.708	3.172	20.597	17.221	24.419	10.060	1.586	4
Elm WC	**6**	15.495	3.530	15.128	12.458	19.266	12.463	1.765	4
Elm WC	**8**	17.431	2.936	17.496	13.772	20.959	8.620	1.468	4
Elm WC	**10**	16.382	4.772	16.825	10.457	21.422	22.768	2.386	4
Elm WC	**12**	14.741	--	--	--	--	--	--	1
Elm WC	**14**	12.188	4.203	12.596	6.689	16.872	17.668	2.102	4
Elm WC	**16**	10.539	4.405	10.097	6.203	15.759	19.404	2.202	4
Elm WC	**18**	8.955	2.791	8.992	5.859	11.975	7.791	1.396	4
Elm WC	**20**	6.407	2.731	6.135	3.512	9.848	7.457	1.365	4
Elm WC	**22**	5.047	1.968	4.634	3.319	7.189	3.872	1.136	3
Elm WC	**24**	3.098	0.348	3.052	2.757	3.529	0.121	0.174	4
Elm SD	**1**	16.668	1.561	16.630	14.908	18.504	2.436	0.780	4
Elm SD	**4**	61.847	12.537	66.839	47.583	71.120	157.185	7.238	3
Elm SD	**6**	56.034	9.766	57.121	43.826	66.069	95.368	4.883	4
Elm SD	**8**	44.774	16.796	48.777	21.302	60.241	282.111	8.398	4
Elm SD	**10**	31.688	6.181	33.192	23.731	36.636	38.202	3.090	4
Elm SD	**12**	46.789	16.456	46.176	27.796	70.960	270.811	6.718	6
Elm SD	**14**	18.568	3.447	18.414	15.311	22.135	11.882	1.723	4
Elm SD	**16**	6.448	1.998	6.730	4.117	8.217	3.992	0.999	4
Elm SD	**18**	5.575	3.194	5.732	1.818	9.019	10.204	1.597	4
Elm SD	**20**	6.427	4.435	8.005	0.000	9.699	19.670	2.218	4
Elm SD	**22**	3.437	2.917	4.988	0.072	5.252	8.512	1.684	3
Elm SD	**24**	2.623	1.453	3.444	0.946	3.480	2.110	0.839	3
Spruce WC	**1**	0.997	0.196	0.987	0.767	1.247	0.039	0.098	4
Spruce WC	**4**	0.553	0.363	0.424	0.277	1.086	0.132	0.182	4
Spruce WC	**6**	0.778	0.201	0.774	0.580	0.984	0.040	0.100	4
Spruce WC	**8**	0.707	0.140	0.745	0.509	0.830	0.020	0.070	4
Spruce WC	**10**	1.089	0.124	1.095	0.932	1.234	0.015	0.062	4
Spruce WC	**12**	0.657	0.155	0.593	0.556	0.887	0.024	0.077	4
Spruce WC	**14**	1.299	0.265	1.307	1.025	1.558	0.070	0.133	4
Spruce WC	**16**	0.705	0.121	0.721	0.552	0.824	0.015	0.060	4
Spruce WC	**18**	1.182	0.452	1.010	0.868	1.841	0.204	0.226	4
Spruce WC	**20**	1.176	0.405	1.131	0.728	1.712	0.164	0.203	4
Spruce WC	**22**	1.349	0.380	1.403	0.906	1.683	0.145	0.190	4
Spruce WC	**24**	1.290	0.508	1.174	0.839	1.974	0.258	0.254	4
Spruce SD	**1**	1.625	0.255	--	1.445	1.805	0.065	0.180	2
Spruce SD	**4**	0.366	0.153	0.382	0.165	0.535	0.023	0.076	4
Spruce SD	**6**	0.193	0.078	0.231	0.076	0.234	0.006	0.039	4
Spruce SD	**8**	0.466	0.050	0.445	0.430	0.523	0.002	0.029	3
Spruce SD	**10**	0.206	0.002	--	0.204	0.207	0.000	0.002	2
Spruce SD	**12**	0.360	0.267	0.292	0.078	0.867	0.071	0.094	8
Spruce SD	**14**	0.032	0.019	0.029	0.016	0.056	0.000	0.009	4
Spruce SD	**16**	0.512	0.436	0.388	0.131	1.139	0.190	0.218	4
Spruce SD	**18**	0.181	0.166	0.105	0.085	0.429	0.027	0.083	4
Spruce SD	**20**	1.044	0.036	1.042	1.007	1.086	0.001	0.018	4
Spruce SD	**22**	0.007	0.015	0.000	0.000	0.029	0.000	0.007	4
Spruce SD	**24**	0.114	0.047	0.103	0.072	0.179	0.002	0.024	4
Morris	**1**	2.222	1.045	2.079	1.138	3.593	1.091	0.522	4
Morris	**4**	6.414	2.530	6.256	3.500	9.644	6.401	1.265	4
Morris	**6**	2.930	0.675	3.008	2.135	3.571	0.455	0.337	4
Morris	**8**	2.560	0.997	2.164	1.898	4.015	0.994	0.498	4
Morris	**10**	3.100	0.188	3.023	2.973	3.379	0.035	0.094	4
Morris	**12**	1.369	0.568	1.466	0.593	1.953	0.323	0.284	4
Morris	**14**	1.123	0.487	1.218	0.449	1.606	0.237	0.243	4
Morris	**16**	0.501	0.246	0.613	0.219	0.670	0.060	0.142	3
Morris	**18**	1.066	0.380	1.044	0.636	1.541	0.145	0.190	4
Morris	**20**	0.654	0.356	0.630	0.267	1.089	0.127	0.178	4
Morris	**22**	1.705	0.477	1.695	1.160	2.270	0.228	0.239	4
Morris	**24**	0.924	0.194	0.815	0.810	1.148	0.038	0.112	3

Table A29: Mineral nitrogen (NH_4-N and NO_3-N) from corn cobs (CC), corn stover (CS), flax straw (FS), compost and soil, measured during pulse experiment

ID	#	Mean	Std Dev	Median	Min	Max	Variance	Std Error	n
Blank	**all**	1.633	0.725	1.763	0.520	2.801	0.525	0.171	18
CC	**1**	2.876	0.796	2.886	1.918	3.814	0.633	0.398	4
CC	**4**	0.729	0.175	--	0.605	0.853	0.031	0.124	2
CC	**6**	1.658	0.383	1.803	1.098	1.928	0.146	0.191	4
CC	**8**	0.900	0.475	0.835	0.405	1.527	0.226	0.237	4
CC	**10**	0.315	0.244	0.348	0.000	0.565	0.059	0.122	4
CC	**12**	0.532	0.376	0.389	0.269	1.079	0.141	0.188	4
CC	**14**	0.575	0.144	0.637	0.360	0.666	0.021	0.072	4
CC	**16**	0.539	0.124	0.525	0.409	0.696	0.015	0.062	4
CC	**18**	0.576	0.123	0.554	0.466	0.728	0.015	0.062	4
CC	**20**	0.256	0.136	0.256	0.068	0.498	0.019	0.048	8
CC	**22**	0.450	0.258	0.529	0.077	0.666	0.066	0.129	4
CC	**24**	0.191	0.102	0.190	0.096	0.289	0.010	0.051	4
CS	**1**	5.278	1.843	5.401	3.024	7.285	3.396	0.921	4
CS	**4**	1.074	0.615	0.953	0.481	1.909	0.378	0.307	4
CS	**6**	1.672	0.312	1.618	1.376	2.075	0.097	0.156	4
CS	**8**	1.606	0.369	1.619	1.201	1.986	0.136	0.184	4
CS	**10**	1.526	0.295	1.533	1.168	1.871	0.087	0.148	4
CS	**12**	1.181	0.450	1.158	0.697	1.710	0.202	0.225	4
CS	**14**	1.130	0.566	1.054	0.565	1.845	0.321	0.283	4
CS	**16**	1.019	0.985	0.785	0.139	2.367	0.971	0.493	4
CS	**18**	0.754	0.510	0.567	0.364	1.331	0.260	0.294	3
CS	**22**	0.520	0.594	0.284	0.121	1.392	0.353	0.297	4
CS	**24**	0.895	0.006	--	0.890	0.899	0.000	0.005	2
FS	**1**	0.628	0.273	0.612	0.352	0.935	0.074	0.136	4
FS	**4**	3.684	1.115	3.910	2.139	4.779	1.242	0.557	4
FS	**6**	2.911	0.794	2.696	2.255	3.998	0.631	0.397	4
FS	**8**	2.339	0.584	2.081	1.928	3.008	0.342	0.337	3
FS	**10**	2.327	1.565	2.445	0.458	3.961	2.450	0.783	4
FS	**12**	2.311	0.824	2.458	1.204	3.126	0.678	0.412	4
FS	**14**	3.206	0.944	2.990	2.324	4.520	0.890	0.472	4
FS	**16**	2.493	0.951	2.172	1.755	3.874	0.905	0.476	4
FS	**18**	2.142	0.986	2.072	1.039	3.386	0.973	0.493	4
FS	**20**	5.433	--	--	--	--	--	--	1
FS	**22**	3.164	2.127	2.800	1.254	5.803	4.524	1.063	4
FS	**24**	3.203	1.273	2.825	2.137	5.026	1.621	0.637	4
Comp	**1**	76.230	13.269	76.579	63.455	88.306	176.074	6.635	4
Comp	**4**	41.374	2.930	42.091	37.222	44.093	8.583	1.465	4
Comp	**6**	18.955	5.073	20.136	11.798	23.750	25.739	2.537	4
Comp	**8**	4.497	1.658	4.554	2.812	6.126	2.748	0.957	3
Comp	**10**	2.091	1.441	1.582	0.974	3.717	2.075	0.832	3
Comp	**12**	1.574	0.505	1.579	0.963	2.177	0.255	0.253	4
Comp	**14**	2.007	1.004	1.760	1.076	3.432	1.008	0.502	4
Comp	**16**	2.098	1.951	1.314	0.820	4.946	3.808	0.976	4
Comp	**18**	2.351	1.723	--	1.132	3.569	2.969	1.219	2
Comp	**20**	1.889	1.020	1.336	1.264	3.066	1.041	0.589	3
Comp	**22**	1.563	1.063	1.138	0.834	3.141	1.130	0.532	4
Comp	**24**	1.079	0.854	0.767	0.468	2.314	0.729	0.427	4
Soil	**1**	42.424	52.310	--	5.435	79.412	2736.298	36.989	2
Soil	**4**	7.660	0.482	7.612	7.027	8.382	0.232	0.215	5
Soil	**6**	9.820	0.467	9.831	9.250	10.367	0.218	0.233	4
Soil	**8**	10.248	0.786	10.395	9.191	11.010	0.618	0.393	4
Soil	**10**	10.100	0.092	--	10.035	10.165	0.008	0.065	2
Soil	**12**	4.849	6.032	--	0.584	9.114	36.380	4.265	2
Soil	**14**	5.804	2.876	5.916	2.620	8.766	8.269	1.438	4
Soil	**16**	7.635	2.313	8.089	4.519	9.844	5.352	1.157	4
Soil	**18**	5.517	2.215	5.786	3.054	7.441	4.906	1.107	4
Soil	**20**	6.033	2.871	5.850	3.502	8.932	8.243	1.436	4
Soil	**22**	5.458	2.816	5.443	2.749	8.195	7.931	1.408	4
Soil	**24**	6.341	2.741	6.318	3.842	8.888	7.514	1.371	4

Table A30: Ammonia (NH_4-N) from elm WC, elm SD, spruce WC, spruce SD and Morris WC, measured during 22-day pulse experiment. WC = woodchips, SD = sawdust

ID	#	Mean	Std Dev	Median	Min	Max	Variance	Std Error	n
Blank	**all**	1.525	0.703	1.729	0.294	2.766	0.495	0.166	18
Elm WC	**1**	5.339	1.568	5.287	3.612	7.169	2.459	0.784	4
Elm WC	**4**	20.674	3.159	20.527	17.221	24.419	9.980	1.580	4
Elm WC	**6**	15.458	3.533	15.060	12.445	19.266	12.479	1.766	4
Elm WC	**8**	17.431	2.936	17.496	13.772	20.959	8.620	1.468	4
Elm WC	**10**	16.382	4.772	16.825	10.457	21.422	22.768	2.386	4
Elm WC	**12**	14.372	--	--	--	--	--	--	1
Elm WC	**14**	11.255	4.124	11.609	5.894	15.909	17.010	2.062	4
Elm WC	**16**	9.935	4.382	9.460	5.645	15.174	19.203	2.191	4
Elm WC	**18**	8.895	2.864	8.954	5.698	11.975	8.205	1.432	4
Elm WC	**20**	5.953	2.598	5.681	3.211	9.240	6.751	1.299	4
Elm WC	**22**	4.995	1.981	4.599	3.242	7.145	3.926	1.144	3
Elm WC	**24**	2.537	0.310	2.494	2.272	2.887	0.096	0.155	4
Elm SD	**1**	13.984	1.393	14.226	12.167	15.316	1.941	0.697	4
Elm SD	**4**	61.676	12.631	66.579	47.328	71.120	159.547	7.293	3
Elm SD	**6**	56.034	9.766	57.121	43.826	66.069	95.368	4.883	4
Elm SD	**8**	44.774	16.796	48.777	21.302	60.241	282.111	8.398	4
Elm SD	**10**	31.618	6.210	33.052	23.731	36.636	38.564	3.105	4
Elm SD	**12**	45.859	16.248	45.207	26.890	69.802	263.993	6.633	6
Elm SD	**14**	17.056	3.144	16.982	13.957	20.302	9.887	1.572	4
Elm SD	**16**	5.983	1.895	6.253	3.803	7.623	3.589	0.947	4
Elm SD	**18**	5.397	3.234	5.548	1.575	8.915	10.460	1.617	4
Elm SD	**20**	8.054	1.507	8.317	6.433	9.412	2.270	0.870	3
Elm SD	**22**	3.280	2.843	4.809	0.000	5.032	8.083	1.641	3
Elm SD	**24**	2.528	1.378	3.171	0.946	3.467	1.899	0.796	3
Spruce WC	**1**	0.858	0.200	0.806	0.688	1.133	0.040	0.100	4
Spruce WC	**4**	0.463	0.213	0.405	0.277	0.765	0.045	0.106	4
Spruce WC	**6**	0.736	0.227	0.720	0.536	0.968	0.052	0.113	4
Spruce WC	**8**	0.654	0.147	0.690	0.452	0.785	0.022	0.074	4
Spruce WC	**10**	1.089	0.124	1.095	0.932	1.234	0.015	0.062	4
Spruce WC	**12**	0.539	0.143	0.497	0.416	0.746	0.021	0.072	4
Spruce WC	**14**	1.297	0.268	1.307	1.017	1.558	0.072	0.134	4
Spruce WC	**16**	0.605	0.131	0.624	0.434	0.736	0.017	0.065	4
Spruce WC	**18**	1.064	0.415	0.910	0.770	1.665	0.173	0.208	4
Spruce WC	**20**	0.930	0.330	0.918	0.539	1.345	0.109	0.165	4
Spruce WC	**22**	1.331	0.378	1.380	0.882	1.683	0.143	0.189	4
Spruce WC	**24**	0.942	0.374	0.916	0.554	1.382	0.140	0.187	4
Spruce SD	**1**	0.917	0.150	--	0.811	1.023	0.022	0.106	2
Spruce SD	**4**	0.343	0.132	0.367	0.165	0.475	0.018	0.066	4
Spruce SD	**6**	0.134	0.074	0.169	0.023	0.176	0.006	0.037	4
Spruce SD	**8**	0.466	0.050	0.445	0.430	0.523	0.002	0.029	3
Spruce SD	**10**	0.206	0.002	--	0.204	0.207	0.000	0.002	2
Spruce SD	**12**	0.229	0.247	0.207	0.000	0.714	0.061	0.087	8
Spruce SD	**14**	0.028	0.024	0.029	0.000	0.056	0.001	0.012	4
Spruce SD	**16**	0.278	0.425	0.102	0.000	0.909	0.181	0.213	4
Spruce SD	**18**	0.035	0.071	0.000	0.000	0.141	0.005	0.035	4
Spruce SD	**20**	0.761	0.143	0.816	0.551	0.859	0.020	0.071	4
Spruce SD	**22**	0.002	0.003	0.000	0.000	0.006	0.000	0.002	4
Spruce SD	**24**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4
Morris	**1**	1.595	0.650	1.544	0.856	2.434	0.423	0.325	4
Morris	**4**	6.293	2.550	6.125	3.365	9.559	6.504	1.275	4
Morris	**6**	2.923	0.666	3.008	2.135	3.543	0.444	0.333	4
Morris	**8**	2.560	0.997	2.164	1.898	4.015	0.994	0.498	4
Morris	**10**	3.100	0.188	3.023	2.973	3.379	0.035	0.094	4
Morris	**12**	1.230	0.558	1.311	0.477	1.823	0.312	0.279	4
Morris	**14**	0.807	0.475	0.885	0.161	1.298	0.225	0.237	4
Morris	**16**	0.492	0.253	0.604	0.203	0.670	0.064	0.146	3
Morris	**18**	1.022	0.418	1.001	0.545	1.541	0.175	0.209	4
Morris	**20**	0.644	0.347	0.619	0.267	1.071	0.120	0.173	4
Morris	**22**	0.254	0.366	0.120	0.000	0.777	0.134	0.183	4
Morris	**24**	0.708	0.183	0.629	0.578	0.918	0.034	0.106	3

Table A31: NH_4-N from corn cobs (CC), corn stover (CS), flax straw (FS), compost and soil, measured during 22-day pulse experiment

ID	#	Mean	Std Dev	Median	Min	Max	Variance	Std Error	n
Blank	**all**	1.525	0.703	1.729	0.294	2.766	0.495	0.166	18
CC	**1**	1.544	0.506	1.495	0.986	2.200	0.256	0.253	4
CC	**4**	0.622	0.185	--	0.491	0.753	0.034	0.131	2
CC	**6**	1.658	0.383	1.803	1.098	1.928	0.146	0.191	4
CC	**8**	0.897	0.479	0.832	0.396	1.527	0.229	0.239	4
CC	**10**	0.312	0.245	0.341	0.000	0.565	0.060	0.122	4
CC	**12**	0.211	0.071	0.242	0.107	0.255	0.005	0.035	4
CC	**14**	0.532	0.139	0.568	0.344	0.649	0.019	0.069	4
CC	**16**	0.530	0.123	0.507	0.409	0.696	0.015	0.062	4
CC	**18**	0.498	0.134	0.498	0.357	0.640	0.018	0.067	4
CC	**20**	0.234	0.130	0.235	0.063	0.435	0.017	0.046	8
CC	**22**	0.422	0.234	0.505	0.077	0.601	0.055	0.117	4
CC	**24**	0.031	0.039	0.023	0.000	0.079	0.001	0.019	4
CS	**1**	2.149	0.815	1.875	1.526	3.318	0.665	0.408	4
CS	**4**	1.003	0.581	0.925	0.405	1.756	0.337	0.290	4
CS	**6**	1.644	0.325	1.594	1.334	2.052	0.106	0.163	4
CS	**8**	1.595	0.353	1.619	1.201	1.939	0.125	0.177	4
CS	**10**	1.526	0.295	1.533	1.168	1.871	0.087	0.148	4
CS	**12**	0.919	0.436	0.885	0.457	1.449	0.190	0.218	4
CS	**14**	0.591	0.613	0.305	0.246	1.507	0.376	0.307	4
CS	**16**	1.003	0.992	0.754	0.139	2.367	0.984	0.496	4
CS	**18**	0.589	0.522	0.433	0.162	1.171	0.273	0.301	3
CS	**22**	0.483	0.600	0.238	0.095	1.362	0.360	0.300	4
CS	**24**	0.764	0.103	--	0.691	0.837	0.011	0.073	2
FS	**1**	0.229	0.089	0.199	0.165	0.355	0.008	0.045	4
FS	**4**	3.663	1.105	3.879	2.139	4.755	1.222	0.553	4
FS	**6**	2.817	0.839	2.621	2.082	3.946	0.704	0.420	4
FS	**8**	2.339	0.584	2.081	1.928	3.008	0.342	0.337	3
FS	**10**	2.318	1.581	2.445	0.419	3.961	2.499	0.790	4
FS	**12**	1.922	0.751	2.075	0.893	2.644	0.564	0.376	4
FS	**14**	2.871	0.947	2.623	2.051	4.186	0.897	0.474	4
FS	**16**	2.477	0.968	2.172	1.692	3.874	0.937	0.484	4
FS	**18**	1.767	1.018	1.445	0.943	3.234	1.036	0.509	4
FS	**20**	5.433	--	--	--	--	--	--	1
FS	**22**	3.070	2.162	2.635	1.206	5.803	4.674	1.081	4
FS	**24**	2.984	1.246	2.582	1.983	4.788	1.552	0.623	4
Comp	**1**	4.859	1.976	5.290	2.300	6.554	3.903	0.988	4
Comp	**4**	40.251	3.204	40.983	35.747	43.293	10.266	1.602	4
Comp	**6**	18.761	5.045	19.748	11.798	23.750	25.449	2.522	4
Comp	**8**	4.497	1.659	4.554	2.810	6.126	2.751	0.958	3
Comp	**10**	2.091	1.441	1.582	0.974	3.717	2.075	0.832	3
Comp	**12**	1.416	0.509	1.410	0.809	2.033	0.259	0.254	4
Comp	**14**	1.969	1.027	1.705	1.034	3.432	1.054	0.513	4
Comp	**16**	2.022	2.012	1.236	0.670	4.946	4.047	1.006	4
Comp	**18**	2.162	1.831	--	0.867	3.456	3.351	1.295	2
Comp	**20**	1.509	1.108	0.890	0.849	2.789	1.229	0.640	3
Comp	**22**	1.408	1.112	0.942	0.685	3.063	1.236	0.556	4
Comp	**24**	0.785	0.836	0.468	0.205	1.998	0.698	0.418	4
Soil	**1**	5.795	0.509	--	5.435	6.155	0.259	0.360	2
Soil	**4**	7.597	0.492	7.489	7.027	8.382	0.242	0.220	5
Soil	**6**	9.675	0.501	9.542	9.250	10.367	0.251	0.250	4
Soil	**8**	10.191	0.890	10.395	8.963	11.010	0.792	0.445	4
Soil	**10**	9.944	0.129	--	9.852	10.035	0.017	0.092	2
Soil	**12**	4.414	5.839	--	0.285	8.543	34.097	4.129	2
Soil	**14**	5.799	2.884	5.916	2.598	8.766	8.316	1.442	4
Soil	**16**	6.797	3.733	7.937	1.469	9.844	13.937	1.867	4
Soil	**18**	5.165	2.234	5.419	2.645	7.175	4.993	1.117	4
Soil	**20**	5.730	3.236	5.714	2.558	8.932	10.469	1.618	4
Soil	**22**	5.348	2.899	5.286	2.626	8.195	8.405	1.450	4
Soil	**24**	5.671	3.167	5.841	2.430	8.572	10.030	1.583	4

