South Dakota Water Research Institute
Annual Technical Report
FY 2013

Introduction

South Dakota Water Resources Institute's (SDWRI) programs are administered through the College of Agricultural and Biological Sciences at South Dakota State University (SDSU). Dr. Van Kelley has served as the Director for the Institute since August 1, 2000. Dr. Kelley is also the head of the Agricultural and Biological Engineering Department. In addition to the Director, the Institute's programs are administered and executed by a staff consisting of an Assistant Director, a Program Manager, a Program Assistant, an Assistant Professor and a Research Associate. During FY 2013 the SDWRI financially supported, through its base funding or through externally funded projects, three PhD students, six MS students and four undergraduate research assistants. The annual base grant from the United States Geological Survey (USGS) and a South Dakota legislative appropriation form the core of the SDWRI budget. The core budget is supplemented by research grants from a state and federal agencies as well as private organizations and industry interested in specific water-related issues.

The mission of the South Dakota Water Resources Institute is to address the current and future water resource needs of the people, industry and the environment through research, education, and service. To accomplish this mission, SDWRI provides leadership by coordinating research and training at South Dakota State University and other public educational institutions and agencies across the state in the broad area of water resources. Graduate research training, technology transfer, and information transfer are services which are provided through the Institute. This report is a summary of the activities conducted by the SDWRI during the period March 1 2013 through February 28 2014.

Research Program Introduction

Water is one of the most important resources in South Dakota. Together with the state's largest industry, agriculture, it will play an important role in the economic future of the state. Enhancement of the agricultural industry and allied industries, the industrial base and, therefore, the economy of South Dakota all depend on compatible development of our water resources. During FY 2013, the South Dakota Water Resources Institute (SDWRI) used its 104B Grant Program fund to conduct research of local, state, regional, and national importance addressing a variety of water problems in the state and the upper Midwest region. The WRI 104B External Review Panel reviewed 13 grant applications and recommended 2 projects for funding that addressed research priorities that had a good chance of success, and would increase our scientific knowledge. The projects were titled Subsurface Drainage Impacts on Evapotranspiration and Water II. PI's C. Hay, J. Kjaersgaard, T. Trooien and G. Sands, South Dakota State University. Evaluating the Nitrate-Removal Effectiveness of Denitrifying Bioreactors II. PI's J. Kjaersgaard, C. Hay, T. Trooien, South Dakota State University. In addition, the following projects selected for funding during FY2011 and FY2012 were previously granted no-cost project extensions: Life Cycle Assessment Analysis of Engineered Stormwater Control Methods Common to South Dakota. PI's Molly Gribb, James Stone and Jennifer Benning. South Dakota School of Mines and Technology. Identifying barriers for adopting new drainage technology among agricultural producers. PI's N. Benesh, J. Kjaersgaard and C. Hay, South Dakota State University. Evaluation of the performance of two vegetated treatment systems. PI T. Trooien, South Dakota State University. Evaluation of wastewater produced in biomass pyrolysis process. PI's L. Wei, T. Trooien, South Dakota State University. Subsurface Drainage Impacts on Evapotranspiration and Water I. PI's C. Hay, J. Kjaersgaard, T. Trooien and G. Sands, South Dakota State University. Evaluating the Nitrate-Removal Effectiveness of Denitrifying Bioreactors I. PI's J. Kjaersgaard, C. Hay, T. Trooien, South Dakota State University. Progress and completion reports for these projects are enclosed on the following pages.

Life Cycle Assessment Analysis of Engineered Stormwater Control Methods Common to South Dakota

Basic Information

Title:	Life Cycle Assessment Analysis of Engineered Stormwater Control Methods Common to South Dakota
Project Number:	2011SD195B
Start Date:	3/1/2011
End Date:	1/31/2014
Funding Source:	104B
Congressional District:	SD First District
Research Category:	Water Quality
Focus Category:	Surface Water, Models, Non Point Pollution
Descriptors:	None
Principal Investigators:	Molly Gribb, Jennifer L Benning, James Stone

Publications

1. Hengen, T., Squillace, M., O'Sullivan, A., Stone, J.J., 2014. Life cycle assessment analysis of active and passive acid mine drainage treatment technologies. Resources, Conservation and Recycling. 86: 160-167. http://dx.doi.org/10.1016/j.resconrec.2014.01.003
2. Hengen, T., Sieverding, H., Stone, J.J. Life cycle assessment analysis of engineered stormwater control methods common to urban watersheds. To be submitted to ASCE Journal of Water Resources May 2014 Tyler J. Hengena, Heidi L. Sieverdinga, James J. Stonea*

Life cycle assessment analysis of engineered stormwater control methods common to urban watersheds

Tyler J. Hengen[a], Heidi L. Sieverding[a], James J. Stone[a]*

[a] Department of Civil and Environmental Engineering, South Dakota School of Mines and Technology, Rapid City, SD 57701, USA

Corresponding author: james.stone@sdsmt.edu

Abstract:

Life cycle assessment (LCA) models to evaluate the environmental impacts of implementing and operating different stormwater best management practices (BMPs) common within Upper Midwest urban watersheds were compiled. While BMPs are required to meet Clean Water Act and US Environmental Protection Agency (EPA) Phase II Final Rule criteria, BMP selection typically focus on economic costs and treatment criteria. Generally, there is very little consideration of LCA-determined environmental impacts associated with treatment implementation and operation, although mandates requiring LCA considerations are becoming increasingly common within state governments and industries as part of sustainability initiatives. LCA modeling provides a comprehensive evaluation of the environmental impacts of a product or process in a 'cradle to grave' scenario following sustainability standards. LCA impacts of several common urban stormwater treatment scenarios were evaluated, including traditional (porous detention and sand filtration basins) and 'green' BMPs (rain gardens, vegetated swales, porous pavement). Treatment designs were based on an existing Rapid City, South Dakota USA drainage basin configuration and national stormwater design manuals. Both midpoint and endpoint LCA impacts were determined based on a 30-year design life and functional unit of the water quality volume (WQV) based on 51mm of rain in 24 hours. LCA modeling results demonstrated that while implementation of green stormwater BMP offsets did effectively reduce LCA impacts compared to traditional treatment strategies, there was little difference between each of the green BMPs implemented. Transportation of treatment infrastructure was greatest LCA-impact contributor, while the use of locally sourced materials provided significant benefits to the impact categories examined.

1 Introduction

While the treatment of stormwater is a mandatory objective per US Environmental Protection Agency (EPA) regulations {EPA, 2005 #9}, the sustainability of these systems is frequently overlooked. Many stormwater BMPs simply use quarried substrates as a filtration mechanism to remove suspected solids and bacteria found within stormwater. However, these quarried substrates often have high environmental impacts, and alternative substrates and BMPs should be considered to minimize the environmental impacts of stormwater treatment and enhance system sustainability. Historically in the US, stormwater has often been simply and rapidly transported away from the catchment with little regards to treatment or impacts to downstream users. Improperly managed stormwater can effectively transport pollutants into natural waterways, potentially harming ecosystems and wildlife. Urban stormwater can be highly polluted, resulting in significant loadings of suspended solids, phosphorous, nitrogen, lead, and zinc from urban catchments {Strassler, 2006 #14}, and potentially resulting in eutrophication and other ecological impairments {Davis, 2001 #8}. Recent US EPA Phase II regulations (64 FR 68722) now require an 80%

annual average total suspended solids (TSS) removal rate for urban stormwater treatment strategies {EPA, 2005 #9}. In addition, EPA policy now encourages stormwater management measures that promote infiltration instead of traditional curb-and-gutter systems (which emphasize conveyance) as part of BMP strategies for urban catchments {EPA, 2007 #5; EPA, 2005 #9}. The design, construction, and implementation of urban stormwater treatment systems is well established, adhering to the EPA Phase II Final Rule standards and guidelines {EPA, 2005 #9} where each US state is required to have a fully developed stormwater treatment system in place for urban populations exceeding 50,000 people. The TR-55 hydrologic manual {Cronshey, 1986 #7} serves as a primary stormwater treatment standard in the US, while similar guidelines exist in other developed countries such as the European Union Water Framework Directive {Jacqueline Hoyer, 2011 #12}, the New Zealand Resource Management Act {Council, 2003 #11}, and Australia National Water Quality Management Strategy Guidelines {Association, 2000 #13}.

Porous detention basins (PD) and sand filtration (SF) are two common stormwater treatment and mitigation methods that are commonly utilized to effectively remove TSS, metals, and nutrients through sedimentation, adsorption, and biological uptake. Both porous detention and sand filtration operate similarly, where stormwater is routed into a basin and interacts with substrate media intended to remove the metals and TSS from the influent water. For sand filtration, sand and gravel aggregate are common substrates, while porous detention uses a mixture of sand and compost for stormwater treatment. The primary focus of stormwater BMPs is minimizing pollutant loading while managing large runoff events.

Many construction materials used within these systems have significant environmental burdens which should be considered. For example, when Portland cement is used as an aggregate substrate, it has 1.39 kg of CO_2 eq. emissions embodied per kg of aggregate produced. This significant burden demonstrates that, by weight, greenhouse gas emissions of the byproduct are greater than the product {Consultants, 2008 #15}. Transportation is a key component, where one kg per km of transport by a large (7.5 to 16 t) truck contributes 0.24 g CO_2 eq. emissions; thus environmental burdens will accrue quickly simply due to transportation of heavy materials. As a result of these emission impacts, there has been a considerable push towards the development of sustainable approaches to offset or minimize these potentially avoidable environmental burdens. Many of these ‘green’ approaches have recently included treatment systems such as bioretention, porous pavement, and vegetated swales, amongst others, where implementation of these upstream treatment measures result in reducing the volume of impervious area in a watershed, promoting groundwater recharge, reducing the total volume of water requiring treatment, and minimizing the size of traditional porous detention and sand filtration systems {Conservation, 2010 #6}. Additionally, many of these systems can serve as beautification measures, as they very often increase green space when implemented in an area.

Despite the fact that the design and construction of stormwater treatment systems based on storm volume and impervious area are well developed, there is little motivation to consider or include the life cycle environmental impacts associated with the construction and maintenance of these systems. Treatment systems are often chosen by responsible parties based upon treatment efficiency and costs, with little regards to the triple-bottom line of sustainability (economics, environment, and societal implications) associated with system or materials selection. Through the use of LCA, the environmental impacts can be quantitatively determined for a specific process or system using a cradle-to-grave or a cradle-to-cradle approach (encouraging resource recycling), accounting for the (reasonable) burdens from the entire supply chain for a specific item or process {Goedkoop, 2009 #2}. It is inherently important that one consider the long-term environmental effects of stormwater treatment implementation, as well as potential benefits of associated with introducing 'green' offsets within the treatment watershed. For this study, the LCA impacts were determined for an existing urban catchment within Rapid City, a small municipality in western South Dakota (SD) US that is required to meet EPA Phase II criteria. The approach consists of an evaluation of PD and SF implementation from a life cycle prospective, and to determine LCA-impact changes associated with 'green' BMP implementation ('offsets') within the catchment. These green offsets mimic natural systems via increased infiltration and evapotranspiration, decreased stormwater conveyance, and the encouragement of a more natural hydrologic cycle in a watershed. These offsets result in reducing the specific stormwater volume that a PD or SF would be required to treat.

2 Methods

2.1 Goal

The goal of this project was to analyze and compare the LCA environmental impacts associated with constructing and maintaining two hypothetical PD and SF stormwater treatment systems within an urban watershed located within Rapid City, SD US. Rapid City is located in the upper mid-western US in a semi-arid climate within a mountain-prairie transition region which is subjected to flash-flooding events. The average annual rainfall is 423 mm {NOAA, 2013 #16}, with average winter and summer temperatures of -5.5°C and 22°C, respectively {NOAA, 2013 #17}.

The existing urban watershed sub-basin selected has a surface area of 36.5 hectare and an impervious area of 52% (Fig. S1). The watershed contains a wide variety of urban land uses, including zoning for: general commercial, medium density residential, neighborhood commercial, park/forest district, light industrial, low density residential, and school/public land. The slope is variable, ranging from 2% in the densely occupied valley bottom to over 30% on sparsely occupied hillsides. Streets and lots are terraced in the areas skirting steep hillsides. Within the sub-basin of concern, an older transitioning area exists that was initially developed during the 1940-60s and is in need of urban renewal. Property maintenance levels are highly variable and range from well-kept residences to poorly maintained rental properties and abandoned lots. Occupied residential lots are typically vegetated with mature trees, shrubs and grass cover. Commercial and industrial areas are heavily paved. Unoccupied or abandoned lots have sparse grass cover and are often weedy. Park/forest district areas are grasslands, typically steeply sloped with sparse shrubs and occasional trees. Localized areas of soil instability and erosion are present in the steep, hilly areas. The soil is clay-rich with a low organic content and permeability, an overall high runoff potential exists throughout almost the entire sub-basin. Streets in this neighborhood will completely fill with water and act as channels during intense rain events, overwhelming the existing storm sewer system.

Twenty scenarios were evaluated within the context of this study to determine the LCA impacts of the stormwater treatment systems, including:

- PD used to treat the entire design storm (2-year, 24-hour event resulting in 51mm storm volume depth) from the watershed;
- Extended SF detention basin used to treat the same stormwater volume;
- Implementation of upgradient 'green' offsets within both the PD and SF catchments that would subsequently reduce the volume of water required for treatment. Green offsets included

deployment of vegetated swales (VS), porous pavement (PP), and rain gardens (RG) within the catchment.

It is important to note that while the focus of this study is a sub-basin in Rapid City, SD, material availability and sourcing assumptions were made in order to make the study representative for typical urban areas. Compost, rock, sand, and cement were assumed to have been transported within 100 km; whereas PVC, HDPE, and ryegrass were assumed to have been sourced on a national level with transport being greater than 2000 km.

2.2 Functional Unit

The functional unit for this study was the materials, construction and operation required to treat the water quality control volume (WQV) from a 2-yr, 24-hr storm event within the Rapid City watershed which consists of a 51 mm of rainfall depth across the sub-basin (storm volume). This study assumed the life cycle of a system was designed for water quality improvements per EPA Phase II standards, requiring 80% TSS reduction during the design storm event. Using methodology outlined within {City, 2009 #3} and {Conservation, 2010 #6}, a WQV was determined for each system based on the total impervious area in the sub-basin, as well as the drain time characteristics for each of the primary BMPs. The values for each WQV are provided in Table S1. The approach included construction of the system, operations and maintenance, and recycling of materials where applicable during a 30-yr design life for each treatment systems.

2.3 System Boundaries

The system boundaries for this study consisted of the processes and scenario alternatives shown in Figure 1. Each system consisted of raw material processing, transportation, construction, operations and maintenance, and material recycling with the exception of porous pavement. For porous pavement, the system boundaries included excavation of an existing paved area, recycling of that material, processing of additional raw materials, transportation, and construction, so the system boundaries stared with site excavation. A developer or city planner would likely opt to install porous pavement within a site already paved, unlike a vegetated swale and rain garden which would be implemented within an unpaved area.

2.4 Inventory Analysis

The LCA model was developed using SimaPro 7.3 (Pré Consultants, Netherlands) LCA modeling software following ISO 14040 protocols {Goedkoop, 2009 #2}. Each basin or treatment was sized based on municipal {City, 2009 #3} and or national {Conservation, 2010 #6} stormwater guidelines. The input parameters for design were selected from the US LCI {NREL, 2010 #33} and the EcoInvent v 2.1 databases (Zurich, Switzerland).

The systems were designed to adequately treat the storm volume from a 2-year, 24-hour storm. An initial water quality control volume was determining following {City, 2009 #3} for the SF and PD. Upgradient green BMPs are designed to reduce the impervious area, so as they were introduced within the catchment at various levels revised water quality control volumes were determined for downgradient PD and SF treatments. Green BMPs sizing and changes to water quality control volumes were estimated from {Conservation, 2010 #6}. Inherently, each ‘system’ design has differing site-specific design functions, such as the small footprint of SFs or PDs large water retention capacity. While important, it should be noted that these inherent system design aspects were not considered, but instead it was our intent to evaluate a wide range of designs primarily using an LCA perspective.

A total of 20 different stormwater treatment scenarios were modeled based on differing combinations of traditional and green stormwater BMPs and associated impervious area reductions (Table 1). Summaries of all input parameters and design sizing calculations are provided in Tables S1-6. The construction energy for each of the following inventories, with the exception of the porous pavement, consisted of the excavation of earth using a 45 kW skid-steer and substrate emplacement using a 132 kW front-end loader. Additionally, roundtrip transportation distances specified in Table 2 were assumed 100% load for long haul and assumed 50% load factor for local and regional. Long distance trucks are seldom empty, whereas local and regional trucks are often sent to a destination to deliver a load and return empty. Below are design specifics for each of the treatment system components. Man hours were not included in the operations and maintenance models because they were too dependent on outside factors to be accurately projected or calculated.

2.4.1 Porous Landscape Detention Basin

An impermeable liner of polyvinyl chloride (PVC) film was installed on the bottom and sides of the PD. A high density polyethylene (HDPE) 16.8 cm diameter underdrain pipe was placed at 6 m spacing for the entire width draining to Rapid Creek via a stormwater conveyance system. Porous media was spread throughout the basin consisting of a 0.9 m thick layer of a soil-peat (3:1, sand to peat). A 16-tonne diesel truck was used for material and other transport (Table 2). The PDs were grass lined, and operations and maintenance included lawn mowing using a 22 HP mower, four times per year. Transportation of the lawn mower to and from the site (10 km roundtrip) was assumed using a single-unit standard diesel truck.

2.4.2 Extended Sand Filter Detention Basin

An impermeable liner of PVC film was installed on the bottom and sides of the SF. Materials consisted of a 46 cm basal layer of gravel and aggregate followed by 20 cm top drape of sand to complete the filter media. A 16-tonne diesel truck was assumed for materials transport (Table 2). Operations and maintenance consist of scarification of the top half of the sand every five years and full replacement of the sand three times during the 30-year maintenance period.

2.4.3 Vegetated Swale

The VS design consisted of a 10 cm layer of topsoil seeded with perennial ryegrass (14 kg per acre). Topsoil was assumed obtained from the Rapid City Landfill, which is a product produced from a composted mix of biosolids and post-consumer waste, and was transported to the site with a 16-tonne truck. The transportation of the excavator or loader was not included because VS was assumed built in conjunction with either the PD or SF, already including this attribute. Operations and maintenance consisted of mowing the full swale length four times a year for the entire system life cycle using a 22 HP lawn mower. The transport of the lawn-mower (10 km roundtrip) with a single-unit standard diesel truck was included for all scenarios except VS–PD due to redundancy.

2.4.4 Rain Garden

The RG consisted of soil media containing 60% sand, 35% topsoil, and 5% organic material, and a 30 cm thick layer of washed gravel. Transportation for the excavator and loader were not included, but instead integrated into PD or SF. All of the transportation inputs for the RG inventory were assumed to be carried out using a 16-tonne truck. All maintenance for the RG consisted of man hours, and were not included.

2.4.5 Porous Pavement

Porous Pavement was assumed implemented only in place of an existing paved area within a previously developed urban area (Fig. 1). The material inputs (Table 2) consisted of a bed of American Association of State Highway and Transportation Officials (AASHTO) No.67 stone to a variable depth dependent on the volume of stormwater influent into the system, and overlain by 15 cm pavement layer. An HDPE underdrain was placed every 6 m beneath the PP, leading to the downgradient stormwater system. A Portland cement curb was also added into the design to increase the ponding depth, to lower the surface area of the paved area, and to prevent overflow into adjacent properties and into storm sewers during large storm events. The construction energy included the excavation of the previous pavement area with a 45 kW excavator; crushing the excavated material with a portable crusher to recycle material as no. 67 stone; and placement of the substrate bed and the pavement. Maintenance requirements were considered highly variable and dependent on antecedent factors, and thus not included. Maintenance for these systems requires vacuuming and unclogging of the porous substrate, and influent loading can vary greatly depending on seasonality, land use, and characteristics of upstream catchments.

3 Results

Impacts assessment using the ReCiPe method allows the user to investigate a variety of midpoint and endpoint categories during its life cycle impacts evaluation. For the purposes of this study, the following midpoint impacts categories will be presented and discussed within the following sections: climate change (kg CO_2 eq.), terrestrial acidification (kg SO_2 eq.), freshwater and marine eutrophication (kg N eq. and kg P eq., respectively), and terrestrial ecotoxicity (kg 1,4-DB eq.) The categories selected best quantify ecological impact assessments where land and water management are the primary areas of concern. A summary of all impact category results has been provided in Tables S7-11. In general, the midpoint and endpoint impacts were primarily attributable to transportation and materials used for various scenarios. Construction, operations and maintenance, and disposal all resulted in relatively minor contributions to the LCA impacts determined.

3.1 Climate Change

The PD resulted in 207% greater climate change impacts compared to the SF when no green offsets were considered within the watershed (Fig. 2). As green offsets were introduced into the systems, the magnitude of climate change impacts were reduced compared to its corresponding baseline condition. The results demonstrate that all of the green offsets assessed resulted in similar climate change mitigation affects, with the PD scenarios resulting in a slightly steeper slope as green offsets were introduced due the greater reliance of non-local materials and subsequent high transportation burdens. Transportation of materials and machinery to the construction site was the primary contributor for climate change impacts, thus sourcing of local materials would provide important benefits to the impacts determined. Since most SF materials were locally sourced, its green offset benefits were less prevalent. Due to the high degree of material recycling for PP resulting in minimization of virgin substrate materials, its coupled impacts were similar to RG and VS.

3.2 Terrestrial Acidification

The terrestrial acidification impact trends (Fig. 2) were similar to those determined for climate change. Baseline PD impacts were 200% greater compared to SF, while green BMPs reduced their impacts with RGs resulting in greater reductions. Transportation was again the primary contributor, re-emphasizing the importance of considering locally source materials.

3.3 Freshwater Eutrophication

PD scenarios resulted in a much steeper decrease in freshwater eutrophication (kg phosphorous equivalent) as percent of impervious area reduction increased compared to the SF scenarios (Fig. 2). The SF and offsets range from 185 to 217% lower freshwater eutrophication results than PD with similar offsets. Sourcing and mining of the peat, and transportation were significant contributors to freshwater eutrophication for the PD scenarios.

3.4 Marine Eutrophication

The primary source of marine eutrophication (kg nitrogen equivalent) was the operation of the trucks for transport for both PD and SF scenarios. As additional green offsets were introduced, the impacts were decreased due to the reduction in transportation burden and overall reduction in storm volume (Fig. 2). The PD scenarios were between 172 and 197% greater than the respective SF scenarios. The utilization of local material sources would reduce marine eutrophication impacts due to transportation burdens. For example, the use of peat which is a depletable resource could be substituted with locally produced yard-waste and wood-chip mixed compost which has similar properties.

3.5 Terrestrial Ecotoxicity

Terrestrial ecotoxicity (g 1,4-dichlorobenzene equivalent, or kg 1,4-DB eq) results were similar to those observed for ecotoxicity (Fig. 2) results, where PD scenarios were greater (175 to 199%). Much of the ecotoxicity burden resulted from the manufacturing of PVC and HDPE materials, thus providing motivation to utilize less harmful materials within the designs.

3.6 Total Damage Assessment

The total damage assessment was determined following the ReCiPe Endpoint(H) method {Goedkoop, 2009 #2; Goedkoop, 2009 #2} for 0 and 20% offset for the scenarios. The three damage categories determined were: damage to human health, measured in DALY (disability adjusted life years, a measure of the number of years of life lost per 100,000 people due to illness); damage to ecosystems, measured in species per yr (a measure of the number of species, both plant and animal, to go extinct per year due to a process); and damage to resources, measured in dollars. Transportation was the greatest contributor followed by materials for most damage assessment categories, while combined materials and transport consisted of greater than 95% contribution for each damage assessment category (Fig. 3; Tables S12-15). The remaining 5% included operations and maintenance, construction energy, and disposal. Again, the utilization of locally sourced materials is paramount to reducing LCA-impacts for stormwater treatment system.

4 Discussion

While LCA modeling is a well-established field, LCA evaluation of stormwater management systems is still in its infancy. Many large metropolitan areas are now focusing on Low Impact Development (LID) through implementation of ‘green’ BMPs and have begun to include LCAs as part of their urban stormwater management plans {Spatari, 2011 #27}. For example, Kirk et al {, 2006 #24} used LCA to evaluate stormwater BMP systems in Vermont, where twelve BMPs including PP and VS were investigated. Various LCAs have been conducted on effectiveness of material substitution such work from Guo et al {2010 #31} on PD infiltration media studies, all of which highlight the applicability of LCA to BMP design improvement. For example, Ramberg {, 2007 #23} used LCA as a tool to compare the stormwater impact of a traditional pavement to a PP project in the Puget Sound watershed in Washington, incorporating construction costs and economic factors. In a similar study to ours, Flynn et al {, 2011 #22} compared green roofs to RGs for a campus Pennsylvania (not a sub-basin) using the economic and life-cycle advantages of RGs. In that study, RG reduced climate change impacts by 63,304 kg CO_2 eq., significantly higher than values determined within our study. These differences could be attributed to 1) the small size of our RGs (ranging from ~20 to ~370 m^2) and their integration within an urban setting of existing development; 2) differences in impacts assessment methodology (TRACI compared to ReCiPe); and 3) differing material sourcing, planting, and design characteristics. Further comparisons can be made to a New Zealand study comparing RG to SF {Andrew, 2008 #1} where RG implementation resulted in 30% less climate change impacts. While our work did not directly compare these two systems, however the coupled results for our PD compared to SF were significantly greater for climate change impacts. As ‘green’ offsets were introduced, the BMP results for both studies declined in a similar fashion, and were found attributable to material sourcing and types, water retention times, transportation distances, and design variance. While Andrew et al {, 2008 #1} modeled an existing treatment area and system already constructed compared to our approach, both studies highlight the importance of transport distances and their relation to LCA-impacts for stormwater treatment design and operations.

The importance of transportation and material sourcing within the framework of LCA-impacts minimization was determined through a scenario that strictly utilized locally sourced materials. Within this scenario, a regional source of ryegrass seed was identified, while yard-waste compost was substituted in place of peat where applicable, providing a significantly reduced LCA-burden. Ryegrass seed farms are considered geographically limited, so transport was reduced by 50%. The implementation of these two ‘sustainable’ alternatives resulted in considerable LCA-impacts reductions: climate change by 44%, terrestrial acidification by 85%, freshwater eutrophication by 65%, marine eutrophication by 66%, and terrestrial ecotoxicity by 85%. These large impacts reductions incurred through transport savings and compost utilization would be very much achievable within many urban metro regions.

While LCA in this study has been shown effective for stormwater BMP implementation, there are limitations as to what can be effectively assessed for this study. For example, PP alternatives compared to traditional pavement would still contribute to the heat-island effect, where heat from the sun can raise the temperature of an exposed surface by several degrees Celsius {Streutker, 2003 #4}. While these effects are not commonly evaluated using LCA {Martineau, 2011 #28}, they should nonetheless be considered within a project sustainability evaluations. Another factor that is challenging to evaluate using LCA is the assumption that stormwater water quality after BMP treatment is consistent. BMPs are designed meet TR-55 hydrologic standards (REF) which should result in contaminant minimization, however improper layering and inadequate maintenance can impact water quality including harmful organisms and pollutants {Saygin, 2011 #18} emanating from these systems. The societal benefits associated with green BMPs are further challenging to assess with traditional LCA methodology. Raingardens provide features which people enjoy and provide community enhancement, and may also improve property values {CNT, 2010 #25}. Finally, the importance of undertaking an economic analysis should not be understated. In order to complete a triple-bottom line analysis: the environmental impact analysis should be completed through LCA, the societal benefits can be completed through a quality of life assessment, and a life cycle cost completed with an input-output economic analysis. While a cost analysis was deemed outside the scope of this current project, considerable work has been published on cost forecasting for implementation and operation of similar systems {Brown, 1997 #20;Wossink, 2003 #19, Ellis, 2004 #21}, including the California Department of Transportation work for life-cycle cost analyses and environmental LCAs of PPs {Wang, 2010 #29}. The integration of a cost analysis and LCA will complement the EPA's initiative to reduce stormwater costs through LID which includes implementation of practices such as upgradient 'green' BMPs {EPA, 2007 #30}.

All of the green BMPs demonstrated LCA impact reductions as they were more heavily implemented and reduced storm volume. The PP generally had slightly higher impacts than the RGs and VSs, but the benefit of using recycled pavement for the drainage bed likely assisted in aligning the LCA impact. SFs generally had lower impacts than PDs, though the PDs seemed to be more influenced by the introduction of the green BMPs. The reason why SFs showed lower influence from green offsets than the PDs is that generally SFs are simply more efficient systems, requiring lower surface area to treat the same volume of water.

5 Conclusion PDPDPD

This study is meant primarily to be a guideline, as many of the assumptions were idealized (virgin materials, flat land, water influx). Site-specific design characteristics would need to be appropriately studied and accommodated within the BMP designs when implemented in a real-life situation. LCA results of this study demonstrate that transportation and material sourcing is key regardless of 'green' BMP design or site assumptions. Using virgin or raw materials (mined, quarried, manufactured) means that all sourcing of the material sourcing and associated impacts are included in the LCA. Whereas byproduct, recycled, or reused materials typically have a lesser environmental impact. Identifying local or nearby material sourcing/manufacturers is critical to reducing environmental impact due to the sheer weight and volume of the materials involved in stormwater BMPs. High transportation costs likely correlate with high environmental costs for stormwater BMPs; therefore a local material sourcing study prior to construction plans assessing and identifying local and nearby resource alternatives, recycled products, and cost prior to design and construction may be environmentally and fiscally advantageous. For example, a standard BMP design identifies peat but a local, cost-effective substitute is yard-waste compost.

‘Green’ BMPs can have a greater function than solely infrastructure as stormwater control. Not included in this assessment are the current street, curb and gutter, and water drainage conditions, which are in need of repair. The neighborhood is overall in a state of quasi-disrepair, and as such, the potentially significant societal benefit of investment in improved roads and drainage may provide the revitalization the community needs.

