1.0 Project Description
Demonstrating the Nitrate-Removal Effectiveness of Bioreactors for Improved Drainage Water Management in Eastern South Dakota

1.1 Project Background
Subsurface (tile) drainage on agricultural land with poor natural drainage allows more timely field operation access and contributes to improved crop yields. While properly designed and installed subsurface drainage typically reduces sediment and phosphorus losses, many studies show that subsurface drainage enhances the movement of nitrate-nitrogen to surface waters. Nitrogen is an essential plant nutrient, but excess nitrogen leads to eutrophication and hypoxic conditions in aquatic ecosystems, particularly in estuaries. Many scientists suspect that nitrate-nitrogen in drinking water supplies pose a health hazard, especially for infants and pregnant women, and are expensive to treat. This creates a critical need for strategies that minimize nitrate losses through subsurface drainage of agricultural land. While improved management of nitrogen fertilizer and animal manure is one important method for reducing nitrate losses, it is often not enough: therefore, water quality goals for nitrate require additional, off-field drainage water and nutrient management methods.

Our long-term goal is investigating, developing, evaluating, and transferring practices that maintain the benefits of agricultural subsurface drainage while minimizing unwanted environmental impacts. The overall objective of this project is demonstrating and evaluating denitrification drainage bioreactors placed on the edge of fields to reduce nitrate loads from subsurface drainage systems to receiving waters in eastern South Dakota.

Several studies show bioreactors as effective methods for reducing nitrate concentrations of drainage flow (e.g. van Driel et al., 2006; Appleford et al., 2008; and Jaynes et al., 2008). Van Driel et al. (2006) found bioreactors remove nitrate at rates of an order of magnitude greater than treatment wetlands and use only 10% of the area typically required for constructed wetlands (Kovacic, et al., 2000). However, bioreactors for treatment of drainage water are still an emerging technology, and a recent focus group study conducted among drainage professionals indicated a need for further information and demonstration to establish their effectiveness (Lewandowski, 2010).

Denitrification bioreactors for agricultural drainage were pioneered in Ontario, Canada followed by early research in Illinois and Iowa. Bioreactors as a nitrate treatment technology generated interest from the Midwest because of the potentially cost effective means for reducing nitrogen loads to surface waters (Schipper et al., 2010). Bioreactors utilize biological denitrification to reduce nitrate to inert dinitrogen gas (N2). This requires suitable bacteria, a carbon source, and anoxic conditions (Christianson et al., 2009). Bioreactors consist of an excavated trench filled with a carbon source, typically woodchips. The drainage water from the field is routed into the reactor from the end of the drainage pipe at one end, and collected in a pipe at the other end and discharged into the surface water system (Figure 1.1). In the design phase, it is critical to size bioreactors appropriately to create hydraulic retention times that are long enough to maximize nitrate removal but short enough to minimize potential negative side effects (Christianson et al.,
However, sizing is difficult because of the inherently variable flows of subsurface drainage systems. While periods of high flow would demand a very large bioreactor, this would be impractical as peak flows are infrequent. Instead of building a larger bioreactor, a design flow rate is chosen and excess water is allowed to bypass the reactor. Inlet and outlet control structures are used to adjust the hydraulic retention time (Christianson et al., 2011). USDA-NRCS has developed an interim practice standard for denitrifying bioreactors in Iowa (USDA NRCS, 2009). The interim standard gives guidance on design capacities, but it does not contain a design methodology. More work is needed to evaluate different design procedures and their impact on nitrate removal (Christianson et al., 2011).

![Figure 1.1. Schematic diagram of a typical denitrification drainage bioreactor](image)

**Graphic courtesy of Dr. Richard Cooke, University of Illinois**

### 1.2 Project Objectives

1. Demonstrate and evaluate four field-scale bioreactor designs by installing, monitoring, analyzing and documenting their effectiveness for removing nitrate from subsurface drainage water in South Dakota; evaluate the transferability of this method and these designs to South Dakota
2. Evaluate the potential for nitrous oxide emission to the atmosphere
3. Estimate the cost per pound of nitrate removed
4. Support the development of NRCS Conservation Practice Standards and Best Management Practices (BMPs) for management of nitrate in subsurface tile drainage water
5. Transfer information about the bioreactor design and performance through outreach and demonstration activities, factsheets, and train one or two undergraduate research assistants in environmental and agricultural water management.
1.3 Project Methods