Table A32: Nitrate (NO3-N) from elm WC, elm SD, spruce WC, spruce SD and Morris WC, measured during 22-day pulse experiment. WC = woodchips, SD = sawdust

ID	#	Mean	Std Dev	Median	Min	Max	Variance	Std Error	n
Blank	**all**	0.108	0.163	0.045	0.000	0.636	0.026	0.038	18
Elm WC	**1**	1.979	0.161	2.020	1.751	2.125	0.026	0.081	4
Elm WC	**4**	0.035	0.056	0.011	0.000	0.118	0.003	0.028	4
Elm WC	**6**	0.037	0.043	0.034	0.000	0.081	0.002	0.022	4
Elm WC	**8**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4
Elm WC	**10**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4
Elm WC	**12**	0.369	--	--	--	--	--	--	1
Elm WC	**14**	0.933	0.105	0.945	0.795	1.047	0.011	0.052	4
Elm WC	**16**	0.605	0.056	0.587	0.558	0.686	0.003	0.028	4
Elm WC	**18**	0.060	0.077	0.039	0.000	0.161	0.006	0.038	4
Elm WC	**20**	0.454	0.134	0.454	0.301	0.608	0.018	0.067	4
Elm WC	**22**	0.052	0.022	0.044	0.035	0.077	0.000	0.013	3
Elm WC	**24**	0.561	0.079	0.562	0.477	0.642	0.006	0.039	4
Elm SD	**1**	2.684	0.378	2.615	2.319	3.188	0.143	0.189	4
Elm SD	**4**	0.172	0.149	0.255	0.000	0.260	0.022	0.086	3
Elm SD	**6**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4
Elm SD	**8**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4
Elm SD	**10**	0.070	0.140	0.000	0.000	0.280	0.020	0.070	4
Elm SD	**12**	0.930	0.802	1.032	0.000	1.937	0.644	0.328	6
Elm SD	**14**	1.513	0.325	1.541	1.136	1.833	0.105	0.162	4
Elm SD	**16**	0.465	0.116	0.477	0.314	0.594	0.013	0.058	4
Elm SD	**18**	0.179	0.066	0.184	0.104	0.243	0.004	0.033	4
Elm SD	**20**	0.515	0.208	0.566	0.287	0.693	0.043	0.120	3
Elm SD	**22**	0.157	0.076	0.179	0.072	0.220	0.006	0.044	3
Elm SD	**24**	0.095	0.154	0.013	0.000	0.273	0.024	0.089	3
Spruce WC	**1**	0.139	0.083	0.107	0.079	0.262	0.007	0.042	4
Spruce WC	**4**	0.090	0.155	0.019	0.000	0.321	0.024	0.077	4
Spruce WC	**6**	0.042	0.038	0.027	0.016	0.098	0.001	0.019	4
Spruce WC	**8**	0.053	0.018	0.051	0.033	0.076	0.000	0.009	4
Spruce WC	**10**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4
Spruce WC	**12**	0.118	0.030	0.128	0.077	0.141	0.001	0.015	4
Spruce WC	**14**	0.002	0.004	0.000	0.000	0.008	0.000	0.002	4
Spruce WC	**16**	0.100	0.014	0.097	0.088	0.118	0.000	0.007	4
Spruce WC	**18**	0.118	0.039	0.101	0.095	0.176	0.001	0.019	4
Spruce WC	**20**	0.246	0.082	0.214	0.189	0.367	0.007	0.041	4
Spruce WC	**22**	0.017	0.022	0.012	0.000	0.045	0.000	0.011	4
Spruce WC	**24**	0.349	0.163	0.274	0.254	0.592	0.027	0.081	4
Spruce SD	**1**	0.708	0.105	--	0.634	0.782	0.011	0.074	2
Spruce SD	**4**	0.023	0.029	0.015	0.000	0.060	0.001	0.014	4
Spruce SD	**6**	0.059	0.009	0.057	0.051	0.070	0.000	0.004	4
Spruce SD	**8**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3
Spruce SD	**10**	0.000	0.000	--	0.000	0.000	0.000	0.000	2
Spruce SD	**12**	0.131	0.080	0.108	0.067	0.304	0.006	0.028	8
Spruce SD	**14**	0.004	0.008	0.000	0.000	0.016	0.000	0.004	4
Spruce SD	**16**	0.233	0.086	0.230	0.131	0.342	0.007	0.043	4
Spruce SD	**18**	0.146	0.095	0.105	0.085	0.288	0.009	0.048	4
Spruce SD	**20**	0.284	0.168	0.209	0.181	0.535	0.028	0.084	4
Spruce SD	**22**	0.006	0.012	0.000	0.000	0.023	0.000	0.006	4
Spruce SD	**24**	0.114	0.047	0.103	0.072	0.179	0.002	0.024	4
Morris	**1**	0.628	0.414	0.535	0.282	1.159	0.171	0.207	4
Morris	**4**	0.121	0.025	0.128	0.085	0.142	0.001	0.013	4
Morris	**6**	0.007	0.014	0.000	0.000	0.028	0.000	0.007	4
Morris	**8**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4
Morris	**10**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4
Morris	**12**	0.139	0.023	0.135	0.116	0.171	0.001	0.012	4
Morris	**14**	0.316	0.022	0.320	0.288	0.335	0.000	0.011	4
Morris	**16**	0.008	0.008	0.009	0.000	0.016	0.000	0.005	3
Morris	**18**	0.044	0.038	0.043	0.000	0.091	0.001	0.019	4
Morris	**20**	0.010	0.011	0.010	0.000	0.021	0.000	0.006	4
Morris	**22**	1.451	0.745	1.695	0.383	2.031	0.554	0.372	4
Morris	**24**	0.216	0.031	0.230	0.181	0.237	0.001	0.018	3

Table A33: NO_3-N from corn cobs (CC), corn stover (CS), flax straw (FS), compost and soil, measured during 22-day pulse experiment

ID	#	Mean	Std Dev	Median	Min	Max	Variance	Std Error	n
Blank	**all**	0.108	0.163	0.045	0.000	0.636	0.026	0.038	18
CC	**1**	1.332	0.304	1.391	0.932	1.614	0.092	0.152	4
CC	**4**	0.107	0.010	--	0.100	0.114	0.000	0.007	2
CC	**6**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4
CC	**8**	0.004	0.004	0.003	0.000	0.009	0.000	0.002	4
CC	**10**	0.003	0.007	0.000	0.000	0.013	0.000	0.003	4
CC	**12**	0.320	0.345	0.208	0.041	0.824	0.119	0.173	4
CC	**14**	0.043	0.075	0.008	0.000	0.155	0.006	0.038	4
CC	**16**	0.009	0.014	0.004	0.000	0.030	0.000	0.007	4
CC	**18**	0.077	0.029	0.080	0.041	0.109	0.001	0.014	4
CC	**20**	0.022	0.024	0.013	0.000	0.063	0.001	0.008	8
CC	**22**	0.028	0.033	0.024	0.000	0.065	0.001	0.017	4
CC	**24**	0.160	0.065	0.161	0.096	0.222	0.004	0.033	4
CS	**1**	3.129	1.345	3.279	1.498	4.462	1.810	0.673	4
CS	**4**	0.071	0.063	0.066	0.000	0.153	0.004	0.032	4
CS	**6**	0.028	0.022	0.033	0.000	0.048	0.000	0.011	4
CS	**8**	0.012	0.024	0.000	0.000	0.047	0.001	0.012	4
CS	**10**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4
CS	**12**	0.262	0.024	0.256	0.240	0.296	0.001	0.012	4
CS	**14**	0.539	0.347	0.393	0.318	1.053	0.121	0.174	4
CS	**16**	0.016	0.019	0.012	0.000	0.038	0.000	0.009	4
CS	**18**	0.165	0.034	0.160	0.134	0.202	0.001	0.020	3
CS	**22**	0.037	0.015	0.032	0.026	0.060	0.000	0.008	4
CS	**24**	0.131	0.097	--	0.062	0.199	0.009	0.069	2
FS	**1**	0.398	0.225	0.351	0.187	0.705	0.051	0.113	4
FS	**4**	0.022	0.029	0.012	0.000	0.062	0.001	0.015	4
FS	**6**	0.094	0.058	0.076	0.050	0.173	0.003	0.029	4
FS	**8**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3
FS	**10**	0.010	0.020	0.000	0.000	0.039	0.000	0.010	4
FS	**12**	0.390	0.079	0.383	0.311	0.482	0.006	0.039	4
FS	**14**	0.335	0.091	0.304	0.269	0.465	0.008	0.046	4
FS	**16**	0.016	0.032	0.000	0.000	0.063	0.001	0.016	4
FS	**18**	0.376	0.473	0.162	0.096	1.083	0.223	0.236	4
FS	**20**	0.000	--	--	--	--	--	--	1
FS	**22**	0.094	0.083	0.106	0.000	0.166	0.007	0.042	4
FS	**24**	0.220	0.059	0.217	0.154	0.291	0.003	0.029	4
Comp	**1**	71.371	11.597	72.152	59.144	82.037	134.487	5.798	4
Comp	**4**	1.123	0.287	1.109	0.800	1.475	0.082	0.143	4
Comp	**6**	0.194	0.388	0.000	0.000	0.776	0.151	0.194	4
Comp	**8**	0.001	0.001	0.000	0.000	0.002	0.000	0.001	3
Comp	**10**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3
Comp	**12**	0.159	0.012	0.161	0.144	0.170	0.000	0.006	4
Comp	**14**	0.038	0.031	0.038	0.000	0.076	0.001	0.016	4
Comp	**16**	0.076	0.069	0.078	0.000	0.150	0.005	0.035	4
Comp	**18**	0.189	0.107	--	0.113	0.265	0.012	0.076	2
Comp	**20**	0.379	0.105	0.374	0.277	0.487	0.011	0.061	3
Comp	**22**	0.155	0.057	0.165	0.078	0.211	0.003	0.029	4
Comp	**24**	0.294	0.024	0.299	0.263	0.316	0.001	0.012	4
Soil	**1**	36.629	51.801	--	0.000	73.257	2683.294	36.629	2
Soil	**4**	0.063	0.092	0.000	0.000	0.203	0.008	0.041	5
Soil	**6**	0.145	0.289	0.000	0.000	0.578	0.084	0.145	4
Soil	**8**	0.057	0.114	0.000	0.000	0.228	0.013	0.057	4
Soil	**10**	0.157	0.221	--	0.000	0.313	0.049	0.157	2
Soil	**12**	0.435	0.192	--	0.299	0.571	0.037	0.136	2
Soil	**14**	0.006	0.011	0.000	0.000	0.022	0.000	0.006	4
Soil	**16**	0.839	1.481	0.153	0.000	3.050	2.194	0.741	4
Soil	**18**	0.352	0.077	0.360	0.266	0.424	0.006	0.038	4
Soil	**20**	0.304	0.446	0.136	0.000	0.944	0.199	0.223	4
Soil	**22**	0.110	0.102	0.098	0.000	0.242	0.010	0.051	4
Soil	**24**	0.670	0.514	0.477	0.316	1.412	0.264	0.257	4

Table A34: Soluble P for elm WC, elm SD, spruce WC, spruce SD and Morris WC, measured during 22-day pulse experiment. WC = woodchips, SD = sawdust

ID	#	Mean	Std Dev	Median	Min	Max	Variance	Std Error	CV	n
Blank	**all**	6.64	1.347	6.42	4.27	10.33	1.814	0.287	20.296	22
Elm WC	**4**	9.22	1.028	9.05	8.16	10.62	1.057	0.514	11.154	4
Elm WC	**6**	8.96	0.819	8.81	8.23	10.00	0.671	0.409	9.138	4
Elm WC	**8**	8.50	0.580	8.43	7.93	9.23	0.336	0.290	6.822	4
Elm WC	**10**	5.50	0.342	5.54	5.07	5.84	0.117	0.171	6.224	4
Elm WC	**12**	4.98	0.403	4.92	4.61	5.46	0.162	0.201	8.091	4
Elm WC	**14**	4.94	0.585	4.88	4.37	5.61	0.342	0.292	11.850	4
Elm WC	**16**	3.46	0.308	3.56	3.02	3.71	0.095	0.154	8.914	4
Elm WC	**18**	5.44	0.413	5.40	5.05	5.90	0.171	0.207	7.603	4
Elm WC	**20**	4.64	0.447	4.62	4.11	5.20	0.199	0.223	9.631	4
Elm WC	**22**	5.13	0.356	5.20	4.74	5.44	0.127	0.205	6.939	3
Elm WC	**24**	3.75	0.343	3.73	3.42	4.12	0.117	0.171	9.140	4
Elm SD	**4**	14.57	1.840	15.32	11.85	15.78	3.386	0.920	12.634	4
Elm SD	**6**	11.72	2.136	11.81	9.54	13.70	4.561	1.068	18.229	4
Elm SD	**8**	9.10	0.868	8.93	8.31	10.23	0.753	0.434	9.538	4
Elm SD	**10**	5.61	0.610	5.58	4.99	6.31	0.372	0.305	10.862	4
Elm SD	**12**	7.76	1.641	7.16	6.62	10.10	2.693	0.820	21.147	4
Elm SD	**14**	6.74	0.708	6.47	6.23	7.78	0.501	0.354	10.513	4
Elm SD	**16**	4.66	0.536	4.47	4.27	5.44	0.288	0.268	11.510	4
Elm SD	**18**	4.96	0.574	5.09	4.20	5.44	0.329	0.287	11.579	4
Elm SD	**20**	3.88	0.796	3.76	3.10	4.89	0.634	0.398	20.536	4
Elm SD	**22**	4.06	0.611	4.12	3.42	4.58	0.373	0.305	15.049	4
Elm SD	**24**	3.91	0.607	4.08	3.03	4.43	0.369	0.304	15.547	4
Spruce WC	**4**	5.54	0.785	5.65	4.62	6.23	0.616	0.392	14.168	4
Spruce WC	**6**	9.02	0.308	8.93	8.77	9.46	0.095	0.154	3.419	4
Spruce WC	**8**	9.87	0.290	9.85	9.54	10.23	0.084	0.145	2.938	4
Spruce WC	**10**	8.93	0.994	8.98	7.85	9.89	0.988	0.497	11.137	4
Spruce WC	**12**	8.27	0.250	8.29	8.01	8.48	0.063	0.125	3.030	4
Spruce WC	**14**	8.94	0.541	8.83	8.48	9.64	0.293	0.271	6.054	4
Spruce WC	**16**	6.85	0.592	6.85	6.23	7.46	0.351	0.296	8.655	4
Spruce WC	**18**	9.12	0.552	8.89	8.77	9.93	0.305	0.276	6.059	4
Spruce WC	**20**	7.81	0.321	7.85	7.46	8.08	0.103	0.160	4.106	4
Spruce WC	**22**	8.15	0.127	8.15	7.99	8.30	0.016	0.063	1.554	4
Spruce WC	**24**	6.60	0.273	6.52	6.37	6.98	0.074	0.136	4.131	4
Spruce SD	**4**	4.12	0.098	4.12	4.00	4.23	0.010	0.049	2.385	4
Spruce SD	**6**	7.70	0.141	7.70	7.54	7.85	0.020	0.070	1.827	4
Spruce SD	**8**	9.06	0.512	8.93	8.62	9.62	0.262	0.296	5.652	3
Spruce SD	**10**	9.84	0.092	9.79	9.79	9.95	0.009	0.053	0.938	3
Spruce SD	**12**	10.88	1.499	11.15	8.86	12.35	2.248	0.750	13.786	4
Spruce SD	**14**	9.77	0.585	9.99	8.94	10.18	0.342	0.292	5.983	4
Spruce SD	**16**	9.77	0.555	9.87	9.01	10.33	0.308	0.277	5.680	4
Spruce SD	**18**	9.99	0.359	9.93	9.62	10.47	0.129	0.180	3.597	4
Spruce SD	**20**	9.05	0.353	9.05	8.62	9.48	0.124	0.176	3.896	4
Spruce SD	**22**	8.83	0.634	8.77	8.15	9.62	0.402	0.317	7.182	4
Spruce SD	**24**	7.57	0.428	7.61	7.06	7.99	0.183	0.214	5.656	4
Morris	**4**	9.60	1.647	9.22	8.09	11.88	2.712	0.823	17.155	4
Morris	**6**	7.20	0.859	7.12	6.23	8.32	0.737	0.429	11.928	4
Morris	**8**	6.12	0.761	6.12	5.23	7.01	0.578	0.380	12.433	4
Morris	**10**	6.70	1.749	6.43	4.99	8.94	3.058	0.874	26.119	4
Morris	**12**	5.60	0.929	5.77	4.45	6.39	0.863	0.464	16.599	4
Morris	**14**	4.84	0.454	4.92	4.22	5.30	0.206	0.227	9.386	4
Morris	**16**	6.20	0.775	6.61	5.31	6.69	0.600	0.447	12.488	3
Morris	**18**	5.46	0.833	5.67	4.27	6.21	0.693	0.416	15.262	4
Morris	**20**	5.07	1.096	5.09	3.88	6.21	1.200	0.548	21.629	4
Morris	**22**	6.13	0.711	6.06	5.36	7.06	0.506	0.356	11.596	4
Morris	**24**	6.93	0.817	7.06	6.06	7.68	0.668	0.472	11.789	3

Table A35: Soluble P for corn cobs (CC), corn stover (CS), flax straw (FS), compost and soil, measured during 22-day pulse experiment