ACKNOWLEGEMENTS

REFERENCES

FIGURES

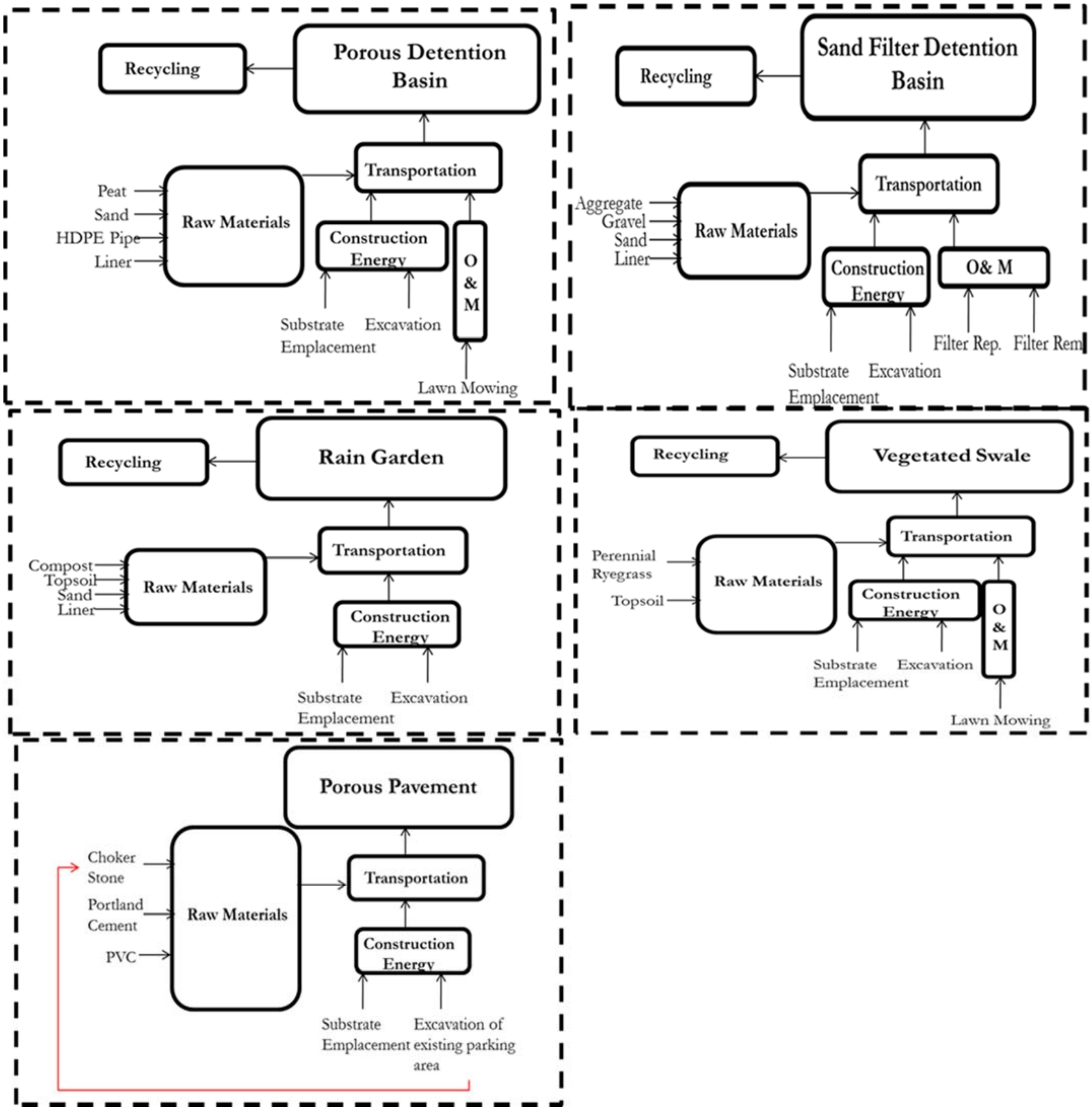
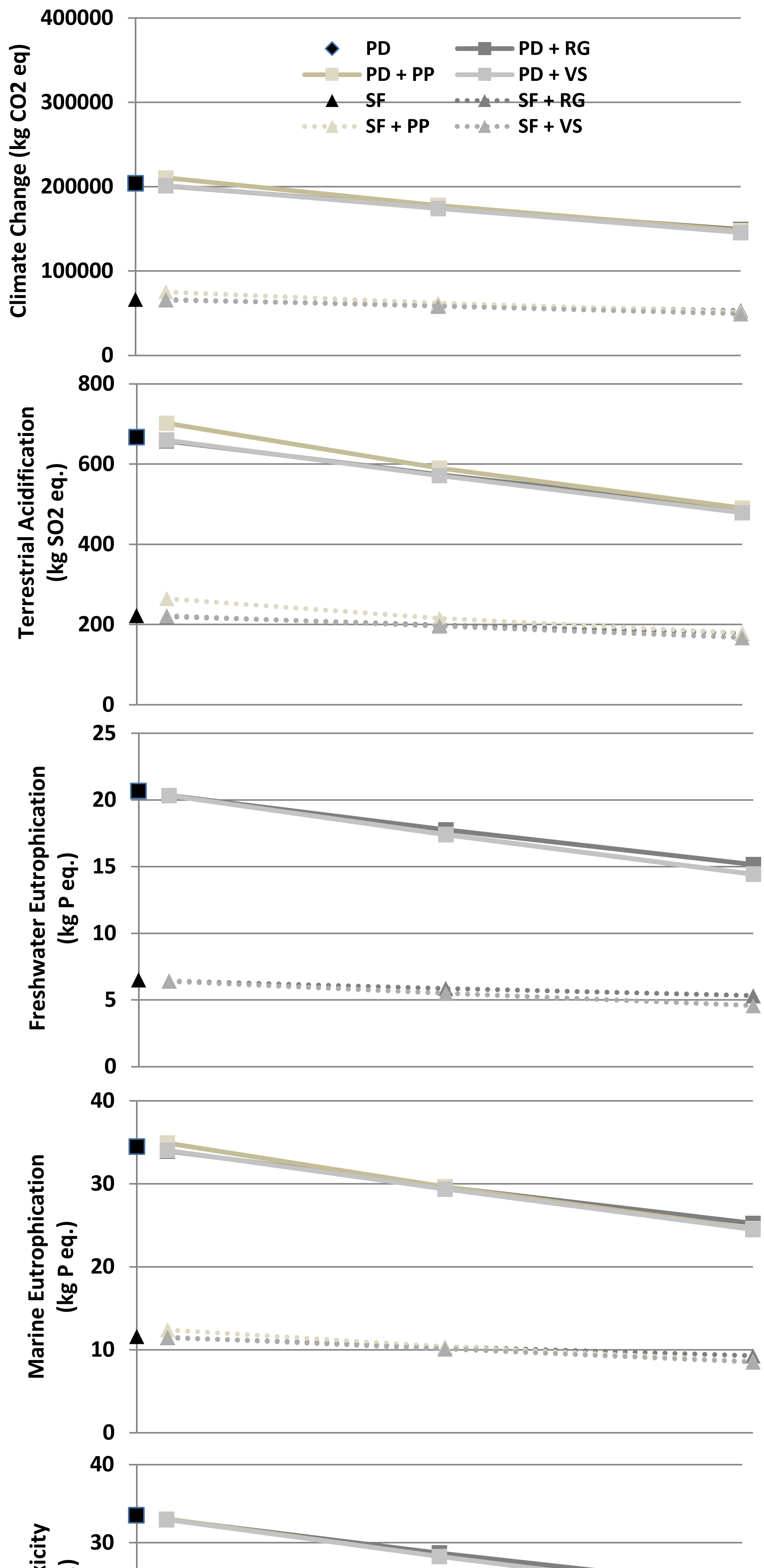


Figure 1: Stormwater BMP System Boundaries, red lines indicate recycling of materials



PD
PD + RG
PD + PP
PD + VS
SF
SF + RG
SF + PP
SF + VS
Climate Change (kg CO2 eq)
400000
300000
200000
100000
0
Terrestrial Acidification (kg SO2 eq.)
800
600
400
200
0
Freshwater Eutrophication (kg P eq.)
25
20
15
10
5
0
Marine Eutrophication (kg P eq.)
40
30
20
10
0
40
30

Figure 2: Summary of climate change, terrestrial acidification, freshwater eutrophication, marine eutrophication, and terrestrial ecotoxity midpoint LCA results as a function of percent of impervious area reduction for the stormwater BMP scenarios.

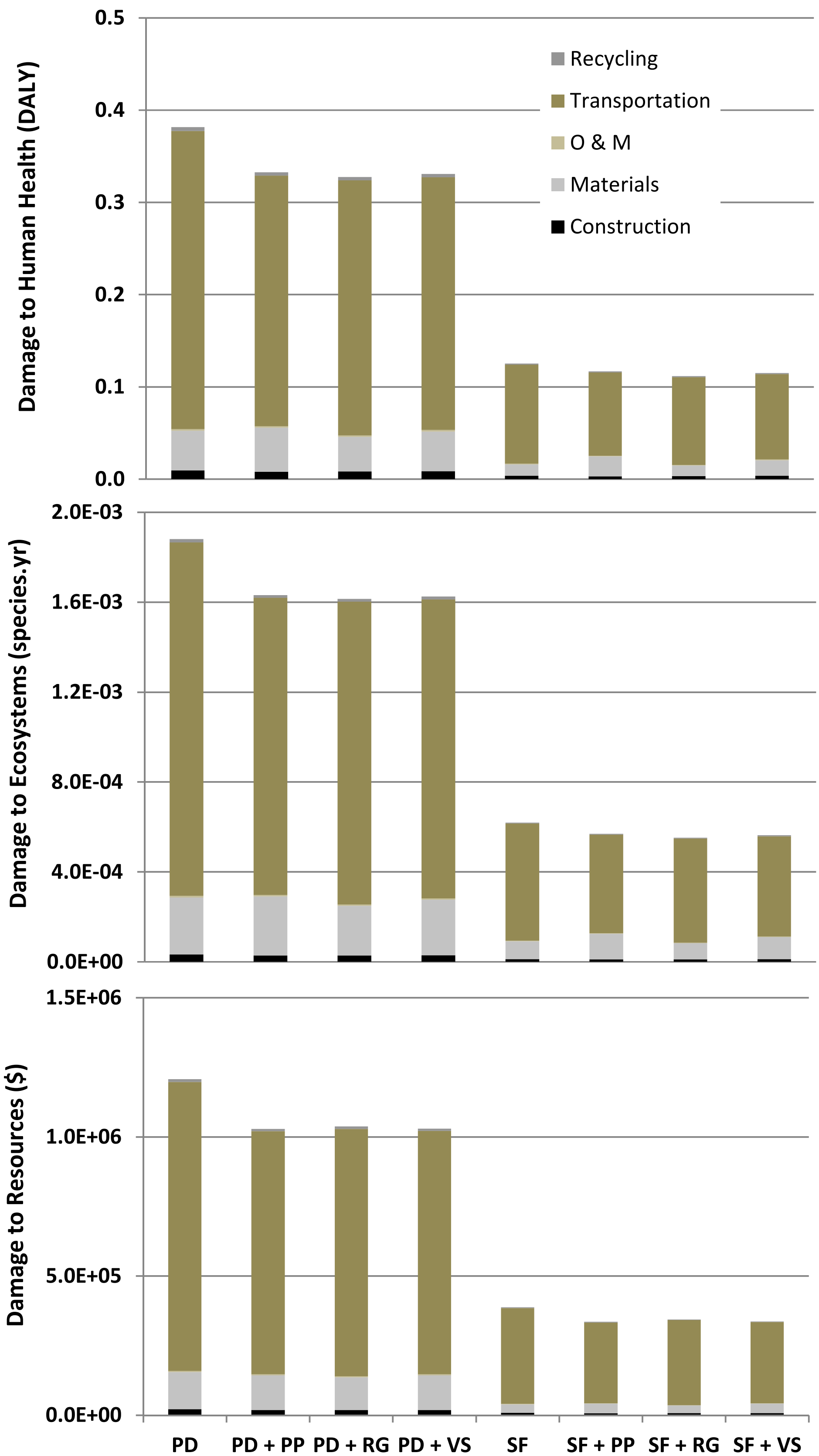

Damage to Human Health (DALY)
0.5
0.4
0.3
0.2
0.1
0.0
Recycling
Transportation
O & M
Materials
Construction
Damage to Ecosystems (species.yr)
2.0E-03
1.6E-03
1.2E-03
8.0E-04
4.0E-04
0.0E+00
Damage to Resources ($)
1.5E+06
1.0E+06
5.0E+05
0.0E+00
PD
PD + PP
PD + RG
PD + VS
SF
SF + PP
SF + RG
SF + VS

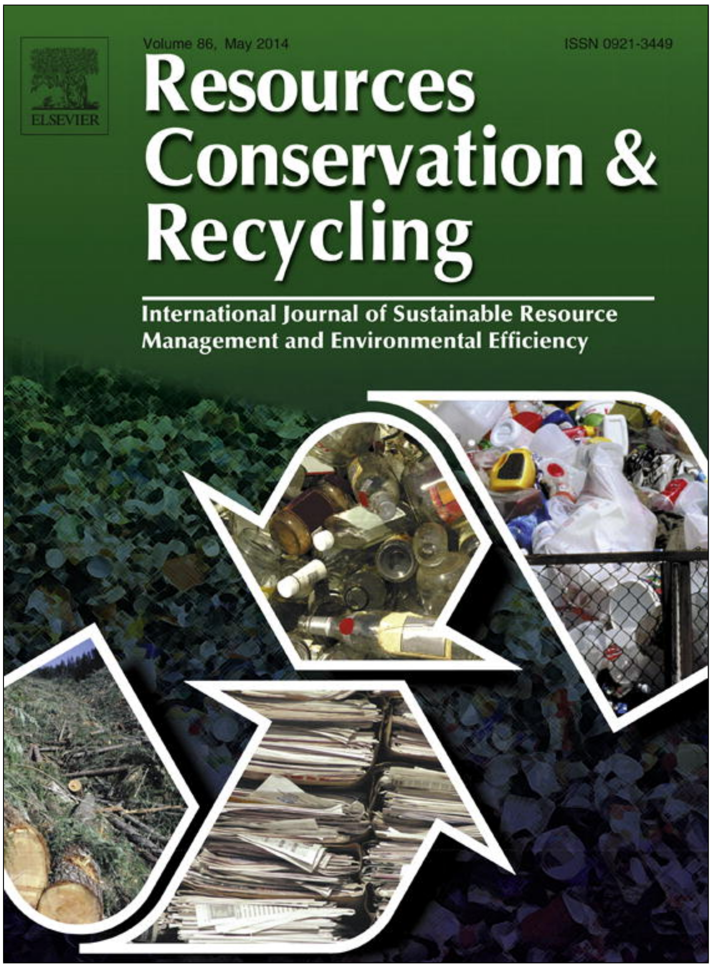
Figure 3: Summary of endpoint results for human health, ecosystems, and resources damage for all study scenarios.

Table 1. Summary table showing basin dimensions scenarios for all green stormwater BMPs.

Impervious Area Reduction	0%	1%	10%	20%
Porous Detention Basin Dimension Side Length (meters)	59	58	54	49
Sand Filter Extended Detention Basin Dimension Side Length (meters)	36	35.5	33	30
Vegetated Swale Dimensions Length by Depth by Width (meters)	-	45*x*0.6*x*0.9	137*x*0.6*x*0.9	182*x*0.6*x*0.9
Rain Garden Dimensions Side Length by Depth (meters)	-	4.8*x*0.3	3.8*x*0.45	3.4*x*0.45

Table 2. Summary table showing material, source and transport distances for all green stormwater BMPs.

	Material	Source	Distance	
Porous Detention Basin	HDPE Pipe	Cornelia, OH	2460 km	(one-way)
	Impermeable Liner	Cornelia, OH	2460 km	(one-way)
	Peat	Fort Lupton, CO	590 km	(one-way)
	Sand	Wasta, SD	150 km	(roundtrip)
	Excavator & Loader	Rapid City, SD	20 km	(roundtrip)
Sand Filter Extended Detention Basin	Impermeable Liner	Cornelia, OH	2460 km	(one-way)
	Sand	Wasta, SD	150 km	(roundtrip)
	Aggregate	Rapid City, SD	20 km	(roundtrip)
	Excavator & Loader	Rapid City, SD	20 km	(roundtrip)
Vegetated Swale	Perennial Ryegrass	Salem, OR	2030 km	(one-way)
	Topsoil	Rapid City, SD	10 km	(roundtrip)
Rain Garden	Sand	Wasta, SD	150 km	(roundtrip)
	Choker-Stone	Rapid City, SD	20 km	(roundtrip)
	Compost	Rapid City, SD	10 km	(roundtrip)
	Topsoil	Rapid City, SD	10 km	(roundtrip)
Porous Pavement	HDPE Pipe	Cornelia, OH	2460 km	(one-way)
	Portland Cement	Rapid City, SD	20 km	(roundtrip)
	Asphalt	Rapid City, SD	20 km	(roundtrip)
	No. 67 Stone	Rapid City, SD	20 km	(roundtrip)
	Excavator	Rapid City, SD	20 km	(roundtrip)
	Portable Crusher	Rapid City, SD	20 km	(roundtrip)
	Recycled Aggregate	Onsite	0 km	(--)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Life cycle assessment analysis of active and passive acid mine drainage treatment technologies

Tyler J. Hengen[a], Maria K. Squillace[a], Aisling D. O'Sullivan[b], James J. Stone[a,*]

[a] Department of Civil and Environmental Engineering, South Dakota School of Mines and Technology, Rapid City, SD 57701, USA
[b] Department of Civil and Natural Resources Engineering, University of Canterbury, Christchurch 8140, New Zealand

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ABSTRACT

Acid mine drainage (AMD), resulting from open-cast coal mining, is currently one of the largest environmental challenges facing the mining industry. In this study, a life cycle assessment (LCA) was conducted to evaluate the environmental impacts associated with the construction, operation and maintenance of different AMD treatment options typically employed. LCA is a well-reported tool but is not documented for AMD treatment systems despite their ubiquitous implementation worldwide. This study conducted detailed LCA analysis for various passive and active AMD treatment approaches implemented or considered at a major coal mine in New Zealand using a comparative functional unit of kg acidity removed per day for each treatment option. Eight treatment scenarios were assessed including active limestone and hydrated lime treatments, and compared to passive treatments using limestone and waste materials such as mussel shells. Both midpoint and endpoint LCA impact categories were assessed. Generally, the active treatment scenarios demonstrated greater LCA impacts compared to an equivalent level of treatment for the passive treatment approaches. Lime slaking had the greatest LCA impacts, while passive treatment approaches incurred consistently less impacts except for one passive treatment with a purchased energy scenario. A 50% reduction in transportation distances resulted in the lowest LCA impacts for all scenarios. This study highlights the importance of evaluating the environmental and social impacts of AMD treatment for the mining industry.

1. Introduction

Untreated AMD negatively impacts thousands of kilometers of waterways worldwide, severely affecting the aquatic and neighboring terrestrial environment, so is recognized as the current largest environmental problem facing the mining industry (Hudson-Edwards et al., 2011). Younger et al. (2002), Watzlaf et al. (2004), and McCauley et al. (2006) describe the relevant mineral dissolution kinetics in great detail.

Active AMD treatment typically incurs chemically dosing with lime [applied as calcium oxide (CaO) or as a slurry of hydrated calcium hydroxide ($Ca(OH)_2$)] to neutralize acidity resulting in precipitation of metals (Brown et al., 2002; Waters et al., 2008; Younger et al., 2002). Active treatment options are a proven and reliable AMD mitigation approach, however their high energy and chemical costs result in high net environmental impacts (Younger et al., 2002). Passive treatments are therefore an attractive alternative since they do not require continual pumping of chemical amendments and can operate more sustainably using biogeochemical processes inherent within engineered biosystems (Younger et al., 2002). For these passive designs, mine water is also typically gravity-fed to minimize pumping requirements otherwise needed to convey AMD. Numerous passive AMD-treatment designs have evolved over the past three decades (Johnson and Hallberg, 2005; Wildeman et al., 2006; Younger et al., 2002). The most common design is a sulfate-reducing bioreactor, which relies on the principle of sulfidogenesis to convert sulfates to sulfides through microbial reduction (Chang et al., 2000; Sheoran et al., 2010). Bioreactors have become one of the most proven passive-treatment options for treating acidity (Doshi, 2006; Gusek, 2002) and metals (Gusek, 2004; Neculita et al., 2007; Wildeman et al., 2006) in AMD. Their biogeochemical conditions treat AMD by using an alkalinity source to mitigate the acidity and carbon sources to sustain the microbial community responsible for metal immobilization. Metals are removed via precipitation as hydroxide complexes, sulfides, carbonates, silicates or sulfates or, sorption to organic matter, carbonates, etc. (Gibert et al., 2003; Gusek, 2002; Lo and Yang, 1998; Waybrant et al., 1998; Zagury et al., 2006). Limestone has been the most common alkaline material utilized in AMD bioreactors, primarily because of its effective dissolution rates, and due to its relative abundance near mine sites (Watzlaf et al., 2004; Waybrant et al., 1998; Wildeman et al., 2006; Younger et al., 2002). However,

* Corresponding author. Tel.: +1 6053942443.
E-mail address: james.stone@sdsmt.edu (J.J. Stone).

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alternative substrate media can be employed such as the waste product mussel shells for highly effective acidity mitigation and wood by-products that provide carbon sources for the microbial communities (e.g. McCauley et al., 2009). These waste products can often be sourced cheaply and potentially locally, thus likely affording a lower environmental impact than mining virgin limestone for the same purpose.

It is commonly assumed that in addition to economic savings, passive AMD treatment will incur lower environmental impacts costs compared to an equivalent active treatment approach, primarily due to the lack of chemical and energy requirements. However, a comprehensive analysis of their net environmental impacts evaluated through sustainability assessments such as LCA has not yet been conducted aside from Tuazon and Corder (2008) who assessed red mud as a treatment option for Australian mines by employing LCA tools. This study found that although the alternative material, in their case seawater neutralized red mud, was a very effective and environmentally friendly AMD treatment approach, issues with the transport and treatment efficiency of the red mud introduced some serious potential obstacles for large scale usage. Our results, discussed in Section 5, reflect these issues as they pertain to our study.

LCA provides a 'sustainability audit' through a 'cradle to grave' assessment of all products and processes. LCA modeling has numerous applications in determining the long term, indirect and cumulative impacts of human actions, and has been applied to building design (Ligthart et al., 2010; Mithraratne and Vale, 2004), agricultural production (Beauchemin et al., 2010; Haas et al., 2001; Stone et al., 2010), biofuel production (Cherubini et al., 2009; Davis et al., 2009), and industrial applications (Graedel and Allenby, 2010), metal production (Norgate and Lovel, 2004), and aspects of the mining sector (Norgate and Haque, 2010). Project financial aspects may also be incorporated within an LCA using the Carnegie–Mellon Economic Input–Output Life Cycle Assessment Tool (EIO-LCA, 2008). However, in practice a cost-benefit analysis of the different options would likely be considered in parallel before implementation by the industry.

This research compared the environmental impacts over the life cycles of several implemented and optional AMD treatment methods, incorporating both passive and active approaches employed at Stockton Coal Mine in New Zealand, a site with a wealth of treatment data and knowledge regarding historical AMD challenges (McCauley, 2011; McCauley et al., 2008).

2. Methods

Life cycle assessments were conducted for both active and passive AMD treatment systems using the SimaPro 7.3 LCA modeling software (PRé Consultants, Netherlands) and life cycle inventory EcoInvent (Swiss Centre for Life Cycle Inventories, Switzerland) database (Frischknecht et al., 2007), and the EcoInvent Australasian LCI Database (Australasian-LCI, 2011) following ISO 14040:2006 and ISO 14044:2006 protocols (Finkbeiner et al., 2006). A total of 7 different scenarios were modeled, including five active and two passive treatment systems. A summary of all components and their amounts in each treatment design along with the system abbreviations is provided in Table S1.

2.1. System boundary

A general system boundary for modeling the LCA of each system is shown in Fig. 1, while detailed system boundaries for each treatment scenario are provided in Figs. S1–S6. The system boundaries encompass all substantial components and processes used in each of the treatment scenarios, encompassing raw materials including extraction and processing for mined materials, transportation for all materials, construction including earth excavation and/or substrate emplacement, and process energy required for pumping and processing. For all scenarios, infrastructure processes were not included in the LCA model. These infrastructure processes apply specifically to the infrastructure associated with the production of materials, production of transportation methods, or production of pumping mechanisms. All infrastructure relevant to the treatment approaches was included, such as piping utilized in P-BME or A-LD. Human labor hours associated with operation and maintenance of the systems were also not included, as these pertain more to social issues than environmental issues (Cotton-Incorporated, 2012). For the 'waste products' materials from other industries (i.e. mussel shells), no manufacturing or use process energy was included (since these products did not undergo any modification) and thus their system boundary began with transporting them to the study site.

2.2. Functional unit

The scenarios were all normalized using a functional unit of 1 kg of acidity neutralized per day as the basis of comparison. A 16.9 yr design life was assumed for all passive and active treatment scenarios. This design life was based on laboratory-determined limestone dissolution rates for the AMD at the mine site (700 mg/L acidity fed at 2.29 L/s) determined by McCauley et al. (2009). This acidity loading equated to 85.2 kg acidity as $CaCO_3$ per day neutralized by each passive treatment system with the exception of the mussel shell leaching bed, which only neutralized 11.53 kg acidity as $CaCO_3$ per day, based on an influent flow rate of 0.31 L/s and identical acidity loading parameters to the bioreactors. Acidity loading rates for the active treatment systems were much higher, at 17,808 kg acidity as $CaCO_3$ per day, due to their higher treatment efficiencies.

2.3. Site description

The majority of AMD-impacted streams in New Zealand are located on the West Coast of the South Island within estuarine coal formations. The Stockton Coal Mine on the West coast of the South Island was the basis for this study due to a wealth of data and knowledge regarding historical AMD challenges at this site (McCauley, 2011; McCauley et al., 2008). It is the largest opencast coal mine in New Zealand with an active mining area of ~900 ha and is expected to have AMD treatment issues for the next 100 years. Stockton Mine AMD is characterized by low pH and high concentrations of iron and aluminum, typically accounting for >98.0% of metals (on molar basis) (McCauley et al., 2008). To date, the primary method of treatment has been utilizing ultra-fine limestone (UFL), while more recent studies have investigated lab and field based passive bioreactor and leaching bed systems, which utilize mussel shells as an acidity neutralizing agent instead of limestone (Crombie et al., 2013).

3. Treatment scenarios

A total of seven scenarios were modeled including both passive and active treatment systems (Table 1). The passive systems included a gravity-fed AMD bioreactor utilizing mussel shells as the primary substrate (P-BM); a bioreactor with limestone (P-BL); a bioreactor identical to P-BM, pumping AMD into the system (P-BME); a bioreactor identical to P-BM, but with a 50% reduction in transport distances for all materials (P-BMT); and a mussel shell leaching bed (P-LB). The active treatment systems included ultrafine lime-dosing (A-LD), and lime slaking (A-LS). Inventory summaries of material inputs for the seven treatment scenarios are provided in Tables S1 and S2. Sizing of each system was based

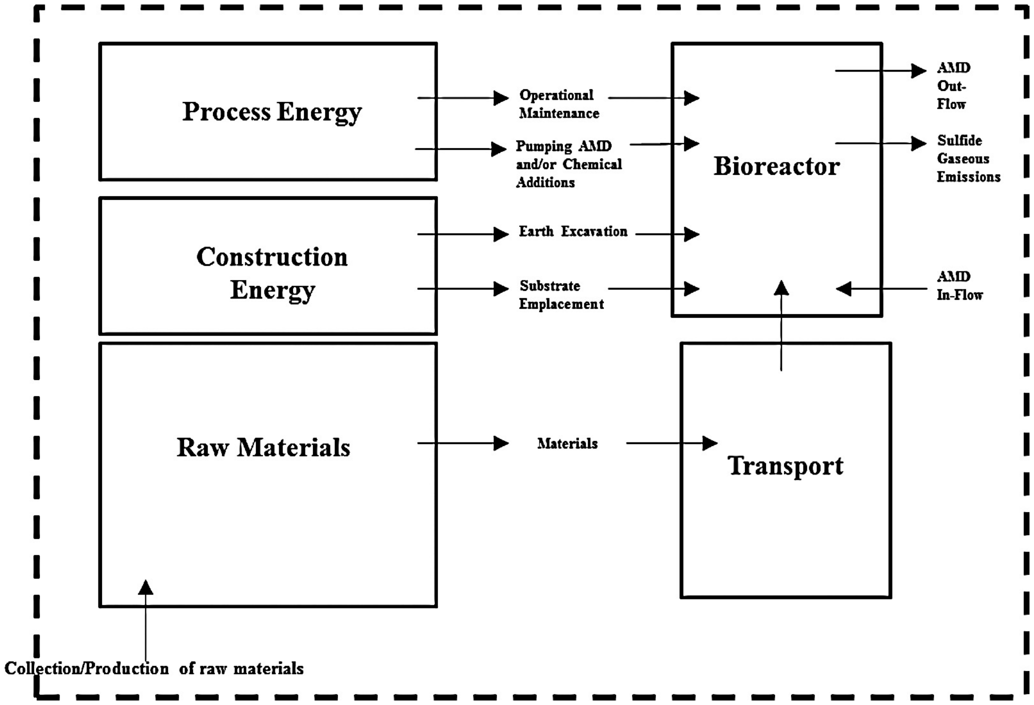

Fig. 1. General system boundaries for AMD treatment LCA.

upon the treatment efficiencies determined from mesocosm-scale laboratory experiments or implemented systems (Crombie et al., 2013; McCauley, 2011).

3.1. Materials and transport

For the passive bioreactor scenarios (P-BM, P-BME, P-BMT), their design was based upon a previous study by McCauley (2011) using an excavated basin 32 m wide, 40 m long, and 2 m deep. The substrate consisted of a mixture (by volume) of mussel shells (30%), *Pinus Radiata* bark (30%), post-peel (25%), a by-product of fence post manufacture, and forestry compost The bioreactor bedding material was 0.09 m deep river gravel and low-density polyethylene (LDPE) piping was used for plumbing within the bioreactor and associated sedimentation pond, and water conveyance. A 2-mm high density polyethylene (HDPE) liner was also used, beneath which a base course of sandstone was placed for providing a level construction platform.

For the P-LB scenario, a mussel shell leaching bed was designed to treat the AMD gravity-fed to it from the upstream sedimentation pond. The scenario was modeled with mussel shells replaced twice over the 16.9-yr life cycle. Material inputs for P-LB were mussel shells and LDPE piping. A separate process was modeled that included processing (assumed similar to gravel crushing) the mussel shells. Since mussel shells constituted a waste product, the system boundaries did not account for or allocate impacts associated with harvesting or the fileting of the mussel meat.