We will demonstrate the efficiency of bioreactors in removing nitrate depending on the bioreactor size, design and the type of carbon substrate used, along with sampling nitrous oxide gas vented from the bioreactor to the atmosphere and performing an economic analysis of the removal rates. To reach these goals, we will undertake the following activities:

Establish an advisory board
We will form an advisory board with representatives from South Dakota businesses, organizations and agencies, such as conservation districts, agricultural commodity groups, water development districts, interest groups, contractors, and state and federal agencies. The board will provide insight into the needs and interests of the businesses, organizations and agencies relating to drainage water management and ensure agency and industry buy-in of the bioreactor demonstration efforts. The board will be formed during the initial phase of the project in order to provide project support. Several of these organizations, including the South Dakota Farm Bureau, the South Dakota Soybean Research and Promotion Council, the East Dakota Water Development District and the Vermillion Basin Water Development District have indicated their support by providing cash funds for the project. In addition, the Brookings County Conservation District, Moody County Conservation District and Minnehaha Conservation District have provided letters of support with expressed interest in collaborating throughout all phases of the project. The letters are attached to this proposal.

Assemble and compile current information on bioreactor design and installation
In the very early phases of the project, the project directors, Drs. Kjaersgaard and Hay, will assemble an archive with current information and knowledge relating to bioreactor use, design, capacity, installation, carbon media type and control structures. The information will be assembled through literature studies, advice from the advisory board and discussions with out-of-state researchers, agency and industry personnel.

Because field sites with bioreactors have been established in other states in the upper Midwest, the directors will make a three-day trip to visit and inspect Minnesota and Iowa field sites and to interact with technicians, researchers, funding agencies and other personnel involved in designing, installing, maintaining, monitoring and evaluating the bioreactors.

Bioreactor Design and Installation
We will install four demonstration bioreactors as edge-of-field treatment for agricultural tile drain systems serving 40–70 acre areas; this acreage size is typical for targeted or random tile drainage systems in eastern South Dakota. The target fields will be managed using typical agricultural practices with cropping and drainage patterns representative of eastern South Dakota. The size of each bioreactor will depend on the acreage being drained and its expected drainage flow rates. The bioreactor designs will characterize the most recent criteria and recommendations.

In order to evaluate design variations two of the bioreactors will be installed in a pair. Each of the two reactors will be located on separate tile outflows from the same field, or from two nearby fields managed under comparable agricultural practices. The reactors in the pair will be of different design or will utilize different carbon media such as woodchips and corn biomass. Two additional bioreactors, funded by an EPA 319 grant to the Central Big Sioux Watershed Project (CBSWP), will be installed by the CBSWP. We have agreed with the CBSWD to
manage, monitor, maintain and evaluate these two additional bioreactors in parallel to the four bioreactors installed as part of this project. We will utilize the data from the parallel project in this project’s reporting and information dissemination.

To determine realistic cost, our bioreactor installation will mirror the same set of conditions a South Dakota producer would face. Our installation and maintenance of the bioreactors will utilize the same local resources and service providers available to producers. Examples include acquisition of wood chips generated by a nearby city park service during their tree removal programs, use of local excavating contractors, and buying materials in local stores or through typical drainage hardware suppliers.

**Bioreactor Monitoring Program**
We will implement a standard bioreactor monitoring program where we collect water samples from the bioreactors inflow and outflow points and upstream from the discharge point where it transfers into existing waterways. We will analyze the water sample for nitrate content. We will install instruments to record air temperature and rainfall near the bioreactors.

In addition to the standard monitoring program we will intensify the monitoring at two bioreactor sites. The intensified monitoring program will include sampling of nitrous oxide gas, a greenhouse gas and intermediate product in the denitrification process, vented to the atmosphere from the bioreactor. We will install sensors to record ambient soil moisture and temperature to provide information needed in the evaluation of the gas emissions. Additionally, we will install equipment within the bioreactors to monitor the bioreactor internal temperature and moisture content and enable withdrawal of water samples in a grid pattern with four columns and five rows, totaling 20 sample points.

The water and gas sampling and analysis are described below. One or two undergraduate student research assistants will be, under supervision from the project directors, undertaking most of the routine sample collection and water and gas analysis efforts.