ID	#	Mean	Std Dev	Median	Min	Max	Variance	Std Error	n
Blank	**all**	6.64	1.347	6.42	4.27	10.33	1.814	0.287	22
CC	**4**	5.87	1.425	5.85	4.46	7.31	2.031	0.823	3
CC	**6**	7.31	0.467	7.39	6.69	7.77	0.218	0.234	4
CC	**8**	6.56	0.666	6.50	5.92	7.31	0.444	0.333	4
CC	**10**	5.94	0.291	5.92	5.69	6.23	0.084	0.145	4
CC	**12**	5.30	0.669	5.27	4.53	6.15	0.448	0.335	4
CC	**14**	5.96	0.432	5.89	5.53	6.54	0.186	0.216	4
CC	**16**	4.49	0.423	4.40	4.09	5.08	0.179	0.212	4
CC	**18**	6.29	0.639	6.21	5.59	7.14	0.408	0.320	4
CC	**20**	4.66	0.549	4.74	3.96	5.20	0.301	0.274	4
CC	**22**	4.82	0.912	4.90	3.73	5.75	0.832	0.456	4
CC	**24**	3.71	0.743	3.69	3.03	4.43	0.551	0.371	4
CS	**4**	2.81	0.791	2.52	2.25	3.96	0.625	0.395	4
CS	**6**	7.40	1.237	7.73	5.75	8.39	1.531	0.619	4
CS	**8**	7.19	1.188	7.46	5.51	8.31	1.412	0.594	4
CS	**10**	6.90	1.572	7.38	4.62	8.22	2.471	0.786	4
CS	**12**	5.45	1.585	5.84	3.20	6.91	2.513	0.793	4
CS	**14**	5.99	1.267	6.41	4.13	6.99	1.605	0.633	4
CS	**16**	7.06	0.421	7.22	6.44	7.37	0.177	0.210	4
CS	**18**	5.81	0.196	5.83	5.60	5.99	0.038	0.113	3
CS	**20**	5.85	0.426	5.93	5.39	6.23	0.181	0.246	3
CS	**22**	7.17	0.609	7.15	6.46	7.92	0.371	0.304	4
CS	**24**	8.57	0.375	--	8.30	8.83	0.140	0.265	2
FS	**4**	3.03	0.364	3.03	2.71	3.34	0.132	0.182	4
FS	**6**	9.03	0.203	8.97	8.86	9.32	0.041	0.101	4
FS	**8**	7.95	0.276	7.92	7.69	8.24	0.076	0.159	3
FS	**10**	9.12	1.021	8.88	8.22	10.52	1.043	0.511	4
FS	**12**	7.38	0.302	7.41	6.99	7.69	0.091	0.151	4
FS	**14**	8.44	0.537	8.46	7.84	9.00	0.289	0.269	4
FS	**16**	9.06	0.653	9.04	8.46	9.70	0.427	0.327	4
FS	**18**	7.51	0.756	7.27	6.91	8.61	0.572	0.378	4
FS	**20**	9.01	0.485	9.29	8.45	9.29	0.235	0.280	3
FS	**22**	10.08	1.116	9.60	9.29	11.36	1.246	0.645	3
FS	**24**	9.75	0.933	9.72	8.68	10.90	0.870	0.466	4
Comp	**4**	62.61	11.251	63.06	51.20	73.10	126.581	5.625	4
Comp	**6**	37.96	9.131	38.49	26.97	47.89	83.374	4.565	4
Comp	**8**	32.89	4.456	30.63	30.01	38.02	19.859	2.573	3
Comp	**10**	26.23	2.147	26.13	24.14	28.43	4.609	1.239	3
Comp	**12**	25.25	4.029	25.58	20.75	29.10	16.235	2.015	4
Comp	**14**	23.55	2.858	23.50	20.83	26.39	8.167	1.429	4
Comp	**16**	21.05	2.005	20.43	19.38	23.95	4.019	1.002	4
Comp	**18**	19.63	3.663	--	17.04	22.22	13.416	2.590	2
Comp	**20**	18.35	2.517	19.02	15.57	20.47	6.336	1.453	3
Comp	**22**	18.02	1.578	18.02	16.41	19.63	2.491	0.789	4
Comp	**24**	17.20	1.769	17.33	15.19	18.94	3.130	0.885	4
Soil	**4**	0.27	0.065	0.26	0.20	0.36	0.004	0.033	4
Soil	**6**	0.41	0.088	0.37	0.34	0.54	0.008	0.044	4
Soil	**8**	0.36	0.102	0.36	0.24	0.49	0.010	0.051	4
Soil	**10**	0.26	0.049	0.26	0.22	0.32	0.002	0.024	4
Soil	**12**	0.08	0.136	0.00	0.00	0.24	0.018	0.078	3
Soil	**14**	0.07	0.105	0.03	0.00	0.23	0.011	0.052	4
Soil	**16**	0.30	0.124	0.28	0.19	0.44	0.015	0.062	4
Soil	**18**	0.19	0.055	0.21	0.10	0.22	0.003	0.028	4
Soil	**20**	0.26	0.036	0.27	0.21	0.29	0.001	0.018	4
Soil	**22**	1.39	0.525	1.44	0.78	1.93	0.276	0.186	8
Soil	**24**	0.37	0.071	0.38	0.29	0.45	0.005	0.035	4

APPENDIX B – DATA BIOFILTER MORRIS

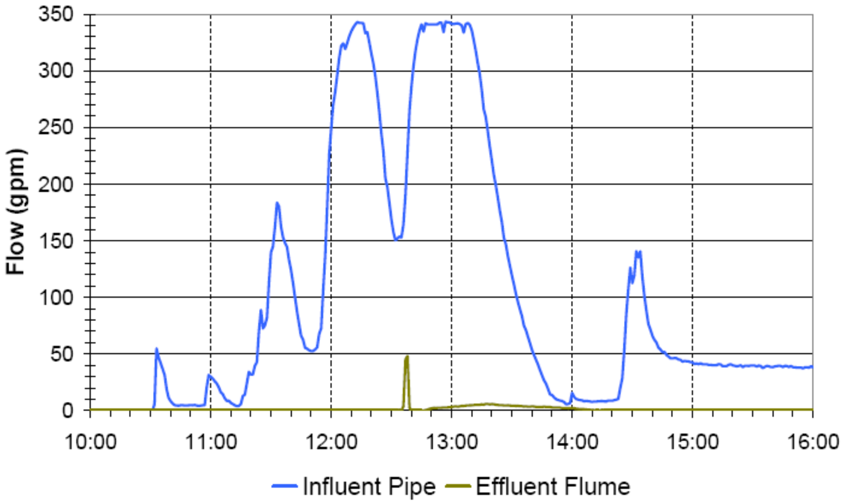


Figure B1: Flow (gallons per minute) during feedlot runoff simulation

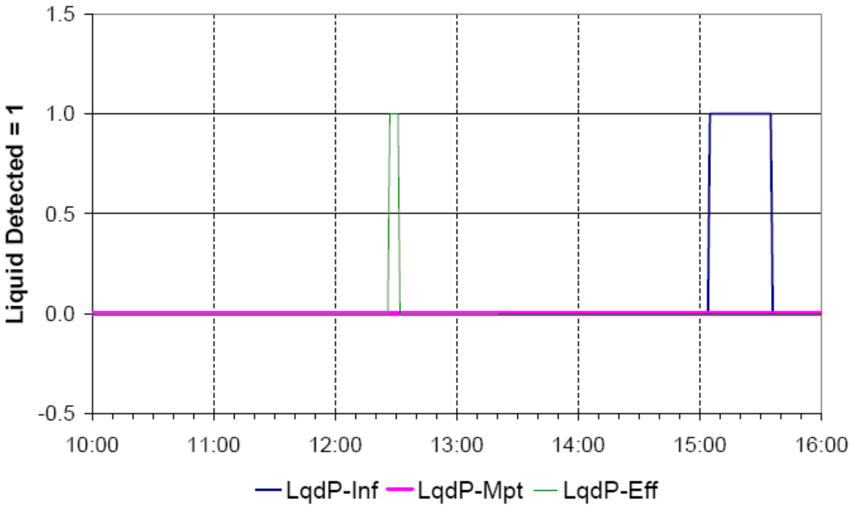


Figure B2: Presence of liquid during feedlot runoff simulation (LqdP = liquid present, Inf = influent, Mpt = midpoint, Eff = effluent)

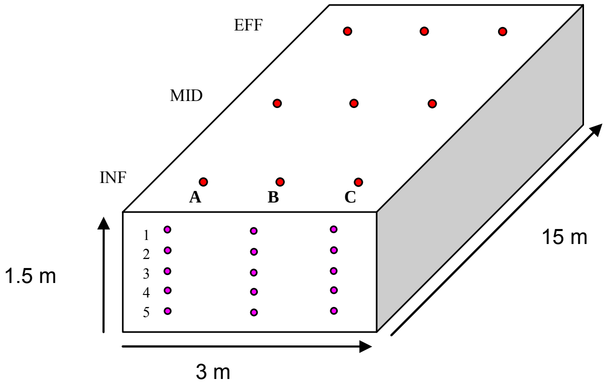


Figure B3: Sampling points for temperature profile

Table B1: Temperature profile of Biofilter upon decommissioning

ID	Temp (ºC)	ID	Temp (ºC)	ID	Temp (ºC)
Inf A1	25.3	Mid A1	24.2	Eff A1	n/a
Inf A2	25.4	Mid A2	25.2	Eff A2	25.9
Inf A3	26.1	Mid A3	26.0	Eff A3	27.3
Inf A4	26.5	Mid A4	23.8	Eff A4	n/a
Inf A5	26.6	Mid A5	23.8	Eff A5	n/a
Inf B1	22.9	Mid B1	24.5	Eff B1	24.0
Inf B2	22.5	Mid B2	24.3	Eff B2	23.5
Inf B3	22.4	Mid B3	23.4	Eff B3	23.5
Inf B4	21.6	Mid B4	22.6	Eff B4	23.6
Inf B5	21.6	Mid B5	21.6	Eff B5	23.6
Inf C1	23.6	Mid C1	26.9	Eff C1	24.1
Inf C2	25.1	Mid C2	27.7	Eff C2	24.7
Inf C3	25.5	Mid C3	27.9	Eff C3	26.2
Inf C4	25.7	Mid C4	27.5	Eff C4	26.7
Inf C5	25.9	Mid C5	24.6	Eff C5	25.8

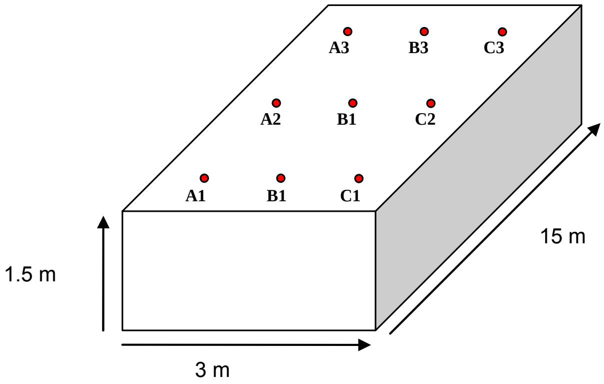


Figure B4: Sampling points for penetrometer reading

Table B2: Penetrometer reading at different depths (kPa). N/A = no resistance was measured

Depth (cm)	A1	B1	C1	A2	B2	C2	A3	B3	C3
2.54	137.90	34.47	68.95	68.95	68.95	0.00	137.90	137.90	34.47
5.08	103.42	34.47	137.90	137.90	0.00	0.00	489.53	206.84	0.00
7.62	241.32	34.47	420.58	68.95	137.90	0.00	103.42	137.90	0.00
10.16	1082.48	275.79	310.26	206.84	68.95	0.00	206.84	420.58	34.47
12.70	n/a	310.26	420.58	172.37	68.95	386.11	489.53	661.90	206.84
15.24	n/a	820.48	137.90	206.84	103.42	420.58	386.11	275.79	310.26
17.78	n/a	206.84	310.26	310.26	34.47	0.00	34.47	137.90	455.05
20.32	455.05	413.69	n/a	206.84	0.00	0.00	386.11	206.84	206.84
22.86	n/a	n/a	n/a	455.05	0.00	0.00	241.32	0.00	661.90
25.40	n/a	n/a	n/a	944.58	0.00	0.00	489.53	n/a	558.48
27.50	n/a	n/a	n/a	944.58	137.90	n/a	524.00	n/a	627.42
30.48	n/a	n/a	n/a	944.58	34.47	n/a	627.42	n/a	0.00

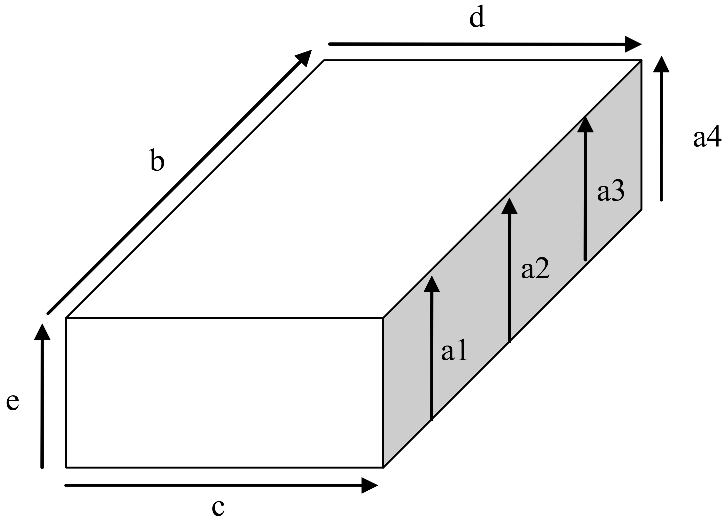


Figure B5: Measure point for biofilter dimension upon decommissioning

Table B3: Actual dimensions measured upon decommissioning

a1	1.35 m
a2	1.58 m
a3	1.80 m
a4	1.17 m
b	12.65 m
c	4.12 m
d	4.12 m
e	0.81 m

Data in Table B3 indicates that the biofilter showed preferential flow on the left side over the two years and the media on the side with preferential flow was more used by microorganisms.

Result 2 – Woodchip Biofilter - Field Results Summary

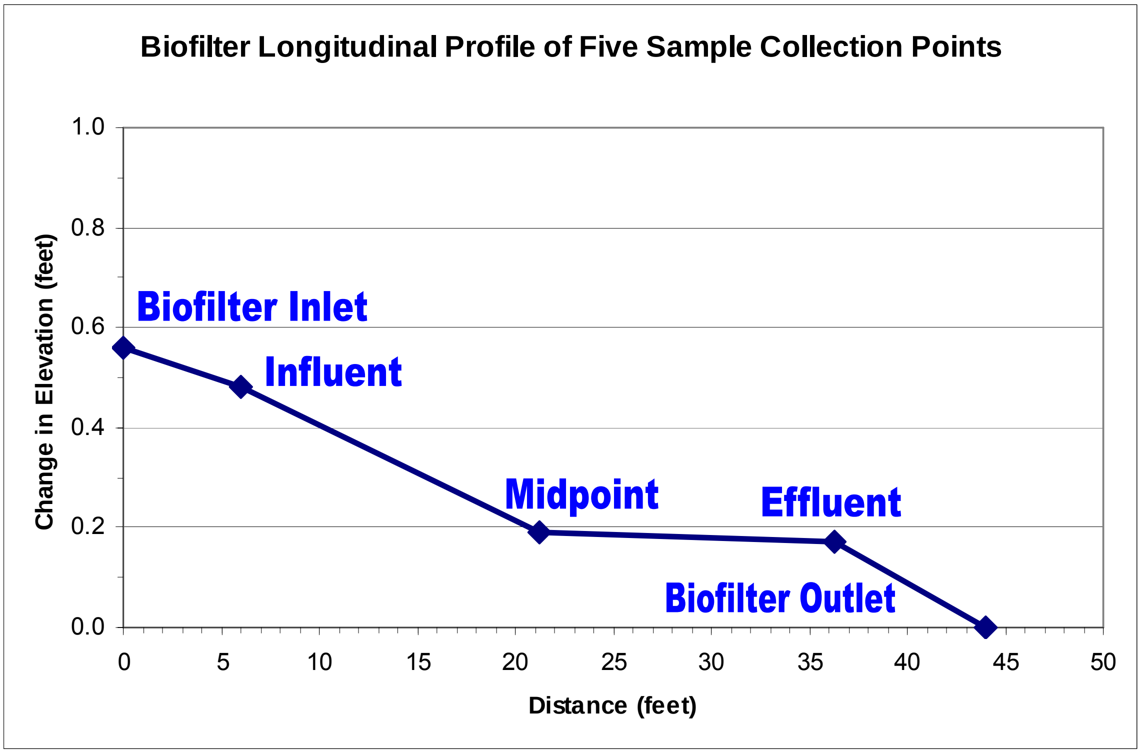
Phase 2 of this project involved the construction of a prototype woodchip biofilter at the University of Minnesota West-Central Research and Outreach Center (WCROC) in Morris, Minnesota. The biofilter was located downslope from a small feedlot (0.25-acre catchment area). The woodchips for the biofilter utilized locally-derived media obtained from storm-damaged trees. The woodchips were placed on a plastic (Tu-Tuff) liner that extended up sidewalls comprised of straw bales. At the base of the biofilter water samples were obtained from shallow wells constructed from ADS polyethylene drainage panels with a connecting 6-inch diameter riser pipe.

Precipitation/Runoff Threshold and Flow-Path Sequence

Unless the ground was frozen, at least 0.60 inches of rainfall was needed to generate sufficient runoff for feedlot runoff to accumulate in the (pre-biofilter) settling basin and discharge to the to the biofilter intake by means of a 4-inch diameter outlet pipe containing a 2-inch diameter restrictor plate. When the ground surface was frozen only one third of this amount (approximately 0.20 inches of rainfall) was needed for runoff to accumulate in the settling basin and flow into the biofilter's inlet pipe. Diurnal melting of the snow pack produced a sustained flow of approximately 5 gallons per minute (gpm). Water derived from either rainfall or melting snow and ice flowed across the feedlot surface, transported manure particulates and soluble

- Settling Basin (no samples collected)
- Biofilter Inlet (settling basin outflow; samples collected manually)
- Biofilter Influent (water samples collected automatically)
- Biofilter Midpoint (water samples collected automatically)
- Biofilter Effluent (water samples collected automatically)
- Biofilter Outlet (water samples collected manually)

Manually-collected biofilter samples were obtained from the outflows to the settling basin (biofilter inlet) or biofilter outflow (discharge). In the flow sequence these correspond to flow-path sequence positions 1 and 5. The three automatically collected biofilter samples were obtained from the influent, midpoint, and effluent and generally correspond to flow-path sequence positions 2, 3, and 4. In 2 of the 12 sample events, the midpoint samples were collected after the effluent samples and likely resulted from slight differences in the positioning of the water contact sensor. Automatically collected samples were pumped from the base of the biofilter to a refrigerated ISCO sampler containing six one-gallon polyethylene jars using three dedicated sampling lines and three separate controllers. A three-way valve assembly enabled two water samples to be collected from each water line. After sample collection the water lines were purged by the associated controller (peristaltic pump).



Collected water samples were analyzed for the following parameters:

- Nitrogen
  - Total Kjeldahl Nitrogen (TKN; organic nitrogen)
  - Ammonia
  - Nitrate
- Total Phosphorus
- 5-day Biological Oxygen Demand (BOD5)
- Chemical Oxygen Demand (COD)
- Chloride
- Bromide (effluent only)
- Total Dissolved Solids
- Total Suspended Solids
- *E. coli* (fecal coliform)

Water chemistry, temperature, and presence measurements were also recorded from within the biofilter using the following dedicated sensors located in the specified positions.

- pH – (three sensors - influent, midpoint, effluent)
- Oxidation-Reduction Potential (ORP; three sensors - influent, midpoint, effluent)
- Conductivity (three sensors - influent, midpoint, effluent)

- Temperature (three sensors - influent, midpoint, effluent)
- Water presence (three sensors - influent, midpoint, effluent that activated the controllers for sample collection)
- Bromide (one sensor - effluent only)

This water data was recorded by a Sensaphone SCADA 3000 remote monitoring system. Other collected information included flow and media temperature. However, this data generally was deemed to be inconsistent and generally unusable due to water accumulation (ponding) and unreliable temperature sensors (faulty thermisters).