Table 1
AMD treatment scenario abbreviations and process descriptions.

Abbreviation	Description
P-BM	Bioreactor with mussel shells as primary substrate
P-BL	Bioreactor with limestone as primary substrate
P-BME	Bioreactor with purchased energy
P-BMT	Bioreactor with modified transport
P-LB	Mussel shell leaching bed
A-LD	Ultrafine lime-dosing
A-LS	Lime slaking

Transportation of materials for all scenarios was modeled using a 32-ton diesel truck operating at 50% load capacity round-trip (100% one-way, empty return). For the P-BMT scenarios, all transport distances were reduced by 50% to assess the effect of reduced transport on net environmental impacts.

3.2. Construction

The construction inputs for the bioreactor treatment scenarios (P-BM, P-BL, P-BME, and P-BMT) consisted of 2560 m^3 of earth excavation and placement of substrate using a 500 kW hydraulic excavator. For the leaching bed (P-LB) scenario, construction inputs consisted of 18 m^3 of earth excavation, and 18 m^3 of substrate emplacement, both undertaken with a 500 kW hydraulic excavator (Table S1).

3.3. Maintenance and process energy

Most passive treatment scenarios (P-BM, P-BL, P-BMT, and P-LB) were gravity-fed AMD and required no operational energy such as mechanical pumping. Operational maintenance consisted of the replacement of the mussel shells twice during the 16.9-yr life cycle, completed by a hydraulic excavator. The P-BL scenario was modeled with no removal or replacement of the limestone over its design life. The P-BME scenario utilized mechanical pumping of AMD to the system, assuming an energy mix of 70% hydropower and 30% coal-fired power common to the region. The process was assumed to constantly pump AMD using a 0.75 kW pump, resulting in a total energy usage of 19,272 kWh per yr, or 3800 kWh per kg acidity removed (Table S2).

3.4. A-LD

Ultrafine limestone (UFL) was directly injected into the AMD-impacted stream on Stockton Mine to provide acidity neutralization. UFL materials included 12,000 metric tones UFL/yr, and 2.58 m^3 of steel for the associated hopper and feeder. UFL was transported 550 km, while the galvanized metal used for both the hopper and the feeder were sourced 680 km away from Sydney, Australia. 450 km of the total 680 km for transport of galvanized steel were modeled as barged from Sydney (Australia) to Nelson (New Zealand), while the remaining 230 km incurred truck transport to the Stockton Mine (Table S1). For A-LD scenario, the UFL was pumped into the treatment zone, while AMD was gravity-fed. The energy associated with UFL pumping was modeled as 70% hydropower, 30% coal using 2–80 mm Verderflex peristaltic pumps operating 12 h daily, 365 days per yr. This translated into consuming 87,600 kWh of power per yr, or an equivalent of 83 kWh of power per kg acidity removed (Table S2), which was substantially less than for the P-BME scenario attributed to the different treatment efficiencies of the systems. Specifically, the fast dissolution and effectiveness of ultrafine limestone resulted in a high efficiency system requiring a small amount of chemical required relative to the large amount of AMD being treated.

3.5. A-LS

Lime slaking, while not currently utilized in New Zealand, is commonly deployed worldwide for AMD treatment and uses hydrated quicklime as its neutralizing agent. The A-LS design was based on Escher et al. (1983) and in this study consisted of 1.2 m^3 of galvanized steel for infrastructure, 16.5 m^3 of concrete for piping, 150 million kg of hydrated quicklime consumed over the 16.9-yr life cycle of the treatment life, and 24,239 m^3 of clay liner, used in both the equalization and settling basin at a depth of 0.91 m (Table S2). Concrete was transported 160 km from the source, the hydrated lime 97 km, the clay liner 400 km, and the galvanized steel 680 km. Construction for A-LS consisted of 58,000 m^3 of earth excavation, undertaken with a 500 kW hydraulic excavator (Table S1). The process energy for A-LS operation was modeled 70% hydropower, 30% coal-fired energy for operating a 0.75 kW aerator pump, resulting in an energy usage of 960,000 kWh per yr, or 911 kWh per kg acidity removed (Table S2). A dry-feed system was modeled, meaning that hydrated quicklime was fed directly into the equalization basin to attain the desired slurry concentration, rather than sludge feeding.

3.6. Ultrafine limestone and hydrated lime

Hydrated lime has nearly 17 times the amount of embodied energy per kg of material, and is 10 times the weight of heavy machinery per kg of material compared to ultrafine limestone (EcoInvent, 2013). While UFL processing consists of crushing, washing, and transportation, quicklime incurs additional milling, cyclone filtering, de-dusting, and storage requirements. UFL machinery consists of 2 crushers, 2 sieves, and 2 small silos, while quicklime heavy machinery inputs consist of a crusher, a roller mill, a de-dusting plant, a cyclone, and a small silo, each of which have additional operational energy associated with them.

3.7. Environmental impact assessment

The impact assessment was completed using ReCiPe 2008 impacts assessment method (Goedkoop et al., 2009), assuming a 'Hierarchist' perspective that addressed key environmental impact metrics (midpoint categories) of climate change (kg CO_2 eq), human toxicity (kg 1,4-db eq.), particulate matter formation (kg PM10 eq.), and fossil depletion (kg oil eq.), for the construction, transportation and operation of each system. These impact metrics were selected based on their relative contribution (>10%) to the total endpoint impact categories. When determining the total endpoint impacts for each scenario (damage to ecosystems, damage to resources, damage to human health; all discussed in Section 4.5), the model segregates contributions to each of the different environmental impact categories (climate change, human toxicity, etc.), allowing their relative endpoint contributions to be determined.

4. Results

4.1. Climate change

Climate change refers to the impact associated with the discharge of carbon dioxide and other greenhouses gases such as methane and nitrous oxide to the atmosphere. All greenhouses gas (GHG) emissions were converted to carbon dioxide equivalents following Intergovernmental Panel on Climate Change (IPCC) protocol (Watson et al., 1996). Climate change impacts ranged from 62 kg CO_2 eq. for a passive bioreactor treatment system with half the transport distance (P-BMT) to 5180 kg CO_2 eq. for the active lime slaking treatment (A-LS) (Fig. 2A, Table 2). Both active treatment systems involving lime dosing and especially lime slaking (A-LD and A-LS, respectively) had higher climate change impacts per kg acidity treated compared with most passive bioreactor treatment systems apart from the bioreactor with purchased energy (P-BME) or the mussel shell leaching bed (P-LB). P-BME required 3800 kWh of pumped energy per kg acidity treated per day compared to only 911 kWh for A-LS or 83 kWh for A-LD, while crushing the mussel shells for the leaching bed (for P-LB) resulted in an additional energy input of 1500 kWh that was not incurred within the bioreactor scenarios that contained uncrushed mussels (Landfield and Karra, 2000). A-LS demonstrated 4.5 times greater climate change impacts than P-BME (1155 kg CO_2 eq.) and 39 times higher climate change impacts than A-LD (132 kg CO_2 eq.) resulting from the high processing energy embodied within the manufacturing of hydrated lime explained earlier.

4.2. Human toxicity

Human toxicity is concerned with the soil, air, and water emissions of certain substances (apart from GHG) that can adversely affect human health. The toxicity measurements are based on the Human Toxicity Potential, which defines the amount of a chemical based on toxicity and dose (Hertwich et al., 2009). Active treatment with lime slaking (A-LS) resulted in human toxicity emissions of 1053 kg 1,4-db eq. but only 58 kg 1,4-db eq. for lime dosing (Fig. 2C, Table 2), which appears to result from 17 times greater energy requirements for processing hydrated lime used in lime slaking compared with lime dosing. The passive treatment systems' emissions were typically lower than active systems, ranging from 31 kg 1,4-db eq. for a 50% reduction in materials transport distances (P-BMT) to 52 kg 1,4-db eq. for the standard mussel shell bioreactor (P-BM), except for the bioreactor with purchased energy (P-BME) with emissions of 68 kg 1,4-db eq. and the mussel shell leaching bed at 148 kg 1,4-db eq. (Fig. 2). Energy incurred in transport of the mussel shells accounted for substantial human toxicity impacts. For instance, with a 50% reduction in transport distances (P-BMT compared with P-BM), the human toxicity emissions were reduced by 40.4% from 52 kg 1,4-db eq. to 31 kg 1,4-db eq.

4.3. Particulate matter formation

Particulate matter is the mixture of solid particles and liquid droplets suspended in the air. Coarse particles (PM10) have an aerodynamic diameter between 2.5 and 10 mm. They are primarily formed by mechanical disruption including crushing, grinding, abrasion of surfaces, evaporation of sprays, and dust suspension (Ferro, 2000). Elevated levels of PM10 particles can result in a number of respiratory issues in humans, such as tissue damage and even cancer (US-EPA, 2003). Out of all scenarios modeled, lime slaking (A-LS) was the highest contributor to particulate matter formation

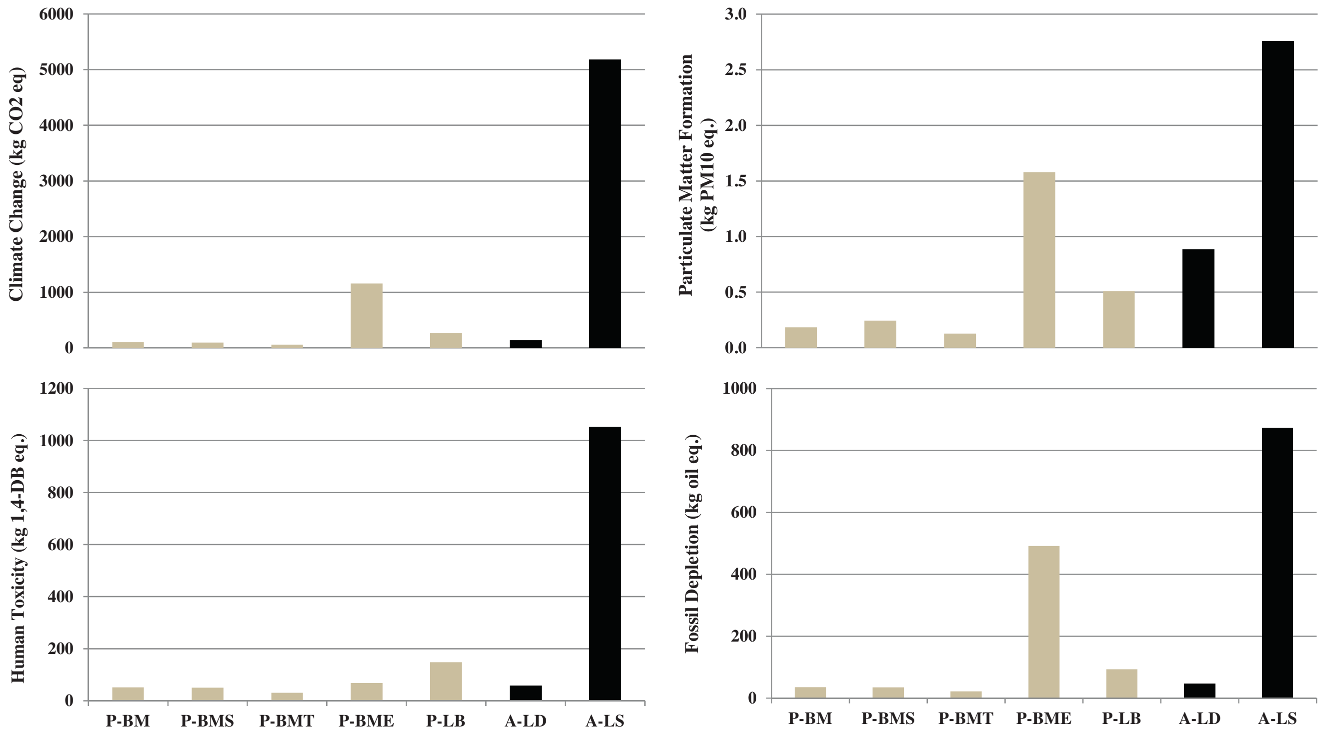

Fig. 2. Midpoint results for passive and active treatment scenarios: (A) climate change (kg CO_2 eq.), (B) particulate matter formation (kg PM10 eq.), (C) fossil depletion (kg oil eq.) and (D) human toxicity (kg 1,4-DB eq.).

at 2.76 kg PM10 eq., followed by the bioreactor with purchased energy (P-BME), which had 1.58 kg PM10 eq. (Fig. 2C, Table 2). The bioreactor with 50% reduced transport (P-BMT) showed the lowest particulate matter formation at 0.13 kg PM10 eq. (Fig. 2). Particulate matter formation results from fossil fuel combustion such as that from coal powered electricity generation and vehicle transport. New Zealand's energy profile is predominantly hydropower but electricity-intensive processes such as quicklime production along with transport can contribute to particulate matter discharges to the air as reflected within the modeling results.

4.4. Fossil depletion

Fossil depletion is associated with extraction of fossil fuels, most specifically for energy use. Active treatment with lime slaking (A-LS) had a fossil depletion impact of 874 kg oil eq., while lime-dosing (A-LD) only had a fossil depletion impact of 48 kg oil eq. Two passive treatment systems (i) the bioreactor with purchased energy (P-BME) and (ii) the mussel shell leaching bed (P-LB) had higher fossil depletion impacts (491 kg oil eq. for P-BME and 94 kg oil eq. for P-LB) than the active lime dosing but were much lower than lime slaking. The remaining passive treatment systems had fossil depletion values lower than the active treatment scenarios ranging from 22 kg oil eq. for the bioreactor with 50% reduced transport (P-BMT) to 36 kg oil eq. for the standard mussel shell bioreactor (P-BM). These results demonstrate the significance of energy consumption on fossil depletion, as the highest impact values were found in scenarios that had high process energy (P-BME, A-LS) or high transportation values (A-LD).

4.5. Endpoint metrics

The ReCiPe impact assessment method further classifies the midpoint categories into endpoint categories such as damage to human health and ecosystem quality (Goedkoop et al., 2009). While the midpoint results reflect the physical environmental impacts, the endpoint categories reflect the societal impacts of these environmental impacts. Generally, there is a higher degree of uncertainty with the endpoint analysis; however, the units for the endpoint analysis tend to be more understandable in the context of a discussion of environmental impacts. The endpoint categories assessed in this study were: damage to human health (DALY), damage to ecosystems (species.yr), and damage to resources ($) as shown in Fig. 3 and Table S3.

4.5.1. Damage to human health

Damage to human health summarizes potential impacts to humans from all stages of the life cycle of a product or process (materials to disposal) and is quantified as the number of life years lost per 100,000 people. Midpoint values used to determine the DALY metric include climate change, ozone depletion, human toxicity, photochemical oxidant formation, particulate matter formation, and ionizing radiation midpoint categories (Goedkoop et al., 2009). Human health impact(s) from the active AMD

Table 2
Summary of midpoint impact category results.

Impact category	Unit	P-BM	P-BL	P-BMT	P-BME	P-LB	A-LD	A-LS
Climate change	kg CO_2 eq.	99.84	98.09	61.72	1155.27	270.91	131.99	5180.36
Human toxicity	kg 1,4-DB eq.	51.62	50.79	30.74	68.05	148.43	57.53	1053.03
Particulate matter formation	kg PM10 eq.	0.18	0.25	0.13	1.58	0.51	0.88	2.76
Fossil depletion	kg oil eq.	35.53	35.06	22.41	491.41	93.71	47.80	873.92

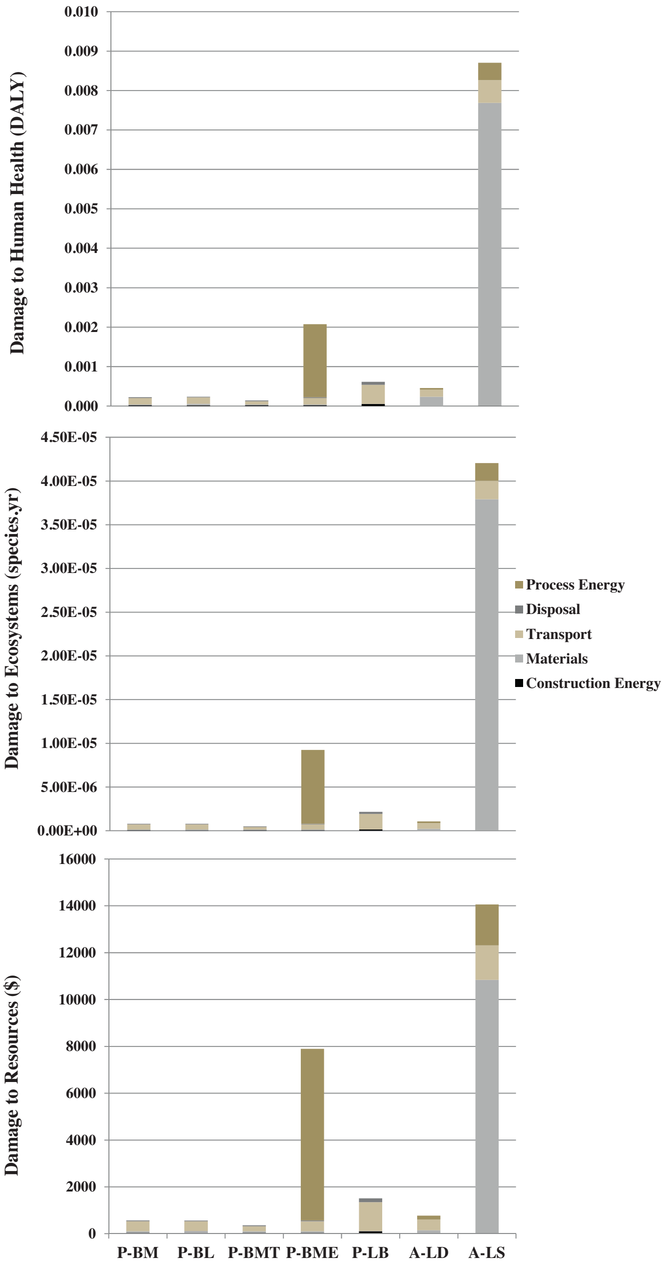

Fig. 3. Endpoint results for both passive and active treatment scenarios. From top to bottom, the endpoint categories evaluated were: damage to human health (DALY), damage to ecosystems (species.yr), damage to resources ($).

treatment scenario of lime-slaking (8.71E-3 DALY) was an order of magnitude greater than the other treatment methods (between 1.41E-4 DALY for P-BMT and 6.15E-4 DALY for P-LB) as shown in Fig. 3A. The impact of materials alone from lime slaking constituted 7.68E-3 DALY, or 88% of the total DALY, and 52% of the total DALY for lime dosing, at 1.79E-4 DALY (Table S3 and Fig. 3A). However, the largest contribution to DALY for most other scenarios (apart from P-BME) was transport. For instance, transport impacts ranged from 8.26E-5 DALY, or 59% of the total DALY, for P-BMT to 4.84E-4 DALY, or 79% of the total DALY, for P-LB (Table S3 and Fig. 3A)

4.5.2. Damage to ecosystems

Damage to ecosystems in LCA modeling is the expected loss of species per year (species.yr) resulting from a certain activity. It includes ozone layer depletion, photochemical oxidation, aquatic and terrestrial ecotoxicity, aquatic acidification, aquatic eutrophication, and land occupation midpoint categories (Goedkoop et al., 2009). Similar to human health impacts, damage to ecosystems was highest from lime-slaking with 4.20E−5 species yr^{-1} impacted (90% from materials), followed by 9.25E−6 species yr^{-1} from P-BME. Passive treatment systems resulted in impacts ranging from 1.07E−6 species yr^{-1} for a P-LB down to 7.97E−7 species yr^{-1} for a P-BM. Process energy for pumping AMD into a bioreactor as opposed to gravity-feeding it (P-BME) accounted for 91% of the damage to ecosystems at 8.45E−6 species yr^{-1} highlighting the impact of energy consumption on ecosystems. Transport accounted for 7% (P-BME) to 82% (P-LB) (average of 61%) of the total ecosystems impact for passive treatments and 61% for lime-dosing; however, only 5% for lime slaking (Table S3 and Fig. 3B).

4.5.3. Damage to resources

Damage to resources, measured in US dollars, is an LCA metric used to quantify the financial loss of minerals and non-renewable energy resulting from an activity and is calculated in a similar way to that of the other endpoint metrics described earlier. Damage to resources ($) demonstrated similar trends between scenarios seen for damage to human health (DALY) and ecosystems (species.yr), with the highest impacts demonstrated by lime slaking (A-LS) and pumped AMD (P-BME). A-LS incurred a loss in resources of $14,057 (of which 77% was from materials), and was 18 times higher than lime dosing (A-LD) at $769 (of which 60% was from transport). For the passive treatment scenarios, a 50% reduction in transport for a bioreactor had the lowest impact at $572, while the bioreactor with purchased energy yielded $7891 in resource depletion (Fig. 3C, Table S3). All other passive treatment transport impacts accounted for approximately 72% of the total damage to resources, with the exception of (P-BME), whose energy requirements constituted 93% of the total impact.

5. Discussion

Climate change impacts, notably highest for the active lime slaking system, resulted from the high processing energy embodied within the manufacturing of hydrated lime while most passive treatment systems incurred far less CO_2 eq. impacts apart from the bioreactor that pumped its AMD feed or the mussel shell leaching bed using crushed mussels. Energy incurred in processing lime for slaking and transport of the mussel shells for all passive systems contributed the most during the life cycles toward human toxicity and fossil depletion impacts. Transport of resources also dominated the contribution to particulate matter discharges emphasizing the importance of utilizing locally sourced materials when possible since increased transport (especially vehicular) distances resulted in greater impacts, and thus had a strong influence on overall LCA results.

Lime used in active lime slaking and lime dosing treatment dominated the contribution to each end-point (human health, ecosystem damage and damage to resources) impacts; however, for the passive scenarios, materials transport was the determinant except for the scenario where AMD was pumped to the bioreactor. These results highlight the negative implications of relying on raw lime and the consequences of sourcing alterative acidity-mitigating materials from afar.

Differences in the material contributions to overall end-point impacts for active treatment scenarios may be attributed to the different forms and treatment efficiencies of limestone used in their respective operations. For an equivalent treatment, quicklime requires 17 times the process energy, 10 times the weight of heavy machinery, and additional truck and rail transport compared to ultrafine limestone. Quicklime production has higher air emissions including carbon monoxide, carbon dioxide, heat, particulates, and sulfur dioxide. Lime slaking utilizing quicklime is also a less efficient process by design, resulting in added process energy in addition to the process energy already embodied within quicklime production.

Several design differences influence the life cycle environmental impacts between passive and active AMD treatment systems. Since the passive treatment systems utilize inherent biogeochemical treatment approaches, their energy and resource requirements are minimal throughout their design-life. In contrast, active treatment approaches require continuous chemical and energy applications, and are generally considered less 'sustainable' methods of AMD treatment (Skousen, 1997). However, active treatment systems typically afford a considerably greater quantity of AMD to be treated, in generally the same, or less, areal footprints compared to passive treatment systems. Passive treatment systems require often voluminous materials to be transported by road-freight although impacts associated with this can be offset substantially by employing 'waste' (i.e. reused) products and ideally locally sourced materials.

6. Conclusions and recommendations

At the Stockton Coal Mine, several passive and active treatment systems currently exist to treat the AMD at the site. This study investigated five passive treatment and two active treatment scenarios that either exist or could be considered through LCA to determine the environmental impacts of each treatment methodology per kg of acidity removed. Results indicate that passive treatment generally had lower overall environmental impacts compared to active treatment technologies. The minimization of transport distances and using recycled materials or materials requiring a lesser degree of (pre)processing provided enhanced environmental benefits. It is unlikely that large-scale mining operations would rely solely on passive treatment for AMD mitigation, as effective treatment systems rely on a number of site-specific factors such as required footprint, land availability, topography, AMD discharge (and chemical signature) and operational temperatures (impacting treatment efficiencies). However, one should consider combination of both active and passive treatment systems to provide a balance between meeting operational AMD-treatment requirements and lowering environmental impacts compared to the sole consideration of active treatment. While this study focused specifically on conditions at the Stockton Coal Mine, several general recommendations could be inferred from our study results. Gravity-fed, passive treatment result in lower environmental impacts compared to active treatment systems, with the important caveat of increased process footprint requirement. Important design considerations for 'sustainable' AMD treatment should include utilizing materials with a reduced degree of processing, sourcing local materials, and minimizing pumping energy.

Acknowledgments

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.resconrec.2014.01.003.

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Evaluation of the performance of two vegetated treatment systems

Basic Information

Title:	Evaluation of the performance of two vegetated treatment systems
Project Number:	2012SD210B
Start Date:	3/1/2012
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	First
Research Category:	Engineering
Focus Category:	Acid Deposition, Water Quality, None
Descriptors:	
Principal Investigators:	Todd P. Trooien

Publications

1. Trooien, TP, A Mathiowetz, S Pohl, A Boe, R Gelderman, D Todey, CH Hay, JH Khaersgaard. 2013. Performance of vegetative systems for CAFOs in a northern subhumid climate. ASABE Paper 131619798.
2. ASABE paper, Trooien et al, presented to the 2013 Summer Annual International Meeting, Kansas City, MO, USA.

Project Annual Report

Project Title: Evaluation of the performance of two vegetated treatment systems

PI: Todd P Trooien
Reporting Period: March 1, 2013 to Feb. 28, 2014
Date of Report: May 1, 2014
Written By: Todd P Trooien

Executive summary
The major accomplishments completed in the reporting period include:

- Collected baseline soil samples from the VTA at the Southeast Research Farm.
- Analyzed a subset of the soil samples for pH, total nitrogen, and phosphorus concentrations.
- Trained two undergraduate Agricultural and Biosystems Enginering (ABE) students.

Background

Animal agriculture seeks efficient production of economical food by placing many animals together in animal feeding operations (AFO). These operations make efficient use of space, labor, and investments in technology and other capital such as vehicles, feeders, storage, and infrastructure. But these operations also concentrate the animal waste products such that they could be deleterious to the environment if not managed properly.

Beef feedlots are an example of animal feeding operations. The runoff from open feedlots must be controlled and managed properly to prevent adverse impacts on the environment. The standard runoff control system for beef feedlots is collection of the runoff into a holding pond or lagoon. This technology is routinely accepted by USEPA and state regulatory agencies Design and management guidelines for holding ponds are well established.

Holding ponds are not optimal for every site, however. Alternative technologies that perform as well as or better than holding ponds would be useful to many producers and regulatory agencies, as long as they manage the runoff well enough to protect the environment. This project is designed to monitor one alternative technology for beef feedlot runoff, the Vegetated Treatment System (VTS).

A VTS, as used in this proposal, consists of a solids settling basin (SSB), a distribution method to apply the runoff, and a Vegetated Treatment Area (VTA) to receive the runoff. This project will test two different distribution methods- (1) gravity flow through multiple outlets and (2) sprinkler distribution.

Previous research has shown that a gravity-driven VTS, if properly designed and managed, has the potential to prevent surface water release. Two of the system requirements for a properly designed and managed system are: (1) active control of the SSB outlet to delay the application of water to the VTA and (2) water spreading methods to apply runoff to the entire VTA.

A sprinkler VTS can adequately address both of the requirements but that technology has not been tested in South Dakota. Tests in Nebraska have shown that a sprinkler VTS can control runoff and apply it effectively. But the harsher weather of South Dakota may make sprinkler VTS management more difficult, especially at the beginning and end of the growing season. Thus, sprinkler VTS technology should be tested in South Dakota.

Our hypothesis is that a gravity-driven or sprinkler vegetated treatment system can successfully control and manage the runoff from a beef feedlot. The goal of this study is to evaluate the performance of two vegetated treatment systems, one gravity system and one sprinkler system, in their control and management of surface water.

The objectives of this project are to measure and sample the surface water flows at two VTS sites to document the effectiveness of the VTS at each site in managing the feedlot runoff.

Planned activities:

Table 1. Timeline of activities

Activity	Months
Install monitoring equipment at both VTS sites	March to April
Test pump flow rates at sprinkler VTS	May
Monitor surface water flows at both sites, collect VTA inflow samples	March to October
Transport VTA inflow samples to lab	When collected

Actual Accomplishments:

1. *Analyze feedlot runoff/wastewater sample*

A wastewater sample was collected from the solids settling basin (SSB) in mid-November of 2013. This is quite late in the season but the sample was still representative of the system. The water in the SSB had been held for many days so some settling had taken place. This is not uncommon for a well-managed VTS.

Analysis of the sample showed the concentrations to be:
Ammonium-N: 6 mg/L
Total nitrogen: 51.6 mg/L
Total phosphorus: 288.7 as P_2O_5
total solids: 2294 mg/L

These are modest values, especially the nitrogen concentrations.

1. *Education and training*

There were two undergraduate ABE students, Patrick Hofer and Lane Stockland, trained in this project in its first year. One was paid directly by this project and the other student was paid from other grant funds. They were trained in surface water measurement and sample collection, plant biomass sampling and processing, groundwater measurement and sampling, and preliminary data analysis with spreadsheets. Not all of these tasks were related to this funded 104 b project but all were related to research efforts at the two VTS sites.

2. *Project outcomes and challenges*

The outcomes of this project included:

- Collected baseline soil samples from the VTA at the Southeast Research Farm (previous year).
- Analyzed a subset of the soil samples for pH, total nitrogen, and phosphorus concentrations (previous year).
- Analyzed a wastewater sample from the solids settling basin of the sprinkler VTS site (this year).
- Trained two undergraduate ABE students (previous year).

There are still some challenges for the use of VTS as a routine method for feedlot runoff management.

- Because of the historically dry conditions at the sprinklers VTS site, the actual performance of the system is still unknown.
- Weather varies from year so multiple years of monitoring are required to adequately and confidently characterize the long-term performance of VTS.

Summary

Two students were trained in VTS monitoring at two sites. The sprinkler VTS site was historically dry. One runoff/wastewater sample was collected at that site and analyzed. Baseline soil samples were collected. A subset of the samples was analyzed for N and P and showed little or no difference among the analyzed locations.