**Water sampling and analysis**
We will install equipment to collect water samples from the inflow and outflow and monitor flow rates in and out of the bioreactors. In addition, water will be sampled upstream from where the bioreactor discharges into an existing waterway or water body to identify the background water quality of the receiving water. The sampling interval will depend on the amount of water flow through the bioreactor, with more frequent sampling during the start-up period and periods of high flows, and more periodic sampling at lower flow rates. Each bioreactor site will be visited on average 24 times during the year for sample collection and bioreactor and site maintenance.

In order to quantify the nitrate removal, we will analyze the water sampled at the inlet and the outlet of each bioreactor for nitrate using appropriate methods. The difference in nitrate content between the inlet and the outlet will, when coupled with the volume of water flowing through the system, provide a direct measurement of the relative (% removed) and absolute (pounds of nitrogen removed) amount of nitrate removed from the tile drain water. The majority of the water samples will be analyzed using a Hach DR 4000 spectrophotometer owned by East Dakota Water Development District and made available for nitrate analysis on a non-profit basis. Ten percent of the water samples collected at the bioreactors will be duplicated and analyzed for nitrate content in parallel to the Hach DR 4000 spectrophotometer. The parallel samples will be
submitted as blind samples and analyzed at a certified testing lab. The water sampling and analysis program is assumed to handle the same number of samples each of the three project years. To make up for the shorter sampling period during the first year while the bioreactors are being installed we will increase the sampling frequency in order to document the bioreactor performance in removing nitrate during the start-up period.

Additionally, electrical conductivity (EC) and pH will be measured at the time of sampling with a portable meter to characterize the water mineral content and document changes over time.

_Nitrous oxide gas sampling and analysis_
Since aerial nitrous oxide (N\textsubscript{2}O) emissions from the bioreactor are a concern, static chamber-based gas flux measurements will be employed to assess the amount of N\textsubscript{2}O released from the bioreactor surface. This widely-used methodology is low-cost and facilitates multiple measurement sites. Baker et al. (2003) provides a protocol for flux measurements including chamber design and sampling frequency. In short, a PVC end cap, when placed on a collar in the soil, serves as the chamber. Over a 60-min period, gas samples are withdrawn by syringe for later analysis by gas chromatography at the Department of Plant Science at SDSU. The area-based flux is determined based on the change in gas concentration over time in the chamber using the calculation procedures in Baker et al. (2003).

An initial emission study will occur at one bioreactor site. A minimum of two chambers per bioreactor will be deployed, plus an additional chamber outside of the bioreactor area but over similar vegetation for comparison. On sample collection days, samples will be collected mid-morning when the air temperature most closely resembles the daily average temperature. Three samples will be collected per chamber at 0, 30 and 60 minutes, plus one sample of ambient air. Samples will be collected weekly in conjunction with water quality sampling. Prior to and after each sampling event, the chamber collars will be left in place, but the chamber covers removed. Gas samples will be analyzed for nitrous oxide gas.

_Supporting information_
Supporting information, such as field records and field management logs, will be collected and maintained in collaboration with the landowners. Climatic information will be obtained from the nearby weather stations managed by the South Dakota State Climate Office. Information about soil type, drainage plans, tile outlines and similar will be obtained in collaboration with the landowners or operators and with NRCS or local Conservation Districts.

1.4 Location and size of project and project areas
The project directors have undertaken a preliminary assessment of the suitability of two field locations belonging to separate landowners to be used for the project. The assessment, based on field observations, drainage maps, soil type maps and other supporting materials indicated that both locations are suitable for installing and demonstrating the bioreactors. The two collaborating agricultural producers have agreed to have the bioreactors installed on their properties. The properties are located in the Big Sioux Watershed in eastern South Dakota near Nunda and Baltic, respectively. Both landowners have tile-drained fields that are managed using normal agricultural practices. The drained acreages at those fields range in size from 30 – 70 acres, which is a very suitable size for this demonstration project. Letters of commitment from the two landowners stating their willingness to collaborate and have bioreactors installed on their properties are enclosed.
Contacts to other landowners have been established to identify additional locations for bioreactor installations. Additional landowners to participate in the project by having bioreactors installed on their properties will be identified, as needed in the Big Sioux and the Vermillion Basin Watersheds in collaboration with local NRCS and conservation district offices and water development districts.