Runoff events were limited by exceptionally dry conditions. A total of 12 runoff sample events were obtained in the course of the investigation. Because of the dry weather, a rain simulation event was conducted on August 29, 2006, by pumping 7,500 gallons of water onto the feedlot surface where it flowed to the earthen settling basin and into the biofilter. An additional potassium-bromide (KBr) tracer test was conducted in May 15 and 16, 2007, by pumping 750 gallons of water into the biofilter inlet and directly onto the liner (May 15) to obtain breakthrough conditions. The following day (May 16) and additional 250 gallons of a 1,400 mg/l KBr solution was pumped into the inlet pipe and directly onto the biofilter liner at an approximate constant rate of 5.6 gpm. Water samples were then collected from the influent, midpoint, effluent, and biofilter discharge points and the volume of discharge was then measured volumetrically at the outlet. Media samples were collected from the base of the biofilter prior to KBr solute release

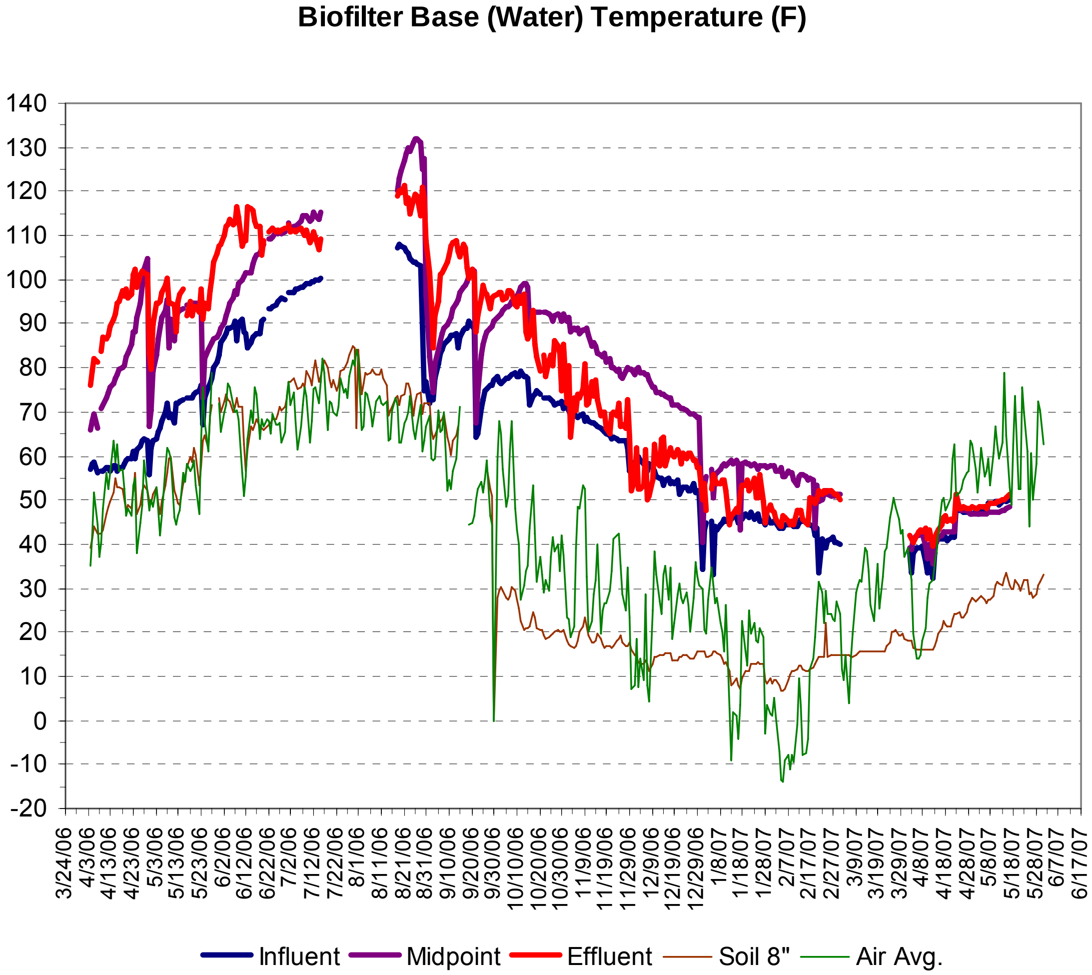
During the tracer test water elevations were measured at the front of the biofilter and at the influent, midpoint, and effluent locations in order to estimate the hydraulic gradient and hydraulic conductivity of the woodchip media.

Results

Non-weighted analytical results from the 12 biofilter runoff events are compiled and summarized in Table 1. Typically as water passed through the biofilter concentrations of ammonia, nitrate and TKN nitrogen decreased. As indicated in Table 1, TKN accounted for most of the nitrogen contained in the runoff and nitrate the least. Nitrogen concentrations tended to be higher during the winter months when there were reduced rates of volatilization and nitrification by microbes in the manure pack. BOD5 concentrations exhibited a similar seasonality during the winter months.

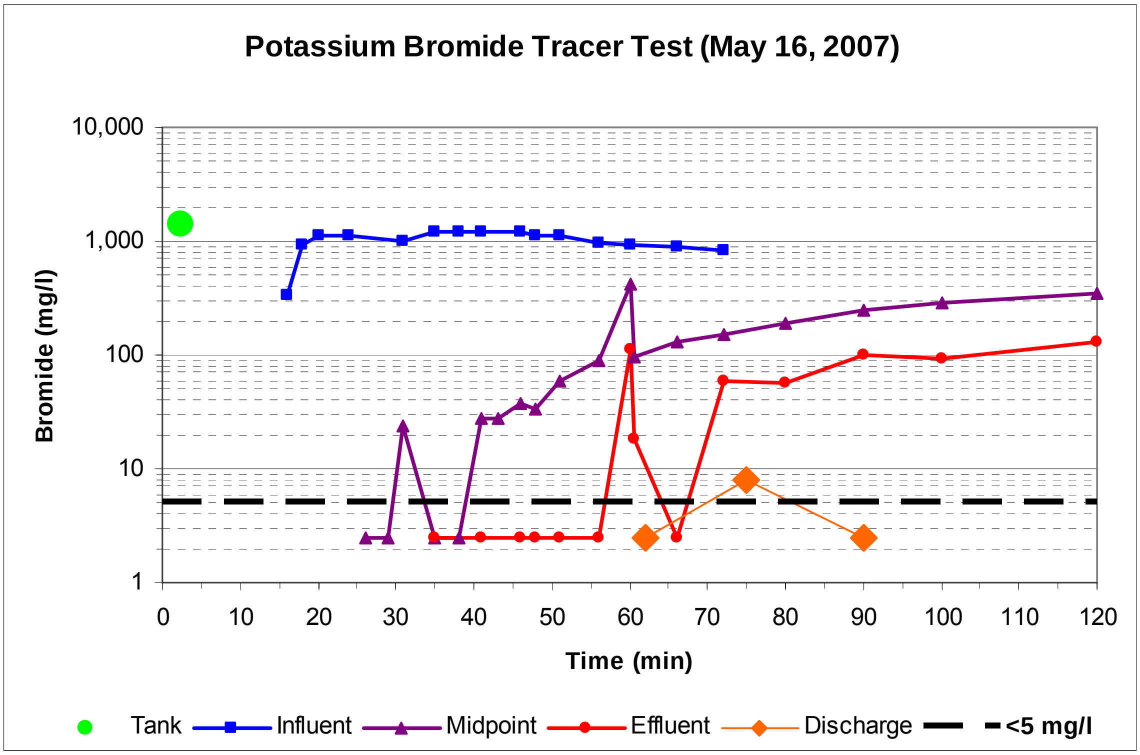
Total phosphorus exhibited decreasing concentration trends following a slight rise after biofilter construction. Total suspended solids typically decreased, while total dissolved solids and chloride concentrations generally increased. On a non-weighted basis, there was little change in *E. coli* concentrations. However, during the closely monitored August rain simulation test, the net discharge of E. coli from the biofilter was about 0.3 percent of the total feedlot runoff (or a 99.7 percent reduction after biofilter treatment) as the bulk of the water entering the biofilter was trapped in the pore space or absorbed by the woodchip media. Compared to nitrogen and BOD5, there was less seasonal variation of phosphorus content in the runoff entering the biofilter.

Field sensor results were collected by the telemetry system. For much of the operating period water within the biofilter was either stagnant or non-existent as pore waters were absorbed by the media. Basal (water) temperature served as an indirect indicator of biological activity relative to ambient air and soil (8-inch depth) temperatures as indicated in the following graph.



The warmest temperatures within the biofilter were encountered in August and September 2006 following the application of approximately 10,000 gallons of water to the top of the pile in early August. Through the remainder of 2006 and the first part of 2007, the woodchips dried out as moisture was driven out through both microbial respiration and temperature/humidity contrast between the woodchips and generally much drier air. This resulted in the cooling of the pile. However, the core of the biofilter was able to maintain temperatures above the biological activity 50 degree F threshold through the end of February 2007. Prior to conducting the tracer test on May 16, 2007, the woodchips were observed to be quite dry to nearly the base of the pile and much of the moisture encountered at the base was likely from the 750 gallons of water that was discharged onto the line the preceding day.

The KBr tracer test results are summarized in Table 2 and depicted in the following graph.



Following the pumping of 250 gallons of a potassium bromide solution (1,400 mg/l and bright green dot) from a tank directly to front of the biofilter. The water then arrived sequentially to the influent, midpoint, and effluent sample points, and barely trickled out of the end of the biofilter's discharge pipe. Bromide concentrations increased (spiked) at all locations, but tapered at the influent, while increasing at the midpoint and effluent sample ports. Significant dilution effects were encountered in the midpoint and effluent positions suggesting mixing and partial displacement of existing pore waters as the KBr solute passed through the woodchip media. The increased slope (higher hydraulic gradient) of the influent position allowed for increased pore-water drainage from water that was applied to the biofilter the preceding day. The total volume of water that was discharged from the biofilter was less than a gallon and this fluid likely represents displaced pore water rather than the KBr solute. Lower (negative) ORP values in the effluent position also suggest the presence of stagnant pore water and the localized development of anaerobic conditions within the biofilter.

Estimated non-steady state woodchip media hydraulic conductivity values for the woodchip media at the base of the biofilter were 0.9 cm/sec. Actual values are likely dependent on particle size and degree of media swelling as water is absorbed.

Table 3 summarizes woodchip carbon-nitrogen (C/N) ratios and media bromide concentrations prior to the application of the KBr solute. On a part per million (ppm) basis, the bromide concentration of the woodchip sample at the effluent position (53.3 mg/kg) is significantly greater than the average pre-tracer test bromide concentration for water passing through the effluent sample port (6.1 mg/l).

Information Learned

Observations to date suggest that the biofilter can be an effective tool for water-resource protection. The biofilter offers some real benefits and compliments existing conservation practice standards during critical time periods:

- **Late Winter and Early Spring -** The melting of the snow pack during March can lead to the suspension and transport of manure particulates across the frozen-ground surface. Because of cold temperatures that limit biological activity and ammonia volatilization, the runoff flowing across the feedlot lot surface is rich in both nutrients and bacteria. Normally, much of this material drops out of suspension once the water reaches the settling basin commonly located at the base of the feedlot (Natural Resources Conservation Service Practice Standards 350 or 638). However, in late winter and early spring much of the settling basin's storage volume has been displaced by snow and ice. This leads to concentrated channelized flow that effectively by passes the settling basin and can result in the transport of suspended manure particulates to surface water. Under these conditions, the porous biofilter media functions as a mechanical filter trapping manure-derived nutrients and bacteria.
- **Late Summer** – Summer thunderstorms can lead to sudden downpours that on the bare ground of the feedlot surface can lead to preferential and concentrated surface runoff, but only limited runoff from vegetated land. Under these conditions, the biofilter functions as a giant sponge storing storm-derived feedlot runoff and preventing the rapid conveyance of manure particulates and sediment to nearby streams and other water bodies. During the mid- and late-summer months, streams are commonly subject to low flow conditions. A sudden influx of feedlot runoff can induce aquatic stress due to increased biological oxygen demand and nutrient-induced eutrophication. The biofilter has the potential to mitigate these adverse effects. The biofilter also has great potential for use in watersheds where animal agriculture has been implicated for exceeding Total Maximum Daily Loads (TMDLs).
- **Longevity** – It is estimated that a woodchip biofilter can function effectively for a three- to five-year time period.

Potential Public Health Benefits

From a public health perspective the biofilter has the potential benefits for reducing bacterial *E. coli* discharge to surface water as well as trapping and inactivating oocytes from the protozoan *Cryptosporidium parvum*. In Minnesota, many of the larger cities obtain drinking water from rivers or lakes. *Cryptosporidium* oocytes are proficient "hitch hikers" that are readily transported by sediment or manure particulates. The oocytes are difficult to remove by filtration in water-treatment plants and are highly resistant to chlorination (as they can survive for several days in a chlorinated swimming pool). It is estimated that more than half the dairy herds in the USA are infected with *C. parvum* and cattle are recognized as the primary domestic reservoir for this protozoan. The egg-like oocytes are excreted with the manure. Ingestion of oocyte-contaminated water can produce cryptosporidiosis. In Milwaukee, Wisconsin during the early spring of 1993, more than 400,000 people were infected by a cryptosporidios outbreak that left nearly 100 people dead from drinking the contaminated city water derived from Lake Michigan. In 2006 199 illnesses and 3 deaths resulted from the consumption of *E. coli*-contaminated spinach that was grown in a California field. According to the Food and Drug Administration (FDA) investigation report, storm-water runoff transported cattle feces onto an adjacent field where the spinach was grown resulting in the tainted spinach. The biofilter can diminish health risks posed by feedlots located in sensitive areas by reducing the volume of runoff discharged and inactivating ("pasteurizing") oocytes and other pathogens due to its absorptive capacity and elevated internal temperatures.

Conclusions

Based on the information obtained from Phase 2 of this investigation the following conclusions are offered:

1. A well-designed woodchip biofilter provides a viable alternative to vegetative filter strips (VFS) for treating feedlot runoff as it can offer the following advantages to Minnesota farmers:
    - Filters particulates and sequesters nutrients (i.e., nitrogen and phosphorus) as water (feedlot runoff) passes through the woodchip media. Similarly, the biofilter also reduces BOD5. The woodchip biofilter offers increased protection to surface water in decreasing elevated concentrations of nitrogen and BOD5 during the winter months.
    - Absorbs Water – the absorption capacity of the woodchip biofilter is significant absorbing up to 100 percent of the runoff entering the media and reducing the discharge volume and functioning as a "giant sponge." This effect is a particularly valuable attribute for reducing annual loads calculated by the Minnesota Feedlot Annualized Runoff Model (MinnFARM) as the absorbed water significantly sequesters nutrients and reduces or eliminates the net discharge to surface water. As such, the biofilter is well suited for placement near feedlots that adjoin sensitive waters.
    - Reduces size of treatment area relative to a VFS enabling the biofilter to be placed in locations where there is insufficient space for the placement of a vegetative filter between the feedlot and surface water body.
    - Simple design enables passive flow (by gravity) through the woodchip media prior to discharge (if the water is not completely absorbed.
    - Benefits the environment by putting woodchip waste (that would typically be burned) to a secondary use.

2. Design criteria for the installations of a woodchip biofilter should include the following considerations that have been or will be incorporated into the recently constructed woodchip biofilter at a dairy farm located in Melrose, Minnesota for Phase 3 of the Woodchip Biofilter Project:
    - Reduce the slope of the ground surface (through grading if needed) to increase the residence time of the runoff within the media. This should lead to increased filtering and sequestering of nutrients.
    - Increase sinuosity of the flow path within the biofilter by placing flow diverters beneath the liner. This will further decrease the hydraulic gradient.
    - Contain woodchips at the front face of the biofilter with a screen barrier to prevent slumping and freezing of the woodchips during the winter.

- Restrict the amount of manure and sediment particulate matter entering the biofilter through proper settling basin design. There should be adequate basin freeboard to accommodate snow and ice displacement of runoff during the melting of the winter snow pack.
- Regulate the flow into the biofilter from the settling basin during the melting of the snow pack so that temperatures do not drastically plummet and quench biological activity. This can be accomplished by restricting the size of the settling basin's outlet restrictor plate.
- Select well-graded materials of various sizes for the woodchip media to increase capillarity, increase moisture in order to sustain a more-active microbial population.
- Regulate water levels at the base of the media during dry periods and prior to the onset of winter to conserve moisture and sustain biological activity through sluice gates or pipe risers. Moisture loss can also be controlled by placing a plastic cover over portions of the biofilter.

Table 1. Analytical Results Summary from 12 Runoff Sample Events

Run-off Event	Position	Sample	Date	Time	Analyte	Method	Reporting Limit	Unit	Result	Comments
1	1	INF-01-SM-1M	3/9/05	13:10	Ammonia Nitrogen	EPA 350.2	<0.008	mg/L	195	Snow Melt
1	5	EFF-01-SM-3M	3/9/05	13:00	Ammonia Nitrogen	EPA 350.2	<0.008	mg/L	166	Snow Melt
2	1	INF-02-RF-1M	4/30/06	15:30	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	39.0	
2	3	MID-02-RF-2A	4/30/06	14:45	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	38.8	
2	4	EFF-02-R1-3A	4/30/06	14:45	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	28.6	
3	2	INF-03-RF-1A	5/23/06	22:22	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	5.04	
3	4	EFF-03-RF-1A	5/23/06	22:49	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	2.24	
3	3	MID-03-RF-1A	5/24/06	3:31	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	9.26	
3	3	MID-03-RF-2A	5/24/06	3:54	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	9.73	
4	1	INF-04-AR-1M	8/29/06	11:43	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	0.440	Rain Simulation
4	2	INF-04-AR-1A	8/29/06	12:02	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	2.20	Rain Simulation
4	3	MID-04-AR-1A	8/29/06	12:30	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	2.06	Rain Simulation
4	4	EFF-04-AR-1A	8/29/06	12:35	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	1.99	Rain Simulation
4	5	EFF-04-AR-1M	8/29/06	12:50	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	3.20	Rain Simulation
5	2	INF-05-RF-1A	9/1/06	8:00	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	1.62	
5	2	INF-05-RF-1B	9/1/06	9:20	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	2.75	
5	3	MID-05-RF-1A	9/1/06	9:00	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	1.65	
5	4	EFF-05-RF-1A	9/1/06	9:25	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	0.500	
5	4	EFF-05-RF-1B	9/1/06	10:22	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	0.860	
6	3	MID-06-RF-1B	9/1/06	9:57	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	4.37	
6	3	MID-06-RF-1A	9/1/06	21:50	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	3.82	
6	4	EFF-06-RF-1A	9/1/06	15:23	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	2.03	
6	4	EFF-06-RF-1B	9/1/06	18:03	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	0.760	
7	1	INF-07-RF-1M	9/2/06	19:45	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	6.30	
7	2	INF-07-RF-1A	9/2/06	19:50	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	5.01	

7	4	EFF-07-RF-1A	9/2/06	21:00	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	3.60	
7	5	EFF-07-RF-1M	9/2/06	20:05	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	3.19	
7	3	MID-07-RF-1A	9/3/06	5:33	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	7.65	
7	3	MID-07-RF-1B	9/3/06	8:27	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	9.37	
8	2	INF-08-RF-1A	9/22/06	14:25	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	7.53	
8	3	MID-08-RF-1A	9/22/06	14:25	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	2.53	
8	3	MID-08-RF-1A	9/22/06	14:25	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	2.53	
8	4	EFF-08-RF-1A	9/22/06	11:45	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	2.41	
8	4	EFF-08-RF-1B	9/22/06	14:25	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	4.28	
9	2	INF-09-RF-1B	9/23/06	3:00	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	8.04	
9	3	MID-09-RF-1A	9/23/06	15:05	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	6.25	
9	3	MID-09-RF-1B	9/23/06	18:14	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	7.39	
9	4	EFF-09-RF-1A	9/23/06	6:01	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	4.30	
10	1	INF-10-RF-1M	12/30/06	20:45	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	49.0	
10	2	INF-10-RF-1A	12/30/06	20:00	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	47.1	
10	3	MID-10-RF-1A	12/30/06	20:50	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	28.3	
10	4	EFF-10-RF-1A	12/30/06	20:19	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	9.67	
10	5	EFF-10-RF-1M	12/30/06	20:40	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	12.2	
11	1	INF-11-RF-1M	3/31/07	14:20	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	50.5	
11	2	INF-11-RF-1A	3/31/07	14:47	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	47.9	
11	3	MID-11-RF-1A	3/31/07	14:57	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	31.4	
11	4	EFF-11-RF-1A	3/31/07	15:07	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	16.7	
11	5	EFF-11-RF-1M	3/31/07	15:14	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	18.8	
12	1	IN-12-RF-1M	4/22/07	13:40	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	29.7	
12	2	IN-12-RF-1A	4/22/07	13:48	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	17.3	
12	3	MID-12-RF-1A	4/22/07	14:00	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	23.5	
12	4	EFF-12-RF-1A	4/22/07	14:10	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	21.4	
12	5	EFF-12-RF-1M	4/22/07	14:20	Ammonia Nitrogen	SM 4500-NH3 D	<0.10	mg/L	17.7	
1	1	INF-01-SM-1M	3/9/05	13:10	BOD5	SM 5210B	<2.0	mg/L	2,000	Snow Melt