Identifying barriers for adopting new drainage technology among agricultural producers

Basic Information

Title:	Identifying barriers for adopting new drainage technology among agricultural producers
Project Number:	2012SD211B
Start Date:	3/1/2012
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	First
Research Category:	Social Sciences
Focus Category:	Management and Planning, Agriculture, Water Quality
Descriptors:	
Principal Investigators:	Nickolas Benesh, Jeppe H Kjaersgaard

Publications

1. Kjaersgaard, Jeppe, Benesh, Nicholas, Hay, Chris, 2012, Identifying barriers for adopting drainage technology among agricultural producers, 2012 Western South Dakota Hydrology Conference. Rapid City, SD
2. Davis, Molly, Goodale, Brooke, Kjaersgaard, Jeppe, Benesh, Nicholas, Hay, Chris, 2012, Measures of innovation diffusion of sub-surface drainage in South Dakota, Poster session presented at the Eastern South Dakota Water Conference. Brookings, SD.
3. Kjaersgaard, Jeppe, Benesh, Nicholas, Hay, Chris, 2012, Identifying barriers for adopting drainage technology among agricultural producers, 2012 Western South Dakota Hydrology Conference. Rapid City, SD
4. Davis, Molly, Goodale, Brooke, Kjaersgaard, Jeppe, Benesh, Nicholas, Hay, Chris, 2012, Measures of innovation diffusion of sub-surface drainage in South Dakota, Poster session presented at the Eastern South Dakota Water Conference. Brookings, SD.
5. Identifying Characteristics of Innovation in South Dakota Agricultural Producers. (July 2013) Journal of Environmental Psychology (http://www.journals.elsevier.com/journal-of-environmental-psychology/)

Project Completion Report

Project Title: Identifying Barriers to Conservation Drainage Water Management among Agricultural Producers

PIs: Nick Benesh, Jeppe Kjaersgaard, & Chris Hays

Reporting Period: March 1 2013 - February 28 2014

Written by: Nick Benesh

Brief Summary

Goal of project was to explore reasons why agricultural producers in the SD area may be slow to adopt a new innovation, such as filtration for subsurface water drainage tile. Accomplishments:

- Developed a preliminary set of questions to assess the target population.
- Based on pilot study results a questionnaire was created to acquire demographic information and views on conservation drainage.
- Trained two Psychology undergraduates on survey methods

Introduction

The diffusion of innovations is something that can happen seemingly overnight like television programming or take decades to be fully accepted as in seat belt usage. Research on this suggests that persuading people to use an innovation is not as straight forward as simply telling them it is better (Rogers, 2003). The decision to use something new involves not only internal considerations (usefulness, ability to use, etc.), but also external considerations (environment, social norms, etc.). Whether the user finds the innovation useful or not will depend on a person's perceptions of the innovation. However, there are models and theories that assist in understanding the likelihood of adoption; specifically, Everett's (2003) Innovation Diffusion Theory (IDT) has been influential in this area for more than half a century.

Diffusion of innovation can be broadly defined as a change that alters structure and function of a social system (Rogers, 2003, 6). The different rates of diffusion of innovations are difficult to predict due to the varying contexts of them. Rogers' (2003) IDT involves four elements: innovation, communication channels of diffusion, timing, and current social system. Each element can be adapted to the context and further broken down into more specific aspects and functions each play in the broader concept of innovation diffusion.

The first step of diffusion is getting users to want the innovation. Rogers (2003) outlines five components of the first step: 1) perceived relative advantage, 2) compatibility with norms and values, 3) opportunity to try innovation to reduce uncertainty, 4) observability of a change to the current system, and 5) perceived difficulty of use. The first four components are theorized to be positively related to rates of adoption, while the fifth is theorized to be negatively correlated. On the other hand, when the innovation is perceived as complex and difficult to implement, the theory would predict the adoption rate to be low or slow. Lee, Hsieh, and Hsu (2011) applied the five IDT components in regards to using and promoting online learning systems. They found that people's perceptions of usefulness were influenced most by the compatibility and relative advantage of the innovation. In addition, ease of use perceptions were influenced positively by relative advantage and trialability, but negatively by perceived complexity. Their overall findings suggest the components are not all equally related, but instead cover a variety of variables related to innovation adoption behavior.

Edward-Jones (2006) advocates the importance of an individual's unique attitudes in regards to innovation adoption, suggesting they are tightly coupled with decision making processes. For example, crop farmers make large decisions that have long term and geographical implications. These implications mean they must carefully consider multiple factors before selecting a course of action. As a result, Edward-Jones has encouraged researchers to examine the importance of identifying norms locally and personally.

Innovation Context

Recently the U.S. Department of Agriculture (2011) revised its nutrient management conservation practices to promote use of technology and local information. It calls for stricter water management to reduce the loss of nutrients from water runoff, specifically in the Upper Mississippi Basin. To address this, researchers are looking into innovation diffusion from many perspectives and in various areas of application. Each local area has its own norms/values, ways of implication, outcomes, and audience. More specifically, soil nutrient run off has become an issue in South Dakota (Bartos, 2012) with the recent increase in subsurface tiling (Johnson, 2012).

Due to the need to increase food production to feed the world's growing population, there is a requisite for more effective yet sustainable methods of food production. One such method of promoting this is the installation of subsurface, or tile, drainage systems to maximize land usage.

The use of subsurface drainage on agricultural land with poor natural drainage allows more timely access for field operations and leads to improved crop yields. Subsurface drainage has become increasingly popular in eastern South Dakota in recent years. Increasing trends in precipitation, high agricultural commodity prices, rising land prices and the advent of computer-aided tile drain installation equipment all contribute to the increased interest in tile drainage. However, studies have found elevated nitrogen (in the form of nitrate) concentrations in tile drainage water (e.g. Randall and Goss, 2008) compared to surface runoff.

Nitrogen is an essential plant nutrient. However excess nitrogen leads to nutrient enrichment, algae growth and hypoxic conditions in which aquatic organisms can no longer survive. Current tile drainage systems can increase the nitrate concentration in water that comes off of crop fields, which then flows into larger river systems impacting their quality level. David et al. (2010) found that fertilized crops on tile drained lands were the greatest contributing factor for riverine nitrate yields in the Mississippi River basin. Studies looking at the nitrogen transported by the Mississippi River have been linked to the 'dead zone' found in the Gulf of Mexico (USEP, 2007). In addition, exposure to elevated nitrate levels in drinking water is a public health concern as it may reduce adequate amounts of oxygen in organs and lead to acute methemoglobinemia (*blue-baby syndrome*) in infants.

Elevated nitrate levels create a critical need among water managers and policy makers for strategies to minimize nitrate losses through subsurface drainage of agricultural land. This is done in order to balance profitable agricultural production with clean drinking water needs, environmental sustainability and the security of future ecosystem services. There are several effective management practices for reducing the amount of nitrate in drainage water available, including good management of nitrogen fertilizer, changes in cropping systems or optimization of the drainage system design. However, these practices are often not enough, and it is necessary to have an edge-of-field treatment system to reach the goals for decreasing the amount of nitrogen that is discharged into waterways to acceptable levels. Several studies show that installing edge-of-field treatment systems are effective technologies for reducing nitrate concentrations of drainage flow (e.g. Luo et al., 2010). Currently, the most common treatment systems include controlled drainage water management using drainage control structures, denitrifying bioreactors as filters for nitrates, and wetlands.

Study Goal

Treatment technologies that were developed several decades ago have not been widely adopted by the agricultural landowners. The goal of the project was to explore the barriers and identify incentives that may increase the adoption rate of innovations, specifically drainage water treatment systems by agricultural landowners. Our hypothesis is that the very modest adoption rate for these nitrate treatment systems relates to producers either: 1) Are not informed about nitrate problems related to tile drainage, 2) Are not informed about treatment options, 3) Feel environmental concerns regarding tile drainage are unwarranted or 4) lack incentives.

Methodology

Edward-Jones (2006) points to five non-financial variables influencing producer decision making: personal characteristics, household characteristics, farm structure, social milieu and characteristic of the innovation. We used two rounds of questionnaires to determine agricultural producers' use of drainage technology and motivations to adopt new ones.

Pilot Study

In spring 2012, questionnaire was presented at a South Dakota subsurface tile drainage workshop. The questions explored reasons and likeliness for adopting recent innovations in general, social influences, recent technology for drainage management, years of agricultural experience, and which basin the drained acreage primarily resides (see Appendix 1). Questions were displayed using PowerPoint and participants used TurningPoint Clickers to respond.

Results: An exploratory analysis of the nominal data was evaluated visually looking for large patterns demographic or tile drainage opinion. Knowledge of Soil Science and Impact of Drainage on Environment were strongly correlated, $r(164)=.47$, $p<.01$. This suggests or confirms that extension workshops are fulfilling a need. A moderate correlation was found for relying on Own Experience and Experts' recommendations, $r(161)=.15$, $p<.05$. Suggesting agricultural producers may seek out expert opinions and compare it with their own experiences. Another moderate correlation was found for relying on Experts' recommendations and neighbors' opinion on tiling, $r(161)=.21$, $p<.01$. This may suggest that agricultural producers are just as likely to rely on experts as their neighbors opinions.

Main Study

For the main study we generated over 40 questions to address the range of possible influences on adopter behavior. However, it was believed that the participants would be unlikely to answer all of them with the limited time they have (Rogelberg, 2005). Therefore, the list of questions was streamlined to 14 (mix of multiple choice, and open-ended). In the winter of 2013, the second questionnaire was distributed at a South Dakota subsurface tile drainage workshop in Aberdeen, SD. It focused on specific motivational aspects as based on the information collected in the initial questionnaire, along with the TIPI, which measures the Big Five personality traits of extraversion, agreeableness, conscientiousness, emotional stability, and openness to new experiences (see Appendix 2).

Results

Thirty nine participants filled out the questionnaire. The participants came from the following river basins: Big Sioux river 7.7%, James river 48.7%, Red river 41%, and other 2.6%. Mean farming experience of participants was 25 years (range 3-50 years). On average, participants had first heard of tiling 11 years (range 2-48 years) prior to attending the workshop. In addition, almost 75% of attendants had already installed some tiling indicating the general idea of tiling is well known. Participants' personality scores on the TIPI did not differ significantly from the normative data for the measure. We also asked about activities related to wildlife around the farm in order to gauge participants connection with and awareness of the surrounding nature (Table 1). Most participants partake in some form of outdoor recreation, with most valuing wildlife habitat areas, and about a third providing

When deciding whether to use new farming innovations most participants say they seek outside consultants, other producers, extension specialists, friends/family/neighbors, and to a lesser extent their employees (Table 2). While extension specialists are being used, they are not the primary source of information. Most producers are getting information from multiple sources. When providing workshops on innovations it may be worthwhile to expand these to communities, as well as agricultural producers. Furthermore, most participants attend quarterly agriculture meetings (56%), or annual meetings (26%), with a few attending meetings every couple weeks (15%).

Table 1. Responses to: *How do you interact with the wildlife and environment near and on the farm?*

Wildlife Interactions Near Farm	Percentage
Recreational hunting, fishing or other outdoor activities	72%
Maintain habitat areas for wildlife	54%
Leave food plots for wildlife	36%
Other	5%

Table 2. Responses to *Who do you consult before using a new technique, method or other innovation? Check all that apply.*

Source of Information	**Percentage**
Outside Consultants	85%
Other Producers	64%
Extension Specialists	59%
Friends/Family/Neighbors	44%
Employees	18%

Participants were asked specific questions about conservation drainage (CD), motivation for implementation, and incentives for implementation. Few participants were unaware of the negative impact tiling can have on nitrate losses (Table 3). However, most expressed interest in additional information about conservation drainage. When asked about financial incentives for installing a CD system, most participants were unwilling to pay additional costs. Although, a few were willing to pay some additional costs for installation of a CD system (Table 4). We asked a follow-up question to gauge what might increase participant's motivation to implement a CD system (Table 4). Most participants would be willing if they felt it corresponded with principles of being a good steward to the land. They were also interested in ways of demonstrating to the public the environmentally responsible actions modern farms are taking. On the other hand, they would feel more motivated if the system provided something for them in the way of information on soil moisture in the field.

Table 3. Responses to: *One concern about tiling is nitrate losses from the drains. Conservation drainage (CD) practices are one way to address these concerns. Would you be willing to implement CD practices?*

Would you be willing to implement CD?	**# of Participants**
I would implement CD practices but I need more information	22
I think the environmental concerns relating tiling are unwarranted	5
I am ready to implement CD practices	4
I was not aware of any negative impacts of tiling	2
I would implement CD practices if there were financial incentives to do so	2
I have implemented CD practices already	1
Other	2

Table 4. Responses to: *If you implemented field tiling, would you also be willing to implement in-field or end-of-tile CD practices if it does not interfere with the tile system efficiency?*

Willing to implement in-field or end-of-tile CD practices	**# of Participants**
I would not install CD practices	1
I would install CD if it was no additional cost to me	16
I would install CD if it was only an additional 1-5% of the cost of tile installation	7
I would install CD if it was only an additional 5-10% of the cost of tile installation	7
I would install CD if it was only an additional 10-15% of the cost of tile installation	2
I would install CD if it was only an additional 15-20% of the cost of tile installation	2
I would install CD if it was an additional 20% or more of the cost of tile installation	1
Other	2

Table 5. Responses to: *What would motivate you to implement Conservation Drainage (CD) management practices? Check all that apply.*

What would motivate you?	**Percentage**
Being a good steward of the environment	80%
It can help me manage soil moisture better	56%
Help with public perception of farming	54%
Reduce the environmental footprint	33%
Cost share or other financial incentives	31%
My neighbors are doing it	8%

Discussion

These results provide an initial representation of agricultural producers in the regional area. Most producers are aware of new innovations, but would like to know more about them before committing. Moreover, it is recommended that future incentives to increase usage and implementation of CD should focus on cost of installation, along with explaining the practical benefits to soil/water management. While aiming this information at the producers has been a good start, additional targets of information delivery (outside consultants, friends/family/neighbors, etc.) could potentially boost awareness of and adoption of CD. This information could be beneficial for those interested in extension programs and working with local agricultural producers, in order to facilitate meeting their needs. The long-term goal of this study is to collect preliminary information that could be applied in future project proposals (such as to USDA NIFA Integrated Grants). These topics might include similar water resource management areas and populations addressing both economic feasibility of implementation and societal impacts on water resource problems, such as agricultural waste land application or agricultural and environmental resilience towards variations in climate and changes in policies and economics.

Student Involvement in Project

Two undergraduate Psychology students were heavily involved in the overall process of the project. They searched out articles and assisted in writing up the literature review. Gained valuable knowledge by going through Went through multiple iterations of the questionnaires, and collection of data from participants. One of the students presented the pilot study results at the Eastern SD Water conference.

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Appendix 1: Pilot Study Questionnaire

1) What is your main occupation?
   - I farm my own farm
   - I manage a farm but I am not the owner
   - Farm worker
   - Drainage contractor
   - County agency/policymaker
   - State agency/policymaker
   - Federal agency/policymaker
   - Other, farm related
   - Other

2) How many years have you been doing your main occupation?
   - 0-5 years
   - 5-10 years
   - 10-15 years
   - 15-20 years
   - 25-30 years
   - More than 30 years

3) In which river basin is most of your land or business located?
   - Big Sioux River Basin
   - James River Basin
   - Minnesota River Basin
   - Red River Basin
   - Vermillion River Basin
   - Other basin in SD
   - Other basin in ND
   - Other basin in MN
   - Other basin in NE
   - Other basin

4) If you own or manage a farm,
   - I have no tile
   - I have no tile but I consider putting some in myself
   - I have no tile but I consider having a contractor putting some in
   - I have some tile, and would like to put in more myself
   - I have some tile and I consider having a contractor putting in more
   - None of the above
   - I do not own or manage a farm

5) How many acres do you farm?
   - 1-199
   - 200-399
   - 400-599
   - 600-799
   - 800-999
   - 1,000-1,199
   - 1,200-1,399
   - 1,400-1,599
   - 1,600+

6) How much of a concern is excess water on fields compared to other crop concerns?
   - 1 - Not at all important
   - 2
   - 3
   - 4 - Just as important as others
   - 5
   - 6
   - 7 - Most Important

7) What is the biggest challenge for you relating to tile installation
   - I am not sure tiling will benefit me
   - I am not sure how to design the tiling system
   - Cost of installation
   - Getting a wetland determination done by the NRCS
   - Getting a tiling permit
   - Downstream neighbors
   - Environmental concerns, nitrogen management
   - Public perceptions
   - Other

8) What is the second biggest challenge for you relating to tile installation?
   - I am not sure tiling will benefit me
   - I am not sure how to design the tiling system
   - Cost of installation
   - Getting a wetland determination done by the NRCS
   - Getting a tiling permit
   - Downstream neighbors
   - Environmental concerns, nitrogen management
   - Public perceptions
   - Other

9) How much do you feel you know about tiling and its benefits/drawbacks?
   - 1 - Not informed at all
   - 2
   - 3
   - 4 – Informed enough to talk about it
   - 5
   - 6
   - 7 – Very informed

10) How familiar are you with soil science in general?
   - 1 - Not informed at all
   - 2
   - 3
   - 4 – Informed enough to talk about it
   - 5
   - 6
   - 7 – Very informed

11) How aware are you of the impact tiling drainage has on the immediate environment?
   - 1 - Not informed at all
   - 2

3
4 – Informed enough to talk about it
5
6
7 – Very informed

12) How aware are you of the impact tiling drainage has on the environment at large?
    1 - Not informed at all
    2
    3
    4 – Informed enough to talk about it
    5
    6
    7 – Very informed

13) Tile drainage typically increases the amount of nitrate coming off a field compared to surface runoff. Some negative impacts of tile drainage can be reduced by implementing conservation drainage (CD) practices (practices to keep the benefits of drainage while minimizing negative impacts). Would you be willing to implement CD practices?
    I was not aware of any negative impacts of tiling
    I think the environmental concerns relating tiling are unwarranted
    I would implement CD practices but I am not aware of how they work
    I have implemented CD practices already
    Other

14) Would you be willing to implement in-field or end-of-tile Conservation Drainage (CD) practices if it does not interfere with the tile system efficiency?
    I would not install CD practices
    I would install CD if they are available at no cost to me
    I would install CD if they are available at less than 5% of the cost of tile installation
    I would install CD if they are available at 5-10% of the cost of tile installation
    I would install CD if they are available at 10-15% of the cost of tile installation
    I would install CD if they are available at 15-20% of the cost of tile installation
    I would install CD if they are available at 20% or more of the cost of tile installation
    Other

15) What would motivate you to implement Conservation Drainage (CD) management practices?
    I would not implement CD practices
    Reduce the environmental footprint
    Being a good steward of the environment
    Help with public perception of farming
    My neighbors are doing it
    It can help me manage soil moisture better
    Other

16) How frequently do you interact with the closest neighbors to your fields?
    1 - Never
    2
    3
    4 – Every other week
    5
    6

7 – Every 1-2 days

17) How important are the opinions of your closest neighbors' when making your decisions on tiling?
    1 - Not at all important
    2
    3
    4 - Just as important as others
    5
    6
    7 - Most Important

18) How important is the cost-to-benefits ratio in your consideration for using tiling?
    1 - Not at all important
    2
    3
    4 - Just as important as others
    5
    6
    7 - Most Important

19) How would you feel about possible future regulations on tiling?
    1 – Very negative
    2
    3
    4 – Depends on the regulations
    5
    6
    7 – Very positive

20) I view more crops as more profit to help sustain my operation and employees.
    1 – Strongly disagree
    2
    3
    4 – Unsure
    5
    6
    7 – Strongly agree

21) I view more crops as contributing more resources to the world at large that can be used by others.
    1 – Strongly disagree
    2
    3
    4 – Unsure
    5
    6
    7 – Strongly agree

22) Do you feel that farming innovations are beneficial?
    1 – Rarely
    2
    3
    4 – Occasionally

5
6
7 – Always

23) I primarily rely on my experience to make judgments about trying new things.

1 – Never
2
3
4 – Somewhat
5
6
7 – A great deal

24) I primarily rely on experts' explanations and recommendations about trying new things.

1 – Never
2
3
4 – Somewhat
5
6
7 – A great deal

Appendix 2: Main Study Questionnaire

1) What river basin is the majority of your land in?

a) Big Sioux River Basin
b) James River Basin
c) Minnesota River Basin
d) Red River Basin
e) Vermillion River Basin
f) Other _________________

2) How many years of experience do you have working in farming or other agricultural production?

_____ years.

3) Who do you consult anyone before using a new technique, method or other innovation?

(Circle all that apply)

a) No one
b) Other producers
c) Friends
d) Family
e) Neighbors
f) Employees
g) Outside consultants
h) Extension specialist
i) Other__________________

4) How often do you attend meetings/presentations/demonstrations on agricultural innovations?

a) Never
b) Yearly
c) Quarterly
d) Monthly
e) Every couple weeks

5) Have you or any of your friends/neighbors already tiled some fields?

Yes or No

6) When did you first hear about or start using tiling?

_______(year)

7) One concern about tiling is nitrate losses from the drains. Conservation drainage (CD) practices are one way to address these concerns. Would you be willing to implement CD practices?

(Circle best one)

a) I was not aware of any negative impacts of tiling
b) I think the environmental concerns relating tiling are unwarranted
c) I am ready to implement CD practices
d) I would implement CD practices but I need more information
e) I would implement CD practices if there were financial incentives to do so
f) I have implemented CD practices already
g) Other _____________________________

8) If you implemented field tiling, would you also be willing to implement in-field or end-of-tile Conservation Drainage (CD) practices if it does not interfere with the tile system efficiency?

(Circle best one)

a) I would not install CD practices

b) I would install CD if it was no additional cost to me
c) I would install CD if it was only an additional 1-5% of the cost of tile installation
d) I would install CD if it was only an additional 5-10% of the cost of tile installation
e) I would install CD if it was only an additional 10-15% of the cost of tile installation
f) I would install CD if it was only an additional 15-20% of the cost of tile installation
g) I would install CD if it was an additional 20% or more of the cost of tile installation
h) Other

9) What would motivate you to implement Conservation Drainage (CD) management practices?
(Circle all that apply)
a) I would not implement CD practices
b) Reduce the environmental footprint
c) Being a good steward of the environment
d) Help with public perception of farming
e) Cost share or other financial incentives
f) My neighbors are doing it
g) It can help me manage soil moisture better
h) Other

10) What are some of the biggest challenges for you relating to tile installation?

11) How do you interact with the wildlife and environment near and on the farm?
(Circle all that apply)
a) Recreational hunting, fishing or other outdoor activities
b) Leave food plots for wildlife
c) Maintain habitat areas for wildlife
d) Other ___________________

12) How concerned would you say others in your community are about agricultural impacts on the local environment?
a) Not interested
b) Not worried
c) Indifferent
d) To a certain extent
e) Greatly concerned

13) Are you involved in local community organizations? (Ex. school board, Scouts, church committee, 4-H, township board etc.)

TIPI

Here are a number of personality traits that may or may not apply to you. Please write a number next to each statement to indicate the extent to which you agree or disagree with that statement. You should rate the extent to which the pair of traits applies to you, even if one characteristic applies more strongly than the other.

There are no right or wrong answers. Your responses are kept anonymous.

Rating Scale
1 = Disagree strongly
2 = Disagree moderately
3 = Disagree a little
4 = Neither agree nor disagree
5 = Agree a little
6 = Agree moderately
7 = Agree strongly

I see myself as:
______ Extraverted, enthusiastic.
______ Critical, quarrelsome.
______ Dependable, self-disciplined.
______ Anxious, easily upset.
______ Open to new experiences, complex.
______ Reserved, quiet.
______ Sympathetic, warm.
______ Disorganized, careless.
______ Calm, emotionally stable.
______ Conventional, uncreative.

Subsurface Drainage Impacts on Evapotranspiration and Water

Basic Information

Title:	Subsurface Drainage Impacts on Evapotranspiration and Water
Project Number:	2012SD212B
Start Date:	3/1/2012
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	First
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Agriculture, Water Quantity
Descriptors:	
Principal Investigators:	Christopher Hay, Jeppe H Kjaersgaard, Todd P. Trooien

Publications

1. Evapotranspiration for fields with and without tile drainage. To be submitted to Transactions of the American Society of Agricultural and Biological Engineers by 31 Dec 2014.
2. Khand, K., C. Hay, J. Kjaersgaard, and T. Trooien. 2013. Subsurface drainage impacts on evapotranspiration (ET). Eastern South Dakota Water Conference. Brookings, S.D. 30 Oct.

Subsurface Drainage Impacts on Evapotranspiration and Water Yield

Progress Report: March 1, 2013 to February 28, 2014

Investigators:

Christopher Hay, South Dakota State University
Jeppe Kjaersgaard, South Dakota State University
Todd Trooien, South Dakota State University
Gary Sands, University of Minnesota

Introduction

Subsurface drainage has increased dramatically in eastern South Dakota with increases in precipitation, commodity prices, and land prices. Subsurface drainage improves agricultural production by increasing yields and reducing risk, but there are concerns about its environmental impacts. A key concern is to what extent does subsurface drainage contribute to downstream flow alterations and flooding through changes in the amount and timing of water leaving the field. Changes in evapotranspiration (ET), as a result of drainage, are a primary determinant of the hydrologic alterations from subsurface drainage. However, the impacts of drainage on ET are not yet well understood. Lack of such knowledge is an important problem, because without it, we are limited in our ability to accurately quantify the impacts of subsurface drainage on watershed hydrology and flooding.

Project Information

The overall goal of this project is to develop a method to account for the impact of yield reductions from poor drainage on evapotranspiration in drainage model simulations. Our central hypothesis, based on water productivity functions that relate crop yield and ET, is that current drainage model simulations overestimate ET under undrained or poorly drained conditions. The rationale for the proposed research is that once we are able to accurately simulate ET under undrained and poorly drained conditions, we can then better estimate the impacts that subsurface drainage development will have on hydrology. Our contribution here is expected to be an improved understanding of the impacts of subsurface drainage on ET. Once such knowledge is available, we can better evaluate the hydrologic impacts of increased subsurface drainage in eastern South Dakota.

The drought in 2012 and less than expected drain flow in 2013 resulted in insufficient data with which to develop enough DRAINMOD simulations for the original objectives. Therefore, a different approach was developed using a remote sensing approach to compare ET from drained and undrained fields. The new approach remains within the overall project goal, but resulted in a new set of objective. The new research objectives for this project are:

1. Develop a weather dataset from existing weather monitoring sites for use in calculating reference ET at sites where onsite data and limited data are available.

2. Compare ET between drained and undrained fields using the METRIC model for estimating ET based on satellite remote sensing imagery.
3. Compare the METRIC estimated ET to ground-based measured ET for the site where these data were available.

The METRIC model will be used for direct comparisons of ET between similar fields with and without drainage. Three sites have been chosen for doing the ET comparisons: near Fairmount, ND; near Lamberton, MN; and near Lennox, SD. Landsat satellite imagery has been obtained and been processed for use in the METRIC model. METRIC ET estimations have been developed for the ND site. A comparison has been made between the METRIC-estimated ET and field-measured ET from and eddy covariance system located at the North Dakota site. Weather data have been processed for the Minnesota site, and work continues on developing METRIC ET estimates for the Minnesota and South Dakota sites. As results of this work are developed, they will be presenting at upcoming professional conferences in the coming year, and a manuscript for submission to a peer-reviewed journal will be developed.

Evaluating the Nitrate-Removal Effectiveness of Denitrifying Bioreactors

Basic Information

Title:	Evaluating the Nitrate-Removal Effectiveness of Denitrifying Bioreactors
Project Number:	2012SD215B
Start Date:	3/1/2012
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	First
Research Category:	Water Quality
Focus Category:	Water Quality, Agriculture, Non Point Pollution
Descriptors:	
Principal Investigators:	Jeppe H Kjaersgaard, Christopher Hay, Todd P. Trooien

Publications

1. Kjaersgaard, J., 2013. Denitrifying Bioreactors for N Removal from Tile Drainage Water. NDCDEA, ND/SD 319 Coordinators Meeting, Bismarck, ND, March 20-21 2013.
2. Kjaersgaard, J., Hay, C., Trooien, T., 2013. Conservation Drainage Practices to Remove Nitrate from Tile Drain Water. ASA, CSSA, and SSSA International Annual Meeting, Tampa, FL, November 3-6 2013.
3. Partheeban, C., Kjaersgaard, J., Hay, C., Trooien, T., 2013. Demonstrating the Nitrogen-removal Effectiveness of Denitrifying Bioreactors for Improved Drainage Water Management. Eastern South Dakota Water Conference, Brookings, SD. October 30 2013.
4. Partheeban, C., Kjaersgaard, J., Hay, C., Trooien, T., 2013. Demonstrating the Nitrogen-removal Effectiveness of Denitrifying Bioreactors in South Dakota for Improved Drainage Water Management. ASA, CSSA, and SSSA International Annual Meeting, Tampa, FL, November 3-6 2013.

Demonstrating the Nitrogen-Removal Effectiveness of Denitrifying Bioreactors for Improved Drainage Water Management

Progress Report: March 1, 2013 to February 28, 2014.

By C. Partheeban and J. Kjaersgaard, South Dakota State University. May 2014.

Report submitted to the South Dakota Water Resources Institute under the USGS 104b program.

Introduction.

The hypoxic zone of northern Gulf of Mexico (NGOM) is the largest in the USA and the second largest in worldwide (EPA-SAB, 2007). Enrichment of nutrients beyond the natural levels into the aquatic systems causes dramatic growth of algae, increased primary production, and the accumulation of organic matter which increases the greater demand for oxygen (Diaz & Rosenberg, 2008). The Mississippi River basin is the major contributor of freshwater and nutrient to the northern Gulf of Mexico. A large proportion of the nutrients enter into the Mississippi river basin from crop land through the tile drainage systems and surface runoff (EPA-SAB, 2007). Agricultural subsurface tile drainage helps to increase the agricultural productivity by allowing timely field operations and creating well aerated soil conditions to enhance the plant uptake of nutrients and reduce the surface runoff water quality issues (Crumpton & Helmers, 2004; OSU-Extension, 1998). However, the nitrate-nitrogen content of the tile water is a major environmental and health concern. Previous studies show that nitrogen fertilizer management alone is not sufficient to reduce the nitrate concentration in tile drain water (Dinnes et al., 2002). Therefore, there is an urgent and critical need to develop additional approaches to reduce the nitrate nitrogen loads in the tile drainage water before it exits the drainage systems. To reduce the nitrate accumulation and to cease the nitrogen cascade, nitrates can be converted back to inert nitrogen gas through the multi-step process called denitrification (Galloway et al., 2003).