1.5 Producer participation
The project will involve installation of bioreactors and direct participation of several EQIP-eligible producers. It is expected that a much greater number of producers will be involved through

- affiliation with the project advisory board formed to provide insight into the needs and challenges of drainage water management and ideas and advice for the project execution,
- direct interactions with the agricultural commodity groups such as the organizations supporting the proposed project including the South Dakota Corn Utilization Council, the South Dakota Farm Bureau and the South Dakota Soybean Research and Promotion Council,
- producers serving on local forms of government including County Commissioners and County Conservation District Boards,
- interactions with NRCS field office personnel
- producers participating in field tours and field demonstration events
- interactions with SDSU Extension personnel,
- meetings and other events targeted for the outreach activities.

The project directors will solicit voluntary participation from historically underserved clients who qualify as a beginning farmer or rancher, socially disadvantaged farmer or rancher or limited resource farmer or rancher and self-certify that they meet the criteria as required by the Food, Conservation and Energy Act of 2008.

1.6 Project action plan and timeline
Table 1.1 shows the project timeline.

1.7 Project Management
The project will be managed and directed collaboratively by Dr. Jeppe Kjaersgaard and Dr. Chris Hay. Dr. Kjaersgaard will be the main contact person for the collaborating landowners and other partners, managing the day-to-day operations of the project, overseeing undergraduate student research assistants and ensuring the project plan is being followed. Co-PI Hay will co-manage the project, including being an additional point of contact to collaborators and will have primary responsibility for the dissemination of project related information to agricultural producers, agencies, organizations and the general public through meetings, field days, and publications through SDSU Extension and other outreach activities.

Kjaersgaard and Hay will both be responsible for project planning, initial assimilation of information regarding bioreactors, designing the bioreactors, directing the installation of the bioreactors, and analyzing and interpreting the results of the analysis.
Table 1.1. Timeline and action plan for the project.

<table>
<thead>
<tr>
<th>Project phase</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
</tr>
<tr>
<td>Project planning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advisory Board</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current Knowledge Benchmarking</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identify Additional Cooperators</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gather Baseline and Supporting Information</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design Bioreactors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project Implementation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bioreactor Installation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Research Assistant Training</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Sampling and Analysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrous Oxide Gas Sampling and Analysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaluation Development</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaluation of Bioreactor Performance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outreach and Information Transfer</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Education and Outreach</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Progress Reporting</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final Report</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Dr. Kjaersgaard is an Assistant Professor at the South Dakota Water Resources Institute at South Dakota State University (SDSU), where he conducts research and provides service to the general public in the area of agricultural water management. His research program and outreach activities focus on water quality for domestic, livestock and irrigation use, field nutrient and water management and use of remote sensing technologies in quantifying plant and crop water use. He holds BS and MS degrees in Agronomy from the Royal Veterinary and Agricultural University, Denmark, and a PhD in Environment, Resources and Technology from the University of Copenhagen, Denmark. Dr. Kjaersgaard has been working in the area of agricultural water management for several years.

Dr. Hay is an Assistant Professor and Extension Water Management Specialist in the Department of Agricultural and Biosystems Engineering at South Dakota State University, where he teaches and conducts research in the areas of soil and water engineering and agricultural hydrology. His Extension outreach program focuses on agricultural water management, particularly agricultural subsurface drainage. He holds BS and MS degrees in Agricultural and Bioresource Engineering from Colorado State University and a PhD in Agricultural and Biological Systems Engineering from the University of Nebraska-Lincoln. In addition to his academic training, Dr. Hay has several years of experience in consulting, industry, and government in the areas of water resources engineering and environmental management. He is a licensed Professional Engineer in the State of Nebraska.

In addition, the following collaborators will be directly involved in the project by providing know-how and advice, equipment and contacts to collaborating landowners:
Dr. Erin Cortus, Assistant Professor in Air Quality and Agric. Waste Management at SDSU
Dr. Todd Trooien, Professor of Water Resources at SDSU
Mr. John Hay, District Manager, Moody County Conservation District
1.8 Project deliverables/products

We will:

1. Provide semi-annual and final reports describing project activities including
   a. A description of the reactor designs and suggestions for design changes.
   b. Monitoring results and an assessment of the effectiveness of different reactor designs in removing nitrate from the drainage water.
   c. Evaluate the potential for nitrous oxide production as a byproduct of incomplete denitrification
   d. A calculation of the cost per pound of nitrate removed from the drainage water, based on the expected lifetime of each reactor.
   e. An analysis of the cost to the producer of ‘losing’ the measured amount of nitrogen from the fields through the tiles during each season.
   f. Development of new technology and innovative approach fact sheets

2. Quantify the expected ‘startup’ period following installation where the denitrifying bacteria colonies inhabit the reactor and during which the nitrate removal capacity may be small.