1	5	EFF-01-SM-3M	3/9/05	13:00	BOD5	SM 5210B	<2.0	mg/L	2,130	Snow Melt
2	1	INF-02-RF-1M	4/30/06	15:30	BOD5	SM 5210B	<2.0	mg/L	272	
2	3	MID-02-RF-2A	4/30/06	14:45	BOD5	SM 5210B	<2.0	mg/L	212	
2	4	EFF-02-R1-3A	4/30/06	14:45	BOD5	SM 5210B	<2.0	mg/L	178	
3	2	INF-03-RF-1A	5/23/06	22:22	BOD5	SM 5210B	<2.0	mg/L	78.0	
3	4	EFF-03-RF-1A	5/23/06	22:49	BOD5	SM 5210B	<2.0	mg/L	34.0	
3	3	MID-03-RF-1A	5/24/06	3:31	BOD5	SM 5210B	<2.0	mg/L	88.0	
3	3	MID-03-RF-2A	5/24/06	3:54	BOD5	SM 5210B	<2.0	mg/L	94.0	
4	1	INF-04-AR-1M	8/29/06	11:43	BOD5	SM 5210B	<2.0	mg/L	27.0	Rain Simulation
4	2	INF-04-AR-1A	8/29/06	12:02	BOD5	SM 5210B	<2.0	mg/L	46.0	Rain Simulation
4	3	MID-04-AR-1A	8/29/06	12:30	BOD5	SM 5210B	<2.0	mg/L	23.0	Rain Simulation
4	4	EFF-04-AR-1A	8/29/06	12:35	BOD5	SM 5210B	<2.0	mg/L	41.0	Rain Simulation
4	5	EFF-04-AR-1M	8/29/06	12:50	BOD5	SM 5210B	<2.0	mg/L	77.0	Rain Simulation
5	2	INF-05-RF-1A	9/1/06	8:00	BOD5	SM 5210B	<2.0	mg/L	47.0	* BOD Analyzed Beyond Holding Time
5	2	INF-05-RF-1B	9/1/06	9:20	BOD5	SM 5210B	<2.0	mg/L	52.0	* BOD Analyzed Beyond Holding Time
5	3	MID-05-RF-1A	9/1/06	9:00	BOD5	SM 5210B	<2.0	mg/L	41.0	* BOD Analyzed Beyond Holding Time
5	4	EFF-05-RF-1A	9/1/06	9:25	BOD5	SM 5210B	<2.0	mg/L	21.0	* BOD Analyzed Beyond Holding Time
5	4	EFF-05-RF-1B	9/1/06	10:22	BOD5	SM 5210B	<2.0	mg/L	25.0	* BOD Analyzed Beyond Holding Time
6	3	MID-06-RF-1B	9/1/06	9:57	BOD5	SM 5210B	<2.0	mg/L	92.0	* BOD Analyzed Beyond Holding Time
6	3	MID-06-RF-1A	9/1/06	21:50	BOD5	SM 5210B	<2.0	mg/L	82.0	* BOD Analyzed Beyond Holding Time
6	4	EFF-06-RF-1A	9/1/06	15:23	BOD5	SM 5210B	<2.0	mg/L	54.0	* BOD Analyzed Beyond Holding Time
6	4	EFF-06-RF-1B	9/1/06	18:03	BOD5	SM 5210B	<2.0	mg/L	68.0	* BOD Analyzed Beyond Holding Time
7	1	INF-07-RF-1M	9/2/06	19:45	BOD5	SM 5210B	<2.0	mg/L	77.0	* BOD Analyzed Beyond Holding Time
7	2	INF-07-RF-1A	9/2/06	19:50	BOD5	SM 5210B	<2.0	mg/L	61.0	* BOD Analyzed Beyond Holding Time
7	4	EFF-07-RF-1A	9/2/06	21:00	BOD5	SM 5210B	<2.0	mg/L	54.0	* BOD Analyzed Beyond Holding Time
7	5	EFF-07-RF-1M	9/2/06	20:05	BOD5	SM 5210B	<2.0	mg/L	53.0	* BOD Analyzed Beyond Holding Time
7	3	MID-07-RF-1A	9/3/06	5:33	BOD5	SM 5210B	<2.0	mg/L	74.0	* BOD Analyzed Beyond Holding Time
7	3	MID-07-RF-1B	9/3/06	8:27	BOD5	SM 5210B	<2.0	mg/L	70.0	* BOD Analyzed Beyond Holding Time
8	2	MID-08-RF-1A	9/22/06	14:25	BOD5	SM 5210B	<2.0	mg/L	48.0	* BOD Analyzed Beyond Holding Time

8	3	EFF-08-RF-1B	9/22/06	14:25	BOD5	SM 5210B	<2.0	mg/L	44.0	* BOD Analyzed Beyond Holding Time
8	3	INF-08-RF-1A	9/22/06	14:25	BOD5	SM 5210B	<2.0	mg/L	45.0	* BOD Analyzed Beyond Holding Time
8	4	EFF-08-RF-1A	9/22/06	11:45	BOD5	SM 5210B	<2.0	mg/L	50.0	* BOD Analyzed Beyond Holding Time
8	4	MID-08-RF-1A	9/22/06	14:25	BOD5	SM 5210B	<2.0	mg/L	48.0	* BOD Analyzed Beyond Holding Time
9	2	INF-09-RF-1B	9/23/06	3:00	BOD5	SM 5210B	<2.0	mg/L	61.0	* BOD Analyzed Beyond Holding Time
9	3	MID-09-RF-1A	9/23/06	15:05	BOD5	SM 5210B	<2.0	mg/L	32.0	* BOD Analyzed Beyond Holding Time
9	3	MID-09-RF-1B	9/23/06	18:14	BOD5	SM 5210B	<2.0	mg/L	26.0	* BOD Analyzed Beyond Holding Time
9	4	EFF-09-RF-1A	9/23/06	6:01	BOD5	SM 5210B	<2.0	mg/L	33.0	* BOD Analyzed Beyond Holding Time
10	1	INF-10-RF-1M	12/30/06	20:45	BOD5	SM 5210B	<2.0	mg/L	672	
10	2	INF-10-RF-1A	12/30/06	20:00	BOD5	SM 5210B	<2.0	mg/L	701	
10	3	MID-10-RF-1A	12/30/06	20:50	BOD5	SM 5210B	<2.0	mg/L	666	
10	4	EFF-10-RF-1A	12/30/06	20:19	BOD5	SM 5210B	<2.0	mg/L	414	
10	5	EFF-10-RF-1M	12/30/06	20:40	BOD5	SM 5210B	<2.0	mg/L	492	
11	1	INF-11-RF-1M	3/31/07	14:20	BOD5	SM 5210B	<2.0	mg/L	463	
11	2	INF-11-RF-1A	3/31/07	14:47	BOD5	SM 5210B	<2.0	mg/L	375	
11	3	MID-11-RF-1A	3/31/07	14:57	BOD5	SM 5210B	<2.0	mg/L	308	
11	4	EFF-11-RF-1A	3/31/07	15:07	BOD5	SM 5210B	<2.0	mg/L	223	
11	5	EFF-11-RF-1M	3/31/07	15:14	BOD5	SM 5210B	<2.0	mg/L	355	
12	1	IN-12-RF-1M	4/22/07	13:40	BOD5	SM 5210B	<2.0	mg/L	477	
12	2	IN-12-RF-1A	4/22/07	13:48	BOD5	SM 5210B	<2.0	mg/L	203	
12	3	MID-12-RF-1A	4/22/07	14:00	BOD5	SM 5210B	<2.0	mg/L	303	
12	4	EFF-12-RF-1A	4/22/07	14:10	BOD5	SM 5210B	<2.0	mg/L	483	
12	5	EFF-12-RF-1M	4/22/07	14:20	BOD5	SM 5210B	<2.0	mg/L	163	
1	5	EFF-01-SM-3M	3/9/05	13:00	Bromide		<0.010	mg/L	31.3	Snow Melt
2	4	EFF-02-R1-3A	4/30/06	14:45	Bromide		<0.010	mg/L	6.17	
3	4	EFF-03-RF-1A	5/23/06	22:49	Bromide		<0.010	mg/L	3.31	
4	4	EFF-04-AR-1A	8/29/06	12:35	Bromide		<0.010	mg/L	2.06	Rain Simulation
6	4	EFF-06-RF-1A	9/1/06	15:23	Bromide		<0.010	mg/L	1.67	
6	4	EFF-06-RF-1B	9/1/06	18:03	Bromide		<0.010	mg/L	1.61	

7	4	EFF-07-RF-1A	9/2/06	21:00	Bromide		<0.010	mg/L	2.36	
8	4	EFF-08-RF-1A	9/22/06	11:45	Bromide		<0.010	mg/L	1.91	
8	4	EFF-08-RF-1B	9/22/06	14:25	Bromide		<0.010	mg/L	2.26	
9	4	EFF-09-RF-1A	9/23/06	6:01	Bromide		<0.010	mg/L	1.86	
10	4	EFF-10-RF-1A	12/30/06	20:19	Bromide		<0.010	mg/L	12.5	
1	1	INF-01-SM-1M	3/9/05	13:10	Cbod	SM 5210B	<2.0	mg/L	2,160	Snow Melt
1	5	EFF-01-SM-3M	3/9/05	13:00	Cbod	SM 5210B	<2.0	mg/L	2,180	Snow Melt
1	1	INF-01-SM-1M	3/9/05	13:10	Chloride	SM 4500-CL B	<0.250	mg/L	195	Snow Melt
1	5	EFF-01-SM-3M	3/9/05	13:00	Chloride	SM 4500-CL B	<0.250	mg/L	240	Snow Melt
2	1	INF-02-RF-1M	4/30/06	15:30	Chloride	SM 4500-CL B	<0.50	mg/L	309	
2	3	MID-02-RF-2A	4/30/06	14:45	Chloride	SM 4500-CL B	<0.50	mg/L	317	
2	4	EFF-02-R1-3A	4/30/06	14:45	Chloride	SM 4500-CL B	<0.50	mg/L	262	
3	2	INF-03-RF-1A	5/23/06	22:22	Chloride	SM 4500-CL B	<0.50	mg/L	138	
3	4	EFF-03-RF-1A	5/23/06	22:49	Chloride	SM 4500-CL B	<0.50	mg/L	184	
3	3	MID-03-RF-1A	5/24/06	3:31	Chloride	SM 4500-CL B	<0.50	mg/L	291	
3	3	MID-03-RF-2A	5/24/06	3:54	Chloride	SM 4500-CL B	<0.50	mg/L	277	
4	1	INF-04-AR-1M	8/29/06	11:43	Chloride	SM 4500-CL B	<0.50	mg/L	77.8	Rain Simulation
4	2	INF-04-AR-1A	8/29/06	12:02	Chloride	SM 4500-CL B	<0.50	mg/L	65.0	Rain Simulation
4	3	MID-04-AR-1A	8/29/06	12:30	Chloride	SM 4500-CL B	<0.50	mg/L	88.6	Rain Simulation
4	4	EFF-04-AR-1A	8/29/06	12:35	Chloride	SM 4500-CL B	<0.50	mg/L	78.9	Rain Simulation
4	5	EFF-04-AR-1M	8/29/06	12:50	Chloride	SM 4500-CL B	<0.50	mg/L	55.7	Rain Simulation
5	2	INF-05-RF-1A	9/1/06	8:00	Chloride	SM 4500-CL B	<0.50	mg/L	136	
5	2	INF-05-RF-1B	9/1/06	9:20	Chloride	SM 4500-CL B	<0.50	mg/L	197	
5	3	MID-05-RF-1A	9/1/06	9:00	Chloride	SM 4500-CL B	<0.50	mg/L	85.0	
5	4	EFF-05-RF-1A	9/1/06	9:25	Chloride	SM 4500-CL B	<0.50	mg/L	75.0	
5	4	EFF-05-RF-1B	9/1/06	10:22	Chloride	SM 4500-CL B	<0.50	mg/L	86.0	
6	3	MID-06-RF-1B	9/1/06	9:57	Chloride	SM 4500-CL B	<0.50	mg/L	281	
6	3	MID-06-RF-1A	9/1/06	21:50	Chloride	SM 4500-CL B	<0.50	mg/L	266	
6	4	EFF-06-RF-1A	9/1/06	15:23	Chloride	SM 4500-CL B	<0.50	mg/L	169	

6	4	EFF-06-RF-1B	9/1/06	18:03	Chloride	SM 4500-CL B	<0.50	mg/L	193	
7	1	INF-07-RF-1M	9/2/06	19:45	Chloride	SM 4500-CL B	<0.50	mg/L	225	
7	2	INF-07-RF-1A	9/2/06	19:50	Chloride	SM 4500-CL B	<0.50	mg/L	219	
7	4	EFF-07-RF-1A	9/2/06	21:00	Chloride	SM 4500-CL B	<0.50	mg/L	241	
7	5	EFF-07-RF-1M	9/2/06	20:05	Chloride	SM 4500-CL B	<0.50	mg/L	246	
7	3	MID-07-RF-1A	9/3/06	5:33	Chloride	SM 4500-CL B	<0.50	mg/L	251	
7	3	MID-07-RF-1B	9/3/06	8:27	Chloride	SM 4500-CL B	<0.50	mg/L	252	
8	2	EFF-08-RF-1B	9/22/06	14:25	Chloride	SM 4500-CL B	<0.50	mg/L	467	
8	3	INF-08-RF-1A	9/22/06	14:25	Chloride	SM 4500-CL B	<0.50	mg/L	406	
8	3	MID-08-RF-1A	9/22/06	14:25	Chloride	SM 4500-CL B	<0.50	mg/L	450	
8	4	EFF-08-RF-1A	9/22/06	11:45	Chloride	SM 4500-CL B	<0.50	mg/L	464	
8	4	MID-08-RF-1A	9/22/06	14:25	Chloride	SM 4500-CL B	<0.50	mg/L	450	
9	2	INF-09-RF-1B	9/23/06	3:00	Chloride	SM 4500-CL B	<0.50	mg/L	417	
9	3	MID-09-RF-1A	9/23/06	15:05	Chloride	SM 4500-CL B	<0.50	mg/L	434	
9	3	MID-09-RF-1B	9/23/06	18:14	Chloride	SM 4500-CL B	<0.50	mg/L	435	
9	4	EFF-09-RF-1A	9/23/06	6:01	Chloride	SM 4500-CL B	<0.50	mg/L	426	
10	1	INF-10-RF-1M	12/30/06	20:45	Chloride	SM 4500-CL B	<0.50	mg/L	221	
10	2	INF-10-RF-1A	12/30/06	20:00	Chloride	SM 4500-CL B	<0.50	mg/L	265	
10	3	MID-10-RF-1A	12/30/06	20:50	Chloride	SM 4500-CL B	<0.50	mg/L	263	
10	4	EFF-10-RF-1A	12/30/06	20:19	Chloride	SM 4500-CL B	<0.50	mg/L	290	
10	5	EFF-10-RF-1M	12/30/06	20:40	Chloride	SM 4500-CL B	<0.50	mg/L	266	
11	1	INF-11-RF-1M	3/31/07	14:20	Chloride	SM 4500-CL B	<0.50	mg/L	246	
11	2	INF-11-RF-1A	3/31/07	14:47	Chloride	SM 4500-CL B	<0.50	mg/L	264	
11	3	MID-11-RF-1A	3/31/07	14:57	Chloride	SM 4500-CL B	<0.50	mg/L	294	
11	4	EFF-11-RF-1A	3/31/07	15:07	Chloride	SM 4500-CL B	<0.50	mg/L	286	
11	5	EFF-11-RF-1M	3/31/07	15:14	Chloride	SM 4500-CL B	<0.50	mg/L	287	
12	1	IN-12-RF-1M	4/22/07	13:40	Chloride	SM 4500-CL B	<0.50	mg/L	223	
12	2	IN-12-RF-1A	4/22/07	13:48	Chloride	SM 4500-CL B	<0.50	mg/L	252	
12	3	MID-12-RF-1A	4/22/07	14:00	Chloride	SM 4500-CL B	<0.50	mg/L	264	

12	4	EFF-12-RF-1A	4/22/07	14:10	Chloride	SM 4500-CL B	<0.50	mg/L	225	
12	5	EFF-12-RF-1M	4/22/07	14:20	Chloride	SM 4500-CL B	<0.50	mg/L	216	
1	1	INF-01-SM-1M	3/9/05	13:10	COD	SM 5220D	<2.0	mg/L	9,120	Snow Melt
1	5	EFF-01-SM-3M	3/9/05	13:00	COD	SM 5220D	<2.0	mg/L	7,440	Snow Melt
2	1	INF-02-RF-1M	4/30/06	15:30	COD	SM 5220D	<2.0	mg/L	2,190	
2	3	MID-02-RF-2A	4/30/06	14:45	COD	SM 5220D	<2.0	mg/L	2,320	
2	4	EFF-02-R1-3A	4/30/06	14:45	COD	SM 5220D	<2.0	mg/L	2,000	
3	2	INF-03-RF-1A	5/23/06	22:22	COD	SM 5220D	<2.0	mg/L	510	
3	4	EFF-03-RF-1A	5/23/06	22:49	COD	SM 5220D	<2.0	mg/L	794	
3	3	MID-03-RF-1A	5/24/06	3:31	COD	SM 5220D	<2.0	mg/L	1,380	
3	3	MID-03-RF-2A	5/24/06	3:54	COD	SM 5220D	<2.0	mg/L	1,510	
4	1	INF-04-AR-1M	8/29/06	11:43	COD	SM 5220D	<2.0	mg/L	994	Rain Simulation
4	2	INF-04-AR-1A	8/29/06	12:02	COD	SM 5220D	<2.0	mg/L	537	Rain Simulation
4	3	MID-04-AR-1A	8/29/06	12:30	COD	SM 5220D	<2.0	mg/L	837	Rain Simulation
4	4	EFF-04-AR-1A	8/29/06	12:35	COD	SM 5220D	<2.0	mg/L	1,010	Rain Simulation
4	5	EFF-04-AR-1M	8/29/06	12:50	COD	SM 5220D	<2.0	mg/L	1,140	Rain Simulation
5	2	INF-05-RF-1A	9/1/06	8:00	COD	SM 5220D	<2.0	mg/L	733	
5	2	INF-05-RF-1B	9/1/06	9:20	COD	SM 5220D	<2.0	mg/L	816	
5	3	MID-05-RF-1A	9/1/06	9:00	COD	SM 5220D	<2.0	mg/L	490	
5	4	EFF-05-RF-1A	9/1/06	9:25	COD	SM 5220D	<2.0	mg/L	515	
5	4	EFF-05-RF-1B	9/1/06	10:22	COD	SM 5220D	<2.0	mg/L	532	
6	3	MID-06-RF-1B	9/1/06	9:57	COD	SM 5220D	<2.0	mg/L	1,220	
6	3	MID-06-RF-1A	9/1/06	21:50	COD	SM 5220D	<2.0	mg/L	1,130	
6	4	EFF-06-RF-1A	9/1/06	15:23	COD	SM 5220D	<2.0	mg/L	814	
6	4	EFF-06-RF-1B	9/1/06	18:03	COD	SM 5220D	<2.0	mg/L	963	
7	1	INF-07-RF-1M	9/2/06	19:45	COD	SM 5220D	<2.0	mg/L	1,070	
7	2	INF-07-RF-1A	9/2/06	19:50	COD	SM 5220D	<2.0	mg/L	940	
7	4	EFF-07-RF-1A	9/2/06	21:00	COD	SM 5220D	<2.0	mg/L	1,330	
7	5	EFF-07-RF-1M	9/2/06	20:05	COD	SM 5220D	<2.0	mg/L	1,220	

7	3	MID-07-RF-1A	9/3/06	5:33	COD	SM 5220D	<2.0	mg/L	1,070	
7	3	MID-07-RF-1B	9/3/06	8:27	COD	SM 5220D	<2.0	mg/L	1,090	
8	2	EFF-08-RF-1B	9/22/06	14:25	COD	SM 5220D	<2.0	mg/L	1,130	
8	3	INF-08-RF-1A	9/22/06	14:25	COD	SM 5220D	<2.0	mg/L	1,080	
8	3	MID-08-RF-1A	9/22/06	14:25	COD	SM 5220D	<2.0	mg/L	1,120	
8	4	EFF-08-RF-1A	9/22/06	11:45	COD	SM 5220D	<2.0	mg/L	1,180	
8	4	MID-08-RF-1A	9/22/06	14:25	COD	SM 5220D	<2.0	mg/L	1,120	
9	2	INF-09-RF-1B	9/23/06	3:00	COD	SM 5220D	<2.0	mg/L	**	** COD Not Enough Sample
9	3	MID-09-RF-1A	9/23/06	15:05	COD	SM 5220D	<2.0	mg/L	1,050	
9	3	MID-09-RF-1B	9/23/06	18:14	COD	SM 5220D	<2.0	mg/L	1,030	
9	4	EFF-09-RF-1A	9/23/06	6:01	COD	SM 5220D	<2.0	mg/L	999	
10	1	INF-10-RF-1M	12/30/06	20:45	COD	SM 5220D	<2.0	mg/L	1,930	
10	2	INF-10-RF-1A	12/30/06	20:00	COD	SM 5220D	<2.0	mg/L	2,800	
10	3	MID-10-RF-1A	12/30/06	20:50	COD	SM 5220D	<2.0	mg/L	2,360	
10	4	EFF-10-RF-1A	12/30/06	20:19	COD	SM 5220D	<2.0	mg/L	1,870	
10	5	EFF-10-RF-1M	12/30/06	20:40	COD	SM 5220D	<2.0	mg/L	2,250	
11	1	INF-11-RF-1M	3/31/07	14:20	COD	SM 5220D	<2.0	mg/L	2,299	
11	2	INF-11-RF-1A	3/31/07	14:47	COD	SM 5220D	<2.0	mg/L	2,029	
11	3	MID-11-RF-1A	3/31/07	14:57	COD	SM 5220D	<2.0	mg/L	2,110	
11	4	EFF-11-RF-1A	3/31/07	15:07	COD	SM 5220D	<2.0	mg/L	2,407	
11	5	EFF-11-RF-1M	3/31/07	15:14	COD	SM 5220D	<2.0	mg/L	2,431	
12	1	IN-12-RF-1M	4/22/07	13:40	COD	SM 5220D	<2.0	mg/L	1,068	
12	2	IN-12-RF-1A	4/22/07	13:48	COD	SM 5220D	<2.0	mg/L	670	
12	3	MID-12-RF-1A	4/22/07	14:00	COD	SM 5220D	<2.0	mg/L	1,022	
12	4	EFF-12-RF-1A	4/22/07	14:10	COD	SM 5220D	<2.0	mg/L	1,171	
12	5	EFF-12-RF-1M	4/22/07	14:20	COD	SM 5220D	<2.0	mg/L	259	
1	1	INF-01-SM-1M	3/9/05	13:10	E. Coli	m-ColiBlue24	<1/100ml	cfu	295,200	Snow Melt
1	5	EFF-01-SM-3M	3/9/05	13:00	E. Coli	m-ColiBlue24	<1/100ml	cfu	374,400	Snow Melt
2	1	INF-02-RF-1M	4/30/06	15:30	E. Coli	m-ColiBlue24	<1/100ml	cfu	331,200	