Denitrifying woodchip bioreactors are examples of a cost effective and simple edge-of-field approach to treat the drainage water for nitrate concentration (Laura Elizabeth Christianson, 2011). Several bioreactors have been installed within the last decade or so in the US Midwest and internationally e.g. New Zealand (Schipper, Robertson, Gold, Jaynes, & Cameron, 2010). A study in Iowa by Christianson (2011) showed approximately 43% of nitrate nitrogen concentration reduction obtained by denitrifying bioreactors. Schipper et al. (2010) has investigated that both denitrification walls and denitrification beds have an ability to remove nitrate effectively with nitrate removal rates ranging from 0.01 to 3.6 g N/m3/day for walls and 2 to 22 g N/m3/day for beds. Denitrification walls mean construction of wall (generally filled with saw dust and soil mix) vertically across the groundwater flow, and denitrification beds refers to containers which are filled with carbon materials and contaminated drainage water runs out through it. This is called denitrifying bioreactors (Schipper et al., 2010; Schmidt & Clark, 2012). Although a number of investigations explain the bioreactor performance, there is still a lack of information about the effectiveness, factors controlling the bioreactor performance, site suitability, and the challenges and possible side effects of using bioreactors (Schipper et al., 2010). The objectives of this project are to demonstrate and evaluate of field scale bioreactor design by installing, monitoring, analyzing and documenting their effectiveness for removing nitrate from the subsurface drainage water in eastern South Dakota, and to estimate the cost per pound of nitrate removed and cost of nitrate removed from the tile water based on the treatment area per year.

Denitrifying woodchip bioreactors

Earlier, biological waste water treatment was practiced with the concept of denitrification reaction under anaerobic conditions where municipality and industrial wastes consisted of soluble organic impurities (Mittal, 2011). In 1988, a study was carried out to treat the groundwater based on denitrification where groundwater was pumped out and sent to reactors containing organic matter (mixture of straw), then the water was redistributed into aquifers through the soil (Boussaid, Martin, & Morvan, 1988). Same principle behind the denitrifying woodchip bioreactors can be employed in agricultural fields to remove nitrate from tile drain water.

A denitrifying bioreactor is a trench in the ground filled with labile carbonaceous materials to allow colonization of denitrifying bacteria under anaerobic conditions. The anaerobic bacteria convert the nitrate in the drainage water to inert nitrogen gas through the multi-step process called denitrification (Figure.1). Commonly, denitrification reactions are carried out by facultative anaerobic heterotrophs, such as Pseudomonas sp., that use nitrate for their respiration process to obtain oxygen (energy) using organic carbon as the electron donor (Blowes, Robertson, Ptacek, & Merkley, 1994; Rivett, Buss, Morgan, Smith, & Bemment, 2008). Thus, inoculation of microbes is not necessary for the bioreactor operation. However, studies suggest surface soil can be randomly mixed with woodchips to act as a microbial inoculant (Jaynes, Kaspar, Moorman, & Parkin, 2008; Rodriguez, 2010). Blowes et al. (1994) first carried out the application of denitrifying bioreactors in the agricultural environment in Ontario, Canada. He used barrels containing organic materials partially buried in a stream bank. Four different types of materials including sand (control), grow bark, woodchips and composted leaf material with different ratios were used as organic sources. They suggested that nitrate concentration of 3-6 mg/l was successfully reduced to below 0.02 mg/l through these bioreactors. Subsequent studies have confirmed that denitrifying bioreactors are cost effective, simple edge-of-field technology to effectively remove the nitrate from tile drain water with minimal land required (Driel, W.D.Robertson, & L.C.Merkley, 2006; Schipper et al., 2010).

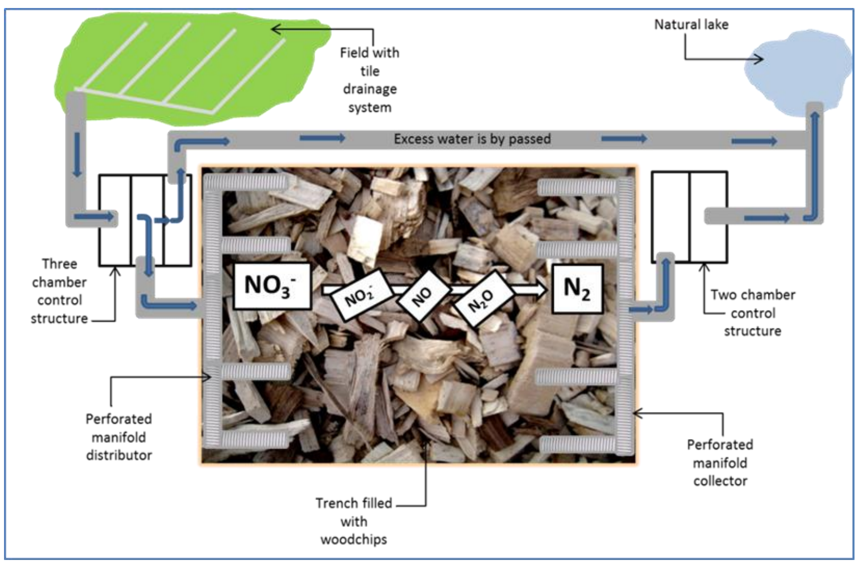

Figure 1. Plan view of schematic of woodchip bioreactor plan view (not in scale)

Bioreactor design

Two main design criteria for the dimensions of a bioreactor are the design flow rate and the design retention time. The design method is optimized for maximum nitrate removal capacity and cost efficiency. One of the major design challenges is the fluctuation of drainage flow rates throughout the year. Oftentimes, the drainage water system is not running at full capacity but at some lower, unknown flow rate. Flow rates during the year vary widely depending on changes in the field water balance components, such as after precipitation events (Laura Elizabeth Christianson, 2011). Handling the peak flow rate during the heavy rainfall events or after snowmelt is a challenge when designing a bioreactor (Driel et al., 2006). Designing a bioreactor to handle the entire volume of water at peak flow would result in an uneconomically large installation. When treating the whole water in the larger bioreactors by either increaseing the design flow rate or the retention time into the bioreactor; it results in a high extent of nitrate removal, but it has a lower removal rate (L. Christianson, Christianson, Helmers, Pederson, & Bhandari, 2013). Thus, studies suggest designing the bioreactor to treat approximately 20% of the peak flow is appropriate, which provides treatment of the majority of drained water (approximately 70%) (Laura

E. Christianson, Bhandari, Helmers, & Clair, 2009; Driel et al., 2006).

Methods and materials

Installation of bioreactors

We have installed three bioreactors in different locations in Eastern South Dakota. During 2012, we installed two bioreactors: one near Baltic, SD and one near Montrose, SD. In 2013, we installed another bioreactor near Arlington, SD.

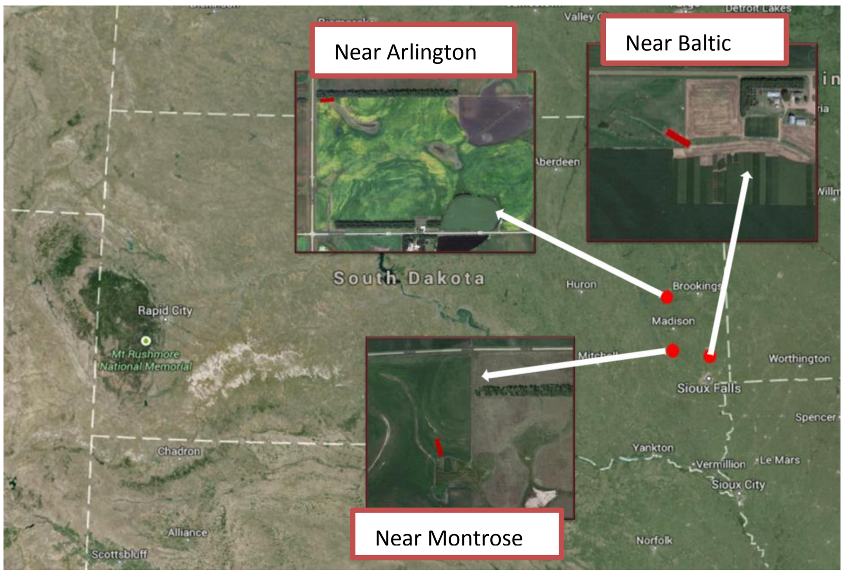

Figure 2. Approximate locations of three bioreactors installed in eastern SD (Background map: Google earth)

Bioreactor installation process

A trench was excavated with the dimensions based on the design criteria. The trench was lined with a black plastic sheeting to prevent movement of water through the bottom or the sides of the trench. Perforated PVC distribution/collector pipes were placed at both ends which were connected to the control structure by solid PVC pipes. The trench was filled with woodchips up to 3 ft. Hardwood woodchips of ¼ inch to 2 inch in size were used for this purpose. We used between 200 and 250 cu. yards of woodchips per bioreactor. the woodchips were then covered with geo-textile fabric material before covering with top soil. The geotextile fabric material allows gas to escape and prevents the woodchips from being contaminated by soil. Drainage control structures were installed to divert water through the trench and control the water entrance into the trench as per the design criteria.

Installation of monitoring equipment

Monitoring equipment was installed near both the upstream and the downstream control structure to measure meteorological information and water quality data. At the Baltic bioreactor, sensors were connected with a data-logger (CS CR1000) to collect and store the data every 10 minutes. Data was downloaded from the data-logger during the field visits. Desiccated case (A150, Campbell scientific product) was used to extend the cable downstream from the data-logger to install a pressure transducer at the downstream control structure. “Logger net” software was used to create program for the data-logger to communicate with the sensors. At the Montrose site, Decagon sensors were used to measure the meteorological and water quality data. Two separate data-loggers (Em50) were installed near the upstream and downstream control structures. In Arlington, we installed “Decagon” made sensors connected with “Campbell scientific” made data logger.

Water sampling and analysis

Water samples were collected from the upstream and downstream control structures in each bioreactor on the same day twice per week (approximately 4 days interval). To grab the water, a water bottle attached to a steel rod was used. The sample bottle was filled completely to prevent air-water reactions and placed in a cooler immediately after sampling. The collected water samples were kept refrigerated in the lab until analyzed. Water sampling was done during the end of the April 2013 to mid-July 2013.Thereafter, no water flow was observed. A spectrophotometer (DR 2800) was used to measure the concentration of nitrate nitrogen in the water sample. Total Kjehldahl Nitrogen (TKN) was measured for selected samples by South Dakota Agricultural Laboratories.

Results and Discussion

Nitrate removal

All samples were analyzed for nitrate concentration. At the Baltic bioreactor, measured nitrate concentrations from the outlet water at most of the sampling events were less than 10 ppm which is the threshold level for drinking water quality (WHO, 2011) except at a few instances (Figure. 3). The relative water flow rate and the rainfall amounts were during the flow period is shown in Figure 4. We observed frequent rainfall events from the end of the April to early June, 2013. Even during this period, a small spike of flow rate was observed. This is because soil pores were filled with water. During mid-June, due to the high intensity of rainfall, high fluctuation of flow was observed. High flow through the bioreactor results in less nitrate removal due to the insufficient retention time for the water inside the reactor. Again during early July, there was larger rainfall event (Figure. 4) which did not result in any increases in flow rate as the growing crop had depleted some of the soil moisture.

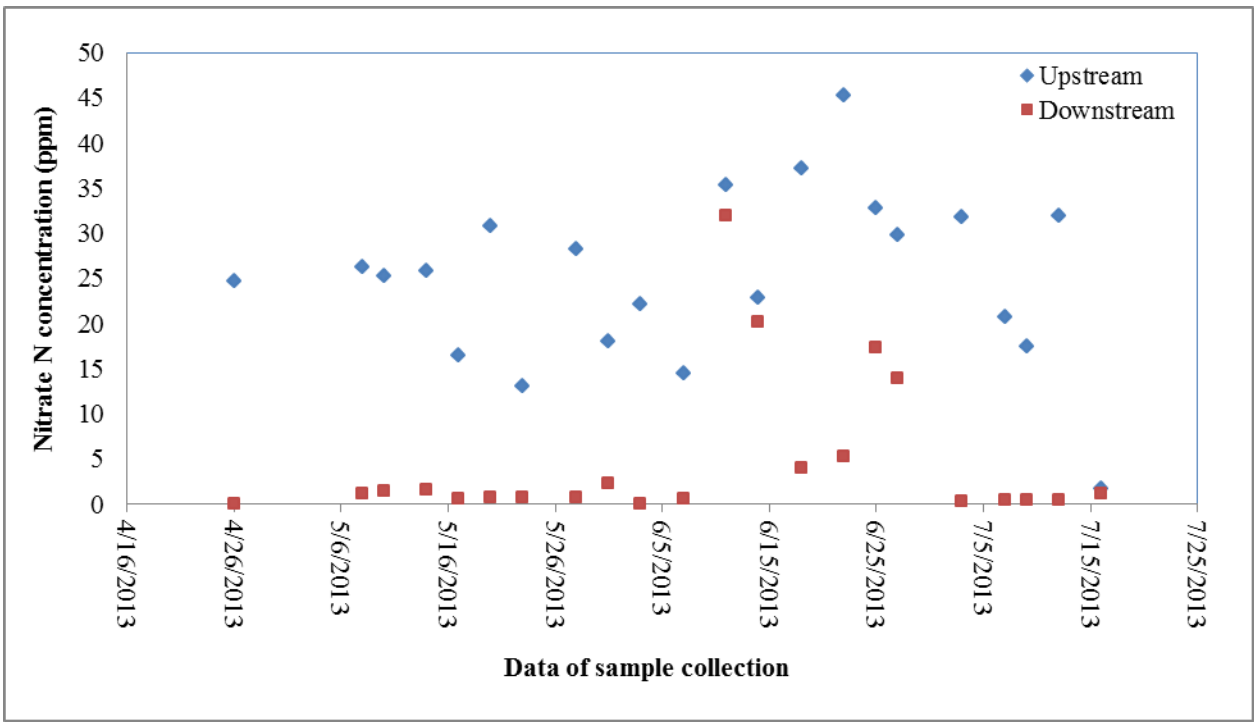

Figure 3. Nitrate N concentration of both upstream and downstream water from the Baltic site bioreactor

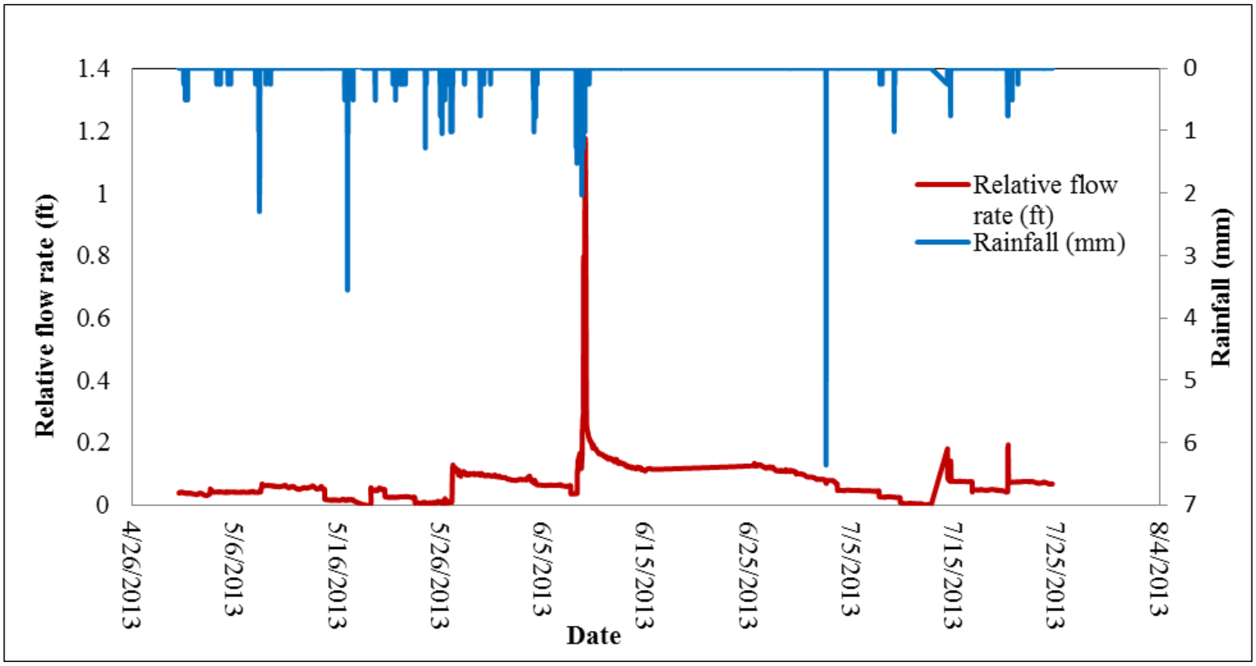

Figure 4. Relative flow rate of water through the control structure and rainfall in Baltic site bioreactor

At the Montrose bioreactor, the pattern of nitrate concentration in the water collected from the upstream control structure and the downstream control structure indicates frequent fluctuation of flow of water throughout the sampling period (early May to late July) (Figure. 5). Rainfall event history and the relative flow rate through the reactor during the sampling period are shown in Figure. 6. Compared with the Baltic site, here a high frequency of rainfall was observed. Flow rate pattern changed with rainfall pattern. During June 9 2013 to June 16 2013, flow rate data were lost due to dislodging of the sensor.

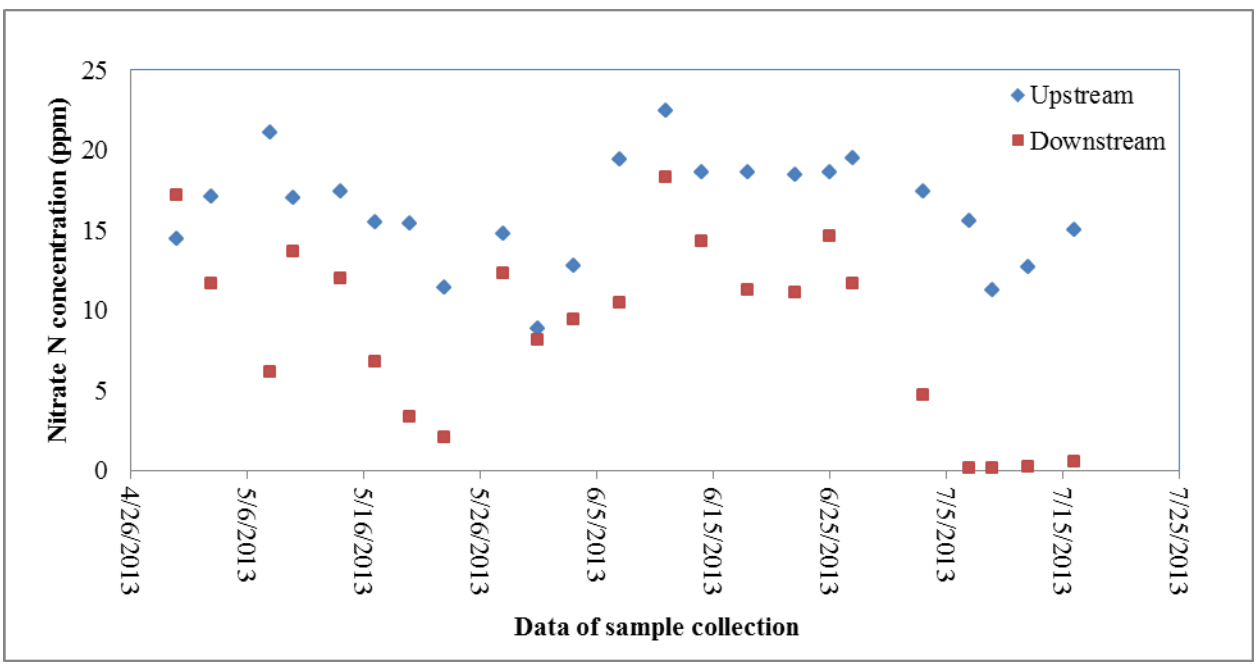

Figure 5. Nitrate N concentration of both upstream and downstream water from Montrose site bioreactor

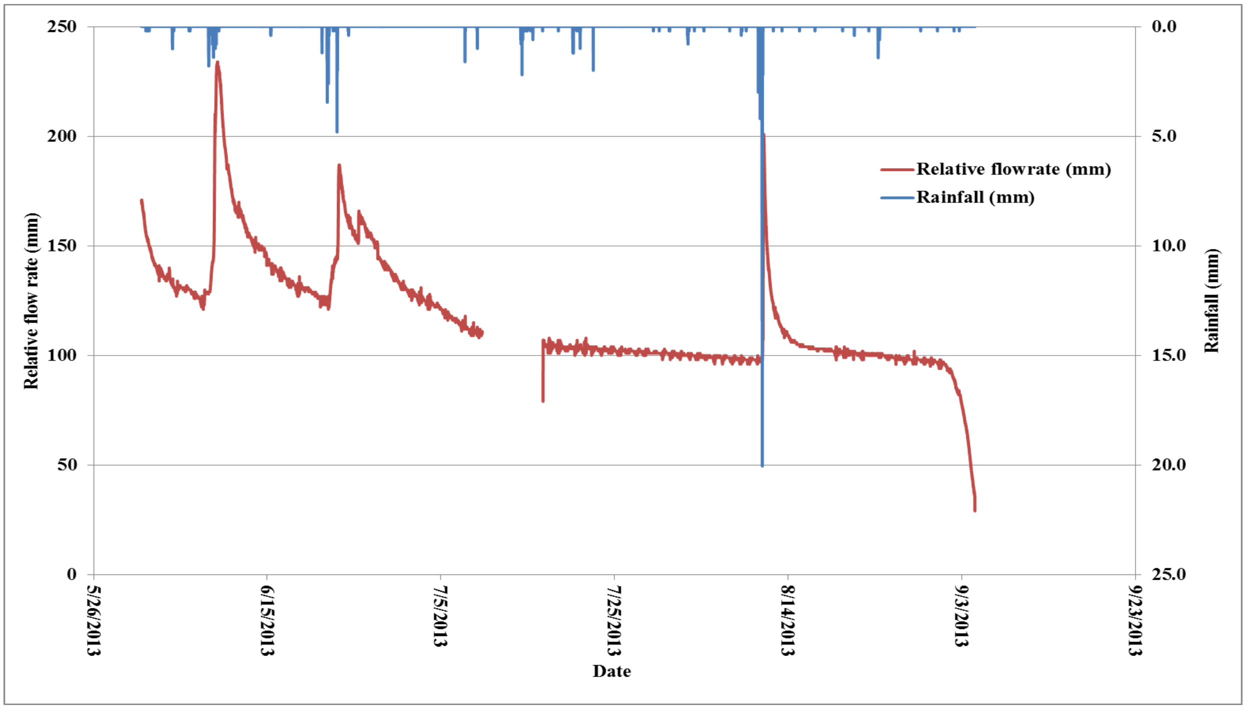

Figure 6. Relative flow rate of water through the control structure and rainfall in Montrose site bioreactor

Factors controlling the bioreactor performance

In addition to the meteorological data, some water quality parameters, such as water temperature, electrical conductivity (EC), and relative humidity were recorded in the both Baltic and Montrose bioreactor. Temperature affects the growth rate of denitrifying organisms, with high growth rate at higher temperatures within the temperature range typically found in the soil environment (Lakha et al., 2009). In Eastern South Dakota, drainage water from the field starts to enter into the bioreactor at the temperature range from just above the freezing and around 22^{o}C. After that, during the late summer water flow through the bioreactor was ceased. Still, we had good nitrate removal performance from the bioreactor indicates denitrification occurs even below 22^{0}C. Since we had a very low temperature during the study period, we were unable to get the results of bioreactor performance based on temperature change. Multiple regression analysis was completed using SAS with the percentage reduction of nitrate as independent variable, and temperature, electrical conductivity, initial nitrate concentration, and relative flow rate as dependent variables. For the Baltic bioreactor, both temperature and initial nitrate concentration effects on percentage reduction of nitrate are not statistically significant. The effect of EC on nitrate removal percentage has positively statistically significance (with alpha 0.05). Electrical conductivity can be defined as water's ability to conduct electrical current. The EC of water is affected by the total amount of salts (ions) dissolved in the water. Here in tile drain water, the presence of nitrate ions (negative ions) facilitates the EC. The nitrate removal percentage has changed positively with EC shows concentration of nitrate plays a role in nitrate removal process while other factors such as temperature remain low. Relative flow rate however negatively affected the percentage nitrate removal significantly (it is statistically highly significant with alpha 0.01). High flow rate results in insufficient reaction time for nitrate removal.

In the Montrose bioreactor, both temperature and initial nitrate concentration effects on percentage reduction of nitrate are not statistically significant. Effect of EC and the effect of relative flow rate on the percentage removal of nitrate are statistically significant with alpha 0.05. Unfortunately, water quality parameters were not recorded at the Montrose site until during the mid-part of the sampling period.

Cost estimation

A preliminary economic analysis of the maintenance and installation costs was done for each bioreactor. The costs were estimated to treat tile drain water for nitrate normalized to a unit area (ha and ac) of field per year for each bioreactor (table 1, table 2 and table 3). Total cost for the bioreactor installation was categorized for different cost components. For each component, the life expectancy was assumed based on the previous studies regarding the lifespan of a bioreactor to calculate the cost per year. Here, we used a 4%/year interest rate was added and annual depreciation value applied.

Table 1. Cost detail for Baltic site bioreactor installation.

Cost category	Installation cost ($)	Interest (4% /yr.) ($)	Replacement period (years)	Cost per years ($)
Excavation and backfilling	1,900	798	20	135
Woodchips	3,925	1649	20	279
Plastic liner	500	210	20	36
Control structure	1,675	1374	40	76
Other (personnel transport, labor)	1,000	820	40	46
Stop logs	14	3	8	4
Total cost per year				$ 576
Total treatment area				16.2 ha
Cost per treatment area				$ 36/year/ha
				$ 14/year/ac

Table 2. Cost detail for Montrose site bioreactor installation.

Cost category	Installation cost ($)	Interest (4% /yr.) ($)	Replacement period (years)	Cost per years ($)
Excavation and backfilling	2,000	840	20	142
Woodchips	4,500	1890	20	320
Plastic liner and other supplies	1,300	546	20	92
Control structure	2,100	1722	40	96
Other (personnel transport, labor)	5,00	410	40	23
Stop logs	14	3	8	2
Total cost per year				$ 675
Total treatment area				15.4 ha
Cost per treatment area				$ 44/year/ha
				$ 18/year/ac

Table 3. Cost detail for Arlington site bioreactor installation.

Cost category	Installation cost ($)	Interest (4% /yr.) ($)	Replacement period (years)	Cost per years ($)
Excavation and backfilling	2,100	882	20	149
Woodchips	3,000	1260	20	213
Plastic liner	100	42	20	7
Control structure	2,300	1886	40	105
Other (personnel transport, labor)	4,00	328	40	18
Stop logs	14	3	8	2
Total cost per year				$ 494
Total treatment area				6.9 ha
Cost per treatment area				$ 72/year/ha
				$ 29/year/ac

Conclusion or Summary

A denitrifying woodchip bioreactor is a promising best management approach for reducing the nitrogen exports from agricultural fields into the surface waters through the tile drainage systems. In Eastern South Dakota, the average concentration-based nitrate removal at two bioreactors installed near Baltic and Montrose were 81% and 51% respectively during the 2013 season. Those values are higher than the value obtained from a study in Iowa. Since temperature is the most influencing factor for microbial activity, we had good nitrate removal across a temperature range from just above the freezing to 22^{o}C. The flow rate through the reactor significantly affected the nitrate removal percent. The effect of EC on the nitrate removal percent shows concentration of nitrate affects the nitrate removal percent. Preliminary economic analysis was done. Cost per pound of nitrate removed per volume of reactor per day will be calculated and compared with other approaches.

Acknowledgements

This project is funded by the USGS 104b program. Project collaborators include the South Dakota USDA NRCS, East Dakota Water Development District, South Dakota Soybean Research and Promotion Council, South Dakota Farm Bureau, South Dakota Corn Utilization Council, and the Vermillion Basin Water Development District whose help and support are gratefully acknowledged.

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Evaluation of wastewater produced in biomass pyrolysis process

Basic Information

Title:	Evaluation of wastewater produced in biomass pyrolysis process
Project Number:	2012SD216B
Start Date:	3/1/2012
End Date:	2/29/2014
Funding Source:	104B
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Research Category:	Engineering
Focus Category:	Acid Deposition, Water Use, Treatment
Descriptors:	
Principal Investigators:	Lin Wei, Todd P. Trooien

Publications

1. Liu, Z., L. Wei, J. Julson, Y. Huang, Y. Gao, X. Zhao, Characterization of bio-oil aqueous phase for recovery of organic acids. Poster, 2014 ASABE/CSAE Intersectional Meeting, Brookings, SD 57007
2. Liu, Z., L. Wei, J. Julson, Y. Huang, Y. Gao, X. Zhao, Evaluation of wastewater produced in biomass pyrolysis process, 2013 ASABE Annual International Meeting, Kansas city, MO 64101
3. Liu, Z., L. Wei, J. Julson, Y. Huang, Y. Gao, X. Zhao, Evaluation of wastewater produced in biomass pyrolysis process, journal of biomass and bioenergy, plan to submit in Oct. 2014
4. Evaluation of wastewater produced in biomass pyrolysis process, full paper to be presented in 2014, ASABE/CSAE Annual International Meeting, Montreal, Quebec, Canada

Project Annual Report

Project Title: Evaluation of wastewater produced in biomass pyrolysis process

PI: Dr. Lin Wei; Co-PI: Dr. Todd Trooien
Reporting Period: March 1st, 2013 to March 20th, 2014
Date of Report: April. 20th, 2014
Written By: Dr. Lin Wei, Dr. Todd Trooien

Executive summary

The major accomplishments completed in this period include:

1) We converted sawdust to crude bio-oil using fast pyrolysis process. After storage in containers for two more weeks, the produced crude bio-oil separated into two phases, an oil phase and an aqueous phase (wastewater), due to re-polymerization and oxidation reactions. The oil phase of crude bio-oil was upgraded to a drop-in fuel using a catalytic cracking process. The wastewater was diluted and then divided to colorless wastewater and lipophilic wastewater using a Sep-Pak SPE column. The colorless wastewater samples were analyzed for determinations of organic acids using HPLC and GC-MS. The lipophilic wastewater was analyzed for identification of functional groups in the wastewater using NMR.
2) We upgraded crude sawdust bio-oil to a new liquid product that consists of two phases: drop-in fuel and wastewater. The drop-in fuel was sent to another ongoing project for further analysis. Similarly, the wastewater was diluted and then divided to colorless wastewater and lipophilic wastewater using a Sep-Pak SPE column. The colorless wastewater samples were analyzed for determinations of organic acids using HPLC and GC-MS. The lipophilic wastewater was analyzed using NMR. The organic component profiles are different between the wastewater samples produced from bio-oil upgrading and crude bio-oil.