3. Demonstrate conservation practices for tile drain water management to support the development of BMPs and NRCS Conservation Practice Standards and provide information about edge-of-field tile drain water treatment systems to be evaluated under (and possibly supported through) the NRCS EQIP program.

4. Organize demonstrations and outreach events to the public. We will present monitoring data and efficiencies through the project website, SDSU Extension and at meetings and conferences. It is expected that project personnel will participate in at least one NRCS CIG Showcase or comparable NRCS event during the period of the grant.

5. Keep monitoring the effectiveness of the bioreactors beyond the three-year project period conditioned on additional funding. The life expectancy of field scale bioreactors is 20 years or more. Hence, the reactors will continue removing nitrate from the drainage water for a period reaching far beyond the project period.

6. Conduct follow-up monitoring of biodegradation and removal of other chemical compounds, including pesticides and pharmaceuticals in the drainage water, and monitoring of the chemical composition of the nitrogen gas vented to the atmosphere provided financial support can be secured from other sources.

In addition, supplemental narratives will be provided to explain and support payment requests to the NRCS.

Another educational component of the project is the training and education of future water managers and decision makers. One or two undergraduate student research assistants will be trained and directly involved in the project by assisting with the installation of the bioreactors, water sampling, nitrogen gas sampling, water and gas analysis and measurement data management. Through these efforts the students will gain an understanding of and experience with agricultural field and water management, water and gas sampling philosophy and
techniques and water and gas analysis. The demonstration sites will additionally be incorporated in student teaching activities including field tours, class room discussion and student projects at South Dakota State University and other schools and institutions of higher learning.

1.9 Benefits or results expected and transferability
We expect this project to enhance water conservation and improve water quality in the receiving waters, including wetlands, creeks and streams, lakes and large water bodies. Other benefits include

- Supporting development of NRCS Conservation Practice Standards, innovative technology fact sheets and BMPs for drain water management,
- Demonstrating conservation practices for tile drain water management which can provide information about edge-of-field tile drain water treatment systems to be evaluated under (and possibly supported through) the NRCS EQIP program,
- Demonstrating solutions and tools to reduce the environmental impacts of tile drainage to local drainage permitting authorities, including county drainage boards or county commissions,
- Demonstrating a cost-effective method to reduce nitrate from tile drain water to mitigate concerns towards tile drain installations from federal or state regulatory agencies,
- Facilitating agricultural producers being good neighbors by reducing water quality impacts on downstream water users including private and public landowners and municipalities,
- Improving recreational value to the public of ecosystems sensitive to nitrate loading from the tile drainage, including wetlands, lakes and streams,
- Calculating the cost to the producer of the amount of nitrogen lost from the field to reinforce the importance of good nitrogen management.

The project will demonstrate the use of bioreactors as a tool for tile drain water management and assist producers in the decision making process regarding tile drain installation, system design and cost. In addition, the project will provide input for updating the interim practice standards for denitrifying bioreactors developed by the NRCS in Iowa. The observations from the monitoring of the demonstration bioreactors will be directly transferable to other regions in eastern South Dakota, including the James River basin, and to regions with similar drainage patterns, climatic conditions and soil types including eastern North Dakota and western Minnesota.

1.10 Project evaluation
Specific metrics that will be used to evaluate the success of the project include:

- Actual cost within reasonable proximity to proposed budget
- Milestones, as identified in the time line, and objectives met
- Collaboration with stakeholders, including conservation districts, agricultural commodity groups, agricultural producers, water development districts, interest groups, contractors and state and federal agencies established with on-going collaboration beyond the three year timeframe of the project
- Research assistants trained and experience gained in environmental measurement technology and agricultural and environmental water management
- A satisfaction survey conducted among the cooperating agricultural producers to evaluate their satisfaction of participating in the project and the bioreactor installation
- Quantification of the amount of nitrogen that is lost from the fields through the tile drains, and an analysis of the cost to the producer to replenish the nitrogen for subsequent crops
- Evaluations conducted at outreach meetings and events to assess the level of impact on knowledge gain regarding bioreactors and drainage in general and the level of interest in bioreactors as a conservation drainage practice
- Results communicated to all indicated recipients and to any additional recipients identified during the project

References
Lewandowski, A. 2010. Review of conservation drainage practices and designs in Minnesota: Results from focus groups with drainage professionals around the state. Saint Paul, MN: University of Minnesota Water Resources Center.