2	3	EFF-02-R1-3A	4/30/06	14:45	E. Coli	m-ColiBlue24	<1/100ml	cfu	518,400	
2	4	MID-02-RF-2A	4/30/06	14:45	E. Coli	m-ColiBlue24	<1/100ml	cfu	432,000	
3	2	INF-03-RF-1A	5/23/06	22:22	E. Coli	m-ColiBlue24	<1/100ml	cfu	201,600	
3	4	EFF-03-RF-1A	5/23/06	22:49	E. Coli	m-ColiBlue24	<1/100ml	cfu	518,400	
3	3	MID-03-RF-1A	5/24/06	3:31	E. Coli	m-ColiBlue24	<1/100ml	cfu	432,000	
3	3	MID-03-RF-2A	5/24/06	3:54	E. Coli	m-ColiBlue24	<1/100ml	cfu	345,600	
4	1	INF-04-AR-1M	8/29/06	11:43	E. Coli	m-ColiBlue24	<1/100ml	cfu	1,353,600	Rain Simulation
4	2	INF-04-AR-1A	8/29/06	12:02	E. Coli	m-ColiBlue24	<1/100ml	cfu	1,094,400	Rain Simulation
4	3	MID-04-AR-1A	8/29/06	12:30	E. Coli	m-ColiBlue24	<1/100ml	cfu	1,353,600	Rain Simulation
4	4	EFF-04-AR-1A	8/29/06	12:35	E. Coli	m-ColiBlue24	<1/100ml	cfu	1,094,400	Rain Simulation
4	5	EFF-04-AR-1M	8/29/06	12:50	E. Coli	m-ColiBlue24	<1/100ml	cfu	748,800	Rain Simulation
5	2	INF-05-RF-1A	9/1/06	8:00	E. Coli	m-ColiBlue24	<1/100ml	cfu	1,152,000	
5	2	INF-05-RF-1B	9/1/06	9:20	E. Coli	m-ColiBlue24	<1/100ml	cfu	1,296,000	
5	3	MID-05-RF-1A	9/1/06	9:00	E. Coli	m-ColiBlue24	<1/100ml	cfu	806,400	
5	4	EFF-05-RF-1A	9/1/06	9:25	E. Coli	m-ColiBlue24	<1/100ml	cfu	1,123,200	
5	4	EFF-05-RF-1B	9/1/06	10:22	E. Coli	m-ColiBlue24	<1/100ml	cfu	1,065,600	
6	3	MID-06-RF-1B	9/1/06	9:57	E. Coli	m-ColiBlue24	<1/100ml	cfu	518,400	* E.Coli Analyzed Beyond Holding Time
6	3	MID-06-RF-1A	9/1/06	21:50	E. Coli	m-ColiBlue24	<1/100ml	cfu	633,600	* E.Coli Analyzed Beyond Holding Time
6	4	EFF-06-RF-1A	9/1/06	15:23	E. Coli	m-ColiBlue24	<1/100ml	cfu	633,600	* E.Coli Analyzed Beyond Holding Time
6	4	EFF-06-RF-1B	9/1/06	18:03	E. Coli	m-ColiBlue24	<1/100ml	cfu	864,000	* E.Coli Analyzed Beyond Holding Time
7	1	INF-07-RF-1M	9/2/06	19:45	E. Coli	m-ColiBlue24	<1/100ml	cfu	806,400	* E.Coli Analyzed Beyond Holding Time
7	2	INF-07-RF-1A	9/2/06	19:50	E. Coli	m-ColiBlue24	<1/100ml	cfu	748,800	* E.Coli Analyzed Beyond Holding Time
7	4	EFF-07-RF-1A	9/2/06	21:00	E. Coli	m-ColiBlue24	<1/100ml	cfu	518,400	* E.Coli Analyzed Beyond Holding Time
7	5	EFF-07-RF-1M	9/2/06	20:05	E. Coli	m-ColiBlue24	<1/100ml	cfu	633,600	* E.Coli Analyzed Beyond Holding Time
7	3	MID-07-RF-1A	9/3/06	5:33	E. Coli	m-ColiBlue24	<1/100ml	cfu	691,200	* E.Coli Analyzed Beyond Holding Time
7	3	MID-07-RF-1B	9/3/06	8:27	E. Coli	m-ColiBlue24	<1/100ml	cfu	633,600	* E.Coli Analyzed Beyond Holding Time
8	2	EFF-08-RF-1B	9/22/06	14:25	E. Coli	m-ColiBlue24	<1/100ml	cfu	468,000	* E.Coli Analyzed Beyond Holding Time
8	3	INF-08-RF-1A	9/22/06	14:25	E. Coli	m-ColiBlue24	<1/100ml	cfu	424,800	* E.Coli Analyzed Beyond Holding Time
8	3	MID-08-RF-1A	9/22/06	14:25	E. Coli	m-ColiBlue24	<1/100ml	cfu	453,600	* E.Coli Analyzed Beyond Holding Time

8	4	EFF-08-RF-1A	9/22/06	11:45	E. Coli	m-ColiBlue24	<1/100ml	cfu	597,600	* E.Coli Analyzed Beyond Holding Time
8	4	MID-08-RF-1A	9/22/06	14:25	E. Coli	m-ColiBlue24	<1/100ml	cfu	453,600	* E.Coli Analyzed Beyond Holding Time
9	2	INF-09-RF-1B	9/23/06	3:00	E. Coli	m-ColiBlue24	<1/100ml	cfu	280,800	* E.Coli Analyzed Beyond Holding Time
9	3	MID-09-RF-1A	9/23/06	15:05	E. Coli	m-ColiBlue24	<1/100ml	cfu	367,200	* E.Coli Analyzed Beyond Holding Time
9	3	MID-09-RF-1B	9/23/06	18:14	E. Coli	m-ColiBlue24	<1/100ml	cfu	288,000	* E.Coli Analyzed Beyond Holding Time
9	4	EFF-09-RF-1A	9/23/06	6:01	E. Coli	m-ColiBlue24	<1/100ml	cfu	302,400	* E.Coli Analyzed Beyond Holding Time
10	1	INF-10-RF-1M	12/30/06	20:45	E. Coli	m-ColiBlue24	<1/100ml	cfu	604,800	
10	2	INF-10-RF-1A	12/30/06	20:00	E. Coli	m-ColiBlue24	<1/100ml	cfu	460,800	
10	3	MID-10-RF-1A	12/30/06	20:50	E. Coli	m-ColiBlue24	<1/100ml	cfu	547,200	
10	4	EFF-10-RF-1A	12/30/06	20:19	E. Coli	m-ColiBlue24	<1/100ml	cfu	432,000	
10	5	EFF-10-RF-1M	12/30/06	20:40	E. Coli	m-ColiBlue24	<1/100ml	cfu	489,600	
11	1	INF-11-RF-1M	3/31/07	14:20	E. Coli	m-ColiBlue24	<1/100ml	cfu	201,600	
11	2	INF-11-RF-1A	3/31/07	14:47	E. Coli	m-ColiBlue24	<1/100ml	cfu	259,200	
11	3	MID-11-RF-1A	3/31/07	14:57	E. Coli	m-ColiBlue24	<1/100ml	cfu	208,800	
11	4	EFF-11-RF-1A	3/31/07	15:07	E. Coli	m-ColiBlue24	<1/100ml	cfu	288,000	
11	5	EFF-11-RF-1M	3/31/07	15:14	E. Coli	m-ColiBlue24	<1/100ml	cfu	345,600	
12	1	IN-12-RF-1M	4/22/07	13:40	E. Coli	m-ColiBlue24	<1/100ml	cfu	100,800	
12	2	IN-12-RF-1A	4/22/07	13:48	E. Coli	m-ColiBlue24	<1/100ml	cfu	158,400	
12	3	MID-12-RF-1A	4/22/07	14:00	E. Coli	m-ColiBlue24	<1/100ml	cfu	136,800	
12	4	EFF-12-RF-1A	4/22/07	14:10	E. Coli	m-ColiBlue24	<1/100ml	cfu	172,800	
12	5	EFF-12-RF-1M	4/22/07	14:20	Fecal Coliform	SM 9222D	<1/100ml	cfu	223,200	
1	1	INF-01-SM-1M	3/9/05	13:10	Nitrate Nitrogen	SM 4500-N03 D	0.01	mg/L	4.12	Snow Melt
1	5	EFF-01-SM-3M	3/9/05	13:00	Nitrate Nitrogen	SM 4500-N03 D	0.01	mg/L	4.63	Snow Melt
2	1	INF-02-RF-1M	4/30/06	15:30	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	0.760	
2	3	MID-02-RF-2A	4/30/06	14:45	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	0.290	
2	4	EFF-02-R1-3A	4/30/06	14:45	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	0.220	
3	2	INF-03-RF-1A	5/23/06	22:22	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	2.72	
3	4	EFF-03-RF-1A	5/23/06	22:49	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	1.22	
3	3	MID-03-RF-1A	5/24/06	3:31	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	<0.10	

3	3	MID-03-RF-2A	5/24/06	3:54	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	0.219	
4	1	INF-04-AR-1M	8/29/06	11:43	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	0.398	Rain Simulation
4	2	INF-04-AR-1A	8/29/06	12:02	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	5.20	Rain Simulation
4	3	MID-04-AR-1A	8/29/06	12:30	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	0.558	Rain Simulation
4	4	EFF-04-AR-1A	8/29/06	12:35	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	4.18	Rain Simulation
4	5	EFF-04-AR-1M	8/29/06	12:50	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	4.68	Rain Simulation
5	2	INF-05-RF-1A	9/1/06	8:00	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	8.95	
5	2	INF-05-RF-1B	9/1/06	9:20	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	8.26	
5	3	MID-05-RF-1A	9/1/06	9:00	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	3.39	
5	4	EFF-05-RF-1A	9/1/06	9:25	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	1.58	
5	4	EFF-05-RF-1B	9/1/06	10:22	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	1.55	
6	3	MID-06-RF-1B	9/1/06	9:57	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	0.573	
6	3	MID-06-RF-1A	9/1/06	21:50	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	0.432	
6	4	EFF-06-RF-1A	9/1/06	15:23	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	0.448	
6	4	EFF-06-RF-1B	9/1/06	18:03	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	0.485	
7	1	INF-07-RF-1M	9/2/06	19:45	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	0.683	
7	2	INF-07-RF-1A	9/2/06	19:50	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	2.10	
7	4	EFF-07-RF-1A	9/2/06	21:00	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	1.142	
7	5	EFF-07-RF-1M	9/2/06	20:05	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	0.965	
7	3	MID-07-RF-1A	9/3/06	5:33	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	0.702	
7	3	MID-07-RF-1B	9/3/06	8:27	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	0.594	
8	2	MID-08-RF-1A	9/22/06	14:25	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	14.0	
8	3	INF-08-RF-1A	9/22/06	14:25	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	11.6	
8	3	EFF-08-RF-1B	9/22/06	14:25	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	13.3	
8	4	EFF-08-RF-1A	9/22/06	11:45	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	11.0	
8	4	MID-08-RF-1A	9/22/06	14:25	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	14.0	
9	2	INF-09-RF-1B	9/23/06	3:00	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	7.08	
9	3	MID-09-RF-1A	9/23/06	15:05	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	7.61	
9	3	MID-09-RF-1B	9/23/06	18:14	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	1.59	

9	4	EFF-09-RF-1A	9/23/06	6:01	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	3.12	
10	1	INF-10-RF-1M	12/30/06	20:45	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	0.673	
10	2	INF-10-RF-1A	12/30/06	20:00	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	0.858	
10	3	MID-10-RF-1A	12/30/06	20:50	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	0.659	
10	4	EFF-10-RF-1A	12/30/06	20:19	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	0.260	
10	5	EFF-10-RF-1M	12/30/06	20:40	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	0.179	
11	1	INF-11-RF-1M	3/31/07	14:20	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	<0.01	
11	2	INF-11-RF-1A	3/31/07	14:47	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	<0.010	
11	3	MID-11-RF-1A	3/31/07	14:57	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	<0.010	
11	4	EFF-11-RF-1A	3/31/07	15:07	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	<0.010	
11	5	EFF-11-RF-1M	3/31/07	15:14	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	<0.010	
12	1	IN-12-RF-1M	4/22/07	13:40	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	<0.03	
12	2	IN-12-RF-1A	4/22/07	13:48	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	<0.03	
12	3	MID-12-RF-1A	4/22/07	14:00	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	<0.03	
12	4	EFF-12-RF-1A	4/22/07	14:10	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	<0.03	
12	5	EFF-12-RF-1M	4/22/07	14:20	Nitrate Nitrogen	SM 4500-N03F	0.01	mg/L	<0.03	
1	1	INF-01-SM-1M	3/9/05	13:10	TKN Nitrogen	EPA 351.2	<0.150	mg/L	448	Snow Melt
1	5	EFF-01-SM-3M	3/9/05	13:00	TKN Nitrogen	EPA 351.2	<0.150	mg/L	416	Snow Melt
2	1	INF-02-RF-1M	4/30/06	15:30	TKN Nitrogen	EPA 351.2	<1.000	mg/L	164	
2	3	MID-02-RF-2A	4/30/06	14:45	TKN Nitrogen	EPA 351.2	<1.000	mg/L	157	
2	4	EFF-02-R1-3A	4/30/06	14:45	TKN Nitrogen	EPA 351.2	<1.000	mg/L	110	
3	2	INF-03-RF-1A	5/23/06	22:22	TKN Nitrogen	EPA 351.2	<1.000	mg/L	73.7	
3	4	EFF-03-RF-1A	5/23/06	22:49	TKN Nitrogen	EPA 351.2	<1.000	mg/L	4.40	
3	3	MID-03-RF-1A	5/24/06	3:31	TKN Nitrogen	EPA 351.2	<1.000	mg/L	45.6	
3	3	MID-03-RF-2A	5/24/06	3:54	TKN Nitrogen	EPA 351.2	<1.000	mg/L	3.98	
4	1	INF-04-AR-1M	8/29/06	11:43	TKN Nitrogen	EPA 351.2	<1.000	mg/L	39.8	Rain Simulation
4	2	INF-04-AR-1A	8/29/06	12:02	TKN Nitrogen	EPA 351.2	<1.000	mg/L	42.4	Rain Simulation
4	3	MID-04-AR-1A	8/29/06	12:30	TKN Nitrogen	EPA 351.2	<1.000	mg/L	33.2	Rain Simulation
4	4	EFF-04-AR-1A	8/29/06	12:35	TKN Nitrogen	EPA 351.2	<1.000	mg/L	33.9	Rain Simulation

4	5	EFF-04-AR-1M	8/29/06	12:50	TKN Nitrogen	EPA 351.2	<1.000	mg/L	43.1	Rain Simulation
5	2	INF-05-RF-1A	9/1/06	8:00	TKN Nitrogen	EPA 351.2	<1.000	mg/L	35.0	
5	2	INF-05-RF-1B	9/1/06	9:20	TKN Nitrogen	EPA 351.2	<1.000	mg/L	47.6	
5	3	MID-05-RF-1A	9/1/06	9:00	TKN Nitrogen	EPA 351.2	<1.000	mg/L	24.0	
5	4	EFF-05-RF-1A	9/1/06	9:25	TKN Nitrogen	EPA 351.2	<1.000	mg/L	22.2	
5	4	EFF-05-RF-1B	9/1/06	10:22	TKN Nitrogen	EPA 351.2	<1.000	mg/L	24.2	
6	3	MID-06-RF-1B	9/1/06	9:57	TKN Nitrogen	EPA 351.2	<1.000	mg/L	62.0	
6	3	MID-06-RF-1A	9/1/06	21:50	TKN Nitrogen	EPA 351.2	<1.000	mg/L	58.4	
6	4	EFF-06-RF-1A	9/1/06	15:23	TKN Nitrogen	EPA 351.2	<1.000	mg/L	38.2	
6	4	EFF-06-RF-1B	9/1/06	18:03	TKN Nitrogen	EPA 351.2	<1.000	mg/L	47.2	
7	1	INF-07-RF-1M	9/2/06	19:45	TKN Nitrogen	EPA 351.2	<1.000	mg/L	56.4	
7	2	INF-07-RF-1A	9/2/06	19:50	TKN Nitrogen	EPA 351.2	<1.000	mg/L	52.0	
7	4	EFF-07-RF-1A	9/2/06	21:00	TKN Nitrogen	EPA 351.2	<1.000	mg/L	56.0	
7	5	EFF-07-RF-1M	9/2/06	20:05	TKN Nitrogen	EPA 351.2	<1.000	mg/L	51.2	
7	3	MID-07-RF-1A	9/3/06	5:33	TKN Nitrogen	EPA 351.2	<1.000	mg/L	59.6	
7	3	MID-07-RF-1B	9/3/06	8:27	TKN Nitrogen	EPA 351.2	<1.000	mg/L	62.0	
8	2	INF-08-RF-1A	9/22/06	14:25	TKN Nitrogen	EPA 351.2	<1.000	mg/L	52.0	
8	3	MID-08-RF-1A	9/22/06	14:25	TKN Nitrogen	EPA 351.2	<1.000	mg/L	24.0	
8	3	MID-08-RF-1A	9/22/06	14:25	TKN Nitrogen	EPA 351.2	<1.000	mg/L	24.0	
8	4	EFF-08-RF-1A	9/22/06	11:45	TKN Nitrogen	EPA 351.2	<1.000	mg/L	49.6	
8	4	EFF-08-RF-1B	9/22/06	14:25	TKN Nitrogen	EPA 351.2	<1.000	mg/L	50.4	
9	2	INF-09-RF-1B	9/23/06	3:00	TKN Nitrogen	EPA 351.2	<1.000	mg/L	53.6	
9	3	MID-09-RF-1A	9/23/06	15:05	TKN Nitrogen	EPA 351.2	<1.000	mg/L	48.0	
9	3	MID-09-RF-1B	9/23/06	18:14	TKN Nitrogen	EPA 351.2	<1.000	mg/L	47.2	
9	4	EFF-09-RF-1A	9/23/06	6:01	TKN Nitrogen	EPA 351.2	<1.000	mg/L	39.8	
10	1	INF-10-RF-1M	12/30/06	20:45	TKN Nitrogen	EPA 351.2	<1.000	mg/L	138	
10	2	INF-10-RF-1A	12/30/06	20:00	TKN Nitrogen	EPA 351.2	<1.000	mg/L	153	
10	3	MID-10-RF-1A	12/30/06	20:50	TKN Nitrogen	EPA 351.2	<1.000	mg/L	115	
10	4	EFF-10-RF-1A	12/30/06	20:19	TKN Nitrogen	EPA 351.2	<1.000	mg/L	77.6	

10	5	EFF-10-RF-1M	12/30/06	20:40	TKN Nitrogen	EPA 351.2	<1.000	mg/L	93.2	
11	1	INF-11-RF-1M	3/31/07	14:20	TKN Nitrogen	EPA 351.2	<1.000	mg/L	213	
11	2	INF-11-RF-1A	3/31/07	14:47	TKN Nitrogen	EPA 351.2	<1.000	mg/L	170	
11	3	MID-11-RF-1A	3/31/07	14:57	TKN Nitrogen	EPA 351.2	<1.000	mg/L	181	
11	4	EFF-11-RF-1A	3/31/07	15:07	TKN Nitrogen	EPA 351.2	<1.000	mg/L	158	
11	5	EFF-11-RF-1M	3/31/07	15:14	TKN Nitrogen	EPA 351.2	<1.000	mg/L	174	
12	1	IN-12-RF-1M	4/22/07	13:40	TKN Nitrogen	EPA 351.2	<1.000	mg/L	156	
12	2	IN-12-RF-1A	4/22/07	13:48	TKN Nitrogen	EPA 351.2	<1.000	mg/L	141	
12	3	MID-12-RF-1A	4/22/07	14:00	TKN Nitrogen	EPA 351.2	<1.000	mg/L	160	
12	4	EFF-12-RF-1A	4/22/07	14:10	TKN Nitrogen	EPA 351.2	<1.000	mg/L	167	
12	5	EFF-12-RF-1M	4/22/07	14:20	TKN Nitrogen	EPA 351.2	<1.000	mg/L	141	
11	1	INF-11-RF-1M	3/31/07	14:20	Total Dissolved Solids	USGS I-1750-85	<0.50	mg/L	2,289	
11	2	INF-11-RF-1A	3/31/07	14:47	Total Dissolved Solids	USGS I-1750-85	<0.50	mg/L	2,230	
11	3	MID-11-RF-1A	3/31/07	14:57	Total Dissolved Solids	USGS I-1750-85	<0.50	mg/L	2,514	
11	4	EFF-11-RF-1A	3/31/07	15:07	Total Dissolved Solids	USGS I-1750-85	<0.50	mg/L	2,935	
11	5	EFF-11-RF-1M	3/31/07	15:14	Total Dissolved Solids	USGS I-1750-85	<0.50	mg/L	2,994	
12	1	IN-12-RF-1M	4/22/07	13:40	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	2,311	
12	2	IN-12-RF-1A	4/22/07	13:48	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	3,048	
12	3	MID-12-RF-1A	4/22/07	14:00	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	3,058	
12	4	EFF-12-RF-1A	4/22/07	14:10	Total Dissolved Solids	USGS I-1750-85	<1.000	mg/L	2,927	
12	5	EFF-12-RF-1M	4/22/07	14:20	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	2,800	
1	1	INF-01-SM-1M	3/9/05	13:10	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	3,260	Snow Melt
1	5	EFF-01-SM-3M	3/9/05	13:00	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	4,282	Snow Melt
2	1	INF-02-RF-1M	4/30/06	15:30	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	3,010	
2	3	MID-02-RF-2A	4/30/06	14:45	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	3,055	
2	4	EFF-02-R1-3A	4/30/06	14:45	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	2,666	
3	2	INF-03-RF-1A	5/23/06	22:22	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	915	
3	4	EFF-03-RF-1A	5/23/06	22:49	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	*	TDS & TSS Received Preserved, Unable To Do That Analysis
3	3	MID-03-RF-1A	5/24/06	3:31	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	2,136	