- We measured the heavy metal residues in the wastewater produced from sawdust bio-oil upgrading. There was 6.18 PPM (mg/kg) of Mo residues in the wastewater sample when 9% of Mo supported with HZSM-5 was used as catalyst in the sawdust bio-oil upgrading process.
- Two presentations were given at the 2014 annual ASABE sectional conference.
- Four PhD/M.S. graduate students (Zhongwei Liu, Xianhui Zhao, Yinbin Huang, and Wangda Qu) and two postdocs (Chunkai Shi and Yang Gao) participated in the biomass thermochemical conversion and wastewater analysis.

Background

Because of world population explosion and rapidly growing economy, food, water, and energy are the most urgent challenges need to be addressed today. Currently biomass is known as the only source for production of renewable liquid transportation fuels. Pyrolysis is a very promising process to effectively convert biomass materials such as corn stover, switchgrass, wood residues, etc. to liquid transportation fuels. Properly utilizing biomass may have important positive impacts on national energy security, local economic growth, and environmental protection. However, biomass pyrolysis also produce wastewater during biofuel production, as much as 20 –

50% of the volume of biofuel produced, depending on the biomass pyrolysis and bio-oil upgrading technologies used. This wastewater may have various contaminants and a high chemical oxygen demand (COD) level, which would cause severe pollution if released into the environment without treatment. The contaminants make the wastewater unusable for some purposes. Even after processing for extra value-added products, many of these compounds may still left behind and resist biological degradation or exert significant toxicity towards environments. But the wastewater may be usable for other purposes or treatments may be available to make the wastewater usable for still other purposes. The goal of this research is to evaluate the wastewater produced during catalytic pyrolysis of biomass feedstocks and upgrading the bio-oil to drop-in fuel. In addition, the wastewater produced from vegetable oil upgrading to drop-in fuel was also examined. The specific objectives of the research are:

1) Conduct catalytic fast pyrolysis process for converting various biomass feedstocks into liquid drop-in biofuels.
2) Characterization of the wastewater produced
3) Explore possible solutions for wastewater utilization.

Planned activities:

Table 1 planned tasks to be completed in this study

Task 1	Set up pyrolysis reactors and prepare biomass feedstocks including corn stover and wood sawdust.
Task 2	Conduct pyrolysis tests for converting the feedstocks into bio-oil. Evaluate the bio-oil and collect the wastewater generated for evaluation.
Task 3	Upgrade the bio-oil to drop-in fuels. Evaluate the drop-in fuels and collect the wastewater generated for analysis.
Task 4	Characterize the wastewater generated from fast pyrolysis and evaluate its potential
Task 5	Characterize the wastewater produced from bio-oil upgrading and evaluate its potential
Task 6	Based on the results of characterization and analysis of the wastewater, the study will provide suggestions for renewable energy industries, biomass producers, and/or lawmakers and the research team will search more external funds for further research.

We completed tasks 1, 2, and 4 in 2012, but were unable to finish tasks 3, 5, and 6 as planned by February 28, 2013 due to personnel changes and analytic instrument limitations. We have been approved to extend the end day of this project to 08/30/2014. The work we have done in the period of March 1^{st}, 2013 to March 30^{th}, 2014 is reported here.

Actual Accomplishments during March 1^{st}, 2013 to March 30^{th}, 2014:

<u>Task 3. Upgrade crude sawdust bio-oil and vegetable oil to drop-in fuel using a bench scale fixed-bed reactor</u>

Two new bench scale tubular fixed-bed reactors were assembled and used for the bio-oil and vegetable oil upgrading experiment. Heavy metal Molybdenum (Mo) and HZSM-5 were used to prepare catalysts applying in the upgrading processing. The schematic diagram of the reactors is shown in Figure 1. This system consists of a pre-heater (furnace 1), a catalytic cracking fixed-bed reactor (furnace 2) and a condenser unit. When the test starts, nitrogen is used to purge the air inside the system for about 10 minutes. The furnace 1 preheats and vapors the raw bio-oil/vegetable oil. This oil vapor enters the fixed-bed reactor where the furnace 2 heated to reaction temperatures. The actual catalytic cracking reactions take place in the reactor. The products of these reactions are condensed to liquid consisting primarily of a mixture of water phase and oil phase. The non-condensable gases called syngas exits the condenser and is delivered to storage. The oil phase samples are collected and sent to another ongoing project to analyze their chemical composition and physicochemical properties. Typical GC-MS profiles of the oil phase chemical compositions of crude sawdust bio-oil and the upgraded bio-oil are shown in Figure 2 and 3. The water phase (so called wastewater in this project) samples are also collected and analyzed in this report.

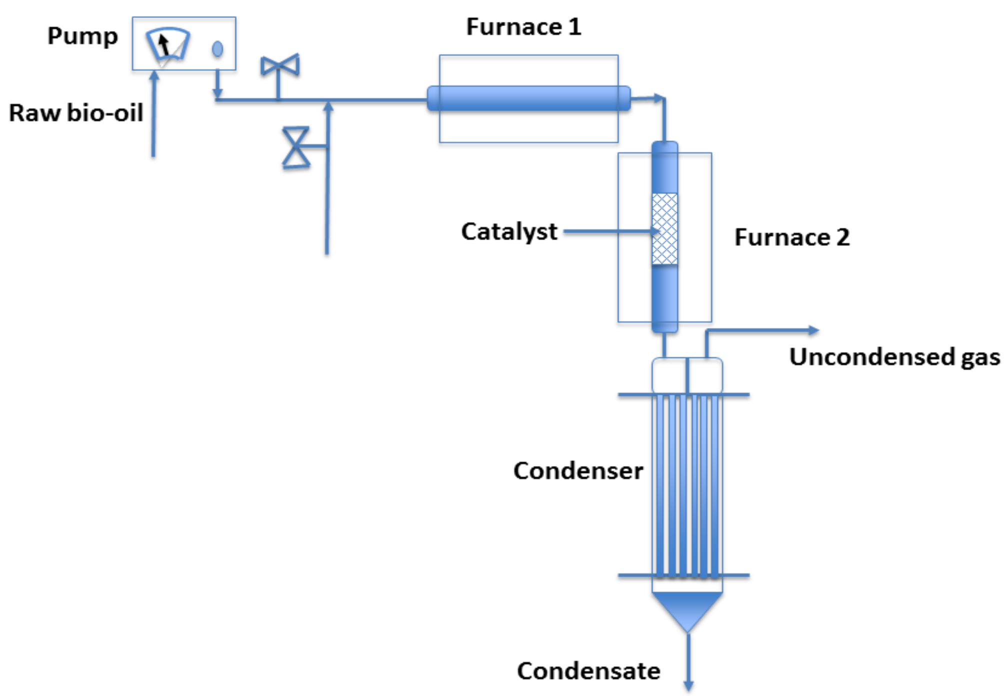

Figure 1. The schematic diagram of the experiment system

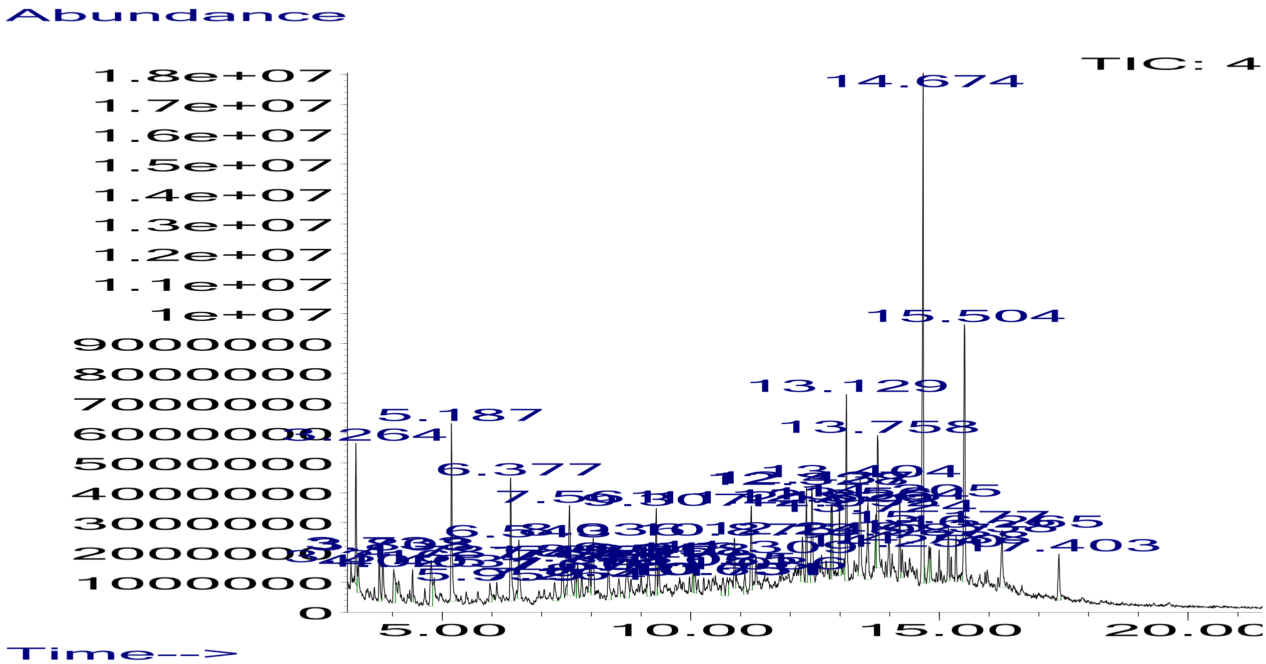

Figure 2. GC/MS profile of crude sawdust bio-oil

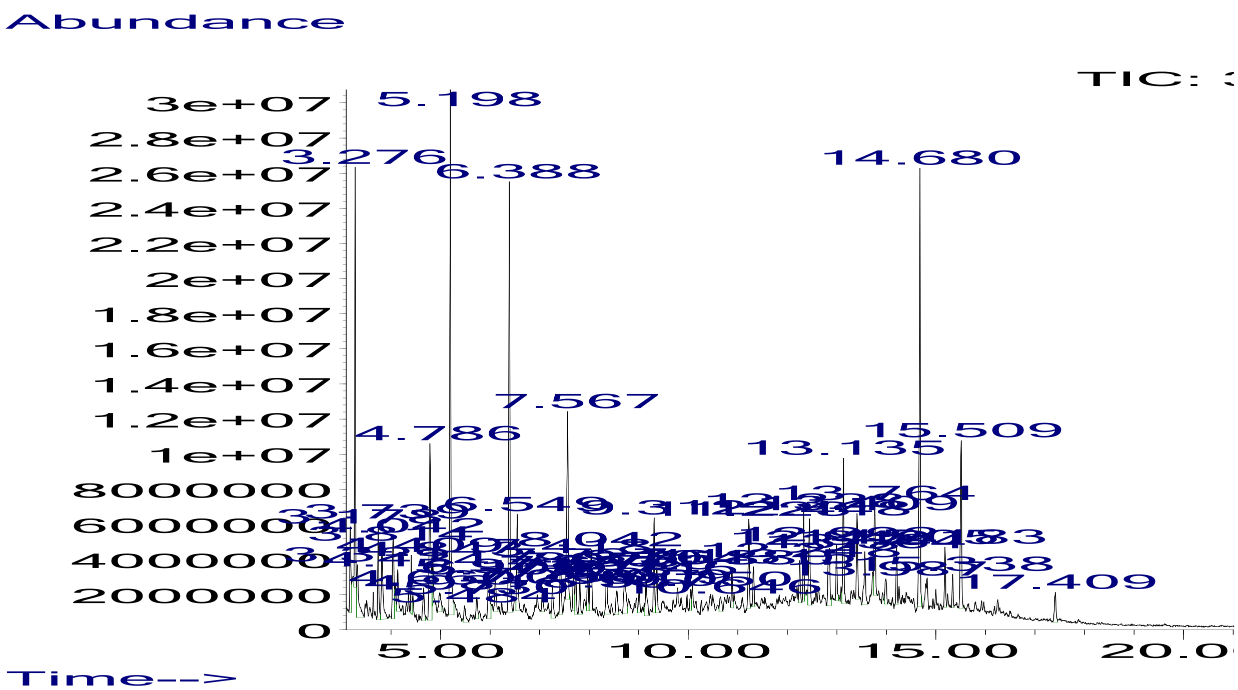

Figure 3. A GCMS profile of upgraded sawdust bio-oil

Task 5. Characterization of wastewater samples

The wastewater samples collected from sawdust pyrolysis were characterized by using the following protocols.

3) Wastewater sample of raw sawdust bio-oil was diluted 20 times.
4) The diluted samples were applied to Sep-Pak SPE column to remove lipophilic components that will be analyzed by NMR
5) The purified samples were analyzed by HPLC using an Aminex HPX-87H Column, and thus compared to individual organic acid standards for qualitative and quantitative analysis of the samples.

The HPLC profile of the wastewater sample produced from crude sawdust bio-oil is showed as Figure 4. Compared with organic acid standards, four peaks in the profile were identified. They are acetic acid (46.8 mg/ml), formic acid (13.68 mg/ml), butanoic acid (4.5 mg/ml), and propionic acid (3.7 mg/ml). The other two peaks were unable to be identified in this HPLC analysis, but will be identified by later GC-MS analysis.

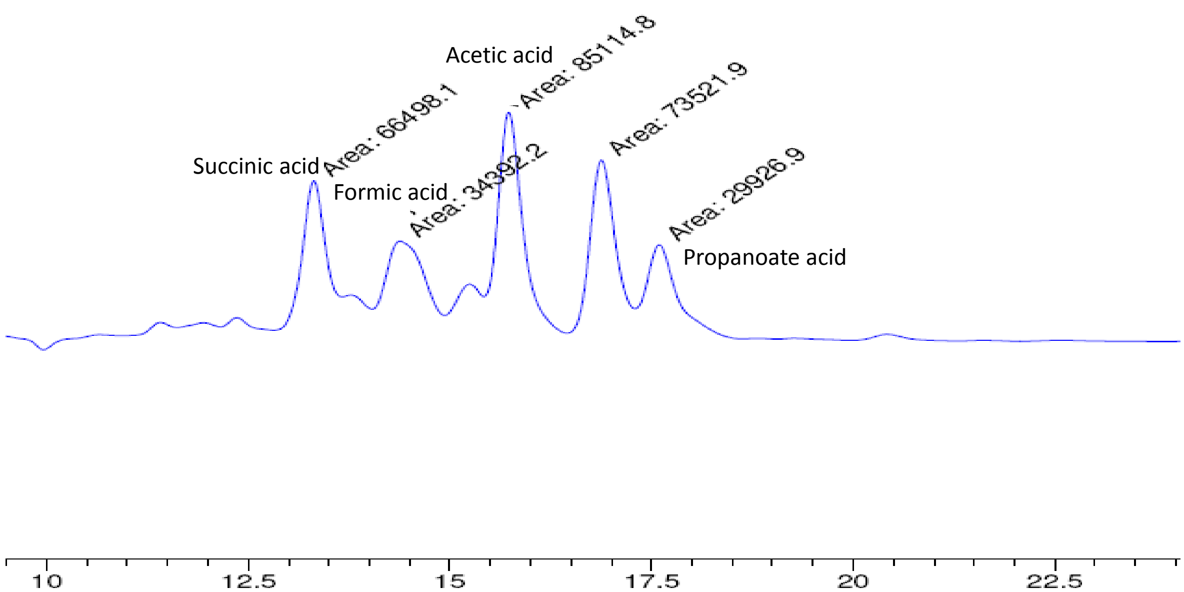

Figure 4. The HPLC profile of wastewater sample from crude sawdust bio-oil

The HPLC profile of organic acid in the wastewater samples produced from sawdust bio-oil upgrading is shown in Figure 5. Compared with the wastewater samples from crude bio-oil, the succinic acid (2.5 mg/ml), formic acid (6mg/ml), and acetic acid (10.2 mg/ml) concentrations have significantly decreased. Again, the peak at retention time of 19 minute will be identified by later GC-MS analysis.

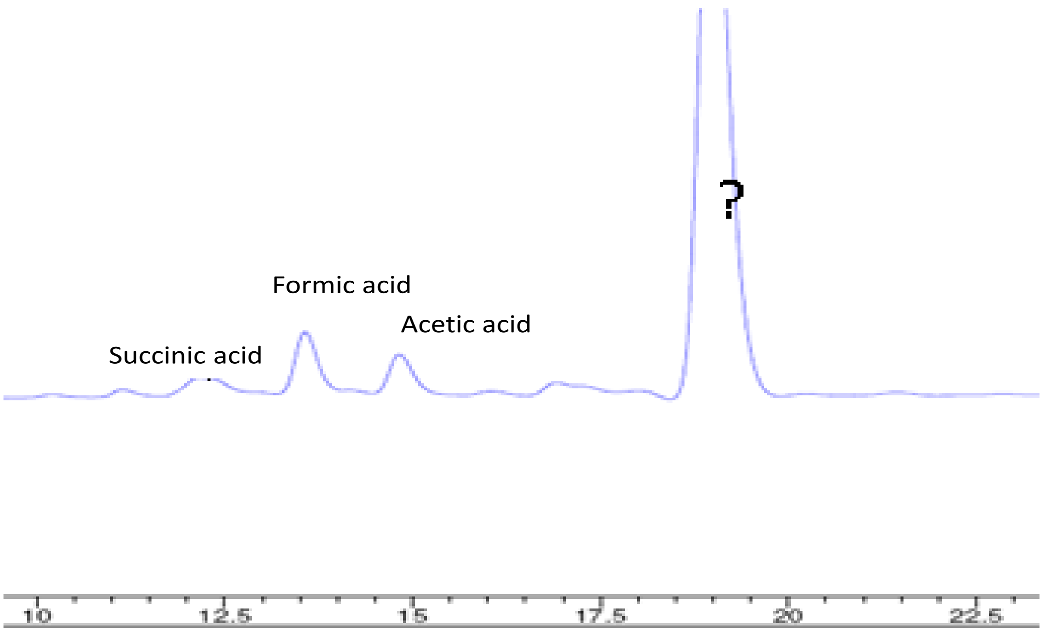

Figure 5 the HPLC profile of organic acids in the wastewater produced from sawdust bio-oil upgrading.

Similarly, the wastewater samples collected from vegetable oil (sunflower oil) upgrading to drop-in fuels were also characterized by using HPLC analysis. The HPLC profile of the wastewater is shown in Figure 6. Compared with organic acid standards, two peaks in the profile were identified. They are acetic acid (74.52 mg/ml), succinic Acid (1.69 mg/ml), and propionic acid (5.55 mg/ml). The other two peaks were unable to be identified in this HPLC analysis, but will be identified by another GC-MS analysis conducted in next quarter.

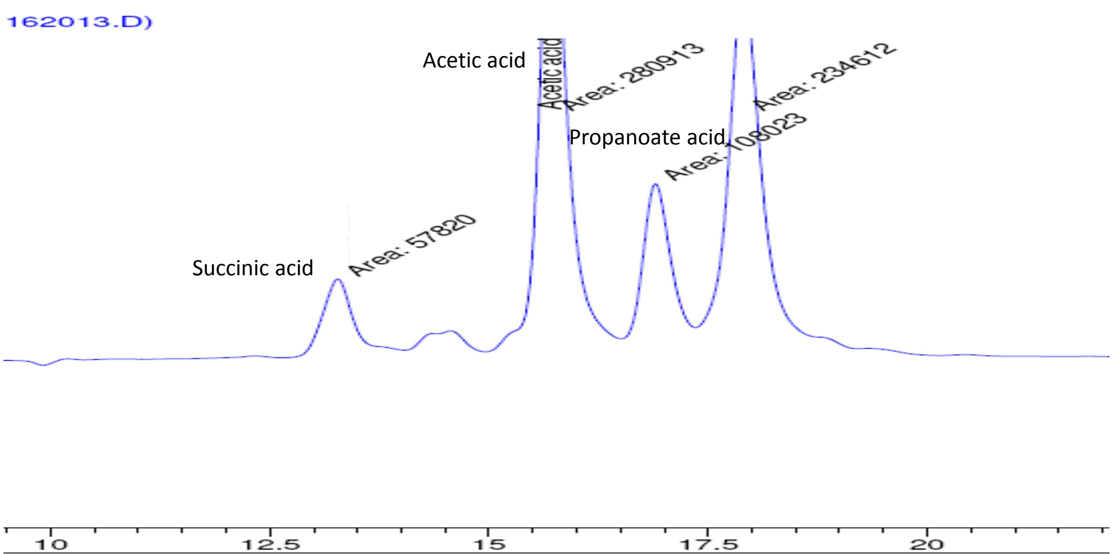

Figure 6. A HPLC profile of wastewater sample from sunflower oil upgrading to drop-in fuel

GC-MS analyses of organic acids in wastewater samples produced from crude sawdust bio-oil and the bio-oil upgrading were carried out. In addition, GC-MS analyses of organic acids in wastewater samples produced from sunflower oil upgrading process was also conducted in this study since non-food vegetable oil (sunflower oil) may be one of important sources for biofuel productions. After Sep-Pak SPE extraction, the bio-oil wastewater was divided into colorless portion which was passed through the SPE column directly, and dark-brown portion which was retained on the SPE column and eluted out by methanol. GC-MS analyses of the colorless portions were performed by following the method described below:

1) 1 μL of sample was injected in a split mode (7:1) into the GC-MS system (Agilent 6890 with an Agilent 5973 mass selective detector and Agilent 7683B auto sampler).
2) Gas chromatography was performed on a 15 m ZB-FFAP column with 0.25 mm inner diameter (I.D.) and 0.25 μm film thickness (Phenomenex, Torrance, CA, USA) with an injection temperature of 200℃, MSD transfer line of 250℃, and the ion source adjusted to 230℃. The helium carrier gas was set at a constant flow rate of 1.6 ml min^{-1}. The temperature program was isothermal 105℃ for 6 min. The mass spectrometer was operated in positive electron impact mode (EI) at 69.9 eV ionization energy in m/z 33-150 scan range.
3) The spectra of all chromatogram peaks were evaluated using the HP Chemstation (Agilent, Palo Alto, CA, USA). The spectra of all chromatogram peaks were compared with EI mass spectra obtained for authentic standards. Calibration curves were built for the concentration range 0.1-1g/L.

The GC-MS analysis results are shown in Figure 7 and 8. Since the wastewater samples for GC-MS analyses had been diluted 20 times, a proportional method was used to calculate the actual acetate and propanoate concentrations (Figure 9). The calculations are listed in table 1. The actual acetate concentrations were 1.242 M and 0.782 M while propanoate concentrations were 74 mM and 46 mM in the wastewater samples produced from sunflower oil and crude bio-oil, respectively.

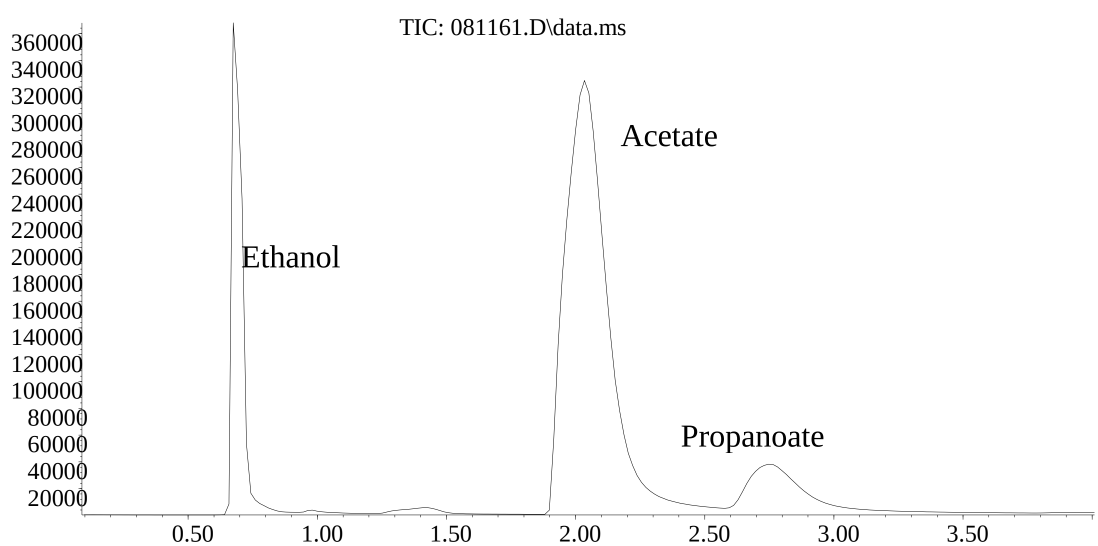

Figure 7 GC-MS profile of wastewater produced from vegetable oil upgrading to drop-in fuel

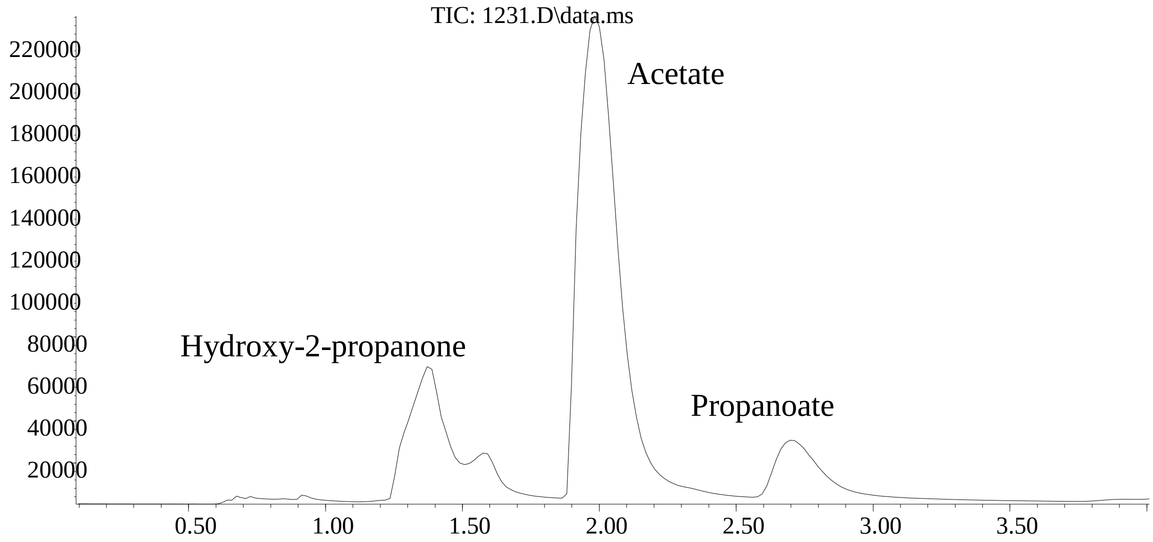

Figure 8 GC-MS profile of wastewater produced from crude sawdust bio-oil

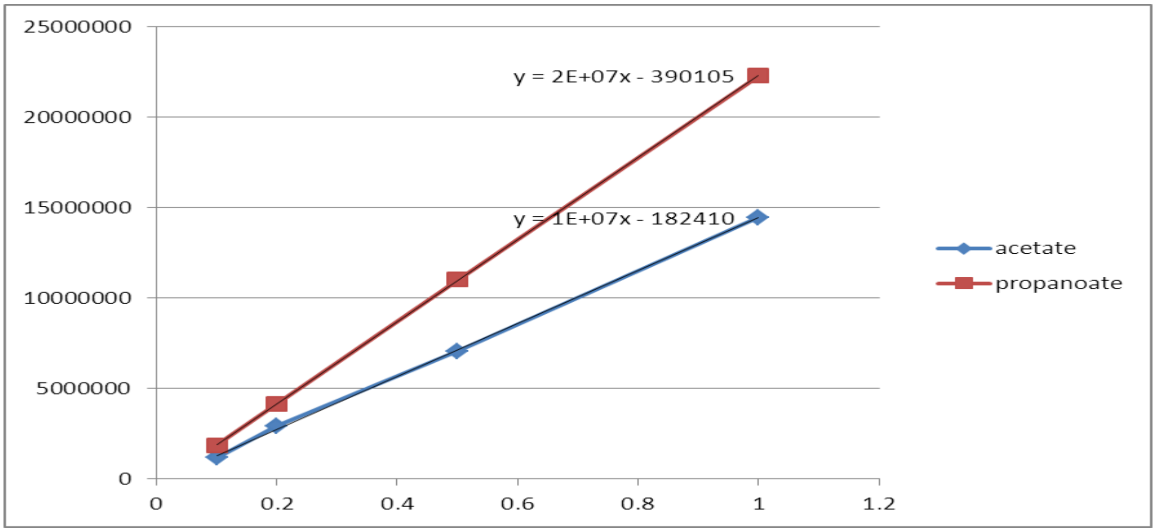

Figure 9 Calculation of organic acid concentration in the wastewater samples what are the values and units on the X and Y axes?

Table 1 calculations of acetate and propanoate concentrations in the wastewater samples

sample data	Vegetable oil wastewater **(mM)**	Bio-oil wastewater **(mM)**
acetate	62.1	39.1
propanoate	3.7	2.3

NMR analyses were used to examine function groups of the methanol elute colorful portions of the wastewater produced from sawdust bio-oil. The chemical shifts 6.5-7 ppm in the ^{1}H spectrum (Figure 10) of the methanol elute portion clearly indicated the presence of lignin pyrolysis phenolics which also contribute to the dark brown color of the wastewater. The hydrogen percentage of aromatic region (6.5-7 ppm) is about 35% while there are no significant peaks in the carbohydrate region (4-5.5 ppm). This result is consistent with our previous result and revealed that there are no monosaccharides in the wastewater of the crude sawdust bio-oil.

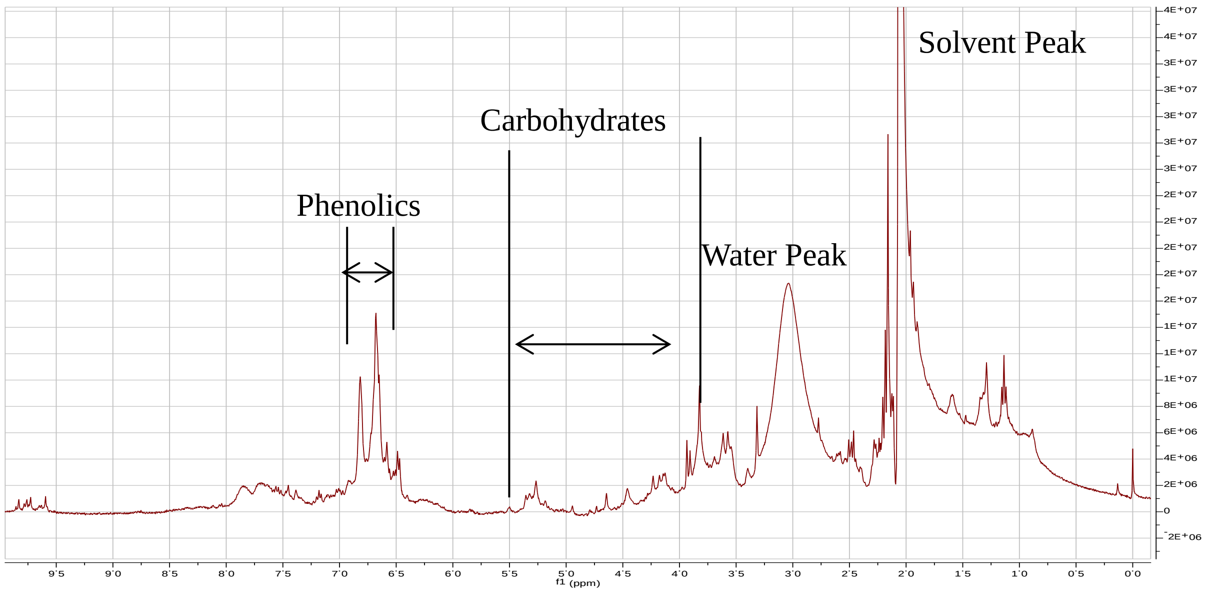

Figure 10 The NMR ^{1}H spectrum of wastewater samples produced from crude sawdust bio-oil

Since heavy metal Molybdenum (Mo) was used as catalyst for upgrading bio-oil, the presence of Mo in the produced wastewater should be detected. By using ICP-OES, the determination of heavy metal (Mo) remaining in the wastewater samples was carried out by the laboratory, Analytical Consulting Services, Inc. Houston TX 77084. The sample preparation protocols and instrument operations are briefly described as below:

The steps of preparing wastewater sample

- Microwave digestion was performed using a state of the art CEM (MARS 6) closed vessel technology.
- 0.5 g of sample was digested in duplicate with matrix blanks by use of microwave.
- Samples were poured up to a known volume and sent to the analytic labs for analysis using ICP-OES.

Operations of the Thermo 6500 ICP-OES

- Calibration standards are matrix matched to perform 3 point curve, 0, .1, 1.0 ppm.
- Samples are diluted and run against the calibration curve.
- Matrix blanks, sample blanks, and spike samples are run as well as the wastewater samples.

- Known results are calculated by known weight and volume. Results given are reported in PPM values.
- Detection limits of known samples are 10ppb and higher.

The result is shown as Figure 11. It was found that the concentration of Mo was 6.18 PPM (mg/kg) in the wastewater sample produced from sawdust bio-oil upgrading process using 9% of Mo supported with HZSM-5 as catalyst.

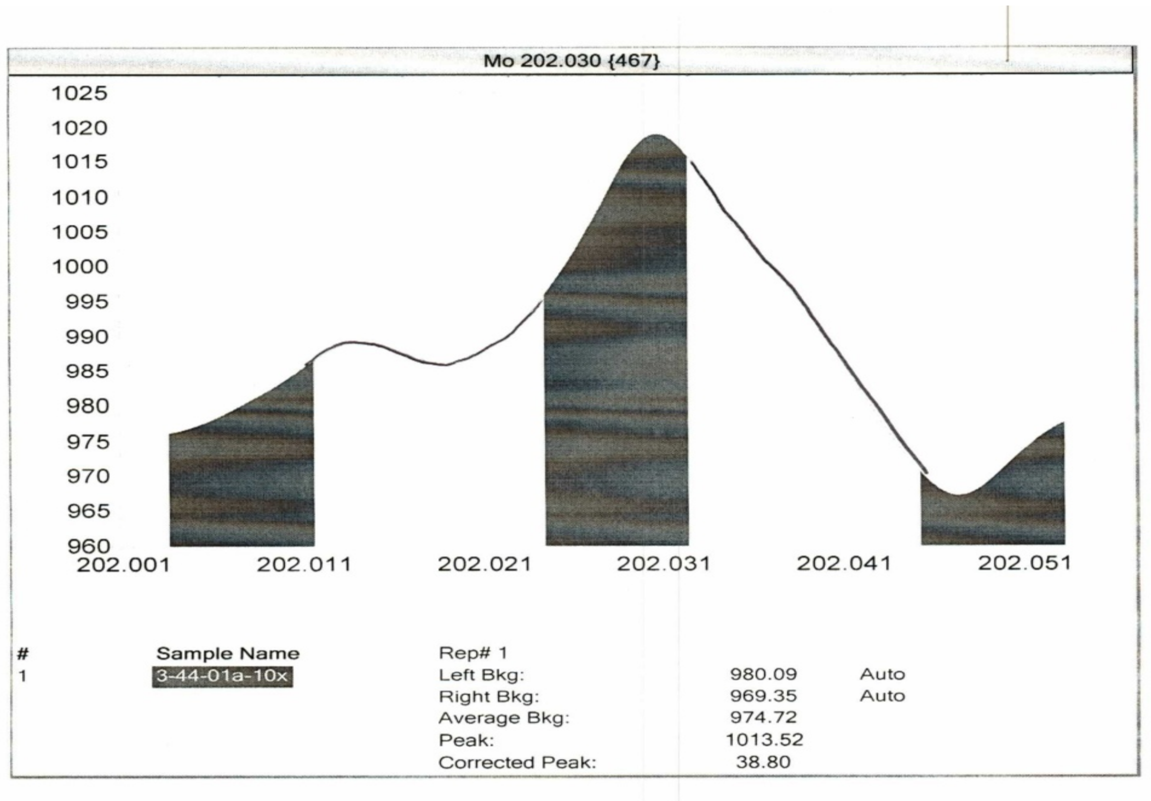

Figure 11 The ICP-OES result of Mo detection in the wastewater sample produced from sawdust bio-oil upgrading. Note: The bottom reading (numbers) is the wavelength element of choice. The left upper is the intensity of measurement.

Education and training in the project

There were four PhD/M.S. graduate students (Zhongwei Liu, Xianhui Zhao, Yinbin Huang, Wangda Qu) and two postdocs (Yang Gao and Chunkai Shi) have been involved in the projects. The students (Xianhui Zhao, Yinbin Huang, Wangda Qu) and two Postdocs were supported by the funds from DOE (DE-FG36-08GO88073) and USDA projects (2011-67009-20030). They have been working on the biomass pyrolysis and bio-oil upgrading. The PhD student (Zhongwei Liu) mainly focused on wastewater collection and characterization.

Project outcomes and challenges

The outcomes of this project included:

- Completed catalytic upgrading of sawdust bio-oil and sunflower oil to drop in fuels.
- Collected the wastewater samples and partially completed the characterization of the wastewater.
- Used the preliminary data in a new proposal to apply for USDA NIFA research funding.
- Trained four PhD/M.S. graduate students and two postdocs for bio-refinery and wastewater evaluation research.
- Presented two presentations in the 2014 ASABE Sectional meeting

Huang, Y., L. Wei, J. Julson, 2014. Upgrading of bio-oil into advanced bio-fuel over Mo/H-ZSM5 catalysts. *The ASABE/CSBE North-Central Intersectional Meeting***,** March 28-29, Brookings, SD.

Z. Liu, L. Wei, J. Julson, Y. Huang, X. Zhao, Y. Gao, 2014. Characterization of wastewater produced in pyrolysis bio-oil production and upgrading for recovery of organic acids. *The ASABE/CSBE North-Central Intersectional Meeting*, March 28-29, Brookings, SD

Plans for the non-cost extension

- Evaluate the potential of harnessing value-added chemicals from the wastewater. Suggest/develop innovation processes for the wastewater disposal.
- Publish research results, new finding, or new technologies in professional conferences or journals.
- Explore external funding supports and collaborations to improve the research

Evaluating the Nitrate-Removal Effectiveness of Denitrifying Bioreactors (part 2)

Basic Information

Title:	Evaluating the Nitrate-Removal Effectiveness of Denitrifying Bioreactors (part 2)
Project Number:	2013SD226B
Start Date:	3/1/2013
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	South Dakota First
Research Category:	Water Quality
Focus Category:	Agriculture, Non Point Pollution, None
Descriptors:	None
Principal Investigators:	Jeppe H Kjaersgaard, Christopher Hay, Todd P. Trooien

Publications

1. Kjaersgaard, J., 2013. Denitrifying Bioreactors for N Removal from Tile Drainage Water. NDCDEA, ND/SD 319 Coordinators Meeting, Bismarck, ND, March 20-21 2013.
2. Partheeban, C., Kjaersgaard, J., Hay, C., Trooien, T., 2013. Demonstrating the Nitrogen-removal Effectiveness of Denitrifying Bioreactors for Improved Drainage Water Management. Eastern South Dakota Water Conference, Brookings, SD. October 30 2013.
3. Partheeban, C., Kjaersgaard, J., Hay, C., Trooien, T., 2013. Demonstrating the Nitrogen-removal Effectiveness of Denitrifying Bioreactors for Improved Drainage Water Management. Eastern South Dakota Water Conference, Brookings, SD. October 30 2013.
4. Partheeban, C., Kjaersgaard, J., Hay, C., Trooien, T., 2013. Demonstrating the Nitrogen-removal Effectiveness of Denitrifying Bioreactors in South Dakota for Improved Drainage Water Management. ASA, CSSA, and SSSA International Annual Meeting, Tampa, FL, November 3-6 2013.

Demonstrating the Nitrogen-Removal Effectiveness of Denitrifying Bioreactors for Improved Drainage Water Management

Progress Report: March 1, 2013 to February 28, 2014.

By C. Partheeban and J. Kjaersgaard, South Dakota State University. May 2014.

Report submitted to the South Dakota Water Resources Institute under the USGS 104b program.

Introduction.

The hypoxic zone of northern Gulf of Mexico (NGOM) is the largest in the USA and the second largest in worldwide (EPA-SAB, 2007). Enrichment of nutrients beyond the natural levels into the aquatic systems causes dramatic growth of algae, increased primary production, and the accumulation of organic matter which increases the greater demand for oxygen (Diaz & Rosenberg, 2008). The Mississippi River basin is the major contributor of freshwater and nutrient to the northern Gulf of Mexico. A large proportion of the nutrients enter into the Mississippi river basin from crop land through the tile drainage systems and surface runoff (EPA-SAB, 2007). Agricultural subsurface tile drainage helps to increase the agricultural productivity by allowing timely field operations and creating well aerated soil conditions to enhance the plant uptake of nutrients and reduce the surface runoff water quality issues (Crumpton & Helmers, 2004; OSU-Extension, 1998). However, the nitrate-nitrogen content of the tile water is a major environmental and health concern. Previous studies show that nitrogen fertilizer management alone is not sufficient to reduce the nitrate concentration in tile drain water (Dinnes et al., 2002). Therefore, there is an urgent and critical need to develop additional approaches to reduce the nitrate nitrogen loads in the tile drainage water before it exits the drainage systems. To reduce the nitrate accumulation and to cease the nitrogen cascade, nitrates can be converted back to inert nitrogen gas through the multi-step process called denitrification (Galloway et al., 2003).

Denitrifying woodchip bioreactors are examples of a cost effective and simple edge-of-field approach to treat the drainage water for nitrate concentration (Laura Elizabeth Christianson, 2011). Several bioreactors have been installed within the last decade or so in the US Midwest and internationally e.g. New Zealand (Schipper, Robertson, Gold, Jaynes, & Cameron, 2010). A study in Iowa by Christianson (2011) showed approximately 43% of nitrate nitrogen concentration reduction obtained by denitrifying bioreactors. Schipper et al. (2010) has investigated that both denitrification walls and denitrification beds have an ability to remove nitrate effectively with nitrate removal rates ranging from 0.01 to 3.6 g N/m3/day for walls and 2 to 22 g N/m3/day for beds. Denitrification walls mean construction of wall (generally filled with saw dust and soil mix) vertically across the groundwater flow, and denitrification beds refers to containers which are filled with carbon materials and contaminated drainage water runs out through it. This is called denitrifying bioreactors (Schipper et al., 2010; Schmidt & Clark, 2012). Although a number of investigations explain the bioreactor performance, there is still a lack of information about the effectiveness, factors controlling the bioreactor performance, site suitability, and the challenges and possible side effects of using bioreactors (Schipper et al., 2010). The objectives of this project are to demonstrate and evaluate of field scale bioreactor design by installing, monitoring, analyzing and documenting their effectiveness for removing nitrate from the subsurface drainage water in eastern South Dakota, and to estimate the cost per pound of nitrate removed and cost of nitrate removed from the tile water based on the treatment area per year.

Denitrifying woodchip bioreactors

Earlier, biological waste water treatment was practiced with the concept of denitrification reaction under anaerobic conditions where municipality and industrial wastes consisted of soluble organic impurities (Mittal, 2011). In 1988, a study was carried out to treat the groundwater based on denitrification where groundwater was pumped out and sent to reactors containing organic matter (mixture of straw), then the water was redistributed into aquifers through the soil (Boussaid, Martin, & Morvan, 1988). Same principle behind the denitrifying woodchip bioreactors can be employed in agricultural fields to remove nitrate from tile drain water.

A denitrifying bioreactor is a trench in the ground filled with labile carbonaceous materials to allow colonization of denitrifying bacteria under anaerobic conditions. The anaerobic bacteria convert the nitrate in the drainage water to inert nitrogen gas through the multi-step process called denitrification (Figure.1). Commonly, denitrification reactions are carried out by facultative anaerobic heterotrophs, such as Pseudomonas sp., that use nitrate for their respiration process to obtain oxygen (energy) using organic carbon as the electron donor (Blowes, Robertson, Ptacek, & Merkley, 1994; Rivett, Buss, Morgan, Smith, & Bemment, 2008). Thus, inoculation of microbes is not necessary for the bioreactor operation. However, studies suggest surface soil can be randomly mixed with woodchips to act as a microbial inoculant (Jaynes, Kaspar, Moorman, & Parkin, 2008; Rodriguez, 2010). Blowes et al. (1994) first carried out the application of denitrifying bioreactors in the agricultural environment in Ontario, Canada. He used barrels containing organic materials partially buried in a stream bank. Four different types of materials including sand (control), grow bark, woodchips and composted leaf material with different ratios were used as organic sources. They suggested that nitrate concentration of 3-6 mg/l was successfully reduced to below 0.02 mg/l through these bioreactors. Subsequent studies have confirmed that denitrifying bioreactors are cost effective, simple edge-of-field technology to effectively remove the nitrate from tile drain water with minimal land required (Driel, W.D.Robertson, & L.C.Merkley, 2006; Schipper et al., 2010).

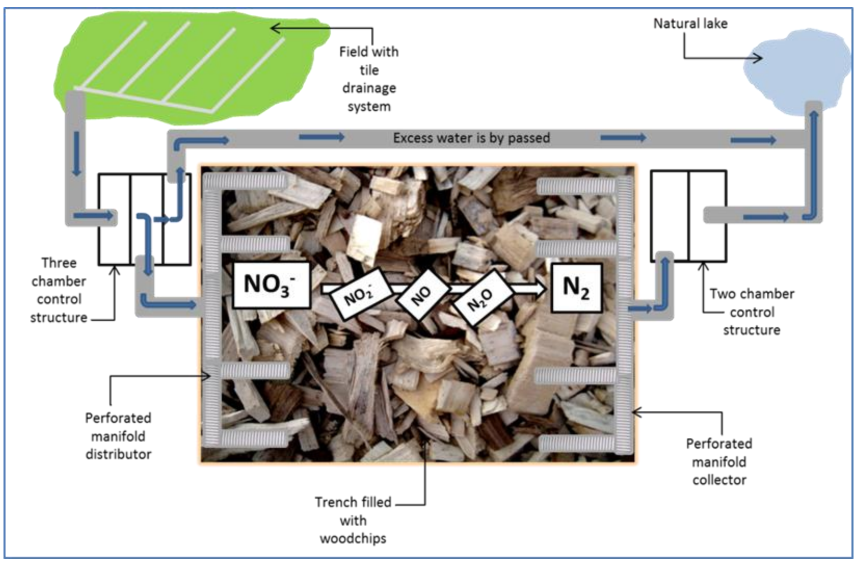

Figure 1. Plan view of schematic of woodchip bioreactor plan view (not in scale)

Bioreactor design

Two main design criteria for the dimensions of a bioreactor are the design flow rate and the design retention time. The design method is optimized for maximum nitrate removal capacity and cost efficiency. One of the major design challenges is the fluctuation of drainage flow rates throughout the year. Oftentimes, the drainage water system is not running at full capacity but at some lower, unknown flow rate. Flow rates during the year vary widely depending on changes in the field water balance components, such as after precipitation events (Laura Elizabeth Christianson, 2011). Handling the peak flow rate during the heavy rainfall events or after snowmelt is a challenge when designing a bioreactor (Driel et al., 2006). Designing a bioreactor to handle the entire volume of water at peak flow would result in an uneconomically large installation. When treating the whole water in the larger bioreactors by either increaseing the design flow rate or the retention time into the bioreactor; it results in a high extent of nitrate removal, but it has a lower removal rate (L. Christianson, Christianson, Helmers, Pederson, & Bhandari, 2013). Thus, studies suggest designing the bioreactor to treat approximately 20% of the peak flow is appropriate, which provides treatment of the majority of drained water (approximately 70%) (Laura

E. Christianson, Bhandari, Helmers, & Clair, 2009; Driel et al., 2006).

Methods and materials

Installation of bioreactors

We have installed three bioreactors in different locations in Eastern South Dakota. During 2012, we installed two bioreactors: one near Baltic, SD and one near Montrose, SD. In 2013, we installed another bioreactor near Arlington, SD.

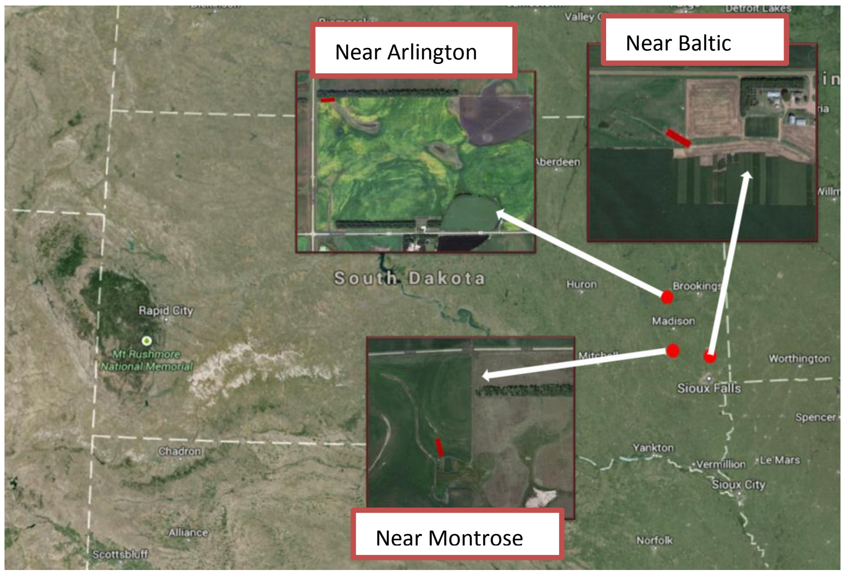

Figure 2. Approximate locations of three bioreactors installed in eastern SD (Background map: Google earth)

Bioreactor installation process

A trench was excavated with the dimensions based on the design criteria. The trench was lined with a black plastic sheeting to prevent movement of water through the bottom or the sides of the trench. Perforated PVC distribution/collector pipes were placed at both ends which were connected to the control structure by solid PVC pipes. The trench was filled with woodchips up to 3 ft. Hardwood woodchips of ¼ inch to 2 inch in size were used for this purpose. We used between 200 and 250 cu. yards of woodchips per bioreactor. the woodchips were then covered with geo-textile fabric material before covering with top soil. The geotextile fabric material allows gas to escape and prevents the woodchips from being contaminated by soil. Drainage control structures were installed to divert water through the trench and control the water entrance into the trench as per the design criteria.

Installation of monitoring equipment

Monitoring equipment was installed near both the upstream and the downstream control structure to measure meteorological information and water quality data. At the Baltic bioreactor, sensors were connected with a data-logger (CS CR1000) to collect and store the data every 10 minutes. Data was downloaded from the data-logger during the field visits. Desiccated case (A150, Campbell scientific product) was used to extend the cable downstream from the data-logger to install a pressure transducer at the downstream control structure. “Logger net” software was used to create program for the data-logger to communicate with the sensors. At the Montrose site, Decagon sensors were used to measure the meteorological and water quality data. Two separate data-loggers (Em50) were installed near the upstream and downstream control structures. In Arlington, we installed “Decagon” made sensors connected with “Campbell scientific” made data logger.

Water sampling and analysis

Water samples were collected from the upstream and downstream control structures in each bioreactor on the same day twice per week (approximately 4 days interval). To grab the water, a water bottle attached to a steel rod was used. The sample bottle was filled completely to prevent air-water reactions and placed in a cooler immediately after sampling. The collected water samples were kept refrigerated in the lab until analyzed. Water sampling was done during the end of the April 2013 to mid-July 2013.Thereafter, no water flow was observed. A spectrophotometer (DR 2800) was used to measure the concentration of nitrate nitrogen in the water sample. Total Kjehldahl Nitrogen (TKN) was measured for selected samples by South Dakota Agricultural Laboratories.

Results and Discussion

Nitrate removal

All samples were analyzed for nitrate concentration. At the Baltic bioreactor, measured nitrate concentrations from the outlet water at most of the sampling events were less than 10 ppm which is the threshold level for drinking water quality (WHO, 2011) except at a few instances (Figure. 3). The relative water flow rate and the rainfall amounts were during the flow period is shown in Figure 4. We observed frequent rainfall events from the end of the April to early June, 2013. Even during this period, a small spike of flow rate was observed. This is because soil pores were filled with water. During mid-June, due to the high intensity of rainfall, high fluctuation of flow was observed. High flow through the bioreactor results in less nitrate removal due to the insufficient retention time for the water inside the reactor. Again during early July, there was larger rainfall event (Figure. 4) which did not result in any increases in flow rate as the growing crop had depleted some of the soil moisture.

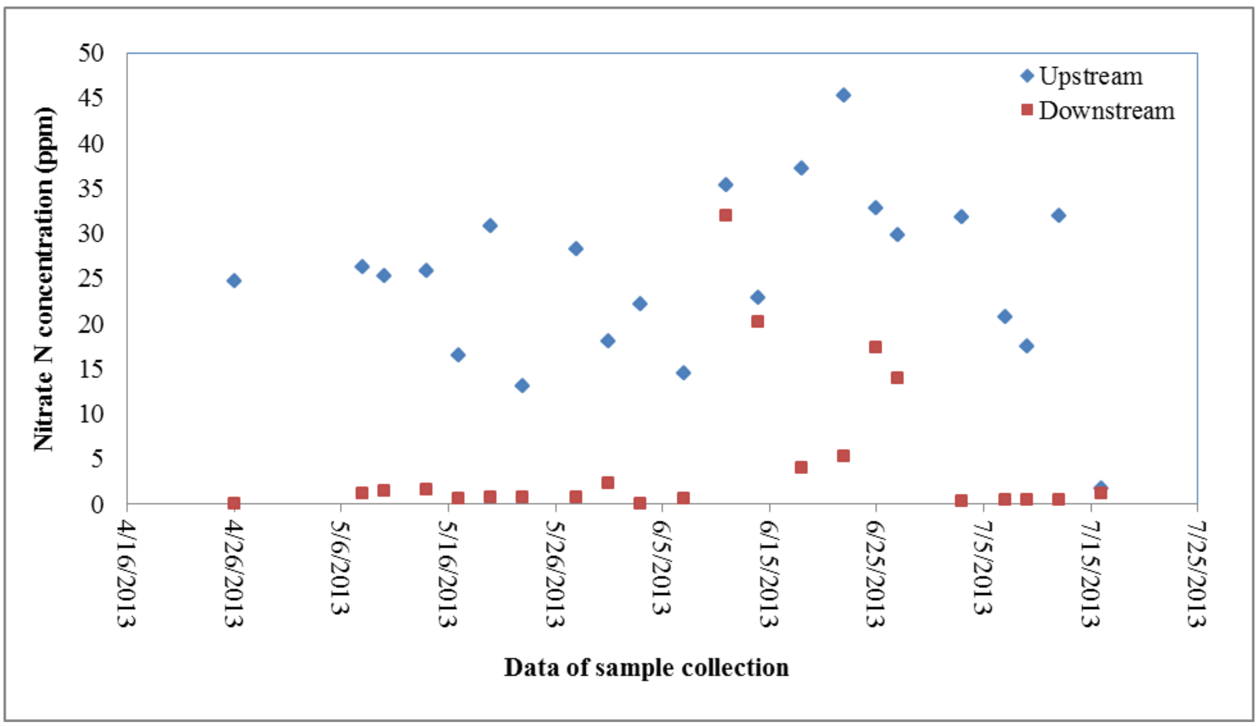

Figure 3. Nitrate N concentration of both upstream and downstream water from the Baltic site bioreactor

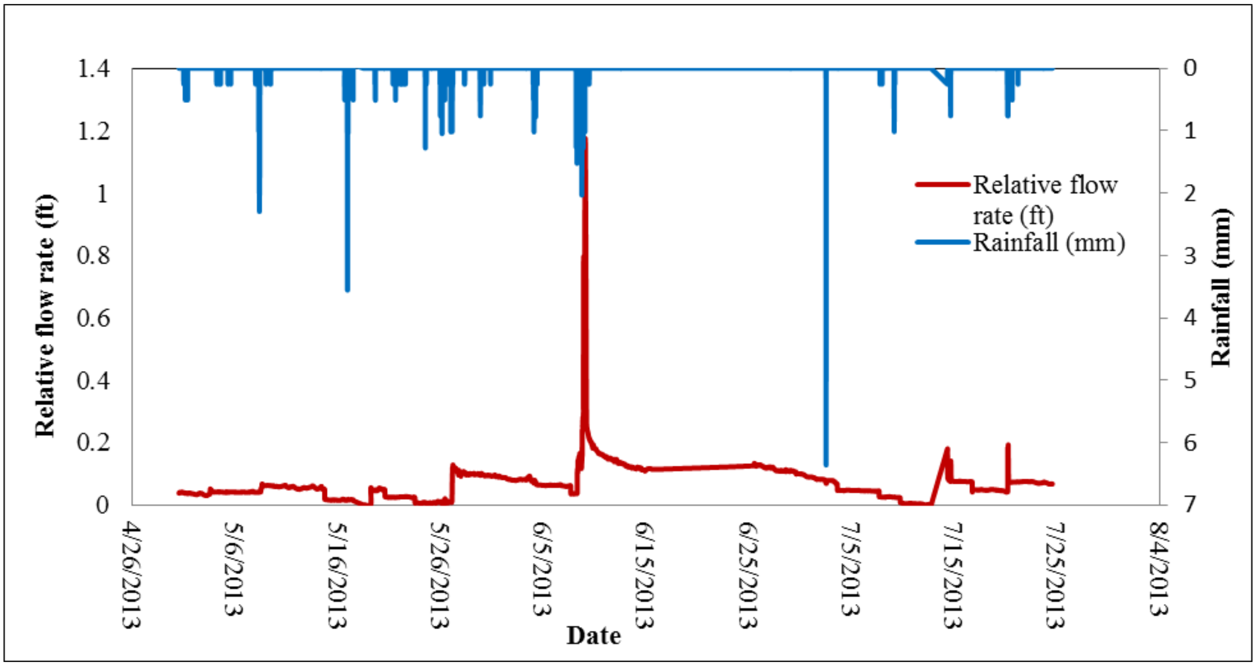

Figure 4. Relative flow rate of water through the control structure and rainfall in Baltic site bioreactor

At the Montrose bioreactor, the pattern of nitrate concentration in the water collected from the upstream control structure and the downstream control structure indicates frequent fluctuation of flow of water throughout the sampling period (early May to late July) (Figure. 5). Rainfall event history and the relative flow rate through the reactor during the sampling period are shown in Figure. 6. Compared with the Baltic site, here a high frequency of rainfall was observed. Flow rate pattern changed with rainfall pattern. During June 9 2013 to June 16 2013, flow rate data were lost due to dislodging of the sensor.