3	3	MID-03-RF-2A	5/24/06	3:54	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	2,195	
4	1	INF-04-AR-1M	8/29/06	11:43	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	2,089	Rain Simulation
4	2	INF-04-AR-1A	8/29/06	12:02	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	1,294	Rain Simulation
4	3	MID-04-AR-1A	8/29/06	12:30	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	1,838	Rain Simulation
4	4	EFF-04-AR-1A	8/29/06	12:35	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	2,191	Rain Simulation
4	5	EFF-04-AR-1M	8/29/06	12:50	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	1,286	Rain Simulation
5	2	INF-05-RF-1A	9/1/06	8:00	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	946	
5	2	INF-05-RF-1B	9/1/06	9:20	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	1,123	
5	3	MID-05-RF-1A	9/1/06	9:00	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	1,306	
5	4	EFF-05-RF-1A	9/1/06	9:25	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	1,489	
5	4	EFF-05-RF-1B	9/1/06	10:22	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	1,401	
6	3	MID-06-RF-1B	9/1/06	9:57	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	2,012	
6	3	MID-06-RF-1A	9/1/06	21:50	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	2,062	
6	4	EFF-06-RF-1A	9/1/06	15:23	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	1,441	
6	4	EFF-06-RF-1B	9/1/06	18:03	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	1,409	
7	1	INF-07-RF-1M	9/2/06	19:45	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	1,085	
7	2	INF-07-RF-1A	9/2/06	19:50	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	1,155	
7	4	EFF-07-RF-1A	9/2/06	21:00	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	2,608	
7	5	EFF-07-RF-1M	9/2/06	20:05	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	2,353	
7	3	MID-07-RF-1A	9/3/06	5:33	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	1,757	
7	3	MID-07-RF-1B	9/3/06	8:27	Total Dissolved Solids	USGS I-1750-85	<1.00	mG/L	1,808	
8	2	EFF-08-RF-1B	9/22/06	14:25	Total Dissolved Solids	S USGS I-1750-85	<1.00	mg/L	2,736	
8	3	INF-08-RF-1A	9/22/06	14:25	Total Dissolved Solids	DS USGS I-1750-85	<1.00	mg/L	2,483	
8	3	MID-08-RF-1A	9/22/06	14:25	Total Dissolved Solids	DS USGS I-1750-85	<1.00	mg/L	2,566	
8	4	EFF-08-RF-1A	9/22/06	11:45	Total Dissolved Solids	S USGS I-1750-85	<1.00	mg/L	2,651	
8	4	MID-08-RF-1A	9/22/06	14:25	Total Dissolved Solids	DS USGS I-1750-85	<1.00	mg/L	2,566	
9	2	INF-09-RF-1B	9/23/06	3:00	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	2,197	
9	3	MID-09-RF-1A	9/23/06	15:05	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	2,398	
9	3	MID-09-RF-1B	9/23/06	18:14	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	2,472	

9	4	EFF-09-RF-1A	9/23/06	6:01	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	2,364	
10	1	INF-10-RF-1M	12/30/06	20:45	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	1,814	
10	2	INF-10-RF-1A	12/30/06	20:00	Total Dissolved Solids	USGU I-1750-85	<1.00	mg/L	2,194	
10	3	MID-10-RF-1A	12/30/06	20:50	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	2,317	
10	4	EFF-10-RF-1A	12/30/06	20:19	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	2,334	
10	5	EFF-10-RF-1M	12/30/06	20:40	Total Dissolved Solids	USGS I-1750-85	<1.00	mg/L	2,627	
1	1	INF-01-SM-1M	3/9/05	13:10	Total Phosphorus	EPA 365.4	<0.003	mg/L	44.0	Snow Melt
1	5	EFF-01-SM-3M	3/9/05	13:00	Total Phosphorus	EPA 365.4	<0.003	mg/L	37.0	Snow Melt
2	1	INF-02-RF-1M	4/30/06	15:30	Total Phosphorus	SM 4500-P E	<0.050	mg/L	25.0	
2	3	EFF-02-R1-3A	4/30/06	14:45	Total Phosphorus	SM 4500-P E	<0.050	mg/L	28.0	
2	4	MID-02-RF-2A	4/30/06	14:45	Total Phosphorus	SM 4500-P E	<0.050	mg/L	26.0	
3	2	INF-03-RF-1A	5/23/06	22:22	Total Phosphorus	SM 4500-P E	<0.050	mg/L	10.8	
3	4	EFF-03-RF-1A	5/23/06	22:49	Total Phosphorus	SM 4500-P E	<0.050	mg/L	15.4	
3	3	MID-03-RF-1A	5/24/06	3:31	Total Phosphorus	SM 4500-P E	<0.050	mg/L	12.2	
3	3	MID-03-RF-2A	5/24/06	3:54	Total Phosphorus	SM 4500-P E	<0.050	mg/L	10.6	
4	1	INF-04-AR-1M	8/29/06	11:43	Total Phosphorus	SM 4500-P E	<0.050	mg/L	4.40	Rain Simulation
4	2	INF-04-AR-1A	8/29/06	12:02	Total Phosphorus	SM 4500-P E	<0.050	mg/L	6.60	Rain Simulation
4	3	MID-04-AR-1A	8/29/06	12:30	Total Phosphorus	SM 4500-P E	<0.050	mg/L	5.60	Rain Simulation
4	4	EFF-04-AR-1A	8/29/06	12:35	Total Phosphorus	SM 4500-P E	<0.050	mg/L	4.20	Rain Simulation
4	5	EFF-04-AR-1M	8/29/06	12:50	Total Phosphorus	SM 4500-P E	<0.050	mg/L	13.2	Rain Simulation
5	2	INF-05-RF-1A	9/1/06	8:00	Total Phosphorus	SM 4500-P E	<0.050	mg/L	10.0	
5	2	INF-05-RF-1B	9/1/06	9:20	Total Phosphorus	SM 4500-P E	<0.050	mg/L	9.00	
5	3	MID-05-RF-1A	9/1/06	9:00	Total Phosphorus	SM 4500-P E	<0.050	mg/L	6.00	
5	4	EFF-05-RF-1A	9/1/06	9:25	Total Phosphorus	SM 4500-P E	<0.050	mg/L	5.40	
5	4	EFF-05-RF-1B	9/1/06	10:22	Total Phosphorus	SM 4500-P E	<0.050	mg/L	5.90	
6	3	MID-06-RF-1B	9/1/06	9:57	Total Phosphorus	SM 4500-P E	<0.050	mg/L	10.4	
6	3	MID-06-RF-1A	9/1/06	21:50	Total Phosphorus	SM 4500-P E	<0.050	mg/L	10.6	
6	4	EFF-06-RF-1A	9/1/06	15:23	Total Phosphorus	SM 4500-P E	<0.050	mg/L	8.60	
6	4	EFF-06-RF-1B	9/1/06	18:03	Total Phosphorus	SM 4500-P E	<0.050	mg/L	10.2	

7	1	INF-07-RF-1M	9/2/06	19:45	Total Phosphorus	SM 4500-P E	<0.050	mg/L	16.0	
7	2	INF-07-RF-1A	9/2/06	19:50	Total Phosphorus	SM 4500-P E	<0.050	mg/L	11.6	
7	4	EFF-07-RF-1A	9/2/06	21:00	Total Phosphorus	SM 4500-P E	<0.050	mg/L	9.80	
7	5	EFF-07-RF-1M	9/2/06	20:05	Total Phosphorus	SM 4500-P E	<0.050	mg/L	12.6	
7	3	MID-07-RF-1A	9/3/06	5:33	Total Phosphorus	SM 4500-P E	<0.050	mg/L	14.0	
7	3	MID-07-RF-1B	9/3/06	8:27	Total Phosphorus	SM 4500-P E	<0.050	mg/L	15.6	
8	2	MID-08-RF-1A	9/22/06	14:25	Total Phosphorus	SM 4500-P E	<0.050	mg/L	15.0	
8	3	EFF-08-RF-1B	9/22/06	14:25	Total Phosphorus	SM 4500-P E	<0.050	mg/L	11.0	
8	3	INF-08-RF-1A	9/22/06	14:25	Total Phosphorus	SM 4500-P E	<0.050	mg/L	12.0	
8	4	EFF-08-RF-1A	9/22/06	11:45	Total Phosphorus	SM 4500-P E	<0.050	mg/L	11.0	
8	4	MID-08-RF-1A	9/22/06	14:25	Total Phosphorus	SM 4500-P E	<0.050	mg/L	15.0	
9	2	INF-09-RF-1B	9/23/06	3:00	Total Phosphorus	SM 4500-P E	<0.050	mg/L	20.0	
9	3	MID-09-RF-1A	9/23/06	15:05	Total Phosphorus	SM 4500-P E	<0.050	mg/L	13.0	
9	3	MID-09-RF-1B	9/23/06	18:14	Total Phosphorus	SM 4500-P E	<0.050	mg/L	14.0	
9	4	EFF-09-RF-1A	9/23/06	6:01	Total Phosphorus	SM 4500-P E	<0.050	mg/L	13.0	
10	1	INF-10-RF-1M	12/30/06	20:45	Total Phosphorus	SM 4500-P E	<0.050	mg/L	26.0	
10	2	INF-10-RF-1A	12/30/06	20:00	Total Phosphorus	SM 4500-P E	<0.050	mg/L	23.0	
10	3	MID-10-RF-1A	12/30/06	20:50	Total Phosphorus	SM 4500-P E	<0.050	mg/L	23.0	
10	4	EFF-10-RF-1A	12/30/06	20:19	Total Phosphorus	SM 4500-P E	<0.050	mg/L	16.0	
10	5	EFF-10-RF-1M	12/30/06	20:40	Total Phosphorus	SM 4500-P E	<0.050	mg/L	18.0	
11	1	INF-11-RF-1M	3/31/07	14:20	Total Phosphorus	SM 4500-P E	<0.050	mg/L	24.9	
11	2	INF-11-RF-1A	3/31/07	14:47	Total Phosphorus	SM 4500-P E	<0.050	mg/L	23.3	
11	3	MID-11-RF-1A	3/31/07	14:57	Total Phosphorus	SM 4500-P E	<0.050	mg/L	21.5	
11	4	EFF-11-RF-1A	3/31/07	15:07	Total Phosphorus	SM 4500-P E	<0.050	mg/L	18.0	
11	5	EFF-11-RF-1M	3/31/07	15:14	Total Phosphorus	SM 4500-P E	<0.050	mg/L	18.8	
12	1	IN-12-RF-1M	4/22/07	13:40	Total Phosphorus	SM 4500-P E	<0.050	mg/L	10.4	
12	2	IN-12-RF-1A	4/22/07	13:48	Total Phosphorus	SM 4500-P E	<0.050	mg/L	9.80	
12	3	MID-12-RF-1A	4/22/07	14:00	Total Phosphorus	SM 4500-P E	<0.050	mg/L	19.0	
12	4	EFF-12-RF-1A	4/22/07	14:10	Total Phosphorus	SM 4500-P E	<0.050	mg/L	10.3	

12	5	EFF-12-RF-1M	4/22/07	14:20	Total Phosphorus	SM 4500-P E	<0.050	mg/L	7.90	
1	1	INF-01-SM-1M	3/9/05	13:10	Total Suspended Solids	EPA 160.1	<0.50	mg/L	1,564	Snow Melt
1	5	EFF-01-SM-3M	3/9/05	13:00	Total Suspended Solids	EPA 160.1	<0.50	mg/L	242	Snow Melt
2	1	INF-02-RF-1M	4/30/06	15:30	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	103	
2	3	EFF-02-R1-3A	4/30/06	14:45	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	123	
2	4	MID-02-RF-2A	4/30/06	14:45	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	116	
3	2	INF-03-RF-1A	5/23/06	22:22	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	692	
3	4	EFF-03-RF-1A	5/23/06	22:49	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	*	TDS & TSS Received Preserved, Unable To Do That Analysis
3	3	MID-03-RF-1A	5/24/06	3:31	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	78.6	
3	3	MID-03-RF-2A	5/24/06	3:54	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	100	
4	1	INF-04-AR-1M	8/29/06	11:43	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	66.7	Rain Simulation
4	2	INF-04-AR-1A	8/29/06	12:02	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	895	Rain Simulation
4	3	MID-04-AR-1A	8/29/06	12:30	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	86.2	Rain Simulation
4	4	EFF-04-AR-1A	8/29/06	12:35	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	96.8	Rain Simulation
4	5	EFF-04-AR-1M	8/29/06	12:50	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	3,030	Rain Simulation
5	2	INF-05-RF-1A	9/1/06	8:00	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	676	
5	2	INF-05-RF-1B	9/1/06	9:20	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	536	
5	3	MID-05-RF-1A	9/1/06	9:00	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	96.6	
5	4	EFF-05-RF-1A	9/1/06	9:25	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	68.8	
5	4	EFF-05-RF-1B	9/1/06	10:22	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	57.8	
6	3	MID-06-RF-1B	9/1/06	9:57	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	103	
6	3	MID-06-RF-1A	9/1/06	21:50	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	120	
6	4	EFF-06-RF-1A	9/1/06	15:23	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	104	
6	4	EFF-06-RF-1B	9/1/06	18:03	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	83.0	
7	1	INF-07-RF-1M	9/2/06	19:45	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	756	
7	2	INF-07-RF-1A	9/2/06	19:50	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	362	
7	4	EFF-07-RF-1A	9/2/06	21:00	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	114	
7	5	EFF-07-RF-1M	9/2/06	20:05	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	137	
7	3	MID-07-RF-1A	9/3/06	5:33	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	121	

7	3	MID-07-RF-1B	9/3/06	8:27	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	71.9	
8	2	INF-08-RF-1A	9/22/06	14:25	Total Suspended Solids	DS USGS I-3765-85	<0.50	mg/L	106	
8	3	EFF-08-RF-1B	9/22/06	14:25	Total Suspended Solids	S USGS I-3765-85	<0.50	mg/L	36.7	
8	3	MID-08-RF-1A	9/22/06	14:25	Total Suspended Solids	DS USGS I-3765-85	<0.50	mg/L	45.2	
8	4	EFF-08-RF-1A	9/22/06	11:45	Total Suspended Solids	S USGS I-3765-85	<0.50	mg/L	40.0	
8	4	MID-08-RF-1A	9/22/06	14:25	Total Suspended Solids	DS USGS I-3765-85	<0.50	mg/L	45.2	
9	2	INF-09-RF-1B	9/23/06	3:00	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	262	
9	3	MID-09-RF-1A	9/23/06	15:05	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	25.0	
9	3	MID-09-RF-1B	9/23/06	18:14	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	23.7	
9	4	EFF-09-RF-1A	9/23/06	6:01	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	22.5	
10	1	INF-10-RF-1M	12/30/06	20:45	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	1,010	
10	2	INF-10-RF-1A	12/30/06	20:00	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	895	
10	3	MID-10-RF-1A	12/30/06	20:50	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	495	
10	4	EFF-10-RF-1A	12/30/06	20:19	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	168	
10	5	EFF-10-RF-1M	12/30/06	20:40	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	305	
11	1	INF-11-RF-1M	3/31/07	14:20	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	1,360	
11	2	INF-11-RF-1A	3/31/07	14:47	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	932	
11	3	MID-11-RF-1A	3/31/07	14:57	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	394	
11	4	EFF-11-RF-1A	3/31/07	15:07	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	358	
11	5	EFF-11-RF-1M	3/31/07	15:14	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	396	
12	1	IN-12-RF-1M	4/22/07	13:40	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	641	
12	2	IN-12-RF-1A	4/22/07	13:48	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	143	
12	3	MID-12-RF-1A	4/22/07	14:00	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	148	
12	4	EFF-12-RF-1A	4/22/07	14:10	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	226	
12	5	EFF-12-RF-1M	4/22/07	14:20	Total Suspended Solids	USGS I-3765-85	<0.50	mg/L	133	

Note: Blue shading indicates that midpoint sample was collected after effluent sample.

Table 2. Analytical Results for Potassium Bromide Tracer Test

Lab Sample ID	Sample ID	Bromide Concentration (mg/l)	Collection Time After Start (minutes)	Flow-Path Position
F07060281-044	Tank	1,400	0	1
F07060281-052	In 1	330	16	2
F07060281-053	In 2	920	18	2
F0706D281-001	In 3	1,100	20	2
F07060281-002	In 4	1,100	24	2
Not enough sample	In 5	-	26	2
Not enough sample	In 6	-	29	2
F07060281-054	In 7	1,000	31	2
F07060281-003	in 8	1,200	35	2
F07060281-004	In 9	1,200	38	2
F0706D281-005	In 10	1,200	41	2
F07060281-006	In 11	1,200	46	2
FD7060281-007	In 12	1,100	48	2
F0706D281-008	In 13	1,100	51	2
F07060281-009	In 14	960	56	2
F07060281-010	In 15	940	60	2
F07060281-011	In 16	880	66	2
F07060281-012	In 17	840	72	2
F07060281-051	Mid Start	420	60	3
F07060281-013	Mid 4	<5	26	3
F07060281-014	Mid 5	<5	29	3
F07060281-015	Mid 6	24	31	3
F07060281-016	Mid 7	<5	35	3
F07D6D281-017	Mid 8	28	43	3
F07060281-018	Mid 9	28	41	3
F07060281-019	Mid 10	38	46	3
F07060281-020	Mid 11	34	48	3
F07060281-021	Mid 12	58	51	3
F07D60281-022	Mid 13	90	56	3
F07060281-023	Mid 14	97	60	3
F07060281-024	Mid 15a	130	66	3
F07060281-025	Mid 15b	150	72	3
F07060281-026	Mid 16	190	80	3
F07060281-027	Mid 17	250	90	3
F07060281-028	Mid 18	290	100	3
F07D60281-029	Mid 19	350	120	3
FD7060281-050	Eff start	110	60	4
F07D60281-030	Eff 4	<5	35	4
F07060281-031	Eff 5	<5	38	4
F07D60281-032	Eff 6	<5	41	4
FD7060281-033	Eff 7	<5	46	4
F07060281-034	Eff 8	<5	48	4
F07D60281-035	Eff 9	<5	51	4
F07060281-036	Eff 10	<5	56	4
F07060281-037	Eff 11	18	60	4
F07060281-038	Eff 12	<5	66	4
F07060281-039	Eff 13	58	72	4
F07060281-040	Eff 14a	56	80	4
F07060281-041	Eff 14b	99	90	4
F07060281-042	Eff 15	94	100	4
F07060281-D43	Eff 16	130	120	4
F07060281-048	Eff 1M 1	<5	62	5
F07060281-D47	Eff 1M 2	8	75	5
F07060281-049	Eff 1M 3	<5	90	5

Table 3. Pre-Tracer Test Woodchip Media Sample Results

Biofilter Sample Location	**Influent**	**Midpoint**	**Effluent**
Sample Depth (Inches)	44	41	41
Collection Date	5/16/2007	5/16/2007	5/16/2007
Stearns DHIA Laboratories Sample #	21678	21679	21680
Loss on Ignition,%	38.23	33.07	31.41
Organic Matter,%	26.53	22.92	21.75
Carbon:Nitrogen Ratio	62.99	86.52	80.44
Pre-Tracer Test Bromide (mg/kg)	46.09	41.10	53.30

Note: Samples were obtained near base of woodchip biofilter (where moist) using a hand auger.