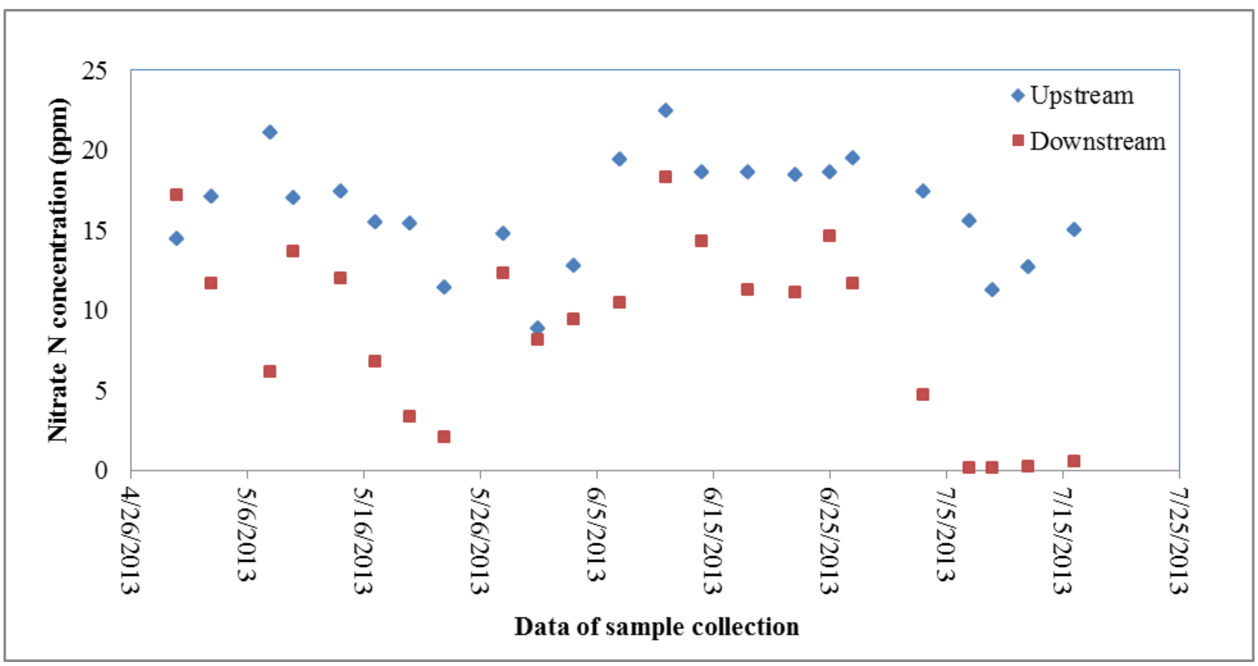

Figure 5. Nitrate N concentration of both upstream and downstream water from Montrose site bioreactor

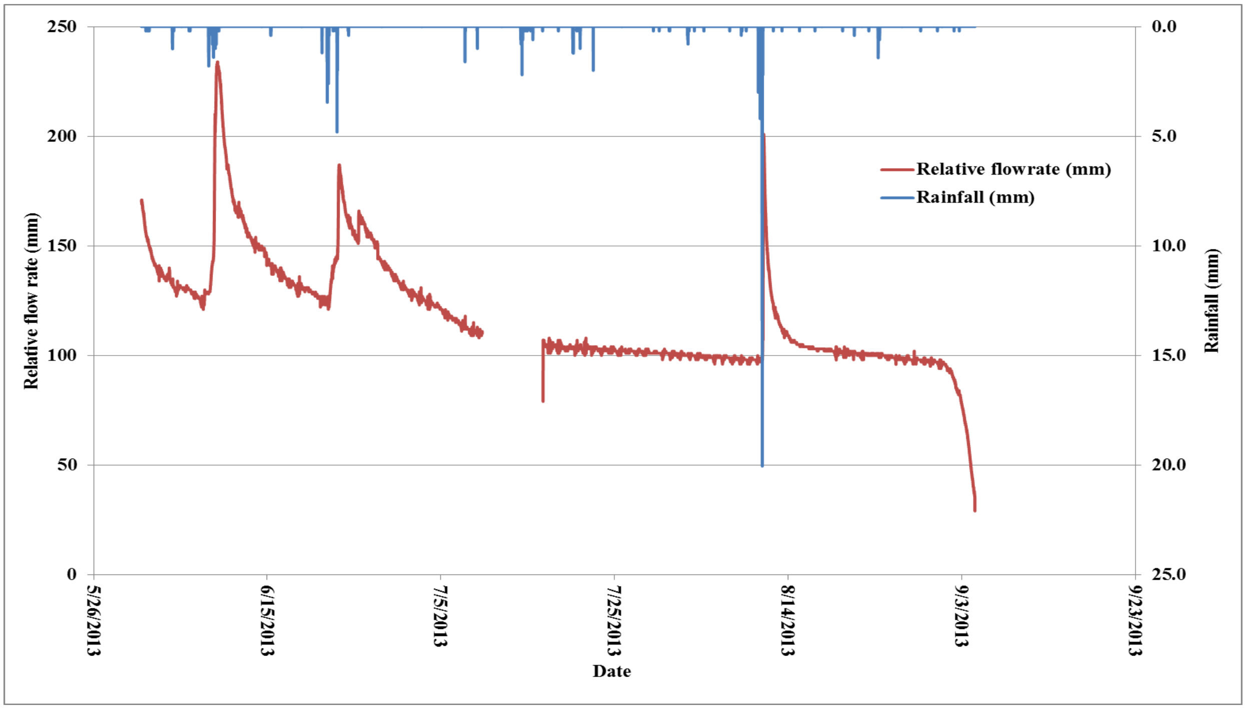

Figure 6. Relative flow rate of water through the control structure and rainfall in Montrose site bioreactor

Factors controlling the bioreactor performance

In addition to the meteorological data, some water quality parameters, such as water temperature, electrical conductivity (EC), and relative humidity were recorded in the both Baltic and Montrose bioreactor. Temperature affects the growth rate of denitrifying organisms, with high growth rate at higher temperatures within the temperature range typically found in the soil environment (Lakha et al., 2009). In Eastern South Dakota, drainage water from the field starts to enter into the bioreactor at the temperature range from just above the freezing and around 22^{o}C. After that, during the late summer water flow through the bioreactor was ceased. Still, we had good nitrate removal performance from the bioreactor indicates denitrification occurs even below 22^{0}C. Since we had a very low temperature during the study period, we were unable to get the results of bioreactor performance based on temperature change. Multiple regression analysis was completed using SAS with the percentage reduction of nitrate as independent variable, and temperature, electrical conductivity, initial nitrate concentration, and relative flow rate as dependent variables. For the Baltic bioreactor, both temperature and initial nitrate concentration effects on percentage reduction of nitrate are not statistically significant. The effect of EC on nitrate removal percentage has positively statistically significance (with alpha 0.05). Electrical conductivity can be defined as water's ability to conduct electrical current. The EC of water is affected by the total amount of salts (ions) dissolved in the water. Here in tile drain water, the presence of nitrate ions (negative ions) facilitates the EC. The nitrate removal percentage has changed positively with EC shows concentration of nitrate plays a role in nitrate removal process while other factors such as temperature remain low. Relative flow rate however negatively affected the percentage nitrate removal significantly (it is statistically highly significant with alpha 0.01). High flow rate results in insufficient reaction time for nitrate removal.

In the Montrose bioreactor, both temperature and initial nitrate concentration effects on percentage reduction of nitrate are not statistically significant. Effect of EC and the effect of relative flow rate on the percentage removal of nitrate are statistically significant with alpha 0.05. Unfortunately, water quality parameters were not recorded at the Montrose site until during the mid-part of the sampling period.

Cost estimation

A preliminary economic analysis of the maintenance and installation costs was done for each bioreactor. The costs were estimated to treat tile drain water for nitrate normalized to a unit area (ha and ac) of field per year for each bioreactor (table 1, table 2 and table 3). Total cost for the bioreactor installation was categorized for different cost components. For each component, the life expectancy was assumed based on the previous studies regarding the lifespan of a bioreactor to calculate the cost per year. Here, we used a 4%/year interest rate was added and annual depreciation value applied.

Table 1. Cost detail for Baltic site bioreactor installation.

Cost category	Installation cost ($)	Interest (4% /yr.) ($)	Replacement period (years)	Cost per years ($)
Excavation and backfilling	1,900	798	20	135
Woodchips	3,925	1649	20	279
Plastic liner	500	210	20	36
Control structure	1,675	1374	40	76
Other (personnel transport, labor)	1,000	820	40	46
Stop logs	14	3	8	4
Total cost per year				$ 576
Total treatment area				16.2 ha
Cost per treatment area				$ 36/year/ha
				$ 14/year/ac

Table 2. Cost detail for Montrose site bioreactor installation.

Cost category	Installation cost ($)	Interest (4% /yr.) ($)	Replacement period (years)	Cost per years ($)
Excavation and backfilling	2,000	840	20	142
Woodchips	4,500	1890	20	320
Plastic liner and other supplies	1,300	546	20	92
Control structure	2,100	1722	40	96
Other (personnel transport, labor)	5,00	410	40	23
Stop logs	14	3	8	2
Total cost per year				$ 675
Total treatment area				15.4 ha
Cost per treatment area				$ 44/year/ha
				$ 18/year/ac

Table 3. Cost detail for Arlington site bioreactor installation.

Cost category	Installation cost ($)	Interest (4% /yr.) ($)	Replacement period (years)	Cost per years ($)
Excavation and backfilling	2,100	882	20	149
Woodchips	3,000	1260	20	213
Plastic liner	100	42	20	7
Control structure	2,300	1886	40	105
Other (personnel transport, labor)	4,00	328	40	18
Stop logs	14	3	8	2
Total cost per year				$ 494
Total treatment area				6.9 ha
Cost per treatment area				$ 72/year/ha
				$ 29/year/ac

Conclusion or Summary

A denitrifying woodchip bioreactor is a promising best management approach for reducing the nitrogen exports from agricultural fields into the surface waters through the tile drainage systems. In Eastern South Dakota, the average concentration-based nitrate removal at two bioreactors installed near Baltic and Montrose were 81% and 51% respectively during the 2013 season. Those values are higher than the value obtained from a study in Iowa. Since temperature is the most influencing factor for microbial activity, we had good nitrate removal across a temperature range from just above the freezing to 22^{o}C. The flow rate through the reactor significantly affected the nitrate removal percent. The effect of EC on the nitrate removal percent shows concentration of nitrate affects the nitrate removal percent. Preliminary economic analysis was done. Cost per pound of nitrate removed per volume of reactor per day will be calculated and compared with other approaches.

Acknowledgements

This project is funded by the USGS 104b program. Project collaborators include the South Dakota USDA NRCS, East Dakota Water Development District, South Dakota Soybean Research and Promotion Council, South Dakota Farm Bureau, South Dakota Corn Utilization Council, and the Vermillion Basin Water Development District whose help and support are gratefully acknowledged.

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Subsurface Drainage Impacts on Evapotranspiration and Water Yield

Basic Information

Title:	Subsurface Drainage Impacts on Evapotranspiration and Water Yield
Project Number:	2013SD228B
Start Date:	3/1/2013
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	First
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Agriculture, Water Quantity
Descriptors:	None
Principal Investigators:	Christopher Hay, Jeppe H Kjaersgaard, Todd P. Trooien

Publications

1. Evapotranspiration for fields with and without tile drainage. To be submitted to Transactions of the American Society of Agricultural and Biological Engineers by 31 Dec 2014.
2. Khand, K., C. Hay, J. Kjaersgaard, and T. Trooien. 2013. Subsurface drainage impacts on evapotranspiration (ET). Eastern South Dakota Water Conference. Brookings, S.D. 30 Oct.

Subsurface Drainage Impacts on Evapotranspiration and Water Yield

Progress Report: March 1, 2013 to February 28, 2014

Investigators:

Christopher Hay, South Dakota State University
Jeppe Kjaersgaard, South Dakota State University
Todd Trooien, South Dakota State University
Gary Sands, University of Minnesota

Introduction

Subsurface drainage has increased dramatically in eastern South Dakota with increases in precipitation, commodity prices, and land prices. Subsurface drainage improves agricultural production by increasing yields and reducing risk, but there are concerns about its environmental impacts. A key concern is to what extent does subsurface drainage contribute to downstream flow alterations and flooding through changes in the amount and timing of water leaving the field. Changes in evapotranspiration (ET), as a result of drainage, are a primary determinant of the hydrologic alterations from subsurface drainage. However, the impacts of drainage on ET are not yet well understood. Lack of such knowledge is an important problem, because without it, we are limited in our ability to accurately quantify the impacts of subsurface drainage on watershed hydrology and flooding.

Project Information

The overall goal of this project is to develop a method to account for the impact of yield reductions from poor drainage on evapotranspiration in drainage model simulations. Our central hypothesis, based on water productivity functions that relate crop yield and ET, is that current drainage model simulations overestimate ET under undrained or poorly drained conditions. The rationale for the proposed research is that once we are able to accurately simulate ET under undrained and poorly drained conditions, we can then better estimate the impacts that subsurface drainage development will have on hydrology. Our contribution here is expected to be an improved understanding of the impacts of subsurface drainage on ET. Once such knowledge is available, we can better evaluate the hydrologic impacts of increased subsurface drainage in eastern South Dakota.

The drought in 2012 and less than expected drain flow in 2013 resulted in insufficient data with which to develop enough DRAINMOD simulations for the original objectives. Therefore, a different approach was developed using a remote sensing approach to compare ET from drained and undrained fields. The new approach remains within the overall project goal, but resulted in a new set of objective. The new research objectives for this project are:

1. Develop a weather dataset from existing weather monitoring sites for use in calculating reference ET at sites where onsite data and limited data are available.

2. Compare ET between drained and undrained fields using the METRIC model for estimating ET based on satellite remote sensing imagery.
3. Compare the METRIC estimated ET to ground-based measured ET for the site where these data were available.

The METRIC model will be used for direct comparisons of ET between similar fields with and without drainage. Three sites have been chosen for doing the ET comparisons: near Fairmount, ND; near Lamberton, MN; and near Lennox, SD. Landsat satellite imagery has been obtained and been processed for use in the METRIC model. METRIC ET estimations have been developed for the ND site. A comparison has been made between the METRIC-estimated ET and field-measured ET from and eddy covariance system located at the North Dakota site. Weather data have been processed for the Minnesota site, and work continues on developing METRIC ET estimates for the Minnesota and South Dakota sites. As results of this work are developed, they will be presenting at upcoming professional conferences in the coming year, and a manuscript for submission to a peer-reviewed journal will be developed.

Information Transfer Program Introduction

The Information Transfer Program includes public outreach, interpretation of laboratory analysis results, active participation in the annual Dakotafest farm show, steering committee representation and leading involvement in the Big Sioux Water Festival hosting 1,000 fourth grade students and in The Eastern South Dakota Water Conference, which is the largest water conference in Eastern South Dakota with 200 participants, interactions with extension agents and local, state and federal agencies, participation and presentations at regional and national conferences, youth education, adult education and university student training and education. Publications, such as pamphlets, educational materials, reports and peer-reviewed journal entries are made available in paper format and electronic through the Institute's website and are designed to support the mission of the Institute.

South Dakota Water Resources Institute FY2013 Information Transfer Program

Basic Information

Title:	South Dakota Water Resources Institute FY2013 Information Transfer Program
Project Number:	2013SD229B
Start Date:	3/1/2013
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	South Dakota First
Research Category:	Biological Sciences
Focus Category:	Education, Management and Planning, Conservation
Descriptors:	
Principal Investigators:	Van Kelley

Publications

1. Allen, R.G., Burnett, B., Kramber, W., Huntington, J., Kjaersgaard, J., Kilic, A., Kelly, C., Trezza, R., 2013. Automated Calibration of the METRIC-Landsat Evapotranspiration Process. Journal of the American Water Resources Association 49, 563–576.
2. Burkhalter, J.P., Martin, T.C., Allen, R.G., Kjaersgaard, J., Wilson, E., Alvarado, R., Polly, J.S., 2013. Estimating Crop Water Use via Remote Sensing Techniques vs. Conventional Methods in the South Platte River Basin, Colorado. Journal of the American Water Resources Association 49, 498–576.
3. Hay, C., Kjaersgaard, J., Trooien, T., 2013. Chapter 47: Managing High Water Tables and Saline Seeps in Soybean Production. In Clay, D.E., Carlson, C.G. Clay, S.A., Wagner, L., Deneke, D., Hay, C. (eds). iGrow Soybean: Best Management Practices. South Dakota State University.
4. Hay, C., Kjaersgaard, J., Trooien, T., 2013. Chapter 49: Soybean Irrigation. In Clay, D.E., Carlson, C.G. Clay, S.A., Wagner, L., Deneke, D., Hay, C. (eds). iGrow Soybean: Best Management Practices. South Dakota State University.
5. Gu, Z., Anderson, G., Wang, X., Vijayakumar, J., Kjaersgaard, J., 2013. Photocatalysis as a Pretreatment to Enable Cyanobacteria Incubation in Wasterwater Containing Biocides. New Horizons Oil & Gas Conference, Rapid City, SD October 9-12 2013.
6. Hay, C., Hankerson, B., Kjaersgaard, J., 2013. Evaluating Cover Crop Evapotranspiration using Field Measurements and Remote Sensing Techniques. ASABE International Meeting, Kansas City, MO, July 21-24 2013.
7. Hay, C., Hankerson, B., Kjaersgaard, J., 2013. Field Measurement and Estimation of Cover Crop Evapotranspiration. AWRA Spring Specialty Conference, St. Louis, MO. March 25-27 2013.
8. Karki, G., Cortus, S., Hay, C., Trooien, T., Kjaersgaard, J., Khand, K.B., Partheeban, C., 2013. Eastern South Dakota Water Conference, Brookings, SD. October 30 2013.
9. Khand, K.B., Hay, C., Kjaersgaard, J., Trooien, T., 2013. Subsurface Drainage Impacts on Evapotranspiration (ET). Eastern South Dakota Water Conference, Brookings, SD. October 30 2013.
10. Kjaersgaard, J., 2013. Nutrient Management from Agricultural Tile Drains. Big Sioux Water Quality Summit, Sioux Falls, SD, September 9 2013.
11. Kjaersgaard, J., Hankerson, B., Hay, C., 2013. Remote Sensing-based Evapotranspiration Estimation for Cover Crops. AWRA Spring Specialty Conference, St. Louis, MO. March 25-27 2013.
12. Kjaersgaard, J., Hankerson, B., Hay, C., 2013. Remote-Sensing-based Evapotranspiration from Fields with and without Cover Crops. UCOWR/NIWR Annual Conference, Lake Tahoe, CA. June 11-13

2013.

13. Kjaersgaard, J., Hankerson, B., Hay, C., 2013. Remote-Sensing-based Evapotranspiration from Fields with and without Cover Crops. Western South Dakota Hydrology Conference, Rapid City, SD. April 18 2013.
14. Reyes-Gonzalez, A., Neale, C., Kjaersgaard, J., 2013. Crop Evapotranspiration using Crop Coefficients Based on Canopy Reflectance. Eastern South Dakota Water Conference, Brookings, SD. October 30 2013.
15. 10/17 2013 at 2:40 PM: Interview at Farm Talk with Mick Kjar: Nitrate Contamination of Well Water. KQLX-AM Ag News 890.

SDWRI FY 2013 Information Transfer Program
South Dakota Water Resources Institute

The Information Transfer Program includes public outreach, interpretation of laboratory analysis results, active participation in the annual Dakotafest farm show, steering committee representation and leading involvement in the Big Sioux Water Festival hosting 1,000 fourth grade students and in The Eastern South Dakota Water Conference, which is the largest water conference in Eastern South Dakota with 200 participants, interactions with extension agents and local, state and federal agencies, participation and presentations at regional and national conferences, youth education, adult education and university student training and education. Publications, such as pamphlets, educational materials, reports and peer-reviewed journal entries are made available in paper format and electronic through the Institute's website and are designed to support the mission of the Institute.

PUBLIC OUTREACH

Public outreach and dissemination of research results are cornerstones of the South Dakota Water Resources Institute's (SDWRI) Information Transfer Program. The Institute distributes information through a variety of outlets, including interactive information via the Internet, pamphlets and reports, direct personal communication, hands-on demonstrations and through presentations and discussions at meetings, symposia and conferences. In addition, the SD WRI actively uses its Facebook page for two-way communication on water-related topics. These outlets are described below.

Water News Newsletter

The South Dakota Water Resources Institute *Water News* quarterly newsletter is in its tenth year of publication. Water-related research including updates on present projects, notification of requests for proposals, state-wide water conditions, conferences, and youth activities are common topics featured in each issue of the newsletter.

The newsletter is an effective method to disseminate information about activities in which the Institute participates, funds, and promotes. The newsletter is distributed at no cost via e-mail to nearly 200 subscribers across the United States. Current and past issues of the newsletter are available through the SDWRI website (http://sdstate.edu/abe/wri) in PDF format. The website additionally has a subscription request form where interested individuals can sign up to receive the newsletter.

SDWRI Website

During the past years, substantial efforts have gone into updating and redesigning the SDWRI website which is accessible through http://www.sdstate.edu/abe/wri/. The website continues to be updated to contain information relating to water resources, current and past research projects, reference material and extension publications. The website content is updated to reflect current conditions relating to water issues, such as water quality impact during drought situations. Since redesigning the website, the Institute has actively used the website as the entry portal relaying information relating to the Institute and water topics. As a result, we continue to see increased traffic to the website. One feature of the SD WRI website is it allows users access to updated links which include publications and on-line tools to help diagnose and treat many water quality problems. The site allows the public access to information about the activities of the Institute, gather information on specific water quality problems, learn about recent research results and links with other water resource related information available on the Internet. The "Research Projects" section of the SD WRI web contains past and present research projects, highlighting the Institute's commitment to improving water quality. An extensive library of information relating to water quality has been developed and continues to be updated on-line.

SDWRI Facebook page

The SDWRI maintains a Facebook page where information of relevance and importance to the SDWRI is posted. News releases are commonly posted to the SDWRI Facebook before other news outlets. The site currently has 62 likes and the most common age group is 25-34 years old.

Water quality analysis interpretation

SD WRI staff continues to provide interpretation of analysis and recommendations for use of water samples submitted for analysis. Assistance to individual water users in identifying and solving water quality problems is a priority of the Institute's Information Transfer Program. Interpretation of analysis and recommendations for suitability of use is produced for water samples submitted for livestock suitability, irrigation, lawn and garden, household, farmstead, heat pump, rural runoff, fish culture, and land application of waste. Printed publications and on-line information addressing specific water quality problems are relayed to lab customers to facilitate public awareness and promote education. SDWRI conducted approximately 45 interpretations during the reporting year.

Eastern South Dakota Water Conference

SDWRI staff chaired the eighth annual Eastern South Dakota Water Conference (ESDWC) held on October 30, 2013 to provide a forum for water professionals to interact and share ideas. Water is an important piece of the economic future of South Dakota, and this conference serves as a mechanism to educate participants on this resource. Sessions throughout the conference offered information important to a wide array of stakeholders including engineers, industry, public officials, agricultural producers, and conservation groups. Speakers highlighted to importance of the scientific method to determine the state of our water resources. The conference abstracts are available at the SDWRI's website at http://www.sdstate.edu/abe/wri/activities/ESDWC/2013-presentations.cfm

The goal of the 2013 Eastern South Dakota Water Conference was to bring together federal, state, and local governments, along with university and citizen insights. The event, in its fifth year, and included speakers and presenters from South Dakota State University , South Dakota School of Mines and Technology, US Geological Survey, South Dakota Department of Environemnt and Natural Resources, North Dakota State University, RESPEC Consulting and many others.

The call for abstracts was released in June 2013. Attendees registered and submitted their conference payment directly through the conference website hosted by the website. A registration fee of $65 was charged for individuals attending the 2013 ESDWC in a professional capacity. Students and citizens attending the conference in a non-professional capacity attended for free. 140 attendees registered for the conference and an estimated additional 50 non-registered individuals (mostly students) attended.

A poster competition for college students was held in which ten student posters were presented. The posters were assessed by 4 judges, who scored each poster and provided written feedback to the student presenters. A first prize of $200 and a second price of $100 were awarded to the two highest ranked poster presentations.

Participation in regional water outreach and experience-sharing activities such as the Eastern South Dakota Water Conference is cost-prohibitive for several agencies and organizations resulting in geographical areas or population groups being underrepresented and underserved by these activities. These agencies and organizations include members of county or tribal government, local and regional interest groups, students and others. To enable their participation, travel stipends covering travel, registration and accommodation costs for representatives from underserved agencies and organizations from South Dakota were provided. The travel stipends were announced on the conference website and promoted in emails sent to the conference attendees. An award committee consisting of Trista Koropatnicki and Jeppe Kjaersgaard from the SDWRI was appointed by the Steering Committee of the ESDWC. The stipends were awarded based on a stated interest and gain for the organization or agency resulting from participation in the conference.

iGrow Publications

SD WRI staff authored or coauthored three SDSU iGrow extension publications, including “Using Web Soil Survey to Identify Disposal Sites.” Published on October 27 2013. [http://igrow.org/livestock/beef/using-web-soil-survey-to-identify-disposal-sites/]; “Nitrate Contamination of Well Water.” Published on October 15 2013. [http://igrow.org/news/nitrate-contamination-of-well-water-concerns/]; and “Storing Water for Emergencies.” SDSU Extension iGrow, Healthy Families, Foods and Nutrition. Published on-line April 8 2013 and again December 10 2013. [http://igrow.org/healthy-families/food-safety/storing-water-for-emergencies/].

Peer-reviewed Publications

The following peer-reviewed publications were published by SDWRI staff during FY2013 under the information transfer program:

Allen, R.G., Burnett, B., Kramber, W., Huntington, J., Kjaersgaard, J., Kilic, A., Kelly, C., Trezza, R., 2013. Automated Calibration of the METRIC-Landsat Evapotranspiration Process. Journal of the American Water Resources Association 49, 563–576.

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Conference Abstracts

The following conference abstracts publications were published by SDWRI staff during FY2013 under the information transfer program:

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Reyes-Gonzalez, A., Neale, C., Kjaersgaard, J., 2013. Crop Evapotranspiration using Crop Coefficients Based on Canopy Reflectance. Eastern South Dakota Water Conference, Brookings, SD. October 30 2013.

Radio Interview

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10/17 2013 at 2:40 PM: Interview at Farm Talk with Mick Kjar: Nitrate Contamination of Well Water. KQLX-AM Ag News 890.

AGENCY INTERACTIONS

The SDWRI Information Transfer program includes interaction with local, state, and federal agencies in the discussions of water-related problems in South Dakota and the development of the processes necessary to solve these problems. One of the most productive agency interactions is with the state Non-Point Source (NPS) Task Force, where the SDWRI is represented as a non-core member. The NPS Task Force is administered by the SD Department of Environment and Natural Resources which coordinates, recommends, and funds research and information projects relating to non-point water pollution sources. Participation on the NPS Task Force allows SDWRI input on non-point source projects funded through the task force and has provided support for research in several key areas such as soil nutrient management, agricultural water management, biomonitoring, and lake research. Many of the information transfer efforts of the Institute are cooperative efforts with the other state-wide and regional entities that serve on the Task Force.

SDWRI personnel additionally served on several technical committees and boards, including

- the Central Big Sioux Master Plan Technical Review Committee, overseeing the monitoring and implementation of the Central Big Sioux water quality master plan for the city of Sioux Falls,
- Member of the steering committee of the USDA WERA 1020 committee,
- South Dakota NRCS Technical Committee, and
- Member of the steering committee for the 2014 eXtension National Conference

Several other local, state and federal agencies conduct cooperative research with SDWRI or contribute funding for research. Feedback to these agencies is often given in the form of reports and presentations at state meetings, service through committees and local boards, and public informational meetings for non-point source and research projects.

YOUTH EDUCATION

Non-point source pollution contributes to the loss of beneficial uses in many impaired water bodies in South Dakota. An important part of reducing non-point pollution is modifying the behavior of people living in watersheds through education. Programs designed to educate youth about how their activities affect water is important because attitudes regarding pollution and the human activities that cause it are formed early in life. For these reasons, Youth Education is an important component of SD WRI’s Information Transfer Program.

Big Sioux Water Festival

Water Festivals provide an opportunity for fourth grade students to learn about water. SDWRI personnel were part of the organizing committee for the 2013 Big Sioux Water Festival held on May 7 2013 with 1050 fourth grade students from eastern South Dakota participating. SD WRI was responsible for coordination of volunteers and helpers, and co-coordinating the exhibit hall.

Eastern South Dakota Science and Engineering Fair

Staff from the SD WRI served as judges at the annual Eastern South Dakota Science and Engineering Fair where 650 middle and high school students showcase projects scientific and creative ideas. The students test theories, perform experiments, test theories and learn about the scientific process. During the fair, the judges have the opportunity to discuss the students' projects and what they have learned from the experiments.

Teach the teacher – 4-H advisor workshops

Two workshops were held during the week of September 23rd 2013 to acquaint 4-H advisors from across the state of South Dakota with geospatial technologies. Twenty-one 4-H advisors attended the workshop on September 23 and 24 at the Mitchell Regional Extension Office on the campus of Mitchell Technical Institute and fifteen 4-H advisors attended the September 26-27 workshop at the Western Agricultural Research Center in Rapid City.

The purpose of these workshops was to provide STEM-related information to the advisors who in turn will transfer their knowledge to the 4-H members and students with whom they interact. This will hopefully result in projects and lessons that utilize geospatial technologies, increased awareness of the many ways that geospatial technologies affect our lives, increased scientific literacy and curiosity, and better preparation for careers that involve geospatial technologies. The geospatial technologies introduced at the workshops include geographic information systems (GIS), global positioning systems (GPS) and remote sensing.

During the intensive two-day workshops, the 4-H advisors learned how to collect data using GPS units, where to look for various types of geospatial data, how remote sensing imagery is collected and used, and how GIS software is used to integrate and analyze various types of geospatial data. Presentations by the Sioux Falls and Rapid City/Pennington County GIS department managers exposed the advisors to real-world examples of how geospatial technology is becoming an increasingly important part of today's society.

ADULT EDUCATION

As part of SDWRI's outreach to the agricultural community, staff hosted a booth at Farmfest and at DakotaFest, each a three-day agricultural fair held in August each year near Redwood Falls, MN and Mitchell, SD, which each draws approximately 30,000 people. A selection of literature an displays regarding water quality is available for distribution and SDWRI staff members field a variety of questions concerning water quality and current research for farm and ranch families. SDWRI staff also hosted a booth at the AgPhD field day held on July 25 near Baltic, SD and the Conservation Connection day held at Bramble Park Zoo in Watertown, SD.

SD WRI personnel additionally participated in and presented at several regional and national meetings and conferences, including

Conference Name	Organizing Organization	Location	Date
Spring Speciality Conference: Agricultural Hydrology and Water Quality II	American Water Resources Association	St. Louis, MO	3/25-27 2013
Sustaining Water Resources and Ecological Functions in Changing Environments	Universities Council on Water Resources	Lake Tahoe, CA	6/11-13 2013
Mayor’s Big Sioux River Water Summit	City of Sioux Falls	Sioux Falls, SD	9/9 2013
Eastern South Dakota Water Conference	South Dakota Water Resources Institute	Brookings, SD	10/30 2013
ASA, CSSA, and SSSA International Annual Meeting	Agronomy, Soil Science and Crop Science Societies of America	Tampa, FL	11/3-6 2013

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	4	0	0	1	5
Masters	6	0	0	1	7
Ph.D.	3	0	0	1	4
Post-Doc.	3	0	0	0	3
Total	16	0	0	3	19

Notable Awards and Achievements

Ms. Cynthuja Partheeban, a graduate research assistant with the SDWRI took second price in the student poster competition at the 7th annual Eastern South Dakota Water Conference held in Brookings, SD on October 30 2013. The title of her poster was "Determining the Nitrogen Removal Effectiveness of Denitrifying Bioreactors for Improved Drainage Water Management".