Attachment A: Budget Detail for 2005 Projects - Summary and Budget page for "Woodchip Biofilter Treatment of Feedlot Runoff (Water Resources O7h)."
(see spreadsheets below for detailed breakdown for Stearns County SWCD, UM, and GES, Inc.)
Proposal Title: "Woodchip Biofilter Treatment of Feedlot Runoff (Water Resources O7h)"
DATE Revised: **8/16/2007**
Project Manager Name: Dennis Fuchs, Stearns County Soil and Water District.

LCMR Requested Dollars: $ *270,000.*

2005 LCMR Total Proposal Budget (see spreadsheets below for details)	**Result 1**	**Amount Spent**	**Balance**	**Result 2**	**Amount Spent**	**Balance**	**Result 3 Budget:**	**Amount Spent**	**Balance**	**TOTAL FOR BUDGET ITEM**	**Total Spent**
	Lab testing and System Design			*Field Installation and Monitoring UN WCROC Morris*			*Farm Demonstration, Stearns County*				
BUDGET ITEM	July 1, 2005 - June 30, 2007			July 1, 2005 - June 30, 2007			July 1, 2005 - June 30, 2007				
PERSONNEL: Staff Expenses, wages, salaries – *University of Minnesota*	**24,960.00**	**27,618.92**	**-2,658.92**	**43,200.00**	**46,605.61**	**-3,405.61**	**0.00**	**0.00**	**0.00**	**68,160.00**	**74,224.53**
PERSONNEL: Staff benefits *– University of Minnesota*	**13,392.35**	**14,404.96**	**-1,012.61**	**20,131.49**	**19,085.69**	**1,045.80**	**0.00**	**0.00**	**0.00**	**33,523.84**	**33,490.65**
Contracts											
Professional/technical *(details below)*											
GES (to be sub contracted under Stearns SWCD)	**1,955.00**	**1,955.00**	**0.00**	**43,998.49**	**43,998.49**	**0.00**	**0.00**	**0.00**	**0.00**	**45,953.49**	**45,953.49**
CMSWCD 5	**0.00**	**0.00**	**0.00**	**1,500.00**	**1,500.00**	**0.00**	**33,000.00**	**33,000.00**	**0.00**	**34,500.00**	**34,500.00**
Bob Guthrie (Includes equip & travel)	**0.00**	**0.00**	**0.00**	**6,537.89**	**5,586.59**	**951.30**	**0.00**	**0.00**	**0.00**	**6,537.89**	**5,586.59**
Vendor Services											
USDA-ARS & DHIA Labs	**0.00**	**0.00**	**0.00**	**10,000.00**	**9,723.08**	**276.92**	**0.00**	**0.00**	**0.00**	**10,000.00**	**9,723.08**
Equipment / Tools *(details below)*	**1,100.00**	**0.00**	**1,100.00**	**26,484.68**	**26,484.68**	**0.00**	**0.00**	**0.00**	**0.00**	**27,584.68**	**26,484.68**
Travel expenses in Minnesota *(details below)*	**621.00**	**506.46**	**114.54**	**2,694.53**	**2,161.94**	**532.59**	**0.00**	**0.00**	**0.00**	**3,315.53**	**2,668.40**
Construction *(details below)*	**0.00**	**0.00**	**0.00**	**7,724.98**	**5,962.95**	**1,762.03**	**0.00**	**0.00**	**0.00**	**7,724.98**	**5,962.95**
Other Laboratory analysis of samples UM: N, P, e. coli, flow, retention curves, etc. (result 2 bio-media analysis)	**11,218.00**	**849.50**	**10,368.50**	**5,015.00**	**2,198.77**	**2,816.23**	**0.00**	**0.00**	**0.00**	**16,233.00**	**3,048.27**
Other, Utility bills for Electricity and telephone at Morris to collect and transmit data (UM).	**0.00**	**0.00**	**0.00**	**1,483.00**	**1,607.66**	**-124.66**	**0.00**	**0.00**	**0.00**	**1,483.00**	**1,607.66**
Other Supplies (*details below*)	**2,900.00**	**3,849.15**	**-949.15**	**12,083.63**	**5,956.04**	**5,719.59**	**0.00**	**0.00**	**0.00**	**14,983.63**	**9,805.19**
COLUMN TOTAL	**56,146.35**	**49,183.99**	**6,962.36**	**180,853.69**	**170,871.50**	**9,574.19**	**33,000.00**	**33,000.00**	**0.00**	**270,000.04**	**253,055.49**

Sub-Budget Detail for 2005 Projects - **Summary and a Budget page for Stearns County Soil and Water District.**

Proposal Title: "Woodchip Biofilter Treatment of Feedlot Runoff (Water Resources O7h)"

Project Manager Name: Dennis Fuchs, Stearns County Soil and Water District.

LCMR Requested Dollars: $ *46,000*

2005 LCMR Proposal Budget	**Result 1**	**Amount Spent**	**Balance**	**Result 2**	**Amount Spent**	**Balance**	**Result 3 Budget:**	**Amount Spent**	**Balance**	**TOTAL FOR BUDGET ITEM**
	Lab testing and System Design			*Field Installation and Monitoring UN WCROC Morris*			*Farm Demonstration, Stearns County*			
BUDGET ITEM	July 1, 2005 - June 30, 2007			July 1, 2005 - June 30, 2007			July 1, 2005 - June 30, 2007			
Contracts										
Professional/technical Contract with Central Minnesota SWCDs Joint Powers Five (CMSWCD 5) technician at $30/hr for a total of 1150 hours ($34,500); identify demo site for Result 3.				**1,500.00**	**1,500.00**	**0.00**	**33,000.00**	**33,000.00**	**0.00**	**34,500.00**
Vendor Services										
Laboratory Services - USDA-ARS Morris Laboratory and DHIA Laboratory - Sample Pickup and Analyses = 3 samples (influent-midpoint-effluent) per event for parameters: Total P, TSS, TDS, Fecal Coliform, DOC, COD, Total N, Ammonia N, Nitrate+Nitrite	0.00			**10,000.00**	**9,723.08**	**276.92**				**10,000.00**
Travel expenses in Minnesota	**500.00**	**385.46**	**114.54**	**1,000.00**	**616.76**	**383.24**	**0.00**			**1,500.00**
COLUMN TOTAL	**500.00**	**385.46**	**114.54**	**12,500.00**	**11,839.84**	**660.16**	**33,000.00**	**33,000.00**	**0.00**	**46,000.00**

Sub-Budget Detail for 2005 Projects - Summary and a Budget page for University of Minnesota.
Proposal Title: "Woodchip Biofilter Treatment of Feedlot Runoff (Water Resources O7h)"

Project Manager Name: **Thomas R. Halbach**
Department of Soil, Water, and Climate, University of Minnesota, Room 225 Soil Science
1991 Upper Buford Circle
St. Paul, MN 55108
ph (612) 625-3135 email: thalbach@umn.edu

LCMR Requested Dollars: **$143,960**

2005 LCMR Proposal Budget	**Result 1**	**Amount Spent**	**Balance**	**Result 2**	**Amount Spent**	**Balance**	**Result 3 Budget:**	**Amount Spent**	**Balance**	**TOTAL FOR BUDGET ITEM**
BUDGET ITEM	*Lab testing and System Design*			*Field Installation and Monitoring UN WCROC Morris*			*Farm Demonstration, Stearns County*			
PERSONNEL: Staff Expenses, wages, salaries – *Be specific on who is paid $, to do what? Make each person paid a separate line item*	July 1, 2005 - June 30, 2007.			July 1, 2005 - June 30, 2007			July 1, 2005 - June 30, 2007			
Thomas R. Halbach, Professor and Extension Educator. Supervise MS student and coordinate U of M team. 3%of total time in 2005-2006 and 4% of total time in 2006-2007.	**2,288.00**	**2,288.00**	**0.00**	**3,142.00**	**3,142.00**	**0.00**	**0.00**	**0.00**	**0.00**	**5,430.00**
Stephanie Widmeier, MS Student, Research Assistant, $17,600 2005-2006 and $18,200 2006-2007.	**18,465.00**	**21,032.88**	**-2,567.88**	**21,333.00**	**23,013.00**	**-1,680.00**	**0.00**	**0.00**	**0.00**	**39,798.00**
Satish Gupta, Professor. Conduct lab analysis N. P, solids and 3 or more media on bench scale testing. 2% of total time.	**2,703.00**	**2,794.04**	**-91.04**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**2,703.00**
~~Yogesh Chander, Post Doc. Measure e.coli, $27.27/hr for 110 hours~~	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Holly Swanson, PhD student 80 hrs @ $17.35/hr lab work	**0.00**	**0.00**	**0.00**	**1,389.00**	**1,389.00**	**0.00**	**0.00**	**0.00**	**0.00**	**1,389.00**
Cluck Clanton, Professor, bench scale testing, result 1 40hrs@ $37.60/hrs. Result 2 Design and field work at Morris, 20 hrs. @ $37.60/hrs.	**1,504.00**	**1,504.00**	**0.00**	**752.00**	**752.00**	**0.00**	**0.00**	**0.00**	**0.00**	**2,256.00**
Gregory Cuomo, UM WCROC Morris, coordinate Morris staff for this project.	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Asst. Scientist, UM WCROC Morris, 544 hours @ $20.22, carry out the field work at Morris.	**0.00**	**0.00**	**0.00**	**11,000.00**	**18,228.61**	**-7,228.61**	**0.00**	**0.00**	**0.00**	**11,000.00**
Summer Assistant Student, Um WCROC Morris, support result 2. 446hrs. @ 12.52/hrs.	**0.00**	**0.00**	**0.00**	**5,584.00**	**81.00**	**5,503.00**	**0.00**	**0.00**	**0.00**	**5,584.00**
Subtotal	**24,960.00**	**27,618.92**	**-2,658.92**	**43,200.00**	**46,605.61**	**-3,405.61**	**0.00**	**0.00**	**0.00**	**68,160.00**
PERSONNEL: Staff benefits – *Be specific; list benefits for each person on a separate line item*								**0.00**	**0.00**	**0.00**
Thomas R. Halbach, 33.0% in 2005-2006; 33.7% in 2006-2007.	**755.04**	**623.66**	**131.38**	**1,058.85**	**476.31**	**582.54**	**0.00**	**0.00**	**0.00**	**1,813.89**
Stephanie Widmeier, 83% in 2005-2006; 87% in 2006-2007.	**11,249.00**	**12,634.56**	**-1,385.56**	**13,637.00**	**12,468.89**	**1,168.11**	**0.00**	**0.00**	**0.00**	**24,886.00**
Satish Gupta, 33.0% in 2005-2006; 33.7% in 2006-2004	**891.99**	**736.78**	**155.21**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**891.99**
Yogesh Chander, 19.4% in 2005-2006; 20.1 % in 2006-2007.	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Holly Swanson, PhD student 67% in 2006-2007	**0.00**	**0.00**	**0.00**	**930.00**	**930.00**	**0.00**	**0.00**	**0.00**	**0.00**	**930.00**
Cluck Clanton, 33.0% in 2005-2006; 33.7% in 2006-2007.	**496.32**	**409.96**	**86.36**	**253.42**	**253.42**	**0.00**	**0.00**	**0.00**	**0.00**	**749.74**
Gregory Cuomo, 0%	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Asst. Scientist, 34.9% in 2005-2007.	**0.00**	**0.00**	**0.00**	**3,839.00**	**4,951.24**	**-1,112.24**	**0.00**	**0.00**	**0.00**	**3,839.00**
Summer Assistant Student, 7.4% in 2005-2007.	**0.00**	**0.00**	**0.00**	**413.22**	**5.83**	**407.39**	**0.00**	**0.00**	**0.00**	**413.22**
Subtotal	**13,392.35**	**14,404.96**	**-1,012.61**	**20,131.49**	**19,085.69**	**1,045.80**	**0.00**	**0.00**	**0.00**	**33,523.84**
Equipment / Tools Lab scale	**1,100.00**	**0.00**	**1,100.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**1,100.00**
Other Supplies									**0.00**	
Lab supplies, chemicals, filters, glass ware, media, etc. Result 1.	**2,900.00**	**3,849.15**	**-949.15**	**5,309.20**	**3,203.29**	**2,105.91**	**0.00**	**0.00**	**0.00**	**8,209.20**
Material installation at Morris	**0.00**	**0.00**	**0.00**	**2,472.00**	**1,684.34**	**787.66**	**0.00**	**0.00**	**0.00**	**2,472.00**
liner at Morris	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Media (woodchips?) at Morris, transport and spreading.	**0.00**	**0.00**	**0.00**	**525.00**	**525.00**	**0.00**	**0.00**	**0.00**	**0.00**	**525.00**
silt fence at Morris	**0.00**	**0.00**	**0.00**	**295.00**	**295.00**	**0.00**	**0.00**	**0.00**	**0.00**	**295.00**
surface mesh tie-downs	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Vendor Service contract: Equipment repair	**0.00**	**0.00**	**0.00**	**3,234.02**	**408.00**	**2,826.02**	**0.00**			
Subtotal	**2,900.00**	**3,849.15**	**-949.15**	**11,835.22**	**5,707.63**	**5,719.59**	**0.00**	**0.00**	**0.00**	**14,735.22**
Travel expenses in Minnesota $0.385/ mile total miles 2598. Result 1 (315 miles). Result (2, 284) miles.	**121.00**	**121.00**	**0.00**	**879.00**	**729.65**	**149.35**	**0.00**	**0.00**	**0.00**	**1,000.00**
Construction										**0.00**
Grade feedlot to design specifications, Morris.	**0.00**	**0.00**	**0.00**	**1,152.00**	**1,152.00**	**0.00**	**0.00**	**0.00**	**0.00**	**1,152.00**
install electrical power and telephone, Morris.	**0.00**	**0.00**	**0.00**	**4,924.98**	**4,810.95**	**114.03**	**0.00**	**0.00**	**0.00**	**4,924.98**
decommissioning, Morris.	**0.00**	**0.00**	**0.00**	**1,648.00**	**0.00**	**1,648.00**	**0.00**	**0.00**	**0.00**	**1,648.00**
Subtotal	**0.00**	**0.00**	**0.00**	**7,724.98**	**5,962.95**	**1,762.03**	**0.00**	**0.00**	**0.00**	**7,724.98**
Other Laboratory analysis of samples: N, P, fecal coliform, flow, retention curves, etc.	**11,218.00**	**849.50**	**10,368.50**	**5,015.00**	**2,198.77**	**2,816.23**	**0.00**	**0.00**	**0.00**	**16,233.00**
Other, Utility bills for Electricity and telephone at Morris to collect and transmit data.	**0.00**	**0.00**	**0.00**	**1,483.00**	**1,607.66**	**-124.66**	**0.00**	**0.00**	**0.00**	**1,483.00**
COLUMN TOTAL	**53,691.35**	**46,843.53**	**6,847.82**	**90,268.69**	**82,305.96**	**7,962.73**	**0.00**	**0.00**	**0.00**	**143,960.04**

Sub-Budget Detail for 2005 Projects - Summary and a Budget page for GES, Inc. (to be sub contracted under Stearns County SWCD)

Proposal Title: "Woodchip Biofilter Treatment of Feedlot Runoff (Water Resources O7h)"

Project Manager Name: Bob Guthrie, GES, Inc.

LCMR Requested Dollars: ~~$80,040.00~~ **73,523.66 ($6537.89 remaining balance transferred to Bob Guthrie's Sub Contractor Budget Below)**

2005 LCMR Proposal Budget	**Result 1**	**Amount Spent**	**Balance**	**Result 2**	**Amount Spent**	**Balance**	**Result 3 Budget:**	**Amount Spent**	**Balance**	**TOTAL SPENT FOR BUDGET ITEM**
	Lab testing and System Design			*Field Installation and Monitoring UN WCROC Morris*			*Farm Demonstration, Stearns County*			
BUDGET ITEM	July 1, 2005 - June 30, 2007			July 1, 2005 - June 30, 2007			July 1, 2005 - June 30, 2007			
Contracts - GES										
PERSONNEL: Staff Expenses, wages, salaries										
Bob Guthrie (GES) - Status and final report preparation (5 reports), sample collection, monitoring system O&M coordination, and technical coordination. 189 hours @ $115 per hour	**1,955.00**	**1,955.00**	**0.00**	**19,262.50**	**19,262.50**	**0.00**	**0.00**	**0.00**	**0.00**	**21,217.50**
Brian Deering (GES) - Install biofilter sensors, ISEs, and ISCO samplers; Control Construct & Testing; system O&M (six visits) 264 hours @ $56 per hour	**0.00**	**0.00**	**0.00**	**11,839.74**	**11,839.74**	**0.00**	**0.00**	**0.00**	**0.00**	**11,839.74**
Kevin Lienau, P.E. (GES) - Design/install biofilter sensor layout and ISCO sampling equipment. Control Construct, Test and Program (sensor configuration and control programming) 122 hours @ $95 per hour	**0.00**	**0.00**	**0.00**	**12,896.25**	**12,896.25**	**0.00**	**0.00**	**0.00**	**0.00**	**12,896.25**
Subtotal	**1,955.00**	**1,955.00**	**0.00**	**43,998.49**	**43,998.49**	**0.00**	**0.00**	**0.00**	**0.00**	**45,953.49**
Equipment										
Ion Selective Electrodes (ISEs) for Bromide (1) and Iodide (1)	**0.00**	**0.00**	**0.00**	**0.00**			**0.00**	**0.00**	**0.00**	**0.00**
Sensor Controls (Main location - 22 In, 2 Out; Includes: SCADA 3000 -22-In 8 Out; universal input module, power supply, modem, control cabinet, 24-VDC power supply [12 amp], surge suppression and distribution block/wire/terminals/breakers)	**0.00**	**0.00**	**0.00**	**5,523.19**	**5,523.19**	**0.00**	**0.00**	**0.00**	**0.00**	**5,523.19**
Biofilter Sensors (3-sets at influent, midpoint, effluent: pH, ORP, Temperature, Conductivity, Liquid Presence)	**0.00**	**0.00**	**0.00**	**9,003.67**	**9,003.67**	**0.00**	**0.00**	**0.00**	**0.00**	**9,003.67**
Distribution wiring to sensors	**0.00**	**0.00**	**0.00**	**4,238.05**	**4,238.05**	**0.00**	**0.00**	**0.00**	**0.00**	**4,238.05**
Miscellaneous supplies for repairs etc.	**0.00**	**0.00**	**0.00**	**573.62**	**573.62**	**0.00**	**0.00**	**0.00**	**0.00**	**573.62**
1 ISCO 6712FR and GLS Sampler and associated equipment (includes tubing stainless steel strainers, couplers, shipping, taxes)	**0.00**	**0.00**	**0.00**	**7,146.15**	**7,146.15**	**0.00**	**0.00**	**0.00**	**0.00**	**7,146.15**
Subtotal	**0.00**	**0.00**	**0.00**	**26,484.68**	**26,484.68**	**0.00**	**0.00**	**0.00**	**0.00**	**26,484.68**
Other supplies										
Potassium Bromide & Potassium Iodide - Conservative Tracers	**0.00**	**0.00**	**0.00**	**85.58**	**85.58**	**0.00**	**0.00**	**0.00**	**0.00**	**85.58**
Four ISCO Sample Containers	**0.00**	**0.00**	**0.00**	**162.83**	**162.83**	**0.00**	**0.00**	**0.00**	**0.00**	**162.83**
Subtotal	**0.00**	**0.00**	**0.00**	**248.41**	**248.41**	**0.00**	**0.00**	**0.00**	**0.00**	**248.41**
Travel expenses in Minnesota										
Travel and per diem ($100 per day)	**0.00**	**0.00**	**0.00**	**815.53**	**815.53**	**0.00**	**0.00**	**0.00**	**0.00**	**815.53**
Vehicle ($85 per day)	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Subtotal	**0.00**	**0.00**	**0.00**	**815.53**	**815.53**	**0.00**	**0.00**	**0.00**	**0.00**	**815.53**
COLUMN TOTAL	**1,955.00**	**1,955.00**	**0.00**	**71,547.11**	**71,547.11**	**0.00**	**0.00**	**0.00**	**0.00**	**73,502.11**

Sub-Budget Detail for 2005 Projects - **Summary and a Budget page for Bob Guthrie (sub contracted under Stearns County SWCD)**

Proposal Title: "Woodchip Biofilter Treatment of Feedlot Runoff (Water Resources O7h)"

Project Manager Name: Bob Guthrie

LCMR Requested Dollars: $6,537.89

2005 LCMR Proposal Budget	Result 1	Amount Spent	Balance	Result 2	Amount Spent	Balance	Result 3 Budget:	Amount Spent	Balance	TOTAL FOR BUDGET ITEM
PERSONNEL: Staff Expenses, wages, salaries	0.00	0.00	0.00	6,537.89	4,225.00	951.30	0.00	0.00	0.00	6,537.89
Equipment	0.00	0.00	0.00		915.00		0.00	0.00	0.00	0.00
Travel expenses in MN	0.00	0.00	0.00		446.59		0.00	0.00	0.00	0.00
COLUMN TOTAL	0.00	0.00	0.00	6,537.89	5,586.59	951.30	0.00	0.00	0.00	6,537.89